DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS
REPUBLIC OF THE PHILIPPINES

JAPAN INTERNATIONAL COOPERATION AGENCY

THE DETAILED DESIGN OF PASIG-MARIKINA RIVER CHANNEL IMPROVEMENT PROJECT (PHASE III)

FINAL REPORT

VOLUME-III-1

STRUCTURAL CALCULATION OF PASIG RIVER

FEBRUARY 2013

CTI Engineering International Co., Ltd.
Consulting Engineers

COMPOSITION OF FINAL REPORT

VOLUME-I	:	SUMMARY
VOLUME-II	:	MAIN REPORT
VOLUME-III-1	:	STRUCTURAL CALCULATION OF PASIG RIVER
VOLUME-III-2	:	STRUCTURAL CALCULATION OF LOWER MARIKINA RIVER
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VOLUME-V	:	COST ESTIMATE

EXCHANGE RATES USED IN THE REPORT:
PHP 1.00 = JPY 1.968
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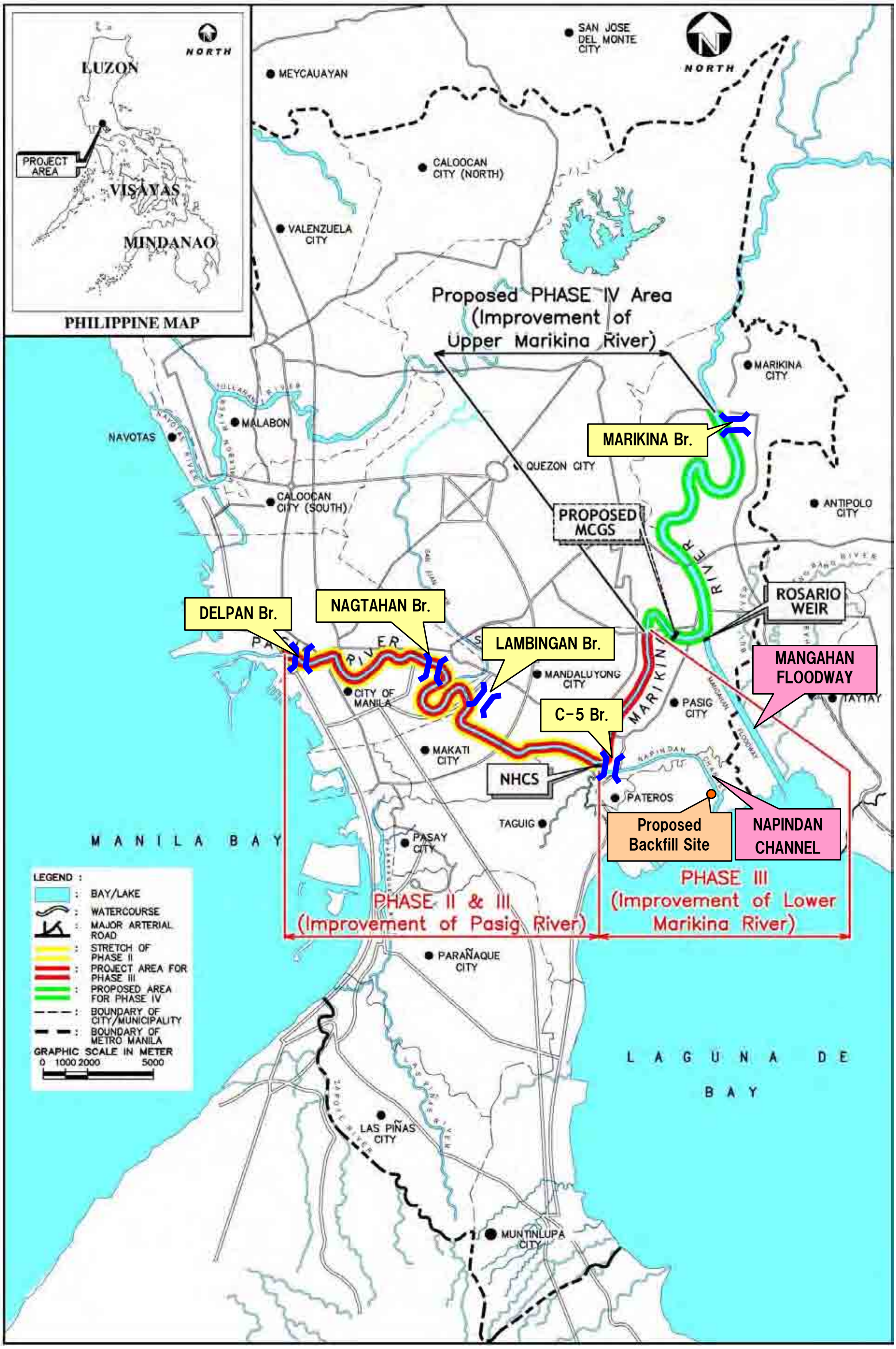
(Monthly Average in November 2012 of Central Bank of the Philippines)



PROJECT LOCATION MAP

THE DETAILED DESIGN
OF
PASIG-MARIKINA RIVER CHANNEL
IMPROVEMENT PROJECT (PHASE III)

DRAFT FINAL REPORT
Vol.-III-1 STRUCTURAL CALCULATION OF PASIG RIVER

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ABBREVIATIONS AND ACRONYMS

Units of Measurement

mm	: millimeter
cm	: centimeter
m	: meter
km	: kilometer
g, gr	: gram
kg	: kilogram
t, ton	: metric ton
m^2	: square meter
ha, has	: hectare, hectares
km^2	: square kilometer
m^3	: cubic meter
s, sec	: second
m, min.	: minute
h, hr	: hour
y, yr	: year
MW	: megawatt
mm/hr	: millimeter per hour
m/s	: meter per second
km/hr	: kilometer per hour
mg/l	: milligram per liter
m^3/s	: cubic meter per second
$m^3/s/km^2$	: cubic meter per second per square kilometer
%	: percent
ppm	: parts per million
x x	: symbol of multiplication (times)
≤ , ≥	: Inequality sign (e.g. A≤B means that value A is less than or equal to value B.)
< , >	: Inequality sign (e.g. A<B means that value A is less than value B.)
Y, Y, JPY	: Japanese Yen
P, P, PHP	: Philippine Peso

CHAPTER 1 STEEL SHEET PILE (SSP) REVETMENT (LEFT BANK)

Table R 3.1.1 Design Results of SSP Revetment in Each Section (Left Bank)

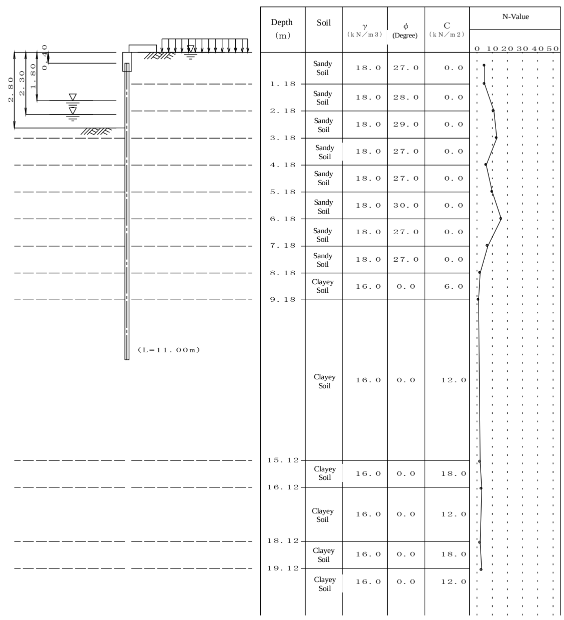
No.	Section				Designed SSP Revetment			Result of Design Calculation			
								Stress (N/mm^2)		Dsiplacement (mm)	
	from	to	Bank	EL. of Design Riverbed (EL. m)	Type	Z_0 (cm^3)	Length (m)	Normal (acceptable)	Seismic (acceptable)	Normal (50)	Seismic (75)
1	2+419	2+550	L	9.6	IV_W	2700	11.0	67 (180)	90 (270)	35.17	50.05
2	2+550	2+694	L	9.6	IV_W	2700	11.5	77 (180)	99 (270)	45.22	62.90
3	2+854	2+950	L	9.6	V_L	3150	12.0	70 (180)	91 (270)	45.62	63.84
4	2+950	3+072	L	9.6	IV_W	2700	12.0	73 (180)	92 (270)	46.62	61.08
5	3+160	3+300	L	9.6	25H	1610	9.0	69 (180)	96 (270)	28.74	42.46
6	6+116	6+219	L	10.0	III_W	1800	10.0	76 (180)	103 (270)	40.51	58.56
7	6+249	6+269	L	10.0	VI_L	3820	12.5	69 (180)	107 (270)	42.72	72.08
8	6+376	6+482	L	10.1	V_L	3150	11.0	76 (180)	111 (270)	42.63	66.49
9	7+326	7+444	L	10.1	VI_L	3820	12.0	66 (180)	98 (270)	40.09	61.52
10	7+494	7+514	L	10.1	VI_L	3820	12.0	68 (180)	100 (270)	41.11	63.39
11	11+500	11+628	L	10.2	V_L	3150	11.0	81 (180)	116 (270)	46.54	70.68
12	12+024	12+173	L	8.2	10H + 750x250x12x25	902+5390	16.5	103 (185)	126 (278)	44.11	54.41
13	13+806	13+900	L	10.2	10H + 450x250x9x22	902+2490	13.0	103 (185)	145 (278)	40.86	58.10
14	13+900	14+000	L	10.2	10H + 600x200x12x28	902+3630	14.5	105 (185)	158 (278)	42.48	64.25
15	14+000	14+150	L	10.2	10H + 450x200x12x25	902+2320	12.5	90 (185)	166 (278)	29.48	60.53
16	14+150	14+250	L	10.2	IV_W	2700	10.0	78 (180)	118 (270)	36.56	57.83
17	14+250	14+272	L	10.2	10H + 400x200x9x22	902+1760	11.5	116 (185)	194 (278)	37.10	65.31
18	15+236	15+311	L	10.2	VI_L	3820	11.0	81 (180)	136 (270)	39.37	71.41
19	15+311	15+424	L	10.2	VI_L	3820	11.0	68 (180)	115 (270)	32.12	59.92
20	15+443	15+548	L	10.2	10H + 450x250x12x28	902+3070	13.0	102 (185)	168 (278)	41.61	70.56
21	15+747	15+870	L	10.2	10H + 450x250x9x22	902+2490	13.5	95 (185)	159 (278)	35.32	64.46
22	15+965	16+150	L	10.2	10H + 400x200x9x22	902+1760	12.0	94 (185)	153 (278)	31.70	55.46
23	16+150	16+200	L	10.2	10H + 400x200x9x22	902+1760	12.5	102 (185)	169 (278)	36.94	67.52
24	16+200	16+300	L	10.2	10H + 400x200x9x22	902+1760	12.5	106 (185)	168 (278)	37.91	65.70
25	16+300	16+450	L	10.2	10H + 400x200x9x22	902+1760	13.0	103 (185)	178 (278)	38.65	72.60
26	16+450	16+552	L	10.2	10H + 400x200x9x22	902+1760	12.5	91 (185)	154 (278)	32.03	59.46
27	16+552	16+564	L	10.2	25H + 850x250x16x28	1610+7240	19.0	91 (185)	146 (278)	45.11	72.99

－Steel Sheet Pile　Design Calculation－

Left Bank No. 01_STA 2+419 - 2+550

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.80 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.30 m (Normal Condition)
	L_{wp}'	=	1.80 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　γ_w = 9.8 kN/m^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	1.0 kN/m	(Normal Condition)
		P_t'	=	4.5 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.13 m	(Normal Condition)
		H_t'	=	0.16 m	(Seismic Condition)
	Moment	M_m	=	0.1 kN·m/m	(Normal Condition)
		M_m'	=	2.9 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　ζ_0 = 10 degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression　　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N'^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	5
2	1.18	5
3	2.18	11
4	3.18	13
5	4.18	6
6	5.18	10
7	6.18	16
8	7.18	7
9	8.18	2
10	9.18	1

No	Depth (m)	N-Value
11	15.18	2
12	16.18	3
13	18.18	2
14	19.19	3
15	20.18	2

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

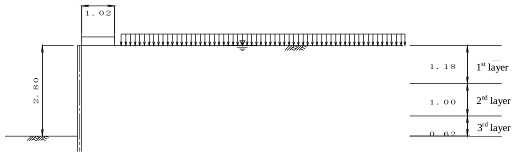
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	1.18	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
2	2.18	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	――	――
3	3.18	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	――	――
4	4.18	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
5	5.18	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
6	6.18	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	――	――
7	7.18	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
8	8.18	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
9	9.18	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	――	――
10	15.12	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
11	16.12	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
12	18.12	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
13	19.12	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
14	20.12	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	0.00	1.02	1.02	0.27	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	1.22	10.00	10.0	5.0

Angle of rupture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 56700 cm^4
Sectional factor Z_0 = 2700 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

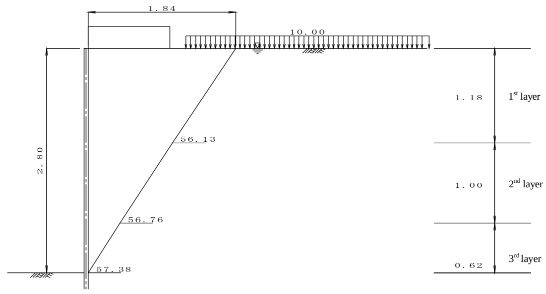
Allowable stress σ_a = 180 N/mm (Normal)
σ_a' = 270 N/mm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	$\gamma w h w$ (kN/m^2)	Angle of rupture Z (degree)
1	2.80～ 2.18	Sandy Soil	29.0	9.0	0.0	28.00	6.07	27.44	57.38
2	2.18～ 1.18	Sandy Soil	28.0	9.0	0.0	21.80	6.07	21.36	56.76
3	1.18～ 0.00	Sandy Soil	27.0	9.0	0.0	11.80	6.07	11.56	56.13

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^o since $\theta = 0^o$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^o$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	57.38	0.62	0.00	0.00	0.40	0.62
2	56.76	1.00	0.40	0.62	1.05	1.62
3	56.13	1.18	1.05	1.62	1.84	2.80

Therefore, width of acting load shall be set as 1.84 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	0.28	4.96
Σ			4.96

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	10.0	0.62	6.24
Σ			6.24

Q: surcharge load
l : width of surcharge load set by line of active rupture

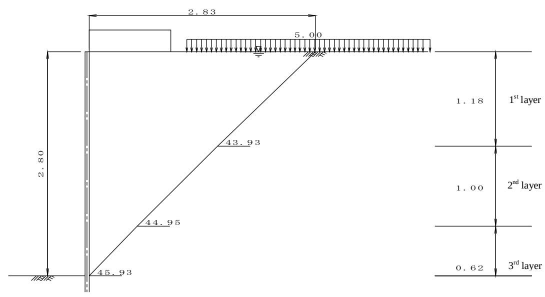
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{4.96 + 6.24 + 0.00}{1.84}$$

$$= 6.07 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	$\gamma w h w$ (kN/m^2)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.80～ 2.18	Sandy Soil	29.0	9.0	0.0	28.00	4.60	27.44	0.200	11.31	45.93
2	2.18～ 1.18	Sandy Soil	28.0	9.0	0.0	21.80	4.60	21.36	0.200	11.31	44.95
3	1.18～ 0.00	Sandy Soil	27.0	9.0	0.0	11.80	4.60	11.56	0.200	11.31	43.93

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^o$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.93	0.62	0.00	0.00	0.60	0.62
2	44.95	1.00	0.60	0.62	1.60	1.62
3	43.93	1.18	1.60	1.62	2.83	2.80

Therefore, width of acting load shall be set as 2.83 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.28	4.96
Σ			4.96

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	1.61	8.04
Σ			8.04

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

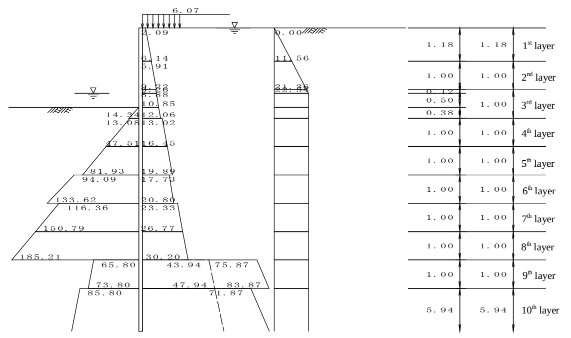
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{4.96 + 8.04 + 0.00}{2.83}$$

$$= 4.60 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



Passive earth pressure   Active earth pressure   Residual water pressure

3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 1.18	Sandy soil	10.0	27.0	—— ——	6.073 17.873	0.34800 0.34800	0.34371 0.34371
2	1.18～ 2.18	Sandy soil	10.0	28.0	—— ——	17.873 27.873	0.33506 0.33506	0.33093 0.33093
3	2.18～ 2.30	Sandy soil	10.0	29.0	—— ——	27.873 29.073	0.32248 0.32248	0.31851 0.31851
4	2.30～ 2.80	Sandy soil	10.0	29.0	—— ——	29.073 34.073	0.32248 0.32248	0.31851 0.31851
5	2.80～ 3.18	Sandy soil	10.0	29.0	—— ——	34.073 37.873	0.32248 0.32248	0.31851 0.31851
6	3.18～ 4.18	Sandy soil	10.0	27.0	—— ——	37.873 47.873	0.34800 0.34800	0.34371 0.34371
7	4.18～ 5.18	Sandy soil	10.0	27.0	—— ——	47.873 57.873	0.34800 0.34800	0.34371 0.34371
8	5.18～ 6.18	Sandy soil	10.0	30.0	—— ——	57.873 67.873	0.31026 0.31026	0.30644 0.30644
9	6.18～ 7.18	Sandy soil	10.0	27.0	—— ——	67.873 77.873	0.34800 0.34800	0.34371 0.34371
10	7.18～ 8.18	Sandy soil	10.0	27.0	—— ——	77.873 87.873	0.34800 0.34800	0.34371 0.34371
11	8.18～ 9.18	Clayey soil	8.0	—	6.0 6.0	87.873 95.873	—— ——	—— ——
12	9.18～ 15.12	Clayey soil	8.0	—	12.0 12.0	95.873 143.393	—— ——	—— ——
13	15.12～ 16.12	Clayey soil	8.0	—	18.0 18.0	143.393 151.393	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	16.12～ 18.12	Clayey soil	8.0	—	12.0 12.0	151.393 167.393	—— ——	—— ——
15	18.12～ 19.12	Clayey soil	8.0	—	18.0 18.0	167.393 175.393	—— ——	—— ——
16	19.12～ 20.12	Clayey soil	8.0	—	12.0 12.0	175.393 183.393	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
5	2.80～ 3.18	Sandy soil	10.0	29.0	—— ——	0.000 3.800	3.82002 3.82002	3.77299 3.77299
6	3.18～ 4.18	Sandy soil	10.0	27.0	—— ——	3.800 13.800	3.48553 3.48553	3.44261 3.44261
7	4.18～ 5.18	Sandy soil	10.0	27.0	—— ——	13.800 23.800	3.48553 3.48553	3.44261 3.44261
8	5.18～ 6.18	Sandy soil	10.0	30.0	—— ——	23.800 33.800	4.00247 4.00247	3.95319 3.95319
9	6.18～ 7.18	Sandy soil	10.0	27.0	—— ——	33.800 43.800	3.48553 3.48553	3.44261 3.44261
10	7.18～ 8.18	Sandy soil	10.0	27.0	—— ——	43.800 53.800	3.48553 3.48553	3.44261 3.44261
11	8.18～ 9.18	Clayey soil	8.0	0.0	6.0 6.0	53.800 61.800	—— ——	—— ——
12	9.18～ 15.12	Clayey soil	8.0	0.0	12.0 12.0	61.800 109.320	—— ——	—— ——
13	15.12～ 16.12	Clayey soil	8.0	0.0	18.0 18.0	109.320 117.320	—— ——	—— ——
14	16.12～ 18.12	Clayey soil	8.0	0.0	12.0 12.0	117.320 133.320	—— ——	—— ——
15	18.12～ 19.12	Clayey soil	8.0	0.0	18.0 18.0	133.320 141.320	—— ——	—— ——
16	19.12～ 20.12	Clayey soil	8.0	0.0	12.0 12.0	141.320 149.320	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

1.4

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 1.18	2.09 6.14	—— ——	2.09 6.14	0.00 11.56	—— ——
2	1.18～ 2.18	5.91 9.22	—— ——	5.91 9.22	11.56 21.36	—— ——
3	2.18～ 2.30	8.88 9.26	—— ——	8.88 9.26	21.36 22.54	—— ——
4	2.30～ 2.80	9.26 10.85	—— ——	9.26 10.85	22.54 22.54	—— ——
5	2.80～ 3.18	10.85 12.06	—— ——	10.85 12.06	22.54 22.54	0.00 14.34
6	3.18～ 4.18	13.02 16.45	—— ——	13.02 16.45	22.54 22.54	13.08 47.51
7	4.18～ 5.18	16.45 19.89	—— ——	16.45 19.89	22.54 22.54	47.51 81.93
8	5.18～ 6.18	17.73 20.80	—— ——	17.73 20.80	22.54 22.54	94.09 133.62
9	6.18～ 7.18	23.33 26.77	—— ——	23.33 26.77	22.54 22.54	116.36 150.79
10	7.18～ 8.18	26.77 30.20	—— ——	26.77 30.20	22.54 22.54	150.79 185.21
11	8.18～ 9.18	75.87 83.87	43.94 47.94	75.87 83.87	22.54 22.54	65.80 73.80
12	9.18～ 15.12	71.87 119.39	47.94 71.70	71.87 119.39	22.54 22.54	85.80 133.32
13	15.12～ 16.12	107.39 115.39	71.70 75.70	107.39 115.39	22.54 22.54	145.32 153.32
14	16.12～ 18.12	127.39 143.39	75.70 83.70	127.39 143.39	22.54 22.54	141.32 157.32
15	18.12～ 19.12	131.39 139.39	83.70 87.70	131.39 139.39	22.54 22.54	169.32 177.32
16	19.12～ 20.12	151.39 159.39	87.70 91.70	151.39 159.39	22.54 22.54	165.32 173.32

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

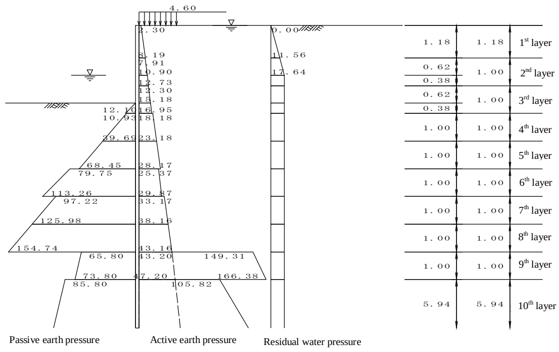
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 1.18	Sandy Soil	10.0	27.0	―― ――	4.60 16.40	0.00 11.56	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
2	1.18～ 1.80	Sandy Soil	10.0	28.0	―― ――	16.40 22.60	11.56 17.64	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	―― ――
3	1.80～ 2.18	Sandy Soil	10.0	28.0	―― ――	22.60 26.40	17.64 21.36	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	―― ――
4	2.18～ 2.80	Sandy Soil	10.0	29.0	―― ――	26.40 32.60	21.36 27.44	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	―― ――
5	2.80～ 3.18	Sandy Soil	10.0	29.0	―― ――	32.60 36.40	27.44 31.16	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	―― ――
6	3.18～ 4.18	Sandy Soil	10.0	27.0	―― ――	36.40 46.40	31.16 40.96	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
7	4.18～ 5.18	Sandy Soil	10.0	27.0	―― ――	46.40 56.40	40.96 50.76	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
8	5.18～ 6.18	Sandy Soil	10.0	30.0	―― ――	56.40 66.40	50.76 60.56	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	―― ――
9	6.18～ 7.18	Sandy Soil	10.0	27.0	―― ――	66.40 76.40	60.56 70.36	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
10	7.18～ 8.18	Sandy Soil	10.0	27.0	―― ――	76.40 86.40	70.36 80.16	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
11	8.18～ 9.18	Clayey Soil	8.0	―	6.0 6.0	86.40 94.40	80.16 89.96	0.200 0.200	11.31 11.31	―― ――	―― ――	10.00 10.00
12	9.18～ 15.12	Clayey Soil	8.0	―	12.0 12.0	94.40 141.92	89.96 148.18	0.200 0.200	11.31 11.31	―― ――	―― ――	22.71 10.00
13	15.12～ 16.12	Clayey Soil	8.0	―	18.0 18.0	141.92 149.92	148.18 157.98	0.200 0.200	11.31 11.31	―― ――	―― ――	23.33 20.62

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	16.12～ 18.12	Clayey Soil	8.0	―	12.0 12.0	149.92 165.92	157.98 177.58	0.200 0.200	11.31 11.31	―― ――	―― ――	10.00 10.00
15	18.12～ 19.12	Clayey Soil	8.0	―	18.0 18.0	165.92 173.92	177.58 187.38	0.200 0.200	11.31 11.31	―― ――	―― ――	12.93 10.00
16	19.12～ 20.12	Clayey Soil	8.0	―	12.0 12.0	173.92 181.92	187.38 197.18	0.200 0.200	11.31 11.31	―― ――	―― ――	10.00 10.00

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.80～ 3.18	Sandy soil	10.00	29.0	―― ――	0.000 3.800	0.00 3.72	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
6	3.18～ 4.18	Sandy soil	10.00	27.0	―― ――	3.800 13.800	3.72 13.52	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	4.18～ 5.18	Sandy soil	10.00	27.0	―― ――	13.800 23.800	13.52 23.32	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	5.18～ 6.18	Sandy soil	10.00	30.0	―― ――	23.800 33.800	23.32 33.12	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
9	6.18～ 7.18	Sandy soil	10.00	27.0	―― ――	33.800 43.800	33.12 42.92	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
10	7.18～ 8.18	Sandy soil	10.00	27.0	―― ――	43.800 53.800	42.92 52.72	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
11	8.18～ 9.18	Clayey soil	8.00	0.0	6.0 6.0	53.800 61.800	52.72 62.52	0.200 0.200	11.31 11.31	―― ――	―― ――
12	9.18～ 15.12	Clayey soil	8.00	0.0	12.0 12.0	61.800 109.320	62.52 120.74	0.200 0.200	11.31 11.31	―― ――	―― ――
13	15.12～ 16.12	Clayey soil	8.00	0.0	18.0 18.0	109.320 117.320	120.74 130.54	0.200 0.200	11.31 11.31	―― ――	―― ――
14	16.12～ 18.12	Clayey soil	8.00	0.0	12.0 12.0	117.320 133.320	130.54 150.14	0.200 0.200	11.31 11.31	―― ――	―― ――
15	18.12～ 19.12	Clayey soil	8.00	0.0	18.0 18.0	133.320 141.320	150.14 159.94	0.200 0.200	11.31 11.31	―― ――	―― ――
16	19.12～ 20.12	Clayey soil	8.00	0.0	12.0 12.0	141.320 149.320	159.94 169.74	0.200 0.200	11.31 11.31	―― ――	―― ――

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 1.18	2.30 8.19	―― ――	2.30 8.19	0.00 11.56	―― ――
2	1.18～ 1.80	7.91 10.90	―― ――	7.91 10.90	11.56 17.64	―― ――
3	1.80～ 2.18	10.90 12.73	―― ――	10.90 12.73	17.64 17.64	―― ――
4	2.18～ 2.80	12.30 15.18	―― ――	12.30 15.18	17.64 17.64	―― ――
5	2.80～ 3.18	15.18 16.95	―― ――	15.18 16.95	17.64 17.64	0.00 12.10
6	3.18～ 4.18	18.18 23.18	―― ――	18.18 23.18	17.64 17.64	10.93 39.69
7	4.18～ 5.18	23.18 28.17	―― ――	23.18 28.17	17.64 17.64	39.69 68.45
8	5.18～ 6.18	25.37 29.87	―― ――	25.37 29.87	17.64 17.64	79.75 113.26
9	6.18～ 7.18	33.17 38.16	―― ――	33.17 38.16	17.64 17.64	97.22 125.98
10	7.18～ 8.18	38.16 43.16	―― ――	38.16 43.16	17.64 17.64	125.98 154.74
11	8.18～ 9.18	149.31 166.38	43.20 47.20	149.31 166.38	17.64 17.64	65.80 73.80
12	9.18～ 15.12	105.82 232.71	47.20 70.96	105.82 232.71	17.64 17.64	85.80 133.32
13	15.12～ 16.12	158.22 174.99	70.96 74.96	158.22 174.99	17.64 17.64	145.32 153.32
14	16.12～ 18.12	249.79 283.94	74.96 82.96	249.79 283.94	17.64 17.64	141.32 157.32
15	18.12～ 19.12	227.91 265.92	82.96 86.96	227.91 265.92	17.64 17.64	169.32 177.32
16	19.12～ 20.12	301.01 318.08	86.96 90.96	301.01 318.08	17.64 17.64	165.32 173.32

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = \left[K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}\right] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = \left[K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}\right] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	1.80	0.00	0.00
2	2.80	1.00	1.72

$$p_{dw} = \pm\frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

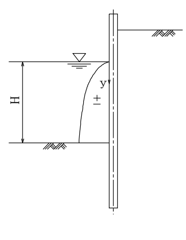
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

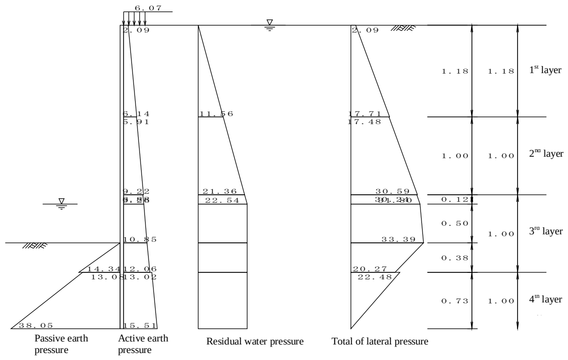
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

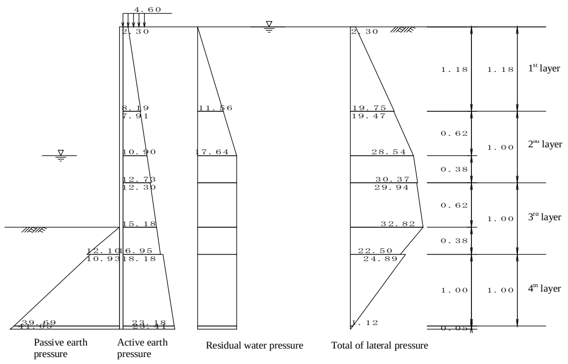


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 1.18	2.09 6.14	0.00 11.56	—— ——	2.09 17.71
2	1.18～ 2.18	5.91 9.22	11.56 21.36	—— ——	17.48 30.59
3	2.18～ 2.30	8.88 9.26	21.36 22.54	—— ——	30.24 31.80
4	2.30～ 2.80	9.26 10.85	22.54 22.54	—— ——	31.80 33.39
5	2.80～ 3.18	10.85 12.06	22.54 22.54	0.00 14.34	33.39 20.27
6	3.18～ 3.91	13.02 15.51	22.54 22.54	13.08 38.05	22.48 0.00
7	3.91～ 4.18	15.51 16.45	22.54 22.54	38.05 47.51	0.00 -8.51

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.11 m (GL -3.91 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 1.18	2.30 8.19	0.00 11.56	—— ——	2.30 19.75
2	1.18～ 1.80	7.91 10.90	11.56 17.64	—— ——	19.47 28.54
3	1.80～ 2.18	10.90 12.73	17.64 17.64	—— ——	28.54 30.37
4	2.18～ 2.80	12.30 15.18	17.64 17.64	—— ——	29.94 32.82
5	2.80～ 3.18	15.18 16.95	17.64 17.64	0.00 12.10	32.82 22.50
6	3.18～ 4.18	18.18 23.18	17.64 17.64	10.93 39.69	24.89 1.12
7	4.18～ 4.23	23.18 23.41	17.64 17.64	39.69 41.05	1.12 0.00
8	4.23～ 5.18	23.41 28.17	17.64 17.64	41.05 68.45	0.00 -22.64

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.43 m (GL -4.23 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴(original condition)
	I	=	39917 cm⁴(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	5
2	1.18	5
3	2.18	11
4	3.18	13
5	4.18	6
6	5.18	10
7	6.18	16
8	7.18	7
9	8.18	2
10	9.18	1

	Depth (m)	N-value
11	15.18	2
12	16.18	3
13	18.18	2
14	19.19	3
15	20.18	2

5-2 Normal Condition

K_h = 17277 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.482 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.07 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.91 m) to 2.07 m depth (GL -5.98 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.91	0.27	7.9	6.0	1.91
2	4.18	1.00	6.0	10.0	8.00
3	5.18	0.80	10.0	14.8	9.90
L =Σh = 2.07			ΣA = 19.81		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{19.81}{2.07}$$

$$= 9.56$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 9.56^{0.406} = 17277$ kN/m³

Kh (normal condition) = 17277 kN/m³

5-3 Seismic Condition

K_h = 18182 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.488 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.05 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.23 m) and 2.05 m depth (GL -6.27 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.23	0.95	6.2	10.0	7.71
2	5.18	1.00	10.0	16.0	13.00
3	6.18	0.09	16.0	15.2	1.47
L =Σh = 2.05			ΣA = 22.18		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{22.18}{2.05}$$

$$= 10.84$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.84^{0.406} = 18182$ kN/m³

Kh (seismic condition) = 18182 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 1.18	1.18	2.09 17.71	1.23 10.45	3.51 3.12	4.32 32.58
2	1.18～ 2.18	1.00	17.48 30.59	8.74 15.29	2.39 2.06	20.90 31.48
3	2.18～ 2.30	0.12	30.24 31.80	1.81 1.91	1.69 1.65	3.06 3.14
4	2.30～ 2.80	0.50	31.80 33.39	7.95 8.35	1.44 1.27	11.44 10.62
5	2.80～ 3.18	0.38	33.39 20.27	6.34 3.85	0.98 0.85	6.21 3.28
6	3.18～ 3.91	0.73	22.48 0.00	8.15 0.00	0.48 0.24	3.94 0.00
				ΣP = 74.08		ΣM = 130.98

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 1.0 kN/m
depth to acting position H_t = -0.13 m
moment M_m = 0.1 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.80 m
Depth of Imaginary riverbed from riverbed L_k = 1.11 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 4.14 kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{135.11}{75.08} = 1.80 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 1.18	1.18	2.30 19.75	1.35 11.65	3.83 3.44	5.19 40.10
2	1.18～ 1.80	0.62	19.47 28.54	6.04 8.85	2.84 2.63	17.15 23.30
3	1.80～ 2.18	0.38	28.54 30.37	5.42 5.77	2.30 2.17	12.47 12.55
4	2.18～ 2.80	0.62	29.94 32.82	9.28 10.18	1.84 1.63	17.08 16.63
5	2.80～ 3.18	0.38	32.82 22.50	6.24 4.27	1.30 1.17	8.11 5.02
6	3.18～ 4.18	1.00	24.89 1.12	12.45 0.56	0.71 0.38	8.88 0.21
7	4.18～ 4.23	0.05	1.12 0.00	0.03 0.00	0.03 0.02	0.00 0.00
				ΣP = 82.09		ΣM = 166.70

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 4.5 kN/m
depth to acting position H_t = 0.16 m
moment M_m = 2.9 kN·m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.80 m
Depth of Imaginary riverbed from riverbed L_k = 1.43 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 21.20 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	1.80～ 2.80	1.00	0.0 1.7	0.00 0.86	2.09 1.76	0.00 1.51
				ΣP_{dw} = 0.86		ΣM_{dw} = 1.51

h_0, Height of acting position of P_0 from imaginary riverbed

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴ (original condition)
	I	=	39917 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 39917 × 10⁻⁸		=	7.983 × 10⁴

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	17277	kN/m³
calculated value	β	=	0.48229	m⁻¹
resultant earth force (lateral)	P_0	=	75.08	kN/m
height of acting position of load	h_0	=	1.80	m
moment	M_0	=	135.11	kN·m/m

in consideration of ψ_m = 1.182,

maximum moment	M_{max}	=	159.70	kN·m/m
depth of generated position of M_{max}	l_m	=	0.727	m
depth of 1st fixed point	l_i	=	2.355	m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	18182	kN/m³
calculated value	β	=	0.48848	m⁻¹
resultant earth force (lateral)	P_0	=	87.44	kN/m
height of acting position of load	h_0	=	2.17	m
moment	M_0	=	189.41	kN·m/m

in consideration of ψ_m = 1.134,

maximum moment	M_{max}	=	214.73	kN·m/m
depth of generated position of M_{max}	l_m	=	0.636	m
depth of 1st fixed point	l_i	=	2.244	m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm³ (original condition)
	Z	=	2376 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{159.70 \times 10^6}{2376 \times 10^3} = 67 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2$$ (ok)

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{214.73 \times 10^6}{2376 \times 10^3} = 90 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2$$ (ok)

6-4 Displacement

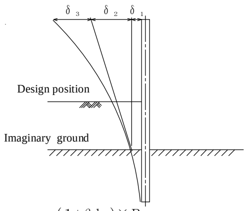
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.18	3.51 3.12	0.899 0.799	0.283 0.234	1.23 10.45	0.349 2.444
2	1.18～ 2.18	2.39 2.06	0.612 0.527	0.149 0.115	8.74 15.29	1.305 1.752
3	2.18～ 2.30	1.69 1.65	0.432 0.421	0.080 0.076	1.81 1.91	0.145 0.146
4	2.30～ 2.80	1.44 1.27	0.368 0.326	0.060 0.047	7.95 8.35	0.473 0.395
5	2.80～ 3.18	0.98 0.85	0.251 0.218	0.029 0.022	6.34 3.85	0.183 0.085
6	3.18～ 3.91	0.48 0.24	0.124 0.062	0.007 0.002	8.15 0.00	0.060 0.000
						ΣQ = 7.335

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4823\times1.80)\times75.08}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4823^3} = 0.00783 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4823\times1.80)\times75.08}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4823^2}\times(2.80+1.11) = 0.02160 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{7.33\times(2.80+1.11)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00547 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00026 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.91 m
Horizontal load: P = 1.00
Moment: M = 0.13

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI}\times(2L-h) \qquad (L=4.23 \text{ m、} h=L-H_m\text{、} H_m=0.80 \text{ m、ただし}_{H=L})$$

$$= \frac{2.90\times3.43}{2\times2.00\times10^8\times39917\times10^{-8}}\times(2\times4.23-3.43) = 0.00031 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00783＋0.02160＋0.00574
= 0.03517 m
= 35.17 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.18	3.83 3.44	0.907 0.814	0.287 0.241	1.35 11.65	0.389 2.813
2	1.18～ 1.80	2.84 2.63	0.672 0.623	0.175 0.154	6.04 8.85	1.058 1.361
3	1.80～ 2.18	2.30 2.17	0.544 0.514	0.121 0.110	5.42 5.77	0.657 0.632
4	2.18～ 2.80	1.84 1.63	0.435 0.387	0.081 0.065	9.28 10.18	0.752 0.662
5	2.80～ 3.18	1.30 1.17	0.308 0.278	0.042 0.035	6.24 4.27	0.265 0.150
6	3.18～ 4.18	0.71 0.38	0.169 0.090	0.013 0.004	12.45 0.56	0.167 0.002
7	4.18～ 4.23	0.03 0.02	0.007 0.004	0.000 0.000	0.03 0.00	0.000 0.000
						ΣQ = 8.908

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

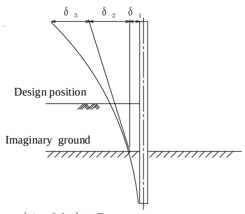
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	1.80～ 2.80	2.09 1.76	0.495 0.416	0.102 0.075	0.00 0.86	0.000 0.064
						ΣQ_{dw} = 0.064

Therefore, modulus of deformation Q is calculated as below:
Q = 10.323＋0.064 ＝ 10.387

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4885\times2.17)\times87.44}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4885^3} = 0.00967 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4885\times2.17)\times87.44}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4885^2}\times(2.80+1.43) = 0.03023 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.39\times(2.80+1.43)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00983 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI}\times(2L-h) \qquad (L=4.23 \text{ m、} h=L-H_m\text{、} H_m=0.80 \text{ m、ただし}_{H=L})$$

$$= \frac{2.90\times3.43}{2\times2.00\times10^8\times39917\times10^{-8}}\times(2\times4.23-3.43) = 0.00031 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00967＋0.03023＋0.01014
= 0.05005 m
= 50.05 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10^{-8}		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 17277 kN/m^3
Calculated value β = 0.44177 m^{-1}

Penetration length of SSP $D = 1.11 + \frac{3}{0.442} = 7.90$ m
Whole length of SSP $L = 2.80 - 0.40 + 7.90 = 10.30$ m

7-1-2 Seismic Conditio

Modules of lateral subgrade reaction K_h = 18182 kN/m^3
Calculated value β = 0.44744 m^{-1}

Penetration length of SSP $D = 1.43 + \frac{3}{0.447} = 8.13$ m
Whole length of SSP $L = 2.80 - 0.40 + 8.13 = 10.53$ m

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

8 Calculation Result

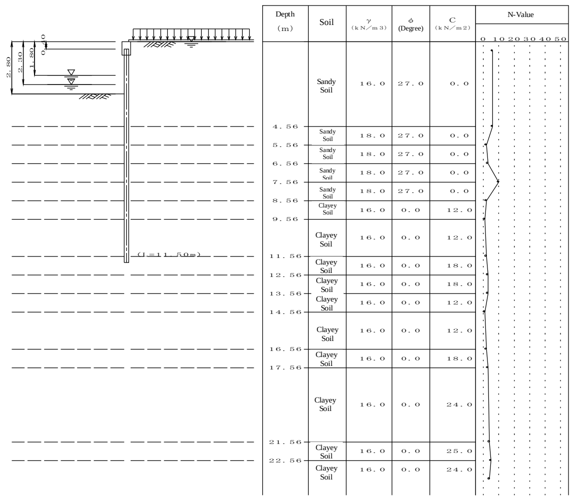
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		159.70	214.73
Stress intensity	σ (N/mm^2)		67 (180)	90 (270)
Lateral displacement	δ (mm)		35.17 (50.0)	50.05 (75.0)
Penetration depth	D (m)		7.90	8.13
Whole length of SSP	L (m)	11.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 02 STA_2+550 - 2+694

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.80 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.30 m (Normal Condition)
	L_{wp}'	=	1.80 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

Sandy Soil

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	0.4 kN/m	(Normal Condition)
		P_t'	=	3.9 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.05 m	(Normal Condition)
		H_t'	=	0.24 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN･m/m	(Normal Condition)
		M_m'	=	2.2 kN･m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	6
2	4.56	6
3	5.56	2
4	6.56	3
5	7.56	10
6	8.56	2
7	9.56	1
8	11.56	2
9	12.56	3
10	13.56	3

No	Depth (m)	N-Value
11	14.56	1
12	16.56	2
13	17.56	3
14	21.56	4
15	22.56	5
16	23.56	4

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

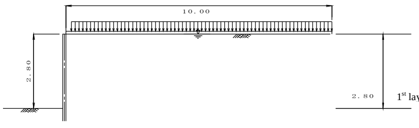
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	4.56	S	6.0	16.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
2	5.56	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
3	6.56	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
4	7.56	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
5	8.56	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
6	9.56	C	1.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
7	11.56	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
8	12.56	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
9	13.56	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
10	14.56	C	1.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
11	16.56	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
12	17.56	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
13	21.56	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	――	――
14	22.56	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	――	――
15	23.56	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	――	――

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active passive	9.00° -9.00°	9.00° -9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.00	10.00	10.00	0.11	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.20	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 56700 cm⁴
Sectional factor Z_0 = 2700 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

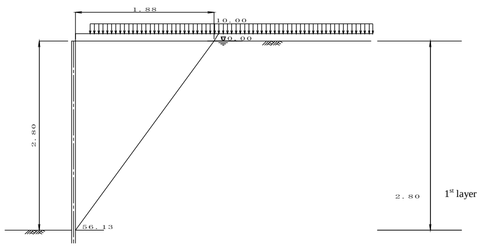
Allowable stress σ_a = 180 N/mm (Normal)
σ_a' = 270 N/mm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.80～ 0.00	Sandy Soil	27.0	9.0	0.0	28.00	11.29	27.44	56.13
2		Embankment	30.0	——	0.0	1.98	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	2.80	0.00	0.00	1.88	2.80
2	60.00	0.11	1.88	2.80	1.94	2.91

Therefore, width of acting load shall be set as 1.88 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.21	3.78
Σ			3.78

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.74	17.43
Σ			17.43

Q: surcharge load
l : width of surcharge load set by line of active rupture

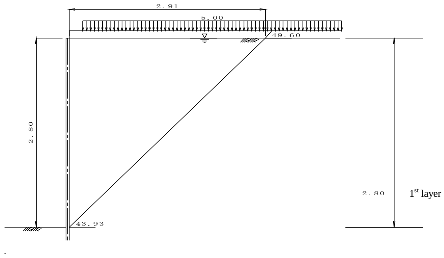
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{3.78 + 17.43 + 0.00}{1.88}$$

$$= 11.29 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.80～ 0.00	Sandy Soil	27.0	9.0	0.0	28.00	6.83	27.44	0.200	11.31	43.93
2		Embankment	30.0	——	0.0	1.98	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	2.80	0.00	0.00	2.91	2.80
2	49.60	0.11	2.91	2.80	3.00	2.91

Therefore, width of acting load shall be set as 2.91 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.32	5.85
Σ			5.85

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.80	14.00
Σ			14.00

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

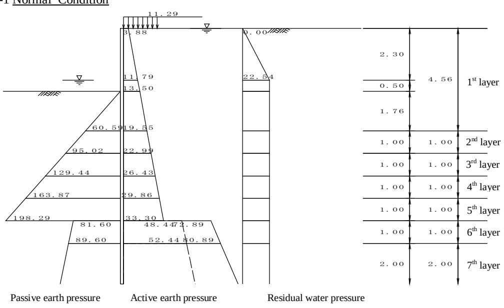
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{5.85 + 14.00 + 0.00}{2.91}$$

$$= 6.83 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.30	Sandy soil	10.0	27.0	—— ——	11.287 34.287	0.34800 0.34800	0.34371 0.34371
2	2.30～ 2.80	Sandy soil	10.0	27.0	—— ——	34.287 39.287	0.34800 0.34800	0.34371 0.34371
3	2.80～ 4.56	Sandy soil	10.0	27.0	—— ——	39.287 56.887	0.34800 0.34800	0.34371 0.34371
4	4.56～ 5.56	Sandy soil	10.0	27.0	—— ——	56.887 66.887	0.34800 0.34800	0.34371 0.34371
5	5.56～ 6.56	Sandy soil	10.0	27.0	—— ——	66.887 76.887	0.34800 0.34800	0.34371 0.34371
6	6.56～ 7.56	Sandy soil	10.0	27.0	—— ——	76.887 86.887	0.34800 0.34800	0.34371 0.34371
7	7.56～ 8.56	Sandy soil	10.0	27.0	—— ——	86.887 96.887	0.34800 0.34800	0.34371 0.34371
8	8.56～ 9.56	Clayey soil	8.0	—	12.0 12.0	96.887 104.887	—— ——	—— ——
9	9.56～ 11.56	Clayey soil	8.0	—	12.0 12.0	104.887 120.887	—— ——	—— ——
10	11.56～ 12.56	Clayey soil	8.0	—	18.0 18.0	120.887 128.887	—— ——	—— ——
11	12.56～ 13.56	Clayey soil	8.0	—	18.0 18.0	128.887 136.887	—— ——	—— ——
12	13.56～ 14.56	Clayey soil	8.0	—	12.0 12.0	136.887 144.887	—— ——	—— ——
13	14.56～ 16.56	Clayey soil	8.0	—	12.0 12.0	144.887 160.887	—— ——	—— ——
14	16.56～ 17.56	Clayey soil	8.0	—	18.0 18.0	160.887 168.887	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
15	17.56～ 21.56	Clayey soil	8.0	—	24.0 24.0	168.887 200.887	—— ——	—— ——
16	21.56～ 22.56	Clayey soil	8.0	—	25.0 25.0	200.887 208.887	—— ——	—— ——
17	22.56～ 23.56	Clayey soil	8.0	—	24.0 24.0	208.887 216.887	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.80～ 4.56	Sandy soil	10.0	27.0	—— ——	0.000 17.600	3.48553 3.48553	3.44261 3.44261
4	4.56～ 5.56	Sandy soil	10.0	27.0	—— ——	17.600 27.600	3.48553 3.48553	3.44261 3.44261
5	5.56～ 6.56	Sandy soil	10.0	27.0	—— ——	27.600 37.600	3.48553 3.48553	3.44261 3.44261
6	6.56～ 7.56	Sandy soil	10.0	27.0	—— ——	37.600 47.600	3.48553 3.48553	3.44261 3.44261
7	7.56～ 8.56	Sandy soil	10.0	27.0	—— ——	47.600 57.600	3.48553 3.48553	3.44261 3.44261
8	8.56～ 9.56	Clayey soil	8.0	0.0	12.0 12.0	57.600 65.600	—— ——	—— ——
9	9.56～ 11.56	Clayey soil	8.0	0.0	12.0 12.0	65.600 81.600	—— ——	—— ——
10	11.56～ 12.56	Clayey soil	8.0	0.0	18.0 18.0	81.600 89.600	—— ——	—— ——
11	12.56～ 13.56	Clayey soil	8.0	0.0	18.0 18.0	89.600 97.600	—— ——	—— ——
12	13.56～ 14.56	Clayey soil	8.0	0.0	12.0 12.0	97.600 105.600	—— ——	—— ——
13	14.56～ 16.56	Clayey soil	8.0	0.0	12.0 12.0	105.600 121.600	—— ——	—— ——
14	16.56～ 17.56	Clayey soil	8.0	0.0	18.0 18.0	121.600 129.600	—— ——	—— ——
15	17.56～ 21.56	Clayey soil	8.0	0.0	24.0 24.0	129.600 161.600	—— ——	—— ——
16	21.56～ 22.56	Clayey soil	8.0	0.0	25.0 25.0	161.600 169.600	—— ——	—— ——
17	22.56～ 23.56	Clayey soil	8.0	0.0	24.0 24.0	169.600 177.600	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.30	3.88 11.79	—— ——	3.88 11.79	0.00 22.54	—— ——
2	2.30～ 2.80	11.79 13.50	—— ——	11.79 13.50	22.54 22.54	—— ——
3	2.80～ 4.56	13.50 19.55	—— ——	13.50 19.55	22.54 22.54	0.00 60.59
4	4.56～ 5.56	19.55 22.99	—— ——	19.55 22.99	22.54 22.54	60.59 95.02
5	5.56～ 6.56	22.99 26.43	—— ——	22.99 26.43	22.54 22.54	95.02 129.44
6	6.56～ 7.56	26.43 29.86	—— ——	26.43 29.86	22.54 22.54	129.44 163.87
7	7.56～ 8.56	29.86 33.30	—— ——	29.86 33.30	22.54 22.54	163.87 198.29
8	8.56～ 9.56	72.89 80.89	48.44 52.44	72.89 80.89	22.54 22.54	81.60 89.60
9	9.56～ 11.56	80.89 96.89	52.44 60.44	80.89 96.89	22.54 22.54	89.60 105.60
10	11.56～ 12.56	84.89 92.89	60.44 64.44	84.89 92.89	22.54 22.54	117.60 125.60
11	12.56～ 13.56	92.89 100.89	64.44 68.44	92.89 100.89	22.54 22.54	125.60 133.60
12	13.56～ 14.56	112.89 120.89	68.44 72.44	112.89 120.89	22.54 22.54	121.60 129.60
13	14.56～ 16.56	120.89 136.89	72.44 80.44	120.89 136.89	22.54 22.54	129.60 145.60
14	16.56～ 17.56	124.89 132.89	80.44 84.44	124.89 132.89	22.54 22.54	157.60 165.60
15	17.56～ 21.56	120.89 152.89	84.44 100.44	120.89 152.89	22.54 22.54	177.60 209.60
16	21.56～ 22.56	150.89 158.89	100.44 104.44	150.89 158.89	22.54 22.54	211.60 219.60
17	22.56～ 23.56	160.89 168.89	104.44 108.44	160.89 168.89	22.54 22.54	217.60 225.60

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

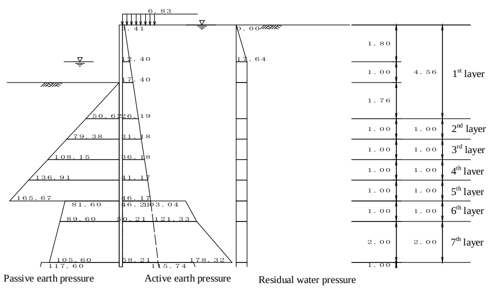
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 1.80	Sandy Soil	10.0	27.0	—— ——	6.83 24.83	0.00 17.64	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
2	1.80～ 2.80	Sandy Soil	10.0	27.0	—— ——	24.83 34.83	17.64 27.44	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.80～ 4.56	Sandy Soil	10.0	27.0	—— ——	34.83 52.43	27.44 44.69	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	4.56～ 5.56	Sandy Soil	10.0	27.0	—— ——	52.43 62.43	44.69 54.49	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	5.56～ 6.56	Sandy Soil	10.0	27.0	—— ——	62.43 72.43	54.49 64.29	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	6.56～ 7.56	Sandy Soil	10.0	27.0	—— ——	72.43 82.43	64.29 74.09	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
7	7.56～ 8.56	Sandy Soil	10.0	27.0	—— ——	82.43 92.43	74.09 83.89	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
8	8.56～ 9.56	Clayey Soil	8.0	—	12.0 12.0	92.43 100.43	83.89 93.69	0.200 0.200	11.31 11.31	—— ——	—— ——	22.58 18.05

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
9	9.56～ 11.56	Clayey Soil	8.0	—	12.0 12.0	100.43 116.43	93.69 113.29	0.200 0.200	11.31 11.31	—— ——	—— ——	18.05 10.00
10	11.56～ 12.56	Clayey Soil	8.0	—	18.0 18.0	116.43 124.43	113.29 123.09	0.200 0.200	11.31 11.31	—— ——	—— ——	29.31 27.49
11	12.56～ 13.56	Clayey Soil	8.0	—	18.0 18.0	124.43 132.43	123.09 132.89	0.200 0.200	11.31 11.31	—— ——	—— ——	27.49 25.44
12	13.56～ 14.56	Clayey Soil	8.0	—	12.0 12.0	132.43 140.43	132.89 142.69	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
13	14.56～ 16.56	Clayey Soil	8.0	—	12.0 12.0	140.43 156.43	142.69 162.29	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
14	16.56～ 17.56	Clayey Soil	8.0	—	18.0 18.0	156.43 164.43	162.29 172.09	0.200 0.200	11.31 11.31	—— ——	—— ——	16.96 12.43
15	17.56～ 21.56	Clayey Soil	8.0	—	24.0 24.0	164.43 196.43	172.09 211.29	0.200 0.200	11.31 11.31	—— ——	—— ——	28.16 21.37
16	21.56～ 22.56	Clayey Soil	8.0	—	25.0 25.0	196.43 204.43	211.29 221.09	0.200 0.200	11.31 11.31	—— ——	—— ——	23.38 21.49
17	22.56～ 23.56	Clayey Soil	8.0	—	24.0 24.0	204.43 212.43	221.09 230.89	0.200 0.200	11.31 11.31	—— ——	—— ——	19.09 16.38

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.80～ 4.56	Sandy soil	10.00	27.0	—— ——	0.000 17.600	0.00 17.25	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
4	4.56～ 5.56	Sandy soil	10.00	27.0	—— ——	17.600 27.600	17.25 27.05	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	5.56～ 6.56	Sandy soil	10.00	27.0	—— ——	27.600 37.600	27.05 36.85	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	6.56～ 7.56	Sandy soil	10.00	27.0	—— ——	37.600 47.600	36.85 46.65	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	7.56～ 8.56	Sandy soil	10.00	27.0	—— ——	47.600 57.600	46.65 56.45	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	8.56～ 9.56	Clayey soil	8.00	0.0	12.0 12.0	57.600 65.600	56.45 66.25	0.200 0.200	11.31 11.31	—— ——	—— ——
9	9.56～ 11.56	Clayey soil	8.00	0.0	12.0 12.0	65.600 81.600	66.25 85.85	0.200 0.200	11.31 11.31	—— ——	—— ——
10	11.56～ 12.56	Clayey soil	8.00	0.0	18.0 18.0	81.600 89.600	85.85 95.65	0.200 0.200	11.31 11.31	—— ——	—— ——
11	12.56～ 13.56	Clayey soil	8.00	0.0	18.0 18.0	89.600 97.600	95.65 105.45	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
12	13.56～ 14.56	Clayey soil	8.00	0.0	12.0 12.0	97.600 105.600	105.45 115.25	0.200 0.200	11.31 11.31	—— ——	—— ——
13	14.56～ 16.56	Clayey soil	8.00	0.0	12.0 12.0	105.600 121.600	115.25 134.85	0.200 0.200	11.31 11.31	—— ——	—— ——
14	16.56～ 17.56	Clayey soil	8.00	0.0	18.0 18.0	121.600 129.600	134.85 144.65	0.200 0.200	11.31 11.31	—— ——	—— ——
15	17.56～ 21.56	Clayey soil	8.00	0.0	24.0 24.0	129.600 161.600	144.65 183.85	0.200 0.200	11.31 11.31	—— ——	—— ——
16	21.56～ 22.56	Clayey soil	8.00	0.0	25.0 25.0	161.600 169.600	183.85 193.65	0.200 0.200	11.31 11.31	—— ——	—— ——
17	22.56～ 23.56	Clayey soil	8.00	0.0	24.0 24.0	169.600 177.600	193.65 203.45	0.200 0.200	11.31 11.31	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 1.80	3.41 12.40	—— ——	3.41 12.40	0.00 17.64	—— ——
2	1.80～ 2.80	12.40 17.40	—— ——	12.40 17.40	17.64 17.64	—— ——
3	2.80～ 4.56	17.40 26.19	—— ——	17.40 26.19	17.64 17.64	0.00 50.62
4	4.56～ 5.56	26.19 31.18	—— ——	26.19 31.18	17.64 17.64	50.62 79.38
5	5.56～ 6.56	31.18 36.18	—— ——	31.18 36.18	17.64 17.64	79.38 108.15
6	6.56～ 7.56	36.18 41.17	—— ——	36.18 41.17	17.64 17.64	108.15 136.91
7	7.56～ 8.56	41.17 46.17	—— ——	41.17 46.17	17.64 17.64	136.91 165.67
8	8.56～ 9.56	103.04 121.33	46.21 50.21	103.04 121.33	17.64 17.64	81.60 89.60
9	9.56～ 11.56	121.33 178.32	50.21 58.21	121.33 178.32	17.64 17.64	89.60 105.60
10	11.56～ 12.56	115.74 128.29	58.21 62.21	115.74 128.29	17.64 17.64	117.60 125.60
11	12.56～ 13.56	128.29 141.70	62.21 66.21	128.29 141.70	17.64 17.64	125.60 133.60
12	13.56～ 14.56	212.47 229.54	66.21 70.21	212.47 229.54	17.64 17.64	121.60 129.60
13	14.56～ 16.56	229.54 263.69	70.21 78.21	229.54 263.69	17.64 17.64	129.60 145.60

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
14	16.56～ 17.56	194.50 228.01	78.21 82.21	194.50 228.01	17.64 17.64	157.60 165.60
15	17.56～ 21.56	168.19 226.11	82.21 98.21	168.19 226.11	17.64 17.64	177.60 209.60
16	21.56～ 22.56	218.66 234.94	98.21 102.21	218.66 234.94	17.64 17.64	211.60 219.60
17	22.56～ 23.56	244.92 268.25	102.21 106.21	244.92 268.25	17.64 17.64	217.60 225.60

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	1.80 2.80	0.00 1.00	0.00 1.72

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

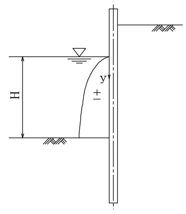
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

y : depth from water surface to the point where active water pressure is calculated

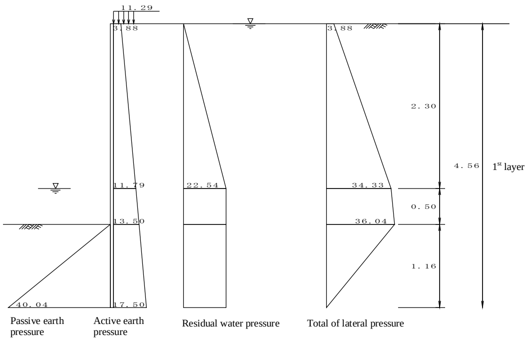


1.13

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

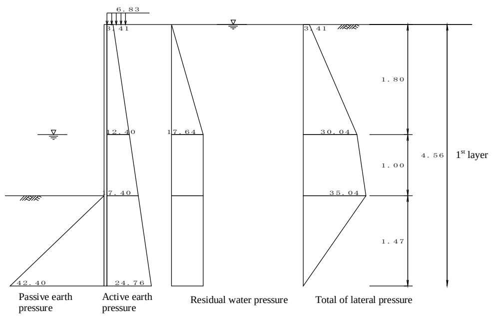


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.30	3.88 11.79	0.00 22.54	—— ——	3.88 34.33
2	2.30～ 2.80	11.79 13.50	22.54 22.54	—— ——	34.33 36.04
3	2.80～ 3.96	13.50 17.50	22.54 22.54	0.00 40.04	36.04 0.00
4	3.96～ 4.56	17.50 19.55	22.54 22.54	40.04 60.59	0.00 -18.50

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.16 m (GL -3.96 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 1.80	3.41 12.40	0.00 17.64	—— ——	3.41 30.04
2	1.80～ 2.80	12.40 17.40	17.64 17.64	—— ——	30.04 35.04
3	2.80～ 4.27	17.40 24.76	17.64 17.64	0.00 42.40	35.04 0.00
4	4.27～ 4.56	24.76 26.19	17.64 17.64	42.40 50.62	0.00 -6.79

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.47 m (GL -4.27 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴(original condition)
	I	=	39917 cm⁴(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	6
2	4.56	6
3	5.56	2
4	6.56	3
5	7.56	10
6	8.56	2
7	9.56	1
8	11.56	2
9	12.56	3
10	13.56	3

	Depth (m)	N-value
11	14.56	1
12	16.56	2
13	17.56	3
14	21.56	4
15	22.56	5
16	23.56	4

5-2 Normal Condition

K_h = 12177 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$
$$= 0.442 \quad m^{-1}$$
$$L = \frac{1}{\beta} = 2.26 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.96 m) to 2.26 m depth (GL -6.23 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.96	0.60	6.0	6.0	3.58
2	4.56	1.00	6.0	2.0	4.00
3	5.56	0.67	2.0	2.7	1.55
	L =Σh = 2.26				ΣA = 9.14

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{9.14}{2.26}$$
$$= 4.04$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 4.04^{0.406} = 12177$ kN/m³

Kh (normal condition) = 12177 kN/m³

5-3 Seismic Condition

K_h = 11614 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$
$$= 0.437 \quad m^{-1}$$
$$L = \frac{1}{\beta} = 2.29 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.27 m) and 2.29 m depth (GL -6.56 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.27	0.29	6.0	6.0	1.71
2	4.56	1.00	6.0	2.0	4.00
3	5.56	1.00	2.0	3.0	2.50
4	6.56	0.00	3.0	3.0	0.01
	L =Σh = 2.29				ΣA = 8.23

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{8.23}{2.29}$$
$$= 3.59$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 3.59^{0.406} = 11614$ kN/m³

Kh (seismic condition) = 11614 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.30	2.30	3.88 34.33	4.46 39.47	3.20 2.43	14.26 95.91
2	2.30～ 2.80	0.50	34.33 36.04	8.58 9.01	1.50 1.33	12.84 11.98
3	2.80～ 3.96	1.16	36.04 0.00	20.96 0.00	0.78 0.39	16.25 0.00
				ΣP = 82.49		ΣM = 151.25

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 0.4 kN/m
depth to acting position H_t = -0.05 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.80 m
Depth of Imaginary riverbed from riverbed L_k = 1.16 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 1.61$ kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{152.86}{82.89} = 1.84 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 1.80	1.80	3.41 30.04	3.07 27.04	3.67 3.07	11.28 83.12
2	1.80～ 2.80	1.00	30.04 35.04	15.02 17.52	2.14 1.81	32.16 31.67
3	2.80～ 4.27	1.47	35.04 0.00	25.83 0.00	0.98 0.49	25.38 0.00
				ΣP = 88.47		ΣM = 183.60

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 3.9 kN/m
depth to acting position H_t = 0.24 m
moment M_m = 2.2 kN·m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.80 m
Depth of Imaginary riverbed from riverbed L_k = 1.47 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 17.93$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	1.80～ 2.80	1.00	0.0 1.7	0.00 0.86	2.14 1.81	0.00 1.55
				ΣPdw = 0.86		ΣMdw = 1.55

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{203.09}{93.23} = 2.18 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 0.80
Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 56700 cm^4 (original condition)
I = 39917 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 12177 kN/m^3
calculated value β = 0.44190 m^{-1}
resultant earth force (lateral) P_0 = 82.89 kN/m
height of acting position of load h_0 = 1.84 m
moment M_0 = 152.86 kN·m/m

in consideration of ψ_m = 1.200,
maximum moment M_{max} = 183.48 kN·m/m
depth of generated position of M_{max} l_m = 0.822 m
depth of 1st fixed point l_i = 2.600 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 11614 kN/m^3
calculated value β = 0.43670 m^{-1}
resultant earth force (lateral) P_0 = 93.23 kN/m
height of acting position of load h_0 = 2.18 m
moment M_0 = 203.09 kN·m/m

in consideration of ψ_m = 1.158,
maximum moment M_{max} = 235.17 kN·m/m
depth of generated position of M_{max} l_m = 0.760 m
depth of 1st fixed point l_i = 2.558 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 1.00
Module of section Z_0 = 2700 cm^3 (original condition)
Z = 2376 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{183.48 \times 10^6}{2376 \times 10^3} = 77 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{235.17 \times 10^6}{2376 \times 10^3} = 99 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

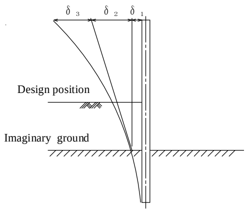
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.30	3.20 2.43	0.807 0.613	0.238 0.150	4.46 39.47	1.061 5.903
2	2.30～ 2.80	1.50 1.33	0.378 0.336	0.062 0.050	8.58 9.01	0.535 0.451
3	2.80～ 3.96	0.78 0.39	0.196 0.098	0.018 0.005	20.96 0.00	0.375 0.000
						ΣQ = 8.324

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3} = \frac{(1+0.4419\times1.84)\times82.89}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4419^3} = 0.01092 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k) = \frac{(1+2\times0.4419\times1.84)\times82.89}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4419^2}\times(2.80+1.16) = 0.02771 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI} = \frac{8.32\times(2.80+1.16)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00649 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00011 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.96 m
Horizontal load: P = 0.40
Moment: M = 0.02

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01092 + 0.02771 + 0.00660$
$= 0.04522$ m
$= 45.22 \leqq \delta a = 50.00$ mm (ok)

Where,

Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.80	3.67 3.07	0.860 0.719	0.264 0.197	3.07 27.04	0.809 5.317
2	1.80～ 2.80	2.14 1.81	0.501 0.423	0.105 0.077	15.02 17.52	1.570 1.346
3	2.80～ 4.27	0.98 0.49	0.230 0.115	0.024 0.006	25.83 0.00	0.630 0.000
						ΣQ ＝ 9.672

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

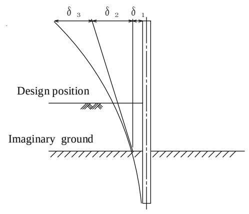
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	1.80～ 2.80	2.14 1.81	0.501 0.423	0.105 0.077	0.00 0.86	0.000 0.066
						ΣQ_{dw} ＝ 0.066

Therefore, modulus of deformation Q is calculated as below:

Q = 10.862＋0.066 ＝ 10.928

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4367\times 2.18)\times 93.23}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.4367^3} = 0.01368 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4367\times 2.18)\times 93.23}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.4367^2}\times(2.80+1.47) = 0.03798 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.93\times(2.80+1.47)^3}{2.00\times 10^8\times 39917\times 10^{-8}} = 0.01069 \text{ m}$$

Additional displacement δ_3’ generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h)$$ （L＝4.27 m、h＝L－H_m、H_m＝0.80 m、ただしh≦L）

$$= \frac{2.20\times 3.47}{2\times 2.00\times 10^8\times 39917\times 10^{-8}}\times(2\times 4.27-3.47) = 0.00024 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01368＋0.03798＋0.01093

= 0.06260 m

= 62.60 ≦ δ_a = 75.00 mm (ok)

Where,

δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young’s modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴ (original condition)
	I	=	56700 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 56700 × 10⁻⁸		=	1.134 × 10⁵

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction
Calculated value

K_h ＝ 12177 kN/m³
β ＝ 0.40477 m⁻¹

Penetration length of SSP
Whole length of SSP

$D = 1.16 + \dfrac{3}{0.405} = 8.57$ m
$L = 2.80 - 0.40 + 8.57 = 10.97$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction
Calculated value

K_h ＝ 11614 kN/m³
β ＝ 0.40002 m⁻¹

Penetration length of SSP
Whole length of SSP

$D = 1.47 + \dfrac{3}{0.400} = 8.97$ m
$L = 2.80 - 0.40 + 8.97 = 11.37$ m

Therefore, whole length of SSP is set as 11.50 m in consideration of round unit of SSP length.

8 Calculation Result

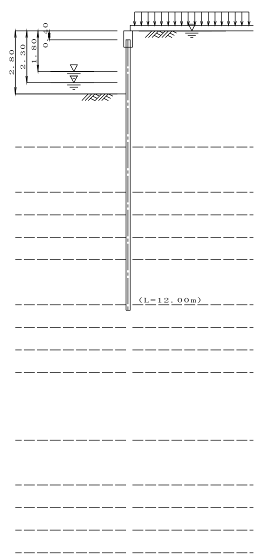
			Normal condition	Seismic condition
Inertia sectional moment	I (cm⁴)	56700		
Section modulus	Z (cm³)	2700		
Maximum bending moment	M_{max} (kN·m/m)		183.48	235.17
Stress intensity	σ (N/mm²)		77 (180)	99 (270)
Lateral displacement	δ (mm)		45.22 (50.0)	62.60 (75.0)
Penetration depth	D (m)		8.57	8.97
Whole length of SSP	L (m)	11.50		

－Steel Sheet Pile Design Calculation－

Left Bank No. 03_STA 2+854 - 2+950

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	ϕ (Degree)	C (kN/m2)	N-Value (0 10 20 30 40 50)
5.16	Sandy Soil	18.0	27.0	0.0	
7.16	Sandy Soil	18.0	27.0	0.0	
8.16	Sandy Soil	18.0	27.0	0.0	
9.16	Sandy Soil	18.0	27.0	0.0	
10.16	Clayey Soil	16.0	0.0	12.0	
12.16	Clayey Soil	16.0	0.0	18.0	
13.16	Clayey Soil	16.0	0.0	24.0	
14.16	Clayey Soil	16.0	0.0	18.0	
15.16	Clayey Soil	16.0	0.0	25.0	
18.16	Clayey Soil	16.0	0.0	24.0	
20.16	Sandy Soil	18.0	27.0	0.0	
21.16	Clayey Soil	16.0	0.0	24.0	
22.16	Clayey Soil	16.0	0.0	25.0	
23.16	Clayey Soil	16.0	0.0	25.0	
	Clayey Soil	16.0	0.0	50.0	

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.80 m	
Depth from coping top to rear side ground	H_h	=	0.00 m	
Depth from coping top to SSP top	H_t	=	0.40 m	
Landside WL	L_{wa}	=	0.00 m	(Normal Condition)
	L_{wa}'	=	0.00 m	(Seismic Condition)
Riverside WL	L_{wn}	=	2.30 m	(Normal Condition)
	L_{wn}'	=	1.80 m	(Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	1.1 kN/m	(Normal Condition)
		P_t'	=	4.7 kN/m	(Seismic Condition)
	Depth of acting point	H	=	-0.13 m	(Normal Condition)
		H'	=	0.14 m	(Seismic Condition)
	Moment	M_m	=	0.1 kN·m/m	(Normal Condition)
		M_m'	=	3.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$

Equilibrium factor of compression K_r = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910\times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	4
2	5.16	4
3	7.16	2
4	8.16	3
5	9.16	2
6	10.16	2
7	12.16	3
8	13.16	4
9	14.16	3
10	15.16	5

No	Depth (m)	N-Value
11	20.16	4
12	21.16	4
13	22.60	5
14	23.16	6
15	24.16	12

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

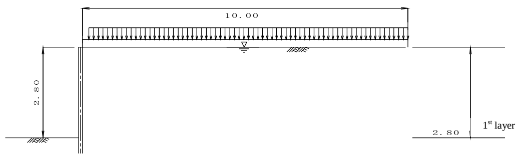
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	ϕ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m^3) normal	kh (kN/m^3) seismic
1	5.16	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
2	7.16	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	8.16	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	9.16	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	10.16	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
6	12.16	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
7	13.16	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
8	14.16	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
9	15.16	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
10	18.16	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
11	20.16	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
12	21.16	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
13	22.16	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
14	23.16	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
15	24.16	C	12.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.00	10.00	10.00	0.24	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.20	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 63000 cm⁴
Sectional factor Z_0 = 3150 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.91
Corrosion rate (to Z_0) η = 0.91
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

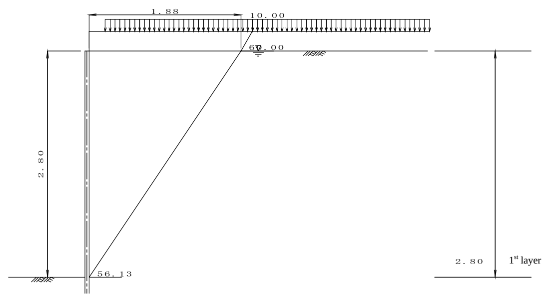
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.80～ 0.00	Sandy Soil	27.0	9.0	0.0	28.00	14.15	27.44	56.13
2		Embankment	30.0	—	0.0	4.32	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	2.80	0.00	0.00	1.88	2.80
2	60.00	0.24	1.88	2.80	2.02	3.04

Therefore, width of acting load shall be set as 1.88 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.47	8.42
Σ			8.42

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.82	18.18
Σ			18.18

Q surcharge load
l : width of surcharge load set by line of active rupture

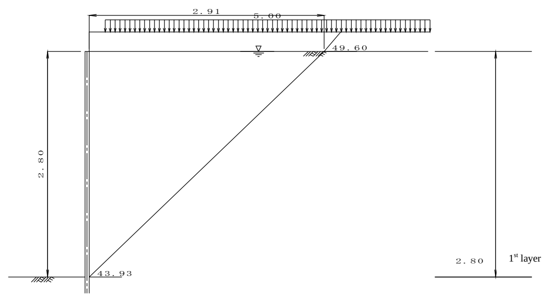
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{8.42 + 18.18 + 0.00}{1.88}$$

$$= 14.15\ \text{kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.80～ 0.00	Sandy Soil	27.0	9.0	0.0	28.00	9.48	27.44	0.200	11.31	43.93
2		Embankment	30.0	—	0.0	4.32	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	2.80	0.00	0.00	2.91	2.80
2	49.60	0.24	2.91	2.80	3.11	3.04

Therefore, width of acting load shall be set as 2.91 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.72	13.00
Σ			13.00

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.91	14.56
Σ			14.56

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

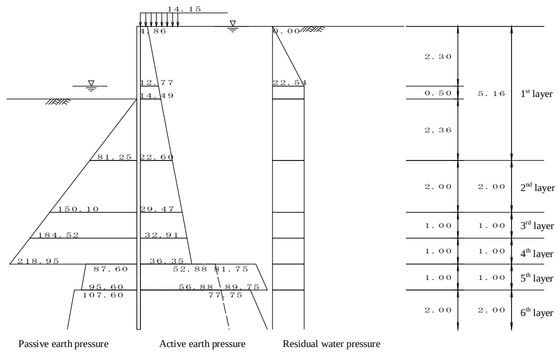
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{13.00 + 14.56 + 0.00}{2.91}$$

$$= 9.48 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.30	Sandy soil	10.0	27.0	— —	14.152 37.152	0.34800 0.34800	0.34371 0.34371
2	2.30~ 2.80	Sandy soil	10.0	27.0	— —	37.152 42.152	0.34800 0.34800	0.34371 0.34371
3	2.80~ 5.16	Sandy soil	10.0	27.0	— —	42.152 65.752	0.34800 0.34800	0.34371 0.34371
4	5.16~ 7.16	Sandy soil	10.0	27.0	— —	65.752 85.752	0.34800 0.34800	0.34371 0.34371
5	7.16~ 8.16	Sandy soil	10.0	27.0	— —	85.752 95.752	0.34800 0.34800	0.34371 0.34371
6	8.16~ 9.16	Sandy soil	10.0	27.0	— —	95.752 105.752	0.34800 0.34800	0.34371 0.34371
7	9.16~ 10.16	Clayey soil	8.0	—	12.0 12.0	105.752 113.752	— —	— —
8	10.16~ 12.16	Clayey soil	8.0	—	18.0 18.0	113.752 129.752	— —	— —
9	12.16~ 13.16	Clayey soil	8.0	—	24.0 24.0	129.752 137.752	— —	— —
10	13.16~ 14.16	Clayey soil	8.0	—	18.0 18.0	137.752 145.752	— —	— —
11	14.16~ 15.16	Clayey soil	8.0	—	25.0 25.0	145.752 153.752	— —	— —
12	15.16~ 18.16	Clayey soil	8.0	—	24.0 24.0	153.752 177.752	— —	— —
13	18.16~ 20.16	Sandy soil	10.0	27.0	— —	177.752 197.752	0.34800 0.34800	0.34371 0.34371

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	20.16~ 21.16	Clayey soil	8.0	—	24.0 24.0	197.752 205.752	— —	— —
15	21.16~ 22.16	Clayey soil	8.0	—	25.0 25.0	205.752 213.752	— —	— —
16	22.16~ 23.16	Clayey soil	8.0	—	25.0 25.0	213.752 221.752	— —	— —
17	23.16~ 24.16	Clayey soil	8.0	—	50.0 50.0	221.752 229.752	— —	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.80~ 5.16	Sandy soil	10.0	27.0	— —	0.000 23.600	3.48553 3.48553	3.44261 3.44261
4	5.16~ 7.16	Sandy soil	10.0	27.0	— —	23.600 43.600	3.48553 3.48553	3.44261 3.44261
5	7.16~ 8.16	Sandy soil	10.0	27.0	— —	43.600 53.600	3.48553 3.48553	3.44261 3.44261
6	8.16~ 9.16	Sandy soil	10.0	27.0	— —	53.600 63.600	3.48553 3.48553	3.44261 3.44261
7	9.16~ 10.16	Clayey soil	8.0	0.0	12.0 12.0	63.600 71.600	— —	— —
8	10.16~ 12.16	Clayey soil	8.0	0.0	18.0 18.0	71.600 87.600	— —	— —
9	12.16~ 13.16	Clayey soil	8.0	0.0	24.0 24.0	87.600 95.600	— —	— —
10	13.16~ 14.16	Clayey soil	8.0	0.0	18.0 18.0	95.600 103.600	— —	— —
11	14.16~ 15.16	Clayey soil	8.0	0.0	25.0 25.0	103.600 111.600	— —	— —
12	15.16~ 18.16	Clayey soil	8.0	0.0	24.0 24.0	111.600 135.600	— —	— —
13	18.16~ 20.16	Sandy soil	10.0	27.0	— —	135.600 155.600	3.48553 3.48553	3.44261 3.44261
14	20.16~ 21.16	Clayey soil	8.0	0.0	24.0 24.0	155.600 163.600	— —	— —
15	21.16~ 22.16	Clayey soil	8.0	0.0	25.0 25.0	163.600 171.600	— —	— —
16	22.16~ 23.16	Clayey soil	8.0	0.0	25.0 25.0	171.600 179.600	— —	— —
17	23.16~ 24.16	Clayey soil	8.0	0.0	50.0 50.0	179.600 187.600	— —	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 2.30	4.86 12.77	— —	4.86 12.77	0.00 22.54	— —
2	2.30~ 2.80	12.77 14.49	— —	12.77 14.49	22.54 22.54	— —
3	2.80~ 5.16	14.49 22.60	— —	14.49 22.60	22.54 22.54	0.00 81.25
4	5.16~ 7.16	22.60 29.47	— —	22.60 29.47	22.54 22.54	81.25 150.10
5	7.16~ 8.16	29.47 32.91	— —	29.47 32.91	22.54 22.54	150.10 184.52
6	8.16~ 9.16	32.91 36.35	— —	32.91 36.35	22.54 22.54	184.52 218.95
7	9.16~ 10.16	81.75 89.75	52.88 56.88	81.75 89.75	22.54 22.54	87.60 95.60
8	10.16~ 12.16	77.75 93.75	56.88 64.88	77.75 93.75	22.54 22.54	107.60 123.60
9	12.16~ 13.16	81.75 89.75	64.88 68.88	81.75 89.75	22.54 22.54	135.60 143.60
10	13.16~ 14.16	101.75 109.75	68.88 72.88	101.75 109.75	22.54 22.54	131.60 139.60
11	14.16~ 15.16	95.75 103.75	72.88 76.88	95.75 103.75	22.54 22.54	153.60 161.60
12	15.16~ 18.16	105.75 129.75	76.88 88.88	105.75 129.75	22.54 22.54	159.60 183.60
13	18.16~ 20.16	61.10 67.97	— —	61.10 67.97	22.54 22.54	466.82 535.67
14	20.16~ 21.16	149.75 157.75	98.88 102.88	149.75 157.75	22.54 22.54	203.60 211.60
15	21.16~ 22.16	155.75 163.75	102.88 106.88	155.75 163.75	22.54 22.54	213.60 221.60
16	22.16~ 23.16	163.75 171.75	106.88 110.88	163.75 171.75	22.54 22.54	221.60 229.60
17	23.16~ 24.16	121.75 129.75	110.88 114.88	121.75 129.75	22.54 22.54	279.60 287.60

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

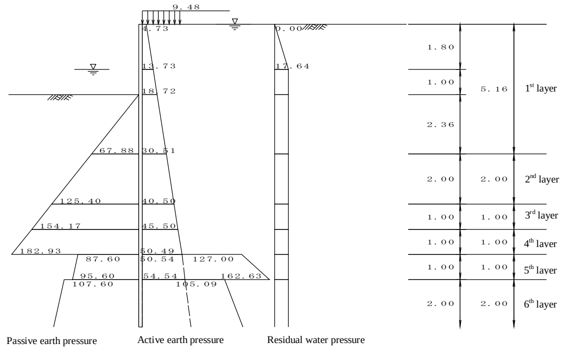
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 1.80	Sandy Soil	10.0	27.0	—— ——	9.48 27.48	0.00 17.64	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
2	1.80~ 2.80	Sandy Soil	10.0	27.0	—— ——	27.48 37.48	17.64 27.44	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.80~ 5.16	Sandy Soil	10.0	27.0	—— ——	37.48 61.08	27.44 50.57	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	5.16~ 7.16	Sandy Soil	10.0	27.0	—— ——	61.08 81.08	50.57 70.17	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	7.16~ 8.16	Sandy Soil	10.0	27.0	—— ——	81.08 91.08	70.17 79.97	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	8.16~ 9.16	Sandy Soil	10.0	27.0	—— ——	91.08 101.08	79.97 89.77	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	9.16~ 10.16	Clayey soil	8.0	—	12.0 12.0	101.08 109.08	89.77 99.57	0.200 0.200	11.31 11.31	—— ——	—— ——	15.67 10.00
8	10.16~ 12.16	Clayey soil	8.0	—	18.0 18.0	109.08 125.08	99.57 119.17	0.200 0.200	11.31 11.31	—— ——	—— ——	30.30 26.68
9	12.16~ 13.16	Clayey soil	8.0	—	24.0 24.0	125.08 133.08	119.17 128.97	0.200 0.200	11.31 11.31	—— ——	—— ——	33.54 32.50
10	13.16~ 14.16	Clayey soil	8.0	—	18.0 18.0	133.08 141.08	128.97 138.77	0.200 0.200	11.31 11.31	—— ——	—— ——	24.52 22.02
11	14.16~ 15.16	Clayey soil	8.0	—	25.0 25.0	141.08 149.08	138.77 148.57	0.200 0.200	11.31 11.31	—— ——	—— ——	32.24 31.17
12	15.16~ 18.16	Clayey soil	8.0	—	24.0 24.0	149.08 173.08	148.57 177.97	0.200 0.200	11.31 11.31	—— ——	—— ——	30.22 26.07
13	18.16~ 20.16	Sandy soil	10.0	27.0	—— ——	173.08 193.08	177.97 197.57	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
14	20.16~ 21.16	Clayey soil	8.0	—	24.0 24.0	193.08 201.08	197.57 207.37	0.200 0.200	11.31 11.31	—— ——	—— ——	21.55 19.30
15	21.16~ 22.16	Clayey soil	8.0	—	25.0 25.0	201.08 209.08	207.37 217.17	0.200 0.200	11.31 11.31	—— ——	—— ——	21.66 19.53
16	22.16~ 23.16	Clayey soil	8.0	—	25.0 25.0	209.08 217.08	217.17 226.97	0.200 0.200	11.31 11.31	—— ——	—— ——	19.53 17.03
17	23.16~ 24.16	Clayey soil	8.0	—	50.0 50.0	217.08 225.08	226.97 236.77	0.200 0.200	11.31 11.31	—— ——	—— ——	36.48 36.08

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below:

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.80~ 5.16	Sandy soil	10.00	27.0	—— ——	0.000 23.600	0.00 23.13	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
4	5.16~ 7.16	Sandy soil	10.00	27.0	—— ——	23.600 43.600	23.13 42.73	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	7.16~ 8.16	Sandy soil	10.00	27.0	—— ——	43.600 53.600	42.73 52.53	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	8.16~ 9.16	Sandy soil	10.00	27.0	—— ——	53.600 63.600	52.53 62.33	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	9.16~ 10.16	Clayey soil	8.00	0.0	12.0 12.0	63.600 71.600	62.33 72.13	0.200 0.200	11.31 11.31	—— ——	—— ——
8	10.16~ 12.16	Clayey soil	8.00	0.0	18.0 18.0	71.600 87.600	72.13 91.73	0.200 0.200	11.31 11.31	—— ——	—— ——
9	12.16~ 13.16	Clayey soil	8.00	0.0	24.0 24.0	87.600 95.600	91.73 101.53	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
10	13.16~ 14.16	Clayey soil	8.00	0.0	18.0 18.0	95.600 103.600	101.53 111.33	0.200 0.200	11.31 11.31	—— ——	—— ——
11	14.16~ 15.16	Clayey soil	8.00	0.0	25.0 25.0	103.600 111.600	111.33 121.13	0.200 0.200	11.31 11.31	—— ——	—— ——
12	15.16~ 18.16	Clayey soil	8.00	0.0	24.0 24.0	111.600 135.600	121.13 150.53	0.200 0.200	11.31 11.31	—— ——	—— ——
13	18.16~ 20.16	Sandy soil	10.00	27.0	—— ——	135.600 155.600	150.53 170.13	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
14	20.16~ 21.16	Clayey soil	8.00	0.0	24.0 24.0	155.600 163.600	170.13 179.93	0.200 0.200	11.31 11.31	—— ——	—— ——
15	21.16~ 22.16	Clayey soil	8.00	0.0	25.0 25.0	163.600 171.600	179.93 189.73	0.200 0.200	11.31 11.31	—— ——	—— ——
16	22.16~ 23.16	Clayey soil	8.00	0.0	25.0 25.0	171.600 179.600	189.73 199.53	0.200 0.200	11.31 11.31	—— ——	—— ——
17	23.16~ 24.16	Clayey soil	8.00	0.0	50.0 50.0	179.600 187.600	199.53 209.33	0.200 0.200	11.31 11.31	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below:

$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 1.80	4.73 13.73	—— ——	4.73 13.73	0.00 17.64	—— ——
2	1.80~ 2.80	13.73 18.72	—— ——	13.73 18.72	17.64 17.64	—— ——
3	2.80~ 5.16	18.72 30.51	—— ——	18.72 30.51	17.64 17.64	0.00 67.88
4	5.16~ 7.16	30.51 40.50	—— ——	30.51 40.50	17.64 17.64	67.88 125.40
5	7.16~ 8.16	40.50 45.50	—— ——	40.50 45.50	17.64 17.64	125.40 154.17
6	8.16~ 9.16	45.50 50.49	—— ——	45.50 50.49	17.64 17.64	154.17 182.93
7	9.16~ 10.16	127.00 162.63	50.54 54.54	127.00 162.63	17.64 17.64	87.60 95.60
8	10.16~ 12.16	105.09 130.00	54.54 62.54	105.09 130.00	17.64 17.64	107.60 123.60
9	12.16~ 13.16	110.70 121.89	62.54 66.54	110.70 121.89	17.64 17.64	135.60 143.60
10	13.16~ 14.16	143.76 159.06	66.54 70.54	143.76 159.06	17.64 17.64	131.60 139.60
11	14.16~ 15.16	130.41 141.92	70.54 74.54	130.41 141.92	17.64 17.64	153.60 161.60

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
12	15.16~ 18.16	145.08 183.04	74.54 86.54	145.08 183.04	17.64 17.64	159.60 183.60
13	18.16~ 20.16	86.46 96.45	—— ——	86.46 96.45	17.64 17.64	390.02 447.55
14	20.16~ 21.16	220.60 238.97	96.54 100.54	220.60 238.97	17.64 17.64	203.60 211.60
15	21.16~ 22.16	229.46 247.63	100.54 104.54	229.46 247.63	17.64 17.64	213.60 221.60
16	22.16~ 23.16	247.63 269.56	104.54 108.54	247.63 269.56	17.64 17.64	221.60 229.60
17	23.16~ 24.16	171.20 181.81	108.54 112.54	171.20 181.81	17.64 17.64	279.60 287.60

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	1.80	0.00	0.00
2	2.80	1.00	1.72

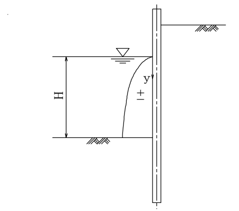
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

y : depth from water surface to the point where active water pressure is calculated

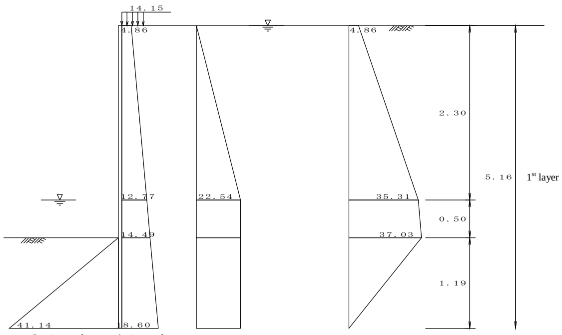


Passive earth pressure　Active earth pressure　Residual water pressure　Total of lateral pressure

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.30	4.86 12.77	0.00 22.54	—— ——	4.86 35.31
2	2.30～ 2.80	12.77 14.49	22.54 22.54	—— ——	35.31 37.03
3	2.80～ 4.00	14.49 18.60	22.54 22.54	0.00 41.14	37.03 0.00
4	4.00～ 5.16	18.60 22.60	22.54 22.54	41.14 81.25	0.00 -36.11

P_a ; Active earth pressure

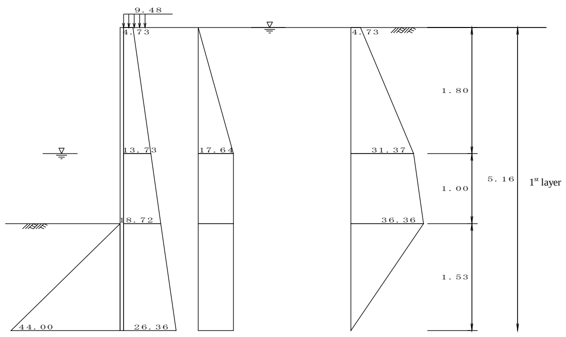
P_w ; Residual water pressure

P_p ; Passive earth pressure

P_s ; Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.20 m (GL -4.00 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 1.80	4.73 13.73	0.00 17.64	—— ——	4.73 31.37
2	1.80～ 2.80	13.73 18.72	17.64 17.64	—— ——	31.37 36.36
3	2.80～ 4.33	18.72 26.36	17.64 17.64	0.00 44.00	36.36 0.00
4	4.33～ 5.16	26.36 30.51	17.64 17.64	44.00 67.88	0.00 -19.73

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.53 m (GL -4.33 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side)　t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	63000 cm^4(original condition)
	I	=	45864 cm^4(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 45864 \times 10^{-8} = 9.173 \times 10^4$

	Depth (m)	N-value
1	0.50	4
2	5.16	4
3	7.16	2
4	8.16	3
5	9.16	2
6	10.16	2
7	12.16	3
8	13.16	4
9	14.16	3
10	15.16	5

	Depth (m)	N-value
11	20.16	4
12	21.16	4
13	22.60	5
14	23.16	6
15	24.16	12

5-2 Normal Condition

K_h = 11748 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.423 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.36 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.99 m) to 2.36 m depth (GL -6.36 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.99	1.17	4.0	4.0	4.66
2	5.16	1.20	4.0	2.8	4.08
	L = Σh = 2.36				ΣA = 8.74

A (upper N-value + lower N-value) × h/2

1.21

Average N-value $N' = \dfrac{\Sigma A}{L} = \dfrac{8.74}{2.36} = 3.70$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 3.70^{0.406} = 11748$ kN/m³

Kh (normal condition) = 11748 kN/m³

5-3 Seismic Condition

K_h = 11486 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.421 \ m^{-1}$$

$$L = \frac{1}{\beta} = 2.38 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.33 m) and 2.38 m depth (GL -6.71 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.33	0.83	4.0	4.0	3.32
2	5.16	1.55	4.0	2.5	4.99
	L = Σh = 2.38				ΣA = 8.31

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L} = \dfrac{8.31}{2.38} = 3.50$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 3.50^{0.406} = 11486$ kN/m³

Kh (seismic condition) = 11486 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.30	2.30	4.86 35.31	5.59 40.61	3.23 2.46	18.06 99.95
2	2.30~ 2.80	0.50	35.31 37.03	8.83 9.26	1.53 1.36	13.49 12.60
3	2.80~ 3.99	1.19	37.03 0.00	22.12 0.00	0.80 0.40	17.62 0.00
				ΣP = 86.41		ΣM = 161.73

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	1.1 kN/m
depth to acting position	H_t	=	-0.13 m
moment	M_m	=	0.1 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.19 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 4.64$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{166.37}{87.51} = 1.90 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.80	1.80	4.73 31.37	4.26 28.23	3.73 3.13	15.89 88.35
2	1.80~ 2.80	1.00	31.37 36.36	15.68 18.18	2.20 1.86	34.45 33.87
3	2.80~ 4.33	1.53	36.36 0.00	27.81 0.00	1.02 0.51	28.37 0.00
				ΣP = 94.17		ΣM = 200.94

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	4.7 kN/m
depth to acting position	H_t	=	0.14 m
moment	M_m	=	3.0 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.53 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 22.69$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	1.80~ 2.80	1.00	0.0 1.7	0.00 0.86	2.20 1.86	0.00 1.60
				ΣPdw = 0.86		ΣM dw = 1.60

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{225.23}{99.73} = 2.26 \ m$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	63000 cm⁴ (original condition)
	I	=	45864 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 45864 × 10⁻⁸		=	9.173 × 10⁴

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	11748 kN/m³
calculated value	β	=	0.42301 m⁻¹
resultant earth force (lateral)	P_0	=	87.51 kN/m
height of acting position of load	h_0	=	1.90 m
moment	M_0	=	166.37 kN·m/m

in consideration of ψ_m = 1.204,

maximum moment	M_{max}	=	200.37 kN·m/m
depth of generated position of M_{max}	l_m	=	0.865 m
depth of 1st fixed point	l_i	=	2.722 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	11486 kN/m³
calculated value	β	=	0.42064 m⁻¹
resultant earth force (lateral)	P_0	=	99.73 kN/m
height of acting position of load	h_0	=	2.26 m
moment	M_0	=	225.23 kN·m/m

in consideration of ψ_m = 1.158,

maximum moment	M_{max}	=	260.89 kN·m/m
depth of generated position of M_{max}	l_m	=	0.789 m
depth of 1st fixed point	l_i	=	2.657 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3150 cm³ (original condition)
	Z	=	2867 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{200.37 \times 10^6}{2867 \times 10^3} = 70 \ N/mm^2 \leqq \sigma_a = 180 \ N/mm^2 \quad (ok)$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{260.89 \times 10^6}{2867 \times 10^3} = 91 \ N/mm^2 \leqq \sigma_a = 270 \ N/mm^2 \quad (ok)$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.30	3.23 2.46	0.808 0.616	0.239 0.151	5.59 40.61	1.334 6.125
2	2.30～ 2.80	1.53 1.36	0.383 0.341	0.064 0.051	8.83 9.26	0.564 0.477
3	2.80～ 3.99	0.80 0.40	0.199 0.100	0.019 0.005	22.12 0.00	0.411 0.000
						ΣQ = 8.910

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

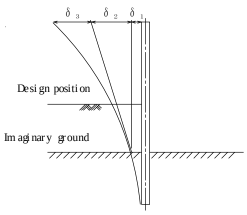
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4230\times1.90)\times87.51}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4230^3} = 0.01137 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4230\times1.90)\times87.51}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4230^2}\times(2.80+1.19) = 0.02778 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{8.91\times(2.80+1.19)^3}{2.00\times10^8\times45864\times10^{-8}} = 0.00619 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00027 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.99 m
Horizontal load: P = 1.10
Moment: M = 0.14

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h)$$ （L＝4.33 m、h＝L－H_m、H_m＝0.80 m、ただ 。)

$$= \frac{3.00\times3.53}{2\times2.00\times10^8\times45864\times10^{-8}}\times(2\times4.33-3.53) = 0.00030 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01137＋0.02778＋0.00647
= 0.04562 m
= 45.62 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.80	3.73 3.13	0.861 0.723	0.264 0.198	4.26 28.23	1.127 5.598
2	1.80～ 2.80	2.20 1.86	0.507 0.430	0.107 0.079	15.68 18.18	1.677 1.442
3	2.80～ 4.33	1.02 0.51	0.236 0.118	0.026 0.007	27.81 0.00	0.711 0.000
						ΣQ = 10.555

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

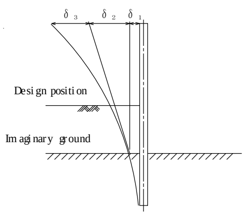
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	1.80～ 2.80	2.20 1.86	0.507 0.430	0.107 0.079	0.00 0.86	0.000 0.068
						ΣQ_{dw} = 0.068

Therefore, modulus of deformation Q is calculated as below:
Q = 12.046＋0.068 = 12.114

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4206\times2.26)\times99.73}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4206^3} = 0.01424 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4206\times2.26)\times99.73}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4206^2}\times(2.80+1.53) = 0.03858 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.11\times(2.80+1.53)^3}{2.00\times10^8\times45864\times10^{-8}} = 0.01072 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h)$$ （L＝4.33 m、h＝L－H_m、H_m＝0.80 m、ただしH＝L)

$$= \frac{3.00\times3.53}{2\times2.00\times10^8\times45864\times10^{-8}}\times(2\times4.33-3.53) = 0.00030 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01424＋0.03858＋0.01102
= 0.06384 m
= 63.84 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below.

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm ^{2}
Inertia sectional moment	I_0	=	63000 cm ^{4} (original condition)
	I	=	63000 cm ^{4} (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63000 \times 10^{-8}$		=	1.260×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 11748$ kN/m ^{3}

Calculated value $\beta = 0.39074$ m $^{-1}$

Penetration length of SSP $D = 1.19 + \frac{3}{0.391} = 8.87$ m

Whole length of SSP $L = 2.80 - 0.40 + 8.87 = 11.27$ m

7-1-2 Seismic Conditio

Modules of lateral subgrade reaction $K_h = 11486$ kN/m ^{3}

Calculated value $\beta = 0.38854$ m $^{-1}$

Penetration length of SSP $D = 1.53 + \frac{3}{0.389} = 9.25$ m

Whole length of SSP $L = 2.80 - 0.40 + 9.25 = 11.65$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

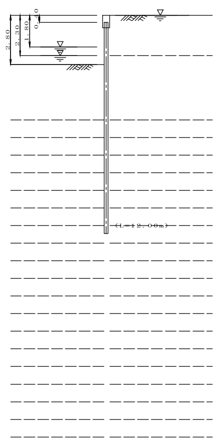
			Normal condition	Seismic condition
Inertia sectional moment	I (cm ^{4})	63000		
Section modulus	Z (cm ^{3})	3150		
Maximum bending moment	M_{max} (kN·m/m)		200.37	260.89
Stress intensity	σ (N/mm ^{2})		70 (180)	91 (270)
Lateral displacement	δ (mm)		45.62 (50.0)	63.84 (75.0)
Penetration depth	D (m)		8.87	9.25
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

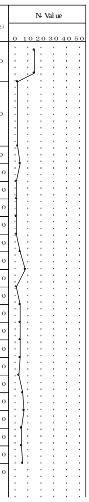
Left Bank No. 04 STA 2+950 - 3+072

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.30	Sandy Soil	18.0	30.0	0.0
5.94	Sandy Soil	18.0	27.0	0.0
6.94	Sandy Soil	18.0	27.0	0.0
7.94	Clayey Soil	16.0	0.0	12.0
8.94	Clayey Soil	16.0	0.0	12.0
9.94	Clayey Soil	16.0	0.0	12.0
10.94	Clayey Soil	16.0	0.0	12.0
11.94	Clayey Soil	16.0	0.0	24.0
12.94	Clayey Soil	16.0	0.0	25.0
13.94	Clayey Soil	16.0	0.0	12.0
14.94	Clayey Soil	16.0	0.0	24.0
15.94	Clayey Soil	16.0	0.0	24.0
16.94	Clayey Soil	16.0	0.0	24.0
17.94	Clayey Soil	16.0	0.0	24.0
18.94	Clayey Soil	16.0	0.0	18.0
19.94	Clayey Soil	16.0	0.0	25.0
20.94	Clayey Soil	16.0	0.0	25.0
21.94	Clayey Soil	16.0	0.0	25.0
22.94	Clayey Soil	16.0	0.0	25.0
23.94	Clayey Soil	16.0	0.0	25.0
	Clayey Soil	16.0	0.0	25.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.80 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.30 m (Normal Condition)
	L_{wp}'	=	1.80 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

Sandy Soil

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load					
Arbitrary load	Horizontal load	P_t	=	0.0 kN/m	(Normal Condition)
		P_t'	=	3.8 kN/m	(Seismic Condition)
	Depth of acting point	H	=	0.00 m	(Normal Condition)
		H'	=	0.29 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m	(Normal Condition)
		M_m'	=	1.9 kN-m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_s = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	12.94	8	21	22.94	5
2	1.80	15	12	13.94	1	22	23.94	6
3	2.30	2	13	14.94	4	23	24.94	8
4	5.94	2	14	15.94	4			
5	6.94	4	15	16.94	4			
6	7.94	1	16	17.94	4			
7	8.94	1	17	18.94	3			
8	9.94	1	18	19.94	6			
9	10.94	1	19	20.94	7			
10	11.94	4	20	21.94	5			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ(degree) normal	ζ(degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	2.30	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	―――	―――
2	5.94	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
3	6.94	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
4	7.94	C	1.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	―――	―――
5	8.94	C	1.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	―――	―――
6	9.94	C	1.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	―――	―――
7	10.94	C	1.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	―――	―――
8	11.94	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	―――	―――
9	12.94	C	8.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――
10	13.94	C	1.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	―――	―――
11	14.94	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	―――	―――
12	15.94	C	4.0	16.00	10.00	0.0	24.0	0.0	0.200	auto	auto	―――	―――
13	16.94	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	―――	―――
14	17.94	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	―――	―――
15	18.94	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	―――	―――
16	19.94	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――
17	20.94	C	7.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――
18	21.94	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――
19	22.94	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――
20	23.94	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――
21	24.94	C	8.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――

Note) depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_0 : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Steel Sheet Pile (SSP)

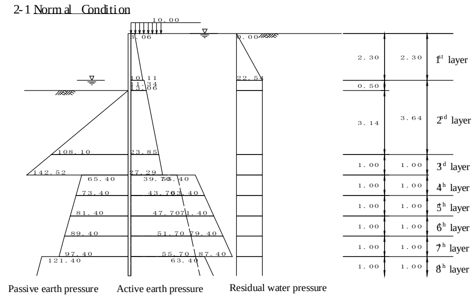
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4
Sectional factor	Z_0	=	2700 cm^3
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.88
Corrosion rate (to Z_0)	η	=	0.88
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 N/mm (Normal)
	σ_a'	=	270 N/mm (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)

Bending of cantilever beam: calculated as distributed load of each layer

Reduction of material modulus:
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Lateral Pressure

2-1 Normal Condition



2-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	□ (kN/m^3)	□ (degree)	C kN/m^2	□□h+Qa (kN/m^2)	Ka	Ka ×cos□
1	0.00~ 2.30	Sandy soil	10.0	30.0	—— ——	10.000 33.000	0.31026 0.31026	0.30644 0.30644
2	2.30~ 2.80	Sandy soil	10.0	27.0	—— ——	33.000 38.000	0.34800 0.34800	0.34371 0.34371
3	2.80~ 5.94	Sandy soil	10.0	27.0	—— ——	38.000 69.400	0.34800 0.34800	0.34371 0.34371
4	5.94~ 6.94	Sandy soil	10.0	27.0	—— ——	69.400 79.400	0.34800 0.34800	0.34371 0.34371
5	6.94~ 7.94	Clayey soil	8.0	—	12.0 12.0	79.400 87.400	—— ——	—— ——
6	7.94~ 8.94	Clayey soil	8.0	—	12.0 12.0	87.400 95.400	—— ——	—— ——
7	8.94~ 9.94	Clayey soil	8.0	—	12.0 12.0	95.400 103.400	—— ——	—— ——
8	9.94~ 10.94	Clayey soil	8.0	—	12.0 12.0	103.400 111.400	—— ——	—— ——
9	10.94~ 11.94	Clayey soil	8.0	—	24.0 24.0	111.400 119.400	—— ——	—— ——
10	11.94~ 12.94	Clayey soil	8.0	—	25.0 25.0	119.400 127.400	—— ——	—— ——
11	12.94~ 13.94	Clayey soil	8.0	—	12.0 12.0	127.400 135.400	—— ——	—— ——
12	13.94~ 14.94	Clayey soil	8.0	—	24.0 24.0	135.400 143.400	—— ——	—— ——
13	14.94~ 15.94	Clayey soil	10.0	—	24.0 24.0	143.400 153.400	—— ——	—— ——
14	15.94~ 16.94	Clayey soil	8.0	—	24.0 24.0	153.400 161.400	—— ——	—— ——
15	16.94~ 17.94	Clayey soil	8.0	—	24.0 24.0	161.400 169.400	—— ——	—— ——

	Depth (m)	Soil	□ (kN/m^3)	□ (degree)	C kN/m^2	□□h+Qa (kN/m^2)	Ka	Ka ×cos□
16	17.94~ 18.94	Clayey soil	8.0	—	18.0 18.0	169.400 177.400	—— ——	—— ——
17	18.94~ 19.94	Clayey soil	8.0	—	25.0 25.0	177.400 185.400	—— ——	—— ——
18	19.94~ 20.94	Clayey soil	8.0	—	25.0 25.0	185.400 193.400	—— ——	—— ——
19	20.94~ 21.94	Clayey soil	8.0	—	25.0 25.0	193.400 201.400	—— ——	—— ——
20	21.94~ 22.94	Clayey soil	8.0	—	25.0 25.0	201.400 209.400	—— ——	—— ——
21	22.94~ 23.94	Clayey soil	8.0	—	25.0 25.0	209.400 217.400	—— ——	—— ——
22	23.94~ 24.94	Clayey soil	8.0	—	25.0 25.0	217.400 225.400	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

2-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m^3)	φ (degree)	C kN/m^2	Σγh+Qp (kN/m^2)	Kp	Kp ×cosδ
3	2.80~ 5.94	Sandy soil	10.0	27.0	—— ——	0.000 31.400	3.48553 3.48553	3.44261 3.44261
4	5.94~ 6.94	Sandy soil	10.0	27.0	—— ——	31.400 41.400	3.48553 3.48553	3.44261 3.44261
5	6.94~ 7.94	Clayey soil	8.0	0.0	12.0 12.0	41.400 49.400	—— ——	—— ——
6	7.94~ 8.94	Clayey soil	8.0	0.0	12.0 12.0	49.400 57.400	—— ——	—— ——
7	8.94~ 9.94	Clayey soil	8.0	0.0	12.0 12.0	57.400 65.400	—— ——	—— ——
8	9.94~ 10.94	Clayey soil	8.0	0.0	12.0 12.0	65.400 73.400	—— ——	—— ——
9	10.94~ 11.94	Clayey soil	8.0	0.0	24.0 24.0	73.400 81.400	—— ——	—— ——
10	11.94~ 12.94	Clayey soil	8.0	0.0	25.0 25.0	81.400 89.400	—— ——	—— ——
11	12.94~ 13.94	Clayey soil	8.0	0.0	12.0 12.0	89.400 97.400	—— ——	—— ——
12	13.94~ 14.94	Clayey soil	8.0	0.0	24.0 24.0	97.400 105.400	—— ——	—— ——
13	14.94~ 15.94	Clayey soil	10.0	0.0	24.0 24.0	105.400 115.400	—— ——	—— ——
14	15.94~ 16.94	Clayey soil	8.0	0.0	24.0 24.0	115.400 123.400	—— ——	—— ——
15	16.94~ 17.94	Clayey soil	8.0	0.0	24.0 24.0	123.400 131.400	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m^3)	φ (degree)	C kN/m^2	Σγh+Qp (kN/m^2)	Kp	Kp ×cosδ
16	17.94~ 18.94	Clayey soil	8.0	0.0	18.0 18.0	131.400 139.400	—— ——	—— ——
17	18.94~ 19.94	Clayey soil	8.0	0.0	25.0 25.0	139.400 147.400	—— ——	—— ——
18	19.94~ 20.94	Clayey soil	8.0	0.0	25.0 25.0	147.400 155.400	—— ——	—— ——
19	20.94~ 21.94	Clayey soil	8.0	0.0	25.0 25.0	155.400 163.400	—— ——	—— ——
20	21.94~ 22.94	Clayey soil	8.0	0.0	25.0 25.0	163.400 171.400	—— ——	—— ——
21	22.94~ 23.94	Clayey soil	8.0	0.0	25.0 25.0	171.400 179.400	—— ——	—— ——
22	23.94~ 24.94	Clayey soil	8.0	0.0	25.0 25.0	179.400 187.400	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

2-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m^2	Pa2 kN/m^2	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2
1	0.00~ 2.30	3.06 10.11	—— ——	3.06 10.11	0.00 22.54	—— ——
2	2.30~ 2.80	11.34 13.06	—— ——	11.34 13.06	22.54 22.54	—— ——
3	2.80~ 5.94	13.06 23.85	—— ——	13.06 23.85	22.54 22.54	0.00 108.10
4	5.94~ 6.94	23.85 27.29	—— ——	23.85 27.29	22.54 22.54	108.10 142.52
5	6.94~ 7.94	55.40 63.40	39.70 43.70	55.40 63.40	22.54 22.54	65.40 73.40
6	7.94~ 8.94	63.40 71.40	43.70 47.70	63.40 71.40	22.54 22.54	73.40 81.40
7	8.94~ 9.94	71.40 79.40	47.70 51.70	71.40 79.40	22.54 22.54	81.40 89.40
8	9.94~ 10.94	79.40 87.40	51.70 55.70	79.40 87.40	22.54 22.54	89.40 97.40
9	10.94~ 11.94	63.40 71.40	55.70 59.70	63.40 71.40	22.54 22.54	121.40 129.40
10	11.94~ 12.94	69.40 77.40	59.70 63.70	69.40 77.40	22.54 22.54	131.40 139.40
11	12.94~ 13.94	103.40 111.40	63.70 67.70	103.40 111.40	22.54 22.54	113.40 121.40
12	13.94~ 14.94	87.40 95.40	67.70 71.70	87.40 95.40	22.54 22.54	145.40 153.40
13	14.94~ 15.94	95.40 105.40	71.70 76.70	95.40 105.40	22.54 22.54	153.40 163.40
14	15.94~ 16.94	105.40 113.40	76.70 80.70	105.40 113.40	22.54 22.54	163.40 171.40

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
15	16.94~ 17.94	113.40 121.40	80.70 84.70	113.40 121.40	22.54 22.54	171.40 179.40
16	17.94~ 18.94	133.40 141.40	84.70 88.70	133.40 141.40	22.54 22.54	167.40 175.40
17	18.94~ 19.94	127.40 135.40	88.70 92.70	127.40 135.40	22.54 22.54	189.40 197.40
18	19.94~ 20.94	135.40 143.40	92.70 96.70	135.40 143.40	22.54 22.54	197.40 205.40
19	20.94~ 21.94	143.40 151.40	96.70 100.70	143.40 151.40	22.54 22.54	205.40 213.40
20	21.94~ 22.94	151.40 159.40	100.70 104.70	151.40 159.40	22.54 22.54	213.40 221.40
21	22.94~ 23.94	159.40 167.40	104.70 108.70	159.40 167.40	22.54 22.54	221.40 229.40
22	23.94~ 24.94	167.40 175.40	108.70 112.70	167.40 175.40	22.54 22.54	229.40 237.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

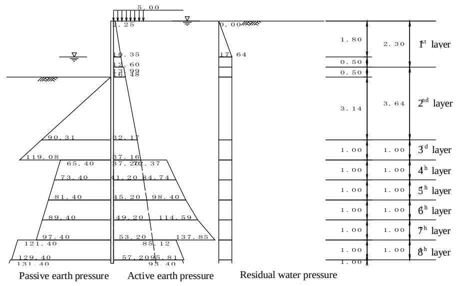
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

2-2 Seismic Condition



2-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 1.80	Sandy Soil	10.0	30.0	—— ——	5.00 23.00	0.00 17.64	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	1.80~ 2.30	Sandy Soil	10.0	30.0	—— ——	23.00 28.00	17.64 22.54	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
3	2.30~ 2.80	Sandy Soil	10.0	27.0	—— ——	28.00 33.00	22.54 27.44	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	2.80~ 5.94	Sandy Soil	10.0	27.0	—— ——	33.00 64.40	27.44 58.21	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	5.94~ 6.94	Sandy Soil	10.0	27.0	—— ——	64.40 74.40	58.21 68.01	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	6.94~ 7.94	Clayey Soil	8.0	—	12.0 12.0	74.40 82.40	68.01 77.81	0.200 0.200	11.31 11.31	—— ——	—— ——	30.19 27.53
7	7.94~ 8.94	Clayey Soil	8.0	—	12.0 12.0	82.40 90.40	77.81 87.61	0.200 0.200	11.31 11.31	—— ——	—— ——	27.53 24.36
8	8.94~ 9.94	Clayey Soil	8.0	—	12.0 12.0	90.40 98.40	87.61 97.41	0.200 0.200	11.31 11.31	—— ——	—— ——	24.36 20.40
9	9.94~ 10.94	Clayey Soil	8.0	—	12.0 12.0	98.40 106.40	97.41 107.21	0.200 0.200	11.31 11.31	—— ——	—— ——	20.40 14.99
10	10.94~ 11.94	Clayey Soil	8.0	—	24.0 24.0	106.40 114.40	107.21 117.01	0.200 0.200	11.31 11.31	—— ——	—— ——	36.20 35.33
11	11.94~ 12.94	Clayey Soil	8.0	—	25.0 25.0	114.40 122.40	117.01 126.81	0.200 0.200	11.31 11.31	—— ——	—— ——	35.86 35.00
12	12.94~ 13.94	Clayey Soil	8.0	—	12.0 12.0	122.40 130.40	126.81 136.61	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
13	13.94~ 14.94	Clayey Soil	8.0	—	24.0 24.0	130.40 138.40	136.61 146.41	0.200 0.200	11.31 11.31	—— ——	—— ——	33.43 32.39
14	14.94~ 15.94	Clayey Soil	10.0	—	24.0 24.0	138.40 148.40	146.41 156.21	0.200 0.200	11.31 11.31	—— ——	—— ——	32.39 30.99
15	15.94~ 16.94	Clayey Soil	8.0	—	24.0 24.0	148.40 156.40	156.21 166.01	0.200 0.200	11.31 11.31	—— ——	—— ——	30.99 29.78
16	16.94~ 17.94	Clayey Soil	8.0	—	24.0 24.0	156.40 164.40	166.01 175.81	0.200 0.200	11.31 11.31	—— ——	—— ——	29.78 28.47
17	17.94~ 18.94	Clayey Soil	8.0	—	18.0 18.0	164.40 172.40	175.81 185.61	0.200 0.200	11.31 11.31	—— ——	—— ——	13.64 10.00
18	18.94~ 19.94	Clayey Soil	8.0	—	25.0 25.0	172.40 180.40	185.61 195.41	0.200 0.200	11.31 11.31	—— ——	—— ——	28.32 26.95
19	19.94~ 20.94	Clayey Soil	8.0	—	25.0 25.0	180.40 188.40	195.41 205.21	0.200 0.200	11.31 11.31	—— ——	—— ——	26.95 25.45
20	20.94~ 21.94	Clayey Soil	8.0	—	25.0 25.0	188.40 196.40	205.21 215.01	0.200 0.200	11.31 11.31	—— ——	—— ——	25.45 23.79
21	21.94~ 22.94	Clayey Soil	8.0	—	25.0 25.0	196.40 204.40	215.01 224.81	0.200 0.200	11.31 11.31	—— ——	—— ——	23.79 21.95
22	22.94~ 23.94	Clayey Soil	8.0	—	25.0 25.0	204.40 212.40	224.81 234.61	0.200 0.200	11.31 11.31	—— ——	—— ——	21.95 19.86
23	23.94~ 24.94	Clayey Soil	8.0	—	25.0 25.0	212.40 220.40	234.61 244.41	0.200 0.200	11.31 11.31	—— ——	—— ——	19.86 17.42

2nd layer

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.

δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$$

2-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.80~ 5.94	Sandy soil	10.00	27.0	—— ——	0.000 31.400	0.00 30.77	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	5.94~ 6.94	Sandy soil	10.00	27.0	—— ——	31.400 41.400	30.77 40.57	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	6.94~ 7.94	Clayey soil	8.00	0.0	12.0 12.0	41.400 49.400	40.57 50.37	0.200 0.200	11.31 11.31	—— ——	—— ——
7	7.94~ 8.94	Clayey soil	8.00	0.0	12.0 12.0	49.400 57.400	50.37 60.17	0.200 0.200	11.31 11.31	—— ——	—— ——
8	8.94~ 9.94	Clayey soil	8.00	0.0	12.0 12.0	57.400 65.400	60.17 69.97	0.200 0.200	11.31 11.31	—— ——	—— ——
9	9.94~ 10.94	Clayey soil	8.00	0.0	12.0 12.0	65.400 73.400	69.97 79.77	0.200 0.200	11.31 11.31	—— ——	—— ——
10	10.94~ 11.94	Clayey soil	8.00	0.0	24.0 24.0	73.400 81.400	79.77 89.57	0.200 0.200	11.31 11.31	—— ——	—— ——
11	11.94~ 12.94	Clayey soil	8.00	0.0	25.0 25.0	81.400 89.400	89.57 99.37	0.200 0.200	11.31 11.31	—— ——	—— ——
12	12.94~ 13.94	Clayey soil	8.00	0.0	12.0 12.0	89.400 97.400	99.37 109.17	0.200 0.200	11.31 11.31	—— ——	—— ——
13	13.94~ 14.94	Clayey soil	8.00	0.0	24.0 24.0	97.400 105.400	109.17 118.97	0.200 0.200	11.31 11.31	—— ——	—— ——
14	14.94~ 15.94	Clayey soil	10.00	0.0	24.0 24.0	105.400 115.400	118.97 128.77	0.200 0.200	11.31 11.31	—— ——	—— ——
15	15.94~ 16.94	Clayey soil	8.00	0.0	24.0 24.0	115.400 123.400	128.77 138.57	0.200 0.200	11.31 11.31	—— ——	—— ——
16	16.94~ 17.94	Clayey soil	8.00	0.0	24.0 24.0	123.400 131.400	138.57 148.37	0.200 0.200	11.31 11.31	—— ——	—— ——
17	17.94~ 18.94	Clayey soil	8.00	0.0	18.0 18.0	131.400 139.400	148.37 158.17	0.200 0.200	11.31 11.31	—— ——	—— ——
18	18.94~ 19.94	Clayey soil	8.00	0.0	25.0 25.0	139.400 147.400	158.17 167.97	0.200 0.200	11.31 11.31	—— ——	—— ——
19	19.94~ 20.94	Clayey soil	8.00	0.0	25.0 25.0	147.400 155.400	167.97 177.77	0.200 0.200	11.31 11.31	—— ——	—— ——
20	20.94~ 21.94	Clayey soil	8.00	0.0	25.0 25.0	155.400 163.400	177.77 187.57	0.200 0.200	11.31 11.31	—— ——	—— ——
21	21.94~ 22.94	Clayey soil	8.00	0.0	25.0 25.0	163.400 171.400	187.57 197.37	0.200 0.200	11.31 11.31	—— ——	—— ——
22	22.94~ 23.94	Clayey soil	8.00	0.0	25.0 25.0	171.400 179.400	197.37 207.17	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
23	23.94~ 24.94	Clayey soil	8.00	0.0	25.0 25.0	179.400 187.400	207.17 216.97	0.200 0.200	11.31 11.31	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.

δ = -9.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}}\right]^2}$$

2-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 1.80	2.25 10.35	—— ——	2.25 10.35	0.00 17.64	—— ——
2	1.80~ 2.30	10.35 12.60	—— ——	10.35 12.60	17.64 17.64	—— ——
3	2.30~ 2.80	13.99 16.48	—— ——	13.99 16.48	17.64 17.64	—— ——
4	2.80~ 5.94	16.48 32.17	—— ——	16.48 32.17	17.64 17.64	0.00 90.31
5	5.94~ 6.94	32.17 37.16	—— ——	32.17 37.16	17.64 17.64	90.31 119.08
6	6.94~ 7.94	72.37 84.74	37.20 41.20	72.37 84.74	17.64 17.64	65.40 73.40
7	7.94~ 8.94	84.74 98.40	41.20 45.20	84.74 98.40	17.64 17.64	73.40 81.40
8	8.94~ 9.94	98.40 114.59	45.20 49.20	98.40 114.59	17.64 17.64	81.40 89.40
9	9.94~ 10.94	114.59 137.85	49.20 53.20	114.59 137.85	17.64 17.64	89.40 97.40
10	10.94~ 11.94	85.12 95.81	53.20 57.20	85.12 95.81	17.64 17.64	121.40 129.40
11	11.94~ 12.94	93.40 104.15	57.20 61.20	93.40 104.15	17.64 17.64	131.40 139.40
12	12.94~ 13.94	191.06 208.14	61.20 65.20	191.06 208.14	17.64 17.64	113.40 121.40
13	13.94~ 14.94	117.71 128.97	65.20 69.20	117.71 128.97	17.64 17.64	145.40 153.40
14	14.94~ 15.94	128.97 143.44	69.20 74.20	128.97 143.44	17.64 17.64	153.40 163.40
15	15.94~ 16.94	143.44 155.39	74.20 78.20	143.44 155.39	17.64 17.64	163.40 171.40
16	16.94~ 17.94	155.39 167.76	78.20 82.20	155.39 167.76	17.64 17.64	171.40 179.40
17	17.94~ 18.94	221.35 262.69	82.20 86.20	221.35 262.69	17.64 17.64	167.40 175.40
18	18.94~ 19.94	176.52 189.49	86.20 90.20	176.52 189.49	17.64 17.64	189.40 197.40

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
19	19.94～ 20.94	189.49 203.15	90.20 94.20	189.49 203.15	17.64 17.64	197.40 205.40
20	20.94～ 21.94	203.15 217.76	94.20 98.20	203.15 217.76	17.64 17.64	205.40 213.40
21	21.94～ 22.94	217.76 233.73	98.20 102.20	217.76 233.73	17.64 17.64	213.40 221.40
22	22.94～ 23.94	233.73 251.78	102.20 106.20	233.73 251.78	17.64 17.64	221.40 229.40
23	23.94～ 24.94	251.78 273.38	106.20 110.20	251.78 273.38	17.64 17.64	229.40 237.40

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

2-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	1.80	0.00	0.00
2	2.80	1.00	1.72

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

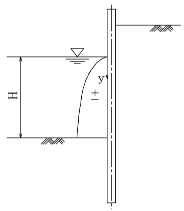
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

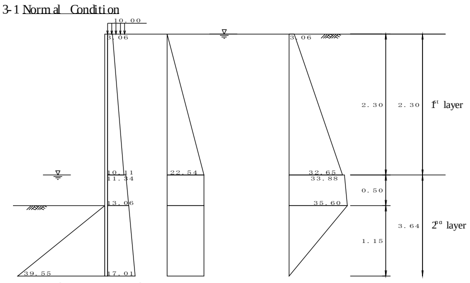
y : depth from water surface to the point where active water pressure is calculated



3 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

3-1 Normal Condition



Passive earth pressure / Active earth pressure / Residual water pressure / Total of lateral pressure

	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.30	3.06 10.11	0.00 22.54	—— ——	3.06 32.65
2	2.30～ 2.80	11.34 13.06	22.54 22.54	—— ——	33.88 35.60
3	2.80～ 3.95	13.06 17.01	22.54 22.54	0.00 39.55	35.60 0.00
4	3.95～ 5.94	17.01 23.85	22.54 22.54	39.55 108.10	0.00 -61.70

P_a : Active earth pressure

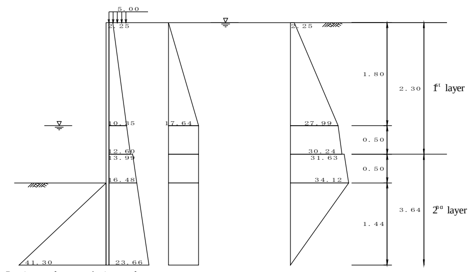
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.15 m (GL -3.95 m)

3-2 Seismic Condition



Passive earth pressure / Active earth pressure / Residual water pressure / Total of lateral pressure

	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 1.80	2.25 10.35	0.00 17.64	—— ——	2.25 27.99
2	1.80～ 2.30	10.35 12.60	17.64 17.64	—— ——	27.99 30.24
3	2.30～ 2.80	13.99 16.48	17.64 17.64	—— ——	31.63 34.12
4	2.80～ 4.24	16.48 23.66	17.64 17.64	0.00 41.30	34.12 0.00
5	4.24～ 5.94	23.66 32.17	17.64 17.64	41.30 90.31	0.00 -40.51

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.44 m (GL -4.24 m)

4th layer

4 Modulus of Lateral Subgrade Reaction

4-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	56700 cm^4(original condition)
	I	=	39917 cm^4(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	15
2	1.80	15
3	2.30	2
4	5.94	2
5	6.94	4
6	7.94	1
7	8.94	1
8	9.94	1
9	10.94	1
10	11.94	4
11	12.94	8
12	13.94	1
13	14.94	4
14	15.94	4
15	16.94	4
16	17.94	4
17	18.94	3
18	19.94	6
19	20.94	7
20	21.94	5
21	22.94	5
22	23.94	6
23	24.94	8

4-2 Normal Condition

K_h = 9296 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.413 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.42 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.95 m) to 2.42 m depth (GL -6.37 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.95	1.99	2.0	2.0	3.98
2	5.94	0.43	2.0	2.9	1.04
	L = Σh = 2.42				ΣA = 5.03

A: (upper N-value + lower N-value) × h/2

Average N-value $$N' = \frac{\Sigma A}{L}$$

$$= \frac{5.03}{2.42}$$

$$= 2.08$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 2.08^{0.406} = 9296$ kN/m^3

Kh (normal condition) = 9296 kNm^3

4-3 Seismic Condition

K_h = 9526 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.416 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.41 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.24 m) and 2.41 m depth (GL -6.64 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.24	1.70	2.0	2.0	3.41
2	5.94	0.70	2.0	3.4	1.90
	L = Σh = 2.41				ΣA = 5.31

A: (upper N-value + lower N-value) × h/2

Average N-value $$N' = \frac{\Sigma A}{L}$$

$$= \frac{5.31}{2.41}$$

$$= 2.21$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 2.21^{0.406} = 9526$ kN/m^3

Kh (seismic condition) = 9526 kNm^3

5 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

5-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

5-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.30	2.30	3.06 32.65	3.52 37.55	3.18 2.42	11.21 90.70
2	2.30～ 2.80	0.50	33.88 35.60	8.47 8.90	1.48 1.32	12.55 11.71
3	2.80～ 3.95	1.15	35.60 0.00	20.45 0.00	0.77 0.38	15.66 0.00
				ΣP = 78.90		ΣM = 141.84

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	0.4 kNm
depth to acting position	H	=	0.00 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_t	=	0.00 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.15 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 0.00 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{141.84}{78.90} = 1.80 \text{ m}$$

5-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 1.80	1.80	2.25 27.99	2.02 25.19	3.64 3.04	7.36 76.46
2	1.80～ 2.30	0.50	27.99 30.24	7.00 7.56	2.27 2.10	15.88 15.89
3	2.30～ 2.80	0.50	31.63 34.12	7.91 8.53	1.77 1.60	13.99 13.67
4	2.80～ 4.24	1.44	34.12 0.00	24.50 0.00	0.96 0.48	23.45 0.00
				ΣP = 82.70		ΣM = 166.69

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.8 kNm
depth to acting position	H	=	0.29 m
moment	M_m	=	1.9 kN·m/m
depth to acting position	H_t	=	0.80 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.44 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 16.89 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	1.80～ 2.80	1.00	0.0 1.7	0.00 0.86	2.10 1.77	0.00 1.52
				ΣP_{dw} = 0.86		ΣM_{dw} = 1.52

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{185.10}{87.36} = 2.12 \text{ m}$$

5-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{-8}$		=	7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

5-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	9296	kNm^3
calculated value	β	=	0.41306	m^{-1}
resultant earth force (lateral)	P_0	=	78.90	kNm
height of acting position of load	h_0	=	1.80	m
moment	M_0	=	141.84	kN·m/m

in consideration of ψ_m = 1.230,

maximum moment	M_{max}	=	174.51	kN·m/m
depth of generated position of M_{max}	l_m	=	0.926	m
depth of 1st fixed point	l_i	=	2.828	m

5-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	9526	kNm^3
calculated value	β	=	0.41559	m^{-1}
resultant earth force (lateral)	P_0	=	87.36	kNm
height of acting position of load	h_0	=	2.12	m
moment	M_0	=	185.10	kN·m/m

in consideration of ψ_m = 1.178,

maximum moment	M_{max}	=	218.05	kN·m/m
depth of generated position of M_{max}	l_m	=	0.836	m
depth of 1st fixed point	l_i	=	2.726	m

5-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm^3 (original condition)
	Z	=	2376 cm^3 (after reduction by corrosion and section)

5-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{174.51\times10^6}{2376\times10^3} = 73\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2$$ (ok)

5-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{218.05\times10^6}{2376\times10^3} = 92\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2$$ ok)

5-4 Displacement

5-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.30	3.18 2.42	0.806 0.612	0.237 0.149	3.52 37.55	0.837 5.593
2	2.30～ 2.80	1.48 1.32	0.375 0.333	0.062 0.049	8.47 8.90	0.522 0.439
3	2.80～ 3.95	0.77 0.38	0.194 0.097	0.018 0.005	20.45 0.00	0.360 0.000
						ΣQ = 7.751

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

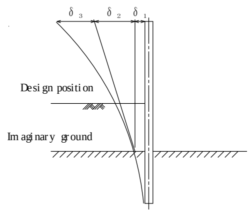
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4131\times1.80)\times78.90}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4131^3} = 0.01222\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.4131\times1.80)\times78.90}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4131^2} \times (2.80+1.15) = 0.02842\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{7.75\times(2.80+1.15)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00598\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01222 + 0.02842 + 0.00598
= 0.04662 m
= 46.62 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

5-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.80	3.64 3.04	0.858 0.717	0.263 0.195	2.02 25.19	0.532 4.923
2	1.80～ 2.30	2.27 2.10	0.536 0.496	0.118 0.103	7.00 7.56	0.825 0.777
3	2.30～ 2.80	1.77 1.60	0.418 0.378	0.075 0.063	7.91 8.53	0.594 0.533
4	2.80～ 4.24	0.96 0.48	0.226 0.113	0.024 0.006	24.50 0.00	0.578 0.000
						ΣQ = 8.763

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

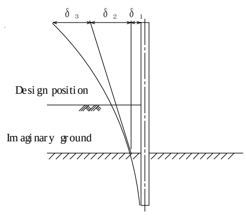
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	1.80～ 2.80	2.10 1.77	0.496 0.418	0.103 0.075	0.00 0.86	0.000 0.064
						ΣQ_{dw} = 0.064

Therefore, modulus of deformation Q is calculated as below:
Q = 9.900 + 0.064 = 9.964

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4156\times2.12)\times87.36}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4156^3} = 0.01433\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.4156\times2.12)\times87.36}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4156^2} \times (2.80+1.44) = 0.03705\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.96\times(2.80+1.44)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00948\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI} \times (2L - h) \qquad (L = 4.27\ m、h = L - H_m、H_m = 0.80\ m、ただし\ h \leqq L)$$

$$= \frac{2.20 \times 3.47}{2 \times 2.00 \times 10^8 \times 39917 \times 10^{-8}} \times (2 \times 4.27 - 3.47) = 0.00024\ m$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= 0.01433 + 0.03705 + 0.00969$$
$$= 0.06108\ m$$
$$= 61.08 \leqq \delta_a = 75.00\ mm\ (ok)$$

Where,
- δ_1 : Displacement at imaginary ground
- δ_2 : Displacement by angle of inclination slope at imaginary ground
- δ_3 : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

6 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 56700 \times 10^{-8}$		=	1.134×10^5

6-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

6-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 9296\ kN/m^3$
Calculated value $\beta = 0.37836\ m^{-1}$

Penetration length of SSP $D = 1.15 + \frac{3}{0.378} = 9.08\ m$
Whole length of SSP $L = 2.80 - 0.40 + 9.08 = 11.48\ m$

6-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 9526\ kN/m^3$
Calculated value $\beta = 0.38068\ m^{-1}$

Penetration length of SSP $D = 1.44 + \frac{3}{0.381} = 9.32\ m$
Whole length of SSP $L = 2.80 - 0.40 + 9.32 = 11.72\ m$

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

7 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		174.51	218.05
Stress intensity	σ (N/mm^2)		73 (180)	92 (270)
Lateral displacement	δ (mm)		46.62 (50.0)	61.08 (75.0)
Penetration depth	D (m)		9.08	9.32
Whole length of SSP	L (m)	12.00		

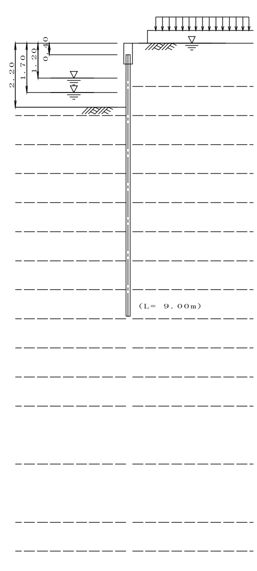
z

－Steel Sheet Pile Design Calculation－

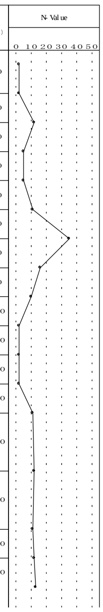
Right Bank No. 05_STA 3+160 - 3+300

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
1.49	Sandy Soil	18.0	27.0	0.0
2.49	Sandy Soil	18.0	28.0	0.0
3.49	Sandy Soil	18.0	27.0	0.0
4.49	Sandy Soil	18.0	27.0	0.0
5.49	Sandy Soil	18.0	28.0	0.0
6.49	Sandy Soil	18.0	38.0	0.0
7.49	Sandy Soil	18.0	30.0	0.0
8.49	Sandy Soil	18.0	27.0	0.0
9.49	Clayey Soil	16.0	0.0	12.0
10.49	Clayey Soil	16.0	0.0	12.0
11.49	Clayey Soil	16.0	0.0	12.0
12.49	Clayey Soil	16.0	0.0	50.0
14.49	Clayey Soil	16.0	0.0	50.0
16.49	Clayey Soil	16.0	0.0	50.0
17.49	Clayey Soil	16.0	0.0	50.0
	Clayey Soil	16.0	0.0	50.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.20 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	1.70 m (Normal Condition)
	L_{wn}'	=	1.20 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　γ_w = 9.8 kN/m^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	0.0 kN/m	(Normal Condition)
		P_t'	=	2.7 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	0.00 m	(Normal Condition)
		H_t'	=	0.40 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	1.1 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　ζ_0 = 10 degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　　K_r = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N'^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.49	2
2	1.49	2
3	2.49	12
4	3.49	5
5	4.49	5
6	5.49	11
7	6.49	35
8	7.49	16
9	8.49	10
10	9.49	2

No	Depth (m)	N-Value
11	10.49	2
12	11.49	2
13	12.49	11
14	14.49	12
15	16.49	11
16	17.49	12
17	18.49	13

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh (kN/m^3)	
										normal	seismic	normal	seismic
1	1.49	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
2	2.49	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
3	3.49	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.49	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.49	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
6	6.49	S	35.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
7	7.49	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
8	8.49	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
9	9.49	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
10	10.49	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
11	11.49	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
12	12.49	C	11.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
13	14.49	C	12.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
14	16.49	C	11.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
15	17.49	C	12.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
16	18.49	C	13.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——

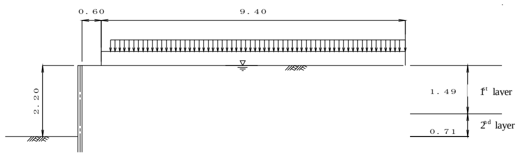
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1.32

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.60	0.60	10.00	10.00	0.44	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.88	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 24400 cm⁴
Sectional factor Z_0 = 1610 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.82
Corrosion rate (to Z_0) η = 0.82
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

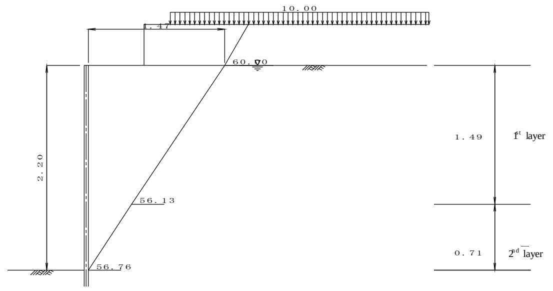
Allowable stress σ_a = 180 N/mm (Normal)
σ_a' = 270 N/mm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.20～ 1.49	Sandy Soil	28.0	9.0	0.0	22.00	11.09	21.56	56.76
2	1.49～ 0.00	Sandy Soil	27.0	9.0	0.0	14.90	11.09	14.60	56.13
3		Embankment	30.0	——	0.0	7.92	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.76	0.71	0.00	0.00	0.47	0.71
2	56.13	1.49	0.47	0.71	1.47	2.20
3	60.00	0.44	1.47	2.20	1.72	2.64

Therefore, width of acting load shall be set as 1.47 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.44	7.86
Σ			7.86

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	0.84	8.39
Σ			8.39

Q surcharge load
l : width of surcharge load set by line of active rupture

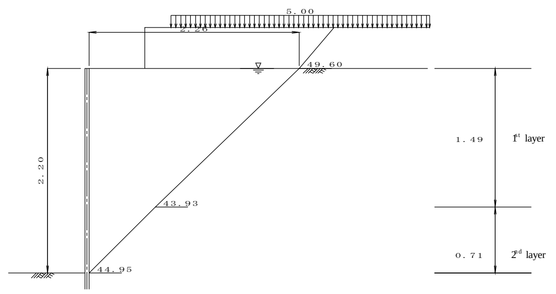
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{7.86 + 8.39 + 0.00}{1.47}$$

$$= 11.09 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.20～ 1.49	Sandy Soil	28.0	9.0	0.0	22.00	10.35	21.56	0.200	11.31	44.95
2	1.49～ 0.00	Sandy Soil	27.0	9.0	0.0	14.90	10.35	14.60	0.200	11.31	43.93
3		Embankment	30.0	——	0.0	7.92	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	44.95	0.71	0.00	0.00	0.71	0.71
2	43.93	1.49	0.71	0.71	2.26	2.20
3	49.60	0.44	2.26	2.20	2.63	2.64

Therefore, width of acting load shall be set as 2.26 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.81	14.62
Σ			14.62

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	1.75	8.76
Σ			8.76

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

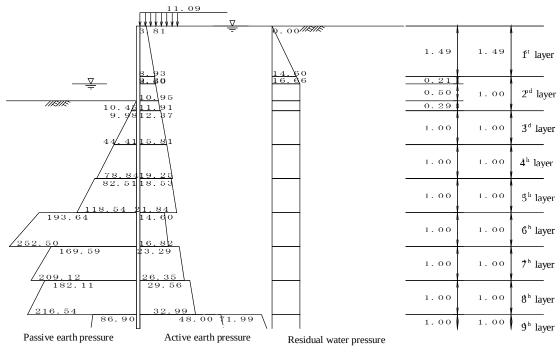
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{14.62 + 8.76 + 0.00}{2.26}$$

$$= 10.35\ \mathrm{kN/m^2}$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 1.49	Sandy soil	10.0	27.0	—— ——	11.092 25.992	0.34800 0.34800	0.34371 0.34371
2	1.49～ 1.70	Sandy soil	10.0	28.0	—— ——	25.992 28.092	0.33506 0.33506	0.33093 0.33093
3	1.70～ 2.20	Sandy soil	10.0	28.0	—— ——	28.092 33.092	0.33506 0.33506	0.33093 0.33093
4	2.20～ 2.49	Sandy soil	10.0	28.0	—— ——	33.092 35.992	0.33506 0.33506	0.33093 0.33093
5	2.49～ 3.49	Sandy soil	10.0	27.0	—— ——	35.992 45.992	0.34800 0.34800	0.34371 0.34371
6	3.49～ 4.49	Sandy soil	10.0	27.0	—— ——	45.992 55.992	0.34800 0.34800	0.34371 0.34371
7	4.49～ 5.49	Sandy soil	10.0	28.0	—— ——	55.992 65.992	0.33506 0.33506	0.33093 0.33093
8	5.49～ 6.49	Sandy soil	10.0	38.0	—— ——	65.992 75.992	0.22404 0.22404	0.22128 0.22128
9	6.49～ 7.49	Sandy soil	10.0	30.0	—— ——	75.992 85.992	0.31026 0.31026	0.30644 0.30644
10	7.49～ 8.49	Sandy soil	10.0	27.0	—— ——	85.992 95.992	0.34800 0.34800	0.34371 0.34371
11	8.49～ 9.49	Clayey soil	8.0	—	12.0 12.0	95.992 103.992	—— ——	—— ——
12	9.49～ 10.49	Clayey soil	8.0	—	12.0 12.0	103.992 111.992	—— ——	—— ——
13	10.49～ 11.49	Clayey soil	8.0	—	12.0 12.0	111.992 119.992	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	11.49～ 12.49	Clayey soil	8.0	—	50.0 50.0	119.992 127.992	—— ——	—— ——
15	12.49～ 14.49	Clayey soil	8.0	—	50.0 50.0	127.992 143.992	—— ——	—— ——
16	14.49～ 16.49	Clayey soil	8.0	—	50.0 50.0	143.992 159.992	—— ——	—— ——
17	16.49～ 17.49	Clayey soil	8.0	—	50.0 50.0	159.992 167.992	—— ——	—— ——
18	17.49～ 18.49	Clayey soil	8.0	—	50.0 50.0	167.992 175.992	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.20～ 2.49	Sandy soil	10.0	28.0	—— ——	0.000 2.900	3.64796 3.64796	3.60305 3.60305
5	2.49～ 3.49	Sandy soil	10.0	27.0	—— ——	2.900 12.900	3.48553 3.48553	3.44261 3.44261
6	3.49～ 4.49	Sandy soil	10.0	27.0	—— ——	12.900 22.900	3.48553 3.48553	3.44261 3.44261
7	4.49～ 5.49	Sandy soil	10.0	28.0	—— ——	22.900 32.900	3.64796 3.64796	3.60305 3.60305
8	5.49～ 6.49	Sandy soil	10.0	38.0	—— ——	32.900 42.900	5.95910 5.95910	5.88573 5.88573
9	6.49～ 7.49	Sandy soil	10.0	30.0	—— ——	42.900 52.900	4.00247 4.00247	3.95319 3.95319
10	7.49～ 8.49	Sandy soil	10.0	27.0	—— ——	52.900 62.900	3.48553 3.48553	3.44261 3.44261
11	8.49～ 9.49	Clayey soil	8.0	0.0	12.0 12.0	62.900 70.900	—— ——	—— ——
12	9.49～ 10.49	Clayey soil	8.0	0.0	12.0 12.0	70.900 78.900	—— ——	—— ——
13	10.49～ 11.49	Clayey soil	8.0	0.0	12.0 12.0	78.900 86.900	—— ——	—— ——
14	11.49～ 12.49	Clayey soil	8.0	0.0	50.0 50.0	86.900 94.900	—— ——	—— ——
15	12.49～ 14.49	Clayey soil	8.0	0.0	50.0 50.0	94.900 110.900	—— ——	—— ——
16	14.49～ 16.49	Clayey soil	8.0	0.0	50.0 50.0	110.900 126.900	—— ——	—— ——
17	16.49～ 17.49	Clayey soil	8.0	0.0	50.0 50.0	126.900 134.900	—— ——	—— ——
18	17.49～ 18.49	Clayey soil	8.0	0.0	50.0 50.0	134.900 142.900	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 1.49	3.81 8.93	—— ——	3.81 8.93	0.00 14.60	—— ——
2	1.49～ 1.70	8.60 9.30	—— ——	8.60 9.30	14.60 16.66	—— ——
3	1.70～ 2.20	9.30 10.95	—— ——	9.30 10.95	16.66 16.66	—— ——
4	2.20～ 2.49	10.95 11.91	—— ——	10.95 11.91	16.66 16.66	0.00 10.45
5	2.49～ 3.49	12.37 15.81	—— ——	12.37 15.81	16.66 16.66	9.98 44.41
6	3.49～ 4.49	15.81 19.25	—— ——	15.81 19.25	16.66 16.66	44.41 78.84
7	4.49～ 5.49	18.53 21.84	—— ——	18.53 21.84	16.66 16.66	82.51 118.54
8	5.49～ 6.49	14.60 16.82	—— ——	14.60 16.82	16.66 16.66	193.64 252.50
9	6.49～ 7.49	23.29 26.35	—— ——	23.29 26.35	16.66 16.66	169.59 209.12
10	7.49～ 8.49	29.56 32.99	—— ——	29.56 32.99	16.66 16.66	182.11 216.54
11	8.49～ 9.49	71.99 79.99	48.00 52.00	71.99 79.99	16.66 16.66	86.90 94.90
12	9.49～ 10.49	79.99 87.99	52.00 56.00	79.99 87.99	16.66 16.66	94.90 102.90
13	10.49～ 11.49	87.99 95.99	56.00 60.00	87.99 95.99	16.66 16.66	102.90 110.90
14	11.49～ 12.49	19.99 27.99	60.00 64.00	60.00 64.00	16.66 16.66	186.90 194.90
15	12.49～ 14.49	27.99 43.99	64.00 72.00	64.00 72.00	16.66 16.66	194.90 210.90
16	14.49～ 16.49	43.99 59.99	72.00 80.00	72.00 80.00	16.66 16.66	210.90 226.90
17	16.49～ 17.49	59.99 67.99	80.00 84.00	80.00 84.00	16.66 16.66	226.90 234.90
18	17.49～ 18.49	67.99 75.99	84.00 88.00	84.00 88.00	16.66 16.66	234.90 242.90

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

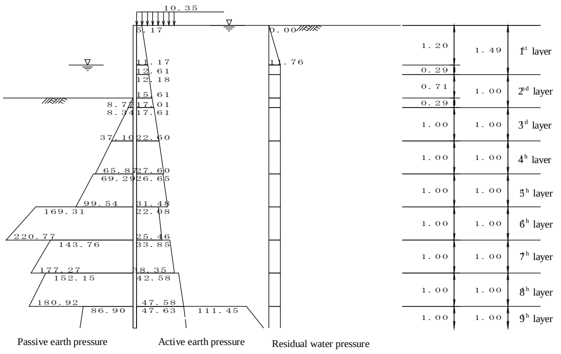
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 1.20	Sandy Soil	10.0	27.0	―― ――	10.35 22.35	0.00 11.76	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
2	1.20～ 1.49	Sandy Soil	10.0	27.0	―― ――	22.35 25.25	11.76 14.60	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
3	1.49～ 2.20	Sandy Soil	10.0	28.0	―― ――	25.25 32.35	14.60 21.56	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	―― ――
4	2.20～ 2.49	Sandy Soil	10.0	28.0	―― ――	32.35 35.25	21.56 24.40	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	―― ――
5	2.49～ 3.49	Sandy Soil	10.0	27.0	―― ――	35.25 45.25	24.40 34.20	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
6	3.49～ 4.49	Sandy Soil	10.0	27.0	―― ――	45.25 55.25	34.20 44.00	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――

Case: Right Bank No. 05_STA 3+160 - 3+300

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	4.49～ 5.49	Sandy Soil	10.0	28.0	―― ――	55.25 65.25	44.00 53.80	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	―― ――
8	5.49～ 6.49	Sandy Soil	10.0	38.0	―― ――	65.25 75.25	53.80 63.60	0.200 0.200	11.31 11.31	0.34256 0.34256	0.33834 0.33834	―― ――
9	6.49～ 7.49	Sandy Soil	10.0	30.0	―― ――	75.25 85.25	63.60 73.40	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	―― ――
10	7.49～ 8.49	Sandy Soil	10.0	27.0	―― ――	85.25 95.25	73.40 83.20	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
11	8.49～ 9.49	Clayey Soil	8.0	―	12.0 12.0	95.25 103.25	83.20 93.00	0.200 0.200	11.31 11.31	―― ――	―― ――	19.10 13.00
12	9.49～ 10.49	Clayey Soil	8.0	―	12.0 12.0	103.25 111.25	93.00 102.80	0.200 0.200	11.31 11.31	―― ――	―― ――	13.00 10.00
13	10.49～ 11.49	Clayey Soil	8.0	―	12.0 12.0	111.25 119.25	102.80 112.60	0.200 0.200	11.31 11.31	―― ――	―― ――	10.00 10.00
14	11.49～ 12.49	Clayey Soil	8.0	―	50.0 50.0	119.25 127.25	112.60 122.40	0.200 0.200	11.31 11.31	―― ――	―― ――	40.72 40.41
15	12.49～ 13.77	Clayey Soil	8.0	―	50.0 50.0	127.25 137.51	122.40 ――	0.200 ――	11.31 ――	―― ――	―― ――	40.41 ――
16	13.77～ 14.49	Clayey Soil	8.0	―	50.0 50.0	137.51 143.25	―― 142.00	―― 0.200	―― 11.31	―― ――	―― ――	―― 39.77
17	14.49～ 16.49	Clayey Soil	8.0	―	50.0 50.0	143.25 159.25	142.00 161.60	0.200 0.200	11.31 11.31	―― ――	―― ――	39.77 39.11
18	16.49～ 17.49	Clayey Soil	8.0	―	50.0 50.0	159.25 167.25	161.60 171.40	0.200 0.200	11.31 11.31	―― ――	―― ――	39.11 38.76
19	17.49～ 18.49	Clayey Soil	8.0	―	50.0 50.0	167.25 175.25	171.40 181.20	0.200 0.200	11.31 11.31	―― ――	―― ――	38.76 38.41

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:

$\delta=9.00$、$\beta=0.00$、$\theta=0.00$

$$K_a=\frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below:

$$\zeta=\tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.20～ 2.49	Sandy soil	10.00	28.0	―― ――	0.000 2.900	0.00 2.84	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
5	2.49～ 3.49	Sandy soil	10.00	27.0	―― ――	2.900 12.900	2.84 12.64	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	3.49～ 4.49	Sandy soil	10.00	27.0	―― ――	12.900 22.900	12.64 22.44	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	4.49～ 5.49	Sandy soil	10.00	28.0	―― ――	22.900 32.900	22.44 32.24	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
8	5.49～ 6.49	Sandy soil	10.00	38.0	―― ――	32.900 42.900	32.24 42.04	0.200 0.200	11.31 11.31	5.21042 5.21042	5.14627 5.14627

Case: Right Bank No. 05_STA 3+160 - 3+300

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
9	6.49～ 7.49	Sandy soil	10.00	30.0	―― ――	42.900 52.900	42.04 51.84	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
10	7.49～ 8.49	Sandy soil	10.00	27.0	―― ――	52.900 62.900	51.84 61.64	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
11	8.49～ 9.49	Clayey soil	8.00	0.0	12.0 12.0	62.900 70.900	61.64 71.44	0.200 0.200	11.31 11.31	―― ――	―― ――
12	9.49～ 10.49	Clayey soil	8.00	0.0	12.0 12.0	70.900 78.900	71.44 81.24	0.200 0.200	11.31 11.31	―― ――	―― ――
13	10.49～ 11.49	Clayey soil	8.00	0.0	12.0 12.0	78.900 86.900	81.24 91.04	0.200 0.200	11.31 11.31	―― ――	―― ――
14	11.49～ 12.49	Clayey soil	8.00	0.0	50.0 50.0	86.900 94.900	91.04 100.84	0.200 0.200	11.31 11.31	―― ――	―― ――
15	12.49～ 13.77	Clayey soil	8.00	0.0	50.0 50.0	94.900 105.153	100.84 ――	0.200 ――	11.31 ――	―― ――	―― ――
16	13.77～ 14.49	Clayey soil	8.00	0.0	50.0 50.0	105.153 110.900	―― 120.44	―― 0.200	―― 11.31	―― ――	―― ――
17	14.49～ 16.49	Clayey soil	8.00	0.0	50.0 50.0	110.900 126.900	120.44 140.04	0.200 0.200	11.31 11.31	―― ――	―― ――
18	16.49～ 17.49	Clayey soil	8.00	0.0	50.0 50.0	126.900 134.900	140.04 149.84	0.200 0.200	11.31 11.31	―― ――	―― ――
19	17.49～ 18.49	Clayey soil	8.00	0.0	50.0 50.0	134.900 142.900	149.84 159.64	0.200 0.200	11.31 11.31	―― ――	―― ――

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta=-9.00$、$\beta=0.00$、$\theta=\tan^{-1}k$

$$K_p=\frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 1.20	5.17 11.17	―― ――	5.17 11.17	0.00 11.76	―― ――
2	1.20～ 1.49	11.17 12.61	―― ――	11.17 12.61	11.76 11.76	―― ――
3	1.49～ 2.20	12.18 15.61	―― ――	12.18 15.61	11.76 11.76	―― ――
4	2.20～ 2.49	15.61 17.01	―― ――	15.61 17.01	11.76 11.76	0.00 8.77
5	2.49～ 3.49	17.61 22.60	―― ――	17.61 22.60	11.76 11.76	8.34 37.10
6	3.49～ 4.49	22.60 27.60	―― ――	22.60 27.60	11.76 11.76	37.10 65.87
7	4.49～ 5.49	26.65 31.48	―― ――	26.65 31.48	11.76 11.76	69.29 99.54
8	5.49～ 6.49	22.08 25.46	―― ――	22.08 25.46	11.76 11.76	169.31 220.77

Case: Right Bank No. 05_STA 3+160 - 3+300

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
9	6.49～ 7.49	33.85 38.35	―― ――	33.85 38.35	11.76 11.76	143.76 177.27
10	7.49～ 8.49	42.58 47.58	―― ――	42.58 47.58	11.76 11.76	152.15 180.92
11	8.49～ 9.49	111.45 137.96	47.63 51.63	111.45 137.96	11.76 11.76	86.90 94.90
12	9.49～ 10.49	137.96 167.27	51.63 55.63	137.96 167.27	11.76 11.76	94.90 102.90
13	10.49～ 11.49	167.27 184.34	55.63 59.63	167.27 184.34	11.76 11.76	102.90 110.90
14	11.49～ 12.49	45.84 55.85	59.63 63.63	59.63 63.63	11.76 11.76	186.90 194.90
15	12.49～ 13.77	55.85 68.75	63.63 68.75	63.63 68.75	11.76 11.76	194.90 205.15
16	13.77～ 14.49	68.75 75.99	68.75 71.63	68.75 75.99	11.76 11.76	205.15 210.90
17	14.49～ 16.49	75.99 96.28	71.63 79.63	75.99 96.28	11.76 11.76	210.90 226.90
18	16.49～ 17.49	96.28 106.49	79.63 83.63	96.28 106.49	11.76 11.76	226.90 234.90
19	17.49～ 18.49	106.49 116.75	83.63 87.63	106.49 116.75	11.76 11.76	234.90 242.90

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m^2)
1	1.20	0.00	0.00
2	2.20	1.00	1.72

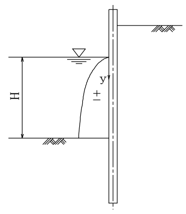
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

y : depth from water surface to the point where active water pressure is calculated

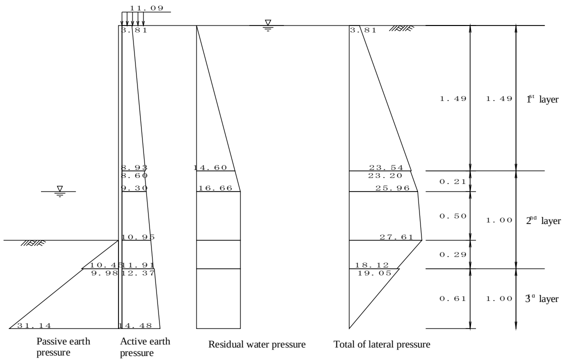


Passive earth pressure　Active earth pressure　Residual water pressure　Total of lateral pressure

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 1.49	3.81 8.93	0.00 14.60	—— ——	3.81 23.54
2	1.49～ 1.70	8.60 9.30	14.60 16.66	—— ——	23.20 25.96
3	1.70～ 2.20	9.30 10.95	16.66 16.66	—— ——	25.96 27.61
4	2.20～ 2.49	10.95 11.91	16.66 16.66	0.00 10.45	27.61 18.12
5	2.49～ 3.11	12.37 14.48	16.66 16.66	9.98 31.14	19.05 0.00
6	3.11～ 3.49	14.48 15.81	16.66 16.66	31.14 44.41	0.00 -11.94

P_a : Active earth pressure

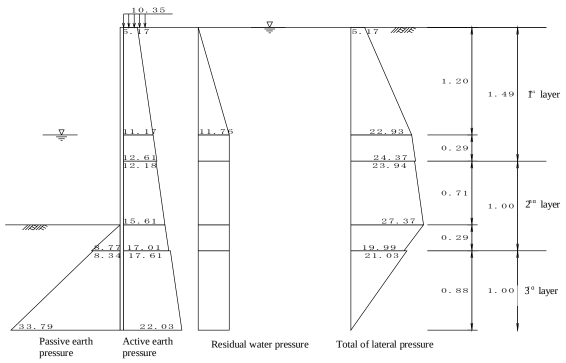
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.91 m (GL -3.11 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 1.20	5.17 11.17	0.00 11.76	—— ——	5.17 22.93
2	1.20～ 1.49	11.17 12.61	11.76 11.76	—— ——	22.93 24.37
3	1.49～ 2.20	12.18 15.61	11.76 11.76	—— ——	23.94 27.37
4	2.20～ 2.49	15.61 17.01	11.76 11.76	0.00 8.77	27.37 19.99
5	2.49～ 3.38	17.61 22.03	11.76 11.76	8.34 33.79	21.03 0.00
6	3.38～ 3.49	22.03 22.60	11.76 11.76	33.79 37.10	0.00 -2.74

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.18 m (GL -3.38 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side)　t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.82
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	24400 cm^4 (original condition)
	I	=	20008 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 20008 \times 10^{-8} = 4.002 \times 10^4$

	Depth (m)	N-value
1	0.49	2
2	1.49	2
3	2.49	12
4	3.49	5
5	4.49	5
6	5.49	11
7	6.49	35
8	7.49	16
9	8.49	10
10	9.49	2

	Depth (m)	N-value
11	10.49	2
12	11.49	2
13	12.49	11
14	14.49	12
15	16.49	11
16	17.49	12
17	18.49	13

5-2 Normal Condition

K_h = 13928 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.543 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.84 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.10 m) to 1.84 m depth (GL -4.95 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.10	0.39	7.7	5.0	2.45
2	3.49	1.00	5.0	5.0	5.00
3	4.49	0.46	5.0	7.7	2.90
L = Σh = 1.84			ΣA = 10.35		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{10.35}{1.84}$

$= 5.62$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 5.62^{0.406} = 13928$ kN/m^3

Kh (normal condition) = 13928 kNm^3

5-3 Seismic Condition

K_h = 14174 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.546$ m^{-1}

$$L = \frac{1}{\beta} = 1.83 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.37 m) and 1.83 m depth (GL -5.21 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	3.37	0.12	5.8	5.0	0.62
2	3.49	1.00	5.0	5.0	5.00
3	4.49	0.72	5.0	9.3	5.14
L = Σh = 1.83				ΣA = 10.76	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{10.76}{1.83}$

$= 5.87$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 5.87^{0.406} = 14174$ kN/m^3

Kh (seismic condition) = 14174 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.49	1.49	3.81 23.54	2.84 17.53	2.61 2.11	7.41 37.02
2	1.49~ 1.70	0.21	23.20 25.96	2.44 2.73	1.54 1.47	3.76 4.02
3	1.70~ 2.20	0.50	25.96 27.61	6.49 6.90	1.24 1.07	8.03 7.40
4	2.20~ 2.49	0.29	27.61 18.12	4.00 2.63	0.81 0.71	3.23 1.87
5	2.49~ 3.10	0.61	19.05 0.00	5.85 0.00	0.41 0.20	2.40 0.00
				ΣP = 51.41		ΣM = 75.14

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	0.0 kNm
depth to acting position	H_t	=	0.00 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.20 m
Depth of Imaginary riverbed from riverbed	L_k	=	0.90 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 00.00$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{75.14}{51.41} = 1.46 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.20	1.20	5.17 22.93	3.10 13.76	2.97 2.57	9.23 35.42
2	1.20~ 1.49	0.29	22.93 24.37	3.32 3.53	2.08 1.98	6.91 7.00
3	1.49~ 2.20	0.71	23.94 27.37	8.50 9.71	1.65 1.41	14.01 13.71
4	2.20~ 2.49	0.29	27.37 19.99	3.97 2.90	1.08 0.98	4.28 2.84
5	2.49~ 3.37	0.88	21.03 0.00	9.30 0.00	0.59 0.29	5.49 0.00
				ΣP = 58.10		ΣM = 98.89

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.7 kNm
depth to acting position	H	=	0.40 m
moment	M_m	=	1.1 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.20 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.17 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 9.13$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	1.20~ 2.20	1.00	0.0 1.7	0.00 0.86	1.84 1.51	0.00 1.29
				ΣPdw = 0.86		ΣMdw = 1.29

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{109.31}{61.66} = 1.77 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.82
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	24400 cm^4 (original condition)
	I	=	20008 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 20008 × 10^{-8}		=	4.002 × 10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	13928 kNm^3
calculated value	β	=	0.54313 m^{-1}
resultant earth force (lateral)	P_0	=	51.41 kNm
height of acting position of load	h_0	=	1.46 m
moment	M_0	=	75.14 kN·m/m

in consideration of ψ_m = 1.208,

maximum moment	M_{max}	=	90.80 kN·m/m
depth of generated position of M_{max}	l_m	=	0.679 m
depth of 1st fixed point	l_i	=	2.125 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	14174 kNm^3
calculated value	β	=	0.54551 m^{-1}
resultant earth force (lateral)	P_0	=	61.66 kNm
height of acting position of load	h_0	=	1.77 m
moment	M_0	=	109.31 kN·m/m

in consideration of ψ_m = 1.154,

maximum moment	M_{max}	=	126.14 kN·m/m
depth of generated position of M_{max}	l_m	=	0.602 m
depth of 1st fixed point	l_i	=	2.042 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	n	=	0.82
Section efficiency	μ	=	1.00
Module of section	Z_0	=	1610 cm^3 (original condition)
	Z	=	1320 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{90.80\times10^6}{1320\times10^3} = 69\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad (ok)$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{126.14\times10^6}{1320\times10^3} = 96\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad (ok)$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.49	2.61 2.11	0.840 0.680	0.254 0.179	2.84 17.53	0.722 3.135
2	1.49～ 1.70	1.54 1.47	0.498 0.475	0.103 0.095	2.44 2.73	0.252 0.259
3	1.70～ 2.20	1.24 1.07	0.399 0.345	0.069 0.053	6.49 6.90	0.447 0.364
4	2.20～ 2.49	0.81 0.71	0.260 0.229	0.031 0.024	4.00 2.63	0.124 0.064
5	2.49～ 3.10	0.41 0.20	0.132 0.066	0.008 0.002	5.85 0.00	0.049 0.000
						ΣQ = 5.415

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

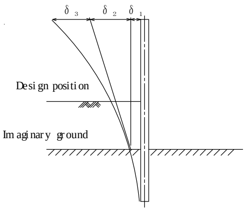
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5431\times1.46)\times51.41}{2\times2.00\times10^8\times20008\times10^{-8}\times0.5431^3} = 0.00719\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5431\times1.46)\times51.41}{2\times2.00\times10^8\times20008\times10^{-8}\times0.5431^2}\times(2.20+0.90) = 0.01750\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{5.41\times(2.20+0.90)^3}{2.00\times10^8\times20008\times10^{-8}} = 0.00405\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.00719 + 0.01750 + 0.00405$
$= 0.02874$ m
$= 28.74 \leqq \delta a = 50.00$ mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.20	2.97 2.57	0.881 0.763	0.274 0.217	3.10 13.76	0.851 2.985
2	1.20～ 1.49	2.08 1.98	0.616 0.587	0.151 0.139	3.32 3.53	0.501 0.490
3	1.49～ 2.20	1.65 1.41	0.488 0.418	0.100 0.075	8.50 9.71	0.849 0.731
4	2.20～ 2.49	1.08 0.98	0.319 0.291	0.046 0.038	3.97 2.90	0.181 0.111
5	2.49～ 3.37	0.59 0.29	0.175 0.087	0.014 0.004	9.30 0.00	0.134 0.000
						ΣQ = 6.832

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

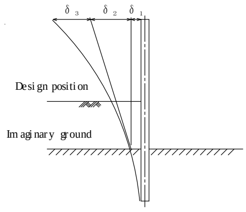
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	1.20～ 2.20	1.84 1.51	0.546 0.447	0.122 0.085	0.00 0.86	0.000 0.073
						ΣQ_{dw} = 0.073

Therefore, modulus of deformation Q is calculated as below:
Q = 7.573 + 0.073 = 7.646

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5455\times1.77)\times61.66}{2\times2.00\times10^8\times20008\times10^{-8}\times0.5455^3} = 0.00934\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5455\times1.77)\times61.66}{2\times2.00\times10^8\times20008\times10^{-8}\times0.5455^2}\times(2.20+1.17) = 0.02564\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{7.65\times(2.20+1.17)^3}{2.00\times10^8\times20008\times10^{-8}} = 0.00734\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

Displacement δ_{m} of cantilever beam by moment M_m is additionally considered.

$$= \frac{1.10\times2.57}{2\times2.00\times10^8\times20008\times10^{-8}}\times(2\times3.37-2.57) = 0.00015\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.00934 + 0.02564 + 0.00749$
$= 0.04246$ m
$= 42.46 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	24400 cm^4 (original condition)
	I	=	24400 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 24400 \times 10^{-8}$		=	4.880×10^4

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 13928$ kN/m^3

Calculated value $\beta = 0.51684$ m^{-1}

Penetration length of SSP $D = 0.90 + \frac{3}{0.517} = 6.71$ m

Whole length of SSP $L = 2.20 - 0.40 + 6.71 = 8.51$ m

7-1-2 Seismic Conditio

Modules of lateral subgrade reaction $K_h = 14174$ kN/m^3

Calculated value $\beta = 0.51911$ m^{-1}

Penetration length of SSP $D = 1.17 + \frac{3}{0.519} = 6.95$ m

Whole length of SSP $L = 2.20 - 0.40 + 6.95 = 8.75$ m

Therefore, whole length of SSP is set as 9.00 m in consideration of round unit of SSP length.

8 Calculation Result

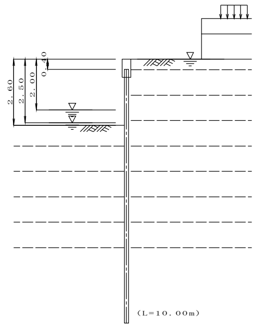
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	24400		
Section modulus	Z (cm^3)	1610		
Maximum bending moment	M_{max} (kN·m/m)		90.80	126.14
Stress intensity	σ (N/mm^2)		69 (180)	96 (270)
Lateral displacement	δ (mm)		28.74 (50.0)	42.46 (75.0)
Penetration depth	D (m)		6.71	6.95
Whole length of SSP	L (m)	9.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 06_STA 6+116 - 6+219

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)	N-Value (0 10 20 30 40 50)
	Sandy Soil	18.0	27.0	0.0	
0.42	Sandy Soil	18.0	27.0	0.0	
1.42	Sandy Soil	18.0	27.0	0.0	
2.42	Sandy Soil	18.0	27.0	0.0	
3.42	Sandy Soil	18.0	27.0	0.0	
4.42	Sandy Soil	18.0	27.0	0.0	
5.42	Sandy Soil	18.0	27.0	0.0	
6.42	Sandy Soil	20.0	45.0	0.0	
7.42	Sandy Soil	20.0	45.0	0.0	

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.50 m (Normal Condition)
	L_{wp}'	=	2.00 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	0.0 kN/m (Normal Condition)
		Pt'	=	2.7 kN/m (Seismic Condition)
	Depth of acting point	Ht	=	0.00 m (Normal Condition)
		Ht'	=	0.40 m (Seismic Condition)
	Moment	Mm	=	0.0 kN･m/m (Normal Condition)
		Mm'	=	1.1 kN･m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.42	11			
2	1.42	2			
3	2.42	2			
4	3.42	5			
5	4.42	5			
6	5.42	3			
7	6.42	8			
8	7.42	50			
9	20.00	50			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

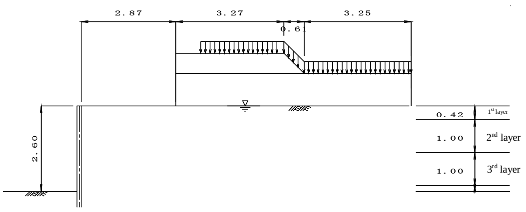
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m^3) normal	kh (kN/m^3) seismic
1	0.42	S	11.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
2	1.42	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	2.42	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	3.42	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	4.42	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	5.42	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	6.42	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	7.42	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
9	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	2.87	2.87	10.00	10.00	0.99	18.0	30.0	0.0	auto	auto
2	Sandy soil	2.87	2.87	6.14	6.75	0.61	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	3.62	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 32400 cm^4
Sectional factor Z_0 = 1800 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.85
Corrosion rate (to Z_0) η = 0.85
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

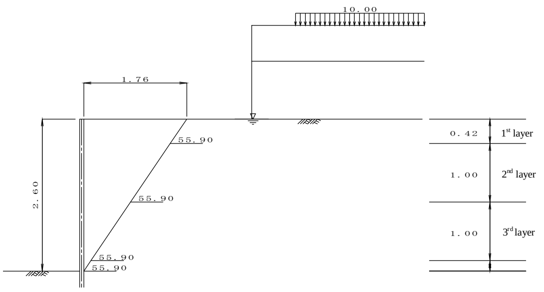
Allowable stress σ_a = 180 N/mm^2 (Normal)
σ_a' = 270 N/mm^2 (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	Angle of rupture Z (degree)
1	2.60～ 2.42	Sandy Soil	27.0	10.0	0.0	26.00	0.00	25.48	55.90
2	2.42～ 1.42	Sandy Soil	27.0	10.0	0.0	24.20	0.00	23.72	55.90
3	1.42～ 0.42	Sandy Soil	27.0	10.0	0.0	14.20	0.00	13.92	55.90
4	0.42～ 0.00	Sandy Soil	27.0	10.0	0.0	4.20	0.00	4.12	55.90

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^o since $\theta = 0^o$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^o$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.18	0.00	0.00	0.12	0.18
2	55.90	1.00	0.12	0.18	0.80	1.18
3	55.90	1.00	0.80	1.18	1.48	2.18
4	55.90	0.42	1.48	2.18	1.76	2.60

Therefore, width of acting load shall be set as 1.76m

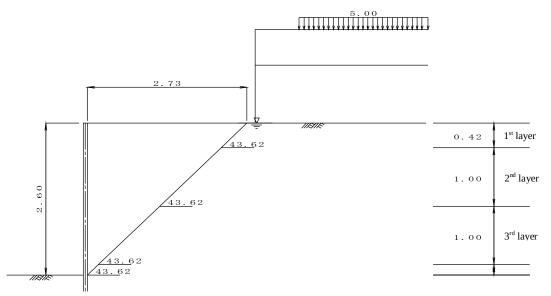
2-1-3 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{0.00 + 0.00 + 0.00}{1.76}$$

$$= 0.00 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.42	Sandy Soil	27.0	10.0	0.0	26.00	0.00	25.48	0.200	11.31	43.62
2	2.42～ 1.42	Sandy Soil	27.0	10.0	0.0	24.20	0.00	23.72	0.200	11.31	43.62
3	1.42～ 0.42	Sandy Soil	27.0	10.0	0.0	14.20	0.00	13.92	0.200	11.31	43.62
4	0.42～ 0.00	Sandy Soil	27.0	10.0	0.0	4.20	0.00	4.12	0.200	11.31	43.62

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^o$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.18	0.00	0.00	0.19	0.18
2	43.62	1.00	0.19	0.18	1.24	1.18
3	43.62	1.00	1.24	1.18	2.29	2.18
4	43.62	0.42	2.29	2.18	2.73	2.60

Therefore, width of acting load shall be set as 2.73 m

2-2-3 Calculation of Total Acting Load

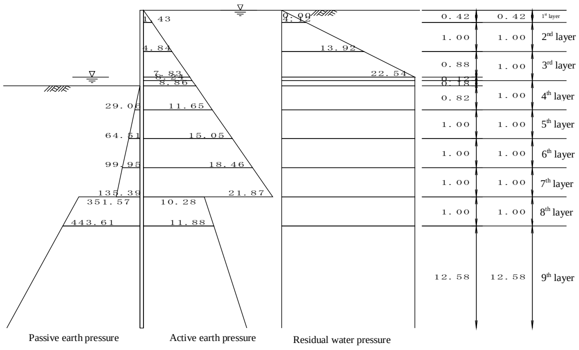
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{0.00 + 0.00 + 0.00}{2.73}$$

$$= 0.00 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 0.42	Sandy soil	10.0	27.0	—— ——	0.000 4.200	0.34585 0.34585	0.34060 0.34060
2	0.42~ 1.42	Sandy soil	10.0	27.0	—— ——	4.200 14.200	0.34585 0.34585	0.34060 0.34060
3	1.42~ 2.42	Sandy soil	10.0	27.0	—— ——	14.200 24.200	0.34585 0.34585	0.34060 0.34060
4	2.42~ 2.50	Sandy soil	10.0	27.0	—— ——	24.200 25.000	0.34585 0.34585	0.34060 0.34060
5	2.50~ 2.60	Sandy soil	10.0	27.0	—— ——	25.000 26.000	0.34585 0.34585	0.34060 0.34060
6	2.60~ 3.42	Sandy soil	10.0	27.0	—— ——	26.000 34.200	0.34585 0.34585	0.34060 0.34060
7	3.42~ 4.42	Sandy soil	10.0	27.0	—— ——	34.200 44.200	0.34585 0.34585	0.34060 0.34060
8	4.42~ 5.42	Sandy soil	10.0	27.0	—— ——	44.200 54.200	0.34585 0.34585	0.34060 0.34060
9	5.42~ 6.42	Sandy soil	10.0	27.0	—— ——	54.200 64.200	0.34585 0.34585	0.34060 0.34060
10	6.42~ 7.42	Sandy soil	10.0	45.0	—— ——	64.200 74.200	0.16262 0.16262	0.16015 0.16015
11	7.42~ 20.00	Sandy soil	10.0	45.0	—— ——	74.200 200.000	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
6	2.60~ 3.42	Sandy soil	10.0	27.0	—— ——	0.000 8.200	3.59892 3.59892	3.54425 3.54425
7	3.42~ 4.42	Sandy soil	10.0	27.0	—— ——	8.200 18.200	3.59892 3.59892	3.54425 3.54425
8	4.42~ 5.42	Sandy soil	10.0	27.0	—— ——	18.200 28.200	3.59892 3.59892	3.54425 3.54425
9	5.42~ 6.42	Sandy soil	10.0	27.0	—— ——	28.200 38.200	3.59892 3.59892	3.54425 3.54425
10	6.42~ 7.42	Sandy soil	10.0	45.0	—— ——	38.200 48.200	9.34548 9.34548	9.20351 9.20351
11	7.42~ 20.00	Sandy soil	10.0	45.0	—— ——	48.200 174.000	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 0.42	0.00 1.43	—— ——	0.00 1.43	0.00 4.12	—— ——
2	0.42~ 1.42	1.43 4.84	—— ——	1.43 4.84	4.12 13.92	—— ——
3	1.42~ 2.42	4.84 8.24	—— ——	4.84 8.24	13.92 23.72	—— ——
4	2.42~ 2.50	8.24 8.51	—— ——	8.24 8.51	23.72 24.50	—— ——
5	2.50~ 2.60	8.51 8.86	—— ——	8.51 8.86	24.50 24.50	—— ——
6	2.60~ 3.42	8.86 11.65	—— ——	8.86 11.65	24.50 24.50	0.00 29.06
7	3.42~ 4.42	11.65 15.05	—— ——	11.65 15.05	24.50 24.50	29.06 64.51
8	4.42~ 5.42	15.05 18.46	—— ——	15.05 18.46	24.50 24.50	64.51 99.95
9	5.42~ 6.42	18.46 21.87	—— ——	18.46 21.87	24.50 24.50	99.95 135.39
10	6.42~ 7.42	10.28 11.88	—— ——	10.28 11.88	24.50 24.50	351.57 443.61
11	7.42~ 20.00	11.88 32.03	—— ——	11.88 32.03	24.50 24.50	443.61 1601.41

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

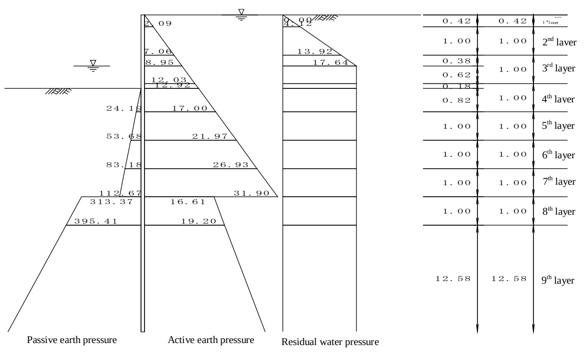
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 0.42	Sandy Soil	10.0	27.0	—— ——	0.00 4.20	0.00 4.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
2	0.42~ 1.42	Sandy Soil	10.0	27.0	—— ——	4.20 14.20	4.12 13.92	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	1.42~ 2.00	Sandy Soil	10.0	27.0	—— ——	14.20 20.00	13.92 19.60	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	2.00~ 2.42	Sandy Soil	10.0	27.0	—— ——	20.00 24.20	19.60 23.72	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	2.42~ 2.60	Sandy Soil	10.0	27.0	—— ——	24.20 26.00	23.72 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	2.60~ 3.42	Sandy Soil	10.0	27.0	—— ——	26.00 34.20	25.48 33.52	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	3.42~ 4.42	Sandy Soil	10.0	27.0	—— ——	34.20 44.20	33.52 43.32	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
8	4.42~ 5.42	Sandy Soil	10.0	27.0	—— ——	44.20 54.20	43.32 53.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
9	5.42~ 6.42	Sandy Soil	10.0	27.0	—— ——	54.20 64.20	53.12 62.92	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
10	6.42~ 7.42	Sandy Soil	10.0	45.0	—— ——	64.20 74.20	62.92 72.72	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
11	7.42~ 20.00	Sandy Soil	10.0	45.0	—— ——	74.20 200.00	72.72 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta=\tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
6	2.60~ 3.42	Sandy soil	10.00	27.0	—— ——	0.000 8.200	0.00 8.04	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	3.42~ 4.42	Sandy soil	10.00	27.0	—— ——	8.200 18.200	8.04 17.84	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
8	4.42~ 5.42	Sandy soil	10.00	27.0	—— ——	18.200 28.200	17.84 27.64	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
9	5.42~ 6.42	Sandy soil	10.00	27.0	—— ——	28.200 38.200	27.64 37.44	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
10	6.42~ 7.42	Sandy soil	10.00	45.0	—— ——	38.200 48.200	37.44 47.24	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
11	7.42~ 20.00	Sandy soil	10.00	45.0	—— ——	48.200 174.000	47.24 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

δ = -10.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 0.42	0.00 2.09	——— ———	0.00 2.09	0.00 4.12	——— ———
2	0.42～ 1.42	2.09 7.06	——— ———	2.09 7.06	4.12 13.92	——— ———
3	1.42～ 2.00	7.06 9.94	——— ———	7.06 9.94	13.92 19.60	——— ———
4	2.00～ 2.42	9.94 12.03	——— ———	9.94 12.03	19.60 19.60	——— ———
5	2.42～ 2.60	12.03 12.92	——— ———	12.03 12.92	19.60 19.60	——— ———
6	2.60～ 3.42	12.92 17.00	——— ———	12.92 17.00	19.60 19.60	0.00 24.19
7	3.42～ 4.42	17.00 21.97	——— ———	17.00 21.97	19.60 19.60	24.19 53.68
8	4.42～ 5.42	21.97 26.93	——— ———	21.97 26.93	19.60 19.60	53.68 83.18
9	5.42～ 6.42	26.93 31.90	——— ———	26.93 31.90	19.60 19.60	83.18 112.67
10	6.42～ 7.42	16.61 19.20	——— ———	16.61 19.20	19.60 19.60	313.37 395.41
11	7.42～ 20.00	19.20 51.75	——— ———	19.20 51.75	19.60 19.60	395.41 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

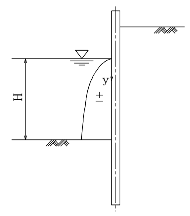
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.00 2.60	0.00 0.60	0.00 1.03

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

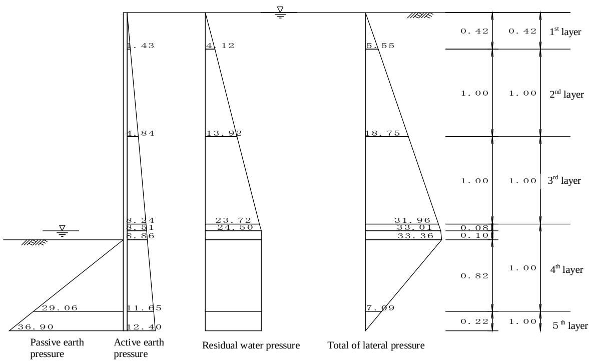
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

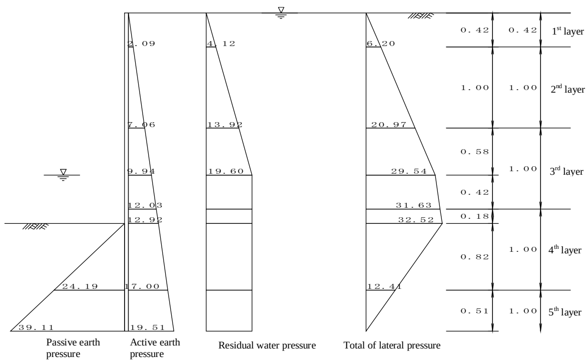


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 0.42	0.00 1.43	0.00 4.12	——— ———	0.00 5.55
2	0.42～ 1.42	1.43 4.84	4.12 13.92	——— ———	5.55 18.75
3	1.42～ 2.42	4.84 8.24	13.92 23.72	——— ———	18.75 31.96
4	2.42～ 2.50	8.24 8.51	23.72 24.50	——— ———	31.96 33.01
5	2.50～ 2.60	8.51 8.86	24.50 24.50	——— ———	33.01 33.36
6	2.60～ 3.42	8.86 11.65	24.50 24.50	0.00 29.06	33.36 7.09
7	3.42～ 3.64	11.65 12.40	24.50 24.50	29.06 36.90	7.09 0.00
8	3.64～ 4.42	12.40 15.05	24.50 24.50	36.90 64.51	0.00 -24.95

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.04 m (GL -3.64 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 0.42	0.00 2.09	0.00 4.12	——— ———	0.00 6.20
2	0.42～ 1.42	2.09 7.06	4.12 13.92	——— ———	6.20 20.97
3	1.42～ 2.00	7.06 9.94	13.92 19.60	——— ———	20.97 29.54
4	2.00～ 2.42	9.94 12.03	19.60 19.60	——— ———	29.54 31.63
5	2.42～ 2.60	12.03 12.92	19.60 19.60	——— ———	31.63 32.52
6	2.60～ 3.42	12.92 17.00	19.60 19.60	0.00 24.19	32.52 12.41
7	3.42～ 3.93	17.00 19.51	19.60 19.60	24.19 39.11	12.41 0.00
8	3.93～ 4.42	19.51 21.97	19.60 19.60	39.11 53.68	0.00 -12.12

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.33 m (GL -3.93 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$K_h = 6910 \times N'^{0.406}$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.85			
Section efficiency	μ	=	0.80			
Young's modulus	E	=	200000 N/mm^2			
Inertia sectional moment	I_0	=	32400 cm^4(original condition)			
	I	=	22032 cm^4(after reduction by corrosion and section)			
Inertia sectional moment	EI	=	200000 x 10^3 x 22032 x 10^{-8} = 4.406 × 10^4			

	Depth (m)	N-value
1	0.42	11
2	1.42	2
3	2.42	2
4	3.42	5
5	4.42	5
6	5.42	3
7	6.42	8
8	7.42	50
9	20.00	50

5-2 Normal Condition

K_h = 12556 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.517 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.94 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.64 m) to 1.94 m depth (GL -5.58 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	3.64	0.78	5.0	5.0	3.89
2	4.42	1.00	5.0	3.0	4.00
3	5.42	0.16	3.0	3.8	0.53
L = Σh = 1.94				ΣA = 8.43	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{8.43}{1.94}$$

$$= 4.35$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 4.35^{0.406} = 12556$ kN/m^3

Kh (normal condition) = 12556 kN/m^3

5-3 Seismic Condition

K_h = 12470 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.516 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.94 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) and 1.94 m depth (GL -5.86 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	3.93	0.49	5.0	5.0	2.47
2	4.42	1.00	5.0	3.0	4.00
3	5.42	0.44	3.0	5.2	1.83
L = Σh = 1.94				ΣA = 8.30	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{8.30}{1.94}$$

$$= 4.28$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 4.28^{0.406} = 12470$ kN/m^3

Kh (seismic condition) = 12470 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 0.42	0.42	0.00 5.55	0.00 1.16	3.50 3.36	0.00 3.91
2	0.42~ 1.42	1.00	5.55 18.75	2.77 9.38	2.89 2.55	8.01 23.95
3	1.42~ 2.42	1.00	18.75 31.96	9.38 15.98	1.89 1.55	17.70 24.84
4	2.42~ 2.50	0.08	31.96 33.01	1.28 1.32	1.19 1.17	1.53 1.54
5	2.50~ 2.60	0.10	33.01 33.36	1.65 1.67	1.11 1.07	1.83 1.79
6	2.60~ 3.42	0.82	33.36 7.09	13.68 2.91	0.77 0.49	10.50 1.44
7	3.42~ 3.64	0.22	7.09 0.00	0.78 0.00	0.15 0.07	0.12 0.00
				ΣP = 61.95		ΣM = 97.16

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load		P_t	=	0.0 kN/m
	depth to acting position	H_t	=	0.00 m
	moment	M_m	=	0.0 kN·m/m
	depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping		H	=	2.60 m
Depth of Imaginary riverbed from riverbed		L_k	=	1.04 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 00.00 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{97.16}{61.95} = 1.57 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 0.42	0.42	0.00 6.20	0.00 1.30	3.79 3.65	0.00 4.75
2	0.42~ 1.42	1.00	6.20 20.97	3.10 10.49	3.17 2.84	9.84 29.77
3	1.42~ 2.00	0.58	20.97 29.54	6.08 8.57	2.31 2.12	14.07 18.15
4	2.00~ 2.42	0.42	29.54 31.63	6.20 6.64	1.79 1.65	11.08 10.93
5	2.42~ 2.60	0.18	31.63 32.52	2.85 2.93	1.45 1.39	4.12 4.06
6	2.60~ 3.42	0.82	32.52 12.41	13.33 5.09	1.05 0.78	14.04 3.97
7	3.42~ 3.93	0.51	12.41 0.00	3.14 0.00	0.34 0.17	1.06 0.00
				ΣP = 69.72		ΣM = 125.83

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load		P_t	=	2.7 kN/m
	depth to acting position	H_t	=	0.40 m
	moment	M_m	=	1.1 kN·m/m
	depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping		H	=	2.60 m
Depth of Imaginary riverbed from riverbed		L_k	=	1.33 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 10.62 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00~ 2.60	0.60	0.0 1.0	0.00 0.31	1.73 1.53	0.00 0.47
				ΣPdw = 0.31		ΣM dw = 0.47

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{136.92}{72.73} = 1.88 \ m$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	32400 cm^4 (original condition)
	I	=	22032 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 39917 x 10^{-8}		=	4.406 × 10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \ (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	12556 kN/m^3
calculated value	β	=	0.51663 m^{-1}
resultant earth force (lateral)	P_0	=	61.95 kN/m
height of acting position of load	h_0	=	1.57 m
moment	M_0	=	97.16 kN・m/m

in consideration of ψ_m = 1.202,

maximum moment	M_{max}	=	116.79 kN・m/m
depth of generated position of M_{max}	l_m	=	0.706 m
depth of 1st fixed point	l_i	=	2.226 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	12470 kN/m^3
calculated value	β	=	0.51574 m^{-1}
resultant earth force (lateral)	P_0	=	72.73 kN/m
height of acting position of load	h_0	=	1.88 m
moment	M_0	=	136.92 kN・m/m

in consideration of ψ_m = 1.153,

maximum moment	M_{max}	=	157.87 kN・m/m
depth of generated position of M_{max}	l_m	=	0.635 m
depth of 1st fixed point	l_i	=	2.158 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	1.00
Module of section	Z_0	=	1800 cm^3 (original condition)
	Z	=	1530 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{116.79\times10^6}{1530\times10^3} = 76 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{157.87\times10^6}{1530\times10^3} = 103 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.42	3.50 3.36	0.962 0.923	0.314 0.295	0.00 1.16	0.000 0.344
2	0.42～ 1.42	2.89 2.55	0.793 0.702	0.231 0.189	2.77 9.38	0.642 1.768
3	1.42～ 2.42	1.89 1.55	0.518 0.427	0.111 0.078	9.38 15.98	1.042 1.249
4	2.42～ 2.50	1.19 1.17	0.328 0.321	0.048 0.046	1.28 1.32	0.061 0.061
5	2.50～ 2.60	1.11 1.07	0.304 0.295	0.042 0.039	1.65 1.67	0.069 0.065
6	2.60～ 3.42	0.77 0.49	0.211 0.136	0.021 0.009	13.68 2.91	0.283 0.026
7	3.42～ 3.64	0.15 0.07	0.041 0.020	0.001 0.000	0.78 0.00	0.001 0.000
						ΣQ = 5.609

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

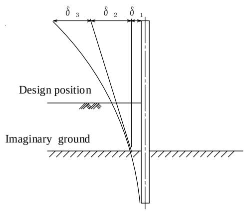
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5166\times1.57)\times61.95}{2\times2.00\times10^8\times22032\times10^{-8}\times0.5166^3} = 0.00923 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5166\times1.57)\times61.95}{2\times2.00\times10^8\times22032\times10^{-8}\times0.5166^2}\times(2.60+1.04) = 0.02513 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{5.61\times(2.60+1.04)^3}{2.00\times10^8\times22032\times10^{-8}} = 0.00615 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00923＋0.02513＋0.00615
= 0.04051 m
= 40.51 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.42	3.79 3.65	0.964 0.929	0.316 0.298	0.00 1.30	0.000 0.388
2	0.42～ 1.42	3.17 2.84	0.808 0.723	0.239 0.198	3.10 10.49	0.740 2.081
3	1.42～ 2.00	2.31 2.12	0.589 0.540	0.139 0.119	6.08 8.57	0.848 1.024
4	2.00～ 2.42	1.79 1.65	0.455 0.419	0.088 0.076	6.20 6.64	0.545 0.502
5	2.42～ 2.60	1.45 1.39	0.368 0.353	0.060 0.055	2.85 2.93	0.169 0.161
6	2.60～ 3.42	1.05 0.78	0.268 0.199	0.033 0.018	13.33 5.09	0.436 0.094
7	3.42～ 3.93	0.34 0.17	0.086 0.043	0.004 0.001	3.14 0.00	0.011 0.000
						ΣQ = 6.999

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

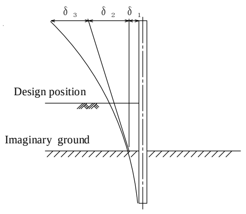
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.00～ 2.60	1.73 1.53	0.440 0.389	0.082 0.066	0.00 0.31	0.000 0.020
						ΣQ_{dw} = 0.020

Therefore, modulus of deformation Q is calculated as below:
Q = 7.762＋0.020 ＝ 7.782

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5157\times1.88)\times72.73}{2\times2.00\times10^8\times22032\times10^{-8}\times0.5157^3} = 0.01186 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5157\times1.88)\times72.73}{2\times2.00\times10^8\times22032\times10^{-8}\times0.5157^2}\times(2.60+1.33) = 0.03583 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{7.78\times(2.60+1.33)^3}{2.00\times10^8\times22032\times10^{-8}} = 0.01069 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01186＋0.03583＋0.01087
= 0.05856 m
= 58.56 ≦ δa = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	32400 cm^4 (original condition)
	I	=	32400 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 32400 x 10^{-8}		=	6.480 × 10^4

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 12556 kN/m^3
Calculated value β = 0.46914 m^{-1}

Penetration length of SSP $D = 1.04 + \frac{3}{0.469} = 7.44$ m
Whole length of SSP $L = 2.60 - 0.40 + 7.44 = 9.64$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 12470 kN/m^3
Calculated value β = 0.46834 m^{-1}

Penetration length of SSP $D = 1.33 + \frac{3}{0.468} = 7.73$ m
Whole length of SSP $L = 2.60 - 0.40 + 7.73 = 9.93$ m

Therefore, whole length of SSP is set as 10.00 m in consideration of round unit of SSP length.

8 Calculation Result

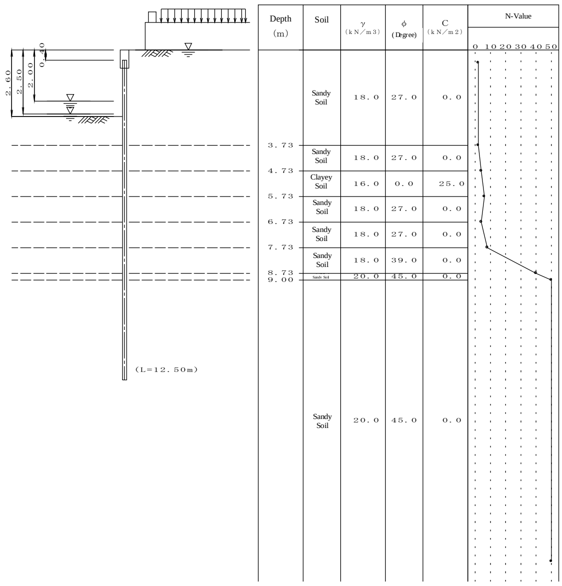
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	32400		
Section modulus	Z (cm^3)	1800		
Maximum bending moment	M_{max} (kN·m/m)		116.79	157.87
Stress intensity	σ (N/mm^2)		76 (180)	103 (270)
Lateral displacement	δ (mm)		40.51 (50.0)	58.56 (75.0)
Penetration depth	D (m)		7.44	7.73
Whole length of SSP	L (m)	10.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 07_STA 6+249_6+269

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.50 m (Normal Condition)
	L_{wp}'	=	2.00 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	6.5 kN/m	(Normal Condition)
		Pt'	=	9.8 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.45 m	(Normal Condition)
		Ht'	=	-0.20 m	(Seismic Condition)
	Moment	Mm	=	2.9 kN･m/m	(Normal Condition)
		Mm'	=	9.8 kN･m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	2			
2	3.73	2			
3	4.73	4			
4	5.73	6			
5	6.73	4			
6	7.73	8			
7	8.73	40			
8	9.00	50			
9	20.00	50			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

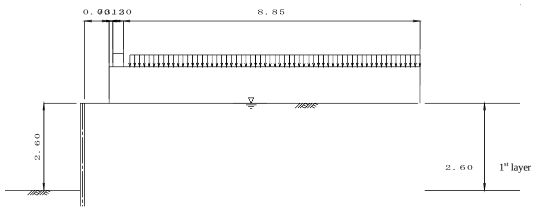
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m^3) normal	kh (kN/m^3) seismic
1	3.73	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
2	4.73	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	5.73	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
4	6.73	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	7.73	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	8.73	S	40.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
7	9.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
8	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.73	0.73	10.00	10.00	1.08	18.0	30.0	0.0	auto	auto
2	Sandy soil	0.85	0.85	1.15	1.15	0.41	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	1.35	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus $E = 200000$ N/mm²
Inertia sectional moment $I_0 = 86000$ cm⁴
Sectional factor $Z_0 = 3820$ cm³

Corrosion margin $t_1 = 1.00$ mm (riverside) $t_2 = 1.00$ mm (landside)

Corrosion rate (to I_0) $\eta = 0.92$
Corrosion rate (to Z_0) $\eta = 0.92$
Section efficiency (to I_0) $\mu = 0.80$
Section efficiency (to Z_0) $\mu = 1.00$

Round unit of SSP length 0.50 m

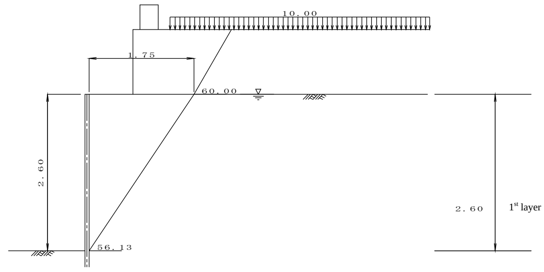
Allowable stress $\sigma_a = 180$ N/mm (Normal)
$\sigma_a' = 270$ N/mm (Seismic)

Allowable displacement $\delta_a = 50.0$ mm (Normal)
$\delta_a' = 75.0$ mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 0.00	Sandy Soil	27.0	9.0	0.0	26.00	21.89	25.48	56.13
2		Embankment	30.0	——	0.0	26.82	0.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\frac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	2.60	0.00	0.00	1.75	2.60
2	60.00	1.08	1.75	2.60	2.37	3.68

Therefore, width of acting load shall be set as 1.75 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.43	25.80
2	18.0	0.12	2.21
Σ			28.01

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.02	10.19
Σ			10.19

Q: surcharge load
l : width of surcharge load set by line of active rupture

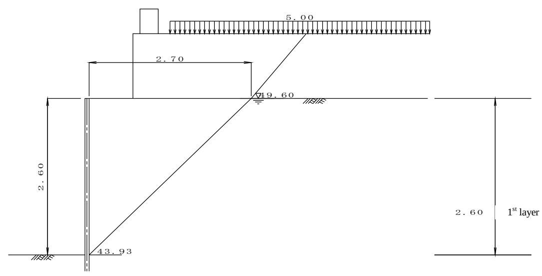
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{28.01 + 10.19 + 0.00}{1.75}$$

$$= 21.89 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 0.00	Sandy Soil	27.0	9.0	0.0	26.00	22.51	25.48	0.200	11.31	43.93
2		Embankment	30.0	——	0.0	26.82	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\frac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	2.60	0.00	0.00	2.70	2.60
2	49.60	1.08	2.70	2.60	3.62	3.68

Therefore, width of acting load shall be set as 2.70 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.62	47.22
2	18.0	0.12	2.21
Σ			49.43

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.27	11.34
Σ			11.34

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

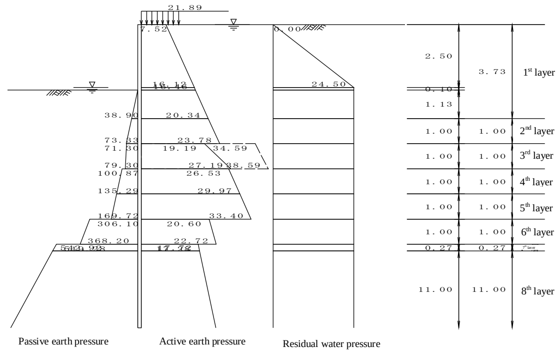
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{49.43 + 11.34 + 0.00}{2.70}$$

$$= 22.51 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.50	Sandy soil	10.0	27.0	—— ——	21.887 46.887	0.34800 0.34800	0.34371 0.34371
2	2.50～ 2.60	Sandy soil	10.0	27.0	—— ——	46.887 47.887	0.34800 0.34800	0.34371 0.34371
3	2.60～ 3.73	Sandy soil	10.0	27.0	—— ——	47.887 59.187	0.34800 0.34800	0.34371 0.34371
4	3.73～ 4.73	Sandy soil	10.0	27.0	—— ——	59.187 69.187	0.34800 0.34800	0.34371 0.34371
5	4.73～ 5.73	Clayey soil	8.0	—	25.0 25.0	69.187 77.187	—— ——	—— ——
6	5.73～ 6.73	Sandy soil	10.0	27.0	—— ——	77.187 87.187	0.34800 0.34800	0.34371 0.34371
7	6.73～ 7.73	Sandy soil	10.0	27.0	—— ——	87.187 97.187	0.34800 0.34800	0.34371 0.34371
8	7.73～ 8.73	Sandy soil	10.0	39.0	—— ——	97.187 107.187	0.21458 0.21458	0.21193 0.21193
9	8.73～ 9.00	Sandy soil	10.0	45.0	—— ——	107.187 109.887	0.16323 0.16323	0.16122 0.16122
10	9.00～ 20.00	Sandy soil	10.0	45.0	—— ——	109.887 219.887	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60～ 3.73	Sandy soil	10.0	27.0	—— ——	0.000 11.300	3.48553 3.48553	3.44261 3.44261
4	3.73～ 4.73	Sandy soil	10.0	27.0	—— ——	11.300 21.300	3.48553 3.48553	3.44261 3.44261
5	4.73～ 5.73	Clayey soil	8.0	0.0	25.0 25.0	21.300 29.300	—— ——	—— ——
6	5.73～ 6.73	Sandy soil	10.0	27.0	—— ——	29.300 39.300	3.48553 3.48553	3.44261 3.44261
7	6.73～ 7.73	Sandy soil	10.0	27.0	—— ——	39.300 49.300	3.48553 3.48553	3.44261 3.44261
8	7.73～ 8.73	Sandy soil	10.0	39.0	—— ——	49.300 59.300	6.28642 6.28642	6.20903 6.20903
9	8.73～ 9.00	Sandy soil	10.0	45.0	—— ——	59.300 62.000	8.86593 8.86593	8.75678 8.75678
10	9.00～ 20.00	Sandy soil	10.0	45.0	—— ——	62.000 172.000	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.50	7.52 16.12	—— ——	7.52 16.12	0.00 24.50	—— ——
2	2.50～ 2.60	16.12 16.46	—— ——	16.12 16.46	24.50 24.50	—— ——
3	2.60～ 3.73	16.46 20.34	—— ——	16.46 20.34	24.50 24.50	0.00 38.90
4	3.73～ 4.73	20.34 23.78	—— ——	20.34 23.78	24.50 24.50	38.90 73.33
5	4.73～ 5.73	19.19 27.19	34.59 38.59	34.59 38.59	24.50 24.50	71.30 79.30
6	5.73～ 6.73	26.53 29.97	—— ——	26.53 29.97	24.50 24.50	100.87 135.29
7	6.73～ 7.73	29.97 33.40	—— ——	29.97 33.40	24.50 24.50	135.29 169.72
8	7.73～ 8.73	20.60 22.72	—— ——	20.60 22.72	24.50 24.50	306.10 368.20
9	8.73～ 9.00	17.28 17.72	—— ——	17.28 17.72	24.50 24.50	519.28 542.92
10	9.00～ 20.00	17.72 35.45	—— ——	17.72 35.45	24.50 24.50	542.92 1506.17

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

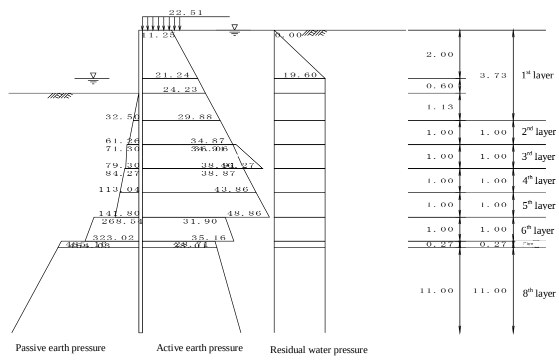
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.00	Sandy Soil	10.0	27.0	—— ——	22.51 42.51	0.00 19.60	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
2	2.00～ 2.60	Sandy Soil	10.0	27.0	—— ——	42.51 48.51	19.60 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.60～ 3.73	Sandy Soil	10.0	27.0	—— ——	48.51 59.81	25.48 36.55	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	3.73～ 4.73	Sandy Soil	10.0	27.0	—— ——	59.81 69.81	36.55 46.35	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	4.73～ 5.73	Clayey Soil	8.0	—	25.0 25.0	69.81 77.81	46.35 56.15	0.200 0.200	11.31 11.31	—— ——	—— ——	38.46 37.73

1.49

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	5.73~ 6.73	Sandy Soil	10.0	27.0	—— ——	77.81 87.81	56.15 65.95	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
7	6.73~ 7.73	Sandy Soil	10.0	27.0	—— ——	87.81 97.81	65.95 75.75	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
8	7.73~ 8.73	Sandy Soil	10.0	39.0	—— ——	97.81 107.81	75.75 85.55	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
9	8.73~ 9.00	Sandy Soil	10.0	45.0	—— ——	107.81 110.51	85.55 88.20	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——
10	9.00~ 20.00	Sandy Soil	10.0	45.0	—— ——	110.51 220.51	88.20 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 3.73	Sandy soil	10.00	27.0	—— ——	0.000 11.300	0.00 11.07	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
4	3.73~ 4.73	Sandy soil	10.00	27.0	—— ——	11.300 21.300	11.07 20.87	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	4.73~ 5.73	Clayey soil	8.00	0.0	25.0 25.0	21.300 29.300	20.87 30.67	0.200 0.200	11.31 11.31	—— ——	—— ——
6	5.73~ 6.73	Sandy soil	10.00	27.0	—— ——	29.300 39.300	30.67 40.47	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	6.73~ 7.73	Sandy soil	10.00	27.0	—— ——	39.300 49.300	40.47 50.27	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	7.73~ 8.73	Sandy soil	10.00	39.0	—— ——	49.300 59.300	50.27 60.07	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
9	8.73~ 9.00	Sandy soil	10.00	45.0	—— ——	59.300 62.000	60.07 62.72	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515
10	9.00~ 20.00	Sandy soil	10.00	45.0	—— ——	62.000 172.000	62.72 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

δ = -9.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.00	11.25 21.24	—— ——	11.25 21.24	0.00 19.60	—— ——
2	2.00~ 2.60	21.24 24.23	—— ——	21.24 24.23	19.60 19.60	—— ——
3	2.60~ 3.73	24.23 29.88	—— ——	24.23 29.88	19.60 19.60	0.00 32.50
4	3.73~ 4.73	29.88 34.87	—— ——	29.88 34.87	19.60 19.60	32.50 61.26
5	4.73~ 5.73	36.06 46.27	34.91 38.91	36.06 46.27	19.60 19.60	71.30 79.30
6	5.73~ 6.73	38.87 43.86	—— ——	38.87 43.86	19.60 19.60	84.27 113.04
7	6.73~ 7.73	43.86 48.86	—— ——	43.86 48.86	19.60 19.60	113.04 141.80
8	7.73~ 8.73	31.90 35.16	—— ——	31.90 35.16	19.60 19.60	268.54 323.02
9	8.73~ 9.00	28.01 28.71	—— ——	28.01 28.71	19.60 19.60	464.03 485.16
10	9.00~ 20.00	28.71 57.29	—— ——	28.71 57.29	19.60 19.60	485.16 1345.93

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.00 2.60	0.00 0.60	0.00 1.03

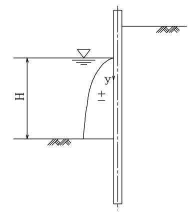
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

y : depth from water surface to the point where active water pressure is calculated

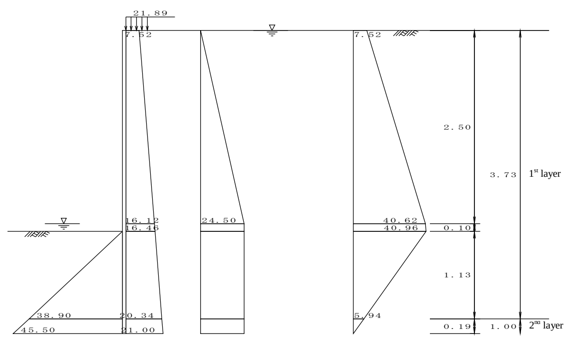


Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.50	7.52 16.12	0.00 24.50	—— ——	7.52 40.62
2	2.50~ 2.60	16.12 16.46	24.50 24.50	—— ——	40.62 40.96
3	2.60~ 3.73	16.46 20.34	24.50 24.50	0.00 38.90	40.96 5.94
4	3.73~ 3.92	20.34 21.00	24.50 24.50	38.90 45.50	5.94 0.00
5	3.92~ 4.73	21.00 23.78	24.50 24.50	45.50 73.33	0.00 -25.05

P_a : Active earth pressure

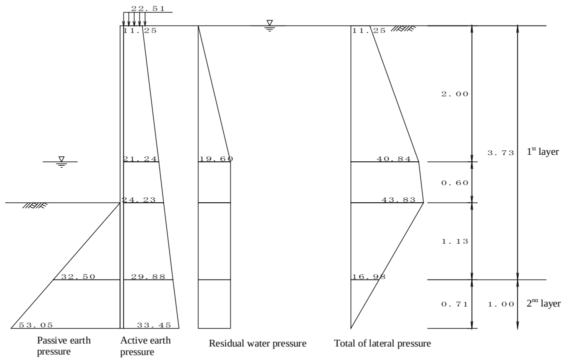
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.32 m (GL -3.92 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.00	11.25 21.24	0.00 19.60	—— ——	11.25 40.84
2	2.00~ 2.60	21.24 24.23	19.60 19.60	—— ——	40.84 43.83
3	2.60~ 3.73	24.23 29.88	19.60 19.60	0.00 32.50	43.83 16.98
4	3.73~ 4.44	29.88 33.45	19.60 19.60	32.50 53.05	16.98 0.00
5	4.44~ 4.73	33.45 34.87	19.60 19.60	53.05 61.26	0.00 -6.79

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.84 m (GL -4.44 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴(original condition)
	I	=	63296 cm⁴(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	2
2	3.73	2
3	4.73	4
4	5.73	6
5	6.73	4
6	7.73	8
7	8.73	40
8	9.00	50
9	20.00	50

5-2 Normal Condition

K_h = 12727 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.398 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.51 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.92 m) to 2.51 m depth (GL -6.43 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	3.92	0.81	2.4	4.0	2.58
2	4.73	1.00	4.0	6.0	5.00
3	5.73	0.70	6.0	4.6	3.72
L = Σh = 2.51			ΣA = 11.30		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{11.30}{2.51}$$

$$= 4.50$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 4.50^{0.406} = 12727$ kN/m³

Kh (normal condition) = 12727 kN/m³

5-3 Seismic Condition

K_h = 13068 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.401 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.49 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.44 m) and 2.49 m depth (GL -6.94 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	4.44	0.29	3.4	4.0	1.06
2	4.73	1.00	4.0	6.0	5.00
3	5.73	1.00	6.0	4.0	5.00
4	6.73	0.21	4.0	4.8	0.92
L = Σh = 2.49			ΣA = 11.99		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{11.99}{2.49}$$

$$= 4.80$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 4.80^{0.406} = 13068$ kN/m³

Kh (seismic condition) = 13068 kN/m³

1.51

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.50	2.50	7.52 40.62	9.40 50.77	3.09 2.26	29.04 114.49
2	2.50~ 2.60	0.10	40.62 40.96	2.03 2.05	1.39 1.36	2.82 2.78
3	2.60~ 3.73	1.13	40.96 5.94	23.14 3.36	0.95 0.57	21.87 1.91
4	3.73~ 3.92	0.19	5.94 0.00	0.57 0.00	0.13 0.06	0.07 0.00
ΣP = 91.32 ΣM = 172.98						

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	6.5 kN/m
depth to acting position	H_t	=	-0.45 m
moment	M_m	=	2.9 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.32 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 31.32$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{204.30}{97.82} = 2.09 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.00	2.00	11.25 40.84	11.25 40.84	3.78 3.11	42.48 127.04
2	2.00~ 2.60	0.60	40.84 43.83	12.25 13.15	2.24 2.04	27.49 26.88
3	2.60~ 3.73	1.13	43.83 16.98	24.77 9.59	1.47 1.09	36.35 10.46
4	3.73~ 4.44	0.71	16.98 0.00	6.06 0.00	0.48 0.24	2.89 0.00
ΣP = 117.90 ΣM = 273.59						

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.8 kN/m
depth to acting position	H_t	=	-0.20 m
moment	M_m	=	9.8 kN・m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.84 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 55.31 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00～ 2.60	0.60	0.0 1.0	0.00 0.31	2.24 2.04	0.00 0.63
					ΣPdw = 0.31	ΣMdw = 0.63

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{329.54}{128.01} = 2.57 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63296 \times 10^{-8}$		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	12727 kN/m³
calculated value	β	=	0.39817 m⁻¹
resultant earth force (lateral)	P_0	=	97.82 kN/m
height of acting position of load	h_0	=	2.09 m
moment	M_0	=	204.30 kN・m/m

in consideration of ψ_m = 1.194,

maximum moment	M_{max}	=	243.99 kN・m/m
depth of generated position of M_{max}	l_m	=	0.902 m
depth of 1st fixed point	l_i	=	2.875 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	13068 kN/m³
calculated value	β	=	0.40081 m⁻¹
resultant earth force (lateral)	P_0	=	128.01 kN/m
height of acting position of load	h_0	=	2.57 m
moment	M_0	=	329.54 kN・m/m

in consideration of ψ_m = 1.139,

maximum moment	M_{max}	=	375.38 kN・m/m
depth of generated position of M_{max}	l_m	=	0.787 m
depth of 1st fixed point	l_i	=	2.747 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm³ (original condition)
	Z	=	3514 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{243.99 \times 10^6}{3514 \times 10^3} = 69 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{375.38 \times 10^6}{3514 \times 10^3} = 107 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.50	3.09 2.26	0.788 0.575	0.229 0.134	9.40 50.77	2.151 6.785
2	2.50～ 2.60	1.39 1.36	0.354 0.346	0.055 0.053	2.03 2.05	0.112 0.108
3	2.60～ 3.73	0.95 0.57	0.241 0.145	0.027 0.010	23.14 3.36	0.618 0.034
4	3.73～ 3.92	0.13 0.06	0.033 0.016	0.001 0.000	0.57 0.00	0.000 0.000
						ΣQ = 9.807

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

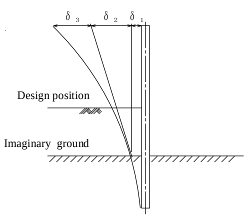
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3982\times2.09)\times97.82}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3982^3} = 0.01121 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.3982\times2.09)\times97.82}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3982^2} \times (2.60+1.32) = 0.02545 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.81\times(2.60+1.32)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00467 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00121 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.92 m
Horizontal load: P = 6.50
Moment: M = 2.93

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI} \times (2L-h)$$ （L＝4.69 m、h＝L－H_m、H_m＝0.80 m、た[illegible]L）

$$= \frac{2.80\times3.89}{2\times2.00\times10^8\times95760\times10^{-8}} \times (2\times4.69-3.89) = 0.00016 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01121＋0.02545＋0.00606
= 0.04272 m
= 42.72 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.00	3.78 3.11	0.850 0.700	0.259 0.188	11.25 40.84	2.912 7.670
2	2.00～ 2.60	2.24 2.04	0.505 0.460	0.106 0.090	12.25 13.15	1.299 1.178
3	2.60～ 3.73	1.47 1.09	0.330 0.245	0.049 0.028	24.77 9.59	1.202 0.265
4	3.73～ 4.44	0.48 0.24	0.107 0.054	0.006 0.001	6.06 0.00	0.034 0.000
						ΣQ = 14.559

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

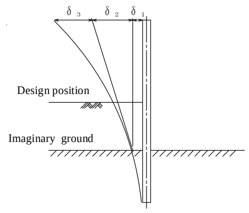
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.00～ 2.60	2.24 2.04	0.505 0.460	0.106 0.090	0.00 0.31	0.000 0.028
						ΣQ_{dw} = 0.028

Therefore, modulus of deformation Q is calculated as below:

Q = 14.559＋0.028 ＝ 14.587

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4008\times 2.57)\times 128.01}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4008^3} = 0.01595\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4008\times 2.57)\times 128.01}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4008^2}\times(2.60+1.84) = 0.04285\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{14.59\times(2.60+1.84)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.01011\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00242 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.44 m
Horizontal load: P = 9.80
Moment: M = 1.96

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.44\ \text{m、}h=L-H_m\text{、}H_m=0.80\ \text{m、ただし}h\leqq L)$$

$$= \frac{9.80\times 3.64}{2\times 2.00\times 10^8\times 63296\times 10^{-8}}\times(2\times 4.44-3.64) = 0.00074\ \text{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01595＋0.04285＋0.01327
= 0.07208 m
= 72.08 ≦ δa = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	86000 cm⁴ (after reduction by corrosion and section)
$EI = 200000\times 10^3\times 86000\times 10^{-8}$		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 12727 kN/m³
Calculated value β = 0.36880 m⁻¹

Penetration length of SSP $D = 1.32 + \dfrac{3}{0.369} = 9.46$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.46 = 11.66$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 13068 kN/m³
Calculated value β = 0.37124 m⁻¹

Penetration length of SSP $D = 1.84 + \dfrac{3}{0.371} = 9.93$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.93 = 12.13$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

1.53

8 Calculation Result

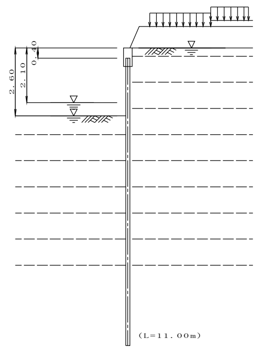
			Normal condition	Seismic condition
Inertia sectional moment	I (cm⁴)	86000		
Section modulus	Z (cm³)	3820		
Maximum bending moment	M_{max} (kN·m/m)		243.99	375.38
Stress intensity	σ (N/mm²)		69 (180)	107 (270)
Lateral displacement	δ (mm)		42.72 (50.0)	72.08 (75.0)
Penetration depth	D (m)		9.46	9.93
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

Left Bank No. 08_STA 6+376 - 6+482

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	ϕ (Degree)	C (kN/m2)	N-Value (0 10 20 30 40 50)
0.32	Clayey Soil	16.0	0.0	50.0	
1.32	Sandy Soil	18.0	29.0	0.0	
2.32	Sandy Soil	18.0	27.0	0.0	
3.32	Sandy Soil	18.0	27.0	0.0	
4.32	Sandy Soil	18.0	27.0	0.0	
5.32	Sandy Soil	18.0	30.0	0.0	
6.32	Sandy Soil	18.0	32.0	0.0	
7.32	Sandy Soil	18.0	33.0	0.0	
8.32	Sandy Soil	18.0	34.0	0.0	
	Sandy Soil	20.0	45.0	0.0	

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.2 kNm	(Normal Condition)
		P_t'	=	7.6 kNm	(Seismic Condition)
	Depth of acting point	H_t	=	-0.40 m	(Normal Condition)
		H_t'	=	-0.15 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.5 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_r = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.32	12
2	1.32	14
3	2.32	4
4	3.32	10
5	4.32	4
6	5.32	16
7	6.32	20
8	7.32	21
9	8.32	25
10	9.00	50

No	Depth (m)	N-Value
11	20.00	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	ϕ	C kNm^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	0.32	C	12.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
2	1.32	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
3	2.32	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	3.32	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	4.32	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	5.32	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
7	6.32	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
8	7.32	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
9	8.32	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
10	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

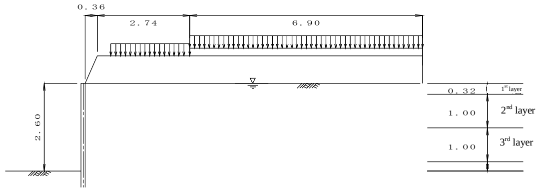
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_0 : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1.54

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.36	10.00	10.00	0.82	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.10	3.10	10.00	10.00	0.23	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.76	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 63000 cm⁴
Sectional factor Z_0 = 3150 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.91
Corrosion rate (to Z_0) η = 0.91
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

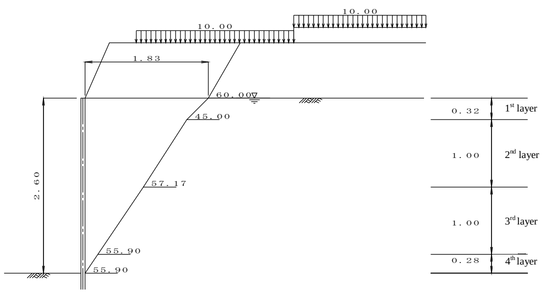
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.32	Sandy Soil	27.0	10.0	0.0	25.36	23.65	25.48	55.90
2	2.32～ 1.32	Sandy Soil	27.0	10.0	0.0	22.56	23.65	22.74	55.90
3	1.32～ 0.32	Sandy Soil	29.0	10.0	0.0	12.56	23.65	12.94	57.17
4	0.32～ 0.00	Clayey Soil	0.0	10.0	50.0	2.56	23.65	3.14	45.00
5		Embankment	30.0	——	0.0	18.90	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where.
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.28	0.00	0.00	0.19	0.28
2	55.90	1.00	0.19	0.28	0.87	1.28
3	57.17	1.00	0.87	1.28	1.51	2.28
4	45.00	0.32	1.51	2.28	1.83	2.60
5	60.00	0.82	1.83	2.60	2.31	3.42

Therefore, width of acting load shall be set as 1.83 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.55	27.87
Σ			27.87

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.55	15.45
Σ			15.45

Q surcharge load
l : width of surcharge load set by line of active rupture

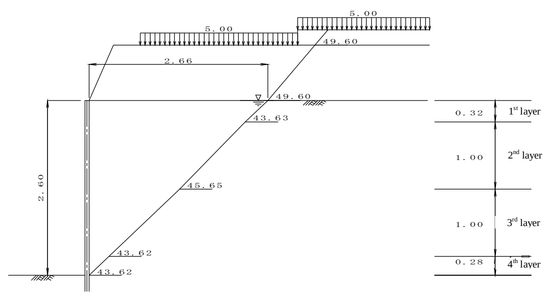
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{27.87 + 15.45 + 0.00}{1.83}$$

$$= 23.65 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.32	Sandy Soil	27.0	10.0	0.0	25.36	21.50	25.48	0.200	11.31	43.62
2	2.32～ 1.32	Sandy Soil	27.0	10.0	0.0	22.56	21.50	22.74	0.200	11.31	43.62
3	1.32～ 0.32	Sandy Soil	29.0	10.0	0.0	12.56	21.50	12.94	0.200	11.31	45.65
4	0.32～ 0.00	Clayey Soil	0.0	10.0	50.0	2.56	21.50	3.14	0.200	11.31	43.63
5		Embankment	30.0	——	0.0	18.90	5.00	0.00	0.200	11.31	49.60
6		Embankment	30.0	——	0.0	4.14	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where.
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.28	0.00	0.00	0.29	0.28
2	43.62	1.00	0.29	0.28	1.34	1.28
3	45.65	1.00	1.34	1.28	2.32	2.28
4	43.63	0.32	2.32	2.28	2.66	2.60
5	49.60	0.82	2.66	2.60	3.35	3.42
6	49.60	0.23	3.35	3.42	3.55	3.65

Therefore, width of acting load shall be set as 2.66 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.32	41.70
2	18.0	0.08	1.46
Σ			43.16

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.34	11.70
2	5.0	0.00	0.00
3	5.0	0.45	2.25
Σ			13.95

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

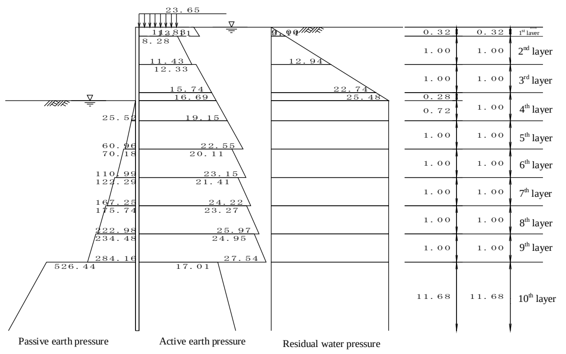
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{43.16 + 13.95 + 0.00}{2.66}$$

$$= 21.50 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 0.32	Clayey soil	8.0	—	50.0 50.0	23.653 26.213	— —	— —
2	0.32~ 1.32	Sandy soil	10.0	29.0	— —	26.213 36.213	0.32058 0.32058	0.31571 0.31571
3	1.32~ 2.32	Sandy soil	10.0	27.0	— —	36.213 46.213	0.34585 0.34585	0.34060 0.34060
4	2.32~ 2.60	Sandy soil	10.0	27.0	— —	46.213 49.013	0.34585 0.34585	0.34060 0.34060
5	2.60~ 3.32	Sandy soil	10.0	27.0	— —	49.013 56.213	0.34585 0.34585	0.34060 0.34060
6	3.32~ 4.32	Sandy soil	10.0	27.0	— —	56.213 66.213	0.34585 0.34585	0.34060 0.34060
7	4.32~ 5.32	Sandy soil	10.0	30.0	— —	66.213 76.213	0.30847 0.30847	0.30378 0.30378
8	5.32~ 6.32	Sandy soil	10.0	32.0	— —	76.213 86.213	0.28525 0.28525	0.28092 0.28092
9	6.32~ 7.32	Sandy soil	10.0	33.0	— —	86.213 96.213	0.27412 0.27412	0.26996 0.26996
10	7.32~ 8.32	Sandy soil	10.0	34.0	— —	96.213 106.213	0.26331 0.26331	0.25931 0.25931
11	8.32~ 20.00	Sandy soil	10.0	45.0	— —	106.213 223.013	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
5	2.60~ 3.32	Sandy soil	10.0	27.0	— —	0.000 7.200	3.59892 3.59892	3.54425 3.54425
6	3.32~ 4.32	Sandy soil	10.0	27.0	— —	7.200 17.200	3.59892 3.59892	3.54425 3.54425
7	4.32~ 5.32	Sandy soil	10.0	30.0	— —	17.200 27.200	4.14330 4.14330	4.08035 4.08035
8	5.32~ 6.32	Sandy soil	10.0	32.0	— —	27.200 37.200	4.56530 4.56530	4.49594 4.49594
9	6.32~ 7.32	Sandy soil	10.0	33.0	— —	37.200 47.200	4.79713 4.79713	4.72425 4.72425
10	7.32~ 8.32	Sandy soil	10.0	34.0	— —	47.200 57.200	5.04448 5.04448	4.96784 4.96784
11	8.32~ 20.00	Sandy soil	10.0	45.0	— —	57.200 174.000	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 0.32	-76.35 -73.79	11.83 13.11	11.83 13.11	0.00 3.14	— —
2	0.32~ 1.32	8.28 11.43	— —	8.28 11.43	3.14 12.94	— —
3	1.32~ 2.32	12.33 15.74	— —	12.33 15.74	12.94 22.74	— —
4	2.32~ 2.60	15.74 16.69	— —	15.74 16.69	22.74 25.48	— —
5	2.60~ 3.32	16.69 19.15	— —	16.69 19.15	25.48 25.48	0.00 25.52
6	3.32~ 4.32	19.15 22.55	— —	19.15 22.55	25.48 25.48	25.52 60.96
7	4.32~ 5.32	20.11 23.15	— —	20.11 23.15	25.48 25.48	70.18 110.99
8	5.32~ 6.32	21.41 24.22	— —	21.41 24.22	25.48 25.48	122.29 167.25
9	6.32~ 7.32	23.27 25.97	— —	23.27 25.97	25.48 25.48	175.74 222.98
10	7.32~ 8.32	24.95 27.54	— —	24.95 27.54	25.48 25.48	234.48 284.16

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
11	8.32~ 20.00	17.01 35.72	— —	17.01 35.72	25.48 25.48	526.44 1601.41

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = \left[K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}\right] \cdot \cos\delta$

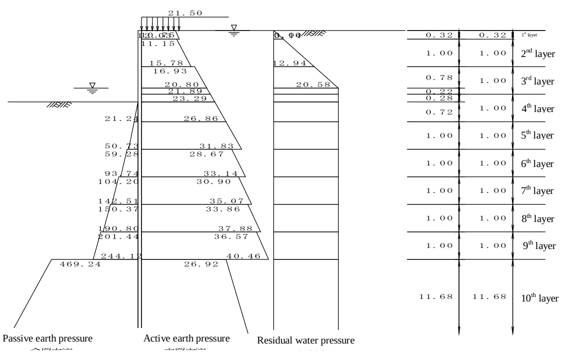
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = \left[K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}\right] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 0.32	Clayey Soil	8.0	—	50.0 50.0	21.50 24.06	0.00 3.14	0.200 0.200	11.31 11.31	— —	— —	43.71 43.63
2	0.32~ 1.32	Sandy Soil	10.0	29.0	— —	24.06 34.06	3.14 12.94	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	— —

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
3	1.32～ 2.10	Sandy Soil	10.0	27.0	—— ——	34.06 41.86	12.94 20.58	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	2.10～ 2.32	Sandy Soil	10.0	27.0	—— ——	41.86 44.06	20.58 22.74	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	2.32～ 2.60	Sandy Soil	10.0	27.0	—— ——	44.06 46.86	22.74 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	2.60～ 3.32	Sandy Soil	10.0	27.0	—— ——	46.86 54.06	25.48 32.54	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	3.32～ 4.32	Sandy Soil	10.0	27.0	—— ——	54.06 64.06	32.54 42.34	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
8	4.32～ 5.32	Sandy Soil	10.0	30.0	—— ——	64.06 74.06	42.34 52.14	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
9	5.32～ 6.32	Sandy Soil	10.0	32.0	—— ——	74.06 84.06	52.14 61.94	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
10	6.32～ 7.32	Sandy Soil	10.0	33.0	—— ——	84.06 94.06	61.94 71.74	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
11	7.32～ 8.32	Sandy Soil	10.0	34.0	—— ——	94.06 104.06	71.74 81.54	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
12	8.32～ 20.00	Sandy Soil	10.0	45.0	—— ——	104.06 220.86	81.54 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below:

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
6	2.60～ 3.32	Sandy soil	10.00	27.0	—— ——	0.000 7.200	0.00 7.06	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	3.32～ 4.32	Sandy soil	10.00	27.0	—— ——	7.200 17.200	7.06 16.86	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
8	4.32～ 5.32	Sandy soil	10.00	30.0	—— ——	17.200 27.200	16.86 26.66	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
9	5.32～ 6.32	Sandy soil	10.00	32.0	—— ——	27.200 37.200	26.66 36.46	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
10	6.32～ 7.32	Sandy soil	10.00	33.0	—— ——	37.200 47.200	36.46 46.26	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
11	7.32～ 8.32	Sandy soil	10.00	34.0	—— ——	47.200 57.200	46.26 56.06	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
12	8.32～ 20.00	Sandy soil	10.00	45.0	—— ——	57.200 174.000	56.06 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ = -10.00、β = 0.00、θ = $\tan^{-1}$k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 0.32	-74.11 -71.01	10.75 12.03	10.75 12.03	0.00 3.14	—— ——
2	0.32～ 1.32	11.15 15.78	—— ——	11.15 15.78	3.14 12.94	—— ——
3	1.32～ 2.10	16.93 20.80	—— ——	16.93 20.80	12.94 20.58	—— ——
4	2.10～ 2.32	20.80 21.89	—— ——	20.80 21.89	20.58 20.58	—— ——
5	2.32～ 2.60	21.89 23.29	—— ——	21.89 23.29	20.58 20.58	—— ——
6	2.60～ 3.32	23.29 26.86	—— ——	23.29 26.86	20.58 20.58	0.00 21.24
7	3.32～ 4.32	26.86 31.83	—— ——	26.86 31.83	20.58 20.58	21.24 50.73
8	4.32～ 5.32	28.67 33.14	—— ——	28.67 33.14	20.58 20.58	59.28 93.74
9	5.32～ 6.32	30.90 35.07	—— ——	30.90 35.07	20.58 20.58	104.20 142.51
10	6.32～ 7.32	33.86 37.88	—— ——	33.86 37.88	20.58 20.58	150.37 190.80
11	7.32～ 8.32	36.57 40.46	—— ——	36.57 40.46	20.58 20.58	201.44 244.12

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
12	8.32～ 20.00	26.92 57.14	—— ——	26.92 57.14	20.58 20.58	469.24 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

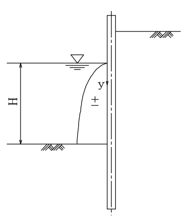
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm\frac{7}{8} k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where,

k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated

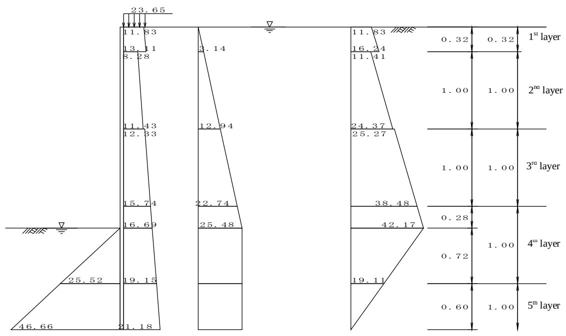


1.57

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

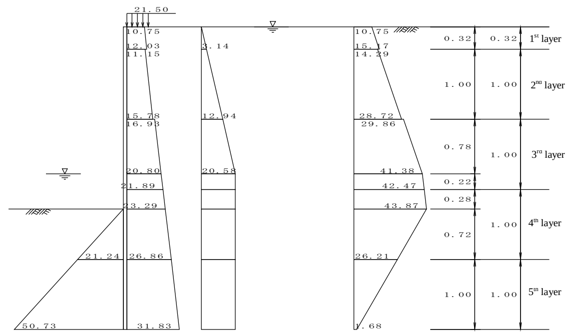


	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 0.32	11.83 13.11	0.00 3.14	―― ――	11.83 16.24
2	0.32～ 1.32	8.28 11.43	3.14 12.94	―― ――	11.41 24.37
3	1.32～ 2.32	12.33 15.74	12.94 22.74	―― ――	25.27 38.48
4	2.32～ 2.60	15.74 16.69	22.74 25.48	―― ――	38.48 42.17
5	2.60～ 3.32	16.69 19.15	25.48 25.48	0.00 25.52	42.17 19.11
6	3.32～ 3.92	19.15 21.18	25.48 25.48	25.52 46.66	19.11 0.00
7	3.92～ 4.32	21.18 22.55	25.48 25.48	46.66 60.96	0.00 -12.93

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.32 m (GL -3.92 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 0.32	10.75 12.03	0.00 3.14	―― ――	10.75 15.17
2	0.32～ 1.32	11.15 15.78	3.14 12.94	―― ――	14.29 28.72
3	1.32～ 2.10	16.93 20.80	12.94 20.58	―― ――	29.86 41.38
4	2.10～ 2.32	20.80 21.89	20.58 20.58	―― ――	41.38 42.47
5	2.32～ 2.60	21.89 23.29	20.58 20.58	―― ――	42.47 43.87
6	2.60～ 3.32	23.29 26.86	20.58 20.58	0.00 21.24	43.87 26.21
7	3.32～ 4.32	26.86 31.83	20.58 20.58	21.24 50.73	26.21 1.68
8	4.32～ 5.32	28.67 33.14	20.58 20.58	59.28 93.74	-10.03 -40.02

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.72 m (GL -4.32 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	45864 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 45864 \times 10^{-8} = 9.173 \times 10^4$

	Depth (m)	N-value
1	0.32	12
2	1.32	14
3	2.32	4
4	3.32	10
5	4.32	4
6	5.32	16
7	6.32	20
8	7.32	21
9	8.32	25
10	9.00	50

	Depth (m)	N-value
11	20.00	50

5-2 Normal Condition

K_h = 18659 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.475 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.11 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.92 m) to 2.11 m depth (GL -6.02 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.92	0.40	6.4	4.0	2.10
2	4.32	1.00	4.0	16.0	10.00
3	5.32	0.70	16.0	18.8	12.22
L = Σh = 2.11			ΣA = 24.32		

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{24.32}{2.11}$$

$$= 11.55$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 11.55^{0.406} = 18659 \ kN/m^3$

Kh (normal condition) = 18659 kN/m^3

5-3 Seismic Condition

K_h = 20281 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.485 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.06 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.32 m) and 2.06 m depth (GL -6.38 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.32	1.00	4.0	16.0	10.00
2	5.32	1.00	16.0	20.0	18.00
3	6.32	0.06	20.0	20.1	1.25
L = Σh = 2.06			ΣA = 29.25		

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{29.25}{2.06}$$

$$= 14.18$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 14.18^{0.406} = 20281 \ kN/m^3$

Kh (seismic condition) = 20281 kN/m^3

1.58

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 0.32	0.32	11.83 16.24	1.89 2.60	3.81 3.70	7.21 9.62
2	0.32～ 1.32	1.00	11.41 24.37	5.71 12.18	3.26 2.93	18.62 35.70
3	1.32～ 2.32	1.00	25.27 38.48	12.63 19.24	2.26 1.93	28.59 37.12
4	2.32～ 2.60	0.28	38.48 42.17	5.39 5.90	1.50 1.41	8.10 8.32
5	2.60～ 3.32	0.72	42.17 19.11	15.18 6.88	1.08 0.84	16.34 5.75
6	3.32～ 3.92	0.60	19.11 0.00	5.70 0.00	0.40 0.20	2.27 0.00
				ΣP = 93.30		ΣM = 177.65

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load		P_t	=	2.2 kN/m
	depth to acting position	H_t	=	-0.40 m
	moment	M_m	=	0.0 kN·m/m
	depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping		H	=	2.60 m
Depth of Imaginary riverbed from riverbed		L_k	=	1.32 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 9.50$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{187.14}{95.50} = 1.96 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 0.32	0.32	10.75 15.17	1.72 2.43	4.21 4.11	7.25 9.96
2	0.32～ 1.32	1.00	14.29 28.72	7.14 14.36	3.67 3.33	26.19 47.87
3	1.32～ 2.10	0.78	29.86 41.38	11.65 16.14	2.74 2.48	31.91 40.02
4	2.10～ 2.32	0.22	41.38 42.47	4.55 4.67	2.15 2.07	9.77 9.69
5	2.32～ 2.60	0.28	42.47 43.87	5.95 6.14	1.91 1.81	11.34 11.14
6	2.60～ 3.32	0.72	43.87 26.21	15.79 9.43	1.48 1.24	23.37 11.70
7	3.32～ 4.32	1.00	26.21 1.68	13.10 0.84	0.67 0.33	8.74 0.28
				ΣP = 113.92		ΣM = 249.22

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load		P_t	=	7.6 kN/m
	depth to acting position	H_t	=	-0.15 m
	moment	M_m	=	0.5 kN·m/m
	depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping		H	=	2.60 m
Depth of Imaginary riverbed from riverbed		L_k	=	1.72 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 34.47$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10～ 2.60	0.50	0.0 0.9	0.00 0.21	2.05 1.89	0.00 0.40
				ΣPdw = 0.21		ΣMdw = 0.40

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{284.10}{121.73} = 2.33 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	63000 cm⁴ (original condition)
	I	=	45864 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 45864 × 10⁻⁸		=	9.173 × 10⁴

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	18659 kN/m³
calculated value	β	=	0.47488 m⁻¹
resultant earth force (lateral)	P_0	=	95.50 kN/m
height of acting position of load	h_0	=	1.96 m
moment	M_0	=	187.14 kN·m/m

in consideration of ψ_m = 1.163,

maximum moment	M_{max}	=	217.74 kN·m/m
depth of generated position of M_{max}	l_m	=	0.708 m
depth of 1st fixed point	l_i	=	2.362 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	20281 kN/m³
calculated value	β	=	0.48488 m⁻¹
resultant earth force (lateral)	P_0	=	121.73 kN/m
height of acting position of load	h_0	=	2.33 m
moment	M_0	=	284.10 kN·m/m

in consideration of ψ_m = 1.120,

maximum moment	M_{max}	=	318.23 kN·m/m
depth of generated position of M_{max}	l_m	=	0.613 m
depth of 1st fixed point	l_i	=	2.233 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3150 cm³ (original condition)
	Z	=	2867 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{217.74\times10^6}{2867\times10^3} = 76 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{318.23\times10^6}{2867\times10^3} = 111 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

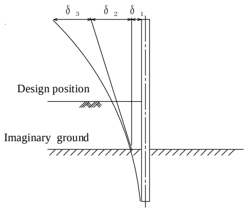
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.32	3.81 3.70	0.973 0.946	0.320 0.306	1.89 2.60	0.605 0.796
2	0.32～ 1.32	3.26 2.93	0.833 0.748	0.251 0.210	5.71 12.18	1.430 2.559
3	1.32～ 2.32	2.26 1.93	0.578 0.493	0.135 0.101	12.63 19.24	1.703 1.952
4	2.32～ 2.60	1.50 1.41	0.384 0.360	0.064 0.057	5.39 5.90	0.346 0.337
5	2.60～ 3.32	1.08 0.84	0.275 0.214	0.034 0.021	15.18 6.88	0.521 0.146
6	3.32～ 3.92	0.40 0.20	0.102 0.051	0.005 0.001	5.70 0.00	0.028 0.000
						ΣQ = 10.423

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4749\times 1.96)\times 95.50}{2\times 2.00\times 10^8\times 45864\times 10^{-8}\times 0.4749^3} = 0.00938\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4749\times 1.96)\times 95.50}{2\times 2.00\times 10^8\times 45864\times 10^{-8}\times 0.4749^2}\times(2.60+1.32) = 0.02587\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.42\times(2.60+1.32)^3}{2.00\times 10^8\times 45864\times 10^{-8}} = 0.00683\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00055 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.92 m
Horizontal load: P = 2.20
Moment: M = 0.88

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00938 + 0.02587 + 0.00738
= 0.04263 m
= 42.63 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.32	4.21 4.11	0.975 0.951	0.321 0.309	1.72 2.43	0.552 0.749
2	0.32～ 1.32	3.67 3.33	0.849 0.772	0.258 0.221	7.14 14.36	1.845 3.175
3	1.32～ 2.10	2.74 2.48	0.634 0.574	0.159 0.133	11.65 16.14	1.847 2.150
4	2.10～ 2.32	2.15 2.07	0.497 0.480	0.103 0.097	4.55 4.67	0.469 0.452
5	2.32～ 2.60	1.91 1.81	0.441 0.420	0.083 0.076	5.95 6.14	0.494 0.465
6	2.60～ 3.32	1.48 1.24	0.343 0.287	0.052 0.037	15.79 9.43	0.821 0.351
7	3.32～ 4.32	0.67 0.33	0.154 0.077	0.011 0.003	13.10 0.84	0.148 0.002
						ΣQ = 13.522

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta\times P$

P : Lateral force

H : Depth to design position

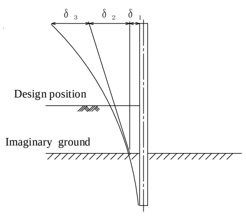
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10～ 2.60	2.05 1.89	0.475 0.437	0.095 0.081	0.00 0.21	0.000 0.017
						ΣQ_{dw} = 0.017

Therefore, modulus of deformation Q is calculated as below:
Q = 13.522 + 0.017 = 13.539

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4849\times 2.33)\times 121.73}{2\times 2.00\times 10^8\times 45864\times 10^{-8}\times 0.4849^3} = 0.01241\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4849\times 2.33)\times 121.73}{2\times 2.00\times 10^8\times 45864\times 10^{-8}\times 0.4849^2}\times(2.60+1.72) = 0.03979\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.54\times(2.60+1.72)^3}{2.00\times 10^8\times 45864\times 10^{-8}} = 0.01190\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00234 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.32 m
Horizontal load: P = 7.60
Moment: M = 1.14

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.32\ \text{m、}\ h=L-H_m\text{、}\ H_m=0.80\ \text{m、ただ[illegible]})$$

$$= \frac{0.50\times 3.52}{2\times 2.00\times 10^8\times 45864\times 10^{-8}}\times(2\times 4.32-3.52) = 0.00005\ \text{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01241 + 0.03979 + 0.01429
= 0.06649 m
= 66.49 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	63000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63000 \times 10^{-8}$		=	1.260×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 18659$ kN/m^3
Calculated value	$\beta = 0.43865$ m^{-1}
Penetration length of SSP	$D = 1.32 + \frac{3}{0.439} = 8.16$ m
Whole length of SSP	$L = 2.60 - 0.40 + 8.16 = 10.36$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 20281$ kN/m^3
Calculated value	$\beta = 0.44788$ m^{-1}
Penetration length of SSP	$D = 1.72 + \frac{3}{0.448} = 8.42$ m
Whole length of SSP	$L = 2.60 - 0.40 + 8.42 = 10.62$ m

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

8 Calculation Result

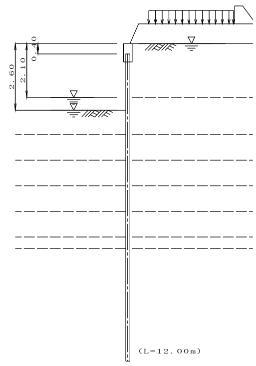
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	63000		
Section modulus	Z (cm^3)	3150		
Maximum bending moment	M_{max} (kN·m/m)		217.74	318.23
Stress intensity	σ (N/mm^2)		76 (180)	111 (270)
Lateral displacement	δ (mm)		42.63 (50.0)	66.49 (75.0)
Penetration depth	D (m)		8.16	8.42
Whole length of SSP	L (m)	11.00		

－Steel Sheet Pile Design Calculation－

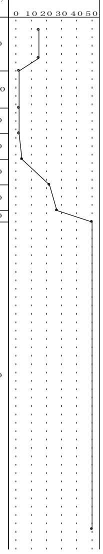
Left Bank No. 09_STA 7 + 326 – 7 + 444

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
	Sandy Soil	18.0	30.0	0.0
2.10	Clayey Soil	16.0	0.0	12.0
3.55	Sandy Soil	18.0	27.0	0.0
4.55	Sandy Soil	18.0	27.0	0.0
5.55	Sandy Soil	18.0	33.0	0.0
6.55	Sandy Soil	18.0	35.0	0.0
7.55	Sandy Soil	20.0	45.0	0.0
8.00	Sandy Soil	20.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.0 kN/m	(Normal Condition)
		P_t'	=	7.9 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.37 m	(Normal Condition)
		H_t'	=	-0.18 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$

Equilibrium factor of compression K_r = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	2			
4	3.55	2			
5	4.55	2			
6	5.55	4			
7	6.55	22			
8	7.55	27			
9	8.00	50			
10	20.00	50			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

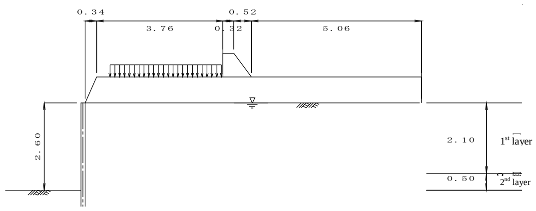
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m^3) normal	kh (kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.55	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	4.55	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	5.55	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	6.55	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
6	7.55	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
7	8.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
8	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_0 : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.34	10.00	10.00	0.77	18.0	30.0	0.0	auto	auto
2	Sandy soil	4.10	4.10	4.42	4.94	0.70	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.74	4.05	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_n = 86000 cm⁴
Sectional factor Z_n = 3820 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_n) η = 0.92
Corrosion rate (to Z_n) η = 0.92
Section efficiency (to I_n) μ = 0.80
Section efficiency (to Z_n) μ = 1.00

Round unit of SSP length 0.50 m

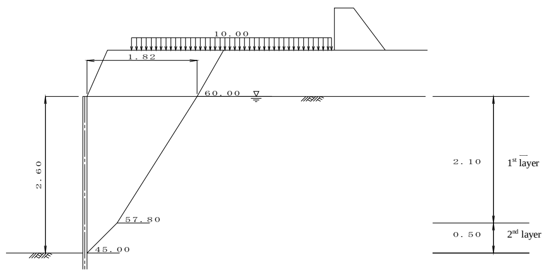
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_n applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_n applied to calculation of penetration depth
Reduced: I_n applied to calculation of section forces and displacement
Reduced: Z_n applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	22.64	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	22.64	20.58	57.80
3		Embankment	30.0	——	0.0	26.46	0.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	0.77	1.82	2.60	2.27	3.37

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.44	25.98
Σ			25.98

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.53	15.27
Σ			15.27

Q surcharge load
l : width of surcharge load set by line of active rupture

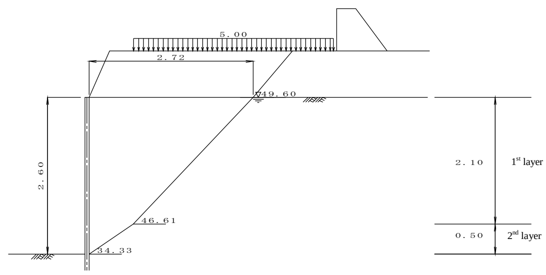
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{25.98 + 15.27 + 0.00}{1.82}$$

$$= 22.64\ \text{kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	19.51	25.48	0.200	11.31	34.33
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	19.51	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	26.46	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	34.33	0.50	0.00	0.00	0.73	0.50
2	46.61	2.10	0.73	0.50	2.72	2.60
3	49.60	0.77	2.72	2.60	3.37	3.37

Therefore, width of acting load shall be set as 2.72 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.21	39.85
Σ			39.85

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.63	13.16
Σ			13.16

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

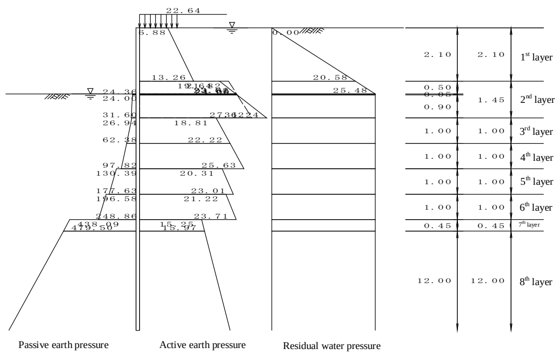
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{39.85 + 13.16 + 0.00}{2.72}$$

$= 19.51$ kN/m²

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	―― ――	22.636 43.636	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Clayey soil	8.0	―	12.0 12.0	43.636 47.636	―― ――	―― ――
3	2.60～ 2.65	Clayey soil	8.0	―	12.0 12.0	47.636 48.000	―― ――	―― ――
4	2.65～ 3.55	Clayey soil	8.0	―	12.0 12.0	48.000 55.236	―― ――	―― ――
5	3.55～ 4.55	Sandy soil	10.0	27.0	―― ――	55.236 65.236	0.34585 0.34585	0.34060 0.34060
6	4.55～ 5.55	Sandy soil	10.0	27.0	―― ――	65.236 75.236	0.34585 0.34585	0.34060 0.34060
7	5.55～ 6.55	Sandy soil	10.0	33.0	―― ――	75.236 85.236	0.27412 0.27412	0.26996 0.26996
8	6.55～ 7.55	Sandy soil	10.0	35.0	―― ――	85.236 95.236	0.25279 0.25279	0.24895 0.24895
9	7.55～ 8.00	Sandy soil	10.0	45.0	―― ――	95.236 99.736	0.16262 0.16262	0.16015 0.16015
10	8.00～ 20.00	Sandy soil	10.0	45.0	―― ――	99.736 219.736	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60～ 2.65	Clayey soil	8.0	0.0	12.0 12.0	0.000 0.364	―― ――	―― ――
4	2.65～ 3.55	Clayey soil	8.0	0.0	12.0 12.0	0.364 7.600	―― ――	―― ――
5	3.55～ 4.55	Sandy soil	10.0	27.0	―― ――	7.600 17.600	3.59892 3.59892	3.54425 3.54425
6	4.55～ 5.55	Sandy soil	10.0	27.0	―― ――	17.600 27.600	3.59892 3.59892	3.54425 3.54425
7	5.55～ 6.55	Sandy soil	10.0	33.0	―― ――	27.600 37.600	4.79713 4.79713	4.72425 4.72425
8	6.55～ 7.55	Sandy soil	10.0	35.0	―― ――	37.600 47.600	5.30876 5.30876	5.22810 5.22810
9	7.55～ 8.00	Sandy soil	10.0	45.0	―― ――	47.600 52.100	9.34548 9.34548	9.20351 9.20351
10	8.00～ 20.00	Sandy soil	10.0	45.0	―― ――	52.100 172.100	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	6.88 13.26	―― ――	6.88 13.26	0.00 20.58	―― ――
2	2.10～ 2.60	19.64 23.64	21.82 23.82	21.82 23.82	20.58 25.48	―― ――
3	2.60～ 2.65	23.64 24.00	23.82 24.00	23.82 24.00	25.48 25.48	24.00 24.36
4	2.65～ 3.55	24.00 31.24	24.00 27.62	24.00 31.24	25.48 25.48	24.36 31.60
5	3.55～ 4.55	18.81 22.22	―― ――	18.81 22.22	25.48 25.48	26.94 62.38
6	4.55～ 5.55	22.22 25.63	―― ――	22.22 25.63	25.48 25.48	62.38 97.82
7	5.55～ 6.55	20.31 23.01	―― ――	20.31 23.01	25.48 25.48	130.39 177.63
8	6.55～ 7.55	21.22 23.71	―― ――	21.22 23.71	25.48 25.48	196.58 248.86
9	7.55～ 8.00	15.25 15.97	―― ――	15.25 15.97	25.48 25.48	438.09 479.50
10	8.00～ 20.00	15.97 35.19	―― ――	15.97 35.19	25.48 25.48	479.50 1583.92

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

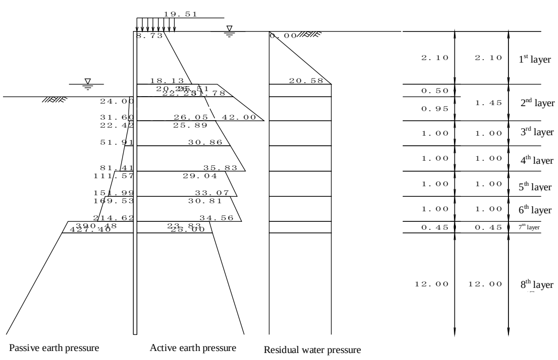
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	―― ――	19.51 40.51	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	―― ――
2	2.10～ 2.60	Clayey Soil	8.0	―	12.0 12.0	40.51 44.51	20.58 25.48	0.200 0.200	11.31 11.31	―― ――	―― ――	35.26 34.33
3	2.60～ 3.55	Clayey Soil	8.0	―	12.0 12.0	44.51 52.11	25.48 34.79	0.200 0.200	11.31 11.31	―― ――	―― ――	34.33 32.41
4	3.55～ 4.55	Sandy Soil	10.0	27.0	―― ――	52.11 62.11	34.79 44.59	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
5	4.55～ 5.55	Sandy Soil	10.0	27.0	―― ――	62.11 72.11	44.59 54.39	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
6	5.55～ 6.55	Sandy Soil	10.0	33.0	―― ――	72.11 82.11	54.39 64.19	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	―― ――

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	6.55~ 7.55	Sandy Soil	10.0	35.0	—— ——	82.11 92.11	64.19 73.99	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
8	7.55~ 8.00	Sandy Soil	10.0	45.0	—— ——	92.11 96.61	73.99 78.40	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
9	8.00~ 20.00	Sandy Soil	10.0	45.0	—— ——	96.61 216.61	78.40 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 3.55	Clayey soil	8.00	0.0	12.0 12.0	0.000 7.600	0.00 9.31	0.200 0.200	11.31 11.31	—— ——	—— ——
4	3.55~ 4.55	Sandy soil	10.00	27.0	—— ——	7.600 17.600	9.31 19.11	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	4.55~ 5.55	Sandy soil	10.00	27.0	—— ——	17.600 27.600	19.11 28.91	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	5.55~ 6.55	Sandy soil	10.00	33.0	—— ——	27.600 37.600	28.91 38.71	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
7	6.55~ 7.55	Sandy soil	10.00	35.0	—— ——	37.600 47.600	38.71 48.51	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
8	7.55~ 8.00	Sandy soil	10.00	45.0	—— ——	47.600 52.100	48.51 52.92	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
9	8.00~ 20.00	Sandy soil	10.00	45.0	—— ——	52.100 172.100	52.92 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 2.10	8.73 18.13	—— ——	8.73 18.13	0.00 20.58	—— ——
2	2.10~ 2.60	26.51 31.78	20.25 22.25	26.51 31.78	20.58 20.58	—— ——
3	2.60~ 3.55	31.78 42.00	22.25 26.05	31.78 42.00	20.58 20.58	24.00 31.60
4	3.55~ 4.55	25.89 30.86	—— ——	25.89 30.86	20.58 20.58	22.42 51.91
5	4.55~ 5.55	30.86 35.83	—— ——	30.86 35.83	20.58 20.58	51.91 81.41
6	5.55~ 6.55	29.04 33.07	—— ——	29.04 33.07	20.58 20.58	111.57 151.99
7	6.55~ 7.55	30.81 34.56	—— ——	30.81 34.56	20.58 20.58	169.53 214.62
8	7.55~ 8.00	23.83 25.00	—— ——	23.83 25.00	20.58 20.58	390.48 427.40
9	8.00~ 20.00	25.00 56.04	—— ——	25.00 56.04	20.58 20.58	427.40 1411.81

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c\cdot(\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}]\cdot\cos\delta$

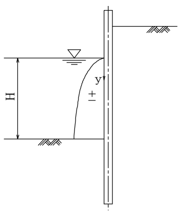
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.10 2.60	0.00 0.50	0.00 0.86

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where,

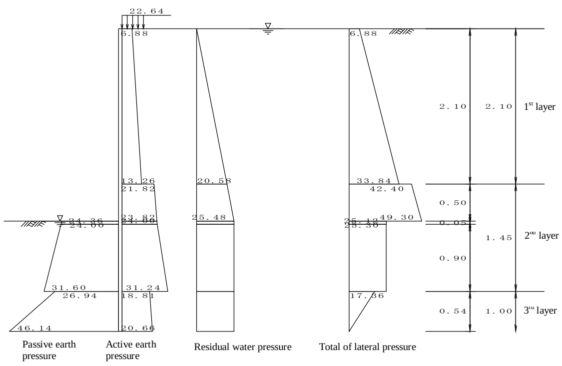
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

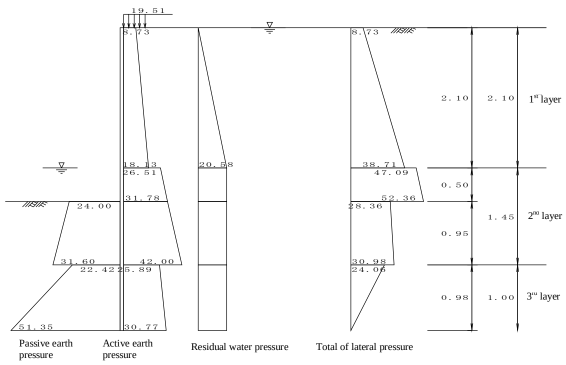


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00~ 2.10	6.88 13.26	0.00 20.58	—— ——	6.88 33.84
2	2.10~ 2.60	21.82 23.82	20.58 25.48	—— ——	42.40 49.30
3	2.60~ 2.65	23.82 24.00	25.48 25.48	24.00 24.36	25.30 25.12
4	2.65~ 3.55	24.00 31.24	25.48 25.48	24.36 31.60	25.12 25.12
5	3.55~ 4.09	18.81 20.66	25.48 25.48	26.94 46.14	17.36 0.00
6	4.09~ 4.55	20.66 22.22	25.48 25.48	46.14 62.38	0.00 -14.68

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.49 m (GL -4.09 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	8.73 18.13	0.00 20.58	—— ——	8.73 38.71
2	2.10～ 2.60	26.51 31.78	20.58 20.58	—— ——	47.09 52.36
3	2.60～ 3.55	31.78 42.00	20.58 20.58	24.00 31.60	28.36 30.98
4	3.55～ 4.53	25.89 30.77	20.58 20.58	22.42 51.35	24.06 0.00
5	4.53～ 4.55	30.77 30.86	20.58 20.58	51.35 51.91	0.00 -0.47

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.93 m (GL -4.53 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	3.55	2
5	4.55	2
6	5.55	4
7	6.55	22
8	7.55	27
9	8.00	50
10	20.00	50

5-2 Normal Condition

K_h = 14884 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.414 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.42 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.09 m) to 2.42 m depth (GL -6.51 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.09	0.46	2.0	2.0	0.92
2	4.55	1.00	2.0	4.0	3.00
3	5.55	0.96	4.0	21.2	12.07
	L = Σh = 2.42				ΣA = 15.98

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{15.98}{2.42}$$

$$= 6.62$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 6.62^{0.406} = 14884$ kN/m³

Kh (normal condition) = 14884 kN/m³

5-3 Seismic Condition

K_h = 12470 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.431 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.32 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.53 m) and 2.32 m depth (GL -6.85 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.53	0.02	2.0	2.0	0.04
2	4.55	1.00	2.0	4.0	3.00
3	5.55	1.00	4.0	22.0	13.00
4	6.55	0.30	22.0	23.5	6.83
	L = Σh = 2.32				ΣA = 22.87

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{22.87}{2.32}$$

$$= 9.86$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 9.86^{0.406} = 17499$ kN/m³

Kh (seismic condition) = 17499 kN/m³

1.66

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	6.88 33.84	7.22 35.53	3.39 2.69	24.49 95.63
2	2.10～ 2.60	0.50	42.40 49.30	10.60 12.32	1.83 1.66	19.35 20.44
3	2.60～ 2.65	0.05	25.30 25.12	0.57 0.57	1.48 1.46	0.85 0.83
4	2.65～ 3.55	0.90	25.12 25.12	11.36 11.36	1.14 0.84	13.00 9.58
5	3.55～ 4.09	0.54	17.36 0.00	4.70 0.00	0.36 0.18	1.70 0.00
				ΣP = 94.24		ΣM = 185.87

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.0 kN/m
depth to acting position	H_t	=	-0.37 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.49 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 8.92$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{194.80}{96.24} = 2.02 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.73 38.71	9.17 40.64	3.83 3.13	35.12 127.25
2	2.10~ 2.60	0.50	47.09 52.36	11.77 13.09	2.26 2.10	26.66 27.46
3	2.60~ 3.55	0.95	28.36 30.98	13.47 14.72	1.61 1.30	21.74 19.10
4	3.55~ 4.53	0.98	24.06 0.00	11.80 0.00	0.65 0.33	7.72 0.00
				ΣP = 114.66		ΣM = 265.04

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load		P_t	=	7.9 kNm
	depth to acting position	H	=	-0.18 m
	moment	M_m	=	0.0 kN·m/m
	depth to acting position	H_t	=	0.00 m
Height from riverbed to top of coping		H	=	2.60 m
Depth of Imaginary riverbed from riverbed		L_k	=	1.93 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 37.22 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.26 2.10	0.00 0.45
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.45

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{302.71}{122.77} = 2.47 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63296 \times 10^{-8}$		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	14884 kNm^3
calculated value	β	=	0.41406 m^{-1}
resultant earth force (lateral)	P_0	=	96.24 kNm
height of acting position of load	h_0	=	2.02 m
moment	M_0	=	194.80 kN·m/m

in consideration of ψ_m = 1.192,

maximum moment	M_{max}	=	232.20 kN·m/m
depth of generated position of M_{max}	l_m	=	0.864 m
depth of 1st fixed point	l_i	=	2.760 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	17499 kNm^3
calculated value	β	=	0.43116 m^{-1}
resultant earth force (lateral)	P_0	=	122.77 kNm
height of acting position of load	h_0	=	2.47 m
moment	M_0	=	302.71 kN·m/m

in consideration of ψ_m = 1.133,

maximum moment	M_{max}	=	342.88 kN·m/m
depth of generated position of M_{max}	l_m	=	0.718 m
depth of 1st fixed point	l_i	=	2.540 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{232.20\times10^6}{3514\times10^3} = 66 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{342.88\times10^6}{3514\times10^3} = 98 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

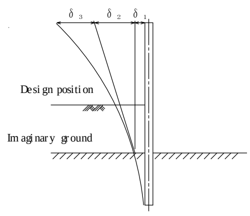
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.39 2.69	0.829 0.658	0.249 0.169	7.22 35.53	1.795 6.002
2	2.10~ 2.60	1.83 1.66	0.446 0.405	0.085 0.071	10.60 12.32	0.898 0.876
3	2.60~ 2.65	1.48 1.46	0.361 0.357	0.057 0.056	0.57 0.57	0.033 0.032
4	2.65~ 3.55	1.14 0.84	0.280 0.206	0.035 0.020	11.36 11.36	0.403 0.225
5	3.55~ 4.09	0.36 0.18	0.088 0.044	0.004 0.001	4.70 0.00	0.018 0.000
						ΣQ = 10.281

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.4141\times2.02)\times96.24}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4141^3} = 0.00984 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$
$$= \frac{(1+2\times0.4141\times2.02)\times96.24}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4141^2}\times(2.60+1.49) = 0.02428 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{10.28\times(2.60+1.49)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00556 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00041 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.09 m
Horizontal load: P = 2.00
Moment: M = 0.74

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00984 + 0.02428 + 0.00597
= 0.04009 m
= 40.09 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.83 3.13	0.846 0.691	0.257 0.184	9.17 40.64	2.353 7.469
2	2.10~ 2.60	2.26 2.10	0.500 0.463	0.104 0.091	11.77 13.09	1.225 1.186
3	2.60~ 3.55	1.61 1.30	0.356 0.286	0.056 0.037	13.47 14.72	0.753 0.546
4	3.55~ 4.53	0.65 0.33	0.144 0.072	0.010 0.003	11.80 0.00	0.117 0.000
						ΣQ = 13.649

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

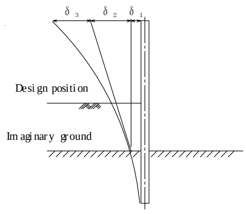
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.26 2.10	0.500 0.463	0.104 0.091	0.00 0.21	0.000 0.019
						ΣQ_{dw} = 0.019

Therefore, modulus of deformation Q is calculated as below:

Q = 13.649 + 0.019 = 13.669

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4312\times 2.47)\times 122.77}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4312^3} = 0.01248 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4312\times 2.47)\times 122.77}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4312^2}\times(2.60+1.93) = 0.03695 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.67\times(2.60+1.93)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.01004 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00205 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.53 m

Horizontal load: P = 7.90

Moment: M = 1.42

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01248 + 0.03695 + 0.01209

= 0.06152 m

= 61.52 ≦ δ_a = 75.00 mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = $200000\times 10^3\times 86000\times 10^{-8}$		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction: K_h = 14884 kN/m^3

Calculated value: β = 0.38352 m^{-1}

Penetration length of SSP: $D = 1.49 + \dfrac{3}{0.384} = 9.31$ m

Whole length of SSP: L = 2.60 − 0.40 + 9.31 = 11.51 m

7-1-2 Seismic Conditi

Modules of lateral subgrade reaction: K_h = 17499 kN/m^3

Calculated value: β = 0.39935 m^{-1}

Penetration length of SSP: $D = 1.93 + \dfrac{3}{0.399} = 9.44$ m

Whole length of SSP: L = 2.60 − 0.40 + 9.44 = 11.64 m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

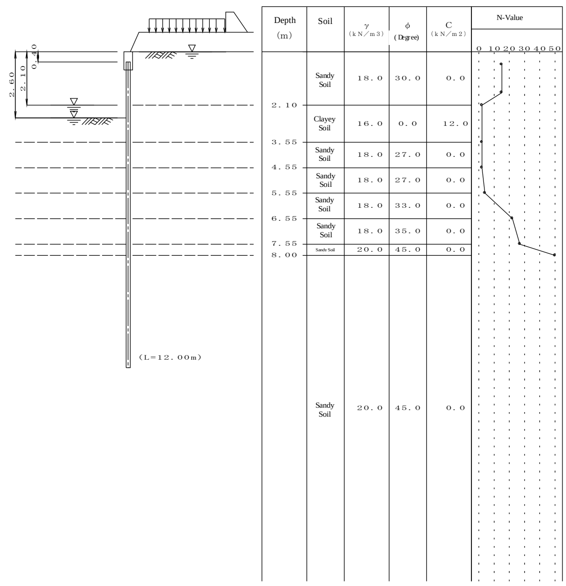
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		232.20	342.88
Stress intensity	σ (N/mm^2)		66 (180)	98 (270)
Lateral displacement	δ (mm)		40.09 (50.0)	61.52 (75.0)
Penetration depth	D (m)		9.31	9.44
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 10_STA 7+494 – 7+514

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{1t}	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.0 kN/m	(Normal Condition)
		P_t'	=	7.9 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.37 m	(Normal Condition)
		H_t'	=	-0.19 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_r = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	2			
4	3.55	2			
5	4.55	2			
6	5.55	4			
7	6.55	22			
8	7.55	27			
9	8.00	50			
10	20.00	50			

1.69

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

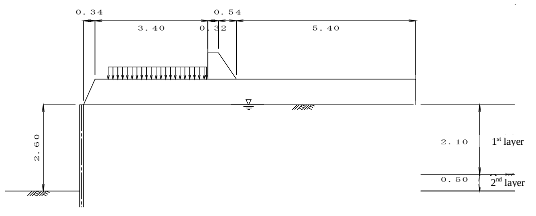
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.55	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	4.55	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	5.55	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	6.55	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
6	7.55	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
7	8.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
8	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.34	10.00	10.00	0.77	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.74	3.74	4.06	4.60	0.79	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.74	3.70	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus $E = 200000 \ N/mm^2$
Inertia sectional moment $I_0 = 86000 \ cm^4$
Sectional factor $Z_0 = 3820 \ cm^3$

Corrosion margin $t_1 = 1.00$ mm (riverside) $t_2 = 1.00$ mm (landside)

Corrosion rate (to I_0) $\eta = 0.92$
Corrosion rate (to Z_0) $\eta = 0.92$
Section efficiency (to I_0) $\mu = 0.80$
Section efficiency (to Z_0) $\mu = 1.00$

Round unit of SSP length 0.50 m

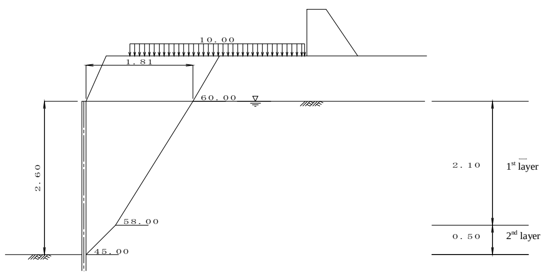
Allowable stress $\sigma_a = 180$ N/mm (Normal)
$\sigma_a' = 270$ N/mm (Seismic)

Allowable displacement $\delta_a = 50.0$ mm (Normal)
$\delta_a' = 75.0$ mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	9.0	12.0	25.00	22.63	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	22.63	20.58	58.00
3		Embankment	30.0	——	0.0	28.08	0.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^{o} since $\theta = 0^{o}$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00^{o}$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	58.00	2.10	0.50	0.50	1.81	2.60
3	60.00	0.77	1.81	2.60	2.26	3.37

Therefore, width of acting load shall be set as 1.81 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.44	25.84
Σ			25.84

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.52	15.17
Σ			15.17

Q surcharge load
l : width of surcharge load set by line of active rupture

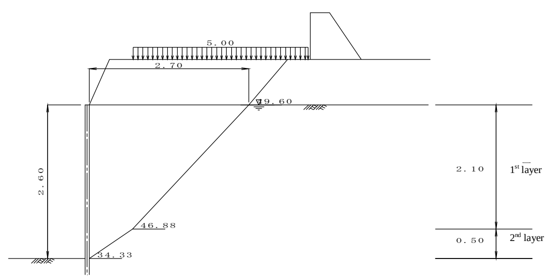
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{25.84 + 15.17 + 0.00}{1.81}$$

$$= 22.63 \ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	9.0	12.0	25.00	19.51	25.48	0.200	11.31	34.33
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	19.51	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	28.08	0.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00^{o}$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	34.33	0.50	0.00	0.00	0.73	0.50
2	46.88	2.10	0.73	0.50	2.70	2.60
3	49.60	0.77	2.70	2.60	3.35	3.37

Therefore, width of acting load shall be set as 2.70 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.20	39.59
Σ			39.59

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.61	13.07
Σ			13.07

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

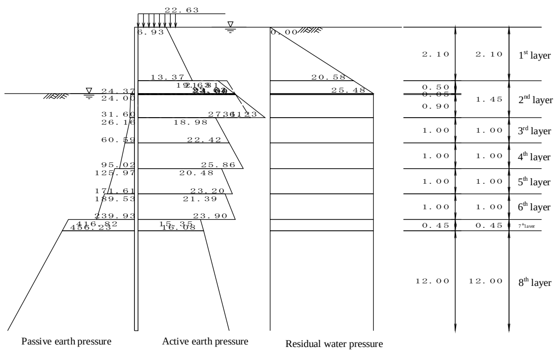
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{39.59 + 13.07 + 0.00}{2.70}$$

$$= 19.51 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	22.630 43.630	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.60	Clayey soil	8.0	—	12.0 12.0	43.630 47.630	—— ——	—— ——
3	2.60~ 2.65	Clayey soil	8.0	—	12.0 12.0	47.630 48.000	—— ——	—— ——
4	2.65~ 3.55	Clayey soil	8.0	—	12.0 12.0	48.000 55.230	—— ——	—— ——
5	3.55~ 4.55	Sandy soil	10.0	27.0	—— ——	55.230 65.230	0.34800 0.34800	0.34371 0.34371
6	4.55~ 5.55	Sandy soil	10.0	27.0	—— ——	65.230 75.230	0.34800 0.34800	0.34371 0.34371
7	5.55~ 6.55	Sandy soil	10.0	33.0	—— ——	75.230 85.230	0.27561 0.27561	0.27222 0.27222
8	6.55~ 7.55	Sandy soil	10.0	35.0	—— ——	85.230 95.230	0.25410 0.25410	0.25097 0.25097
9	7.55~ 8.00	Sandy soil	10.0	45.0	—— ——	95.230 99.730	0.16323 0.16323	0.16122 0.16122
10	8.00~ 20.00	Sandy soil	10.0	45.0	—— ——	99.730 219.730	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 2.65	Clayey soil	8.0	0.0	12.0 12.0	0.000 0.370	—— ——	—— ——
4	2.65~ 3.55	Clayey soil	8.0	0.0	12.0 12.0	0.370 7.600	—— ——	—— ——
5	3.55~ 4.55	Sandy soil	10.0	27.0	—— ——	7.600 17.600	3.48553 3.48553	3.44261 3.44261
6	4.55~ 5.55	Sandy soil	10.0	27.0	—— ——	17.600 27.600	3.48553 3.48553	3.44261 3.44261
7	5.55~ 6.55	Sandy soil	10.0	33.0	—— ——	27.600 37.600	4.62104 4.62104	4.56415 4.56415
8	6.55~ 7.55	Sandy soil	10.0	35.0	—— ——	37.600 47.600	5.10344 5.10344	5.04061 5.04061
9	7.55~ 8.00	Sandy soil	10.0	45.0	—— ——	47.600 52.100	8.86593 8.86593	8.75678 8.75678
10	8.00~ 20.00	Sandy soil	10.0	45.0	—— ——	52.100 172.100	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	6.93 13.37	—— ——	6.93 13.37	0.00 20.58	—— ——
2	2.10~ 2.60	19.63 23.63	21.81 23.81	21.81 23.81	20.58 25.48	—— ——
3	2.60~ 2.65	23.63 24.00	23.81 24.00	23.81 24.00	25.48 25.48	24.00 24.37
4	2.65~ 3.55	24.00 31.23	24.00 27.61	24.00 31.23	25.48 25.48	24.37 31.60
5	3.55~ 4.55	18.98 22.42	—— ——	18.98 22.42	25.48 25.48	26.16 60.59
6	4.55~ 5.55	22.42 25.86	—— ——	22.42 25.86	25.48 25.48	60.59 95.02
7	5.55~ 6.55	20.48 23.20	—— ——	20.48 23.20	25.48 25.48	125.97 171.61
8	6.55~ 7.55	21.39 23.90	—— ——	21.39 23.90	25.48 25.48	189.53 239.93
9	7.55~ 8.00	15.35 16.08	—— ——	15.35 16.08	25.48 25.48	416.82 456.23
10	8.00~ 20.00	16.08 35.43	—— ——	16.08 35.43	25.48 25.48	456.23 1507.04

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$
$P_{a2}=K_c \cdot (\Sigma\gamma h+Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

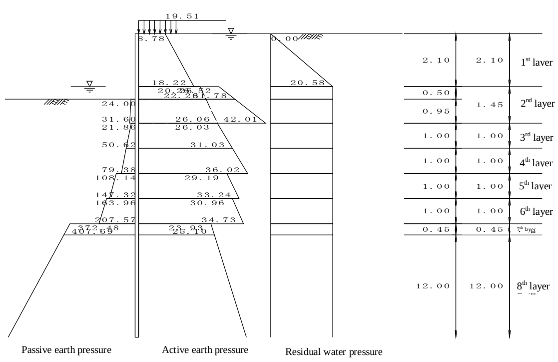
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	19.51 40.51	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	10.0
2	2.10~ 2.60	Clayey Soil	8.0	—	12.0 12.0	40.51 44.51	20.58 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	8.0
3	2.60~ 3.55	Clayey Soil	8.0	—	12.0 12.0	44.51 52.11	25.48 34.79	0.200 0.200	11.31 11.31	—— ——	—— ——	8.0
4	3.55~ 4.55	Sandy Soil	10.0	27.0	—— ——	52.11 62.11	34.79 44.59	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	10.0
5	4.55~ 5.55	Sandy Soil	10.0	27.0	—— ——	62.11 72.11	44.59 54.39	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	10.0
6	5.55~ 6.55	Sandy Soil	10.0	33.0	—— ——	72.11 82.11	54.39 64.19	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	10.0

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	6.55～ 7.55	Sandy Soil	10.0	35.0	—— ——	82.11 92.11	64.19 73.99	0.200 0.200	11.31 11.31	0.38174 0.38174	0.37704 0.37704	—— ——
8	7.55～ 8.00	Sandy Soil	10.0	45.0	—— ——	92.11 96.61	73.99 78.40	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——
9	8.00～ 20.00	Sandy Soil	10.0	45.0	—— ——	96.61 216.61	78.40 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60～ 3.55	Clayey soil	8.00	0.0	12.0 12.0	0.000 7.600	0.00 9.31	0.200 0.200	11.31 11.31	—— ——	—— ——
4	3.55～ 4.55	Sandy soil	10.00	27.0	—— ——	7.600 17.600	9.31 19.11	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	4.55～ 5.55	Sandy soil	10.00	27.0	—— ——	17.600 27.600	19.11 28.91	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	5.55～ 6.55	Sandy soil	10.00	33.0	—— ——	27.600 37.600	28.91 38.71	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819
7	6.55～ 7.55	Sandy soil	10.00	35.0	—— ——	37.600 47.600	38.71 48.51	0.200 0.200	11.31 11.31	4.41499 4.41499	4.36064 4.36064
8	7.55～ 8.00	Sandy soil	10.00	45.0	—— ——	47.600 52.100	48.51 52.92	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515
9	8.00～ 20.00	Sandy soil	10.00	45.0	—— ——	52.100 172.100	52.92 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	8.78 18.22	—— ——	8.78 18.22	0.00 20.58	—— ——
2	2.10～ 2.60	26.52 31.78	20.26 22.26	26.52 31.78	20.58 20.58	—— ——
3	2.60～ 3.55	31.78 42.01	22.26 26.06	31.78 42.01	20.58 20.58	24.00 31.60
4	3.55～ 4.55	26.03 31.03	—— ——	26.03 31.03	20.58 20.58	21.86 50.62
5	4.55～ 5.55	31.03 36.02	—— ——	31.03 36.02	20.58 20.58	50.62 79.38
6	5.55～ 6.55	29.19 33.24	—— ——	29.19 33.24	20.58 20.58	108.14 147.32
7	6.55～ 7.55	30.96 34.73	—— ——	30.96 34.73	20.58 20.58	163.96 207.57
8	7.55～ 8.00	23.93 25.10	—— ——	23.93 25.10	20.58 20.58	372.48 407.69
9	8.00～ 20.00	25.10 56.28	—— ——	25.10 56.28	20.58 20.58	407.69 1346.71

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$
Clayey soil $P_p = \Sigma\gamma h + Q + 2C$
Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

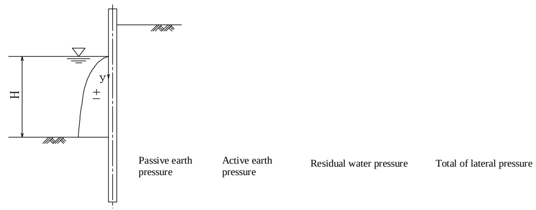
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm\frac{7}{8}\,k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where,

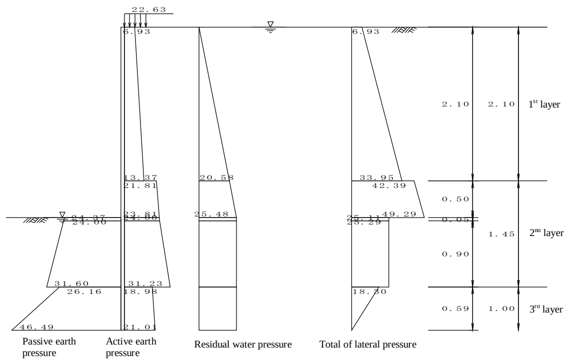
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

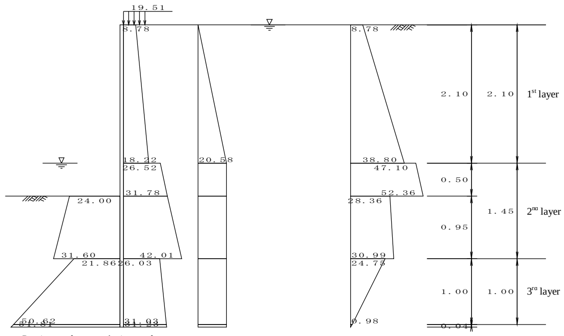


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	6.93 13.37	0.00 20.58	—— ——	6.93 33.95
2	2.10～ 2.60	21.81 23.81	20.58 25.48	—— ——	42.39 49.29
3	2.60～ 2.65	23.81 24.00	25.48 25.48	24.00 24.37	25.29 25.11
4	2.65～ 3.55	24.00 31.23	25.48 25.48	24.37 31.60	25.11 25.11
5	3.55～ 4.14	18.98 21.01	25.48 25.48	26.16 46.49	18.30 0.00
6	4.14～ 4.55	21.01 22.42	25.48 25.48	46.49 60.59	0.00 -12.69

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.54 m (GL -4.14 m)

4-2 Seismic Condition



Passive earth pressure | Active earth pressure | Residual water pressure | Total of lateral pressure

	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	8.78 18.22	0.00 20.58	—— ——	8.78 38.80
2	2.10～ 2.60	26.52 31.78	20.58 20.58	—— ——	47.10 52.36
3	2.60～ 3.55	31.78 42.01	20.58 20.58	24.00 31.60	28.36 30.99
4	3.55～ 4.55	26.03 31.03	20.58 20.58	21.86 50.62	24.75 0.98
5	4.55～ 4.59	31.03 31.23	20.58 20.58	50.62 51.81	0.98 0.00
6	4.59～ 5.55	31.23 36.02	20.58 20.58	51.81 79.38	0.00 -22.78

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.99 m (GL -4.59 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	3.55	2
5	4.55	2
6	5.55	4
7	6.55	22
8	7.55	27
9	8.00	50
10	20.00	50

5-2 Normal Condition

K_h = 15176 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.416 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.40 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.14 m) to 2.40 m depth (GL -6.54 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.14	0.41	2.0	2.0	0.82
2	4.55	1.00	2.0	4.0	3.00
3	5.55	0.99	4.0	21.9	12.87
	L = Σh = 2.40				ΣA = 16.69

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{16.69}{2.40}$$

$$= 6.94$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 6.94^{0.406} = 15176$ kN/m³

Kh (normal condition) = 15176 kN/m³

5-3 Seismic Condition

K_h = 17851 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.433 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.31 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.59 m) and 2.31 m depth (GL -6.90 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.59	0.96	2.1	4.0	2.92
2	5.55	1.00	4.0	22.0	13.00
3	6.55	0.35	22.0	23.7	7.99
	L = Σh = 2.31				ΣA = 23.90

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{23.90}{2.31}$$

$$= 10.36$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 10.36^{0.406} = 17851$ kN/m³

Kh (seismic condition) = 17851 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	6.93 33.95	7.28 35.65	3.44 2.74	25.05 97.69
2	2.10～ 2.60	0.50	42.39 49.29	10.60 12.32	1.87 1.71	19.86 21.04
3	2.60～ 2.65	0.05	25.29 25.11	0.59 0.58	1.53 1.51	0.89 0.88
4	2.65～ 3.55	0.90	25.11 25.11	11.35 11.35	1.19 0.89	13.54 10.12
5	3.55～ 4.14	0.59	18.30 0.00	5.40 0.00	0.39 0.20	2.13 0.00
				ΣP = 95.11		ΣM = 191.19

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.0 kN/m
depth to acting position	H_t	=	-0.37 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.54 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 9.02$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{200.21}{97.11} = 2.06 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	8.78 38.80	9.22 40.74	3.89 3.19	35.86 130.03
2	2.10～ 2.60	0.50	47.10 52.36	11.77 13.09	2.32 2.16	27.37 28.25
3	2.60～ 3.55	0.95	28.36 30.99	13.47 14.72	1.67 1.36	22.56 19.99
4	3.55～ 4.55	1.00	24.75 0.98	12.38 0.49	0.71 0.37	8.76 0.18
5	4.55～ 4.59	0.04	0.98 0.00	0.02 0.00	0.03 0.01	0.00 0.00
				ΣP = 115.90		ΣM = 273.01

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	7.9 kN/m
depth to acting position	H_t	=	-0.19 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.99 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 37.77 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10～ 2.60	0.50	0.0 0.9	0.00 0.21	2.32 2.16	0.00 0.46
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.46

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{311.25}{124.02} = 2.51 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2= 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 63296 × 10⁻⁸		=	1.266 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	15176 kN/m³
calculated value	β	=	0.41607 m⁻¹
resultant earth force (lateral)	P_0	=	97.11 kN/m
height of acting position of load	h_0	=	2.06 m
moment	M_0	=	200.21 kN·m/m

in consideration of ψ_m = 1.185,

maximum moment	M_{max}	=	237.31 kN·m/m
depth of generated position of M_{max}	l_m	=	0.848 m
depth of 1st fixed point	l_i	=	2.736 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	17851 kN/m³
calculated value	β	=	0.43331 m⁻¹
resultant earth force (lateral)	P_0	=	124.02 kN/m
height of acting position of load	h_0	=	2.51 m
moment	M_0	=	311.25 kN·m/m

in consideration of ψ_m = 1.128,

maximum moment	M_{max}	=	351.09 kN·m/m
depth of generated position of M_{max}	l_m	=	0.704 m
depth of 1st fixed point	l_i	=	2.517 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm³ (original condition)
	Z	=	3514 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{237.31\times10^6}{3514\times10^3} = 68 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{351.09\times10^6}{3514\times10^3} = 100 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

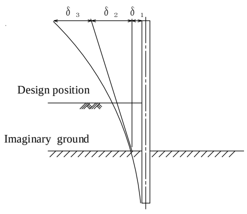
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.44 2.74	0.831 0.662	0.250 0.171	7.28 35.65	1.818 6.086
2	2.10～ 2.60	1.87 1.71	0.453 0.412	0.087 0.073	10.60 12.32	0.922 0.904
3	2.60～ 2.65	1.53 1.51	0.368 0.365	0.060 0.058	0.59 0.58	0.035 0.034
4	2.65～ 3.55	1.19 0.89	0.288 0.215	0.038 0.022	11.35 11.35	0.426 0.244
5	3.55～ 4.14	0.39 0.20	0.095 0.048	0.004 0.001	5.40 0.00	0.024 0.000
						ΣQ = 10.491

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.4161\times2.06)\times97.11}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4161^3} = 0.00989 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$
$$= \frac{(1+2\times0.4161\times2.06)\times97.11}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4161^2}\times(2.60+1.54) = 0.02491 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{10.49\times(2.60+1.54)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00588 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00042 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.14 m
Horizontal load: P = 2.00
Moment: M = 0.74

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00989 + 0.02491 + 0.00631
= 0.04111 m
= 41.11 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.89 3.19	0.848 0.695	0.258 0.186	9.22 40.74	2.375 7.562
2	2.10～ 2.60	2.32 2.16	0.506 0.470	0.107 0.093	11.77 13.09	1.254 1.219
3	2.60～ 3.55	1.67 1.36	0.365 0.296	0.058 0.039	13.47 14.72	0.787 0.580
4	3.55～ 4.55	0.71 0.37	0.154 0.082	0.011 0.003	12.38 0.49	0.140 0.002
5	4.55～ 4.59	0.03 0.01	0.006 0.003	0.000 0.000	0.02 0.00	0.000 0.000
						ΣQ = 13.920

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

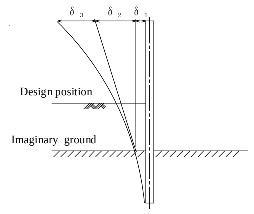
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10～ 2.60	2.32 2.16	0.506 0.470	0.107 0.093	0.00 0.21	0.000 0.020
						ΣQ_{dw} = 0.020

Therefore, modulus of deformation Q is calculated as below:

Q = 13.920＋0.020 ＝ 13.940

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4333\times 2.51)\times 124.02}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4333^3} = 0.01257 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4333\times 2.51)\times 124.02}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4333^2}\times(2.60+1.99) = 0.03803 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.94\times(2.60+1.99)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.01066 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00214 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.59 m

Horizontal load: P = 7.90

Moment: M = 1.50

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01257＋0.03803＋0.01280

= 0.06339 m

= 63.39 ≦ δ_a = 75.00 mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 86000 × 10^{-8}		=	1.720 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction — K_h = 15176 kN/m³

Calculated value — β = 0.38538 m^{-1}

Penetration length of SSP — $D = 1.54 + \dfrac{3}{0.385} = 9.33$ m

Whole length of SSP — L = 2.60−0.40＋9.33 ＝ 11.53 m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction — K_h = 17851 kN/m³

Calculated value — β = 0.40135 m^{-1}

Penetration length of SSP — $D = 1.99 + \dfrac{3}{0.401} = 9.47$ m

Whole length of SSP — L = 2.60−0.40＋9.47 ＝ 11.67 m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		237.31	351.09
Stress intensity	σ (N/mm^2)		68 (180)	100 (270)
Lateral displacement	δ (mm)		41.11 (50.0)	63.39 (75.0)
Penetration depth	D (m)		9.33	9.47
Whole length of SSP	L (m)	12.00		

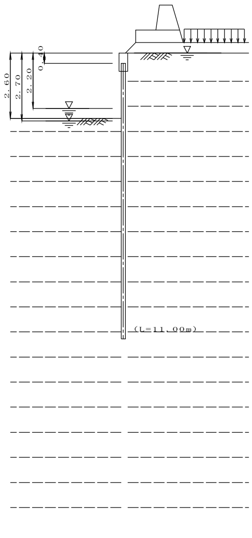
1.75

－Steel Sheet Pile Design Calculation－

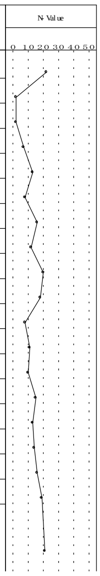
Left Bank No. 11_STA 11+500 - 11+628

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
1.12	Sandy Soil	18.0	33.0	0.0
2.12	Sandy Soil	18.0	27.0	0.0
3.12	Sandy Soil	18.0	27.0	0.0
4.12	Sandy Soil	18.0	27.0	0.0
5.12	Sandy Soil	18.0	29.0	0.0
6.12	Sandy Soil	18.0	27.0	0.0
7.12	Sandy Soil	18.0	30.0	0.0
8.12	Sandy Soil	18.0	28.0	0.0
9.12	Sandy Soil	18.0	32.0	0.0
10.12	Sandy Soil	18.0	31.0	0.0
11.12	Sandy Soil	18.0	27.0	0.0
12.12	Sandy Soil	18.0	28.0	0.0
13.12	Sandy Soil	18.0	27.0	0.0
14.12	Sandy Soil	18.0	30.0	0.0
15.12	Sandy Soil	18.0	29.0	0.0
16.12	Sandy Soil	18.0	29.0	0.0
17.12	Sandy Soil	18.0	30.0	0.0
18.12	Sandy Soil	18.0	32.0	0.0
	Sandy Soil	18.0	33.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load					
	Horizontal load	P_t	=	2.5 kN/m	(Normal Condition)
		P_t'	=	8.9 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.44 m	(Normal Condition)
		H_t'	=	-0.27 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.88	22
2	1.88	2
3	2.88	2
4	3.88	7
5	4.88	13
6	5.88	8
7	6.88	16
8	7.88	12
9	8.88	20
10	9.88	18

No	Depth (m)	N-Value
11	10.88	8
12	11.88	11
13	12.88	10
14	13.88	15
15	14.88	13
16	15.88	14
17	16.88	16
18	17.88	19
19	20.00	21

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

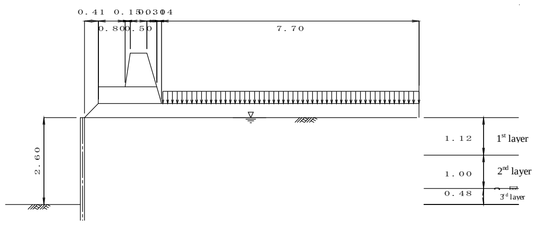
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m^3) normal	kh (kN/m^3) seismic
1	1.12	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
2	2.12	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	3.12	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.12	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.12	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
6	6.12	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	7.12	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
8	8.12	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
9	9.12	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
10	10.12	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
11	11.12	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
12	12.12	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
13	13.12	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
14	14.12	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
15	15.12	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
16	16.12	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
17	17.12	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
18	18.12	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
19	20.00	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	0.41	10.00	10.00	0.42	18.0	30.0	0.0	auto	auto
2	Sandy soil	0.41	0.41	2.16	2.30	0.50	24.0	45.0	0.0	auto	auto
3	Sandy soil	1.21	1.36	1.86	2.16	1.00	24.0	45.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm^2)	Seismic (kNm^2)
1	2.34	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 63000 cm^4
Sectional factor Z_0 = 3150 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.91
Corrosion rate (to Z_0) η = 0.91
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

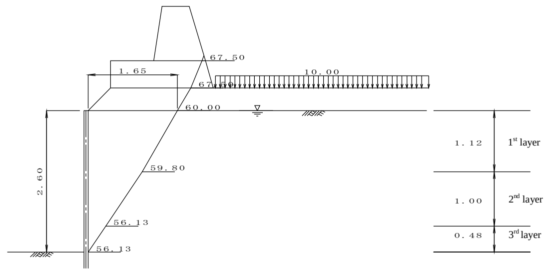
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	Angle of rupture Z (degree)
1	2.60～ 2.12	Sandy Soil	27.0	9.0	0.0	26.00	29.24	25.48	56.13
2	2.12～ 1.12	Sandy Soil	27.0	9.0	0.0	21.20	29.24	20.78	56.13
3	1.12～ 0.00	Sandy Soil	33.0	9.0	0.0	11.20	29.24	10.98	59.80
4		Embankment	30.0	——	0.0	43.56	0.00	0.00	60.00
5		Embankment	45.0	——	0.0	36.00	0.00	0.00	67.50
6		Embankment	45.0	——	0.0	24.00	0.00	0.00	67.50

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm^2)
- C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.48	0.00	0.00	0.32	0.48
2	56.13	1.00	0.32	0.48	0.99	1.48
3	59.80	1.12	0.99	1.48	1.65	2.60
4	60.00	0.42	1.65	2.60	1.89	3.02
5	67.50	0.50	1.89	3.02	2.09	3.52
6	67.50	0.09	2.09	3.52	2.13	3.61

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	0.66	11.80
2	24.0	0.79	18.97
3	24.0	0.72	17.33
Σ			48.11

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

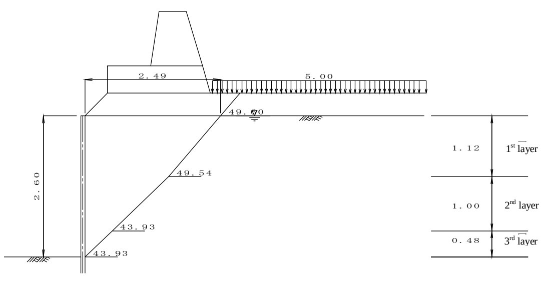
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times 1)+\Sigma P}{L}$$

$$= \frac{48.11 + 0.00 + 0.00}{1.65}$$

$$= 29.24 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.12	Sandy Soil	27.0	9.0	0.0	26.00	24.25	25.48	0.200	11.31	43.93
2	2.12～ 1.12	Sandy Soil	27.0	9.0	0.0	21.20	24.25	20.78	0.200	11.31	43.93
3	1.12～ 0.00	Sandy Soil	33.0	9.0	0.0	11.20	24.25	10.98	0.200	11.31	49.54
4		Embankment	30.0	——	0.0	43.56	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm^2)
- C cohesive force of soil (kNm^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.93	0.48	0.00	0.00	0.50	0.48
2	43.93	1.00	0.50	0.48	1.54	1.48
3	49.54	1.12	1.54	1.48	2.49	2.60
4	49.60	0.42	2.49	2.60	2.85	3.02

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.04	18.64
2	24.0	0.91	21.84
3	24.0	0.73	17.40
Σ			57.88

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	0.51	2.55
Σ			2.55

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

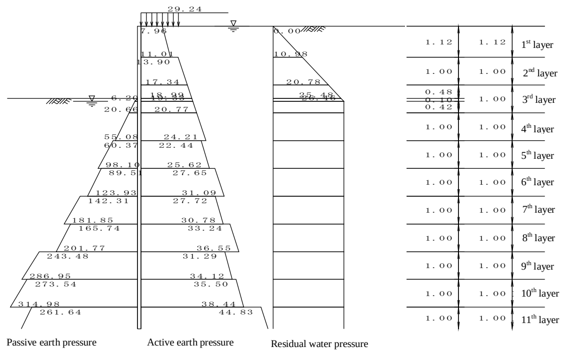
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{57.88 + 2.55 + 0.00}{2.49}$$

$$= 24.25 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00～ 1.12	Sandy soil	10.0	33.0	—— ——	29.242 40.442	0.27561 0.27561	0.27222 0.27222
2	1.12～ 2.12	Sandy soil	10.0	27.0	—— ——	40.442 50.442	0.34800 0.34800	0.34371 0.34371
3	2.12～ 2.60	Sandy soil	10.0	27.0	—— ——	50.442 55.242	0.34800 0.34800	0.34371 0.34371
4	2.60～ 2.70	Sandy soil	10.0	27.0	—— ——	55.242 56.242	0.34800 0.34800	0.34371 0.34371
5	2.70～ 3.12	Sandy soil	10.0	27.0	—— ——	56.242 60.442	0.34800 0.34800	0.34371 0.34371
6	3.12～ 4.12	Sandy soil	10.0	27.0	—— ——	60.442 70.442	0.34800 0.34800	0.34371 0.34371
7	4.12～ 5.12	Sandy soil	10.0	29.0	—— ——	70.442 80.442	0.32248 0.32248	0.31851 0.31851
8	5.12～ 6.12	Sandy soil	10.0	27.0	—— ——	80.442 90.442	0.34800 0.34800	0.34371 0.34371
9	6.12～ 7.12	Sandy soil	10.0	30.0	—— ——	90.442 100.442	0.31026 0.31026	0.30644 0.30644
10	7.12～ 8.12	Sandy soil	10.0	28.0	—— ——	100.442 110.442	0.33506 0.33506	0.33093 0.33093
11	8.12～ 9.12	Sandy soil	10.0	32.0	—— ——	110.442 120.442	0.28683 0.28683	0.28330 0.28330
12	9.12～ 10.12	Sandy soil	10.0	31.0	—— ——	120.442 130.442	0.29838 0.29838	0.29471 0.29471
13	10.12～ 11.12	Sandy soil	10.0	27.0	—— ——	130.442 140.442	0.34800 0.34800	0.34371 0.34371

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	11.12～ 12.12	Sandy soil	10.0	28.0	—— ——	140.442 150.442	0.33506 0.33506	0.33093 0.33093
15	12.12～ 13.12	Sandy soil	10.0	27.0	—— ——	150.442 160.442	0.34800 0.34800	0.34371 0.34371
16	13.12～ 14.12	Sandy soil	10.0	30.0	—— ——	160.442 170.442	0.31026 0.31026	0.30644 0.30644
17	14.12～ 15.12	Sandy soil	10.0	29.0	—— ——	170.442 180.442	0.32248 0.32248	0.31851 0.31851
18	15.12～ 16.12	Sandy soil	10.0	29.0	—— ——	180.442 190.442	0.32248 0.32248	0.31851 0.31851
19	16.12～ 17.12	Sandy soil	10.0	30.0	—— ——	190.442 200.442	0.31026 0.31026	0.30644 0.30644
20	17.12～ 18.12	Sandy soil	10.0	32.0	—— ——	200.442 210.442	0.28683 0.28683	0.28330 0.28330
21	18.12～ 20.00	Sandy soil	10.0	33.0	—— ——	210.442 229.242	0.27561 0.27561	0.27222 0.27222

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60～ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.48553 3.48553	3.44261 3.44261
5	2.70～ 3.12	Sandy soil	10.0	27.0	—— ——	1.800 6.000	3.48553 3.48553	3.44261 3.44261
6	3.12～ 4.12	Sandy soil	10.0	27.0	—— ——	6.000 16.000	3.48553 3.48553	3.44261 3.44261
7	4.12～ 5.12	Sandy soil	10.0	29.0	—— ——	16.000 26.000	3.82002 3.82002	3.77299 3.77299
8	5.12～ 6.12	Sandy soil	10.0	27.0	—— ——	26.000 36.000	3.48553 3.48553	3.44261 3.44261
9	6.12～ 7.12	Sandy soil	10.0	30.0	—— ——	36.000 46.000	4.00247 4.00247	3.95319 3.95319
10	7.12～ 8.12	Sandy soil	10.0	28.0	—— ——	46.000 56.000	3.64796 3.64796	3.60305 3.60305
11	8.12～ 9.12	Sandy soil	10.0	32.0	—— ——	56.000 66.000	4.40199 4.40199	4.34780 4.34780
12	9.12～ 10.12	Sandy soil	10.0	31.0	—— ——	66.000 76.000	4.19615 4.19615	4.14448 4.14448
13	10.12～ 11.12	Sandy soil	10.0	27.0	—— ——	76.000 86.000	3.48553 3.48553	3.44261 3.44261
14	11.12～ 12.12	Sandy soil	10.0	28.0	—— ——	86.000 96.000	3.64796 3.64796	3.60305 3.60305
15	12.12～ 13.12	Sandy soil	10.0	27.0	—— ——	96.000 106.000	3.48553 3.48553	3.44261 3.44261

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
16	13.12～ 14.12	Sandy soil	10.0	30.0	—— ——	106.000 116.000	4.00247 4.00247	3.95319 3.95319
17	14.12～ 15.12	Sandy soil	10.0	29.0	—— ——	116.000 126.000	3.82002 3.82002	3.77299 3.77299
18	15.12～ 16.12	Sandy soil	10.0	29.0	—— ——	126.000 136.000	3.82002 3.82002	3.77299 3.77299
19	16.12～ 17.12	Sandy soil	10.0	30.0	—— ——	136.000 146.000	4.00247 4.00247	3.95319 3.95319
20	17.12～ 18.12	Sandy soil	10.0	32.0	—— ——	146.000 156.000	4.40199 4.40199	4.34780 4.34780
21	18.12～ 20.00	Sandy soil	10.0	33.0	—— ——	156.000 174.800	4.62104 4.62104	4.56415 4.56415

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 1.12	7.96 11.01	—— ——	7.96 11.01	0.00 10.98	—— ——
2	1.12～ 2.12	13.90 17.34	—— ——	13.90 17.34	10.98 20.78	—— ——
3	2.12～ 2.60	17.34 18.99	—— ——	17.34 18.99	20.78 25.48	—— ——
4	2.60～ 2.70	18.99 19.33	—— ——	18.99 19.33	25.48 26.46	0.00 6.20
5	2.70～ 3.12	19.33 20.77	—— ——	19.33 20.77	26.46 26.46	6.20 20.66
6	3.12～ 4.12	20.77 24.21	—— ——	20.77 24.21	26.46 26.46	20.66 55.08
7	4.12～ 5.12	22.44 25.62	—— ——	22.44 25.62	26.46 26.46	60.37 98.10
8	5.12～ 6.12	27.65 31.09	—— ——	27.65 31.09	26.46 26.46	89.51 123.93
9	6.12～ 7.12	27.72 30.78	—— ——	27.72 30.78	26.46 26.46	142.31 181.85
10	7.12～ 8.12	33.24 36.55	—— ——	33.24 36.55	26.46 26.46	165.74 201.77
11	8.12～ 9.12	31.29 34.12	—— ——	31.29 34.12	26.46 26.46	243.48 286.95
12	9.12～ 10.12	35.50 38.44	—— ——	35.50 38.44	26.46 26.46	273.54 314.98
13	10.12～ 11.12	44.83 48.27	—— ——	44.83 48.27	26.46 26.46	261.64 296.06
14	11.12～ 12.12	46.48 49.79	—— ——	46.48 49.79	26.46 26.46	309.86 345.89
15	12.12～ 13.12	51.71 55.15	—— ——	51.71 55.15	26.46 26.46	330.49 364.92
16	13.12～ 14.12	49.17 52.23	—— ——	49.17 52.23	26.46 26.46	419.04 458.57

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
17	14.12~ 15.12	54.29 57.47	—— ——	54.29 57.47	26.46 26.46	437.67 475.40
18	15.12~ 16.12	57.47 60.66	—— ——	57.47 60.66	26.46 26.46	475.40 513.13
19	16.12~ 17.12	58.36 61.42	—— ——	58.36 61.42	26.46 26.46	537.63 577.17
20	17.12~ 18.12	56.79 59.62	—— ——	56.79 59.62	26.46 26.46	634.78 678.26
21	18.12~ 20.00	57.29 62.40	—— ——	57.29 62.40	26.46 26.46	712.01 797.81

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

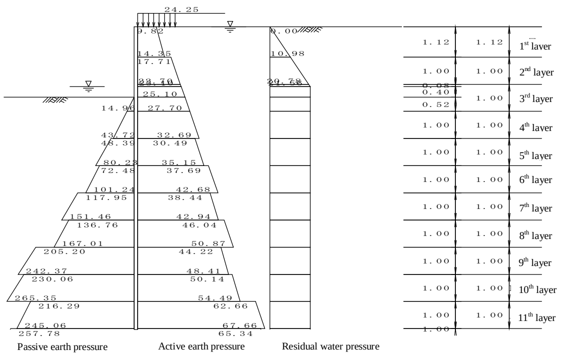
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k)	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 1.12	Sandy Soil	10.0	33.0	—— ——	24.25 35.45	0.00 10.98	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——
2	1.12~ 2.12	Sandy Soil	10.0	27.0	—— ——	35.45 45.45	10.98 20.78	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.12~ 2.20	Sandy Soil	10.0	27.0	—— ——	45.45 46.25	20.78 21.56	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	2.20~ 2.60	Sandy Soil	10.0	27.0	—— ——	46.25 50.25	21.56 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	2.60~ 3.12	Sandy Soil	10.0	27.0	—— ——	50.25 55.45	25.48 30.58	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	3.12~ 4.12	Sandy Soil	10.0	27.0	—— ——	55.45 65.45	30.58 40.38	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49! 9th layer	——
7	4.12~ 5.12	Sandy Soil	10.0	29.0	—— ——	65.45 75.45	40.38 50.18	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
Passive earth pressure	6.12	Soil	1 Active earth pressure			Residual water pressure [illegible]	[illegible]	[illegible]	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
9	6.12~ 7.12	Sandy Soil	10.0	30.0	—— ——	85.45 95.45	59.98 69.78	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
10	7.12~ 8.12	Sandy Soil	10.0	28.0	—— ——	95.45 105.45	69.78 79.58	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——
11	8.12~ 9.12	Sandy Soil	10.0	32.0	—— ——	105.45 115.45	79.58 89.38	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
12	9.12~ 10.12	Sandy Soil	10.0	31.0	—— ——	115.45 125.45	89.38 99.18	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	—— ——
13	10.12~ 11.12	Sandy Soil	10.0	27.0	—— ——	125.45 135.45	99.18 108.98	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
14	11.12~ 12.12	Sandy Soil	10.0	28.0	—— ——	135.45 145.45	108.98 118.78	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——
15	12.12~ 13.12	Sandy Soil	10.0	27.0	—— ——	145.45 155.45	118.78 128.58	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
16	13.12~ 14.12	Sandy Soil	10.0	30.0	—— ——	155.45 165.45	128.58 138.38	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
17	14.12~ 15.12	Sandy Soil	10.0	29.0	—— ——	165.45 175.45	138.38 148.18	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
18	15.12~ 16.12	Sandy Soil	10.0	29.0	—— ——	175.45 185.45	148.18 157.98	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
19	16.12~ 17.12	Sandy Soil	10.0	30.0	—— ——	185.45 195.45	157.98 167.78	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
20	17.12~ 18.12	Sandy Soil	10.0	32.0	—— ——	195.45 205.45	167.78 177.58	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
21	18.12~ 20.00	Sandy Soil	10.0	33.0	—— ——	205.45 224.25	177.58 196.00	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.

δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60~ 3.12	Sandy soil	10.00	27.0	—— ——	0.000 5.200	0.00 5.10	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	3.12~ 4.12	Sandy soil	10.00	27.0	—— ——	5.200 15.200	5.10 14.90	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	4.12~ 5.12	Sandy soil	10.00	29.0	—— ——	15.200 25.200	14.90 24.70	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
8	5.12~ 6.12	Sandy soil	10.00	27.0	—— ——	25.200 35.200	24.70 34.50	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
9	6.12~ 7.12	Sandy soil	10.00	30.0	—— ——	35.200 45.200	34.50 44.30	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
10	7.12~ 8.12	Sandy soil	10.00	28.0	—— ——	45.200 55.200	44.30 54.10	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
11	8.12~ 9.12	Sandy soil	10.00	32.0	—— ——	55.200 65.200	54.10 63.90	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
12	9.12~ 10.12	Sandy soil	10.00	31.0	—— ——	65.200 75.200	63.90 73.70	0.200 0.200	11.31 11.31	3.57258 3.57258	3.52859 3.52859
13	10.12~ 11.12	Sandy soil	10.00	27.0	—— ——	75.200 85.200	73.70 83.50	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
14	11.12~ 12.12	Sandy soil	10.00	28.0	—— ——	85.200 95.200	83.50 93.30	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
15	12.12~ 13.12	Sandy soil	10.00	27.0	—— ——	95.200 105.200	93.30 103.10	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
16	13.12~ 14.12	Sandy soil	10.00	30.0	—— ——	105.200 115.200	103.10 112.90	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
17	14.12~ 15.12	Sandy soil	10.00	29.0	—— ——	115.200 125.200	112.90 122.70	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
18	15.12~ 16.12	Sandy soil	10.00	29.0	—— ——	125.200 135.200	122.70 132.50	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
19	16.12~ 17.12	Sandy soil	10.00	30.0	—— ——	135.200 145.200	132.50 142.30	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
20	17.12~ 18.12	Sandy soil	10.00	32.0	—— ——	145.200 155.200	142.30 152.10	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
21	18.12~ 20.00	Sandy soil	10.00	33.0	—— ——	155.200 174.000	152.10 170.52	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.

δ = -9.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 1.12	9.82 14.35	—— ——	9.82 14.35	0.00 10.98	—— ——
2	1.12~ 2.12	17.71 22.70	—— ——	17.71 22.70	10.98 20.78	—— ——
3	2.12~ 2.20	22.70 23.10	—— ——	22.70 23.10	20.78 21.56	—— ——
4	2.20~ 2.60	23.10 25.10	—— ——	23.10 25.10	21.56 21.56	—— ——
5	2.60~ 3.12	25.10 27.70	—— ——	25.10 27.70	21.56 21.56	0.00 14.96
6	3.12~ 4.12	27.70 32.69	—— ——	27.70 32.69	21.56 21.56	14.96 43.72
7	4.12~ 5.12	30.49 35.15	—— ——	30.49 35.15	21.56 21.56	48.39 80.23
8	5.12~ 6.12	37.69 42.68	—— ——	37.69 42.68	21.56 21.56	72.48 101.24
9	6.12~ 7.12	38.44 42.94	—— ——	38.44 42.94	21.56 21.56	117.95 151.46
10	7.12~ 8.12	46.04 50.87	—— ——	46.04 50.87	21.56 21.56	136.76 167.01
11	8.12~ 9.12	44.22 48.41	—— ——	44.22 48.41	21.56 21.56	205.20 242.37
12	9.12~ 10.12	50.14 54.49	—— ——	50.14 54.49	21.56 21.56	230.06 265.35
13	10.12~ 11.12	62.66 67.66	—— ——	62.66 67.66	21.56 21.56	216.29 245.06
14	11.12~ 12.12	65.34 70.16	—— ——	65.34 70.16	21.56 21.56	257.78 288.03
15	12.12~ 13.12	72.65 77.65	—— ——	72.65 77.65	21.56 21.56	273.82 302.58
16	13.12~ 14.12	69.92 74.42	—— ——	69.92 74.42	21.56 21.56	352.52 386.03
17	14.12~ 15.12	77.07 81.73	—— ——	77.07 81.73	21.56 21.56	366.75 398.58
18	15.12~ 16.12	81.73 86.39	—— ——	81.73 86.39	21.56 21.56	398.58 430.42
19	16.12~ 17.12	83.42 87.92	—— ——	83.42 87.92	21.56 21.56	453.05 486.56
20	17.12~ 18.12	81.96 86.15	—— ——	81.96 86.15	21.56 21.56	539.76 576.93
21	18.12~ 20.00	83.17 90.78	—— ——	83.17 90.78	21.56 21.56	608.10 681.76

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

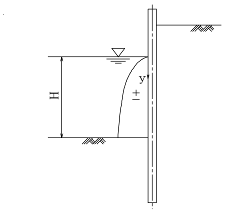
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

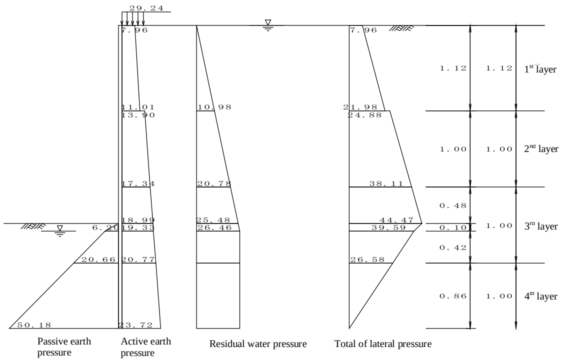
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 1.12	7.96 11.01	0.00 10.98	―― ――	7.96 21.98
2	1.12～ 2.12	13.90 17.34	10.98 20.78	―― ――	24.88 38.11
3	2.12～ 2.60	17.34 18.99	20.78 25.48	―― ――	38.11 44.47
4	2.60～ 2.70	18.99 19.33	25.48 26.46	0.00 6.20	44.47 39.59
5	2.70～ 3.12	19.33 20.77	26.46 26.46	6.20 20.66	39.59 26.58
6	3.12～ 3.98	20.77 23.72	26.46 26.46	20.66 50.18	26.58 0.00
7	3.98～ 4.12	23.72 24.21	26.46 26.46	50.18 55.08	0.00 -4.41

P_a : Active earth pressure

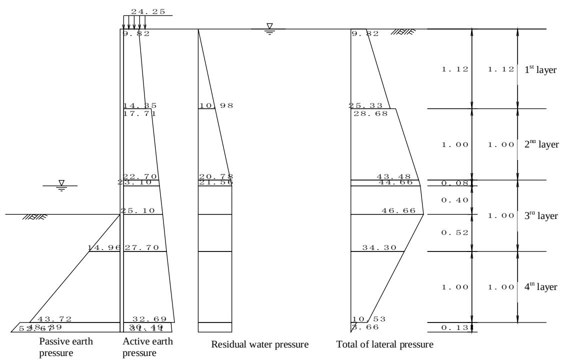
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.38 m (GL -3.98 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 1.12	9.82 14.35	0.00 10.98	―― ――	9.82 25.33
2	1.12～ 2.12	17.71 22.70	10.98 20.78	―― ――	28.68 43.48
3	2.12～ 2.20	22.70 23.10	20.78 21.56	―― ――	43.48 44.66
4	2.20～ 2.60	23.10 25.10	21.56 21.56	―― ――	44.66 46.66
5	2.60～ 3.12	25.10 27.70	21.56 21.56	0.00 14.96	46.66 34.30
6	3.12～ 4.12	27.70 32.69	21.56 21.56	14.96 43.72	34.30 10.53
7	4.12～ 4.26	30.49 31.11	21.56 21.56	48.39 52.67	3.66 0.00
8	4.26～ 5.12	31.11 35.15	21.56 21.56	52.67 80.23	0.00 -23.52

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.66 m (GL -4.26 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	63000 cm⁴ (original condition)
	I	=	45864 cm⁴ (after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 45864 \times 10^{-8} = 9.173 \times 10^4$

	Depth (m)	N-value
1	0.88	22
2	1.88	2
3	2.88	2
4	3.88	7
5	4.88	13
6	5.88	8
7	6.88	16
8	7.88	12
9	8.88	20
10	9.88	18

	Depth (m)	N-value
11	10.88	8
12	11.88	11
13	12.88	10
14	13.88	15
15	14.88	13
16	15.88	14
17	16.88	16
18	17.88	19
19	20.00	21

5-2 Normal Condition

K_h = 17770 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.469 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.98 m) to 2.13 m depth (GL -6.11 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.98	0.90	7.6	13.0	9.29
2	4.88	1.00	13.0	8.0	10.50
3	5.88	0.23	8.0	9.8	2.05
L = Σh = 2.13				ΣA = 21.83	

A (upper N-value + lower N-value) × h/2

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.24^{0.406} = 17770$ kN/m³

Kh (normal condition) = 17770 kN/m³

5-3 Seismic Condition

K_h = 17996 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.471 \quad m^{-1}$

$$L = \frac{1}{\beta} = 2.12 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.25 m) and 2.12 m depth (GL -6.38 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.25	0.63	9.2	13.0	6.96
2	4.88	1.00	13.0	8.0	10.50
3	5.88	0.50	8.0	12.0	4.99
	L = Σh = 2.12				ΣA = 22.45

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{22.45}{2.12} = 10.57$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.57^{0.406} = 17996$ kN/m³

Kh (seismic condition) = 17996 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.12	1.12	7.96 / 21.98	4.46 / 12.31	3.60 / 3.23	16.07 / 39.78
2	1.12~ 2.12	1.00	24.88 / 38.11	12.44 / 19.06	2.52 / 2.19	31.40 / 41.75
3	2.12~ 2.60	0.48	38.11 / 44.47	9.15 / 10.67	1.70 / 1.54	15.53 / 16.41
4	2.60~ 2.70	0.10	44.47 / 39.59	2.22 / 1.98	1.34 / 1.31	2.99 / 2.60
5	2.70~ 3.12	0.42	39.59 / 26.58	8.31 / 5.58	1.14 / 1.00	9.46 / 5.57
6	3.12~ 3.98	0.86	26.58 / 0.00	11.40 / 0.00	0.57 / 0.29	6.52 / 0.00
				ΣP = 97.58		ΣM = 188.07

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 2.5 kN/m
depth to acting position H_t = 0.44 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.38 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 11.04$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{199.11}{100.08} = 1.99 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.12	1.12	9.82 / 25.33	5.50 / 14.18	3.88 / 3.51	21.34 / 49.75
2	1.12~ 2.12	1.00	28.68 / 43.48	14.34 / 21.74	2.80 / 2.47	40.17 / 53.65
3	2.12~ 2.20	0.08	43.48 / 44.66	1.74 / 1.79	2.11 / 2.08	3.67 / 3.72
4	2.20~ 2.60	0.40	44.66 / 46.66	8.93 / 9.33	1.92 / 1.79	17.16 / 16.68
5	2.60~ 3.12	0.52	46.66 / 34.30	12.13 / 8.92	1.48 / 1.31	17.97 / 11.66
6	3.12~ 4.12	1.00	34.30 / 10.53	17.15 / 5.27	0.80 / 0.47	13.74 / 2.46
7	4.12~ 4.25	0.13	3.66 / 0.00	0.25 / 0.00	0.09 / 0.04	0.02 / 0.00
				ΣP = 121.26		ΣM = 252.01

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 8.9 kN/m
depth to acting position H_t = -0.27 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.65 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 40.27$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 / 0.7	0.00 / 0.14	1.92 / 1.79	0.00 / 0.25
				ΣPdw = 0.14		ΣM dw = 0.25

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{292.52}{130.30} = 2.24 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.91
Section efficiency μ = 0.80
Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 63000 cm⁴ (original condition)
I = 45864 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 45864 × 10⁻⁸ = 9.173 × 10⁴

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 17770 kN/m³
calculated value β = 0.46912 m⁻¹
resultant earth force (lateral) P_h = 100.08 kN/m
height of acting position of load h_h = 1.99 m
moment M_0 = 199.11 kN·m/m

in consideration of ψ_m = 1.163,
maximum moment M_{max} = 231.52 kN·m/m
depth of generated position of M_{max} L_m = 0.715 m
depth of 1st fixed point l_i = 2.390 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 17996 kN/m³
calculated value β = 0.47060 m⁻¹
resultant earth force (lateral) P_h = 130.30 kN/m
height of acting position of load h_h = 2.24 m
moment M_0 = 292.52 kN·m/m

in consideration of ψ_m = 1.134,
maximum moment M_{max} = 331.72 kN·m/m
depth of generated position of M_{max} L_m = 0.660 m
depth of 1st fixed point l_i = 2.329 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3150 cm^3 (original condition)
	Z	=	2867 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{231.52\times10^6}{2867\times10^3} = 81\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad (ok)$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{331.72\times10^6}{2867\times10^3} = 116\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad (ok)$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.12	3.60 3.23	0.906 0.812	0.287 0.241	4.46 12.31	1.277 2.962
2	1.12～ 2.12	2.52 2.19	0.635 0.551	0.159 0.124	12.44 19.06	1.975 2.360
3	2.12～ 2.60	1.70 1.54	0.427 0.387	0.078 0.065	9.15 10.67	0.715 0.695
4	2.60～ 2.70	1.34 1.31	0.338 0.330	0.051 0.048	2.22 1.98	0.113 0.096
5	2.70～ 3.12	1.14 1.00	0.286 0.251	0.037 0.029	8.31 5.58	0.308 0.161
6	3.12～ 3.98	0.57 0.29	0.144 0.072	0.010 0.003	11.40 0.00	0.112 0.000
						ΣQ = 10.773

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

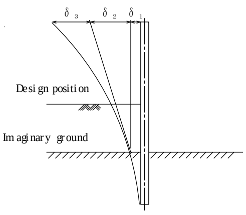
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4691\times1.99)\times100.08}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4691^3} = 0.01022\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4691\times1.99)\times100.08}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4691^2}\times(2.60+1.38) = 0.02827\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.77\times(2.60+1.38)^3}{2.00\times10^8\times45864\times10^{-8}} = 0.00739\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00067 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.98 m
Horizontal load: P = 2.50
Moment: M = 1.10

δ = δ_1 + δ_2 + δ_3
= 0.01022 + 0.02827 + 0.00806
= 0.04654 m
= 46.54 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 1.12	3.88 3.51	0.912 0.825	0.290 0.246	5.50 14.18	1.592 3.496
2	1.12～ 2.12	2.80 2.47	0.658 0.580	0.169 0.136	14.34 21.74	2.426 2.950
3	2.12～ 2.20	2.11 2.08	0.495 0.489	0.102 0.100	1.74 1.79	0.178 0.179
4	2.20～ 2.60	1.92 1.79	0.452 0.420	0.087 0.076	8.93 9.33	0.774 0.709
5	2.60～ 3.12	1.48 1.31	0.348 0.307	0.054 0.042	12.13 8.92	0.650 0.378
6	3.12～ 4.12	0.80 0.47	0.188 0.110	0.017 0.006	17.15 5.27	0.285 0.031
7	4.12～ 4.25	0.09 0.04	0.021 0.011	0.000 0.000	0.25 0.00	0.000 0.000
						ΣQ = 13.647

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

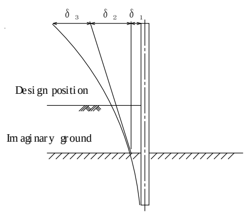
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.92 1.79	0.452 0.420	0.087 0.076	0.00 0.14	0.000 0.010
						$ΣQ_{dw}$ = 0.010

Therefore, modulus of deformation Q is calculated as below:
Q = 13.647 + 0.010 = 13.658

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4706\times2.24)\times130.30}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4706^3} = 0.01401\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4706\times2.24)\times130.30}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4706^2}\times(2.60+1.65) = 0.04248\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.66\times(2.60+1.65)^3}{2.00\times10^8\times45864\times10^{-8}} = 0.01147\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00273 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.25 m
Horizontal load: P = 8.90
Moment: M = 2.40

δ = δ_1 + δ_2 + δ_3
= 0.01401 + 0.04248 + 0.01419
= 0.07068 m
= 70.68 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	63000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63000 \times 10^{-8}$		=	1.260×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 17770\ kN/m^3$

Calculated value $\beta = 0.43333\ m^{-1}$

Penetration length of SSP $D = 1.38 + \frac{3}{0.433} = 8.30\ m$

Whole length of SSP $L = 2.60 - 0.40 + 8.30 = 10.50\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 17996\ kN/m^3$

Calculated value $\beta = 0.43470\ m^{-1}$

Penetration length of SSP $D = 1.65 + \frac{3}{0.435} = 8.56\ m$

Whole length of SSP $L = 2.60 - 0.40 + 8.56 = 10.76\ m$

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

8 Calculation Result

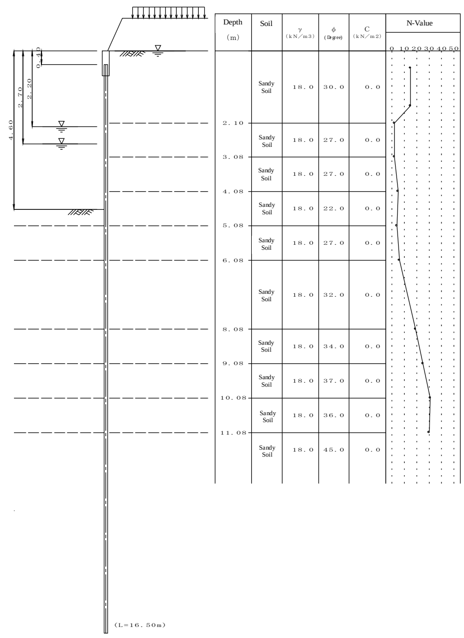
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	63000		
Section modulus	Z (cm^3)	3150		
Maximum bending moment	M_{max} (kN·m/m)		231.52	331.72
Stress intensity	σ (N/mm^2)		81 (180)	116 (270)
Lateral displacement	δ (mm)		46.54 (50.0)	70.68 (75.0)
Penetration depth	D (m)		8.30	8.56
Whole length of SSP	L (m)	11.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 12_STA 12+024 - 12+173

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	4.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.6 kNm (Normal Condition)
		P_t'	=	9.1 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.45 m (Normal Condition)
		H_t'	=	-0.28 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m (Seismic Condition)
		H_m	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_r = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	11.08	30
2	1.60	15	12	12.08	50
3	2.10	2			
4	3.08	2			
5	4.08	5			
6	5.08	4			
7	6.08	6			
8	8.08	19			
9	9.08	25			
10	10.08	31			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

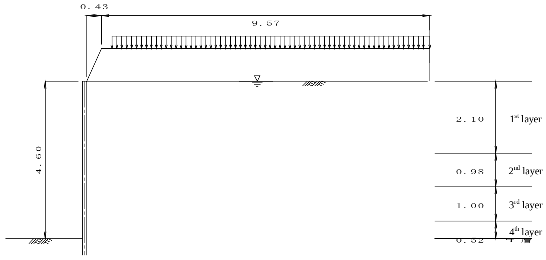
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree)		kh (kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.08	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	4.08	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	5.08	S	4.0	18.00	10.00	22.0	0.0	0.0	0.200	auto	auto	——	——
5	6.08	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	8.08	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
7	9.08	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
8	10.08	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
9	11.08	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
10	12.08	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active passive	9.00° -9.00°	9.00° -9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.43	10.00	10.00	0.95	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.73	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 429000 cm⁴
Sectional factor Z_0 = 7900 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.86
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

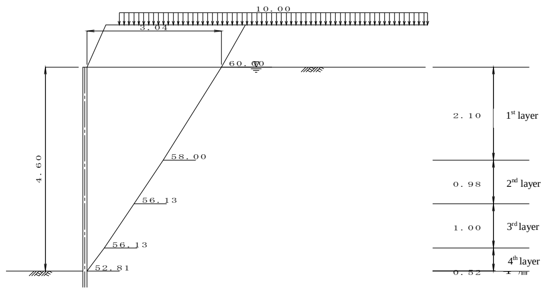
Allowable stress σ_a = 185 Nmm² (Normal)
σ_a' = 278 Nmm² (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Reduced: I_0 applied to calculation of penetration depth
Not reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kNm²)	$\Sigma\gamma h$ (kNm²)	Q (kNm²)	$\gamma w h w$ (kNm²)	Angle of rupture Z (degree)
1	4.60～ 4.08	Sandy Soil	22.0	9.0	0.0	46.00	26.84	45.08	52.81
2	4.08～ 3.08	Sandy Soil	27.0	9.0	0.0	40.80	26.84	39.98	56.13
3	3.08～ 2.10	Sandy Soil	27.0	9.0	0.0	30.80	26.84	30.18	56.13
4	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	26.84	20.58	58.00
5		Embankment	30.0	——	0.0	17.10	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	52.81	0.52	0.00	0.00	0.39	0.52
2	56.13	1.00	0.39	0.52	1.07	1.52
3	56.13	0.98	1.07	1.52	1.72	2.50
4	58.00	2.10	1.72	2.50	3.04	4.60
5	60.00	0.95	3.04	4.60	3.58	5.55

Therefore, width of acting load shall be set as 3.04m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.94	52.93
Σ			52.93

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	2.85	28.54
Σ			28.54

Q surcharge load
l : width of surcharge load set by line of active rupture

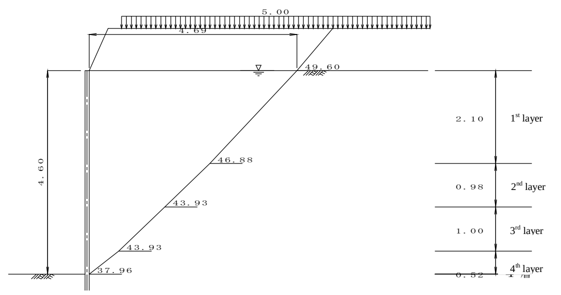
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{52.93 + 28.54 + 0.00}{3.04}$$

$$= 26.84 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	4.60～ 4.08	Sandy Soil	22.0	9.0	0.0	46.00	22.87	45.08	0.200	11.31	37.96
2	4.08～ 3.08	Sandy Soil	27.0	9.0	0.0	40.80	22.87	39.98	0.200	11.31	43.93
3	3.08～ 2.10	Sandy Soil	27.0	9.0	0.0	30.80	22.87	30.18	0.200	11.31	43.93
4	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	22.87	20.58	0.200	11.31	46.88
5		Embankment	30.0	——	0.0	17.10	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	37.96	0.52	0.00	0.00	0.67	0.52
2	43.93	1.00	0.67	0.52	1.70	1.52
3	43.93	0.98	1.70	1.52	2.72	2.50
4	46.88	2.10	2.72	2.50	4.69	4.60
5	49.60	0.95	4.69	4.60	5.50	5.55

Therefore, width of acting load shall be set as 4.69m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.63	83.41
Σ			83.41

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	4.77	23.84
Σ			23.84

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

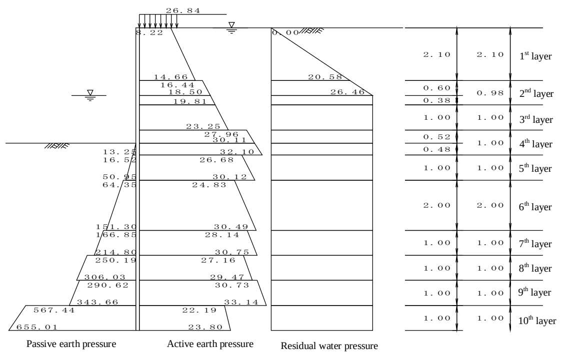
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{83.41 + 23.84 + 0.00}{4.69}$$

$$= 22.87 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	26.836 47.836	0.31026 0.31026	0.30644 0.30644
2	2.10～ 2.70	Sandy soil	10.0	27.0	—— ——	47.836 53.836	0.34800 0.34800	0.34371 0.34371
3	2.70～ 3.08	Sandy soil	10.0	27.0	—— ——	53.836 57.636	0.34800 0.34800	0.34371 0.34371
4	3.08～ 4.08	Sandy soil	10.0	27.0	—— ——	57.636 67.636	0.34800 0.34800	0.34371 0.34371
5	4.08～ 4.60	Sandy soil	10.0	22.0	—— ——	67.636 72.836	0.41860 0.41860	0.41344 0.41344
6	4.60～ 5.08	Sandy soil	10.0	22.0	—— ——	72.836 77.636	0.41860 0.41860	0.41344 0.41344
7	5.08～ 6.08	Sandy soil	10.0	27.0	—— ——	77.636 87.636	0.34800 0.34800	0.34371 0.34371
8	6.08～ 8.08	Sandy soil	10.0	32.0	—— ——	87.636 107.636	0.28683 0.28683	0.28330 0.28330
9	8.08～ 9.08	Sandy soil	10.0	34.0	—— ——	107.636 117.636	0.26470 0.26470	0.26144 0.26144
10	9.08～ 10.08	Sandy soil	10.0	37.0	—— ——	117.636 127.636	0.23377 0.23377	0.23089 0.23089
11	10.08～ 11.08	Sandy soil	10.0	36.0	—— ——	127.636 137.636	0.24379 0.24379	0.24079 0.24079
12	11.08～ 12.08	Sandy soil	10.0	45.0	—— ——	137.636 147.636	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ= 9.00、β= 0.00、θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
6	4.60～ 5.08	Sandy soil	10.0	22.0	—— ——	0.000 4.800	2.79514 2.79514	2.76073 2.76073
7	5.08～ 6.08	Sandy soil	10.0	27.0	—— ——	4.800 14.800	3.48553 3.48553	3.44261 3.44261
8	6.08～ 8.08	Sandy soil	10.0	32.0	—— ——	14.800 34.800	4.40199 4.40199	4.34780 4.34780
9	8.08～ 9.08	Sandy soil	10.0	34.0	—— ——	34.800 44.800	4.85443 4.85443	4.79467 4.79467
10	9.08～ 10.08	Sandy soil	10.0	37.0	—— ——	44.800 54.800	5.65410 5.65410	5.58449 5.58449
11	10.08～ 11.08	Sandy soil	10.0	36.0	—— ——	54.800 64.800	5.36947 5.36947	5.30337 5.30337
12	11.08～ 12.08	Sandy soil	10.0	45.0	—— ——	64.800 74.800	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ= -9.00、β= 0.00、θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	8.22 14.66	—— ——	8.22 14.66	0.00 20.58	—— ——
2	2.10～ 2.70	16.44 18.50	—— ——	16.44 18.50	20.58 26.46	—— ——
3	2.70～ 3.08	18.50 19.81	—— ——	18.50 19.81	26.46 26.46	—— ——
4	3.08～ 4.08	19.81 23.25	—— ——	19.81 23.25	26.46 26.46	—— ——
5	4.08～ 4.60	27.96 30.11	—— ——	27.96 30.11	26.46 26.46	—— ——
6	4.60～ 5.08	30.11 32.10	—— ——	30.11 32.10	26.46 26.46	0.00 13.25
7	5.08～ 6.08	26.68 30.12	—— ——	26.68 30.12	26.46 26.46	16.52 50.95
8	6.08～ 8.08	24.83 30.49	—— ——	24.83 30.49	26.46 26.46	64.35 151.30
9	8.08～ 9.08	28.14 30.75	—— ——	28.14 30.75	26.46 26.46	166.85 214.80

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
10	9.08～ 10.08	27.16 29.47	—— ——	27.16 29.47	26.46 26.46	250.19 306.03
11	10.08～ 11.08	30.73 33.14	—— ——	30.73 33.14	26.46 26.46	290.62 343.66
12	11.08～ 12.08	22.19 23.80	—— ——	22.19 23.80	26.46 26.46	567.44 655.01

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

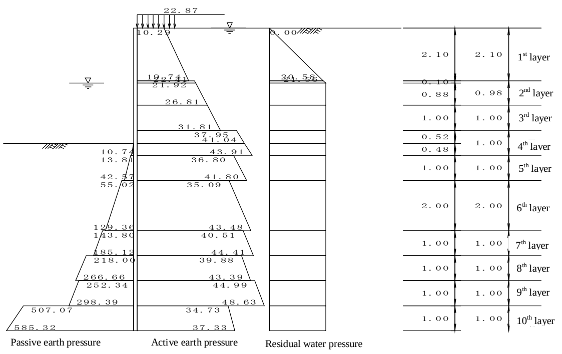
Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$
Clayey soil $P_p = \Sigma\gamma h + Q + 2C$
Mixed $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	22.87 43.87	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	27.0	—— ——	43.87 44.87	20.58 21.56	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.20~ 3.08	Sandy Soil	10.0	27.0	—— ——	44.87 53.67	21.56 30.18	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	3.08~ 4.08	Sandy Soil	10.0	27.0	—— ——	53.67 63.67	30.18 39.98	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	4.08~ 4.60	Sandy Soil	10.0	22.0	—— ——	63.67 68.87	39.98 45.08	0.200 0.200	11.31 11.31	0.60337 0.60337	0.59594 0.59594	—— ——
6	4.60~ 5.08	Sandy Soil	10.0	22.0	—— ——	68.87 73.67	45.08 49.78	0.200 0.200	11.31 11.31	0.60337 0.60337	0.59594 0.59594	—— ——
7	5.08~ 6.08	Sandy Soil	10.0	27.0	—— ——	73.67 83.67	49.78 59.58	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
8	6.08~ 8.08	Sandy Soil	10.0	32.0	—— ——	83.67 103.67	59.58 79.18	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
9	8.08~ 9.08	Sandy Soil	10.0	34.0	—— ——	103.67 113.67	79.18 88.98	0.200 0.200	11.31 11.31	0.39559 0.39559	0.39072 0.39072	—— ——
10	9.08~ 10.08	Sandy Soil	10.0	37.0	—— ——	113.67 123.67	88.98 98.78	0.200 0.200	11.31 11.31	0.35524 0.35524	0.35087 0.35087	—— ——
11	10.08~ 11.08	Sandy Soil	10.0	36.0	—— ——	123.67 133.67	98.78 108.58	0.200 0.200	11.31 11.31	0.36830 0.36830	0.36377 0.36377	—— ——
12	11.08~ 12.08	Sandy Soil	10.0	45.0	—— ——	133.67 143.67	108.58 118.38	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:
δ= 9.00、β= 0.00、θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
6	4.60~ 5.08	Sandy soil	10.00	22.0	—— ——	0.000 4.800	0.00 4.70	0.200 0.200	11.31 11.31	2.26523 2.26523	2.23734 2.23734
7	5.08~ 6.08	Sandy soil	10.00	27.0	—— ——	4.800 14.800	4.70 14.50	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	6.08~ 8.08	Sandy soil	10.00	32.0	—— ——	14.800 34.800	14.50 34.10	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
9	8.08~ 9.08	Sandy soil	10.00	34.0	—— ——	34.800 44.800	34.10 43.90	0.200 0.200	11.31 11.31	4.18373 4.18373	4.13222 4.13222
10	9.08~ 10.08	Sandy soil	10.00	37.0	—— ——	44.800 54.800	43.90 53.70	0.200 0.200	11.31 11.31	4.92675 4.92675	4.86609 4.86609

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
11	10.08~ 11.08	Sandy soil	10.00	36.0	—— ——	54.800 64.800	53.70 63.50	0.200 0.200	11.31 11.31	4.66216 4.66216	4.60476 4.60476
12	11.08~ 12.08	Sandy soil	10.00	45.0	—— ——	64.800 74.800	63.50 73.30	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below:
δ= -9.00、β= 0.00、θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 2.10	10.29 19.74	—— ——	10.29 19.74	0.00 20.58	—— ——
2	2.10~ 2.20	21.92 22.41	—— ——	21.92 22.41	20.58 21.56	—— ——
3	2.20~ 3.08	22.41 26.81	—— ——	22.41 26.81	21.56 21.56	—— ——
4	3.08~ 4.08	26.81 31.81	—— ——	26.81 31.81	21.56 21.56	—— ——
5	4.08~ 4.60	37.95 41.04	—— ——	37.95 41.04	21.56 21.56	—— ——
6	4.60~ 5.08	41.04 43.91	—— ——	41.04 43.91	21.56 21.56	0.00 10.74
7	5.08~ 6.08	36.80 41.80	—— ——	36.80 41.80	21.56 21.56	13.81 42.57
8	6.08~ 8.08	35.09 43.48	—— ——	35.09 43.48	21.56 21.56	55.02 129.36
9	8.08~ 9.08	40.51 44.41	—— ——	40.51 44.41	21.56 21.56	143.80 185.12
10	9.08~ 10.08	39.88 43.39	—— ——	39.88 43.39	21.56 21.56	218.00 266.66
11	10.08~ 11.08	44.99 48.63	—— ——	44.99 48.63	21.56 21.56	252.34 298.39
12	11.08~ 12.08	34.73 37.33	—— ——	34.73 37.33	21.56 21.56	507.07 585.32

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$
$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy $P_p=K_p\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

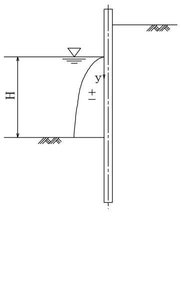
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	3.20	1.00	2.66
3	4.20	2.00	3.76
4	4.60	2.40	4.12

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where,

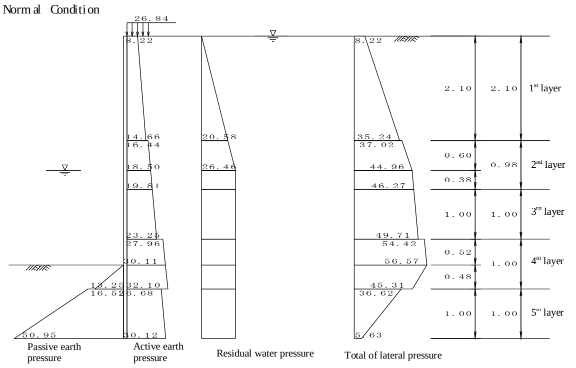
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

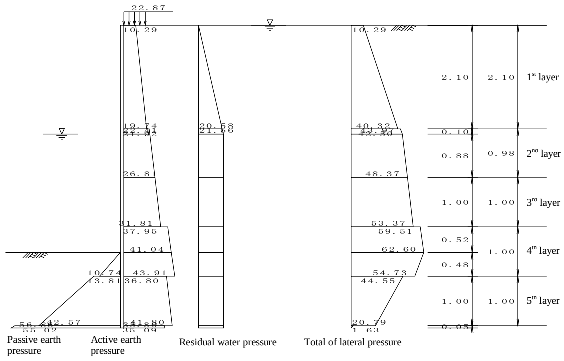


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00~ 2.10	8.22 14.66	0.00 20.58	—— ——	8.22 35.24
2	2.10~ 2.70	16.44 18.50	20.58 26.46	—— ——	37.02 44.96
3	2.70~ 3.08	18.50 19.81	26.46 26.46	—— ——	44.96 46.27
4	3.08~ 4.08	19.81 23.25	26.46 26.46	—— ——	46.27 49.71
5	4.08~ 4.60	27.96 30.11	26.46 26.46	—— ——	54.42 56.57
6	4.60~ 5.08	30.11 32.10	26.46 26.46	0.00 13.25	56.57 45.31
7	5.08~ 6.08	26.68 30.12	26.46 26.46	16.52 50.95	36.62 5.63
8	6.08~ 8.08	24.83 30.49	26.46 26.46	64.35 151.30	-13.06 -94.35

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.48 m (GL-6.08m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.10	10.29 19.74	0.00 20.58	—— ——	10.29 40.32
2	2.10~ 2.20	21.92 22.41	20.58 21.56	—— ——	42.50 43.97
3	2.20~ 3.08	22.41 26.81	21.56 21.56	—— ——	43.97 48.37
4	3.08~ 4.08	26.81 31.81	21.56 21.56	—— ——	48.37 53.37
5	4.08~ 4.60	37.95 41.04	21.56 21.56	—— ——	59.51 62.60
6	4.60~ 5.08	41.04 43.91	21.56 21.56	0.00 10.74	62.60 54.73
7	5.08~ 6.08	36.80 41.80	21.56 21.56	13.81 42.57	44.55 20.79
8	6.08~ 6.13	35.09 35.30	21.56 21.56	55.02 56.86	1.63 0.00
9	6.13~ 8.08	35.30 43.48	21.56 21.56	56.86 129.36	0.00 -64.33

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.53 m (GL-6.13 m)

Case: Left Bank No. 12_STA 12+024 - 12+173

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	429000 cm⁴ (original condition)
	I	=	368940 cm⁴ (after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 368940 \times 10^{-8} = 7.379 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	3.08	2
5	4.08	5
6	5.08	4
7	6.08	6
8	8.08	19
9	9.08	25
10	10.08	31
11	11.08	30
12	12.08	50

5-2 Normal Condition

K_h = 21798 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.293 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.41 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.08) to 3.41m depth (GL -9.49m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	6.08	2.00	6.0	19.0	25.00
2	8.08	1.00	19.0	25.0	22.00
3	9.08	0.41	25.0	27.5	10.79
	L = Σh =	3.41		ΣA =	57.79

A (upper N-value + lower N-value) × h/2

Case: Left Bank No. 12_STA 12+024 - 12+173

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{57.79}{3.41} = 16.94$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$$K_h = 6910 \times N'^{0.406} = 6910 \times 16.94^{0.406} = 21798 \text{ kN/m}^3$$

Kh (normal condition) = 21798 kNm³

5-3 Seismic Condition

K_h = 21950 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.294 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.41 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL-6.13 m) and 3.41 m depth (GL -9.53 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	6.13	1.95	6.3	19.0	24.70
2	8.08	1.00	19.0	25.0	22.00
3	9.08	0.45	25.0	27.7	11.99
	L = Σh =	3.41		ΣA =	58.68

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{58.68}{3.41} = 17.23$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following;

$$K_h = 6910 \times N'^{0.406} = 6910 \times 17.23^{0.406} = 21950 \text{ kN/m}^3$$

Kh (seismic condition) = 21950 kNm³

Case: Left Bank No. 12_STA 12+024 - 12+173

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.22 35.24	8.63 37.00	5.38 4.68	46.46 173.16
2	2.10~ 2.70	0.60	37.02 44.96	11.11 13.49	3.78 3.58	41.98 48.29
3	2.70~ 3.08	0.38	44.96 46.27	8.54 8.79	3.25 3.13	27.79 27.49
4	3.08~ 4.08	1.00	46.27 49.71	23.14 24.85	2.67 2.33	61.69 57.99
5	4.08~ 4.60	0.52	54.42 56.57	14.15 14.71	1.83 1.65	25.85 24.32
6	4.60~ 5.08	0.48	56.57 45.31	13.58 10.87	1.32 1.16	17.92 12.61
7	5.08~ 6.08	1.00	36.62 5.63	18.31 2.82	0.67 0.33	12.21 0.94
			ΣP =	209.99	ΣM =	578.71

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.6 kNm
depth to acting position	H_t	=	-0.45 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.48 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 16.98 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{595.69}{212.59} = 2.80 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	10.29 40.32	10.80 42.33	5.43 4.73	58.66 200.20
2	2.10～ 2.20	0.10	42.50 43.97	2.12 2.20	4.00 3.96	8.49 8.71
3	2.20～ 3.08	0.88	43.97 48.37	19.35 21.28	3.64 3.34	70.36 71.15
4	3.08～ 4.08	1.00	48.37 53.37	24.19 26.68	2.72 2.38	65.69 63.58
5	4.08～ 4.60	0.52	59.51 62.60	15.47 16.28	1.88 1.70	29.03 27.72
6	4.60～ 5.08	0.48	62.60 54.73	15.03 13.13	1.37 1.21	20.58 15.89
7	5.08～ 6.08	1.00	44.55 20.79	22.28 10.39	0.72 0.38	15.95 3.98
8	6.08～ 6.13	0.05	1.63 0.00	0.04 0.00	0.03 0.02	0.00 0.00
			ΣP =	241.58	ΣM =	659.98

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 9.1 kN/m
depth to acting position H_t = -0.28 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 4.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.53 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 58.33 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 3.20	1.00	0.0 2.7	0.00 1.33	3.60 3.26	0.00 4.33
2	3.20～ 4.20	1.00	2.7 3.8	1.33 1.88	2.60 2.26	3.45 4.25
3	4.20～ 4.60	0.40	3.8 4.1	0.75 0.82	1.80 1.66	1.35 1.37
			ΣP_{dw} =	6.11	ΣM_{dw} =	14.75

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{733.06}{256.79} = 2.85 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.86
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 429000 cm^4 (original condition)
I = 368940 cm^4 (after reduction by corrosion and joint)
EI = 200000 × 10^3 × 368940 × 10^{-8} = 7.379 × 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 21798 kN/m^3
calculated value β = 0.29315 m^{-1}
resultant earth force (lateral) P_0 = 212.59 kN/m
height of acting position of load h_0 = 2.80 m
moment M_0 = 595.69 kN·m/m

in consideration of ϕ_m = 1.198,
maximum moment M_{max} = 713.59 kN·m/m
depth of generated position of M_{max} l_m = 1.234 m
depth of 1st fixed point l_i = 3.913 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 21950 kN/m^3
calculated value β = 0.29366 m^{-1}
resultant earth force (lateral) P_0 = 256.79 kN/m
height of acting position of load h_0 = 2.85 m
moment M_0 = 733.06 kN·m/m

in consideration of ϕ_m = 1.192,
maximum moment M_{max} = 873.73 kN·m/m
depth of generated position of M_{max} l_m = 1.218 m
depth of 1st fixed point l_i = 3.892 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 1.00
Module of section Z_0 = 7900 cm^3 (original condition)
Z = 6952 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{713.59\times10^6}{6952\times10^3} = 103 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{ok}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{873.73\times10^6}{6952\times10^3} = 126 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{ok}$$

6-4 Displacement

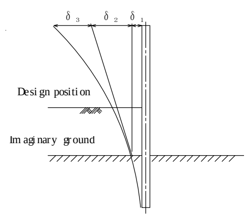
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	5.38 4.68	0.885 0.770	0.276 0.220	8.63 37.00	2.383 8.149
2	2.10～ 2.70	3.78 3.58	0.622 0.589	0.153 0.139	11.11 13.49	1.702 1.879
3	2.70～ 3.08	3.25 3.13	0.535 0.514	0.118 0.110	8.54 8.79	1.005 0.963
4	3.08～ 4.08	2.67 2.33	0.439 0.384	0.082 0.064	23.14 24.85	1.900 1.596
5	4.08～ 4.60	1.83 1.65	0.300 0.272	0.041 0.034	14.15 14.71	0.575 0.495
6	4.60～ 5.08	1.32 1.16	0.217 0.191	0.022 0.017	13.58 10.87	0.297 0.185
7	5.08～ 6.08	0.67 0.33	0.110 0.055	0.006 0.001	18.31 2.82	0.106 0.004
					ΣQ =	21.239

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.2932\times2.80)\times212.59}{2\times2.00\times10^8\times368940\times10^{-8}\times0.2932^3} = 0.01041 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$
$$= \frac{(1+2\times0.2932\times2.80)\times212.59}{2\times2.00\times10^8\times368940\times10^{-8}\times0.2932^2}\times(4.60+1.48) = 0.02693 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{21.24\times(4.60+1.48)^3}{2.00\times10^8\times368940\times10^{-8}} = 0.00647 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00029 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 6.08 m
Horizontal load: P = 2.60
Moment: M = 1.17

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01041 + 0.02693 + 0.00676
= 0.04411 m
= 44.11 ≦ δ_a = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	5.43 4.73	0.886 0.772	0.276 0.221	10.80 42.33	2.987 9.360
2	2.10～ 2.20	4.00 3.96	0.652 0.647	0.166 0.164	2.12 2.20	0.353 0.360
3	2.20～ 3.08	3.64 3.34	0.593 0.545	0.141 0.122	19.35 21.28	2.731 2.590
4	3.08～ 4.08	2.72 2.38	0.443 0.389	0.084 0.066	24.19 26.68	2.024 1.755
5	4.08～ 4.60	1.88 1.70	0.306 0.278	0.042 0.035	15.47 16.28	0.651 0.570
6	4.60～ 5.08	1.37 1.21	0.223 0.197	0.023 0.018	15.03 13.13	0.347 0.239
7	5.08～ 6.08	0.72 0.38	0.117 0.062	0.007 0.002	22.28 10.39	0.146 0.020
8	6.08～ 6.13	0.03 0.02	0.005 0.003	0.000 0.000	0.04 0.00	0.000 0.000
					ΣQ =	24.133

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

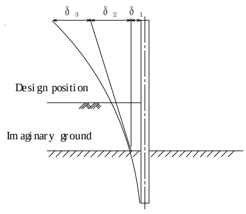
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 3.20	3.60 3.26	0.587 0.532	0.138 0.117	0.00 1.33	0.000 0.155
2	3.20～ 4.20	2.60 2.26	0.424 0.369	0.077 0.060	1.33 1.88	0.102 0.112
3	4.20～ 4.60	1.80 1.66	0.293 0.271	0.039 0.033	0.75 0.82	0.029 0.028
					ΣQ_{dw}=	0.426

Therefore, modulus of deformation Q is calculated as below:

$Q = 24.133 + 0.426 = 24.560$

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.2937\times 2.85)\times 256.79}{2\times 2.00\times 10^8\times 368940\times 10^{-8}\times 0.2937^3} = 0.01263\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.2937\times 2.85)\times 256.79}{2\times 2.00\times 10^8\times 368940\times 10^{-8}\times 0.2937^2}\times(4.60+1.53) = 0.03310\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{24.56\times(4.60+1.53)^3}{2.00\times 10^8\times 368940\times 10^{-8}} = 0.00766\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00101 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 6.13m

Horizontal load: P = 9.10

Moment: M = 2.55

$\delta = \delta_1 + \delta_2 + \delta_3$

$= 0.01263 + 0.03310 + 0.00868$

$= 0.05441$ m

$= 54.41 \leqq \delta_a = 75.00$ mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm ^{2}
Inertia sectional moment	I_0	=	429000 cm ^{4} (original condition)
	I	=	429000cm ^{4} (after reduction by corrosion and joint)
$EI = 200000\times 10^3\times 429000\times 10^{-8}$		=	8.580×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction
Calculated value

$K_h = 21798$ kN/m^3

$\beta = 0.28231$ m^{-1}

Penetration length of SSP
Whole length of SSP

$D = 1.48 + \dfrac{3}{0.282} = 12.11$ m

$L = 4.60 - 0.40 + 12.11 = 16.31$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction
Calculated value

$K_h = 21950$ kN/m^3

$\beta = 0.28280$ m^{-1}

Penetration length of SSP
Whole length of SSP

$D = 1.53 + \dfrac{3}{0.283} = 12.14$ m

$L = 4.60 - 0.40 + 12.14 = 16.34$ m

Therefore, whole length of SSP is set as 16.50 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	429000		
Section modulus	Z (cm^3)	7900		
Maximum bending moment	M_{max} (kN·m/m)		713.59	873.73
Stress intensity	σ (N/mm^2)		103 (185)	126 (278)
Lateral displacement	δ (mm)		44.11 (50.0)	54.41 (75.0)
Penetration depth	D (m)		12.11	12.14
Whole length of SSP	L (m)	16.50		

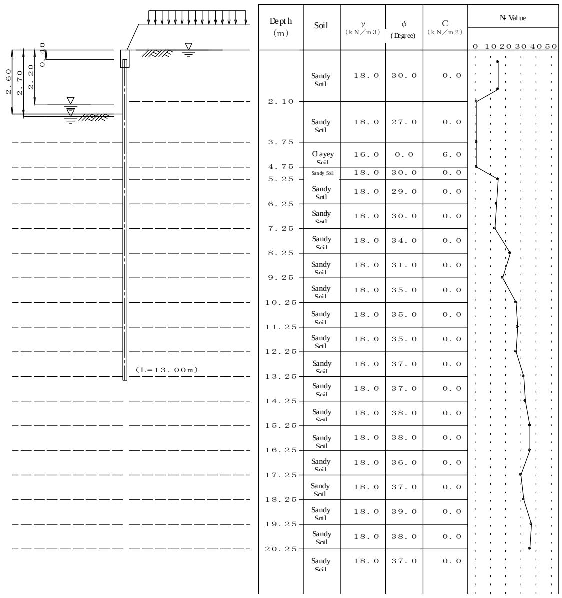
1.90

－Steel Sheet Pile Design Calculation－

Left Bank No. 13_STA 13+806 - 13+900

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　Chang's formula

Penetration depths　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　γ_w = 9.8 kN/m³

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case　- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	3.1 kN/m	(Normal Condition)
		P_t'	=	9.9 kN/m	(Seismic Condition)
	Depth of acting point	H	=	-0.49 m	(Normal Condition)
		H'	=	-0.33 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　ζ_0 = 10 degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N'^{0.406}$

Average N-value　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	10.25	27	21	20.25	36
2	1.60	15	12	11.25	28	22	21.25	32
3	2.10	1	13	12.25	27			
4	3.75	1	14	13.25	32			
5	4.75	1	15	14.25	33			
6	5.25	15	16	15.25	36			
7	6.25	14	17	16.25	36			
8	7.25	13	18	17.25	30			
9	8.25	23	19	18.25	32			
10	9.25	18	20	19.25	37			

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

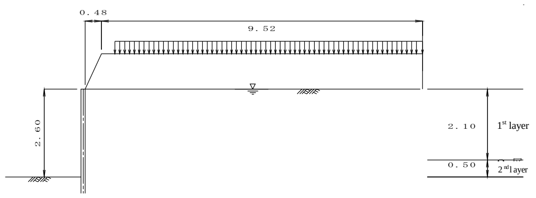
No	Depth (m)	Soil	N-value	γ kN/m³	γ' kN/m³	φ	C kN/m²	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m³) normal	kh (kN/m³) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.75	S	1.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	4.75	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
4	5.25	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
5	6.25	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
6	7.25	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
7	8.25	S	23.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
8	9.25	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
9	10.25	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
10	11.25	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
11	12.25	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
12	13.25	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
13	14.25	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
14	15.25	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
15	16.25	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
16	17.25	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
17	18.25	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
18	19.25	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
19	20.25	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
20	21.25	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.48	10.00	10.00	1.05	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.88	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 154000 cm^4
Sectional factor Z_0 = 4160 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.85
Corrosion rate (to Z_0) η = 0.87
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

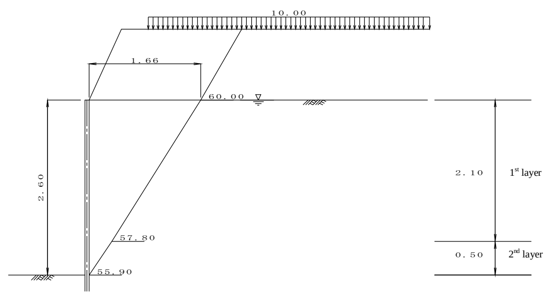
Allowable stress σ_a = 185 Nmm (Normal)
σ_a' = 278 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	27.97	25.48	55.90
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	27.97	20.58	57.80
3		Embankment	30.0	——	0.0	18.90	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^0 since $\theta = 0^0$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00^0$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	1.05	1.66	2.60	2.27	3.65

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.81	32.59
Σ			32.59

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.39	13.87
Σ			13.87

Q surcharge load
l : width of surcharge load set by line of active rupture

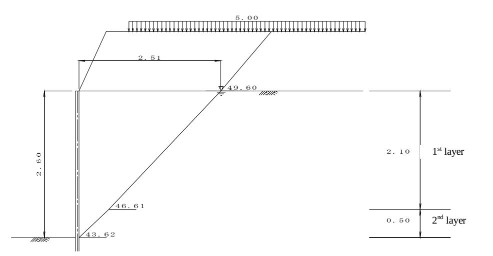
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{32.59 + 13.87 + 0.00}{1.66}$$

$$= 27.97 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	25.48	25.48	0.200	11.31	43.62
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.48	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	18.90	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00^0$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	1.05	2.51	2.60	3.40	3.65

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.85	51.35
Σ			51.35

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.52	12.62
Σ			12.62

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

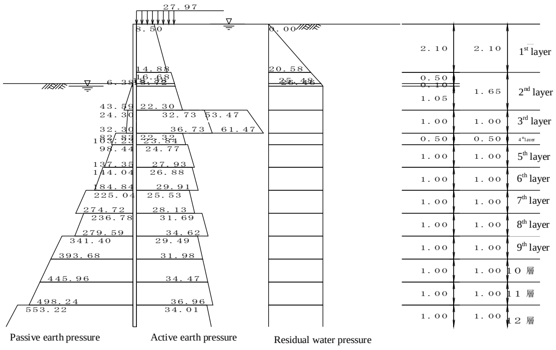
$$= \frac{51.35 + 12.62 + 0.00}{2.51}$$

$$= 25.48 \ kN/m^2$$

Case: Left Bank No. 13_STA 13+806 - 13+900

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	27.970 48.970	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	48.970 53.970	0.34585 0.34585	0.34060 0.34060
3	2.60~ 2.70	Sandy soil	10.0	27.0	—— ——	53.970 54.970	0.34585 0.34585	0.34060 0.34060
4	2.70~ 3.75	Sandy soil	10.0	27.0	—— ——	54.970 65.470	0.34585 0.34585	0.34060 0.34060
5	3.75~ 4.75	Clayey soil	8.0	—	6.0 6.0	65.470 73.470	—— ——	—— ——
6	4.75~ 5.25	Sandy soil	10.0	30.0	—— ——	73.470 78.470	0.30847 0.30847	0.30378 0.30378
7	5.25~ 6.25	Sandy soil	10.0	29.0	—— ——	78.470 88.470	0.32058 0.32058	0.31571 0.31571
8	6.25~ 7.25	Sandy soil	10.0	30.0	—— ——	88.470 98.470	0.30847 0.30847	0.30378 0.30378
9	7.25~ 8.25	Sandy soil	10.0	34.0	—— ——	98.470 108.470	0.26331 0.26331	0.25931 0.25931
10	8.25~ 9.25	Sandy soil	10.0	31.0	—— ——	108.470 118.470	0.29669 0.29669	0.29219 0.29219
11	9.25~ 10.25	Sandy soil	10.0	35.0	—— ——	118.470 128.470	0.25279 0.25279	0.24895 0.24895
12	10.25~ 11.25	Sandy soil	10.0	35.0	—— ——	128.470 138.470	0.25279 0.25279	0.24895 0.24895
13	11.25~ 12.25	Sandy soil	10.0	35.0	—— ——	138.470 148.470	0.25279 0.25279	0.24895 0.24895

Case: Left Bank No. 13_STA 13+806 - 13+900

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	12.25~ 13.25	Sandy soil	10.0	37.0	—— ——	148.470 158.470	0.23264 0.23264	0.22910 0.22910
15	13.25~ 14.25	Sandy soil	10.0	37.0	—— ——	158.470 168.470	0.23264 0.23264	0.22910 0.22910
16	14.25~ 15.25	Sandy soil	10.0	38.0	—— ——	168.470 178.470	0.22298 0.22298	0.21959 0.21959
17	15.25~ 16.25	Sandy soil	10.0	38.0	—— ——	178.470 188.470	0.22298 0.22298	0.21959 0.21959
18	16.25~ 17.25	Sandy soil	10.0	36.0	—— ——	188.470 198.470	0.24257 0.24257	0.23889 0.23889
19	17.25~ 18.25	Sandy soil	10.0	37.0	—— ——	198.470 208.470	0.23264 0.23264	0.22910 0.22910
20	18.25~ 19.25	Sandy soil	10.0	39.0	—— ——	208.470 218.470	0.21359 0.21359	0.21035 0.21035
21	19.25~ 20.25	Sandy soil	10.0	38.0	—— ——	218.470 228.470	0.22298 0.22298	0.21959 0.21959
22	20.25~ 21.25	Sandy soil	10.0	37.0	—— ——	228.470 238.470	0.23264 0.23264	0.22910 0.22910

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.59892 3.59892	3.54425 3.54425
4	2.70~ 3.75	Sandy soil	10.0	27.0	—— ——	1.800 12.300	3.59892 3.59892	3.54425 3.54425
5	3.75~ 4.75	Clayey soil	8.0	0.0	6.0 6.0	12.300 20.300	—— ——	—— ——
6	4.75~ 5.25	Sandy soil	10.0	30.0	—— ——	20.300 25.300	4.14330 4.14330	4.08035 4.08035
7	5.25~ 6.25	Sandy soil	10.0	29.0	—— ——	25.300 35.300	3.95096 3.95096	3.89093 3.89093
8	6.25~ 7.25	Sandy soil	10.0	30.0	—— ——	35.300 45.300	4.14330 4.14330	4.08035 4.08035
9	7.25~ 8.25	Sandy soil	10.0	34.0	—— ——	45.300 55.300	5.04448 5.04448	4.96784 4.96784
10	8.25~ 9.25	Sandy soil	10.0	31.0	—— ——	55.300 65.300	4.34774 4.34774	4.28169 4.28169
11	9.25~ 10.25	Sandy soil	10.0	35.0	—— ——	65.300 75.300	5.30876 5.30876	5.22810 5.22810
12	10.25~ 11.25	Sandy soil	10.0	35.0	—— ——	75.300 85.300	5.30876 5.30876	5.22810 5.22810

Case: Left Bank No. 13_STA 13+806 - 13+900

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
13	11.25~ 12.25	Sandy soil	10.0	35.0	—— ——	85.300 95.300	5.30876 5.30876	5.22810 5.22810
14	12.25~ 13.25	Sandy soil	10.0	37.0	—— ——	95.300 105.300	5.89457 5.89457	5.80501 5.80501
15	13.25~ 14.25	Sandy soil	10.0	37.0	—— ——	105.300 115.300	5.89457 5.89457	5.80501 5.80501
16	14.25~ 15.25	Sandy soil	10.0	38.0	—— ——	115.300 125.300	6.21981 6.21981	6.12532 6.12532
17	15.25~ 16.25	Sandy soil	10.0	38.0	—— ——	125.300 135.300	6.21981 6.21981	6.12532 6.12532
18	16.25~ 17.25	Sandy soil	10.0	36.0	—— ——	135.300 145.300	5.59154 5.59154	5.50659 5.50659
19	17.25~ 18.25	Sandy soil	10.0	37.0	—— ——	145.300 155.300	5.89457 5.89457	5.80501 5.80501
20	18.25~ 19.25	Sandy soil	10.0	39.0	—— ——	155.300 165.300	6.56948 6.56948	6.46967 6.46967
21	19.25~ 20.25	Sandy soil	10.0	38.0	—— ——	165.300 175.300	6.21981 6.21981	6.12532 6.12532
22	20.25~ 21.25	Sandy soil	10.0	37.0	—— ——	175.300 185.300	5.89457 5.89457	5.80501 5.80501

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	8.50 14.88	—— ——	8.50 14.88	0.00 20.58	—— ——
2	2.10~ 2.60	16.68 18.38	—— ——	16.68 18.38	20.58 25.48	—— ——
3	2.60~ 2.70	18.38 18.72	—— ——	18.38 18.72	25.48 26.46	0.00 6.38
4	2.70~ 3.75	18.72 22.30	—— ——	18.72 22.30	26.46 26.46	6.38 43.59
5	3.75~ 4.75	53.47 61.47	32.73 36.73	53.47 61.47	26.46 26.46	24.30 32.30
6	4.75~ 5.25	22.32 23.84	—— ——	22.32 23.84	26.46 26.46	82.83 103.23
7	5.25~ 6.25	24.77 27.93	—— ——	24.77 27.93	26.46 26.46	98.44 137.35
8	6.25~ 7.25	26.88 29.91	—— ——	26.88 29.91	26.46 26.46	144.04 184.84
9	7.25~ 8.25	25.53 28.13	—— ——	25.53 28.13	26.46 26.46	225.04 274.72
10	8.25~ 9.25	31.69 34.62	—— ——	31.69 34.62	26.46 26.46	236.78 279.59
11	9.25~ 10.25	29.49 31.98	—— ——	29.49 31.98	26.46 26.46	341.40 393.68

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
12	10.25~ 11.25	31.98 34.47	—— ——	31.98 34.47	26.46 26.46	393.68 445.96
13	11.25~ 12.25	34.47 36.96	—— ——	34.47 36.96	26.46 26.46	445.96 498.24
14	12.25~ 13.25	34.01 36.31	—— ——	34.01 36.31	26.46 26.46	553.22 611.27
15	13.25~ 14.25	36.31 38.60	—— ——	36.31 38.60	26.46 26.46	611.27 669.32
16	14.25~ 15.25	36.99 39.19	—— ——	36.99 39.19	26.46 26.46	706.25 767.50
17	15.25~ 16.25	39.19 41.39	—— ——	39.19 41.39	26.46 26.46	767.50 828.76
18	16.25~ 17.25	45.02 47.41	—— ——	45.02 47.41	26.46 26.46	745.04 800.11
19	17.25~ 18.25	45.47 47.76	—— ——	45.47 47.76	26.46 26.46	843.47 901.52
20	18.25~ 19.25	43.85 45.95	—— ——	43.85 45.95	26.46 26.46	1004.74 1069.44
21	19.25~ 20.25	47.97 50.17	—— ——	47.97 50.17	26.46 26.46	1012.51 1073.77
22	20.25~ 21.25	52.34 54.63	—— ——	52.34 54.63	26.46 26.46	1017.62 1075.67

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

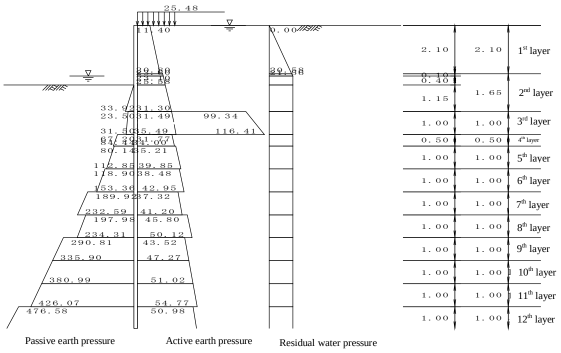
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	25.48 46.48	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	27.0	—— ——	46.48 47.48	20.58 21.56	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.20~ 2.60	Sandy Soil	10.0	27.0	—— ——	47.48 51.48	21.56 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	2.60~ 3.75	Sandy Soil	10.0	27.0	—— ——	51.48 62.98	25.48 36.75	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	3.75~ 4.75	Clayey Soil	8.0	—	6.0 6.0	62.98 70.98	36.75 46.55	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
6	4.75~ 5.25	Sandy Soil	10.0	30.0	—— ——	70.98 75.98	46.55 51.45	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
7	5.25~ 6.25	Sandy Soil	10.0	29.0	—— ——	75.98 85.98	51.45 61.25	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
8	6.25~ 7.25	Sandy Soil	10.0	30.0	—— ——	85.98 95.98	61.25 71.05	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
9	7.25~ 8.25	Sandy Soil	10.0	34.0	—— ——	95.98 105.98	71.05 80.85	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
10	8.25~ 9.25	Sandy Soil	10.0	31.0	—— ——	105.98 115.98	80.85 90.65	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
11	9.25~ 10.25	Sandy Soil	10.0	35.0	—— ——	115.98 125.98	90.65 100.45	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
12	10.25~ 11.25	Sandy Soil	10.0	35.0	—— ——	125.98 135.98	100.45 110.25	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
13	11.25~ 12.25	Sandy Soil	10.0	35.0	—— ——	135.98 145.98	110.25 120.05	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k)	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	12.25~ 13.25	Sandy Soil	10.0	37.0	—— ——	145.98 155.98	120.05 129.85	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
15	13.25~ 14.25	Sandy Soil	10.0	37.0	—— ——	155.98 165.98	129.85 139.65	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
16	14.25~ 15.25	Sandy Soil	10.0	38.0	—— ——	165.98 175.98	139.65 149.45	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
17	15.25~ 16.25	Sandy Soil	10.0	38.0	—— ——	175.98 185.98	149.45 159.25	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
18	16.25~ 17.25	Sandy Soil	10.0	36.0	—— ——	185.98 195.98	159.25 169.05	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—— ——
19	17.25~ 18.25	Sandy Soil	10.0	37.0	—— ——	195.98 205.98	169.05 178.85	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
20	18.25~ 19.25	Sandy Soil	10.0	39.0	—— ——	205.98 215.98	178.85 188.65	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
21	19.25~ 20.25	Sandy Soil	10.0	38.0	—— ——	215.98 225.98	188.65 198.45	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
22	20.25~ 21.25	Sandy Soil	10.0	37.0	—— ——	225.98 235.98	198.45 208.25	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:

δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below:

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k)	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 3.75	Sandy soil	10.00	27.0	—— ——	0.000 11.500	0.00 11.27	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	3.75~ 4.75	Clayey soil	8.00	0.0	6.0 6.0	11.500 19.500	11.27 21.07	0.200 0.200	11.31 11.31	—— ——	—— ——
6	4.75~ 5.25	Sandy soil	10.00	30.0	—— ——	19.500 24.500	21.07 25.97	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
7	5.25~ 6.25	Sandy soil	10.00	29.0	—— ——	24.500 34.500	25.97 35.77	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
8	6.25~ 7.25	Sandy soil	10.00	30.0	—— ——	34.500 44.500	35.77 45.57	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
9	7.25~ 8.25	Sandy soil	10.00	34.0	—— ——	44.500 54.500	45.57 55.37	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
10	8.25~ 9.25	Sandy soil	10.00	31.0	—— ——	54.500 64.500	55.37 65.17	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
11	9.25~ 10.25	Sandy soil	10.00	35.0	—— ——	64.500 74.500	65.17 74.97	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
12	10.25~ 11.25	Sandy soil	10.00	35.0	—— ——	74.500 84.500	74.97 84.77	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872

1.94

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k)	θ (degree)	Kp	Kp ×cosδ
13	11.25~ 12.25	Sandy soil	10.00	35.0	—— ——	84.500 94.500	84.77 94.57	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
14	12.25~ 13.25	Sandy soil	10.00	37.0	—— ——	94.500 104.500	94.57 104.37	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
15	13.25~ 14.25	Sandy soil	10.00	37.0	—— ——	104.500 114.500	104.37 114.17	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
16	14.25~ 15.25	Sandy soil	10.00	38.0	—— ——	114.500 124.500	114.17 123.97	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
17	15.25~ 16.25	Sandy soil	10.00	38.0	—— ——	124.500 134.500	123.97 133.77	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
18	16.25~ 17.25	Sandy soil	10.00	36.0	—— ——	134.500 144.500	133.77 143.57	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
19	17.25~ 18.25	Sandy soil	10.00	37.0	—— ——	144.500 154.500	143.57 153.37	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
20	18.25~ 19.25	Sandy soil	10.00	39.0	—— ——	154.500 164.500	153.37 163.17	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
21	19.25~ 20.25	Sandy soil	10.00	38.0	—— ——	164.500 174.500	163.17 172.97	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
22	20.25~ 21.25	Sandy soil	10.00	37.0	—— ——	174.500 184.500	172.97 182.77	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below:

δ = -10.00、β = 0.00、θ = $\tan^{-1}$k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 2.10	11.40 20.80	—— ——	11.40 20.80	0.00 20.58	—— ——
2	2.10~ 2.20	23.10 23.60	—— ——	23.10 23.60	20.58 21.56	—— ——
3	2.20~ 2.60	23.60 25.58	—— ——	23.60 25.58	21.56 21.56	—— ——
4	2.60~ 3.75	25.58 31.30	—— ——	25.58 31.30	21.56 21.56	0.00 33.92
5	3.75~ 4.75	99.34 116.41	31.49 35.49	99.34 116.41	21.56 21.56	23.50 31.50
6	4.75~ 5.25	31.77 34.00	—— ——	31.77 34.00	21.56 21.56	67.20 84.44
7	5.25~ 6.25	35.21 39.85	—— ——	35.21 39.85	21.56 21.56	80.14 112.85
8	6.25~ 7.25	38.48 42.95	—— ——	38.48 42.95	21.56 21.56	118.90 153.36
9	7.25~ 8.25	37.32 41.20	—— ——	37.32 41.20	21.56 21.56	189.92 232.59

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
10	8.25～ 9.25	45.80 50.12	—— ——	45.80 50.12	21.56 21.56	197.98 234.31
11	9.25～ 10.25	43.52 47.27	—— ——	43.52 47.27	21.56 21.56	290.81 335.90
12	10.25～ 11.25	47.27 51.02	—— ——	47.27 51.02	21.56 21.56	335.90 380.99
13	11.25～ 12.25	51.02 54.77	—— ——	51.02 54.77	21.56 21.56	380.99 426.07
14	12.25～ 13.25	50.98 54.47	—— ——	50.98 54.47	21.56 21.56	476.58 527.01
15	13.25～ 14.25	54.47 57.96	—— ——	54.47 57.96	21.56 21.56	527.01 577.44
16	14.25～ 15.25	55.89 59.26	—— ——	55.89 59.26	21.56 21.56	611.45 664.85
17	15.25～ 16.25	59.26 62.63	—— ——	59.26 62.63	21.56 21.56	664.85 718.25
18	16.25～ 17.25	67.33 70.95	—— ——	67.33 70.95	21.56 21.56	641.11 688.78
19	17.25～ 18.25	68.44 71.93	—— ——	68.44 71.93	21.56 21.56	728.74 779.17
20	18.25～ 19.25	66.87 70.12	—— ——	66.87 70.12	21.56 21.56	874.42 931.01
21	19.25～ 20.25	72.73 76.10	—— ——	72.73 76.10	21.56 21.56	878.46 931.86
22	20.25～ 21.25	78.91 82.40	—— ——	78.91 82.40	21.56 21.56	880.04 930.47

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

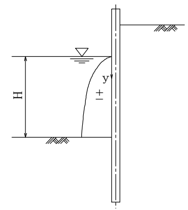
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

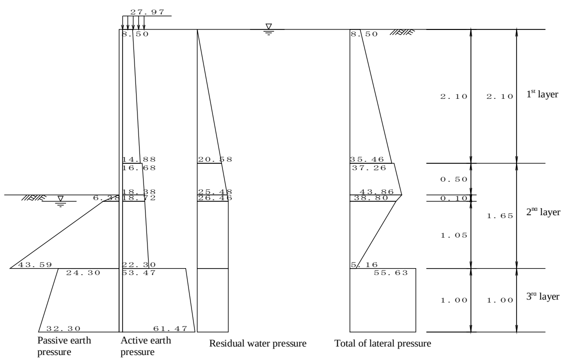
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	8.50 14.88	0.00 20.58	—— ——	8.50 35.46
2	2.10～ 2.60	16.68 18.38	20.58 25.48	—— ——	37.26 43.86
3	2.60～ 2.70	18.38 18.72	25.48 26.46	0.00 6.38	43.86 38.80
4	2.70～ 3.75	18.72 22.30	26.46 26.46	6.38 43.59	38.80 5.16
5	3.75～ 4.75	53.47 61.47	26.46 26.46	24.30 32.30	55.63 55.63
6	4.75～ 5.25	22.32 23.84	26.46 26.46	82.83 103.23	-34.05 -52.94

P_a : Active earth pressure

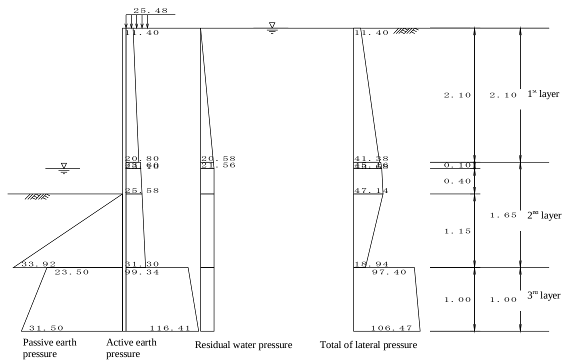
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.15 m (GL -4.75 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	11.40 20.80	0.00 20.58	—— ——	11.40 41.38
2	2.10～ 2.20	23.10 23.60	20.58 21.56	—— ——	43.68 45.16
3	2.20～ 2.60	23.60 25.58	21.56 21.56	—— ——	45.16 47.14
4	2.60～ 3.75	25.58 31.30	21.56 21.56	0.00 33.92	47.14 18.94
5	3.75～ 4.75	99.34 116.41	21.56 21.56	23.50 31.50	97.40 106.47
6	4.75～ 5.25	31.77 34.00	21.56 21.56	67.20 84.44	-13.88 -28.87

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.15 m (GL -4.75 m)

1.95

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4(original condition)
	I	=	130900 cm^4(after reduction by corrosion and sections)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 130900 \times 10^{-8} = 2.618 \times 10^5$

	Depth (m)	N-value		Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	10.25	27	21	20.25	36
2	1.60	15	12	11.25	28	22	21.25	32
3	2.10	1	13	12.25	27			
4	3.75	1	14	13.25	32			
5	4.75	1	15	14.25	33			
6	5.25	15	16	15.25	36			
7	6.25	14	17	16.25	36			
8	7.25	13	18	17.25	30			
9	8.25	23	19	18.25	32			
10	9.25	18	20	19.25	37			

5-2 Normal Condition

K_h = 19512 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.369 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.71 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.75 m) to 2.71 m depth (GL -7.46 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.75	0.50	1.0	15.0	4.00
2	5.25	1.00	15.0	14.0	14.50
3	6.25	1.00	14.0	13.0	13.50
4	7.25	0.21	13.0	15.1	2.90
	L = Σh = 2.71			ΣA = 34.90	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{34.90}{2.71}$$

$$= 12.89$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 12.89^{0.406} = 19512$ kN/m^3

Kh (normal condition) = 19512 kN/m^3

5-3 Seismic Condition

K_h = 19512 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.369 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.71 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.75 m) and 2.71 m depth (GL -7.46 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.75	0.50	1.0	15.0	4.00
2	5.25	1.00	15.0	14.0	14.50
3	6.25	1.00	14.0	13.0	13.50
4	7.25	0.21	13.0	15.1	2.90
	L = Σh = 2.71			ΣA = 34.90	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{34.90}{2.71}$$

$$= 12.89$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 12.89^{0.406} = 19512$ kN/m^3

Kh (seismic condition) = 19512 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	8.50 35.46	8.92 37.23	4.05 3.35	36.13 124.72
2	2.10～ 2.60	0.50	37.26 43.86	9.31 10.97	2.48 2.32	23.13 25.40
3	2.60～ 2.70	0.10	43.86 38.80	2.19 1.94	2.12 2.08	4.64 4.04
4	2.70～ 3.75	1.05	38.80 5.16	20.37 2.71	1.70 1.35	34.63 3.66
5	3.75～ 4.75	1.00	55.63 55.63	27.81 27.81	0.67 0.33	18.54 9.27
				ΣP = 149.28		ΣM = 284.17

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.1 kN/m
depth to acting position	H_t	=	-0.49 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.15 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 16.24$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{300.42}{152.38} = 1.97 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	11.40 41.38	11.97 43.45	4.05 3.35	48.50 145.56
2	2.10～ 2.20	0.10	43.68 45.16	2.18 2.26	2.62 2.58	5.71 5.83
3	2.20～ 2.60	0.40	45.16 47.14	9.03 9.43	2.42 2.28	21.83 21.53
4	2.60～ 3.75	1.15	47.14 18.94	27.11 10.89	1.77 1.38	47.89 15.07
5	3.75～ 4.75	1.00	97.40 106.47	48.70 53.24	0.67 0.33	32.47 17.75
				ΣP = 218.26		ΣM = 362.13

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.9 kN/m
depth to acting position	H_t	=	-0.33 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.15 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 50.29$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	2.42 2.28	0.00 0.31
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.31

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{412.73}{228.30} = 1.81 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	130900 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 130900 × 10^{-8}		=	2.618 × 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	19512	kNm^3
calculated value	β	=	0.36946	m^{-1}
resultant earth force (lateral)	P_0	=	152.38	kNm
height of acting position of load	h_0	=	1.97	m
moment	M_0	=	300.42	kN·m/m

in consideration of ψ_m = 1.237,

maximum moment	M_{max}	=	371.63	kN·m/m
depth of generated position of M_{max}	l_m	=	1.046	m
depth of 1st fixed point	l_i	=	3.172	m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	19512	kNm^3
calculated value	β	=	0.36946	m^{-1}
resultant earth force (lateral)	P_0	=	228.30	kNm
height of acting position of load	h_0	=	1.81	m
moment	M_0	=	412.73	kN·m/m

in consideration of ψ_m = 1.269,

maximum moment	M_{max}	=	523.87	kN·m/m
depth of generated position of M_{max}	l_m	=	1.095	m
depth of 1st fixed point	l_i	=	3.221	m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	4160 cm^3 (original condition)
	Z	=	3619 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{371.63\times10^6}{3619\times10^3} = 103\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2 \quad (ok)$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{523.87\times10^6}{3619\times10^3} = 145\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2 \quad (ok)$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	4.05 3.35	0.853 0.705	0.260 0.190	8.92 37.23	2.321 7.082
2	2.10～ 2.60	2.48 2.32	0.523 0.488	0.113 0.100	9.31 10.97	1.051 1.092
3	2.60～ 2.70	2.12 2.08	0.446 0.439	0.085 0.082	2.19 1.94	0.185 0.159
4	2.70～ 3.75	1.70 1.35	0.358 0.284	0.056 0.037	20.37 2.71	1.149 0.099
5	3.75～ 4.75	0.67 0.33	0.140 0.070	0.009 0.002	27.81 27.81	0.261 0.067
						ΣQ = 13.468

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

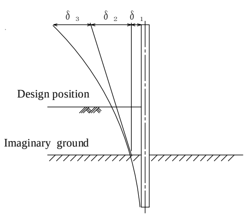
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3695\times1.97)\times152.38}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3695^3} = 0.00997\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3695\times1.97)\times152.38}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3695^2}\times(2.60+2.15) = 0.02488\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.47\times(2.60+2.15)^3}{2.00\times10^8\times130900\times10^{-8}} = 0.00551\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00049 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.75 m
Horizontal load: P = 3.10
Moment: M = 1.52

δ = δ_1 + δ_2 + δ_3
= 0.00997＋0.02488＋0.00600
= 0.04086 m
= 40.86 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	4.05 3.35	0.853 0.705	0.260 0.190	11.97 43.45	3.116 8.266
2	2.10～ 2.20	2.62 2.58	0.551 0.544	0.124 0.121	2.18 2.26	0.271 0.273
3	2.20～ 2.60	2.42 2.28	0.509 0.481	0.107 0.097	9.03 9.43	0.971 0.915
4	2.60～ 3.75	1.77 1.38	0.372 0.291	0.061 0.038	27.11 10.89	1.643 0.417
5	3.75～ 4.75	0.67 0.33	0.140 0.070	0.009 0.002	48.70 53.24	0.457 0.128
						ΣQ = 16.456

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

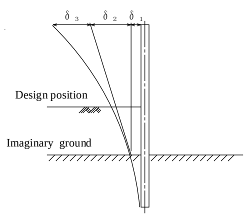
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.42 2.28	0.509 0.481	0.107 0.097	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below:
Q = 16.456＋0.013 ＝ 16.469

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3695\times 1.81)\times 228.30}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3695^3} = 0.01442\ \mathrm{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3695\times 1.81)\times 228.30}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3695^2}\times(2.60+2.15) = 0.03544\ \mathrm{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{16.47\times(2.60+2.15)^3}{2.00\times 10^8\times 130900\times 10^{-8}} = 0.00674\ \mathrm{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00149 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.75 m
Horizontal load: P = 9.90
Moment: M = 3.27

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01442 + 0.03544 + 0.00823
= 0.05810 m
= 58.10 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	154000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 154000 × 10^{-8}		=	3.080 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 19512 kN/m^3
Calculated value β = 0.35475 m^{-1}

Penetration length of SSP $D = 2.15 + \frac{3}{0.355} = 10.61$ m
Whole length of SSP $L = 2.60 - 0.40 + 10.61 = 12.81$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 19512 kN/m^3
Calculated value β = 0.35475 m^{-1}

Penetration length of SSP $D = 2.15 + \frac{3}{0.355} = 10.61$ m
Whole length of SSP $L = 2.60 - 0.40 + 10.61 = 12.81$ m

Therefore, whole length of SSP is set as 13.00 m in consideration of round unit of SSP length.

8 Calculation Result

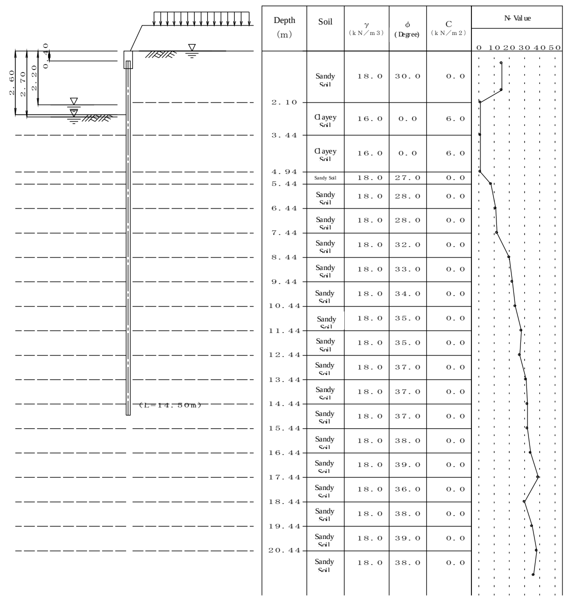
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	154000		
Section modulus	Z (cm^3)	4160		
Maximum bending moment	M_{max} (kN·m/m)		371.63	523.87
Stress intensity	σ (N/mm^2)		103 (185)	145 (278)
Lateral displacement	δ (mm)		40.86 (50.0)	58.10 (75.0)
Penetration depth	D (m)		10.61	10.61
Whole length of SSP	L (m)	13.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 14_STA 13+900 - 14+000

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa} '	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn} '	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	3.1 kN/m	(Normal Condition)
		Pt'	=	9.9 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.49 m	(Normal Condition)
		Ht'	=	-0.34 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_r = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	10.44	24	21	20.44	38
2	1.60	15	12	11.44	28	22	21.44	36
3	2.10	1	13	12.44	27			
4	3.44	1	14	13.44	31			
5	4.94	1	15	14.44	32			
6	5.44	8	16	15.44	32			
7	6.44	11	17	16.44	34			
8	7.44	12	18	17.44	39			
9	8.44	20	19	18.44	30			
10	9.44	22	20	19.44	35			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

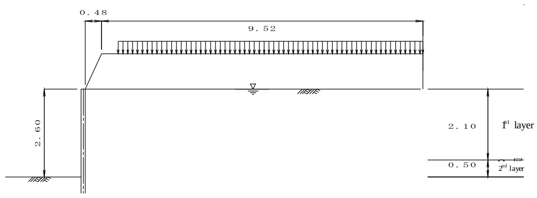
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.44	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	4.94	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
4	5.44	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	6.44	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
6	7.44	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
7	8.44	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
8	9.44	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
9	10.44	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
10	11.44	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
11	12.44	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
12	13.44	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
13	14.44	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
14	15.44	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
15	16.44	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
16	17.44	S	39.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
17	18.44	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
18	19.44	S	35.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
19	20.44	S	38.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
20	21.44	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_0 : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m²)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.48	10.00	10.00	1.05	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.97	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 262000 cm⁴
Sectional factor Z_0 = 5720 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.86
Corrosion rate (to Z_0) η = 0.89
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

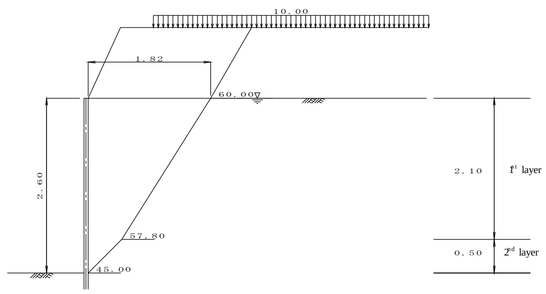
Allowable stress σ_a = 185 Nmm (Normal)
σ_a' = 278 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	27.56	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	27.56	20.58	57.80
3		Embankment	30.0	——	0.0	18.90	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	1.05	1.82	2.60	2.43	3.65

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.98	35.64
Σ			35.64

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.46	14.59
Σ			14.59

Q surcharge load
l : width of surcharge load set by line of active rupture

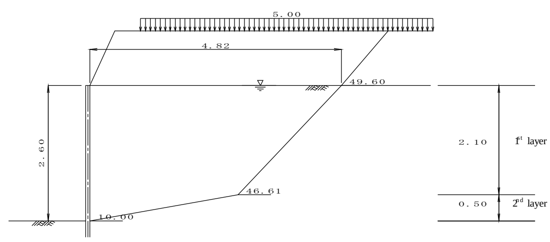
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{35.64 + 14.59 + 0.00}{1.82}$$

$$= 27.56 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	24.63	25.48	0.200	11.31	10.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	24.63	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	18.90	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	10.00	0.50	0.00	0.00	2.84	0.50
2	46.61	2.10	2.84	0.50	4.82	2.60
3	49.60	1.05	4.82	2.60	5.71	3.65

Therefore, width of acting load shall be set as 4.82 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.28	95.02
Σ			95.02

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	4.74	23.72
Σ			23.72

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

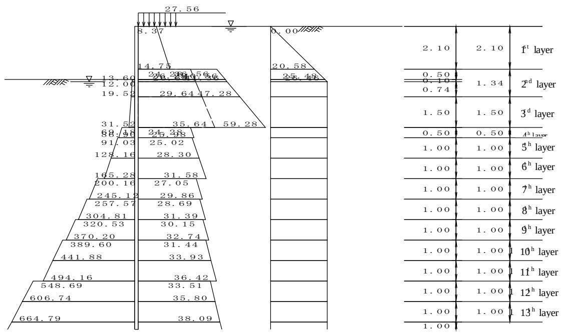
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{95.02 + 23.72 + 0.00}{4.82}$$

$$= 24.63 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



Passive earth pressure   Active earth pressure   Residual water pressure

3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	27.558 48.558	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Clayey soil	8.0	—	6.0 6.0	48.558 52.558	—— ——	—— ——
3	2.60～ 2.70	Clayey soil	8.0	—	6.0 6.0	52.558 53.358	—— ——	—— ——
4	2.70～ 3.44	Clayey soil	8.0	—	6.0 6.0	53.358 59.278	—— ——	—— ——
5	3.44～ 4.94	Clayey soil	8.0	—	6.0 6.0	59.278 71.278	—— ——	—— ——
6	4.94～ 5.44	Sandy soil	10.0	27.0	—— ——	71.278 76.278	0.34585 0.34585	0.34060 0.34060
7	5.44～ 6.44	Sandy soil	10.0	28.0	—— ——	76.278 86.278	0.33303 0.33303	0.32798 0.32798
8	6.44～ 7.44	Sandy soil	10.0	28.0	—— ——	86.278 96.278	0.33303 0.33303	0.32798 0.32798
9	7.44～ 8.44	Sandy soil	10.0	32.0	—— ——	96.278 106.278	0.28525 0.28525	0.28092 0.28092
10	8.44～ 9.44	Sandy soil	10.0	33.0	—— ——	106.278 116.278	0.27412 0.27412	0.26996 0.26996
11	9.44～ 10.44	Sandy soil	10.0	34.0	—— ——	116.278 126.278	0.26331 0.26331	0.25931 0.25931
12	10.44～ 11.44	Sandy soil	10.0	35.0	—— ——	126.278 136.278	0.25279 0.25279	0.24895 0.24895
13	11.44～ 12.44	Sandy soil	10.0	35.0	—— ——	136.278 146.278	0.25279 0.25279	0.24895 0.24895

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	12.44～ 13.44	Sandy soil	10.0	37.0	—— ——	146.278 156.278	0.23264 0.23264	0.22910 0.22910
15	13.44～ 14.44	Sandy soil	10.0	37.0	—— ——	156.278 166.278	0.23264 0.23264	0.22910 0.22910
16	14.44～ 15.44	Sandy soil	10.0	37.0	—— ——	166.278 176.278	0.23264 0.23264	0.22910 0.22910
17	15.44～ 16.44	Sandy soil	10.0	38.0	—— ——	176.278 186.278	0.22298 0.22298	0.21959 0.21959
18	16.44～ 17.44	Sandy soil	10.0	39.0	—— ——	186.278 196.278	0.21359 0.21359	0.21035 0.21035
19	17.44～ 18.44	Sandy soil	10.0	36.0	—— ——	196.278 206.278	0.24257 0.24257	0.23889 0.23889
20	18.44～ 19.44	Sandy soil	10.0	38.0	—— ——	206.278 216.278	0.22298 0.22298	0.21959 0.21959
21	19.44～ 20.44	Sandy soil	10.0	39.0	—— ——	216.278 226.278	0.21359 0.21359	0.21035 0.21035
22	20.44～ 21.44	Sandy soil	10.0	38.0	—— ——	226.278 236.278	0.22298 0.22298	0.21959 0.21959

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Clayey soil	16.0	0.0	6.0 6.0	0.000 1.600	—— ——	—— ——
4	2.70～ 3.44	Clayey soil	8.0	0.0	6.0 6.0	1.600 7.520	—— ——	—— ——
5	3.44～ 4.94	Clayey soil	8.0	0.0	6.0 6.0	7.520 19.520	—— ——	—— ——
6	4.94～ 5.44	Sandy soil	10.0	27.0	—— ——	19.520 24.520	3.59892 3.59892	3.54425 3.54425
7	5.44～ 6.44	Sandy soil	10.0	28.0	—— ——	24.520 34.520	3.76978 3.76978	3.71251 3.71251
8	6.44～ 7.44	Sandy soil	10.0	28.0	—— ——	34.520 44.520	3.76978 3.76978	3.71251 3.71251
9	7.44～ 8.44	Sandy soil	10.0	32.0	—— ——	44.520 54.520	4.56530 4.56530	4.49594 4.49594
10	8.44～ 9.44	Sandy soil	10.0	33.0	—— ——	54.520 64.520	4.79713 4.79713	4.72425 4.72425
11	9.44～ 10.44	Sandy soil	10.0	34.0	—— ——	64.520 74.520	5.04448 5.04448	4.96784 4.96784
12	10.44～ 11.44	Sandy soil	10.0	35.0	—— ——	74.520 84.520	5.30876 5.30876	5.22810 5.22810
13	11.44～ 12.44	Sandy soil	10.0	35.0	—— ——	84.520 94.520	5.30876 5.30876	5.22810 5.22810

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
14	12.44～ 13.44	Sandy soil	10.0	37.0	—— ——	94.520 104.520	5.89457 5.89457	5.80501 5.80501
15	13.44～ 14.44	Sandy soil	10.0	37.0	—— ——	104.520 114.520	5.89457 5.89457	5.80501 5.80501
16	14.44～ 15.44	Sandy soil	10.0	37.0	—— ——	114.520 124.520	5.89457 5.89457	5.80501 5.80501
17	15.44～ 16.44	Sandy soil	10.0	38.0	—— ——	124.520 134.520	6.21981 6.21981	6.12532 6.12532
18	16.44～ 17.44	Sandy soil	10.0	39.0	—— ——	134.520 144.520	6.56948 6.56948	6.46967 6.46967
19	17.44～ 18.44	Sandy soil	10.0	36.0	—— ——	144.520 154.520	5.59154 5.59154	5.50659 5.50659
20	18.44～ 19.44	Sandy soil	10.0	38.0	—— ——	154.520 164.520	6.21981 6.21981	6.12532 6.12532
21	19.44～ 20.44	Sandy soil	10.0	39.0	—— ——	164.520 174.520	6.56948 6.56948	6.46967 6.46967
22	20.44～ 21.44	Sandy soil	10.0	38.0	—— ——	174.520 184.520	6.21981 6.21981	6.12532 6.12532

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	8.37 14.75	—— ——	8.37 14.75	0.00 20.58	—— ——
2	2.10～ 2.60	36.56 40.56	24.28 26.28	36.56 40.56	20.58 25.48	—— ——
3	2.60～ 2.70	40.56 41.36	26.28 26.68	40.56 41.36	25.48 26.46	12.00 13.60
4	2.70～ 3.44	41.36 47.28	26.68 29.64	41.36 47.28	26.46 26.46	13.60 19.52
5	3.44～ 4.94	47.28 59.28	29.64 35.64	47.28 59.28	26.46 26.46	19.52 31.52
6	4.94～ 5.44	24.28 25.98	—— ——	24.28 25.98	26.46 26.46	69.18 86.90
7	5.44～ 6.44	25.02 28.30	—— ——	25.02 28.30	26.46 26.46	91.03 128.16
8	6.44～ 7.44	28.30 31.58	—— ——	28.30 31.58	26.46 26.46	128.16 165.28
9	7.44～ 8.44	27.05 29.86	—— ——	27.05 29.86	26.46 26.46	200.16 245.12
10	8.44～ 9.44	28.69 31.39	—— ——	28.69 31.39	26.46 26.46	257.57 304.81
11	9.44～ 10.44	30.15 32.74	—— ——	30.15 32.74	26.46 26.46	320.53 370.20
12	10.44～ 11.44	31.44 33.93	—— ——	31.44 33.93	26.46 26.46	389.60 441.88

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
13	11.44~ 12.44	33.93 36.42	— —	33.93 36.42	26.46 26.46	441.88 494.16
14	12.44~ 13.44	33.51 35.80	— —	33.51 35.80	26.46 26.46	548.69 606.74
15	13.44~ 14.44	35.80 38.09	— —	35.80 38.09	26.46 26.46	606.74 664.79
16	14.44~ 15.44	38.09 40.39	— —	38.09 40.39	26.46 26.46	664.79 722.84
17	15.44~ 16.44	38.71 40.91	— —	38.71 40.91	26.46 26.46	762.72 823.98
18	16.44~ 17.44	39.18 41.29	— —	39.18 41.29	26.46 26.46	870.30 935.00
19	17.44~ 18.44	46.89 49.28	— —	46.89 49.28	26.46 26.46	795.81 850.88
20	18.44~ 19.44	45.30 47.49	— —	45.30 47.49	26.46 26.46	946.48 1007.74
21	19.44~ 20.44	45.49 47.60	— —	45.49 47.60	26.46 26.46	1064.39 1129.09
22	20.44~ 21.44	49.69 51.88	— —	49.69 51.88	26.46 26.46	1068.99 1130.24

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

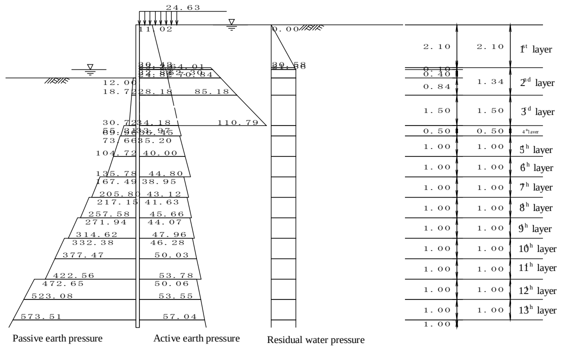
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	— —	24.63 45.63	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
2	2.10~ 2.20	Clayey Soil	8.0	—	6.0 6.0	45.63 46.43	20.58 21.56	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
3	2.20~ 2.60	Clayey Soil	8.0	—	6.0 6.0	46.43 49.63	21.56 25.48	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
4	2.60~ 3.44	Clayey Soil	8.0	—	6.0 6.0	49.63 56.35	25.48 33.71	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
5	3.44~ 4.94	Clayey Soil	8.0	—	6.0 6.0	56.35 68.35	33.71 48.41	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
6	4.94~ 5.44	Sandy Soil	10.0	27.0	— —	68.35 73.35	48.41 53.31	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
7	5.44~ 6.44	Sandy Soil	10.0	28.0	— —	73.35 83.35	53.31 63.11	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	— —
8	6.44~ 7.44	Sandy Soil	10.0	28.0	— —	83.35 93.35	63.11 72.91	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	— —
9	7.44~ 8.44	Sandy Soil	10.0	32.0	— —	93.35 103.35	72.91 82.71	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	— —
10	8.44~ 9.44	Sandy Soil	10.0	33.0	— —	103.35 113.35	82.71 92.51	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	— —
11	9.44~ 10.44	Sandy Soil	10.0	34.0	— —	113.35 123.35	92.51 102.31	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	— —
12	10.44~ 11.44	Sandy Soil	10.0	35.0	— —	123.35 133.35	102.31 112.11	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	— —
13	11.44~ 12.44	Sandy Soil	10.0	35.0	— —	133.35 143.35	112.11 121.91	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	— —

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	12.44~ 13.44	Sandy Soil	10.0	37.0	— —	143.35 153.35	121.91 131.71	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	— —
15	13.44~ 14.44	Sandy Soil	10.0	37.0	— —	153.35 163.35	131.71 141.51	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	— —
16	14.44~ 15.44	Sandy Soil	10.0	37.0	— —	163.35 173.35	141.51 151.31	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	— —
17	15.44~ 16.44	Sandy Soil	10.0	38.0	— —	173.35 183.35	151.31 161.11	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	— —
18	16.44~ 17.44	Sandy Soil	10.0	39.0	— —	183.35 193.35	161.11 170.91	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	— —
19	17.44~ 18.44	Sandy Soil	10.0	36.0	— —	193.35 203.35	170.91 180.71	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	— —
20	18.44~ 19.44	Sandy Soil	10.0	38.0	— —	203.35 213.35	180.71 190.51	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	— —
21	19.44~ 20.44	Sandy Soil	10.0	39.0	— —	213.35 223.35	190.51 200.31	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	— —
22	20.44~ 21.44	Sandy Soil	10.0	38.0	— —	223.35 233.35	200.31 210.11	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:

$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 3.44	Clayey soil	8.00	0.0	6.0 6.0	0.000 6.720	0.00 8.23	0.200 0.200	11.31 11.31	— —	— —
5	3.44~ 4.94	Clayey soil	8.00	0.0	6.0 6.0	6.720 18.720	8.23 22.93	0.200 0.200	11.31 11.31	— —	— —
6	4.94~ 5.44	Sandy soil	10.00	27.0	— —	18.720 23.720	22.93 27.83	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	5.44~ 6.44	Sandy soil	10.00	28.0	— —	23.720 33.720	27.83 37.63	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
8	6.44~ 7.44	Sandy soil	10.00	28.0	— —	33.720 43.720	37.63 47.43	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
9	7.44~ 8.44	Sandy soil	10.00	32.0	— —	43.720 53.720	47.43 57.23	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
10	8.44~ 9.44	Sandy soil	10.00	33.0	— —	53.720 63.720	57.23 67.03	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
11	9.44~ 10.44	Sandy soil	10.00	34.0	— —	63.720 73.720	67.03 76.83	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
12	10.44~ 11.44	Sandy soil	10.00	35.0	— —	73.720 83.720	76.83 86.63	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
13	11.44~ 12.44	Sandy soil	10.00	35.0	— —	83.720 93.720	86.63 96.43	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
14	12.44~ 13.44	Sandy soil	10.00	37.0	— —	93.720 103.720	96.43 106.23	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
15	13.44~ 14.44	Sandy soil	10.00	37.0	— —	103.720 113.720	106.23 116.03	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
16	14.44~ 15.44	Sandy soil	10.00	37.0	— —	113.720 123.720	116.03 125.83	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
17	15.44~ 16.44	Sandy soil	10.00	38.0	— —	123.720 133.720	125.83 135.63	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
18	16.44~ 17.44	Sandy soil	10.00	39.0	— —	133.720 143.720	135.63 145.43	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
19	17.44~ 18.44	Sandy soil	10.00	36.0	— —	143.720 153.720	145.43 155.23	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
20	18.44~ 19.44	Sandy soil	10.00	38.0	— —	153.720 163.720	155.23 165.03	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
21	19.44~ 20.44	Sandy soil	10.00	39.0	— —	163.720 173.720	165.03 174.83	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
22	20.44~ 21.44	Sandy soil	10.00	38.0	— —	173.720 183.720	174.83 184.63	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	11.02 20.42	— —	11.02 20.42	0.00 20.58	— —
2	2.10~ 2.20	62.30 64.01	22.82 23.22	62.30 64.01	20.58 21.56	— —
3	2.20~ 2.60	64.01 70.84	23.22 24.82	64.01 70.84	21.56 21.56	— —
4	2.60~ 3.44	70.84 85.18	24.82 28.18	70.84 85.18	21.56 21.56	12.00 18.72
5	3.44~ 4.94	85.18 110.79	28.18 34.18	85.18 110.79	21.56 21.56	18.72 30.72
6	4.94~ 5.44	33.97 36.45	— —	33.97 36.45	21.56 21.56	55.21 69.96
7	5.44~ 6.44	35.20 40.00	— —	35.20 40.00	21.56 21.56	73.66 104.72
8	6.44~ 7.44	40.00 44.80	— —	40.00 44.80	21.56 21.56	104.72 135.78
9	7.44~ 8.44	38.95 43.12	— —	38.95 43.12	21.56 21.56	167.49 205.80

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
10	8.44～ 9.44	41.63 45.66	—— ——	41.63 45.66	21.56 21.56	217.15 257.58
11	9.44～ 10.44	44.07 47.96	—— ——	44.07 47.96	21.56 21.56	271.94 314.62
12	10.44～ 11.44	46.28 50.03	—— ——	46.28 50.03	21.56 21.56	332.38 377.47
13	11.44～ 12.44	50.03 53.78	—— ——	50.03 53.78	21.56 21.56	377.47 422.56
14	12.44～ 13.44	50.06 53.55	—— ——	50.06 53.55	21.56 21.56	472.65 523.08
15	13.44～ 14.44	53.55 57.04	—— ——	53.55 57.04	21.56 21.56	523.08 573.51
16	14.44～ 15.44	57.04 60.53	—— ——	57.04 60.53	21.56 21.56	573.51 623.94
17	15.44～ 16.44	58.37 61.74	—— ——	58.37 61.74	21.56 21.56	660.68 714.09
18	16.44～ 17.44	59.52 62.77	—— ——	59.52 62.77	21.56 21.56	756.81 813.40
19	17.44～ 18.44	69.99 73.61	—— ——	69.99 73.61	21.56 21.56	685.06 732.73
20	18.44～ 19.44	68.48 71.84	—— ——	68.48 71.84	21.56 21.56	820.89 874.29
21	19.44～ 20.44	69.26 72.51	—— ——	69.26 72.51	21.56 21.56	926.60 983.19
22	20.44～ 21.44	75.21 78.58	—— ——	75.21 78.58	21.56 21.56	927.69 981.09

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

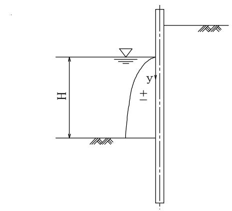
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

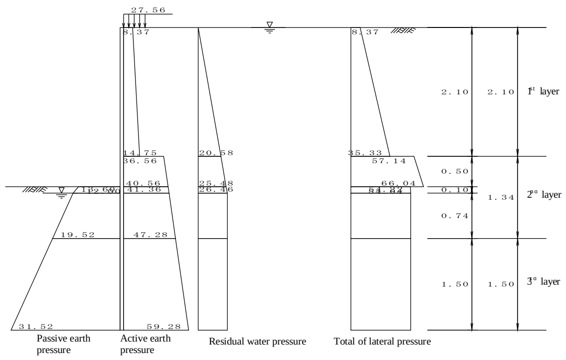
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	8.37 14.75	0.00 20.58	—— ——	8.37 35.33
2	2.10～ 2.60	36.56 40.56	20.58 25.48	—— ——	57.14 66.04
3	2.60～ 2.70	40.56 41.36	25.48 26.46	12.00 13.60	54.04 54.22
4	2.70～ 3.44	41.36 47.28	26.46 26.46	13.60 19.52	54.22 54.22
5	3.44～ 4.94	47.28 59.28	26.46 26.46	19.52 31.52	54.22 54.22
6	4.94～ 5.44	24.28 25.98	26.46 26.46	69.18 86.90	-18.45 -34.46

P_a : Active earth pressure

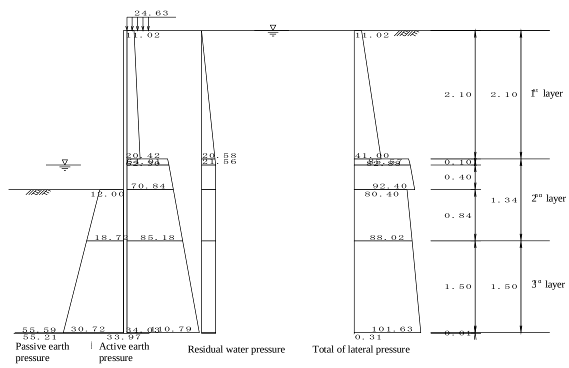
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.34 m (GL -4.94 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	11.02 20.42	0.00 20.58	—— ——	11.02 41.00
2	2.10～ 2.20	62.30 64.01	20.58 21.56	—— ——	82.88 85.57
3	2.20～ 2.60	64.01 70.84	21.56 21.56	—— ——	85.57 92.40
4	2.60～ 3.44	70.84 85.18	21.56 21.56	12.00 18.72	80.40 88.02
5	3.44～ 4.94	85.18 110.79	21.56 21.56	18.72 30.72	88.02 101.63
6	4.94～ 4.95	33.97 34.03	21.56 21.56	55.21 55.59	0.31 0.00
7	4.95～ 5.44	34.03 36.45	21.56 21.56	55.59 69.96	0.00 -11.95

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.35 m (GL -4.95 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	262000 cm^4 (original condition)
	I	=	225320 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 225320 \times 10^{-8} = 4.506 \times 10^5$

	Depth (m)	N-value		Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	10.44	24	21	20.44	38
2	1.60	15	12	11.44	28	22	21.44	36
3	2.10	1	13	12.44	27			
4	3.44	1	14	13.44	31			
5	4.94	1	15	14.44	32			
6	5.44	8	16	15.44	32			
7	6.44	11	17	16.44	34			
8	7.44	12	18	17.44	39			
9	8.44	20	19	18.44	30			
10	9.44	22	20	19.44	35			

5-2 Normal Condition

K_h = 17903 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.316 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.17 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.94 m) to 3.17 m depth (GL -8.11 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.94	0.50	1.0	8.0	2.25
2	5.44	1.00	8.0	11.0	9.50
3	6.44	1.00	11.0	12.0	11.50
4	7.44	0.67	12.0	17.3	9.79
L = Σh = 3.17				ΣA = 33.04	

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{33.04}{3.17} = 10.43$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.43^{0.406} = 17903$ kN/m^3

Kh (normal condition) = 17903 kN/m^3

5-3 Seismic Condition

K_h = 17946 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.316 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.17 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.95 m) and 3.17 m depth (GL -8.12 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.95	0.49	1.2	8.0	2.24
2	5.44	1.00	8.0	11.0	9.50
3	6.44	1.00	11.0	12.0	11.50
4	7.44	0.68	12.0	17.4	9.98
L = Σh = 3.17				ΣA = 33.22	

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{33.22}{3.17} = 10.49$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.49^{0.406} = 17946$ kN/m^3

Kh (seismic condition) = 17946 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.37 35.33	8.79 37.10	4.24 3.54	37.27 131.33
2	2.10~ 2.60	0.50	57.14 66.04	14.28 16.51	2.67 2.51	38.19 41.38
3	2.60~ 2.70	0.10	54.04 54.22	2.70 2.71	2.31 2.27	6.23 6.16
4	2.70~ 3.44	0.74	54.22 54.22	20.06 20.06	1.99 1.75	39.99 35.04
5	3.44~ 4.94	1.50	54.22 54.22	40.66 40.66	1.00 0.50	40.66 20.33
				ΣP = 203.54		ΣM = 396.59

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.1 kN/m
depth to acting position	H_t	=	-0.49 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.34 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 16.83$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{413.42}{206.64} = 2.00 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	11.02 41.00	11.57 43.05	4.25 3.55	49.22 152.95
2	2.10~ 2.20	0.10	82.88 85.57	4.14 4.28	2.82 2.79	11.68 11.92
3	2.20~ 2.60	0.40	85.57 92.40	17.11 18.48	2.62 2.49	44.83 45.94
4	2.60~ 3.44	0.84	80.40 88.02	33.77 36.97	2.07 1.79	69.99 66.28
5	3.44~ 4.94	1.50	88.02 101.63	66.02 76.22	1.01 0.51	66.86 39.08
6	4.94~ 4.95	0.01	0.31 0.00	0.00 0.00	0.01 0.00	0.00 0.00
				ΣP = 311.62		ΣM = 558.76

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.9 kN/m
depth to acting position	H_t	=	-0.34 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.35 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 52.40$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
3	2.20~ 2.60	0.40	85.57 92.40	17.11 18.48	2.62 2.49	44.83 45.94
				ΣPdw = 0.14		ΣMdw = 0.34

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{611.50}{321.66} = 1.90 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	262000 cm^4 (original condition)
	I	=	225320 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 225320 \times 10^{-8}$		=	4.506×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	17903	kNm^3
calculated value	β	=	0.31569	m^{-1}
resultant earth force (lateral)	P_0	=	206.64	kNm
height of acting position of load	h_0	=	2.00	m
moment	M_0	=	413.42	kN·m/m

in consideration of ψ_m = 1.292,

maximum moment	M_{max}	=	534.17	kN·m/m
depth of generated position of M_{max}	l_m	=	1.318	m
depth of 1st fixed point	l_i	=	3.806	m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	17946	kNm^3
calculated value	β	=	0.31588	m^{-1}
resultant earth force (lateral)	P_0	=	321.66	kNm
height of acting position of load	h_0	=	1.90	m
moment	M_0	=	611.50	kN·m/m

in consideration of ψ_m = 1.314,

maximum moment	M_{max}	=	803.55	kN·m/m
depth of generated position of M_{max}	l_m	=	1.350	m
depth of 1st fixed point	l_i	=	3.836	m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	5720 cm^3 (original condition)
	Z	=	5091 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{534.17\times10^6}{5091\times10^3} = 105\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{803.55\times10^6}{5091\times10^3} = 158\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	4.24 3.54	0.858 0.717	0.263 0.195	8.79 37.10	2.311 7.250
2	2.10~ 2.60	2.67 2.51	0.541 0.507	0.120 0.107	14.28 16.51	1.714 1.766
3	2.60~ 2.70	2.31 2.27	0.467 0.460	0.092 0.090	2.70 2.71	0.249 0.243
4	2.70~ 3.44	1.99 1.75	0.404 0.354	0.070 0.055	20.06 20.06	1.413 1.106
5	3.44~ 4.94	1.00 0.50	0.202 0.101	0.019 0.005	40.66 40.66	0.777 0.201
						ΣQ = 17.031

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

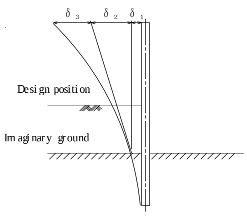
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3157\times2.00)\times206.64}{2\times2.00\times10^8\times225320\times10^{-8}\times0.3157^3} = 0.01189\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.3157\times2.00)\times206.64}{2\times2.00\times10^8\times225320\times10^{-8}\times0.3157^2} \times (2.60+2.34) = 0.02572\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{17.03\times(2.60+2.34)^3}{2.00\times10^8\times225320\times10^{-8}} = 0.00456\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00032 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.94 m
Horizontal load: P = 3.10
Moment: M = 1.52

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01189 + 0.02572 + 0.00487
= 0.04248 m
= 42.48 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	4.25 3.55	0.859 0.717	0.263 0.196	11.57 43.05	3.046 8.428
2	2.10~ 2.20	2.82 2.79	0.569 0.563	0.131 0.129	4.14 4.28	0.544 0.550
3	2.20~ 2.60	2.62 2.49	0.529 0.502	0.115 0.105	17.11 18.48	1.972 1.939
4	2.60~ 3.44	2.07 1.79	0.419 0.362	0.075 0.058	33.77 36.97	2.545 2.130
5	3.44~ 4.94	1.01 0.51	0.204 0.104	0.019 0.005	66.02 76.22	1.286 0.394
6	4.94~ 4.95	0.01 0.00	0.002 0.001	0.000 0.000	0.00 0.00	0.000 0.000
						ΣQ = 22.832

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

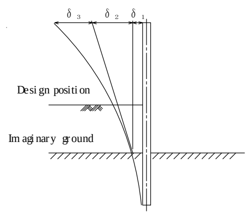
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	2.62 2.49	0.529 0.502	0.115 0.105	0.00 0.14	0.000 0.014
						ΣQ_{dw} = 0.014

Therefore, modulus of deformation Q is calculated as below:
Q = 22.832 + 0.014 = 22.847

1.105

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3159\times 1.90)\times 321.66}{2\times 2.00\times 10^8\times 225320\times 10^{-8}\times 0.3159^3} = 0.01812 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3159\times 1.90)\times 321.66}{2\times 2.00\times 10^8\times 225320\times 10^{-8}\times 0.3159^2}\times(2.60+2.35) = 0.03899 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{22.85\times(2.60+2.35)^3}{2.00\times 10^8\times 225320\times 10^{-8}} = 0.00616 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00098 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.95 m
Horizontal load: P = 9.90
Moment: M = 3.37

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01812 + 0.03899 + 0.00714$
$= 0.06425$ m
$= 64.25 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	262000 cm^4 (original condition)
	I	=	262000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 262000 \times 10^{-8}$		=	5.240×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 17903$ kN/m^3
Calculated value $\beta = 0.30401$ m^{-1}

Penetration length of SSP $D = 2.34 + \frac{3}{0.304} = 12.21$ m
Whole length of SSP $L = 2.60 - 0.40 + 12.21 = 14.41$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 17946$ kN/m^3
Calculated value $\beta = 0.30419$ m^{-1}

Penetration length of SSP $D = 2.35 + \frac{3}{0.304} = 12.22$ m
Whole length of SSP $L = 2.60 - 0.40 + 12.22 = 14.42$ m

Therefore, whole length of SSP is set as 14.50 m in consideration of round unit of SSP length.

8 Calculation Result

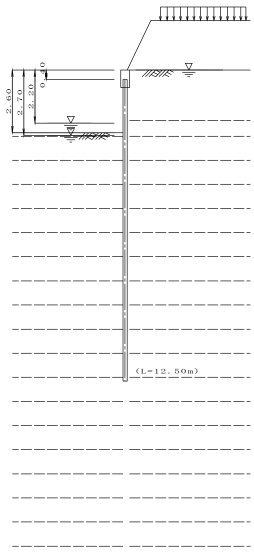
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	262000		
Section modulus	Z (cm^3)	5720		
Maximum bending moment	M_{max} (kN·m/m)		534.17	803.55
Stress intensity	σ (N/mm^2)		105 (185)	158 (278)
Lateral displacement	δ (mm)		42.48 (50.0)	64.25 (75.0)
Penetration depth	D (m)		12.21	12.22
Whole length of SSP	L (m)	14.50		

－Steel Sheet Pile Design Calculation－

Left Bank No. 15_STA 14+000 - 14+150

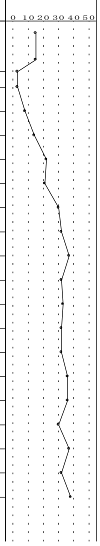
1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN／m3)	φ (Degree)	C (kN／m2)
	Sandy Soil	18.0	30.0	0.0
2.10	Sandy Soil	18.0	27.0	0.0
2.74	Sandy Soil	18.0	27.0	0.0
3.74	Sandy Soil	18.0	29.0	0.0
4.74	Sandy Soil	18.0	33.0	0.0
5.74	Sandy Soil	18.0	33.0	0.0
6.74	Sandy Soil	18.0	36.0	0.0
7.74	Sandy Soil	18.0	37.0	0.0
8.74	Sandy Soil	18.0	39.0	0.0
9.74	Sandy Soil	18.0	37.0	0.0
10.74	Sandy Soil	18.0	37.0	0.0
11.74	Sandy Soil	18.0	37.0	0.0
12.74	Sandy Soil	18.0	37.0	0.0
13.74	Sandy Soil	18.0	38.0	0.0
14.74	Sandy Soil	18.0	38.0	0.0
15.74	Sandy Soil	18.0	36.0	0.0
16.74	Sandy Soil	18.0	39.0	0.0
17.74	Sandy Soil	18.0	37.0	0.0
18.74	Sandy Soil	18.0	39.0	0.0
19.74	Sandy Soil	18.0	39.0	0.0

N-Value



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	8.8 kNm	(Normal Condition)
		P_t'	=	19.7 kNm	(Seismic Condition)
	Depth of acting point	H_f	=	-0.90 m	(Normal Condition)
		H_f'	=	-0.75 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	14.2 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.74	37	21	19.74	38
2	1.60	15	12	10.74	32	22	20.74	39
3	2.10	3	13	11.74	33			
4	2.74	3	14	12.74	32			
5	3.74	8	15	13.74	32			
6	4.74	14	16	14.74	36			
7	5.74	22	17	15.74	36			
8	6.74	21	18	16.74	30			
9	7.74	30	19	17.74	37			
10	8.74	32	20	18.74	32			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

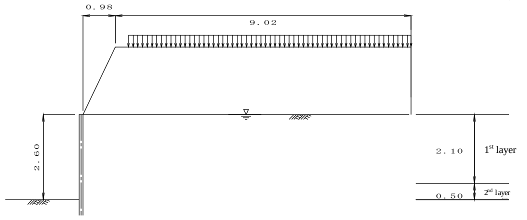
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree)		kh (kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.74	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	3.74	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.74	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
5	5.74	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
6	6.74	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
7	7.74	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
8	8.74	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
9	9.74	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
10	10.74	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
11	11.74	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
12	12.74	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
13	13.74	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
14	14.74	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
15	15.74	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
16	16.74	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
17	17.74	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
18	18.74	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
19	19.74	S	38.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
20	20.74	S	39.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.98	10.00	10.00	2.06	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.38	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 145000 cm⁴
Sectional factor Z_0 = 4070 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

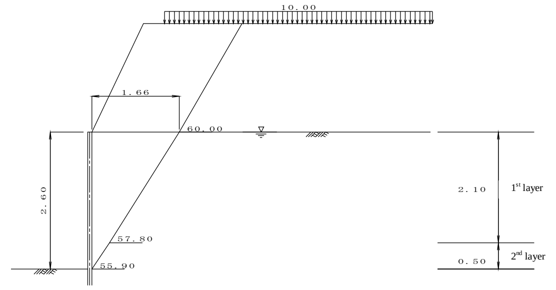
Allowable stress σ_a = 185 N/mm (Normal)
σ_a' = 278 N/mm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	48.27	25.48	55.90
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	48.27	20.58	57.80
3		Embankment	30.0	——	0.0	37.08	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	2.06	1.66	2.60	2.85	4.66

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.64	65.47
Σ			65.47

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.47	14.70
Σ			14.70

Q surcharge load
l : width of surcharge load set by line of active rupture

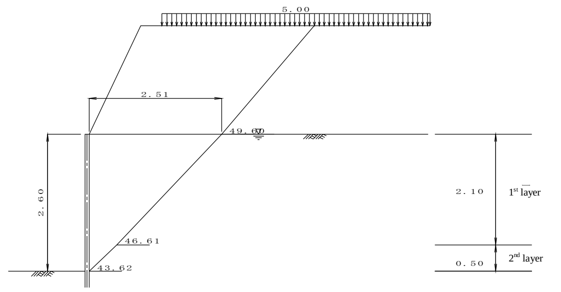
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{65.47 + 14.70 + 0.00}{1.66}$$

$$= 48.27 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	48.53	25.48	0.200	11.31	43.62
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	48.53	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	37.08	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	2.06	2.51	2.60	4.26	4.66

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.97	107.40
Σ			107.40

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.88	14.42
Σ			14.42

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

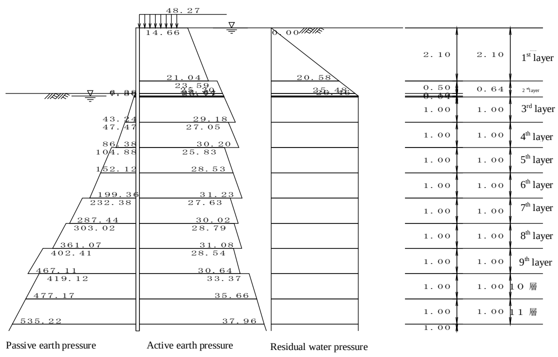
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{107.40 + 14.42 + 0.00}{2.51}$$

$$= 48.53 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka × cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	―― ――	48.269 69.269	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Sandy soil	10.0	27.0	―― ――	69.269 74.269	0.34585 0.34585	0.34060 0.34060
3	2.60～ 2.70	Sandy soil	10.0	27.0	―― ――	74.269 75.269	0.34585 0.34585	0.34060 0.34060
4	2.70～ 2.74	Sandy soil	10.0	27.0	―― ――	75.269 75.669	0.34585 0.34585	0.34060 0.34060
5	2.74～ 3.74	Sandy soil	10.0	27.0	―― ――	75.669 85.669	0.34585 0.34585	0.34060 0.34060
6	3.74～ 4.74	Sandy soil	10.0	29.0	―― ――	85.669 95.669	0.32058 0.32058	0.31571 0.31571
7	4.74～ 5.74	Sandy soil	10.0	33.0	―― ――	95.669 105.669	0.27412 0.27412	0.26996 0.26996
8	5.74～ 6.74	Sandy soil	10.0	33.0	―― ――	105.669 115.669	0.27412 0.27412	0.26996 0.26996
9	6.74～ 7.74	Sandy soil	10.0	36.0	―― ――	115.669 125.669	0.24257 0.24257	0.23889 0.23889
10	7.74～ 8.74	Sandy soil	10.0	37.0	―― ――	125.669 135.669	0.23264 0.23264	0.22910 0.22910
11	8.74～ 9.74	Sandy soil	10.0	39.0	―― ――	135.669 145.669	0.21359 0.21359	0.21035 0.21035
12	9.74～ 10.74	Sandy soil	10.0	37.0	―― ――	145.669 155.669	0.23264 0.23264	0.22910 0.22910
13	10.74～ 11.74	Sandy soil	10.0	37.0	―― ――	155.669 165.669	0.23264 0.23264	0.22910 0.22910

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka × cosδ
14	11.74～ 12.74	Sandy soil	10.0	37.0	―― ――	165.669 175.669	0.23264 0.23264	0.22910 0.22910
15	12.74～ 13.74	Sandy soil	10.0	37.0	―― ――	175.669 185.669	0.23264 0.23264	0.22910 0.22910
16	13.74～ 14.74	Sandy soil	10.0	38.0	―― ――	185.669 195.669	0.22298 0.22298	0.21959 0.21959
17	14.74～ 15.74	Sandy soil	10.0	38.0	―― ――	195.669 205.669	0.22298 0.22298	0.21959 0.21959
18	15.74～ 16.74	Sandy soil	10.0	36.0	―― ――	205.669 215.669	0.24257 0.24257	0.23889 0.23889
19	16.74～ 17.74	Sandy soil	10.0	39.0	―― ――	215.669 225.669	0.21359 0.21359	0.21035 0.21035
20	17.74～ 18.74	Sandy soil	10.0	37.0	―― ――	225.669 235.669	0.23264 0.23264	0.22910 0.22910
21	18.74～ 19.74	Sandy soil	10.0	39.0	―― ――	235.669 245.669	0.21359 0.21359	0.21035 0.21035
22	19.74～ 20.74	Sandy soil	10.0	39.0	―― ――	245.669 255.669	0.21359 0.21359	0.21035 0.21035

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Sandy soil	18.0	27.0	―― ――	0.000 1.800	3.59892 3.59892	3.54425 3.54425
4	2.70～ 2.74	Sandy soil	10.0	27.0	―― ――	1.800 2.200	3.59892 3.59892	3.54425 3.54425
5	2.74～ 3.74	Sandy soil	10.0	27.0	―― ――	2.200 12.200	3.59892 3.59892	3.54425 3.54425
6	3.74～ 4.74	Sandy soil	10.0	29.0	―― ――	12.200 22.200	3.95096 3.95096	3.89093 3.89093
7	4.74～ 5.74	Sandy soil	10.0	33.0	―― ――	22.200 32.200	4.79713 4.79713	4.72425 4.72425
8	5.74～ 6.74	Sandy soil	10.0	33.0	―― ――	32.200 42.200	4.79713 4.79713	4.72425 4.72425
9	6.74～ 7.74	Sandy soil	10.0	36.0	―― ――	42.200 52.200	5.59154 5.59154	5.50659 5.50659
10	7.74～ 8.74	Sandy soil	10.0	37.0	―― ――	52.200 62.200	5.89457 5.89457	5.80501 5.80501
11	8.74～ 9.74	Sandy soil	10.0	39.0	―― ――	62.200 72.200	6.56948 6.56948	6.46967 6.46967
12	9.74～ 10.74	Sandy soil	10.0	37.0	―― ――	72.200 82.200	5.89457 5.89457	5.80501 5.80501
13	10.74～ 11.74	Sandy soil	10.0	37.0	―― ――	82.200 92.200	5.89457 5.89457	5.80501 5.80501

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
14	11.74～ 12.74	Sandy soil	10.0	37.0	―― ――	92.200 102.200	5.89457 5.89457	5.80501 5.80501
15	12.74～ 13.74	Sandy soil	10.0	37.0	―― ――	102.200 112.200	5.89457 5.89457	5.80501 5.80501
16	13.74～ 14.74	Sandy soil	10.0	38.0	―― ――	112.200 122.200	6.21981 6.21981	6.12532 6.12532
17	14.74～ 15.74	Sandy soil	10.0	38.0	―― ――	122.200 132.200	6.21981 6.21981	6.12532 6.12532
18	15.74～ 16.74	Sandy soil	10.0	36.0	―― ――	132.200 142.200	5.59154 5.59154	5.50659 5.50659
19	16.74～ 17.74	Sandy soil	10.0	39.0	―― ――	142.200 152.200	6.56948 6.56948	6.46967 6.46967
20	17.74～ 18.74	Sandy soil	10.0	37.0	―― ――	152.200 162.200	5.89457 5.89457	5.80501 5.80501
21	18.74～ 19.74	Sandy soil	10.0	39.0	―― ――	162.200 172.200	6.56948 6.56948	6.46967 6.46967
22	19.74～ 20.74	Sandy soil	10.0	39.0	―― ――	172.200 182.200	6.56948 6.56948	6.46967 6.46967

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	14.66 21.04	―― ――	14.66 21.04	0.00 20.58	―― ――
2	2.10～ 2.60	23.59 25.30	―― ――	23.59 25.30	20.58 25.48	―― ――
3	2.60～ 2.70	25.30 25.64	―― ――	25.30 25.64	25.48 26.46	0.00 6.38
4	2.70～ 2.74	25.64 25.77	―― ――	25.64 25.77	26.46 26.46	6.38 7.80
5	2.74～ 3.74	25.77 29.18	―― ――	25.77 29.18	26.46 26.46	7.80 43.24
6	3.74～ 4.74	27.05 30.20	―― ――	27.05 30.20	26.46 26.46	47.47 86.38
7	4.74～ 5.74	25.83 28.53	―― ――	25.83 28.53	26.46 26.46	104.88 152.12
8	5.74～ 6.74	28.53 31.23	―― ――	28.53 31.23	26.46 26.46	152.12 199.36
9	6.74～ 7.74	27.63 30.02	―― ――	27.63 30.02	26.46 26.46	232.38 287.44
10	7.74～ 8.74	28.79 31.08	―― ――	28.79 31.08	26.46 26.46	303.02 361.07
11	8.74～ 9.74	28.54 30.64	―― ――	28.54 30.64	26.46 26.46	402.41 467.11
12	9.74～ 10.74	33.37 35.66	―― ――	33.37 35.66	26.46 26.46	419.12 477.17
13	10.74～ 11.74	35.66 37.96	―― ――	35.66 37.96	26.46 26.46	477.17 535.22

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
14	11.74～ 12.74	37.96 40.25	―― ――	37.96 40.25	26.46 26.46	535.22 593.27
15	12.74～ 13.74	40.25 42.54	―― ――	40.25 42.54	26.46 26.46	593.27 651.32
16	13.74～ 14.74	40.77 42.97	―― ――	40.77 42.97	26.46 26.46	687.26 748.51
17	14.74～ 15.74	42.97 45.16	―― ――	42.97 45.16	26.46 26.46	748.51 809.77
18	15.74～ 16.74	49.13 51.52	―― ――	49.13 51.52	26.46 26.46	727.97 783.04
19	16.74～ 17.74	45.37 47.47	―― ――	45.37 47.47	26.46 26.46	919.99 984.68
20	17.74～ 18.74	51.70 53.99	―― ――	51.70 53.99	26.46 26.46	883.52 941.57
21	18.74～ 19.74	49.57 51.68	―― ――	49.57 51.68	26.46 26.46	1049.38 1114.08
22	19.74～ 20.74	51.68 53.78	―― ――	51.68 53.78	26.46 26.46	1114.08 1178.77

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

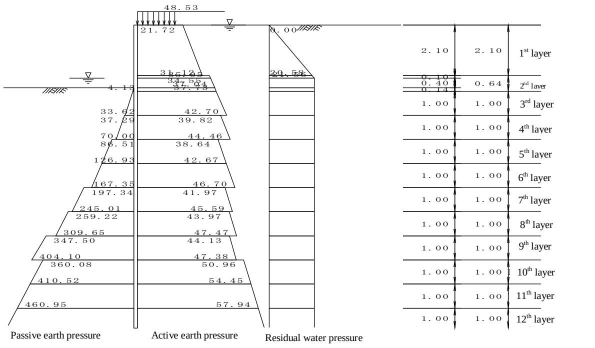
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	―― ――	48.53 69.53	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	―― ――
2	2.10～ 2.20	Sandy Soil	10.0	27.0	―― ――	69.53 70.53	20.58 21.56	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
3	2.20～ 2.60	Sandy Soil	10.0	27.0	―― ――	70.53 74.53	21.56 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
4	2.60～ 2.74	Sandy Soil	10.0	27.0	―― ――	74.53 75.93	25.48 26.85	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
5	2.74～ 3.74	Sandy Soil	10.0	27.0	―― ――	75.93 85.93	26.85 36.65	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
6	3.74～ 4.74	Sandy Soil	10.0	29.0	―― ――	85.93 95.93	36.65 46.45	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	―― ――
7	4.74～ 5.74	Sandy Soil	10.0	33.0	―― ――	95.93 105.93	46.45 56.25	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	―― ――
8	5.74～ 6.74	Sandy Soil	10.0	33.0	―― ――	105.93 115.93	56.25 66.05	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	―― ――
9	6.74～ 7.74	Sandy Soil	10.0	36.0	―― ――	115.93 125.93	66.05 75.85	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	―― ――
10	7.74～ 8.74	Sandy Soil	10.0	37.0	―― ――	125.93 135.93	75.85 85.65	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	―― ――
11	8.74～ 9.74	Sandy Soil	10.0	39.0	―― ――	135.93 145.93	85.65 95.45	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	―― ――
12	9.74～ 10.74	Sandy Soil	10.0	37.0	―― ――	145.93 155.93	95.45 105.25	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	―― ――
13	10.74～ 11.74	Sandy Soil	10.0	37.0	―― ――	155.93 165.93	105.25 115.05	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	―― ――
14	11.74～ 12.74	Sandy Soil	10.0	37.0	―― ――	165.93 175.93	115.05 124.85	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	―― ――

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	12.74～ 13.74	Sandy Soil	10.0	37.0	―― ――	175.93 185.93	124.85 134.65	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	―― ――
16	13.74～ 14.74	Sandy Soil	10.0	38.0	―― ――	185.93 195.93	134.65 144.45	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	―― ――
17	14.74～ 15.74	Sandy Soil	10.0	38.0	―― ――	195.93 205.93	144.45 154.25	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	―― ――
18	15.74～ 16.74	Sandy Soil	10.0	36.0	―― ――	205.93 215.93	154.25 164.05	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	―― ――
19	16.74～ 17.74	Sandy Soil	10.0	39.0	―― ――	215.93 225.93	164.05 173.85	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	―― ――
20	17.74～ 18.74	Sandy Soil	10.0	37.0	―― ――	225.93 235.93	173.85 183.65	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	―― ――
21	18.74～ 19.74	Sandy Soil	10.0	39.0	―― ――	235.93 245.93	183.65 193.45	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	―― ――
22	19.74～ 20.74	Sandy Soil	10.0	39.0	―― ――	245.93 255.93	193.45 203.25	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	―― ――

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:

$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 2.74	Sandy soil	10.00	27.0	―― ――	0.000 1.400	0.00 1.37	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	2.74～ 3.74	Sandy soil	10.00	27.0	―― ――	1.400 11.400	1.37 11.17	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	3.74～ 4.74	Sandy soil	10.00	29.0	―― ――	11.400 21.400	11.17 20.97	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
7	4.74～ 5.74	Sandy soil	10.00	33.0	―― ――	21.400 31.400	20.97 30.77	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
8	5.74～ 6.74	Sandy soil	10.00	33.0	―― ――	31.400 41.400	30.77 40.57	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
9	6.74～ 7.74	Sandy soil	10.00	36.0	―― ――	41.400 51.400	40.57 50.37	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
10	7.74～ 8.74	Sandy soil	10.00	37.0	―― ――	51.400 61.400	50.37 60.17	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
11	8.74～ 9.74	Sandy soil	10.00	39.0	―― ――	61.400 71.400	60.17 69.97	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
12	9.74～ 10.74	Sandy soil	10.00	37.0	―― ――	71.400 81.400	69.97 79.77	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
13	10.74～ 11.74	Sandy soil	10.00	37.0	―― ――	81.400 91.400	79.77 89.57	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
14	11.74～ 12.74	Sandy soil	10.00	37.0	―― ――	91.400 101.400	89.57 99.37	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
15	12.74～ 13.74	Sandy soil	10.00	37.0	―― ――	101.400 111.400	99.37 109.17	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
16	13.74～ 14.74	Sandy soil	10.00	38.0	―― ――	111.400 121.400	109.17 118.97	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
17	14.74～ 15.74	Sandy soil	10.00	38.0	―― ――	121.400 131.400	118.97 128.77	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
18	15.74～ 16.74	Sandy soil	10.00	36.0	―― ――	131.400 141.400	128.77 138.57	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
19	16.74～ 17.74	Sandy soil	10.00	39.0	―― ――	141.400 151.400	138.57 148.37	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
20	17.74～ 18.74	Sandy soil	10.00	37.0	―― ――	151.400 161.400	148.37 158.17	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
21	18.74～ 19.74	Sandy soil	10.00	39.0	―― ――	161.400 171.400	158.17 167.97	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
22	19.74～ 20.74	Sandy soil	10.00	39.0	―― ――	171.400 181.400	167.97 177.77	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta) \cdot \sin(\phi+\beta-\theta)}{\cos(\delta-\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	21.72 31.12	―― ――	21.72 31.12	0.00 20.58	―― ――
2	2.10～ 2.20	34.55 35.05	―― ――	34.55 35.05	20.58 21.56	―― ――
3	2.20～ 2.60	35.05 37.04	―― ――	35.05 37.04	21.56 21.56	―― ――
4	2.60～ 2.74	37.04 37.73	―― ――	37.04 37.73	21.56 21.56	0.00 4.13
5	2.74～ 3.74	37.73 42.70	―― ――	37.73 42.70	21.56 21.56	4.13 33.62
6	3.74～ 4.74	39.82 44.46	―― ――	39.82 44.46	21.56 21.56	37.29 70.00
7	4.74～ 5.74	38.64 42.67	―― ――	38.64 42.67	21.56 21.56	86.51 126.93
8	5.74～ 6.74	42.67 46.70	―― ――	42.67 46.70	21.56 21.56	126.93 167.35
9	6.74～ 7.74	41.97 45.59	―― ――	41.97 45.59	21.56 21.56	197.34 245.01
10	7.74～ 8.74	43.97 47.47	―― ――	43.97 47.47	21.56 21.56	259.22 309.65

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
11	8.74～ 9.74	44.13 47.38	―― ――	44.13 47.38	21.56 21.56	347.50 404.10
12	9.74～ 10.74	50.96 54.45	―― ――	50.96 54.45	21.56 21.56	360.08 410.52
13	10.74～ 11.74	54.45 57.94	―― ――	54.45 57.94	21.56 21.56	410.52 460.95
14	11.74～ 12.74	57.94 61.43	―― ――	57.94 61.43	21.56 21.56	460.95 511.38
15	12.74～ 13.74	61.43 64.93	―― ――	61.43 64.93	21.56 21.56	511.38 561.81
16	13.74～ 14.74	62.61 65.98	―― ――	62.61 65.98	21.56 21.56	594.89 648.30
17	14.74～ 15.74	65.98 69.35	―― ――	65.98 69.35	21.56 21.56	648.30 701.70
18	15.74～ 16.74	74.55 78.17	―― ――	74.55 78.17	21.56 21.56	626.34 674.00
19	16.74～ 17.74	70.10 73.35	―― ――	70.10 73.35	21.56 21.56	800.27 856.87
20	17.74～ 18.74	78.89 82.38	―― ――	78.89 82.38	21.56 21.56	763.54 813.97
21	18.74～ 19.74	76.59 79.84	―― ――	76.59 79.84	21.56 21.56	913.47 970.06
22	19.74～ 20.74	79.84 83.09	―― ――	79.84 83.09	21.56 21.56	970.06 1026.66

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

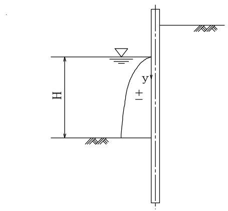
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

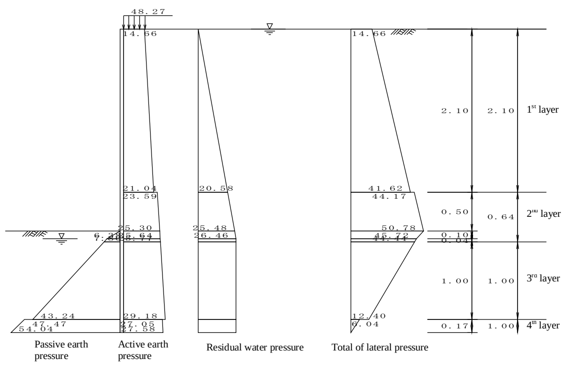
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	14.66 21.04	0.00 20.58	―― ――	14.66 41.62
2	2.10～ 2.60	23.59 25.30	20.58 25.48	―― ――	44.17 50.78
3	2.60～ 2.70	25.30 25.64	25.48 26.46	0.00 6.38	50.78 45.72
4	2.70～ 2.74	25.64 25.77	26.46 26.46	6.38 7.80	45.72 44.44
5	2.74～ 3.74	25.77 29.18	26.46 26.46	7.80 43.24	44.44 12.40
6	3.74～ 3.91	27.05 27.58	26.46 26.46	47.47 54.04	6.04 0.00
7	3.91～ 4.74	27.58 30.20	26.46 26.46	54.04 86.38	0.00 -29.72

P_a : Active earth pressure

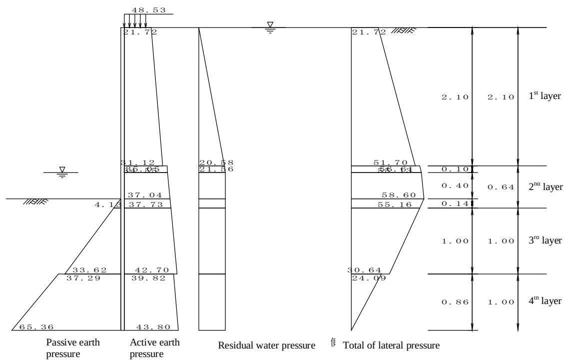
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.31 m (GL -3.91 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	21.72 31.12	0.00 20.58	―― ――	21.72 51.70
2	2.10～ 2.20	34.55 35.05	20.58 21.56	―― ――	55.13 56.61
3	2.20～ 2.60	35.05 37.04	21.56 21.56	―― ――	56.61 58.60
4	2.60～ 2.74	37.04 37.73	21.56 21.56	0.00 4.13	58.60 55.16
5	2.74～ 3.74	37.73 42.70	21.56 21.56	4.13 33.62	55.16 30.64
6	3.74～ 4.60	39.82 43.80	21.56 21.56	37.29 65.36	24.09 0.00
7	4.60～ 4.74	43.80 44.46	21.56 21.56	65.36 70.00	0.00 -3.98

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.00 m (GL -4.60 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	145000 cm⁴ (original condition)
	I	=	127600 cm⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 127600 \times 10^{-8} = 2.552 \times 10^5$

	Depth (m)	N-value		Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	9.74	37	21	19.74	38
2	1.60	15	12	10.74	32	22	20.74	39
3	2.10	3	13	11.74	33			
4	2.74	3	14	12.74	32			
5	3.74	8	15	13.74	32			
6	4.74	14	16	14.74	36			
7	5.74	22	17	15.74	36			
8	6.74	21	18	16.74	30			
9	7.74	30	19	17.74	37			
10	8.74	32	20	18.74	32			

5-2 Normal Condition

K_h = 21838 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.382 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.61 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.91 m) to 2.61 m depth (GL -6.52 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.91	0.83	9.0	14.0	9.56
2	4.74	1.00	14.0	22.0	18.00
3	5.74	0.78	22.0	21.2	16.93
L = Σh = 2.61			ΣA = 44.50		

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{44.50}{2.61} = 17.02$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$$K_h = 6910 \times N'^{0.406} = 6910 \times 17.02^{0.406} = 21838 \text{ kN/m}^3$$

Kh (normal condition) = 21838 kN/m³

5-3 Seismic Condition

K_h = 23292 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.389 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.57 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.60 m) and 2.57 m depth (GL -7.17 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.60	0.14	13.1	14.0	1.92
2	4.74	1.00	14.0	22.0	18.00
3	5.74	1.00	22.0	21.0	21.50
4	6.74	0.43	21.0	24.9	9.89
L = Σh = 2.57			ΣA = 51.32		

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{51.32}{2.57} = 19.94$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$$K_h = 6910 \times N'^{0.406} = 6910 \times 19.94^{0.406} = 23292 \text{ kN/m}^3$$

Kh (seismic condition) = 23292 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	14.66 41.62	15.40 43.70	3.21 2.51	49.40 109.65
2	2.10~ 2.60	0.50	44.17 50.78	11.04 12.69	1.64 1.48	18.14 18.73
3	2.60~ 2.70	0.10	50.78 45.72	2.54 2.29	1.28 1.24	3.24 2.84
4	2.70~ 2.74	0.04	45.72 44.44	0.91 0.89	1.20 1.18	1.09 1.05
5	2.74~ 3.74	1.00	44.44 12.40	22.22 6.20	0.84 0.50	18.56 3.11
6	3.74~ 3.91	0.17	6.04 0.00	0.51 0.00	0.11 0.06	0.06 0.00
				ΣP = 118.39		ΣM = 225.87

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.8 kN/m
depth to acting position	H_t	=	-0.90 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.31 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 42.32 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{268.19}{127.19} = 2.11 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	21.72 51.70	22.80 54.28	3.90 3.20	88.90 173.60
2	2.10~ 2.20	0.10	55.13 56.61	2.76 2.83	2.46 2.43	6.79 6.88
3	2.20~ 2.60	0.40	56.61 58.60	11.32 11.72	2.26 2.13	25.64 24.98
4	2.60~ 2.74	0.14	58.60 55.16	4.10 3.86	1.95 1.90	8.01 7.36
5	2.74~ 3.74	1.00	55.16 30.64	27.58 15.32	1.52 1.19	42.06 18.25
6	3.74~ 4.60	0.86	24.09 0.00	10.34 0.00	0.57 0.29	5.92 0.00
				ΣP = 166.92		ΣM = 408.40

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	19.7 kN/m
depth to acting position	H	=	-0.75 m
moment	M_m	=	14.2 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.00 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 119.56 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.26 2.13	0.00 0.29
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.29

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{528.25}{186.76} = 2.83 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	145000 cm^4 (original condition)
	I	=	127600 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 127600 × 10^{-8}		=	2.552 × 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	21838 kNm^3
calculated value	β	=	0.38245 m^{-1}
resultant earth force (lateral)	P_0	=	127.19 kNm
height of acting position of load	h_0	=	2.11 m
moment	M_0	=	268.19 kN·m/m

in consideration of ψ_m = 1.204,

maximum moment	M_{max}	=	322.78 kN·m/m
depth of generated position of M_{max}	l_m	=	0.956 m
depth of 1st fixed point	l_i	=	3.009 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	23292 kNm^3
calculated value	β	=	0.38866 m^{-1}
resultant earth force (lateral)	P_0	=	186.76 kNm
height of acting position of load	h_0	=	2.83 m
moment	M_0	=	528.25 kN·m/m

in consideration of ψ_m = 1.126,

maximum moment	M_{max}	=	594.71 kN·m/m
depth of generated position of M_{max}	l_m	=	0.780 m
depth of 1st fixed point	l_i	=	2.800 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	4070 cm^3 (original condition)
	Z	=	3582 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{322.78\times10^6}{3582\times10^3} = 90\ \text{N/mm}^2 \leqq \sigma_a = 185\ \text{N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{594.71\times10^6}{3582\times10^3} = 166\ \text{N/mm}^2 \leqq \sigma_a = 278\ \text{N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.21 2.51	0.821 0.642	0.245 0.162	15.40 43.70	3.768 7.076
2	2.10～ 2.60	1.64 1.48	0.420 0.377	0.076 0.062	11.04 12.69	0.838 0.791
3	2.60～ 2.70	1.28 1.24	0.326 0.318	0.047 0.045	2.54 2.29	0.120 0.103
4	2.70～ 2.74	1.20 1.18	0.306 0.302	0.042 0.041	0.91 0.89	0.038 0.037
5	2.74～ 3.74	0.84 0.50	0.214 0.128	0.021 0.008	22.22 6.20	0.471 0.049
6	3.74～ 3.91	0.11 0.06	0.029 0.014	0.000 0.000	0.51 0.00	0.000 0.000
						ΣQ = 13.292

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

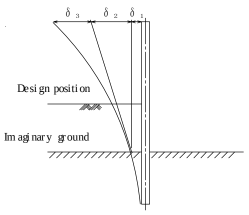
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3825\times2.11)\times127.19}{2\times2.00\times10^8\times127600\times10^{-8}\times0.3825^3} = 0.00805\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.3825\times2.11)\times127.19}{2\times2.00\times10^8\times127600\times10^{-8}\times0.3825^2} \times (2.60+1.31) = 0.01740\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.29\times(2.60+1.31)^3}{2.00\times10^8\times127600\times10^{-8}} = 0.00311\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00092 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.91 m
Horizontal load: P = 8.80
Moment: M = 7.92

δ = δ_1 + δ_2 + δ_3
= 0.00805 + 0.01740 + 0.00403
= 0.02948 m
= 29.48 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.90 3.20	0.848 0.696	0.258 0.186	22.80 54.28	5.879 10.086
2	2.10～ 2.20	2.46 2.43	0.536 0.529	0.118 0.115	2.76 2.83	0.325 0.326
3	2.20～ 2.60	2.26 2.13	0.493 0.464	0.101 0.091	11.32 11.72	1.148 1.065
4	2.60～ 2.74	1.95 1.90	0.424 0.414	0.077 0.074	4.10 3.86	0.317 0.286
5	2.74～ 3.74	1.52 1.19	0.332 0.259	0.049 0.031	27.58 15.32	1.349 0.470
6	3.74～ 4.60	0.57 0.29	0.124 0.062	0.007 0.002	10.34 0.00	0.077 0.000
						ΣQ = 21.327

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

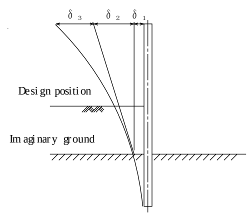
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.26 2.13	0.493 0.464	0.101 0.091	0.00 0.14	0.000 0.012
						ΣQ_{dw} = 0.012

Therefore, modulus of deformation Q is calculated as below:
Q = 21.327 + 0.012 = 21.340

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3887\times 2.83)\times 186.76}{2\times 2.00\times 10^8\times 127600\times 10^{-8}\times 0.3887^3} = 0.01308 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3887\times 2.83)\times 186.76}{2\times 2.00\times 10^8\times 127600\times 10^{-8}\times 0.3887^2}\times(2.60+2.00) = 0.03563 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{21.34\times(2.60+2.00)^3}{2.00\times 10^8\times 127600\times 10^{-8}} = 0.00813 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00311 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.60 m
Horizontal load: P = 19.70
Moment: M = 14.78

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.60\text{ m、}h=L-H_m\text{、}H_m=0.80\text{ m、ただし} \quad)$$

$$= \frac{14.20\times 3.80}{2\times 2.00\times 10^8\times 127600\times 10^{-8}}\times(2\times 4.60-3.80) = 0.00057 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01308+0.03563+0.01181$
$= 0.06053$ m
$= 60.53 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	145000 cm^4 (original condition)
	I	=	145000 cm^4 (after reduction by corrosion and section)
$EI = 200000\times 10^3\times 145000\times 10^{-8}$		=	2.900×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 21838$ kN/m^3
Calculated value $\beta = 0.37042$ m^{-1}

Penetration length of SSP $D = 1.31 + \frac{3}{0.370} = 9.41$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.41 = 11.61$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 23292$ kN/m^3
Calculated value $\beta = 0.37643$ m^{-1}

Penetration length of SSP $D = 2.00 + \frac{3}{0.376} = 9.97$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.97 = 12.17$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

8 Calculation Result

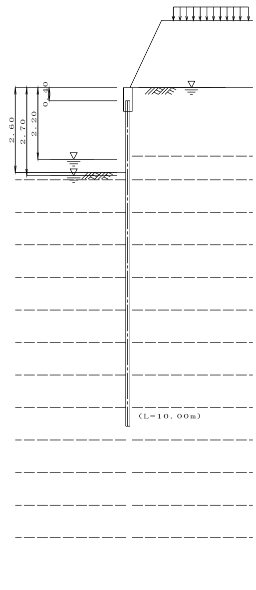
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	145000		
Section modulus	Z (cm^3)	4070		
Maximum bending moment	M_{max} (kN·m/m)		322.78	594.71
Stress intensity	σ (Nmm^2)		90 (185)	166 (278)
Lateral displacement	δ (mm)		29.48 (50.0)	60.53 (75.0)
Penetration depth	D (m)		9.41	9.97
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

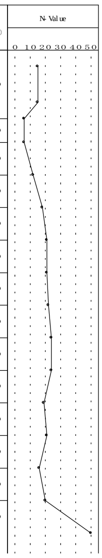
Left Bank No. 16_STA 14+150 - 14+250

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
2.83	Sandy Soil	18.0	27.0	0.0
3.83	Sandy Soil	18.0	28.0	0.0
4.83	Sandy Soil	18.0	31.0	0.0
5.83	Sandy Soil	18.0	33.0	0.0
6.83	Sandy Soil	18.0	33.0	0.0
7.83	Sandy Soil	18.0	33.0	0.0
8.83	Sandy Soil	18.0	34.0	0.0
9.83	Sandy Soil	18.0	34.0	0.0
10.83	Sandy Soil	18.0	32.0	0.0
11.83	Sandy Soil	18.0	33.0	0.0
12.83	Sandy Soil	18.0	30.0	0.0
13.83	Sandy Soil	18.0	32.0	0.0
	Sandy Soil	18.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress: Chang's formula

Penetration depths: $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water: γ_w = 9.8 kN/m^3

Type of water pressure: trapezoidal water pressure

Lateral pressure: calculated in consideration of site conditions

Study case:
- Normal Condition
- Seismic Condition

Design earthquake intensity: k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load					
	Horizontal load	P_t	=	8.9 kN/m	(Normal Condition)
		P_t'	=	19.7 kN/m	(Seismic Condition)
	Depth of acting point	H	=	-0.90 m	(Normal Condition)
		H'	=	-0.75 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	14.2 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load: not considered

Minimum angle of rupture: ζ_0 = 10 degrees

Rear side angle of slope: not considered

Angle of rupture (clayey soil): $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula: $K_h = 6910 \times N'^{0.406}$

Average N-value: calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.83	24
2	1.60	15	12	10.83	19
3	2.10	6	13	11.83	21
4	2.83	6	14	12.83	16
5	3.83	12	15	13.83	20
6	4.83	18	16	14.83	50
7	5.83	21			
8	6.83	21			
9	7.83	22			
10	8.83	24			

1-6 Vertical Load

Vertical load on landside: calculated in consideration of embankment shape on landside

Vertical load on riverside: not considered

1-7 Soil Modulus

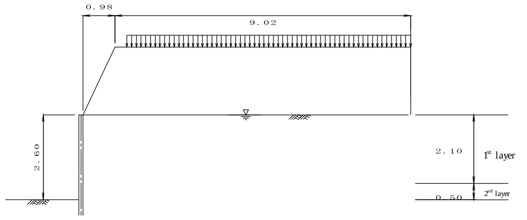
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m^3) normal	kh (kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.83	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	3.83	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
4	4.83	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
5	5.83	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
6	6.83	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
7	7.83	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
8	8.83	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
9	9.83	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
10	10.83	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
11	11.83	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
12	12.83	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
13	13.83	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
14	14.83	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_0 : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kNm^3)	ϕ (degree)	C (kNm^2)	Normal	Seismic
1	Sandy soil	0.00	0.98	10.00	10.00	2.07	1.4	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm^2)	Seismic (kNm^2)
1	1.34	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 56700 cm^4
Sectional factor Z_0 = 2700 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

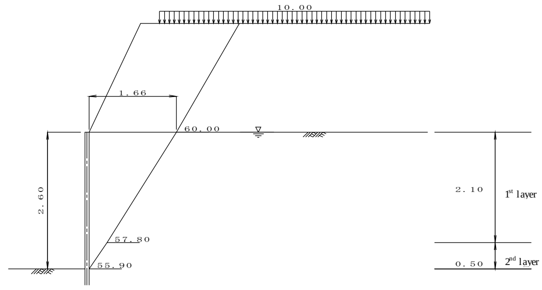
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kNm^2)	$\Sigma\gamma h$ (kNm^2)	Q (kNm^2)	$\gamma w h w$ (kNm^2)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	12.21	25.48	55.90
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	12.21	20.58	57.80
3		Embankment	30.0	——	0.0	2.90	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^0 since θ = 0^0

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^0$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	2.07	1.66	2.60	2.86	4.67

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kNm^3)	A (m^2)	γ X A (kNm)
1	1.4	3.66	5.13
Σ			5.13

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kNm^2)	l (m)	Q X l (kNm)
1	10.0	1.52	15.16
Σ			15.16

Q surcharge load
l : width of surcharge load set by line of active rupture

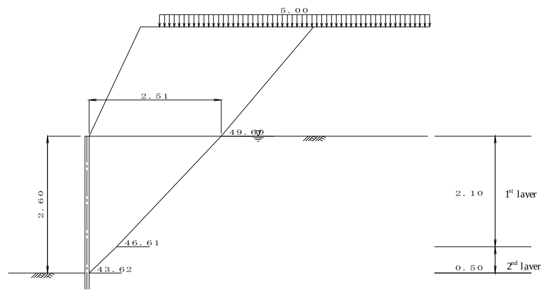
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{5.13 + 15.16 + 0.00}{1.66}$$

$$= 12.21 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kNm^2)	$\Sigma\gamma h$ (kNm^2)	Q (kNm^2)	$\gamma w h w$ (kNm^2)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	9.19	25.48	0.200	11.31	43.62
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	9.19	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	2.90	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^0$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	2.07	2.51	2.60	4.27	4.67

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	1.4	6.00	8.41
Σ			8.41

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kNm²)	l (m)	Q X l (kNm)
1	5.0	2.93	14.66
Σ			14.66

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

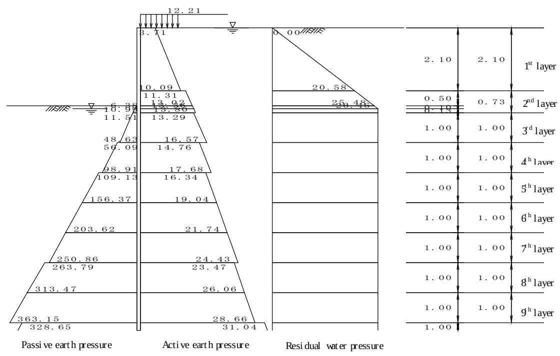
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{8.41 + 14.66 + 0.00}{2.51}$$

$$= 9.19 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	12.213 33.213	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Sandy soil	10.0	27.0	—— ——	33.213 38.213	0.34585 0.34585	0.34060 0.34060
3	2.60～ 2.70	Sandy soil	10.0	27.0	—— ——	38.213 39.213	0.34585 0.34585	0.34060 0.34060
4	2.70～ 2.83	Sandy soil	10.0	27.0	—— ——	39.213 40.513	0.34585 0.34585	0.34060 0.34060
5	2.83～ 3.83	Sandy soil	10.0	28.0	—— ——	40.513 50.513	0.33303 0.33303	0.32798 0.32798
6	3.83～ 4.83	Sandy soil	10.0	31.0	—— ——	50.513 60.513	0.29669 0.29669	0.29219 0.29219
7	4.83～ 5.83	Sandy soil	10.0	33.0	—— ——	60.513 70.513	0.27412 0.27412	0.26996 0.26996
8	5.83～ 6.83	Sandy soil	10.0	33.0	—— ——	70.513 80.513	0.27412 0.27412	0.26996 0.26996
9	6.83～ 7.83	Sandy soil	10.0	33.0	—— ——	80.513 90.513	0.27412 0.27412	0.26996 0.26996
10	7.83～ 8.83	Sandy soil	10.0	34.0	—— ——	90.513 100.513	0.26331 0.26331	0.25931 0.25931
11	8.83～ 9.83	Sandy soil	10.0	34.0	—— ——	100.513 110.513	0.26331 0.26331	0.25931 0.25931
12	9.83～ 10.83	Sandy soil	10.0	32.0	—— ——	110.513 120.513	0.28525 0.28525	0.28092 0.28092
13	10.83～ 11.83	Sandy soil	10.0	33.0	—— ——	120.513 130.513	0.27412 0.27412	0.26996 0.26996

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	11.83～ 12.83	Sandy soil	10.0	30.0	—— ——	130.513 140.513	0.30847 0.30847	0.30378 0.30378
15	12.83～ 13.83	Sandy soil	10.0	32.0	—— ——	140.513 150.513	0.28525 0.28525	0.28092 0.28092
16	13.83～ 14.83	Sandy soil	10.0	45.0	—— ——	150.513 160.513	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.59892 3.59892	3.54425 3.54425
4	2.70～ 2.83	Sandy soil	10.0	27.0	—— ——	1.800 3.100	3.59892 3.59892	3.54425 3.54425
5	2.83～ 3.83	Sandy soil	10.0	28.0	—— ——	3.100 13.100	3.76978 3.76978	3.71251 3.71251
6	3.83～ 4.83	Sandy soil	10.0	31.0	—— ——	13.100 23.100	4.34774 4.34774	4.28169 4.28169
7	4.83～ 5.83	Sandy soil	10.0	33.0	—— ——	23.100 33.100	4.79713 4.79713	4.72425 4.72425
8	5.83～ 6.83	Sandy soil	10.0	33.0	—— ——	33.100 43.100	4.79713 4.79713	4.72425 4.72425
9	6.83～ 7.83	Sandy soil	10.0	33.0	—— ——	43.100 53.100	4.79713 4.79713	4.72425 4.72425
10	7.83～ 8.83	Sandy soil	10.0	34.0	—— ——	53.100 63.100	5.04448 5.04448	4.96784 4.96784
11	8.83～ 9.83	Sandy soil	10.0	34.0	—— ——	63.100 73.100	5.04448 5.04448	4.96784 4.96784
12	9.83～ 10.83	Sandy soil	10.0	32.0	—— ——	73.100 83.100	4.56530 4.56530	4.49594 4.49594
13	10.83～ 11.83	Sandy soil	10.0	33.0	—— ——	83.100 93.100	4.79713 4.79713	4.72425 4.72425
14	11.83～ 12.83	Sandy soil	10.0	30.0	—— ——	93.100 103.100	4.14330 4.14330	4.08035 4.08035
15	12.83～ 13.83	Sandy soil	10.0	32.0	—— ——	103.100 113.100	4.56530 4.56530	4.49594 4.49594
16	13.83～ 14.83	Sandy soil	10.0	45.0	—— ——	113.100 123.100	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	3.71 10.09	—— ——	3.71 10.09	0.00 20.58	—— ——
2	2.10～ 2.60	11.31 13.02	—— ——	11.31 13.02	20.58 25.48	—— ——
3	2.60～ 2.70	13.02 13.36	—— ——	13.02 13.36	25.48 26.46	0.00 6.38
4	2.70～ 2.83	13.36 13.80	—— ——	13.36 13.80	26.46 26.46	6.38 10.99
5	2.83～ 3.83	13.29 16.57	—— ——	13.29 16.57	26.46 26.46	11.51 48.63
6	3.83～ 4.83	14.76 17.68	—— ——	14.76 17.68	26.46 26.46	56.09 98.91
7	4.83～ 5.83	16.34 19.04	—— ——	16.34 19.04	26.46 26.46	109.13 156.37
8	5.83～ 6.83	19.04 21.74	—— ——	19.04 21.74	26.46 26.46	156.37 203.62
9	6.83～ 7.83	21.74 24.43	—— ——	21.74 24.43	26.46 26.46	203.62 250.86
10	7.83～ 8.83	23.47 26.06	—— ——	23.47 26.06	26.46 26.46	263.79 313.47
11	8.83～ 9.83	26.06 28.66	—— ——	26.06 28.66	26.46 26.46	313.47 363.15
12	9.83～ 10.83	31.04 33.85	—— ——	31.04 33.85	26.46 26.46	328.65 373.61
13	10.83～ 11.83	32.53 35.23	—— ——	32.53 35.23	26.46 26.46	392.59 439.83
14	11.83～ 12.83	39.65 42.69	—— ——	39.65 42.69	26.46 26.46	379.88 420.68
15	12.83～ 13.83	39.47 42.28	—— ——	39.47 42.28	26.46 26.46	463.53 508.49
16	13.83～ 14.83	24.11 25.71	—— ——	24.11 25.71	26.46 26.46	1040.92 1132.95

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

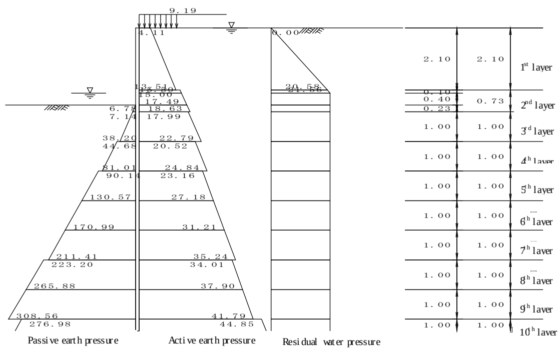
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	9.19 30.19	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	27.0	—— ——	30.19 31.19	20.58 21.56	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.20~ 2.60	Sandy Soil	10.0	27.0	—— ——	31.19 35.19	21.56 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	2.60~ 2.83	Sandy Soil	10.0	27.0	—— ——	35.19 37.49	25.48 27.73	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	2.83~ 3.83	Sandy Soil	10.0	28.0	—— ——	37.49 47.49	27.73 37.53	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
6	3.83~ 4.83	Sandy Soil	10.0	31.0	—— ——	47.49 57.49	37.53 47.33	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
7	4.83~ 5.83	Sandy Soil	10.0	33.0	—— ——	57.49 67.49	47.33 57.13	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
8	5.83~ 6.83	Sandy Soil	10.0	33.0	—— ——	67.49 77.49	57.13 66.93	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
9	6.83~ 7.83	Sandy Soil	10.0	33.0	—— ——	77.49 87.49	66.93 76.73	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
10	7.83~ 8.83	Sandy Soil	10.0	34.0	—— ——	87.49 97.49	76.73 86.53	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
11	8.83~ 9.83	Sandy Soil	10.0	34.0	—— ——	97.49 107.49	86.53 96.33	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
12	9.83~ 10.83	Sandy Soil	10.0	32.0	—— ——	107.49 117.49	96.33 106.13	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
13	10.83~ 11.83	Sandy Soil	10.0	33.0	—— ——	117.49 127.49	106.13 115.93	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
14	11.83~ 12.83	Sandy Soil	10.0	30.0	—— ——	127.49 137.49	115.93 125.73	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	12.83~ 13.83	Sandy Soil	10.0	32.0	—— ——	137.49 147.49	125.73 135.53	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
16	13.83~ 14.83	Sandy Soil	10.0	45.0	—— ——	147.49 157.49	135.53 145.33	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 2.83	Sandy soil	10.00	27.0	—— ——	0.000 2.300	0.00 2.25	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	2.83~ 3.83	Sandy soil	10.00	28.0	—— ——	2.300 12.300	2.25 12.05	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
6	3.83~ 4.83	Sandy soil	10.00	31.0	—— ——	12.300 22.300	12.05 21.85	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
7	4.83~ 5.83	Sandy soil	10.00	33.0	—— ——	22.300 32.300	21.85 31.65	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
8	5.83~ 6.83	Sandy soil	10.00	33.0	—— ——	32.300 42.300	31.65 41.45	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
9	6.83~ 7.83	Sandy soil	10.00	33.0	—— ——	42.300 52.300	41.45 51.25	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
10	7.83~ 8.83	Sandy soil	10.00	34.0	—— ——	52.300 62.300	51.25 61.05	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
11	8.83~ 9.83	Sandy soil	10.00	34.0	—— ——	62.300 72.300	61.05 70.85	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
12	9.83~ 10.83	Sandy soil	10.00	32.0	—— ——	72.300 82.300	70.85 80.65	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
13	10.83~ 11.83	Sandy soil	10.00	33.0	—— ——	82.300 92.300	80.65 90.45	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
14	11.83~ 12.83	Sandy soil	10.00	30.0	—— ——	92.300 102.300	90.45 100.25	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
15	12.83~ 13.83	Sandy soil	10.00	32.0	—— ——	102.300 112.300	100.25 110.05	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
16	13.83~ 14.83	Sandy soil	10.00	45.0	—— ——	112.300 122.300	110.05 119.85	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 2.10	4.11 13.51	—— ——	4.11 13.51	0.00 20.58	—— ——
2	2.10~ 2.20	15.00 15.50	—— ——	15.00 15.50	20.58 21.56	—— ——
3	2.20~ 2.60	15.50 17.49	—— ——	15.50 17.49	21.56 21.56	—— ——
4	2.60~ 2.83	17.49 18.63	—— ——	17.49 18.63	21.56 21.56	0.00 6.78
5	2.83~ 3.83	17.99 22.79	—— ——	17.99 22.79	21.56 21.56	7.14 38.20
6	3.83~ 4.83	20.52 24.84	—— ——	20.52 24.84	21.56 21.56	44.68 81.01
7	4.83~ 5.83	23.16 27.18	—— ——	23.16 27.18	21.56 21.56	90.14 130.57
8	5.83~ 6.83	27.18 31.21	—— ——	27.18 31.21	21.56 21.56	130.57 170.99
9	6.83~ 7.83	31.21 35.24	—— ——	31.21 35.24	21.56 21.56	170.99 211.41
10	7.83~ 8.83	34.01 37.90	—— ——	34.01 37.90	21.56 21.56	223.20 265.88
11	8.83~ 9.83	37.90 41.79	—— ——	37.90 41.79	21.56 21.56	265.88 308.56
12	9.83~ 10.83	44.85 49.02	—— ——	44.85 49.02	21.56 21.56	276.98 315.29
13	10.83~ 11.83	47.32 51.35	—— ——	47.32 51.35	21.56 21.56	332.68 373.10
14	11.83~ 12.83	57.05 61.53	—— ——	57.05 61.53	21.56 21.56	318.10 352.56
15	12.83~ 13.83	57.36 61.54	—— ——	57.36 61.54	21.56 21.56	391.91 430.22
16	13.83~ 14.83	38.16 40.75	—— ——	38.16 40.75	21.56 21.56	921.25 1003.28

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c\cdot(\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}]\cdot\cos\delta$

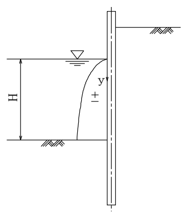
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm\frac{7}{8}\,k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where,

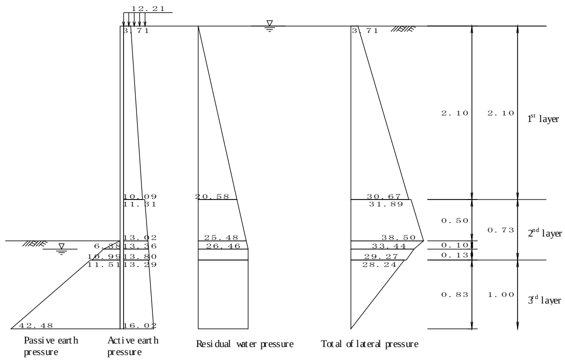
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

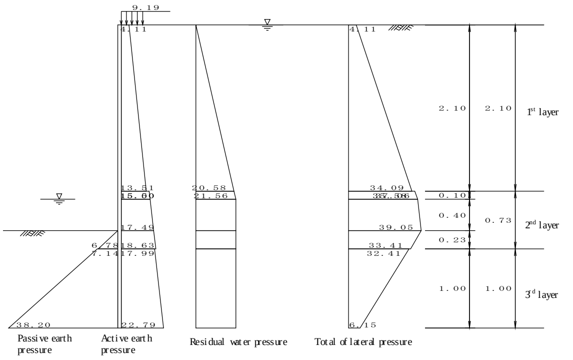


	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.10	3.71 10.09	0.00 20.58	—— ——	3.71 30.67
2	2.10～ 2.60	11.31 13.02	20.58 25.48	—— ——	31.89 38.50
3	2.60～ 2.70	13.02 13.36	25.48 26.46	0.00 6.38	38.50 33.44
4	2.70～ 2.83	13.36 13.80	26.46 26.46	6.38 10.99	33.44 29.27
5	2.83～ 3.66	13.29 16.02	26.46 26.46	11.51 42.48	28.24 0.00
6	3.66～ 3.83	16.02 16.57	26.46 26.46	42.48 48.63	0.00 -5.61

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.06 m (GL -3.66 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.10	4.11 13.51	0.00 20.58	—— ——	4.11 34.09
2	2.10～ 2.20	15.00 15.50	20.58 21.56	—— ——	35.58 37.06
3	2.20～ 2.60	15.50 17.49	21.56 21.56	—— ——	37.06 39.05
4	2.60～ 2.83	17.49 18.63	21.56 21.56	0.00 6.78	39.05 33.41
5	2.83～ 3.83	17.99 22.79	21.56 21.56	7.14 38.20	32.41 6.15
6	3.83～ 4.83	20.52 24.84	21.56 21.56	44.68 81.01	-2.60 -34.61

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.23 m (GL -3.83 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	56700 cm^4(original condition)
	I	=	39917 cm^4(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	6
4	2.83	6
5	3.83	12
6	4.83	18
7	5.83	21
8	6.83	21
9	7.83	22
10	8.83	24

	Depth (m)	N-value
11	9.83	24
12	10.83	19
13	11.83	21
14	12.83	16
15	13.83	20
16	14.83	50

5-2 Normal Condition

K_h = 21518 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.509 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.96 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.66 m) to 1.96 m depth (GL -5.63 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.66	0.17	11.0	12.0	1.91
2	3.83	1.00	12.0	18.0	15.00
3	4.83	0.80	18.0	20.4	15.30
	L = Σh = 1.96			ΣA = 32.21	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{32.21}{1.96}$$

$$= 16.41$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 16.41^{0.406} = 21518$ kN/m^3
Kh (normal condition) = 21518 kNm^3

5-3 Seismic Condition

K_h = 21914 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.512 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.95 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.83 m) and 1.95 m depth (GL -5.78 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.83	1.00	12.0	18.0	15.00
2	4.83	0.95	18.0	20.9	18.53
	L = Σh = 1.95			ΣA = 33.53	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{33.53}{1.95}$$

$$= 17.16$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 17.16^{0.406} = 21914$ kN/m^3
Kh (seismic condition) = 21914 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	3.71 30.67	3.90 32.20	2.96 2.26	11.55 72.92
2	2.10~ 2.60	0.50	31.89 38.50	7.97 9.62	1.40 1.23	11.14 11.85
3	2.60~ 2.70	0.10	38.50 33.44	1.92 1.67	1.03 1.00	1.98 1.67
4	2.70~ 2.83	0.13	33.44 29.27	2.17 1.90	0.92 0.88	2.00 1.67
5	2.83~ 3.66	0.83	28.24 0.00	11.78 0.00	0.56 0.28	6.55 0.00
				ΣP = 73.15		ΣM = 121.33

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.9 kN/m
depth to acting position	H_t	=	-0.90 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.06 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 40.62$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{161.96}{82.05} = 1.97 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	4.11 34.09	4.32 35.79	3.13 2.43	13.51 86.98
2	2.10~ 2.20	0.10	35.58 37.06	1.78 1.85	1.70 1.66	3.02 3.08
3	2.20~ 2.60	0.40	37.06 39.05	7.41 7.81	1.50 1.36	11.09 10.65
4	2.60~ 2.83	0.23	39.05 33.41	4.49 3.84	1.15 1.08	5.18 4.14
5	2.83~ 3.83	1.00	32.41 6.15	16.20 3.08	0.67 0.33	10.80 1.03
				ΣP = 86.58		ΣM = 149.48

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	19.7 kN/m
depth to acting position	H_t	=	-0.75 m
moment	M_m	=	14.2 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.23 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 104.43$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.50 1.36	0.00 0.19
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.19

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{254.09}{106.41} = 2.39 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴ (original condition)
	I	=	39917 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{-8}$		=	7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	21518 kN/m³
calculated value	β	=	0.50949 m⁻¹
resultant earth force (lateral)	P_0	=	82.05 kN/m
height of acting position of load	h_0	=	1.97 m
moment	M_0	=	161.96 kN·m/m

in consideration of ψ_m = 1.145,

maximum moment	M_{max}	=	185.41 kN·m/m
depth of generated position of M_{max}	l_m	=	0.629 m
depth of 1st fixed point	l_i	=	2.171 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	21914 kN/m³
calculated value	β	=	0.51182 m⁻¹
resultant earth force (lateral)	P_0	=	106.41 kN/m
height of acting position of load	h_0	=	2.39 m
moment	M_0	=	254.09 kN·m/m

in consideration of ψ_m = 1.106,

maximum moment	M_{max}	=	281.06 kN·m/m
depth of generated position of M_{max}	l_m	=	0.552 m
depth of 1st fixed point	l_i	=	2.087 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm³ (original condition)
	Z	=	2376 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{185.41\times10^6}{2376\times10^3} = 78 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{281.06\times10^6}{2376\times10^3} = 118 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

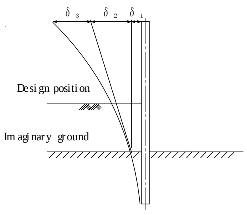
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	2.96 2.26	0.809 0.618	0.239 0.152	3.90 32.20	0.931 4.882
2	2.10~ 2.60	1.40 1.23	0.381 0.336	0.063 0.050	7.97 9.62	0.506 0.482
3	2.60~ 2.70	1.03 1.00	0.281 0.272	0.036 0.034	1.92 1.67	0.069 0.056
4	2.70~ 2.83	0.92 0.88	0.251 0.240	0.029 0.026	2.17 1.90	0.063 0.050
5	2.83~ 3.66	0.56 0.28	0.152 0.076	0.011 0.003	11.78 0.00	0.129 0.000
						ΣQ = 7.169

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5095\times 1.97)\times 82.05}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5095^3} = 0.00779\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times (H+L_k)$$

$$= \frac{(1+2\times 0.5095\times 1.97)\times 82.05}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5095^2}\times (2.60+1.06) = 0.02184\ m$$

$$\delta_3 = \frac{Q\times (H+L_k)^3}{EI}$$

$$= \frac{7.17\times (2.60+1.06)^3}{2.00\times 10^8\times 39917\times 10^{-8}} = 0.00442\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00250 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.66 m
Horizontal load: P = 8.90
Moment: M = 8.01

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00779 + 0.02184 + 0.00692
= 0.03656 m
= 36.56 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.13 2.43	0.817 0.634	0.243 0.159	4.32 35.79	1.049 5.681
2	2.10～ 2.20	1.70 1.66	0.443 0.434	0.084 0.081	1.78 1.85	0.149 0.149
3	2.20～ 2.60	1.50 1.36	0.391 0.356	0.066 0.056	7.41 7.81	0.492 0.436
4	2.60～ 2.83	1.15 1.08	0.301 0.281	0.041 0.036	4.49 3.84	0.183 0.138
5	2.83～ 3.83	0.67 0.33	0.174 0.087	0.014 0.004	16.20 3.08	0.231 0.011
						ΣQ = 8.520

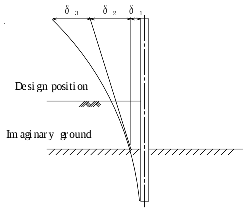
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta\times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.50 1.36	0.391 0.356	0.066 0.056	0.00 0.14	0.000 0.008
						ΣQ_{dw} = 0.008

Therefore, modulus of deformation Q is calculated as below:
Q = 8.520 + 0.008 = 8.527

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5118\times 2.39)\times 106.41}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5118^3} = 0.01105\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times (H+L_k)$$

$$= \frac{(1+2\times 0.5118\times 2.39)\times 106.41}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5118^2}\times (2.60+1.23) = 0.03356\ m$$

$$\delta_3 = \frac{Q\times (H+L_k)^3}{EI}$$

$$= \frac{8.53\times (2.60+1.23)^3}{2.00\times 10^8\times 39917\times 10^{-8}} = 0.00600\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00598 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.83 m
Horizontal load: P = 19.70
Moment: M = 14.78

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times (2L-h) \qquad (L=3.83\ m、h=L-H_m、H_m=0.80\ m、ただしh\leqq L)$$

$$= \frac{14.20\times 3.03}{2\times 2.00\times 10^8\times 39917\times 10^{-8}}\times (2\times 3.83-3.03) = 0.00125\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01105 + 0.03356 + 0.01323
= 0.05783 m
= 57.83 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10^{-8}		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction — K_h = 21518 kN/m^3
Calculated value — β = 0.46669 m^{-1}

Penetration length of SSP — $D = 1.06 + \frac{3}{0.467} = 7.49$ m
Whole length of SSP — L = 2.60 − 0.40 + 7.49 = 9.69 m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction — K_h = 21914 kN/m^3
Calculated value — β = 0.46883 m^{-1}

Penetration length of SSP — $D = 1.23 + \frac{3}{0.469} = 7.63$ m
Whole length of SSP — L = 2.60 − 0.40 + 7.63 = 9.83 m

Therefore, whole length of SSP is set as 10.00 m in consideration of round unit of SSP length.

8 Calculation Result

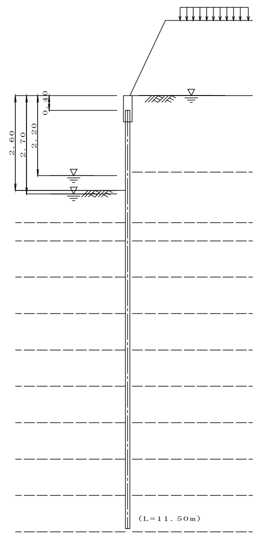
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		185.41	281.06
Stress intensity	σ (N/mm^2)		78 (180)	118 (270)
Lateral displacement	δ (mm)		36.56 (50.0)	57.83 (75.0)
Penetration depth	D (m)		7.49	7.63
Whole length of SSP	L (m)	10.00		

－Steel Sheet Pile　Design Calculation－

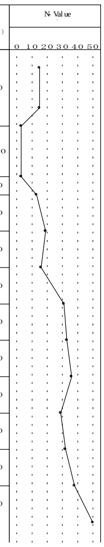
Left Bank No. 17_STA 14+250-14+272

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
3.49	Clayey Soil	16.0	0.0	18.0
3.99	Sandy Soil	18.0	29.0	0.0
4.99	Sandy Soil	18.0	32.0	0.0
5.99	Sandy Soil	18.0	30.0	0.0
6.99	Sandy Soil	18.0	37.0	0.0
7.99	Sandy Soil	18.0	37.0	0.0
8.99	Sandy Soil	18.0	38.0	0.0
9.99	Sandy Soil	18.0	36.0	0.0
10.99	Sandy Soil	18.0	37.0	0.0
11.99	Sandy Soil	18.0	39.0	0.0
	Sandy Soil	20.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　γ_w = 9.8 kN/m^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	8.9 kN/m	(Normal Condition)
		P_t'	=	-19.7 kN/m	(Seismic Condition)
	Depth of acting point	H	=	-0.90 m	(Normal Condition)
		H'	=	-0.75 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	14.2 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　ζ_0 = 10 degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N'^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N- Value	No	Depth (m)	N- Value
1	0.50	15	11	9.99	29
2	1.60	15	12	10.99	32
3	2.10	3	13	11.99	38
4	3.49	3	14	13.00	50
5	3.99	13			
6	4.99	19			
7	5.99	16			
8	6.99	31			
9	7.99	33			
10	8.99	36			

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.49	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
3	3.99	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
4	4.99	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
5	5.99	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
6	6.99	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
7	7.99	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
8	8.99	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
9	9.99	S	29.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
10	10.99	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
11	11.99	S	38.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
12	13.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

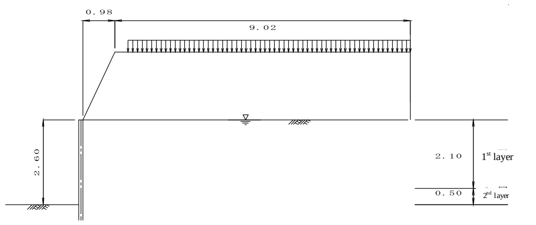
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1.123

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.98	10.00	10.00	2.07	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	1.38	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 114000 cm⁴
Sectional factor Z_0 = 3250 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.84
Corrosion rate (to Z_0) η = 0.87
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

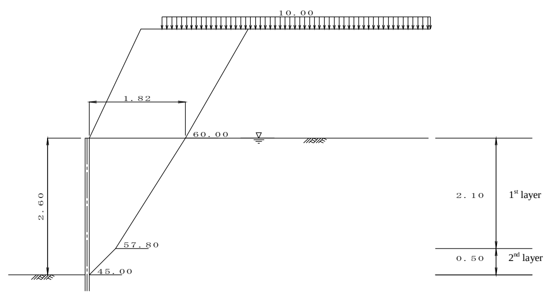
Allowable stress σ_a = 185 Nmm (Normal)
σ_a' = 278 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	18.0	25.00	48.44	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	48.44	20.58	57.80
3		Embankment	30.0	——	0.0	37.26	10.00	0.00	60.00

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	2.07	1.82	2.60	3.02	4.67

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.00	71.91
Σ			71.91

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.64	16.38
Σ			16.38

Q surcharge load
l : width of surcharge load set by line of active rupture

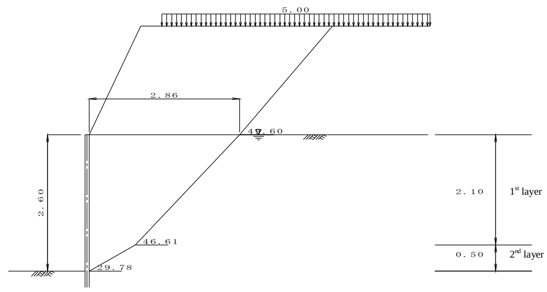
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{71.91 + 16.38 + 0.00}{1.82}$$

$$= 48.44 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	18.0	25.00	48.02	25.48	0.200	11.31	29.78
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	48.02	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	37.26	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	29.78	0.50	0.00	0.00	0.87	0.50
2	46.61	2.10	0.87	0.50	2.86	2.60
3	49.60	2.07	2.86	2.60	4.62	4.67

Therefore, width of acting load shall be set as 2.86 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	6.73	121.08
Σ			121.08

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.24	16.20
Σ			16.20

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

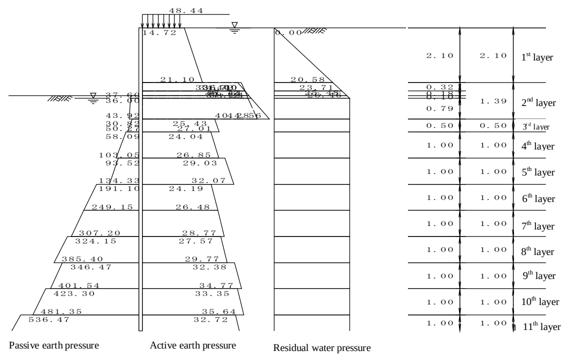
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{121.08 + 16.20 + 0.00}{2.86}$$

$$= 48.02 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	48.445 69.445	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.42	Clayey soil	8.0	—	18.0 18.0	69.445 72.000	—— ——	—— ——
3	2.42~ 2.60	Clayey soil	8.0	—	18.0 18.0	72.000 73.445	—— ——	—— ——
4	2.60~ 2.70	Clayey soil	8.0	—	18.0 18.0	73.445 74.245	—— ——	—— ——
5	2.70~ 3.49	Clayey soil	8.0	—	18.0 18.0	74.245 80.565	—— ——	—— ——
6	3.49~ 3.99	Sandy soil	10.0	29.0	—— ——	80.565 85.565	0.32058 0.32058	0.31571 0.31571
7	3.99~ 4.99	Sandy soil	10.0	32.0	—— ——	85.565 95.565	0.28525 0.28525	0.28092 0.28092
8	4.99~ 5.99	Sandy soil	10.0	30.0	—— ——	95.565 105.565	0.30847 0.30847	0.30378 0.30378
9	5.99~ 6.99	Sandy soil	10.0	37.0	—— ——	105.565 115.565	0.23264 0.23264	0.22910 0.22910
10	6.99~ 7.99	Sandy soil	10.0	37.0	—— ——	115.565 125.565	0.23264 0.23264	0.22910 0.22910
11	7.99~ 8.99	Sandy soil	10.0	38.0	—— ——	125.565 135.565	0.22298 0.22298	0.21959 0.21959
12	8.99~ 9.99	Sandy soil	10.0	36.0	—— ——	135.565 145.565	0.24257 0.24257	0.23889 0.23889
13	9.99~ 10.99	Sandy soil	10.0	37.0	—— ——	145.565 155.565	0.23264 0.23264	0.22910 0.22910

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	10.99~ 11.99	Sandy soil	10.0	39.0	—— ——	155.565 165.565	0.21359 0.21359	0.21035 0.21035
15	11.99~ 13.00	Sandy soil	10.0	45.0	—— ——	165.565 175.665	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60~ 2.70	Clayey soil	16.0	0.0	18.0 18.0	0.000 1.600	—— ——	—— ——
5	2.70~ 3.49	Clayey soil	8.0	0.0	18.0 18.0	1.600 7.920	—— ——	—— ——
6	3.49~ 3.99	Sandy soil	10.0	29.0	—— ——	7.920 12.920	3.95096 3.95096	3.89093 3.89093
7	3.99~ 4.99	Sandy soil	10.0	32.0	—— ——	12.920 22.920	4.56530 4.56530	4.49594 4.49594
8	4.99~ 5.99	Sandy soil	10.0	30.0	—— ——	22.920 32.920	4.14330 4.14330	4.08035 4.08035
9	5.99~ 6.99	Sandy soil	10.0	37.0	—— ——	32.920 42.920	5.89457 5.89457	5.80501 5.80501
10	6.99~ 7.99	Sandy soil	10.0	37.0	—— ——	42.920 52.920	5.89457 5.89457	5.80501 5.80501
11	7.99~ 8.99	Sandy soil	10.0	38.0	—— ——	52.920 62.920	6.21981 6.21981	6.12532 6.12532
12	8.99~ 9.99	Sandy soil	10.0	36.0	—— ——	62.920 72.920	5.59154 5.59154	5.50659 5.50659
13	9.99~ 10.99	Sandy soil	10.0	37.0	—— ——	72.920 82.920	5.89457 5.89457	5.80501 5.80501
14	10.99~ 11.99	Sandy soil	10.0	39.0	—— ——	82.920 92.920	6.56948 6.56948	6.46967 6.46967
15	11.99~ 13.00	Sandy soil	10.0	45.0	—— ——	92.920 103.020	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

1.125

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 2.10	14.72 21.10	—— ——	14.72 21.10	0.00 20.58	—— ——
2	2.10~ 2.42	33.44 36.00	34.72 36.00	34.72 36.00	20.58 23.71	—— ——
3	2.42~ 2.60	36.00 37.44	36.00 36.72	36.00 37.44	23.71 25.48	—— ——
4	2.60~ 2.70	37.44 38.24	36.72 37.12	37.44 38.24	25.48 26.46	36.00 37.60
5	2.70~ 3.49	38.24 44.56	37.12 40.28	38.24 44.56	26.46 26.46	37.60 43.92
6	3.49~ 3.99	25.43 27.01	—— ——	25.43 27.01	26.46 26.46	30.82 50.27
7	3.99~ 4.99	24.04 26.85	—— ——	24.04 26.85	26.46 26.46	58.09 103.05
8	4.99~ 5.99	29.03 32.07	—— ——	29.03 32.07	26.46 26.46	93.52 134.33
9	5.99~ 6.99	24.19 26.48	—— ——	24.19 26.48	26.46 26.46	191.10 249.15
10	6.99~ 7.99	26.48 28.77	—— ——	26.48 28.77	26.46 26.46	249.15 307.20
11	7.99~ 8.99	27.57 29.77	—— ——	27.57 29.77	26.46 26.46	324.15 385.40
12	8.99~ 9.99	32.38 34.77	—— ——	32.38 34.77	26.46 26.46	346.47 401.54
13	9.99~ 10.99	33.35 35.64	—— ——	33.35 35.64	26.46 26.46	423.30 481.35
14	10.99~ 11.99	32.72 34.83	—— ——	32.72 34.83	26.46 26.46	536.47 601.16
15	11.99~ 13.00	26.52 28.13	—— ——	26.52 28.13	26.46 26.46	855.19 948.15

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

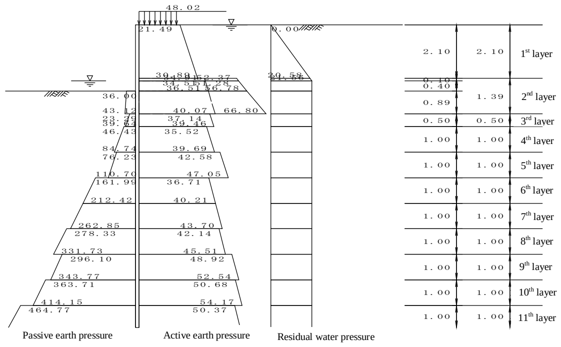
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	48.02 69.02	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Clayey Soil	8.0	—	18.0 18.0	69.02 69.82	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	30.60 30.44
3	2.20~ 2.60	Clayey Soil	8.0	—	18.0 18.0	69.82 73.02	21.56 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	30.44 29.78
4	2.60~ 3.49	Clayey Soil	8.0	—	18.0 18.0	73.02 80.14	25.48 34.20	0.200 0.200	11.31 11.31	—— ——	—— ——	29.78 28.22
5	3.49~ 3.99	Sandy Soil	10.0	29.0	—— ——	80.14 85.14	34.20 39.10	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
6	3.99~ 4.99	Sandy Soil	10.0	32.0	—— ——	85.14 95.14	39.10 48.90	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
7	4.99~ 5.99	Sandy Soil	10.0	30.0	—— ——	95.14 105.14	48.90 58.70	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
8	5.99~ 6.99	Sandy Soil	10.0	37.0	—— ——	105.14 115.14	58.70 68.50	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
9	6.99~ 7.99	Sandy Soil	10.0	37.0	—— ——	115.14 125.14	68.50 78.30	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
10	7.99~ 8.99	Sandy Soil	10.0	38.0	—— ——	125.14 135.14	78.30 88.10	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
11	8.99~ 9.99	Sandy Soil	10.0	36.0	—— ——	135.14 145.14	88.10 97.90	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—— ——
12	9.99~ 10.99	Sandy Soil	10.0	37.0	—— ——	145.14 155.14	97.90 107.70	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
13	10.99~ 11.99	Sandy Soil	10.0	39.0	—— ——	155.14 165.14	107.70 117.50	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
14	11.99~ 13.00	Sandy Soil	10.0	45.0	—— ——	165.14 175.24	117.50 127.40	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below:

$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below:

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 3.49	Clayey soil	8.00	0.0	18.0 18.0	0.000 7.120	0.00 8.72	0.200 0.200	11.31 11.31	—— ——	—— ——
5	3.49~ 3.99	Sandy soil	10.00	29.0	—— ——	7.120 12.120	8.72 13.62	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
6	3.99~ 4.99	Sandy soil	10.00	32.0	—— ——	12.120 22.120	13.62 23.42	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
7	4.99~ 5.99	Sandy soil	10.00	30.0	—— ——	22.120 32.120	23.42 33.22	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
8	5.99~ 6.99	Sandy soil	10.00	37.0	—— ——	32.120 42.120	33.22 43.02	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
9	6.99~ 7.99	Sandy soil	10.00	37.0	—— ——	42.120 52.120	43.02 52.82	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
10	7.99~ 8.99	Sandy soil	10.00	38.0	—— ——	52.120 62.120	52.82 62.62	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
11	8.99~ 9.99	Sandy soil	10.00	36.0	—— ——	62.120 72.120	62.62 72.42	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
12	9.99~ 10.99	Sandy soil	10.00	37.0	—— ——	72.120 82.120	72.42 82.22	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
13	10.99~ 11.99	Sandy soil	10.00	39.0	—— ——	82.120 92.120	82.22 92.02	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
14	11.99~ 13.00	Sandy soil	10.00	45.0	—— ——	92.120 102.220	92.02 101.92	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below:

$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	21.49 30.89	—— ——	21.49 30.89	0.00 20.58	—— ——
2	2.10~ 2.20	51.28 52.37	34.51 34.91	51.28 52.37	20.58 21.56	—— ——
3	2.20~ 2.60	52.37 56.78	34.91 36.51	52.37 56.78	21.56 21.56	—— ——
4	2.60~ 3.49	56.78 66.80	36.51 40.07	56.78 66.80	21.56 21.56	36.00 43.12
5	3.49~ 3.99	37.14 39.46	—— ——	37.14 39.46	21.56 21.56	23.29 39.64
6	3.99~ 4.99	35.52 39.69	—— ——	35.52 39.69	21.56 21.56	46.43 84.74
7	4.99~ 5.99	42.58 47.05	—— ——	42.58 47.05	21.56 21.56	76.23 110.70
8	5.99~ 6.99	36.71 40.21	—— ——	36.71 40.21	21.56 21.56	161.99 212.42
9	6.99~ 7.99	40.21 43.70	—— ——	40.21 43.70	21.56 21.56	212.42 262.85
10	7.99~ 8.99	42.14 45.51	—— ——	42.14 45.51	21.56 21.56	278.33 331.73
11	8.99~ 9.99	48.92 52.54	—— ——	48.92 52.54	21.56 21.56	296.10 343.77
12	9.99~ 10.99	50.68 54.17	—— ——	50.68 54.17	21.56 21.56	363.71 414.15
13	10.99~ 11.99	50.37 53.61	—— ——	50.37 53.61	21.56 21.56	464.77 521.37
14	11.99~ 13.00	42.73 45.34	—— ——	42.73 45.34	21.56 21.56	755.70 838.56

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = \left[K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}\right]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = \left[K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}\right]\cdot\cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

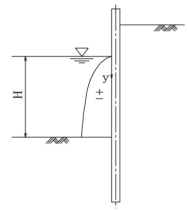
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

y : depth from water surface to the point where active water pressure is calculated



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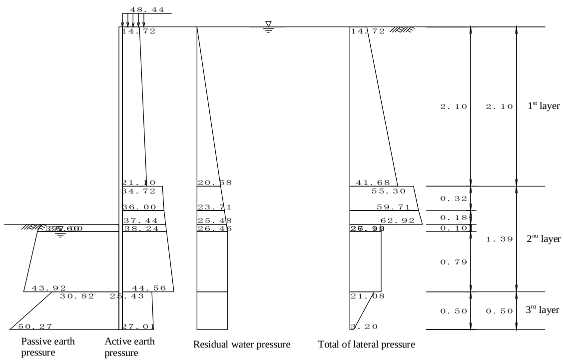
4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

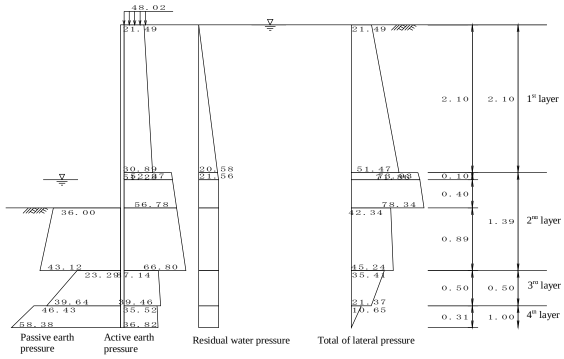


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.10	14.72 21.10	0.00 20.58	—— ——	14.72 41.68
2	2.10~ 2.42	34.72 36.00	20.58 23.71	—— ——	55.30 59.71
3	2.42~ 2.60	36.00 37.44	23.71 25.48	—— ——	59.71 62.92
4	2.60~ 2.70	37.44 38.24	25.48 26.46	36.00 37.60	26.92 27.10
5	2.70~ 3.49	38.24 44.56	26.46 26.46	37.60 43.92	27.10 27.10
6	3.49~ 3.99	25.43 27.01	26.46 26.46	30.82 50.27	21.08 3.20
7	3.99~ 4.99	24.04 26.85	26.46 26.46	58.09 103.05	-7.59 -49.74

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.39 m (GL -3.99 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.10	21.49 30.89	0.00 20.58	—— ——	21.49 51.47
2	2.10~ 2.20	51.28 52.37	20.58 21.56	—— ——	71.86 73.93
3	2.20~ 2.60	52.37 56.78	21.56 21.56	—— ——	73.93 78.34
4	2.60~ 3.49	56.78 66.80	21.56 21.56	36.00 43.12	42.34 45.24
5	3.49~ 3.99	37.14 39.46	21.56 21.56	23.29 39.64	35.41 21.37
6	3.99~ 4.30	35.52 36.82	21.56 21.56	46.43 58.38	10.65 0.00
7	4.30~ 4.99	36.82 39.69	21.56 21.56	58.38 84.74	0.00 -23.49

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.70 m (GL -4.30 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_o	=	114000 cm^4 (original condition)
	I	=	95760 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 95760 \times 10^{-8} = 1.915 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	3
4	3.49	3
5	3.99	13
6	4.99	19
7	5.99	16
8	6.99	31
9	7.99	33
10	8.99	36

	Depth (m)	N-value
11	9.99	29
12	10.99	32
13	11.99	38
14	13.00	50

5-2 Normal Condition

K_h = 21928 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.411 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.43 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.99 m) to 2.43 m depth (GL -6.42 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.99	1.00	13.0	19.0	16.00
2	4.99	1.00	19.0	16.0	17.50
3	5.99	0.43	16.0	22.5	8.29
	L = Σh = 2.43			ΣA = 41.79	

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{41.79}{2.43} = 17.19$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$K_h = 6910 \times N'^{0.406} = 6910 \times 17.19^{0.406} = 21928$ kN/m³

Kh (normal condition) = 21928 kNm^3

5-3 Seismic Condition

K_h = 22602 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.414 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.41 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.30 m) and 2.41 m depth (GL -6.71 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.30	0.69	14.9	19.0	11.65
2	4.99	1.00	19.0	16.0	17.50
3	5.99	0.72	16.0	26.9	15.54
	L = Σh = 2.41			ΣA = 44.69	

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{44.69}{2.41} = 18.52$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$K_h = 6910 \times N'^{0.406} = 6910 \times 18.52^{0.406} = 22602$ kN/m³

Kh (seismic condition) = 22602 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	14.72 41.68	15.45 43.76	3.29 2.59	50.84 113.34
2	2.10~ 2.42	0.32	55.30 59.71	8.83 9.54	1.78 1.68	15.75 15.99
3	2.42~ 2.60	0.18	59.71 62.92	5.39 5.68	1.51 1.45	8.14 8.24
4	2.60~ 2.70	0.10	26.92 27.10	1.35 1.36	1.36 1.32	1.83 1.79
5	2.70~ 3.49	0.79	27.10 27.10	10.71 10.71	1.03 0.76	10.99 8.17
6	3.49~ 3.99	0.50	21.08 3.20	5.27 0.80	0.33 0.17	1.76 0.13
				ΣP = 118.84		ΣM = 236.98

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.9 kNm
depth to acting position	H_t	=	-0.90 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.39 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 43.52$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{280.50}{127.74} = 2.20 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	21.49 51.47	22.56 54.04	3.60 2.90	81.27 156.82
2	2.10~ 2.20	0.10	71.86 73.93	3.59 3.70	2.17 2.14	7.79 7.89
3	2.20~ 2.60	0.40	73.93 78.34	14.79 15.67	1.97 1.84	29.11 28.76
4	2.60~ 3.49	0.89	42.34 45.24	18.84 20.13	1.41 1.11	26.48 22.32
5	3.49~ 3.99	0.50	35.41 21.37	8.85 5.34	0.65 0.48	5.71 2.56
6	3.99~ 4.30	0.31	10.65 0.00	1.66 0.00	0.21 0.10	0.35 0.00
				ΣP = 169.18		ΣM = 369.07

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	19.7 kNm
depth to acting position	H	=	-0.75 m
moment	M_m	=	14.2 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.70 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 113.72$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.97 1.84	0.00 0.25
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.25

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{483.04}{189.02} = 2.56 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 95760 × 10⁻⁸		=	1.915 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	21928	kNm³
calculated value	β	=	0.41132	m⁻¹
resultant earth force (lateral)	P_0	=	127.74	kNm
height of acting position of load	h_0	=	2.20	m
moment	M_0	=	280.50	kN·m/m

in consideration of ψ_m = 1.171,

maximum moment	M_{max}	=	328.52	kN·m/m
depth of generated position of M_{max}	l_m	=	0.832	m
depth of 1st fixed point	l_i	=	2.742	m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	22602	kNm³
calculated value	β	=	0.41445	m⁻¹
resultant earth force (lateral)	P_0	=	189.02	kNm
height of acting position of load	h_0	=	2.56	m
moment	M_0	=	483.04	kN·m/m

in consideration of ψ_m = 1.133,

maximum moment	M_{max}	=	547.52	kN·m/m
depth of generated position of M_{max}	l_m	=	0.749	m
depth of 1st fixed point	l_i	=	2.644	m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm³ (original condition)
	Z	=	2828 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{328.52\times10^6}{2828\times10^3} = 116 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{547.52\times10^6}{2828\times10^3} = 194 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

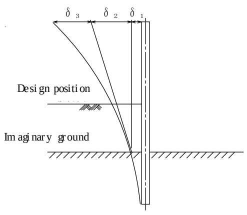
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.29 2.59	0.825 0.649	0.247 0.165	15.45 43.76	3.809 7.224
2	2.10~ 2.42	1.78 1.68	0.447 0.420	0.085 0.076	8.83 9.54	0.751 0.724
3	2.42~ 2.60	1.51 1.45	0.379 0.363	0.063 0.058	5.39 5.68	0.338 0.330
4	2.60~ 2.70	1.36 1.32	0.340 0.332	0.051 0.049	1.35 1.36	0.069 0.066
5	2.70~ 3.49	1.03 0.76	0.257 0.191	0.030 0.017	10.71 10.71	0.324 0.183
6	3.49~ 3.99	0.33 0.17	0.084 0.042	0.003 0.001	5.27 0.80	0.018 0.001
						ΣQ = 13.838

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4113\times 2.20)\times 127.74}{2\times 2.00\times 10^8\times 95760\times 10^{-8}\times 0.4113^3} = 0.00912 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4113\times 2.20)\times 127.74}{2\times 2.00\times 10^8\times 95760\times 10^{-8}\times 0.4113^2}\times(2.60+1.39) = 0.02207 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.84\times(2.60+1.39)^3}{2.00\times 10^8\times 95760\times 10^{-8}} = 0.00459 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00132 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.99 m
Horizontal load: P = 8.90
Moment: M = 8.01

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00912 + 0.02207 + 0.00591
= 0.03710 m
= 37.10 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.60 2.90	0.837 0.675	0.253 0.176	22.56 54.04	5.702 9.531
2	2.10～ 2.20	2.17 2.14	0.504 0.496	0.106 0.103	3.59 3.70	0.380 0.380
3	2.20～ 2.60	1.97 1.84	0.458 0.427	0.089 0.078	14.79 15.67	1.312 1.223
4	2.60～ 3.49	1.41 1.11	0.327 0.258	0.048 0.030	18.84 20.13	0.896 0.611
5	3.49～ 3.99	0.65 0.48	0.150 0.111	0.011 0.006	8.85 5.34	0.095 0.032
6	3.99～ 4.30	0.21 0.10	0.048 0.024	0.001 0.000	1.66 0.00	0.002 0.000
						ΣQ = 20.163

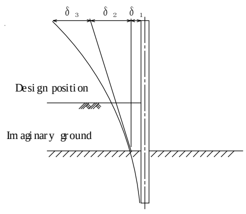
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.97 1.84	0.458 0.427	0.089 0.078	0.00 0.14	0.000 0.011
						ΣQ_{dw} = 0.011

Therefore, modulus of deformation Q is calculated as below.
Q = 20.163 + 0.011 = 20.174

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4145\times 2.56)\times 189.02}{2\times 2.00\times 10^8\times 95760\times 10^{-8}\times 0.4145^3} = 0.01427 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4145\times 2.56)\times 189.02}{2\times 2.00\times 10^8\times 95760\times 10^{-8}\times 0.4145^2}\times(2.60+1.70) = 0.03854 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{20.17\times(2.60+1.70)^3}{2.00\times 10^8\times 95760\times 10^{-8}} = 0.00839 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00344 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.30 m
Horizontal load: P = 19.70
Moment: M = 14.78

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \quad (L=4.30\text{ m、}h=L-H_m\text{、}H_m=0.80\text{ m、ただし})$$

$$= \frac{14.20\times 3.50}{2\times 2.00\times 10^8\times 95760\times 10^{-8}}\times(2\times 4.30-3.50) = 0.00066 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01427 + 0.03854 + 0.01249
= 0.06531 m
= 65.31 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm ^{2}
Inertia sectional moment	I_0	=	114000 cm ^{4} (original condition)
	I	=	114000 cm ^{4} (after reduction by corrosion and section)
EI = 200000 × 10^3 × 114000 × 10^{-8}		=	2.280 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 21928 kN/m³
Calculated value β = 0.39378 m⁻¹

Penetration length of SSP $D = 1.39 + \frac{3}{0.394} = 9.01$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.01 = 11.21$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 22602 kN/m³
Calculated value β = 0.39677 m⁻¹

Penetration length of SSP $D = 1.70 + \frac{3}{0.397} = 9.26$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.26 = 11.46$ m

Therefore, whole length of SSP is set as 11.50 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		328.52	547.52
Stress intensity	σ (N/mm^2)		116 (185)	194 (278)
Lateral displacement	δ (mm)		37.10 (50.0)	65.31 (75.0)
Penetration depth	D (m)		9.01	9.26
Whole length of SSP	L (m)	11.50		

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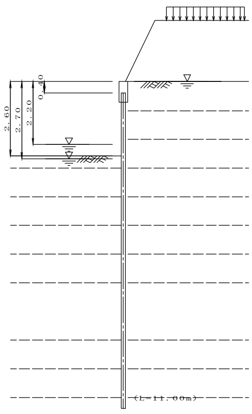
－Steel Sheet Pile Design Calculation－

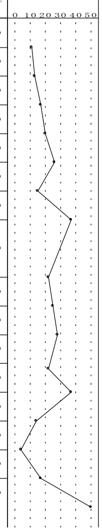
Left Bank No. 18_STA 15+236 - 15+311

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)	N-Value
1.02	Sandy Soil	18.0	28.0	0.0	
2.02	Sandy Soil	18.0	29.0	0.0	
3.02	Sandy Soil	18.0	31.0	0.0	
4.02	Sandy Soil	18.0	32.0	0.0	
5.02	Sandy Soil	18.0	35.0	0.0	
6.02	Sandy Soil	18.0	30.0	0.0	
7.02	Sandy Soil	18.0	39.0	0.0	
9.02	Sandy Soil	18.0	33.0	0.0	
10.02	Sandy Soil	18.0	34.0	0.0	
11.02	Sandy Soil	18.0	35.0	0.0	
12.02	Sandy Soil	18.0	33.0	0.0	
13.02	Sandy Soil	18.0	39.0	0.0	
14.02	Sandy Soil	18.0	29.0	0.0	
15.02	Sandy Soil	18.0	27.0	0.0	
16.02	Sandy Soil	18.0	31.0	0.0	
	Sandy Soil	18.0	45.0	0.0	



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　Chang's formula

Penetration depths　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　$\gamma_w = 9.8$ kNm^3

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	9.3 kNm (Normal Condition)
		P_t'	=	20.2 kNm (Seismic Condition)
	Depth of acting point	H	=	-0.93 m (Normal Condition)
		H'	=	-0.75 m (Seismic Condition)
	Moment	M_m	=	1.8 kN-m/m (Normal Condition)
		M_m'	=	17.1 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00m (Seismic Condition)
		H_m	=	0.80m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　ζ_0 = 10 degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　K_ζ = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N'^{0.406}$

Average N-value　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	1.02	11	11	12.20	22
2	2.02	13	12	13.02	37
3	3.02	17	13	14.02	14
4	4.02	20	14	15.02	4
5	5.02	26	15	16.02	17
6	6.02	15	16	17.02	50
7	7.02	37			
8	9.02	22			
9	10.02	25			
10	11.02	28			

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

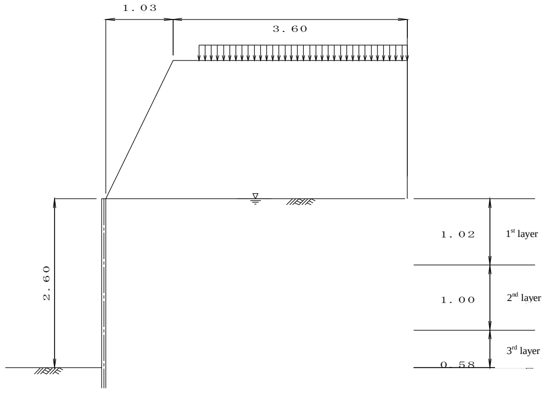
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	1.02	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
2	2.02	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
3	3.02	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
4	4.02	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
5	5.02	S	26.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
6	6.02	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
7	7.02	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
8	9.02	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
9	10.02	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
10	11.02	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
11	12.02	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
12	13.02	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
13	14.02	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
14	15.02	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
15	16.02	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
16	17.02	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	1.03	4.63	4.63	2.13	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	1.43	4.63	10.0	5.0

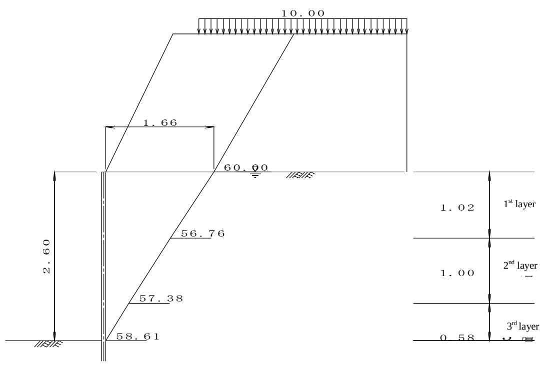
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4
Sectional factor	Z_0	=	3820 cm^3
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 N/mm^2 (Normal)
	σ_a'	=	270 N/mm^2 (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not Reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	Σγh (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	Angle of rupture Z (degree)
1	2.60~ 2.02	Sandy Soil	31.0	9.0	0.0	26.00	49.44	25.48	58.61
2	2.02~ 1.02	Sandy Soil	29.0	9.0	0.0	20.20	49.44	19.80	57.38
3	1.02~ 0.00	Sandy Soil	28.0	9.0	0.0	10.20	49.44	10.00	56.76
4		Embankment	30.0	——	0.0	38.34	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where.
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m^2)
- C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	58.61	0.58	0.00	0.00	0.35	0.58
2	57.38	1.00	0.35	0.58	0.99	1.58
3	56.76	1.02	0.99	1.58	1.66	2.60
4	60.00	2.13	1.66	2.60	2.89	4.73

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	3.75	67.56
Σ			67.56

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	10.0	1.46	14.62
Σ			14.62

Q surcharge load
l : width of surcharge load set by line of active rupture

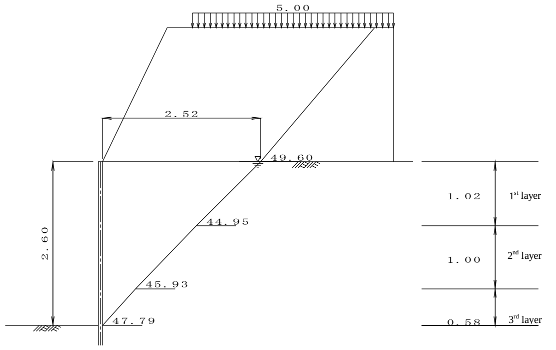
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{67.56 + 14.62 + 0.00}{1.66}$$

$$= 49.44\ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.02	Sandy Soil	31.0	9.0	0.0	26.00	50.06	25.48	0.200	11.31	47.79
2	2.02~ 1.02	Sandy Soil	29.0	9.0	0.0	20.20	50.06	19.80	0.200	11.31	45.93
3	1.02~ 0.00	Sandy Soil	28.0	9.0	0.0	10.20	50.06	10.00	0.200	11.31	44.95
4		Embankment	30.0	——	0.0	38.34	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

Where.
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under W.L)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	47.79	0.58	0.00	0.00	0.53	0.58
2	45.93	1.00	0.53	0.58	1.49	1.58
3	44.95	1.02	1.49	1.58	2.52	2.60
4	49.60	2.13	2.52	2.60	4.33	4.73

Therefore, width of acting load shall be set as 2.52 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	6.19	111.46
Σ			111.46

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.90	14.49
Σ			14.49

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

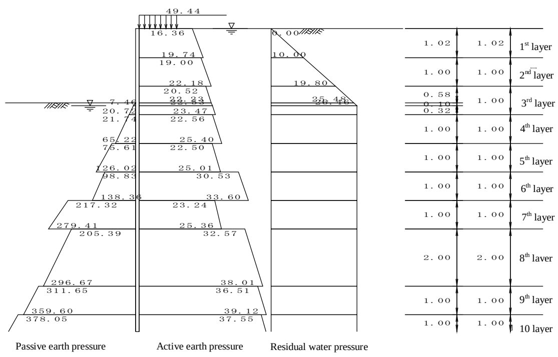
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{111.46 + 14.49 + 0.00}{2.52}$$

$$= 50.06 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 1.02	Sandy soil	10.0	28.0	—— ——	49.439 59.639	0.33506 0.33506	0.33093 0.33093
2	1.02~ 2.02	Sandy soil	10.0	29.0	—— ——	59.639 69.639	0.32248 0.32248	0.31851 0.31851
3	2.02~ 2.60	Sandy soil	10.0	31.0	—— ——	69.639 75.439	0.29838 0.29838	0.29471 0.29471
4	2.60~ 2.70	Sandy soil	10.0	31.0	—— ——	75.439 76.439	0.29838 0.29838	0.29471 0.29471
5	2.70~ 3.02	Sandy soil	10.0	31.0	—— ——	76.439 79.639	0.29838 0.29838	0.29471 0.29471
6	3.02~ 4.02	Sandy soil	10.0	32.0	—— ——	79.639 89.639	0.28683 0.28683	0.28330 0.28330
7	4.02~ 5.02	Sandy soil	10.0	35.0	—— ——	89.639 99.639	0.25410 0.25410	0.25097 0.25097
8	5.02~ 6.02	Sandy soil	10.0	30.0	—— ——	99.639 109.639	0.31026 0.31026	0.30644 0.30644
9	6.02~ 7.02	Sandy soil	10.0	39.0	—— ——	109.639 119.639	0.21458 0.21458	0.21193 0.21193
10	7.02~ 9.02	Sandy soil	10.0	33.0	—— ——	119.639 139.639	0.27561 0.27561	0.27222 0.27222
11	9.02~ 10.02	Sandy soil	10.0	34.0	—— ——	139.639 149.639	0.26470 0.26470	0.26144 0.26144
12	10.02~ 11.02	Sandy soil	10.0	35.0	—— ——	149.639 159.639	0.25410 0.25410	0.25097 0.25097
13	11.02~ 12.02	Sandy soil	10.0	33.0	—— ——	159.639 169.639	0.27561 0.27561	0.27222 0.27222

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	12.02~ 13.02	Sandy soil	10.0	39.0	—— ——	169.639 179.639	0.21458 0.21458	0.21193 0.21193
15	13.02~ 14.02	Sandy soil	10.0	29.0	—— ——	179.639 189.639	0.32248 0.32248	0.31851 0.31851
16	14.02~ 15.02	Sandy soil	10.0	27.0	—— ——	189.639 199.639	0.34800 0.34800	0.34371 0.34371
17	15.02~ 16.02	Sandy soil	10.0	31.0	—— ——	199.639 209.639	0.29838 0.29838	0.29471 0.29471
18	16.02~ 17.02	Sandy soil	10.0	45.0	—— ——	209.639 219.639	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 9.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60~ 2.70	Sandy soil	18.0	31.0	—— ——	0.000 1.800	4.19615 4.19615	4.14448 4.14448
5	2.70~ 3.02	Sandy soil	10.0	31.0	—— ——	1.800 5.000	4.19615 4.19615	4.14448 4.14448
6	3.02~ 4.02	Sandy soil	10.0	32.0	—— ——	5.000 15.000	4.40199 4.40199	4.34780 4.34780
7	4.02~ 5.02	Sandy soil	10.0	35.0	—— ——	15.000 25.000	5.10344 5.10344	5.04061 5.04061
8	5.02~ 6.02	Sandy soil	10.0	30.0	—— ——	25.000 35.000	4.00247 4.00247	3.95319 3.95319
9	6.02~ 7.02	Sandy soil	10.0	39.0	—— ——	35.000 45.000	6.28642 6.28642	6.20903 6.20903
10	7.02~ 9.02	Sandy soil	10.0	33.0	—— ——	45.000 65.000	4.62104 4.62104	4.56415 4.56415
11	9.02~ 10.02	Sandy soil	10.0	34.0	—— ——	65.000 75.000	4.85443 4.85443	4.79467 4.79467
12	10.02~ 11.02	Sandy soil	10.0	35.0	—— ——	75.000 85.000	5.10344 5.10344	5.04061 5.04061
13	11.02~ 12.02	Sandy soil	10.0	33.0	—— ——	85.000 95.000	4.62104 4.62104	4.56415 4.56415
14	12.02~ 13.02	Sandy soil	10.0	39.0	—— ——	95.000 105.000	6.28642 6.28642	6.20903 6.20903
15	13.02~ 14.02	Sandy soil	10.0	29.0	—— ——	105.000 115.000	3.82002 3.82002	3.77299 3.77299

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
16	14.02~ 15.02	Sandy soil	10.0	27.0	— —	115.000 125.000	3.48553 3.48553	3.44261 3.44261
17	15.02~ 16.02	Sandy soil	10.0	31.0	— —	125.000 135.000	4.19615 4.19615	4.14448 4.14448
18	16.02~ 17.02	Sandy soil	10.0	45.0	— —	135.000 145.000	8.86593 8.86593	8.75678 8.75678

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -9.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 1.02	16.36 19.74	— —	16.36 19.74	0.00 10.00	— —
2	1.02~ 2.02	19.00 22.18	— —	19.00 22.18	10.00 19.80	— —
3	2.02~ 2.60	20.52 22.23	— —	20.52 22.23	19.80 25.48	— —
4	2.60~ 2.70	22.23 22.53	— —	22.23 22.53	25.48 26.46	0.00 7.46
5	2.70~ 3.02	22.53 23.47	— —	22.53 23.47	26.46 26.46	7.46 20.72
6	3.02~ 4.02	22.56 25.40	— —	22.56 25.40	26.46 26.46	21.74 65.22
7	4.02~ 5.02	22.50 25.01	— —	22.50 25.01	26.46 26.46	75.61 126.02
8	5.02~ 6.02	30.53 33.60	— —	30.53 33.60	26.46 26.46	98.83 138.36
9	6.02~ 7.02	23.24 25.36	— —	23.24 25.36	26.46 26.46	217.32 279.41
10	7.02~ 9.02	32.57 38.01	— —	32.57 38.01	26.46 26.46	205.39 296.67
11	9.02~ 10.02	36.51 39.12	— —	36.51 39.12	26.46 26.46	311.65 359.60
12	10.02~ 11.02	37.55 40.06	— —	37.55 40.06	26.46 26.46	378.05 428.45
13	11.02~ 12.02	43.46 46.18	— —	43.46 46.18	26.46 26.46	387.95 433.59
14	12.02~ 13.02	35.95 38.07	— —	35.95 38.07	26.46 26.46	589.86 651.95
15	13.02~ 14.02	57.22 60.40	— —	57.22 60.40	26.46 26.46	396.16 433.89
16	14.02~ 15.02	65.18 68.62	— —	65.18 68.62	26.46 26.46	395.90 430.33
17	15.02~ 16.02	58.84 61.78	— —	58.84 61.78	26.46 26.46	518.06 559.51
18	16.02~ 17.02	33.80 35.41	— —	33.80 35.41	26.46 26.46	1182.16 1269.73

- Formula for active earth pressure

Sandy soil $P_a = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c: Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_a = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

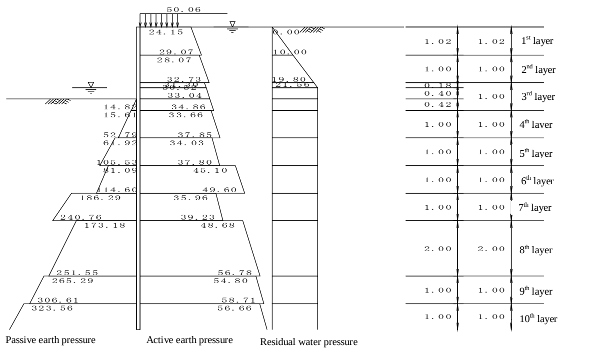
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 1.02	Sandy Soil	10.0	28.0	— —	50.06 60.26	0.00 10.00	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	— —
2	1.02~ 2.02	Sandy Soil	10.0	29.0	— —	60.26 70.26	10.00 19.80	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	— —
3	2.02~ 2.20	Sandy Soil	10.0	31.0	— —	70.26 72.06	19.80 21.56	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	— —
4	2.20~ 2.60	Sandy Soil	10.0	31.0	— —	72.06 76.06	21.56 25.48	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	— —
5	2.60~ 3.02	Sandy Soil	10.0	31.0	— —	76.06 80.26	25.48 29.60	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	— —
6	3.02~ 4.02	Sandy Soil	10.0	32.0	— —	80.26 90.26	29.60 39.40	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	— —

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	4.02~ 5.02	Sandy Soil	10.0	35.0	— —	90.26 100.26	39.40 49.20	0.200 0.200	11.31 11.31	0.38174 0.38174	0.37704 0.37704	— —
8	5.02~ 6.02	Sandy Soil	10.0	30.0	— —	100.26 110.26	49.20 59.00	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	— —
9	6.02~ 7.02	Sandy Soil	10.0	39.0	— —	110.26 120.26	59.00 68.80	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	— —
10	7.02~ 9.02	Sandy Soil	10.0	33.0	— —	120.26 140.26	68.80 88.40	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	— —
11	9.02~ 10.02	Sandy Soil	10.0	34.0	— —	140.26 150.26	88.40 98.20	0.200 0.200	11.31 11.31	0.39559 0.39559	0.39072 0.39072	— —
12	10.02~ 11.02	Sandy Soil	10.0	35.0	— —	150.26 160.26	98.20 108.00	0.200 0.200	11.31 11.31	0.38174 0.38174	0.37704 0.37704	— —
13	11.02~ 12.02	Sandy Soil	10.0	33.0	— —	160.26 170.26	108.00 117.80	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	— —
14	12.02~ 13.02	Sandy Soil	10.0	39.0	— —	170.26 180.26	117.80 127.60	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	— —
15	13.02~ 14.02	Sandy Soil	10.0	29.0	— —	180.26 190.26	127.60 137.40	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	— —
16	14.02~ 15.02	Sandy Soil	10.0	27.0	— —	190.26 200.26	137.40 147.20	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	— —
17	15.02~ 16.02	Sandy Soil	10.0	31.0	— —	200.26 210.26	147.20 157.00	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	— —
18	16.02~ 17.02	Sandy Soil	10.0	45.0	— —	210.26 220.26	157.00 166.80	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60~ 3.02	Sandy soil	10.00	31.0	— —	0.000 4.200	0.00 4.12	0.200 0.200	11.31 11.31	3.57258 3.57258	3.52859 3.52859
6	3.02~ 4.02	Sandy soil	10.00	32.0	— —	4.200 14.200	4.12 13.92	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
7	4.02~ 5.02	Sandy soil	10.00	35.0	— —	14.200 24.200	13.92 23.72	0.200 0.200	11.31 11.31	4.41499 4.41499	4.36064 4.36064
8	5.02~ 6.02	Sandy soil	10.00	30.0	— —	24.200 34.200	23.72 33.52	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
9	6.02~ 7.02	Sandy soil	10.00	39.0	— —	34.200 44.200	33.52 43.32	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
10	7.02~ 9.02	Sandy soil	10.00	33.0	— —	44.200 64.200	43.32 62.92	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819
11	9.02~ 10.02	Sandy soil	10.00	34.0	— —	64.200 74.200	62.92 72.72	0.200 0.200	11.31 11.31	4.18373 4.18373	4.13222 4.13222
12	10.02~ 11.02	Sandy soil	10.00	35.0	— —	74.200 84.200	72.72 82.52	0.200 0.200	11.31 11.31	4.41499 4.41499	4.36064 4.36064
13	11.02~ 12.02	Sandy soil	10.00	33.0	— —	84.200 94.200	82.52 92.32	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819
14	12.02~ 13.02	Sandy soil	10.00	39.0	— —	94.200 104.200	92.32 102.12	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
15	13.02~ 14.02	Sandy soil	10.00	29.0	— —	104.200 114.200	102.12 111.92	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
16	14.02~ 15.02	Sandy soil	10.00	27.0	— —	114.200 124.200	111.92 121.72	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
17	15.02~ 16.02	Sandy soil	10.00	31.0	— —	124.200 134.200	121.72 131.52	0.200 0.200	11.31 11.31	3.57258 3.57258	3.52859 3.52859
18	16.02~ 17.02	Sandy soil	10.00	45.0	— —	134.200 144.200	131.52 141.32	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 1.02	24.15 29.07	— —	24.15 29.07	0.00 10.00	— —
2	1.02~ 2.02	28.07 32.73	— —	28.07 32.73	10.00 19.80	— —
3	2.02~ 2.20	30.52 31.30	— —	30.52 31.30	19.80 21.56	— —
4	2.20~ 2.60	31.30 33.04	— —	31.30 33.04	21.56 21.56	— —
5	2.60~ 3.02	33.04 34.86	— —	33.04 34.86	21.56 21.56	0.00 14.82
6	3.02~ 4.02	33.66 37.85	— —	33.66 37.85	21.56 21.56	15.61 52.79
7	4.02~ 5.02	34.03 37.80	— —	34.03 37.80	21.56 21.56	61.92 105.53
8	5.02~ 6.02	45.10 49.60	— —	45.10 49.60	21.56 21.56	81.09 114.60
9	6.02~ 7.02	35.96 39.23	— —	35.96 39.23	21.56 21.56	186.29 240.76
10	7.02~ 9.02	48.68 56.78	— —	48.68 56.78	21.56 21.56	173.18 251.55

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
11	9.02~ 10.02	54.80 58.71	—— ——	54.80 58.71	21.56 21.56	265.29 306.61
12	10.02~ 11.02	56.66 60.43	—— ——	56.66 60.43	21.56 21.56	323.56 367.17
13	11.02~ 12.02	64.88 68.92	—— ——	64.88 68.92	21.56 21.56	329.91 369.09
14	12.02~ 13.02	55.53 58.79	—— ——	55.53 58.79	21.56 21.56	513.12 567.59
15	13.02~ 14.02	83.97 88.63	—— ——	83.97 88.63	21.56 21.56	331.73 363.56
16	14.02~ 15.02	95.04 100.03	—— ——	95.04 100.03	21.56 21.56	328.47 357.23
17	15.02~ 16.02	86.98 91.33	—— ——	86.98 91.33	21.56 21.56	438.25 473.54
18	16.02~ 17.02	54.63 57.22	—— ——	54.63 57.22	21.56 21.56	1050.14 1128.39

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

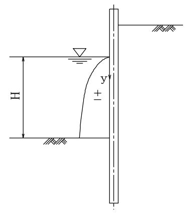
Where,

k_{hs} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

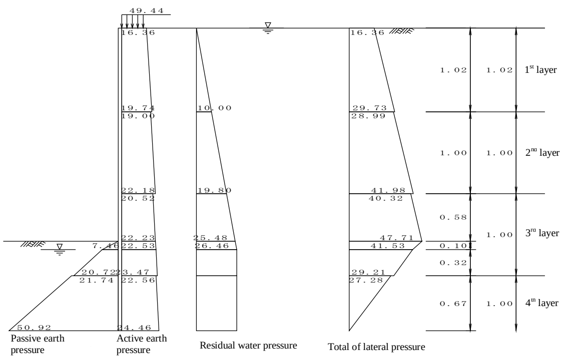
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 1.02	16.36 19.74	0.00 10.00	—— ——	16.36 29.73
2	1.02~ 2.02	19.00 22.18	10.00 19.80	—— ——	28.99 41.98
3	2.02~ 2.60	20.52 22.23	19.80 25.48	—— ——	40.32 47.71
4	2.60~ 2.70	22.23 22.53	25.48 26.46	0.00 7.46	47.71 41.53
5	2.70~ 3.02	22.53 23.47	26.46 26.46	7.46 20.72	41.53 29.21
6	3.02~ 3.69	22.56 24.46	26.46 26.46	21.74 50.92	27.28 0.00
7	3.69~ 4.02	24.46 25.40	26.46 26.46	50.92 65.22	0.00 -13.36

P_a : Active earth pressure

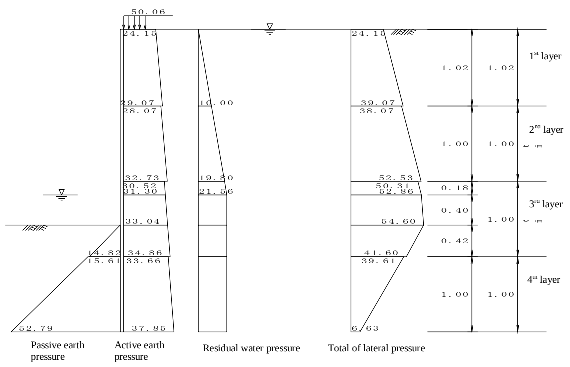
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.09 m (GL -3.69 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 1.02	24.15 29.07	0.00 10.00	—— ——	24.15 39.07
2	1.02~ 2.02	28.07 32.73	10.00 19.80	—— ——	38.07 52.53
3	2.02~ 2.20	30.52 31.30	19.80 21.56	—— ——	50.31 52.86
4	2.20~ 2.60	31.30 33.04	21.56 21.56	—— ——	52.86 54.60
5	2.60~ 3.02	33.04 34.86	21.56 21.56	0.00 14.82	54.60 41.60
6	3.02~ 4.02	33.66 37.85	21.56 21.56	15.61 52.79	39.61 6.63
7	4.02~ 5.02	34.03 37.80	21.56 21.56	61.92 105.53	-6.33 -46.16

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.42 m (GL -4.02 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} = 1.266 x 10^5

	Depth (m)	N-value		Depth (m)	N-value
1	1.02	11	11	12.20	22
2	2.02	13	12	13.02	37
3	3.02	17	13	14.02	14
4	4.02	20	14	15.02	4
5	5.02	26	15	16.02	17
6	6.02	15	16	17.02	50
7	7.02	37			
8	9.02	22			
9	10.02	25			
10	11.02	28			

5-2 Normal Condition

K_h = 24199 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.468 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.14 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.69 m) to 2.14 m depth (GL -5.83 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.69	0.33	19.0	20.0	6.41
2	4.02	1.00	20.0	26.0	23.00
3	5.02	0.81	26.0	17.1	17.45
	L = Σh = 2.14				ΣA = 46.87

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{46.87}{2.14} = 21.91$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 21.91^{0.406} = 24199 \text{ kN/m}^3$$

Kh (normal condition) = 24199 kN/m^3

5-3 Seismic Condition

K_h = 23969 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.466 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.14 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.02 m) to 2.14 m depth (GL -6.16 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.02	1.00	20.0	26.0	23.00
2	5.02	1.00	26.0	15.0	20.50
3	6.02	0.14	15.0	18.2	2.39
	L = Σh = 2.14				ΣA = 45.89

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{45.89}{2.14} = 21.40$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 21.40^{0.406} = 23969 \text{ kN/m}^3$$

Kh (seismic condition) = 23969 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.02	1.02	16.36 29.73	8.34 15.16	3.35 3.01	27.96 45.66
2	1.02~ 2.02	1.00	28.99 41.98	14.50 20.99	2.34 2.00	33.89 42.07
3	2.02~ 2.60	0.58	40.32 47.71	11.69 13.84	1.48 1.28	17.28 17.77
4	2.60~ 2.70	0.10	47.71 41.53	2.39 2.08	1.06 1.02	2.52 2.13
5	2.70~ 3.02	0.32	41.53 29.21	6.64 4.67	0.88 0.78	5.88 3.64
6	3.02~ 3.69	0.67	27.28 0.00	9.16 0.00	0.45 0.22	4.10 0.00
				ΣP = 109.46		ΣM = 202.91

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.3 kN/m
depth to acting position	H_t	=	-0.93 m
moment	M_m	=	1.8 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.09 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 44.78 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{247.68}{118.76} = 2.09 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.02	1.02	24.15 39.07	12.32 19.92	3.68 3.34	45.32 66.54
2	1.02~ 2.02	1.00	38.07 52.53	19.03 26.26	2.67 2.33	50.76 61.28

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
3	2.02~ 2.20	0.18	50.31 52.86	4.53 4.76	1.94 1.88	8.78 8.94
4	2.20~ 2.60	0.40	52.86 54.60	10.57 10.92	1.69 1.55	17.83 16.96
5	2.60~ 3.02	0.42	54.60 41.60	11.47 8.74	1.28 1.14	14.68 9.96
6	3.02~ 4.02	1.00	39.61 6.63	19.80 3.31	0.67 0.33	13.20 1.10
				ΣP = 151.63		ΣM = 315.37

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	20.2 kN/m
depth to acting position	H_t	=	-0.75 m
moment	M_m	=	17.1 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.42 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 113.45 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.69 1.55	0.00 0.21
				ΣPdw = 0.14		ΣMdw = 0.21

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{429.03}{171.97} = 2.49 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266x 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	24199 kNm^3
calculated value	β	=	0.46755 m^{-1}
resultant earth force (lateral)	P_h	=	118.76 kNm
height of acting position of load	h_h	=	2.09 m
moment	M_0	=	247.68 kN-m/m
in consideration of ϕ_m = 1.152,			
maximum moment	M_{max}	=	285.33 kN-m/m
depth of generated position of M_{max}	l_m	=	0.699 m
depth of 1st fixed point	l_i	=	2.379 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	23969 kNm^3
calculated value	β	=	0.46644 m^{-1}
resultant earth force (lateral)	P_h	=	171.97 kNm
height of acting position of load	h_h	=	2.49 m
moment	M_0	=	429.03 kN-m/m
in consideration of ϕ_m = 1.115,			
maximum moment	M_{max}	=	478.31 kN-m/m
depth of generated position of M_{max}	l_m	=	0.626 m
depth of 1st fixed point	l_i	=	2.310 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{285.33\times10^6}{3514\times10^3} = 81\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{478.31\times10^6}{3514\times10^3} = 136\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 1.02	3.35 3.01	0.908 0.816	0.287 0.242	8.34 15.16	2.398 3.674
2	1.02~ 2.02	2.34 2.00	0.633 0.543	0.158 0.121	14.50 20.99	2.294 2.535
3	2.02~ 2.60	1.48 1.28	0.400 0.348	0.069 0.054	11.69 13.84	0.812 0.741
4	2.60~ 2.70	1.06 1.02	0.287 0.278	0.037 0.035	2.39 2.08	0.089 0.073
5	2.70~ 3.02	0.88 0.78	0.240 0.211	0.026 0.021	6.64 4.67	0.176 0.096
6	3.02~ 3.69	0.45 0.22	0.121 0.061	0.007 0.002	9.16 0.00	0.065 0.000
						ΣQ = 12.951

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

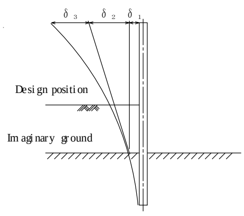
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4676\times2.09)\times118.76}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4676^3} = 0.00906\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4676\times2.09)\times118.76}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4676^2}\times(2.60+1.09) = 0.02337\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.95\times(2.60+1.09)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00515\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00170 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.69 m
Horizontal load: P = 9.30
Moment: M = 8.65

δ = δ_1 + δ_2 + δ_3
= 0.00906 + 0.02337 + 0.00694
= 0.03937 m
= 39.37 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 1.02	3.68 3.34	0.915 0.831	0.291 0.250	12.32 19.92	3.586 4.972
2	1.02~ 2.02	2.67 2.33	0.663 0.580	0.171 0.136	19.03 26.26	3.262 3.568
3	2.02~ 2.20	1.94 1.88	0.483 0.468	0.098 0.092	4.53 4.76	0.442 0.439
4	2.20~ 2.60	1.69 1.55	0.420 0.386	0.076 0.065	10.57 10.92	0.800 0.710
5	2.60~ 3.02	1.28 1.14	0.318 0.284	0.045 0.036	11.47 8.74	0.520 0.318
6	3.02~ 4.02	0.67 0.33	0.166 0.083	0.013 0.003	19.80 3.31	0.257 0.011
						ΣQ = 18.886

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

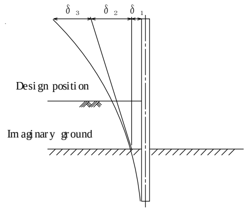
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	1.69 1.55	0.420 0.386	0.076 0.065	0.00 0.14	0.000 0.009
						ΣQ_{dw} = 0.009

Therefore, modulus of deformation Q is calculated as below:
Q = 18.886 + 0.009 = 18.895

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4664\times 2.49)\times 171.97}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4664^3} = 0.01448 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4664\times 2.49)\times 171.97}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4664^2}\times(2.60+1.42) = 0.04176 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{18.89\times(2.60+1.42)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00970 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00442 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.02 m
Horizontal load: P = 20.20
Moment: M = 15.15

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.02 \text{ m}、h=L-H_m、H_m=0.80 \text{ m}、 \qquad h\leqq L)$$

$$= \frac{17.10\times 3.22}{2\times 2.00\times 10^8\times 63296\times 10^{-8}}\times(2\times 4.02-3.22) = 0.00105 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01448 + 0.04176 + 0.01517
= 0.07141 m
= 71.41 $\leqq$ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below.

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720x 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	K_h = 24199 kN/m^3
Calculated value	β = 0.43306 m^{-1}
Penetration length of SSP	$D = 1.09 + \frac{3}{0.433} = 8.02$ m
Whole length of SSP	L = 2.60 − 0.40 + 8.02 = 10.22 m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	K_h = 23969 kN/m^3
Calculated value	β = 0.43203 m^{-1}
Penetration length of SSP	$D = 1.42 + \frac{3}{0.432} = 8.36$ m
Whole length of SSP	L = 2.60 − 0.40 + 8.36 = 10.56 m

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

8 Calculation Result

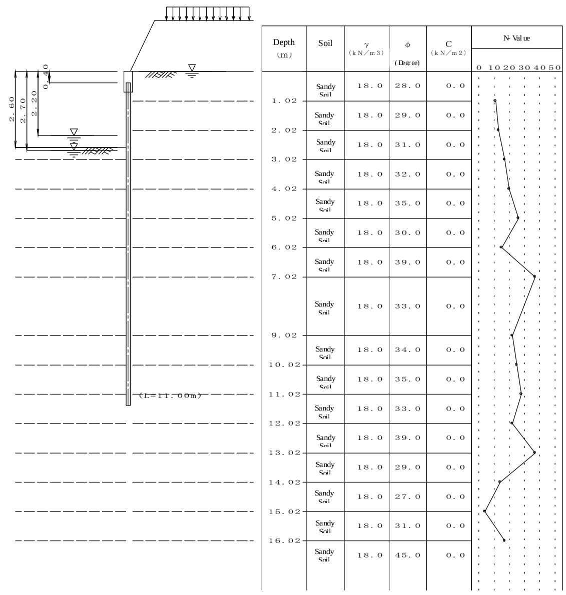
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		285.33	478.31
Stress intensity	σ (N/mm^2)		81 (180)	136 (270)
Lateral displacement	δ (mm)		39.37 (50.0)	71.41 (75.0)
Penetration depth	D (m)		8.02	8.36
Whole length of SSP	L (m)	11.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 19_STA 15+311 - 15+424

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_b	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	6.7 kNm (Normal Condition)
		P_t'	=	15.7 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.77 m (Normal Condition)
		H_t'	=	-0.60 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	8.4 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00m (Seismic Condition)
		H_m	=	0.80m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910\times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	1.02	11
2	2.02	13
3	3.02	17
4	4.02	20
5	5.02	26
6	6.02	15
7	7.02	37
8	9.02	22
9	10.02	25
10	11.02	28

No	Depth (m)	N-Value
11	12.02	22
12	13.02	37
13	14.02	14
14	15.02	4
15	16.02	17
16	17.02	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

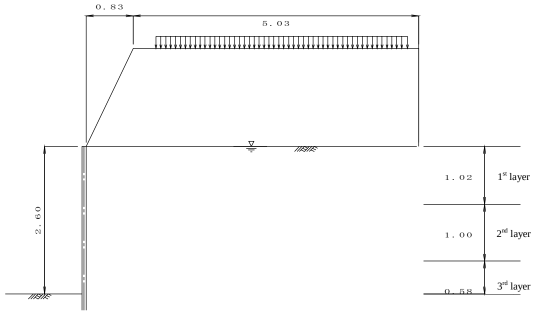
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	1.02	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
2	2.02	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
3	3.02	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
4	4.02	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
5	5.02	S	26.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
6	6.02	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
7	7.02	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
8	9.02	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
9	10.02	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
10	11.02	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
11	12.02	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
12	13.02	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
13	14.02	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
14	15.02	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
15	16.02	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
16	17.02	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate 1 (m)	2 (m)	3 (m)	4 (m)	Embankment height h (m)	Wet unit weight γ (kN/m³)	Internal friction angle ϕ (degree)	Cohesive force C (kN/m²)	Angle of rupture Normal	Seismic
1	Sandy soil	0.00	0.83	5.86	5.86	1.73	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

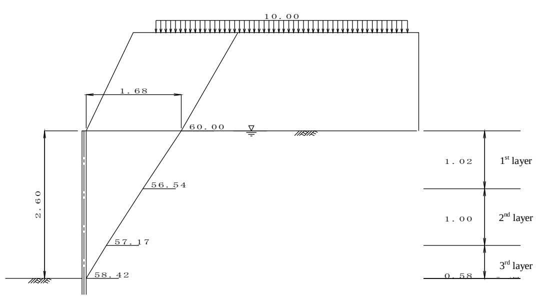
No	Acting period from (m)	to (m)	Load Normal (kN/m²)	Seismic (kN/m²)
1	1.23	5.66	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴
Sectional factor	Z_0	=	3820 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 N/mm² (Normal)
	σ_a'	=	270 N/mm² (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.02	Sandy Soil	31.0	10.0	0.0	26.00	41.33	25.48	58.42
2	2.02~ 1.02	Sandy Soil	29.0	10.0	0.0	20.20	41.33	19.80	57.17
3	1.02~ 0.00	Sandy Soil	28.0	10.0	0.0	10.20	41.33	10.00	56.54
4		Embankment	30.0	——	0.0	31.14	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  θ=tan⁻¹k or θ=tan⁻¹k'
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Y (m)	Coordinate of upper end X (m)	Y (m)
1	58.42	0.58	0.00	0.00	0.36	0.58
2	57.17	1.00	0.36	0.58	1.00	1.58
3	56.54	1.02	1.00	1.58	1.68	2.60
4	60.00	1.73	1.68	2.60	2.67	4.33

Therefore, width of acting load shall be set as 1.68 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.05	54.81
Σ			54.81

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.44	14.45
Σ			14.45

Q surcharge load
l : width of surcharge load set by line of active rupture

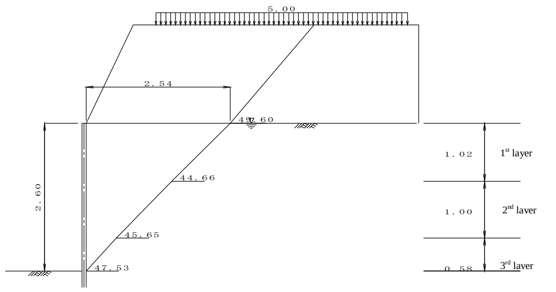
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{54.81 + 14.45 + 0.00}{1.68}$$

$$= 41.33\ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.02	Sandy Soil	31.0	10.0	0.0	26.00	40.55	25.48	0.200	11.31	47.53
2	2.02~ 1.02	Sandy Soil	29.0	10.0	0.0	20.20	40.55	19.80	0.200	11.31	45.65
3	1.02~ 0.00	Sandy Soil	28.0	10.0	0.0	10.20	40.55	10.00	0.200	11.31	44.66
4		Embankment	30.0	——	0.0	31.14	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.
- ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	47.53	0.58	0.00	0.00	0.53	0.58
2	45.65	1.00	0.53	0.58	1.51	1.58
3	44.66	1.02	1.51	1.58	2.54	2.60
4	49.60	1.73	2.54	2.60	4.01	4.33

Therefore, width of acting load shall be set as 2.54 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.95	89.12
Σ			89.12

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.78	13.91
Σ			13.91

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

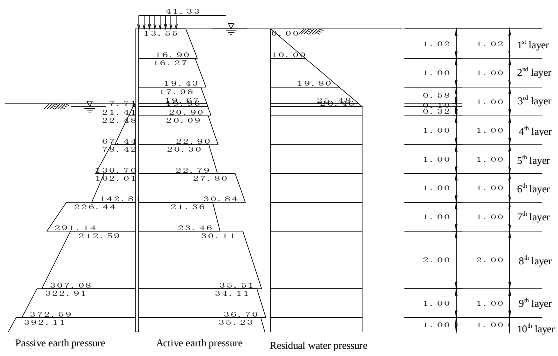
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{89.12 + 13.91 + 0.00}{2.54}$$

$= 40.55$ kN/m²

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 1.02	Sandy soil	10.0	28.0	—— ——	41.329 51.529	0.33303 0.33303	0.32798 0.32798
2	1.02~ 2.02	Sandy soil	10.0	29.0	—— ——	51.529 61.529	0.32058 0.32058	0.31571 0.31571
3	2.02~ 2.60	Sandy soil	10.0	31.0	—— ——	61.529 67.329	0.29669 0.29669	0.29219 0.29219
4	2.60~ 2.70	Sandy soil	10.0	31.0	—— ——	67.329 68.329	0.29669 0.29669	0.29219 0.29219
5	2.70~ 3.02	Sandy soil	10.0	31.0	—— ——	68.329 71.529	0.29669 0.29669	0.29219 0.29219
6	3.02~ 4.02	Sandy soil	10.0	32.0	—— ——	71.529 81.529	0.28525 0.28525	0.28092 0.28092
7	4.02~ 5.02	Sandy soil	10.0	35.0	—— ——	81.529 91.529	0.25279 0.25279	0.24895 0.24895
8	5.02~ 6.02	Sandy soil	10.0	30.0	—— ——	91.529 101.529	0.30847 0.30847	0.30378 0.30378
9	6.02~ 7.02	Sandy soil	10.0	39.0	—— ——	101.529 111.529	0.21359 0.21359	0.21035 0.21035
10	7.02~ 9.02	Sandy soil	10.0	33.0	—— ——	111.529 131.529	0.27412 0.27412	0.26996 0.26996
11	9.02~ 10.02	Sandy soil	10.0	34.0	—— ——	131.529 141.529	0.26331 0.26331	0.25931 0.25931
12	10.02~ 11.02	Sandy soil	10.0	35.0	—— ——	141.529 151.529	0.25279 0.25279	0.24895 0.24895
13	11.02~ 12.02	Sandy soil	10.0	33.0	—— ——	151.529 161.529	0.27412 0.27412	0.26996 0.26996

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	12.02~ 13.02	Sandy soil	10.0	39.0	—— ——	161.529 171.529	0.21359 0.21359	0.21035 0.21035
15	13.02~ 14.02	Sandy soil	10.0	29.0	—— ——	171.529 181.529	0.32058 0.32058	0.31571 0.31571
16	14.02~ 15.02	Sandy soil	10.0	27.0	—— ——	181.529 191.529	0.34585 0.34585	0.34060 0.34060
17	15.02~ 16.02	Sandy soil	10.0	31.0	—— ——	191.529 201.529	0.29669 0.29669	0.29219 0.29219
18	16.02~ 17.02	Sandy soil	10.0	45.0	—— ——	201.529 211.529	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 10.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60~ 2.70	Sandy soil	18.0	31.0	—— ——	0.000 1.800	4.34774 4.34774	4.28169 4.28169
5	2.70~ 3.02	Sandy soil	10.0	31.0	—— ——	1.800 5.000	4.34774 4.34774	4.28169 4.28169
6	3.02~ 4.02	Sandy soil	10.0	32.0	—— ——	5.000 15.000	4.56530 4.56530	4.49594 4.49594
7	4.02~ 5.02	Sandy soil	10.0	35.0	—— ——	15.000 25.000	5.30876 5.30876	5.22810 5.22810
8	5.02~ 6.02	Sandy soil	10.0	30.0	—— ——	25.000 35.000	4.14330 4.14330	4.08035 4.08035
9	6.02~ 7.02	Sandy soil	10.0	39.0	—— ——	35.000 45.000	6.56948 6.56948	6.46967 6.46967
10	7.02~ 9.02	Sandy soil	10.0	33.0	—— ——	45.000 65.000	4.79713 4.79713	4.72425 4.72425
11	9.02~ 10.02	Sandy soil	10.0	34.0	—— ——	65.000 75.000	5.04448 5.04448	4.96784 4.96784
12	10.02~ 11.02	Sandy soil	10.0	35.0	—— ——	75.000 85.000	5.30876 5.30876	5.22810 5.22810
13	11.02~ 12.02	Sandy soil	10.0	33.0	—— ——	85.000 95.000	4.79713 4.79713	4.72425 4.72425
14	12.02~ 13.02	Sandy soil	10.0	39.0	—— ——	95.000 105.000	6.56948 6.56948	6.46967 6.46967

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
15	13.02~ 14.02	Sandy soil	10.0	29.0	—— ——	105.000 115.000	3.95096 3.95096	3.89093 3.89093
16	14.02~ 15.02	Sandy soil	10.0	27.0	—— ——	115.000 125.000	3.59892 3.59892	3.54425 3.54425
17	15.02~ 16.02	Sandy soil	10.0	31.0	—— ——	125.000 135.000	4.34774 4.34774	4.28169 4.28169
18	16.02~ 17.02	Sandy soil	10.0	45.0	—— ——	135.000 145.000	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00,\ \beta = 0.00,\ \theta = 0.00$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 1.02	13.55 16.90	—— ——	13.55 16.90	0.00 10.00	—— ——
2	1.02~ 2.02	16.27 19.43	—— ——	16.27 19.43	10.00 19.80	—— ——
3	2.02~ 2.60	17.98 19.67	—— ——	17.98 19.67	19.80 25.48	—— ——
4	2.60~ 2.70	19.67 19.96	—— ——	19.67 19.96	25.48 26.46	0.00 7.71
5	2.70~ 3.02	19.96 20.90	—— ——	19.96 20.90	26.46 26.46	7.71 21.41
6	3.02~ 4.02	20.09 22.90	—— ——	20.09 22.90	26.46 26.46	22.48 67.44
7	4.02~ 5.02	20.30 22.79	—— ——	20.30 22.79	26.46 26.46	78.42 130.70
8	5.02~ 6.02	27.80 30.84	—— ——	27.80 30.84	26.46 26.46	102.01 142.81
9	6.02~ 7.02	21.36 23.46	—— ——	21.36 23.46	26.46 26.46	226.44 291.14
10	7.02~ 9.02	30.11 35.51	—— ——	30.11 35.51	26.46 26.46	212.59 307.08
11	9.02~ 10.02	34.11 36.70	—— ——	34.11 36.70	26.46 26.46	322.91 372.59
12	10.02~ 11.02	35.23 37.72	—— ——	35.23 37.72	26.46 26.46	392.11 444.39
13	11.02~ 12.02	40.91 43.61	—— ——	40.91 43.61	26.46 26.46	401.56 448.80
14	12.02~ 13.02	33.98 36.08	—— ——	33.98 36.08	26.46 26.46	614.62 679.32
15	13.02~ 14.02	54.15 57.31	—— ——	54.15 57.31	26.46 26.46	408.55 447.46
16	14.02~ 15.02	61.83 65.23	—— ——	61.83 65.23	26.46 26.46	407.59 443.03
17	15.02~ 16.02	55.96 58.88	—— ——	55.96 58.88	26.46 26.46	535.21 578.03
18	16.02~ 17.02	32.28 33.88	—— ——	32.28 33.88	26.46 26.46	1242.47 1334.51

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = \left[K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}\right] \cdot \cos\delta$

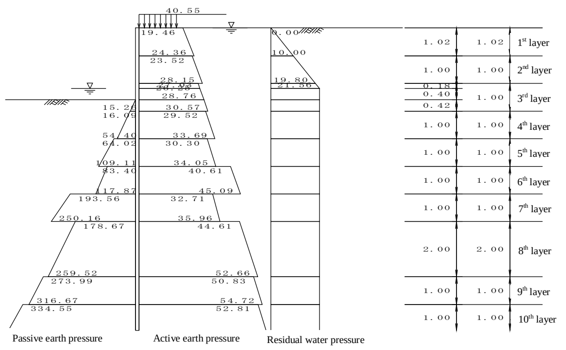
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = \left[K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}\right] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 1.02	Sandy Soil	10.0	28.0	—— ——	40.55 50.75	0.00 10.00	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
2	1.02~ 2.02	Sandy Soil	10.0	29.0	—— ——	50.75 60.75	10.00 19.80	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
3	2.02~ 2.20	Sandy Soil	10.0	31.0	—— ——	60.75 62.55	19.80 21.56	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
4	2.20~ 2.60	Sandy Soil	10.0	31.0	—— ——	62.55 66.55	21.56 25.48	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
5	2.60~ 3.02	Sandy Soil	10.0	31.0	—— ——	66.55 70.75	25.48 29.60	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
6	3.02~ 4.02	Sandy Soil	10.0	32.0	—— ——	70.75 80.75	29.60 39.40	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
7	4.02~ 5.02	Sandy Soil	10.0	35.0	—— ——	80.75 90.75	39.40 49.20	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
8	5.02~ 6.02	Sandy Soil	10.0	30.0	—— ——	90.75 100.75	49.20 59.00	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
9	6.02~ 7.02	Sandy Soil	10.0	39.0	—— ——	100.75 110.75	59.00 68.80	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
10	7.02~ 9.02	Sandy Soil	10.0	33.0	—— ——	110.75 130.75	68.80 88.40	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
11	9.02~ 10.02	Sandy Soil	10.0	34.0	—— ——	130.75 140.75	88.40 98.20	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
12	10.02~ 11.02	Sandy Soil	10.0	35.0	—— ——	140.75 150.75	98.20 108.00	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
13	11.02~ 12.02	Sandy Soil	10.0	33.0	—— ——	150.75 160.75	108.00 117.80	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
14	12.02~ 13.02	Sandy Soil	10.0	39.0	—— ——	160.75 170.75	117.80 127.60	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	13.02~ 14.02	Sandy Soil	10.0	29.0	—— ——	170.75 180.75	127.60 137.40	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
16	14.02~ 15.02	Sandy Soil	10.0	27.0	—— ——	180.75 190.75	137.40 147.20	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
17	15.02~ 16.02	Sandy Soil	10.0	31.0	—— ——	190.75 200.75	147.20 157.00	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
18	16.02~ 17.02	Sandy Soil	10.0	45.0	—— ——	200.75 210.75	157.00 166.80	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00,\ \beta = 0.00,\ \theta = \tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k)	θ (degree)	Kp	Kp × cosδ
5	2.60~ 3.02	Sandy soil	10.00	31.0	—— ——	0.000 4.200	0.00 4.12	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
6	3.02~ 4.02	Sandy soil	10.00	32.0	—— ——	4.200 14.200	4.12 13.92	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
7	4.02~ 5.02	Sandy soil	10.00	35.0	—— ——	14.200 24.200	13.92 23.72	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
8	5.02~ 6.02	Sandy soil	10.00	30.0	—— ——	24.200 34.200	23.72 33.52	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
9	6.02~ 7.02	Sandy soil	10.00	39.0	—— ——	34.200 44.200	33.52 43.32	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
10	7.02~ 9.02	Sandy soil	10.00	33.0	—— ——	44.200 64.200	43.32 62.92	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
11	9.02~ 10.02	Sandy soil	10.00	34.0	—— ——	64.200 74.200	62.92 72.72	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
12	10.02~ 11.02	Sandy soil	10.00	35.0	—— ——	74.200 84.200	72.72 82.52	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
13	11.02~ 12.02	Sandy soil	10.00	33.0	—— ——	84.200 94.200	82.52 92.32	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
14	12.02~ 13.02	Sandy soil	10.00	39.0	—— ——	94.200 104.200	92.32 102.12	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
15	13.02~ 14.02	Sandy soil	10.00	29.0	—— ——	104.200 114.200	102.12 111.92	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
16	14.02~ 15.02	Sandy soil	10.00	27.0	—— ——	114.200 124.200	111.92 121.72	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
17	15.02~ 16.02	Sandy soil	10.00	31.0	—— ——	124.200 134.200	121.72 131.52	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k)	θ (degree)	Kp	Kp ×cosδ
18	16.02~ 17.02	Sandy soil	10.00	45.0	—— ——	134.200 144.200	131.52 141.32	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 1.02	19.46 24.36	—— ——	19.46 24.36	0.00 10.00	—— ——
2	1.02~ 2.02	23.52 28.15	—— ——	23.52 28.15	10.00 19.80	—— ——
3	2.02~ 2.20	26.25 27.03	—— ——	26.25 27.03	19.80 21.56	—— ——
4	2.20~ 2.60	27.03 28.76	—— ——	27.03 28.76	21.56 21.56	—— ——
5	2.60~ 3.02	28.76 30.57	—— ——	28.76 30.57	21.56 21.56	0.00 15.26
6	3.02~ 4.02	29.52 33.69	—— ——	29.52 33.69	21.56 21.56	16.09 54.40
7	4.02~ 5.02	30.30 34.05	—— ——	30.30 34.05	21.56 21.56	64.02 109.11
8	5.02~ 6.02	40.61 45.09	—— ——	40.61 45.09	21.56 21.56	83.40 117.87
9	6.02~ 7.02	32.71 35.96	—— ——	32.71 35.96	21.56 21.56	193.56 250.16
10	7.02~ 9.02	44.61 52.66	—— ——	44.61 52.66	21.56 21.56	178.67 259.52
11	9.02~ 10.02	50.83 54.72	—— ——	50.83 54.72	21.56 21.56	273.99 316.67
12	10.02~ 11.02	52.81 56.56	—— ——	52.81 56.56	21.56 21.56	334.55 379.63
13	11.02~ 12.02	60.72 64.75	—— ——	60.72 64.75	21.56 21.56	340.36 380.78
14	12.02~ 13.02	52.19 55.43	—— ——	52.19 55.43	21.56 21.56	533.14 589.74
15	13.02~ 14.02	79.13 83.77	—— ——	79.13 83.77	21.56 21.56	340.83 373.54
16	14.02~ 15.02	89.82 94.79	—— ——	89.82 94.79	21.56 21.56	336.83 366.32
17	15.02~ 16.02	82.43 86.75	—— ——	82.43 86.75	21.56 21.56	451.19 487.51
18	16.02~ 17.02	51.94 54.53	—— ——	51.94 54.53	21.56 21.56	1100.90 1182.94

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

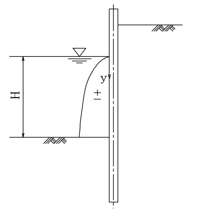
Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

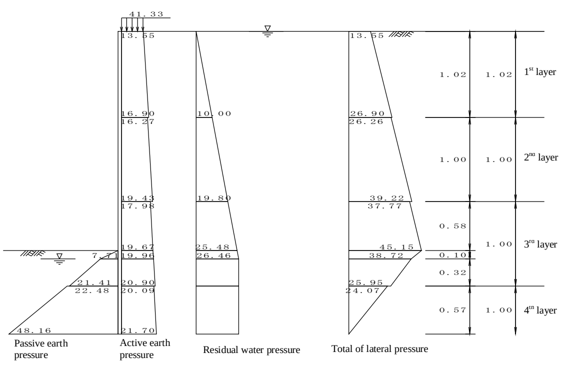
Where,
k_{hs} : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

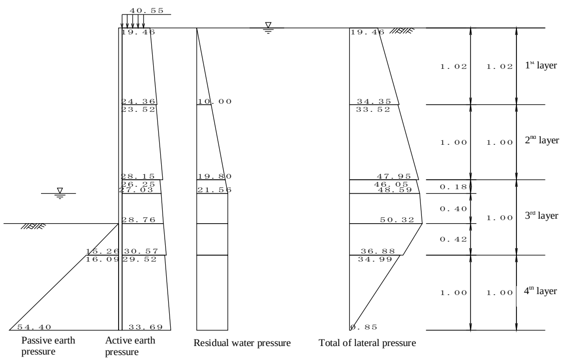


	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 1.02	13.55 16.90	0.00 10.00	—— ——	13.55 26.90
2	1.02~ 2.02	16.27 19.43	10.00 19.80	—— ——	26.26 39.22
3	2.02~ 2.60	17.98 19.67	19.80 25.48	—— ——	37.77 45.15
4	2.60~ 2.70	19.67 19.96	25.48 26.46	0.00 7.71	45.15 38.72
5	2.70~ 3.02	19.96 20.90	26.46 26.46	7.71 21.41	38.72 25.95
6	3.02~ 3.59	20.09 21.70	26.46 26.46	22.48 48.16	24.07 0.00
7	3.59~ 4.02	21.70 22.90	26.46 26.46	48.16 67.44	0.00 -18.08

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 0.99 m (GL -3.59 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 1.02	19.46 24.36	0.00 10.00	—— ——	19.46 34.35
2	1.02~ 2.02	23.52 28.15	10.00 19.80	—— ——	33.52 47.95
3	2.02~ 2.20	26.25 27.03	19.80 21.56	—— ——	46.05 48.59
4	2.20~ 2.60	27.03 28.76	21.56 21.56	—— ——	48.59 50.32
5	2.60~ 3.02	28.76 30.57	21.56 21.56	0.00 15.26	50.32 36.88
6	3.02~ 4.02	29.52 33.69	21.56 21.56	16.09 54.40	34.99 0.85
7	4.02~ 5.02	30.30 34.05	21.56 21.56	64.02 109.11	-12.17 -53.50

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.42 m (GL -4.02 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to $1/\beta$ depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m		
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 =	1.00 mm (passive side)
Corrosion rate	η	=	0.92		
Section efficiency	μ	=	0.80		
Young's modulus	E	=	200000 N/mm^2		
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)		
	I	=	63296 cm^4 (after reduction by corrosion and section)		
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} = 1.266 x 10^5		

	Depth (m)	N-value
1	1.02	11
2	2.02	13
3	3.02	17
4	4.02	20
5	5.02	26
6	6.02	15
7	7.02	37
8	9.02	22
9	10.02	25
10	11.02	28

	Depth (m)	N-value
11	12.02	22
12	13.02	37
13	14.02	14
14	15.02	4
15	16.02	17
16	17.02	50

5-2 Normal Condition

K_h = 24225 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.468 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.14 \ m$$

Therefore, average N-value is calculated on the actual Nvalue from imaginary riverbed (GL -3.59 m) to 2.14 m depth (GL -5.73 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.59	0.43	18.7	20.0	8.30
2	4.02	1.00	20.0	26.0	23.00
3	5.02	0.71	26.0	18.2	15.68
	L = Σh = 2.14				ΣA = 46.98

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{46.98}{2.14} = 21.97$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 21.97^{0.406} = 24225 \ kN/m^3$$

Kh (normal condition) = 24225 kN/m^3

5-3 Seismic Condition

K_h = 23969 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.466 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.14 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.02 m) to 2.14 m depth (GL -6.16 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.02	1.00	20.0	26.0	23.00
2	5.02	1.00	26.0	15.0	20.50
3	6.02	0.14	15.0	18.2	2.39
	L = Σh = 2.14				ΣA = 45.89

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{45.89}{2.14} = 21.40$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 21.40^{0.406} = 23969 \ kN/m^3$$

Kh (seismic condition) = 23969 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.02	1.02	13.55 26.90	6.91 13.72	3.25 2.91	22.48 39.93
2	1.02~ 2.02	1.00	26.26 39.22	13.13 19.61	2.24 1.90	29.39 37.35
3	2.02~ 2.60	0.58	37.77 45.15	10.95 13.09	1.38 1.18	15.09 15.51
4	2.60~ 2.70	0.10	45.15 38.72	2.26 1.94	0.96 0.92	2.16 1.79
5	2.70~ 3.02	0.32	38.72 25.95	6.19 4.15	0.78 0.68	4.86 2.81
6	3.02~ 3.59	0.57	24.07 0.00	6.87 0.00	0.38 0.19	2.62 0.00
				ΣP = 98.84		ΣM = 173.99

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	6.7 kN/m
depth to acting position	H_t	=	-0.77 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	0.99 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 29.22 \ kN \cdot m$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{203.21}{105.54} = 1.93 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.02	1.02	19.46 34.35	9.92 17.52	3.68 3.34	36.52 58.51
2	1.02~ 2.02	1.00	33.52 47.95	16.76 23.97	2.67 2.33	44.69 55.94

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
3	2.02~ 2.20	0.18	46.05 48.59	4.14 4.37	1.94 1.88	8.04 8.22
4	2.20~ 2.60	0.40	48.59 50.32	9.72 10.06	1.69 1.55	16.39 15.63
5	2.60~ 3.02	0.42	50.32 36.88	10.57 7.74	1.28 1.14	13.53 8.83
6	3.02~ 4.02	1.00	34.99 0.85	17.49 0.43	0.67 0.33	11.66 0.14
				ΣP = 132.71		ΣM = 278.11

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	15.7 kN/m
depth to acting position	H_t	=	-0.60 m
moment	M_m	=	8.4 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.42 m

Moment M_t by arbitrary load is as below
$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 80.93 \ kN \cdot m$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.69 1.55	0.00 0.21
				ΣPdw = 0.14		ΣMdw = 0.21

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{359.26}{148.54} = 2.42 \ m$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266 x 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_1 = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\ (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	24225 kNm^3
calculated value	β	=	0.46768 m^{-1}
resultant earth force (lateral)	P_h	=	105.54 kNm
height of acting position of load	h_0	=	1.93 m
moment	M_0	=	203.21 kN·m/m

in consideration of ψ_m = 1.172,			
maximum moment	M_{max}	=	238.16 kN·m/m
depth of generated position of M_{max}	l_m	=	0.733 m
depth of 1st fixed point	l_1	=	2.413 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	23969 kNm^3
calculated value	β	=	0.46644 m^{-1}
resultant earth force (lateral)	P_h	=	148.54 kNm
height of acting position of load	h_0	=	2.42 m
moment	M_0	=	359.26 kN·m/m

in consideration of ψ_m = 1.121,			
maximum moment	M_{max}	=	402.63 kN·m/m
depth of generated position of M_{max}	l_m	=	0.639 m
depth of 1st fixed point	l_1	=	2.323 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{238.16\times10^6}{3514\times10^3} = 68\ \text{N/mm}^2 \leqq \sigma_a = 180\ \text{N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{402.63\times10^6}{3514\times10^3} = 115\ \text{N/mm}^2 \leqq \sigma_a = 270\ \text{N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 1.02	3.25 2.91	0.905 0.811	0.286 0.240	6.91 13.72	1.978 3.289
2	1.02~ 2.02	2.24 1.90	0.623 0.530	0.154 0.116	13.13 19.61	2.020 2.270
3	2.02~ 2.60	1.38 1.18	0.384 0.330	0.064 0.048	10.95 13.09	0.703 0.634
4	2.60~ 2.70	0.96 0.92	0.267 0.257	0.032 0.030	2.26 1.94	0.073 0.059
5	2.70~ 3.02	0.78 0.68	0.218 0.189	0.022 0.017	6.19 4.15	0.137 0.069
6	3.02~ 3.59	0.38 0.19	0.106 0.053	0.005 0.001	6.87 0.00	0.037 0.000
						ΣQ = 11.270

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

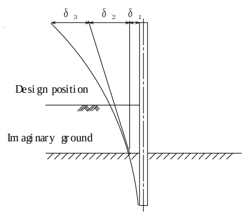
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4677\times1.93)\times105.54}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4677^3} = 0.00774\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4677\times1.93)\times105.54}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4677^2}\times(2.60+0.99) = 0.01917\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.27\times(2.60+0.99)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00412\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00108 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.59 m
Horizontal load: P = 6.70
Moment: M = 5.16

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00774 + 0.01917 + 0.00520
= 0.03212 m
= 32.12 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 1.02	3.68 3.34	0.915 0.831	0.291 0.250	9.92 17.52	2.890 4.372
2	1.02~ 2.02	2.67 2.33	0.663 0.580	0.171 0.136	16.76 23.97	2.872 3.257
3	2.02~ 2.20	1.94 1.88	0.483 0.468	0.098 0.092	4.14 4.37	0.405 0.404
4	2.20~ 2.60	1.69 1.55	0.420 0.386	0.076 0.065	9.72 10.06	0.736 0.655
5	2.60~ 3.02	1.28 1.14	0.318 0.284	0.045 0.036	10.57 7.74	0.479 0.282
6	3.02~ 4.02	0.67 0.33	0.166 0.083	0.013 0.003	17.49 0.43	0.227 0.001
						ΣQ = 16.579

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

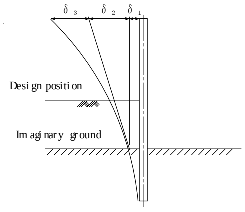
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	1.69 1.55	0.420 0.386	0.076 0.065	0.00 0.14	0.000 0.009
						ΣQ_{dw} = 0.009

Therefore, modulus of deformation Q is calculated as below.
Q = 16.579 + 0.009 = 16.588

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4664\times 2.42)\times 148.54}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4664^3} = 0.01230\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4664\times 2.42)\times 148.54}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4664^2}\times(2.60+1.42) = 0.03530\ m$$

$$= \frac{16.59\times(2.60+1.42)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00851\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00329 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.02 m
Horizontal load: P = 15.70
Moment: M = 9.42

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI}\times(2L-h) \qquad (L=4.02\ m、h=L-H_m、H_m=0.80\ m、\quad h\leqq L)$$

$$= \frac{8.40\times 3.22}{2\times 2.00\times 10^8\times 63296\times 10^{-8}}\times(2\times 4.02-3.22) = 0.00051\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01230 + 0.03530 + 0.01231$
$= 0.05992\ m$
$= 59.92 \leqq \delta_a = 75.00\ mm$

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000x 10^{-8}		=	1.720 x 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 24225\ kN/m^3$
Calculated value	$\beta = 0.43318\ m^{-1}$
Penetration length of SSP	$D = 0.99 + \frac{3}{0.433} = 7.92\ m$
Whole length of SSP	$L = 2.60 - 0.40 + 7.92 = 10.12\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 23969\ kN/m^3$
Calculated value	$\beta = 0.43203\ m^{-1}$
Penetration length of SSP	$D = 1.42 + \frac{3}{0.432} = 8.36\ m$
Whole length of SSP	$L = 2.60 - 0.40 + 8.36 = 10.56\ m$

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

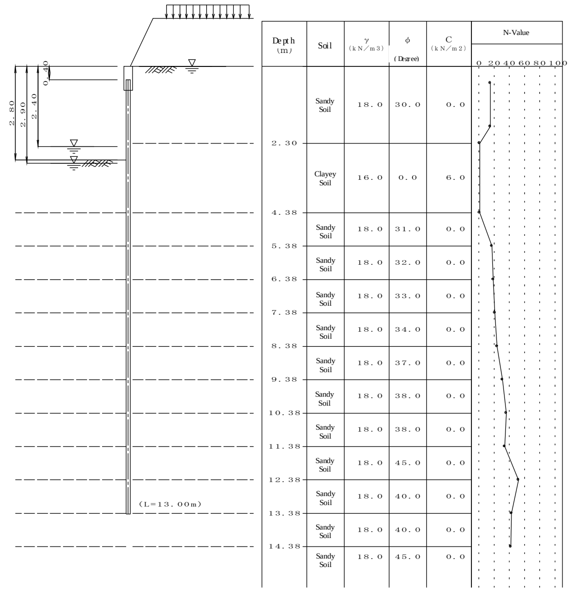
8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		38.16	402.63
Stress intensity	σ (N/mm^2)		68 (180)	115 (270)
Lateral displacement	δ (mm)		32.12 (50.0)	59.92 (75.0)
Penetration depth	D (m)		7.92	8.36
Whole length of SSP	L (m)	11.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 20_STA 15+443 - 15+548

1 Design Conditions



1-1 Longitudinal Section of SSP & Considered Geological Survey Log

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.80 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.90 m (Normal Condition)
	L_{wp}'	=	2.40 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	5.0 kN/m (Normal Condition)
		P_t'	=	12.7 kN/m (Seismic Condition)
	Depth of acting point	H_t	=	-0.65 m (Normal Condition)
		H_t'	=	-0.47 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	4.5 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00m (Seismic Condition)
		H_m	=	0.80m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.80	15
3	2.30	1
4	4.38	1
5	5.38	17
6	6.38	19
7	7.38	21
8	8.38	24
9	9.38	31
10	10.38	36

No	Depth (m)	N-Value
11	11.38	34
12	12.38	52
13	13.38	43
14	14.38	42
15	15.00	50

1.147

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

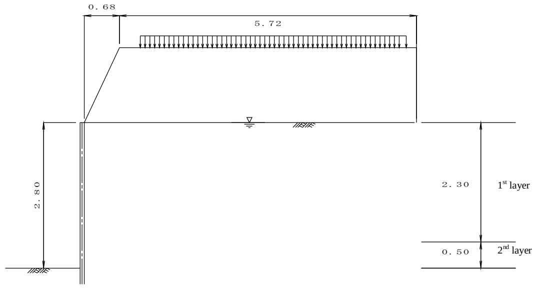
No	Depth (m)	Soil	N-value	γ (kN/m^3)	γ' (kN/m^3)	ϕ	C (kN/m^2)	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.30	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.38	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	5.38	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
4	6.38	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
5	7.38	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
6	8.38	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
7	9.38	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
8	10.38	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
9	11.38	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
10	12.38	S	52.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
11	13.38	S	43.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
12	14.38	S	42.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
13	15.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	0.68	6.40	6.40	1.44	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	1.08	6.20	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 177000 cm^4
Sectional factor Z_0 = 5050 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.86
Corrosion rate (to Z_0) η = 0.89
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

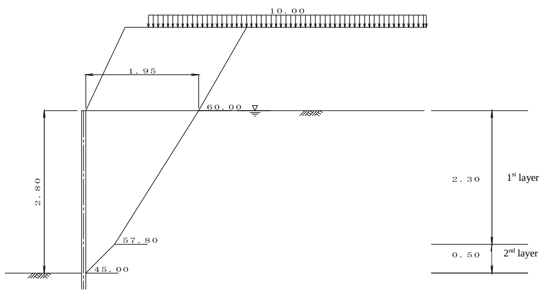
Allowable stress σ_a = 185 Nmm^2 (Normal)
σ_a' = 278 Nmm^2 (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	$\gamma w h w$ (kN/m^2)	Angle of rupture Z (degree)
1	2.80~ 2.30	Clayey Soil	0.0	10.0	6.0	27.00	35.65	27.44	45.00
2	2.30~ 0.00	Sandy Soil	30.0	10.0	0.0	23.00	35.65	22.54	57.80
3		Embankment	30.0	——	0.0	25.92	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^0 since $\theta = 0^0$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00^0$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.30	0.50	0.50	1.95	2.80
3	60.00	1.44	1.95	2.80	2.78	4.24

Therefore, width of acting load shall be set as 1.95 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	2.91	52.46
Σ			52.46

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	10.0	1.70	17.00
Σ			17.00

Q surcharge load
l : width of surcharge load set by line of active rupture

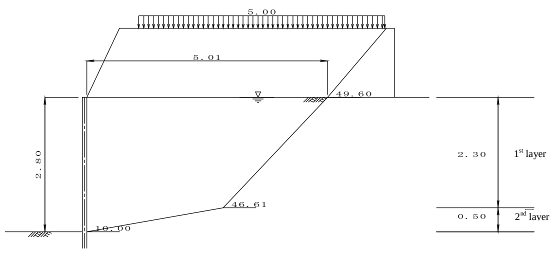
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{52.46 + 17.00 + 0.00}{1.95}$$

$$= 35.65 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.80~ 2.30	Clayey Soil	0.0	10.0	6.0	27.00	32.44	27.44	0.200	11.31	10.00
2	2.30~ 0.00	Sandy Soil	30.0	10.0	0.0	23.00	32.44	22.54	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	25.92	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) θ=tan⁻¹k or θ=tan⁻¹k'
- γ : unit weight of soil (kN/m³) (ascending force considered under W.L)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

Case: Left Bank No. 20_STA 15+443_15+548

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	10.00	0.50	0.00	0.00	2.84	0.50
2	46.61	2.30	2.84	0.50	5.01	2.80
3	49.60	1.44	5.01	2.80	6.24	4.24

Therefore, width of acting load shall be set as 5.01 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	7.61	136.93
Σ			136.93

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	5.12	25.60
Σ			25.60

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

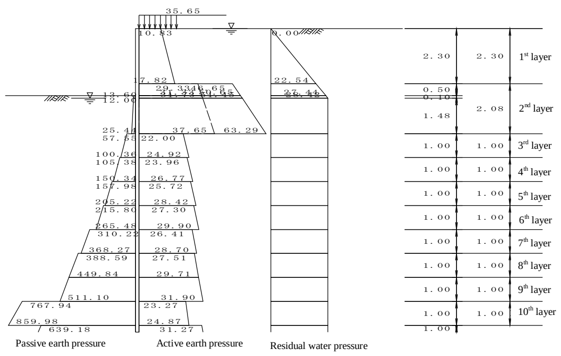
$$= \frac{136.93 + 25.60 + 0.00}{5.01}$$

$$= 32.44 \text{ kN/m}^2$$

Case: Left Bank No. 20_STA 15+443_15+548

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.30	Sandy soil	10.0	30.0	—— ——	35.651 58.651	0.30847 0.30847	0.30378 0.30378
2	2.30~ 2.80	Clayey soil	8.0	——	6.0 6.0	58.651 62.651	—— ——	—— ——
3	2.80~ 2.90	Clayey soil	8.0	——	6.0 6.0	62.651 63.451	—— ——	—— ——
4	2.90~ 4.38	Clayey soil	8.0	——	6.0 6.0	63.451 75.291	—— ——	—— ——
5	4.38~ 5.38	Sandy soil	10.0	31.0	—— ——	75.291 85.291	0.29669 0.29669	0.29219 0.29219
6	5.38~ 6.38	Sandy soil	10.0	32.0	—— ——	85.291 95.291	0.28525 0.28525	0.28092 0.28092
7	6.38~ 7.38	Sandy soil	10.0	33.0	—— ——	95.291 105.291	0.27412 0.27412	0.26996 0.26996
8	7.38~ 8.38	Sandy soil	10.0	34.0	—— ——	105.291 115.291	0.26331 0.26331	0.25931 0.25931
9	8.38~ 9.38	Sandy soil	10.0	37.0	—— ——	115.291 125.291	0.23264 0.23264	0.22910 0.22910
10	9.38~ 10.38	Sandy soil	10.0	38.0	—— ——	125.291 135.291	0.22298 0.22298	0.21959 0.21959
11	10.38~ 11.38	Sandy soil	10.0	38.0	—— ——	135.291 145.291	0.22298 0.22298	0.21959 0.21959
12	11.38~ 12.38	Sandy soil	10.0	45.0	—— ——	145.291 155.291	0.16262 0.16262	0.16015 0.16015
13	12.38~ 13.38	Sandy soil	10.0	40.0	—— ——	155.291 165.291	0.20447 0.20447	0.20137 0.20137

Case: Left Bank No. 20_STA 15+443_15+548

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	13.38~ 14.38	Sandy soil	10.0	40.0	—— ——	165.291 175.291	0.20447 0.20447	0.20137 0.20137
15	14.38~ 15.00	Sandy soil	10.0	45.0	—— ——	175.291 181.491	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.80~ 2.90	Clayey soil	16.0	0.0	6.0 6.0	0.000 1.600	—— ——	—— ——
4	2.90~ 4.38	Clayey soil	8.0	0.0	6.0 6.0	1.600 13.440	—— ——	—— ——
5	4.38~ 5.38	Sandy soil	10.0	31.0	—— ——	13.440 23.440	4.34774 4.34774	4.28169 4.28169
6	5.38~ 6.38	Sandy soil	10.0	32.0	—— ——	23.440 33.440	4.56530 4.56530	4.49594 4.49594
7	6.38~ 7.38	Sandy soil	10.0	33.0	—— ——	33.440 43.440	4.79713 4.79713	4.72425 4.72425
8	7.38~ 8.38	Sandy soil	10.0	34.0	—— ——	43.440 53.440	5.04448 5.04448	4.96784 4.96784
9	8.38~ 9.38	Sandy soil	10.0	37.0	—— ——	53.440 63.440	5.89457 5.89457	5.80501 5.80501
10	9.38~ 10.38	Sandy soil	10.0	38.0	—— ——	63.440 73.440	6.21981 6.21981	6.12532 6.12532
11	10.38~ 11.38	Sandy soil	10.0	38.0	—— ——	73.440 83.440	6.21981 6.21981	6.12532 6.12532
12	11.38~ 12.38	Sandy soil	10.0	45.0	—— ——	83.440 93.440	9.34548 9.34548	9.20351 9.20351
13	12.38~ 13.38	Sandy soil	10.0	40.0	—— ——	93.440 103.440	6.94605 6.94605	6.84053 6.84053
14	13.38~ 14.38	Sandy soil	10.0	40.0	—— ——	103.440 113.440	6.94605 6.94605	6.84053 6.84053
15	14.38~ 15.00	Sandy soil	10.0	45.0	—— ——	113.440 119.640	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.30	10.83 17.82	— —	10.83 17.82	0.00 22.54	— —
2	2.30~ 2.80	46.65 50.65	29.33 31.33	46.65 50.65	22.54 27.44	— —
3	2.80~ 2.90	50.65 51.45	31.33 31.73	50.65 51.45	27.44 28.42	12.00 13.60
4	2.90~ 4.38	51.45 63.29	31.73 37.65	51.45 63.29	28.42 28.42	13.60 25.44
5	4.38~ 5.38	22.00 24.92	— —	22.00 24.92	28.42 28.42	57.55 100.36
6	5.38~ 6.38	23.96 26.77	— —	23.96 26.77	28.42 28.42	105.38 150.34
7	6.38~ 7.38	25.72 28.42	— —	25.72 28.42	28.42 28.42	157.98 205.22
8	7.38~ 8.38	27.30 29.90	— —	27.30 29.90	28.42 28.42	215.80 265.48
9	8.38~ 9.38	26.41 28.70	— —	26.41 28.70	28.42 28.42	310.22 368.27
10	9.38~ 10.38	27.51 29.71	— —	27.51 29.71	28.42 28.42	388.59 449.84
11	10.38~ 11.38	29.71 31.90	— —	29.71 31.90	28.42 28.42	449.84 511.10
12	11.38~ 12.38	23.27 24.87	— —	23.27 24.87	28.42 28.42	767.94 859.98
13	12.38~ 13.38	31.27 33.28	— —	31.27 33.28	28.42 28.42	639.18 707.58
14	13.38~ 14.38	33.28 35.30	— —	33.28 35.30	28.42 28.42	707.58 775.99
15	14.38~ 15.00	28.07 29.07	— —	28.07 29.07	28.42 28.42	1044.05 1101.11

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

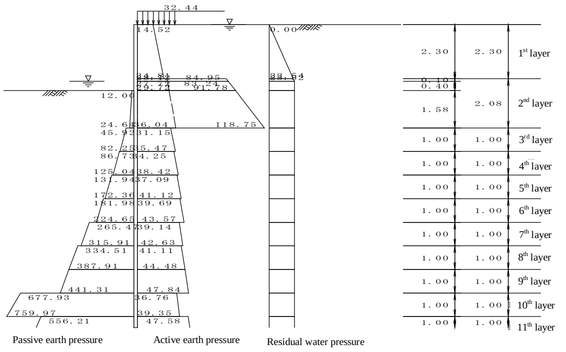
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.30	Sandy Soil	10.0	30.0	— —	32.44 55.44	0.00 22.54	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
2	2.30~ 2.40	Clayey Soil	8.0	—	6.0 6.0	55.44 56.24	22.54 23.52	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
3	2.40~ 2.80	Clayey Soil	8.0	—	6.0 6.0	56.24 59.44	23.52 27.44	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
4	2.80~ 4.38	Clayey Soil	8.0	—	6.0 6.0	59.44 72.08	27.44 42.92	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
5	4.38~ 5.38	Sandy Soil	10.0	31.0	— —	72.08 82.08	42.92 52.72	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	— —
6	5.38~ 6.38	Sandy Soil	10.0	32.0	— —	82.08 92.08	52.72 62.52	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	— —
7	6.38~ 7.38	Sandy Soil	10.0	33.0	— —	92.08 102.08	62.52 72.32	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	— —
8	7.38~ 8.38	Sandy Soil	10.0	34.0	— —	102.08 112.08	72.32 82.12	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	— —
9	8.38~ 9.38	Sandy Soil	10.0	37.0	— —	112.08 122.08	82.12 91.92	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	— —
10	9.38~ 10.38	Sandy Soil	10.0	38.0	— —	122.08 132.08	91.92 101.72	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	— —
11	10.38~ 11.38	Sandy Soil	10.0	38.0	— —	132.08 142.08	101.72 111.52	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	— —
12	11.38~ 12.38	Sandy Soil	10.0	45.0	— —	142.08 152.08	111.52 121.32	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	— —
13	12.38~ 13.38	Sandy Soil	10.0	40.0	— —	152.08 162.08	121.32 131.12	0.200 0.200	11.31 11.31	0.31772 0.31772	0.31289 0.31289	— —
14	13.38~ 14.38	Sandy Soil	10.0	40.0	— —	162.08 172.08	131.12 140.92	0.200 0.200	11.31 11.31	0.31772 0.31772	0.31289 0.31289	— —

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	14.38~ 15.00	Sandy Soil	10.0	45.0	— —	172.08 178.28	140.92 147.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.80~ 4.38	Clayey soil	8.00	0.0	6.0 6.0	0.000 12.640	0.00 15.48	0.200 0.200	11.31 11.31	— —	— —
5	4.38~ 5.38	Sandy soil	10.00	31.0	— —	12.640 22.640	15.48 25.28	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
6	5.38~ 6.38	Sandy soil	10.00	32.0	— —	22.640 32.640	25.28 35.08	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
7	6.38~ 7.38	Sandy soil	10.00	33.0	— —	32.640 42.640	35.08 44.88	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
8	7.38~ 8.38	Sandy soil	10.00	34.0	— —	42.640 52.640	44.88 54.68	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
9	8.38~ 9.38	Sandy soil	10.00	37.0	— —	52.640 62.640	54.68 64.48	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
10	9.38~ 10.38	Sandy soil	10.00	38.0	— —	62.640 72.640	64.48 74.28	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
11	10.38~ 11.38	Sandy soil	10.00	38.0	— —	72.640 82.640	74.28 84.08	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
12	11.38~ 12.38	Sandy soil	10.00	45.0	— —	82.640 92.640	84.08 93.88	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
13	12.38~ 13.38	Sandy soil	10.00	40.0	— —	92.640 102.640	93.88 103.68	0.200 0.200	11.31 11.31	6.09659 6.09659	6.00397 6.00397
14	13.38~ 14.38	Sandy soil	10.00	40.0	— —	102.640 112.640	103.68 113.48	0.200 0.200	11.31 11.31	6.09659 6.09659	6.00397 6.00397
15	14.38~ 15.00	Sandy soil	10.00	45.0	— —	112.640 118.840	113.48 119.56	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.30	14.52 24.81	— —	14.52 24.81	0.00 22.54	— —
2	2.30~ 2.40	83.24 84.95	27.72 28.12	83.24 84.95	22.54 23.52	— —
3	2.40~ 2.80	84.95 91.78	28.12 29.72	84.95 91.78	23.52 23.52	— —
4	2.80~ 4.38	91.78 118.75	29.72 36.04	91.78 118.75	23.52 23.52	12.00 24.64
5	4.38~ 5.38	31.15 35.47	— —	31.15 35.47	23.52 23.52	45.92 82.25
6	5.38~ 6.38	34.25 38.42	— —	34.25 38.42	23.52 23.52	86.73 125.04
7	6.38~ 7.38	37.09 41.12	— —	37.09 41.12	23.52 23.52	131.94 172.36
8	7.38~ 8.38	39.69 43.57	— —	39.69 43.57	23.52 23.52	181.98 224.65
9	8.38~ 9.38	39.14 42.63	— —	39.14 42.63	23.52 23.52	265.47 315.91
10	9.38~ 10.38	41.11 44.48	— —	41.11 44.48	23.52 23.52	334.51 387.91
11	10.38~ 11.38	44.48 47.84	— —	44.48 47.84	23.52 23.52	387.91 441.31
12	11.38~ 12.38	36.76 39.35	— —	36.76 39.35	23.52 23.52	677.93 759.97
13	12.38~ 13.38	47.58 50.71	— —	47.58 50.71	23.52 23.52	556.21 616.25
14	13.38~ 14.38	50.71 53.84	— —	50.71 53.84	23.52 23.52	616.25 676.29
15	14.38~ 15.00	44.52 46.13	— —	44.52 46.13	23.52 23.52	924.04 974.90

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

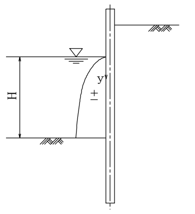
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.40	0.00	0.00
2	2.80	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

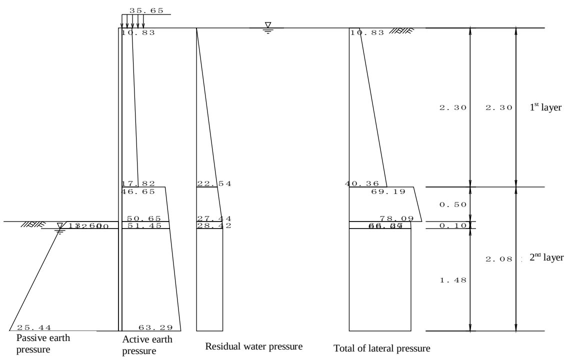
Where,
k_{hs} : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

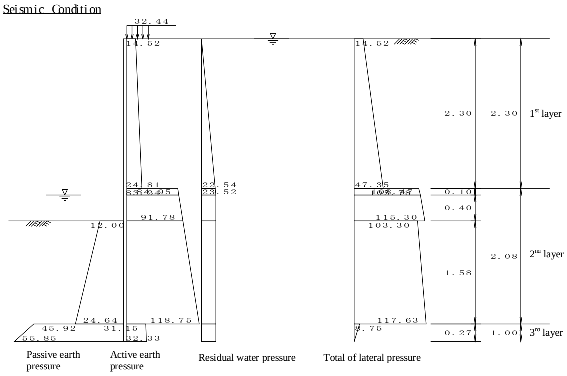


	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 2.30	10.83 17.82	0.00 22.54	—— ——	10.83 40.36
2	2.30~ 2.80	46.65 50.65	22.54 27.44	—— ——	69.19 78.09
3	2.80~ 2.90	50.65 51.45	27.44 28.42	12.00 13.60	66.09 66.27
4	2.90~ 4.38	51.45 63.29	28.42 28.42	13.60 25.44	66.27 66.27
5	4.38~ 5.38	22.00 24.92	28.42 28.42	57.55 100.36	-7.13 -47.02

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.58 m (GL -4.38 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 2.30	14.52 24.81	0.00 22.54	—— ——	14.52 47.35
2	2.30~ 2.40	83.24 84.95	22.54 23.52	—— ——	105.78 108.47
3	2.40~ 2.80	84.95 91.78	23.52 23.52	—— ——	108.47 115.30
4	2.80~ 4.38	91.78 118.75	23.52 23.52	12.00 24.64	103.30 117.63
5	4.38~ 4.65	31.15 32.33	23.52 23.52	45.92 55.85	8.75 0.00
6	4.65~ 5.38	32.33 35.47	23.52 23.52	55.85 82.25	0.00 -23.26

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.85 m (GL -4.65 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.86			
Section efficiency	μ	=	1.00			
Young's modulus	E	=	200000 N/mm²			
Inertia sectional moment	I_0	=	177000 cm⁴ (original condition)			
	I	=	152220 cm⁴ (after reduction by corrosion and section)			
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 152220 \times 10^{-8} = 3.044 \times 10^5$			

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	11.38	34
2	1.80	15	12	12.38	52
3	2.30	1	13	13.38	43
4	4.38	1	14	14.38	42
5	5.38	17	15	15.00	50
6	6.38	19			
7	7.38	21			
8	8.38	24			
9	9.38	31			
10	10.38	36			

5-2 Normal Condition

K_h = 20877 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.362 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.76 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.38 m) to 2.76 m depth (GL -7.14 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	4.38	1.00	1.0	17.0	9.00
2	5.38	1.00	17.0	19.0	18.00
3	6.38	0.76	19.0	20.5	15.09
L = Σh = 2.76					ΣA = 42.09

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{42.07}{2.76} = 15.23$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 15.23^{0.406} = 20877 \text{ kN/m}^3$$

Kh (normal condition) = 20877 kN/m^3

5-3 Seismic Condition

K_h = 21792 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.366 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.73 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.65 m) to 2.73 m depth (GL -7.39 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	4.65	0.73	5.4	17.0	8.13
2	5.38	1.00	17.0	19.0	18.00
3	6.38	1.00	19.0	21.0	20.00
4	7.38	0.01	21.0	21.0	0.16
L = Σh = 2.73					ΣA = 46.29

A: (upper N-value + lower N-value) × h/2

Average N-value

$$' = \frac{\Sigma A}{L} = \frac{46.29}{2.73} = 16.93$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 16.93^{0.406} = 21792 \text{ kN/m}^3$$

K_h (seismic condition) = 21792 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.30	2.30	10.83 40.36	12.45 46.41	3.61 2.85	45.00 132.12
2	2.30~ 2.80	0.50	69.19 78.09	17.30 19.52	1.91 1.75	33.10 34.10
3	2.80~ 2.90	0.10	66.09 66.27	3.30 3.31	1.55 1.51	5.11 5.01
4	2.90~ 4.38	1.48	66.27 66.27	49.04 49.04	0.99 0.49	48.39 24.19
				ΣP = 200.38		ΣM = 327.02

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	5.0 kN/m
depth to acting position	H_t	=	-0.65 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.58 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 25.15 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{352.17}{205.38} = 1.71 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.30	2.30	14.52 47.35	16.70 54.45	3.89 3.12	64.89 169.90
2	2.30~ 2.40	0.10	105.78 108.47	5.29 5.42	2.32 2.29	12.27 12.40
3	2.40~ 2.80	0.40	108.47 115.30	21.69 23.06	2.12 1.99	45.99 45.81
4	2.80~ 4.38	1.58	103.30 117.63	81.60 92.93	1.33 0.80	108.26 74.35

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
5	4.38~ 4.65	0.27	8.75 0.00	1.20 0.00	0.18 0.09	0.22 0.00
				ΣP = 302.34		ΣM = 534.09

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	12.7 kN/m
depth to acting position	H_t	=	-0.47 m
moment	M_m	=	4.5 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.85 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 69.57 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.40~ 2.80	0.40	0.0 0.7	0.00 0.14	2.12 1.99	0.00 0.27
				ΣPdw = 0.14		ΣM dw = 0.27

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{603.93}{315.18} = 1.92 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	177000 cm^4 (original condition)
	I	=	152220 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 152220 x 10^{-8}		=	3.044 x 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	20877 kN/m^3
calculated value	β	=	0.36185 m^{-1}
resultant earth force (lateral)	P_0	=	205.38 kN/m
height of acting position of load	h_0	=	1.71 m
moment	M_0	=	352.17 kN·m/m

in consideration of ϕ_m = 1.300,

maximum moment	M_{max}	=	457.70 kN·m/m
depth of generated position of M_{max}	l_m	=	1.160 m
depth of 1st fixed point	l_i	=	3.330 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	21792 kN/m^3
calculated value	β	=	0.36575 m^{-1}
resultant earth force (lateral)	P_0	=	315.18 kN/m
height of acting position of load	h_0	=	1.92 m
moment	M_0	=	603.93 kN·m/m

in consideration of ϕ_m = 1.251,

maximum moment	M_{max}	=	755.48 kN·m/m
depth of generated position of M_{max}	l_m	=	1.079 m
depth of 1st fixed point	l_i	=	3.226 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	5050 cm^3 (original condition)
	Z	=	4495 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{457.70\times10^{6}}{4495\times10^{3}} = 102\ N/mm^{2} \leqq \sigma_{a} = 185\ N/mm^{2}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{755.48\times10^{6}}{4495\times10^{3}} = 168\ N/mm^{2} \leqq \sigma_{a} = 278\ N/mm^{2}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.30	3.61 2.85	0.825 0.650	0.247 0.165	12.45 46.41	3.073 7.678
2	2.30~ 2.80	1.91 1.75	0.437 0.399	0.082 0.069	17.30 19.52	1.410 1.346
3	2.80~ 2.90	1.55 1.51	0.353 0.346	0.055 0.053	3.30 3.31	0.182 0.175
4	2.90~ 4.38	0.99 0.49	0.225 0.113	0.023 0.006	49.04 49.04	1.151 0.299
						ΣQ = 15.314

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

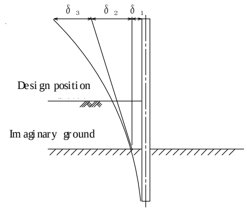
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3619\times1.71)\times205.38}{2\times2.00\times10^{8}\times152220\times10^{-8}\times0.3619^{3}} = 0.01154\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3619\times1.71)\times205.38}{2\times2.00\times10^{8}\times152220\times10^{-8}\times0.3619^{2}}\times(2.80+1.58) = 0.02529\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.31\times(2.80+1.58)^3}{2.00\times10^{8}\times152220\times10^{-8}} = 0.00423\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00056 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.38 m
Horizontal load: P = 5.00
Moment: M = 3.25

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01154 + 0.02529 + 0.00479
= 0.04161 m
= 41.61 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.30	3.89 3.12	0.835 0.670	0.252 0.175	16.70 54.45	4.202 9.504
2	2.30~ 2.40	2.32 2.29	0.499 0.491	0.104 0.101	5.29 5.42	0.548 0.548
3	2.40~ 2.80	2.12 1.99	0.456 0.427	0.088 0.078	21.69 23.06	1.909 1.803
4	2.80~ 4.38	1.33 0.80	0.285 0.172	0.037 0.014	81.60 92.93	3.001 1.295
5	4.38~ 4.65	0.18 0.09	0.039 0.020	0.001 0.000	1.20 0.00	0.001 0.000
						ΣQ = 22.811

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

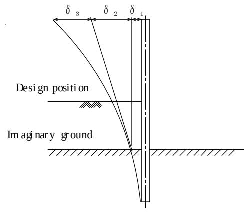
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_w (kN)
1	2.40~ 2.80	2.12 1.99	0.456 0.427	0.088 0.078	0.00 0.14	0.000 0.011
						ΣQ_w = 0.011

Therefore, modulus of deformation Q is calculated as below:
Q = 22.811 + 0.011 = 22.822

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3658\times1.92)\times315.18}{2\times2.00\times10^{8}\times152220\times10^{-8}\times0.3658^{3}} = 0.01799\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3658\times1.92)\times315.18}{2\times2.00\times10^{8}\times152220\times10^{-8}\times0.3658^{2}}\times(2.80+1.85) = 0.04325\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{22.82\times(2.80+1.85)^3}{2.00\times10^{8}\times152220\times10^{-8}} = 0.00755\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00161 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.65 m
Horizontal load: P = 12.70
Moment: M = 5.97

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.65\ m、h=L-H_m、H_m=0.80\ m、\quad h\leqq L)$$

$$= \frac{4.50\times3.85}{2\times2.00\times10^{8}\times152220\times10^{-8}}\times(2\times4.65-3.85) = 0.00016\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01799 + 0.04325 + 0.00932
= 0.07056 m
= 70.56 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	177000 cm^4 (original condition)
	I	=	177000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 177000 \times 10^{-8}$		=	3.540×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 20877$ kN/m^3

Calculated value $\beta = 0.34846$ m^{-1}

Penetration length of SSP $D = 1.58 + \frac{3}{0.348} = 10.19$ m

Whole length of SSP $L = 2.80 - 0.40 + 10.19 = 12.59$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 21792$ kN/m^3

Calculated value $\beta = 0.35222$ m^{-1}

Penetration length of SSP $D = 1.85 + \frac{3}{0.352} = 10.37$ m

Whole length of SSP $L = 2.80 - 0.40 + 10.37 = 12.77$ m

Therefore, whole length of SSP is set as 13.00 m in consideration of round unit of SSP length.

8 Calculation Result

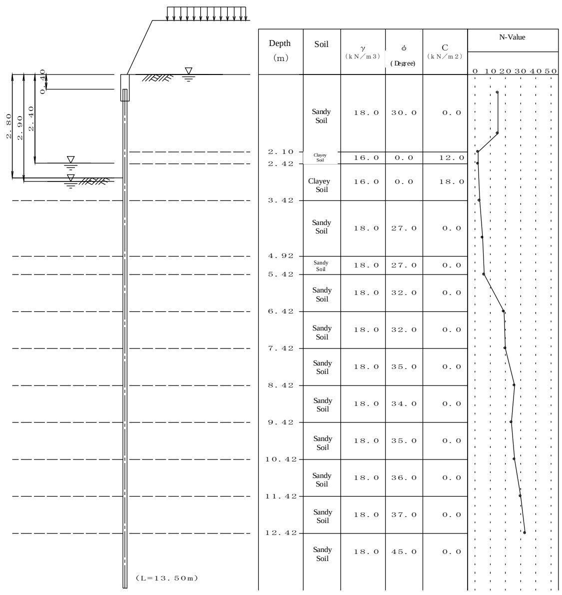
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	177000		
Section modulus	Z (cm^3)	5050		
Maximum bending moment	M_{max} (kN·m/m)		457.70	755.48
Stress intensity	σ (N/mm^2)		102 (185)	168 (278)
Lateral displacement	δ (mm)		41.61 (50.0)	70.56 (75.0)
Penetration depth	D (m)		10.19	10.37
Whole length of SSP	L (m)	13.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 21_STA 15+747 - 15+870

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.80 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.90 m (Normal Condition)
	L_{wp}'	=	2.40 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	5.1 kNm (Normal Condition)
		P_t'	=	12.9 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.66 m (Normal Condition)
		H_t'	=	-0.48 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	4.7 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m (Seismic Condition)
		H_m	=	0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_s = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.42	24
2	1.60	15	12	10.42	26
3	2.10	2	13	11.42	30
4	2.42	2	14	12.42	33
5	3.42	3	15	13.42	50
6	4.42	5	16	20.00	50
7	5.42	6			
8	6.42	19			
9	7.42	20			
10	8.42	26			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	――	――
2	2.42	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
3	3.42	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
4	4.92	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
5	5.42	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
6	6.42	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	――	――
7	7.42	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	――	――
8	8.42	S	26.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	――	――
9	9.42	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	――	――
10	10.42	S	26.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	――	――
11	11.42	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	――	――
12	12.42	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	――	――
13	13.42	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	――	――

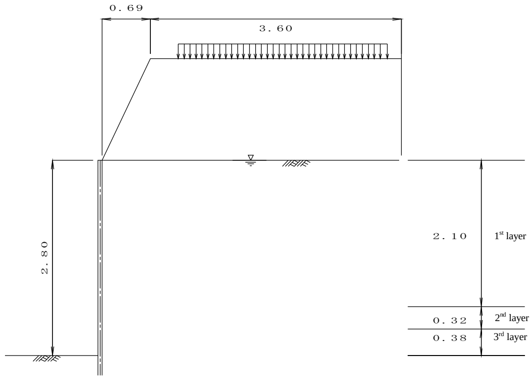
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_0 : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1.155

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.69	4.29	4.29	1.46	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.09	4.09	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

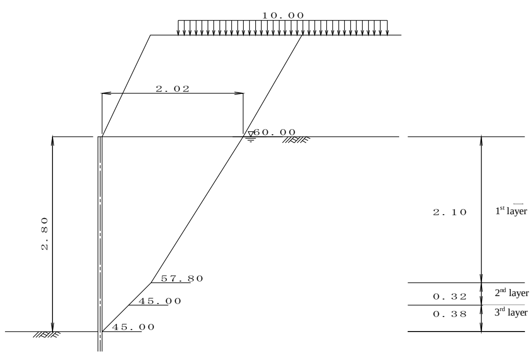
1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm²	
Inertia sectional moment	I_0	=	154000 cm⁴	
Sectional factor	Z_0	=	4160 cm³	
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.85	
Corrosion rate (to Z_0)	η	=	0.87	
Section efficiency (to I_0)	μ	=	1.00	
Section efficiency (to Z_0)	μ	=	1.00	
Round unit of SSP length			0.50 m	
Allowable stress	σ_a	=	187 Nmm² (Normal)	
	σ_a'	=	278 Nmm² (Seismic)	
Allowable displacement	δ_a	=	50.0 mm (Normal)	
	δ_a'	=	75.0 mm (Seismic)	

Bending of cantilever beam: calculated as distributed load of each layer

Reduction of material modulus:
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	Angle of rupture Z (degree)
1	2.80~ 2.42	Clayey Soil	0.0	10.0	18.0	26.60	36.05	27.44	45.00
2	2.42~ 2.10	Clayey Soil	0.0	10.0	12.0	23.56	36.05	23.72	45.00
3	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	36.05	20.58	57.80
4		Embankment	30.0	——	0.0	26.28	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.38	0.00	0.00	0.38	0.38
2	45.00	0.32	0.38	0.38	0.70	0.70
3	57.80	2.10	0.70	0.70	2.02	2.80
4	60.00	1.46	2.02	2.80	2.87	4.26

Therefore, width of acting load shall be set as 2.02 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.06	55.16
Σ			55.16

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.78	17.75
Σ			17.75

Q surcharge load
l : width of surcharge load set by line of active rupture

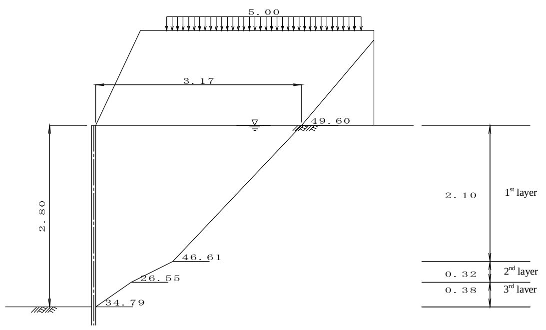
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{55.16 + 17.75 + 0.00}{2.02}$$

$$= 36.05\ \text{kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.80~ 2.42	Clayey Soil	0.0	10.0	18.0	26.60	33.24	27.44	0.200	11.31	34.79
2	2.42~ 2.10	Clayey Soil	0.0	10.0	12.0	23.56	33.24	23.72	0.200	11.31	26.55
3	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	33.24	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	26.28	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,

ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C : cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	34.79	0.38	0.00	0.00	0.55	0.38
2	26.55	0.32	0.55	0.38	1.19	0.70
3	46.61	2.10	1.19	0.70	3.17	2.80
4	49.60	1.31	3.17	2.80	4.29	4.11

Therefore, width of acting load shall be set as 3.17 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.03	90.47
Σ			90.47

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

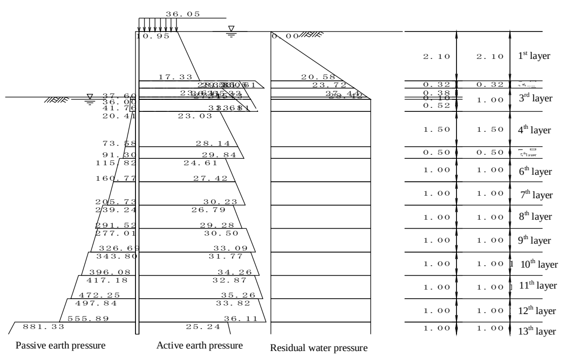
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{90.47 + 15.00 + 0.00}{3.17}$$

$$= 33.24\ \text{kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	36.052 57.052	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.42	Clayey soil	8.0	—	12.0 12.0	57.052 59.612	—— ——	—— ——
3	2.42~ 2.80	Clayey soil	8.0	—	18.0 18.0	59.612 62.652	—— ——	—— ——
4	2.80~ 2.90	Sandy soil	8.0	—	18.0 18.0	62.652 63.452	—— ——	—— ——
5	2.90~ 3.42	Clayey soil	8.0	—	18.0 18.0	63.452 67.612	—— ——	—— ——
6	3.42~ 4.92	Sandy soil	10.0	27.0	—— ——	67.612 82.612	0.34585 0.34585	0.34060 0.34060
7	4.92~ 5.42	Sandy soil	10.0	27.0	—— ——	82.612 87.612	0.34585 0.34585	0.34060 0.34060
8	5.42~ 6.42	Sandy soil	10.0	32.0	—— ——	87.612 97.612	0.28525 0.28525	0.28092 0.28092
9	6.42~ 7.42	Sandy soil	10.0	32.0	—— ——	97.612 107.612	0.28525 0.28525	0.28092 0.28092
10	7.42~ 8.42	Sandy soil	10.0	35.0	—— ——	107.612 117.612	0.25279 0.25279	0.24895 0.24895
11	8.42~ 9.42	Sandy soil	10.0	34.0	—— ——	117.612 127.612	0.26331 0.26331	0.25931 0.25931
12	9.42~ 10.42	Sandy soil	10.0	35.0	—— ——	127.612 137.612	0.25279 0.25279	0.24895 0.24895
13	10.42~ 11.42	Sandy soil	10.0	36.0	—— ——	137.612 147.612	0.24257 0.24257	0.23889 0.23889

1.157

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	11.42~ 12.42	Sandy soil	10.0	37.0	—— ——	147.612 157.612	0.23264 0.23264	0.22910 0.22910
15	12.42~ 13.42	Sandy soil	10.0	45.0	—— ——	157.612 167.612	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.80~ 2.90	Clayey soil	16.0	0.0	18.0 18.0	0.000 1.600	—— ——	—— ——
5	2.90~ 3.42	Clayey soil	8.0	0.0	18.0 18.0	1.600 5.760	—— ——	—— ——
6	3.42~ 4.92	Sandy soil	10.0	27.0	—— ——	5.760 20.760	3.59892 3.59892	3.54425 3.54425
7	4.92~ 5.42	Sandy soil	10.0	27.0	—— ——	20.760 25.760	3.59892 3.59892	3.54425 3.54425
8	5.42~ 6.42	Sandy soil	10.0	32.0	—— ——	25.760 35.760	4.56530 4.56530	4.49594 4.49594
9	6.42~ 7.42	Sandy soil	10.0	32.0	—— ——	35.760 45.760	4.56530 4.56530	4.49594 4.49594
10	7.42~ 8.42	Sandy soil	10.0	35.0	—— ——	45.760 55.760	5.30876 5.30876	5.22810 5.22810
11	8.42~ 9.42	Sandy soil	10.0	34.0	—— ——	55.760 65.760	5.04448 5.04448	4.96784 4.96784
12	9.42~ 10.42	Sandy soil	10.0	35.0	—— ——	65.760 75.760	5.30876 5.30876	5.22810 5.22810
13	10.42~ 11.42	Sandy soil	10.0	36.0	—— ——	75.760 85.760	5.59154 5.59154	5.50659 5.50659
14	11.42~ 12.42	Sandy soil	10.0	37.0	—— ——	85.760 95.760	5.89457 5.89457	5.80501 5.80501
15	12.42~ 13.42	Sandy soil	10.0	45.0	—— ——	95.760 105.760	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	10.95 17.33	—— ——	10.95 17.33	0.00 20.58	—— ——
2	2.10~ 2.42	33.05 35.61	28.53 29.81	33.05 35.61	20.58 23.72	—— ——
3	2.42~ 2.80	23.61 26.65	29.81 31.33	29.81 31.33	23.72 27.44	—— ——
4	2.80~ 2.90	26.65 27.45	31.33 31.73	31.33 31.73	27.44 28.42	36.00 37.60
5	2.90~ 3.42	27.45 31.61	31.73 33.81	31.73 33.81	28.42 28.42	37.60 41.76
6	3.42~ 4.92	23.03 28.14	—— ——	23.03 28.14	28.42 28.42	20.41 73.58
7	4.92~ 5.42	28.14 29.84	—— ——	28.14 29.84	28.42 28.42	73.58 91.30
8	5.42~ 6.42	24.61 27.42	—— ——	24.61 27.42	28.42 28.42	115.82 160.77
9	6.42~ 7.42	27.42 30.23	—— ——	27.42 30.23	28.42 28.42	160.77 205.73
10	7.42~ 8.42	26.79 29.28	—— ——	26.79 29.28	28.42 28.42	239.24 291.52
11	8.42~ 9.42	30.50 33.09	—— ——	30.50 33.09	28.42 28.42	277.01 326.69
12	9.42~ 10.42	31.77 34.26	—— ——	31.77 34.26	28.42 28.42	343.80 396.08
13	10.42~ 11.42	32.87 35.26	—— ——	32.87 35.26	28.42 28.42	417.18 472.25
14	11.42~ 12.42	33.82 36.11	—— ——	33.82 36.11	28.42 28.42	497.84 555.89
15	12.42~ 13.42	25.24 26.84	—— ——	25.24 26.84	28.42 28.42	881.33 973.36

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

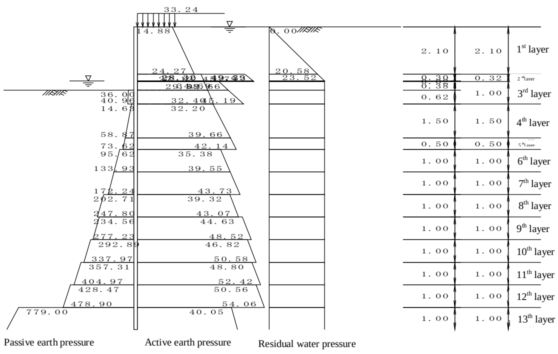
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	33.24 54.24	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.40	Clayey Soil	8.0	—	12.0 12.0	54.24 56.64	20.58 23.52	0.200 0.200	11.31 11.31	—— ——	—— ——	27.50 26.61
3	2.40~ 2.42	Clayey Soil	8.0	—	12.0 12.0	56.64 56.80	23.52 23.72	0.200 0.200	11.31 11.31	—— ——	—— ——	26.61 26.55
4	2.42~ 2.80	Clayey Soil	8.0	—	18.0 18.0	56.80 59.84	23.72 27.44	0.200 0.200	11.31 11.31	—— ——	—— ——	35.26 34.79
5	2.80~ 3.42	Clayey Soil	8.0	—	18.0 18.0	59.84 64.80	27.44 33.52	0.200 0.200	11.31 11.31	—— ——	—— ——	34.79 34.01
6	3.42~ 4.92	Sandy Soil	10.0	27.0	—— ——	64.80 79.80	33.52 48.22	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	4.92~ 5.42	Sandy Soil	10.0	27.0	—— ——	79.80 84.80	48.22 53.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
8	5.42~ 6.42	Sandy Soil	10.0	32.0	—— ——	84.80 94.80	53.12 62.92	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
9	6.42~ 7.42	Sandy Soil	10.0	32.0	—— ——	94.80 104.80	62.92 72.72	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
10	7.42~ 8.42	Sandy Soil	10.0	35.0	—— ——	104.80 114.80	72.72 82.52	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
11	8.42~ 9.42	Sandy Soil	10.0	34.0	—— ——	114.80 124.80	82.52 92.32	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
12	9.42~ 10.42	Sandy Soil	10.0	35.0	—— ——	124.80 134.80	92.32 102.12	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
13	10.42~ 11.42	Sandy Soil	10.0	36.0	—— ——	134.80 144.80	102.12 111.92	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—— ——
14	11.42~ 12.42	Sandy Soil	10.0	37.0	—— ——	144.80 154.80	111.92 121.72	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——

15	12.42~ 13.42	Sandy Soil	10.0	45.0	—— ——	154.80 164.80	121.72 131.52	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= tan⁻¹k

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp × cosδ
5	2.80~ 3.42	Clayey Soil	8.00	0.0	18.0 18.0	0.000 4.960	0.00 6.08	0.200 0.200	11.31 11.31	—— ——	—— ——
6	3.42~ 4.92	Sandy Soil	10.00	27.0	—— ——	4.960 19.960	6.08 20.78	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	4.92~ 5.42	Sandy Soil	10.00	27.0	—— ——	19.960 24.960	20.78 25.68	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
8	5.42~ 6.42	Sandy Soil	10.00	32.0	—— ——	24.960 34.960	25.68 35.48	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
9	6.42~ 7.42	Sandy Soil	10.00	32.0	—— ——	34.960 44.960	35.48 45.28	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
10	7.42~ 8.42	Sandy soil	10.00	35.0	—— ——	44.960 54.960	45.28 55.08	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
11	8.42~ 9.42	Sandy soil	10.00	34.0	—— ——	54.960 64.960	55.08 64.88	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
12	9.42~ 10.42	Sandy soil	10.00	35.0	—— ——	64.960 74.960	64.88 74.68	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
13	10.42~ 11.42	Sandy soil	10.00	36.0	—— ——	74.960 84.960	74.68 84.48	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
14	11.42~ 12.42	Sandy soil	10.00	37.0	—— ——	84.960 94.960	84.48 94.28	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
15	12.42~ 13.42	Sandy soil	10.00	45.0	—— ——	94.960 104.960	94.28 104.08	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= tan⁻¹k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta) \cdot \sin(\phi+\beta-\theta)}{\cos(\delta-\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	14.88 24.27	—— ——	14.88 24.27	0.00 20.58	—— ——
2	2.10~ 2.40	45.79 49.29	27.12 28.32	45.79 49.29	20.58 23.52	—— ——
3	2.40~ 2.42	49.29 49.53	28.32 28.40	49.29 49.53	23.52 23.52	—— ——
4	2.42~ 2.80	34.69 38.66	28.40 29.92	34.69 38.66	23.52 23.52	—— ——
5	2.80~ 3.42	38.66 45.19	29.92 32.40	38.66 45.19	23.52 23.52	36.00 40.96
6	3.42~ 4.92	32.20 39.66	—— ——	32.20 39.66	23.52 23.52	14.63 58.87
7	4.92~ 5.42	39.66 42.14	—— ——	39.66 42.14	23.52 23.52	58.87 73.62
8	5.42~ 6.42	35.38 39.55	—— ——	35.38 39.55	23.52 23.52	95.62 133.93
9	6.42~ 7.42	39.55 43.73	—— ——	39.55 43.73	23.52 23.52	133.93 172.24
10	7.42~ 8.42	39.32 43.07	—— ——	39.32 43.07	23.52 23.52	202.71 247.80
11	8.42~ 9.42	44.63 48.52	—— ——	44.63 48.52	23.52 23.52	234.56 277.23
12	9.42~ 10.42	46.82 50.58	—— ——	46.82 50.58	23.52 23.52	292.89 337.97
13	10.42~ 11.42	48.80 52.42	—— ——	48.80 52.42	23.52 23.52	357.31 404.97
14	11.42~ 12.42	50.56 54.06	—— ——	50.56 54.06	23.52 23.52	428.47 478.90
15	12.42~ 13.42	40.05 42.64	—— ——	40.05 42.64	23.52 23.52	779.00 861.03

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

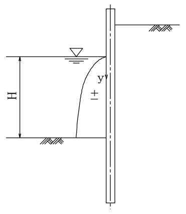
Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m^2)
1	2.40	0.00	0.00
2	2.80	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

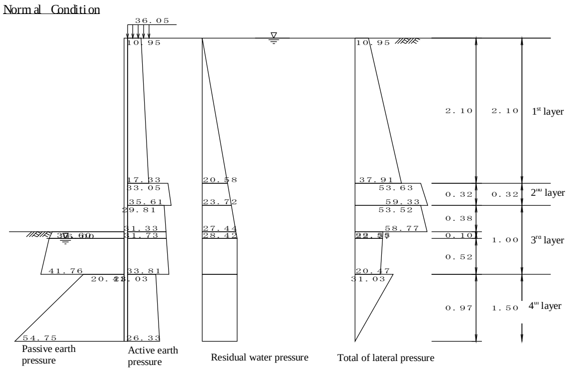
Where,
k_{hs} : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

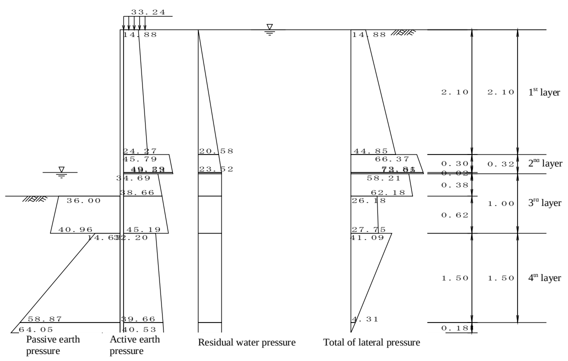


	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	10.95 17.33	0.00 20.58	—— ——	10.95 37.91
2	2.10~ 2.42	33.05 35.61	20.58 23.72	—— ——	53.63 59.33
3	2.42~ 2.80	29.81 31.33	23.72 27.44	—— ——	53.52 58.77
4	2.80~ 2.90	31.33 31.73	27.44 28.42	36.00 37.60	22.77 22.55
5	2.90~ 3.42	31.73 33.81	28.42 28.42	37.60 41.76	22.55 20.47
6	3.42~ 4.39	23.03 26.33	28.42 28.42	20.41 54.75	31.03 0.00
7	4.39~ 4.92	26.33 28.14	28.42 28.42	54.75 73.58	0.00 -17.02

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.59 m (GL -4.39 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	14.88 24.27	0.00 20.58	—— ——	14.88 44.85
2	2.10~ 2.40	45.79 49.29	20.58 23.52	—— ——	66.37 72.81
3	2.40~ 2.42	49.29 49.53	23.52 23.52	—— ——	72.81 73.05
4	2.42~ 2.80	34.69 38.66	23.52 23.52	—— ——	58.21 62.18
5	2.80~ 3.42	38.66 45.19	23.52 23.52	36.00 40.96	26.18 27.75
6	3.42~ 4.92	32.20 39.66	23.52 23.52	14.63 58.87	41.09 4.31
7	4.92~ 5.10	39.66 40.53	23.52 23.52	58.87 64.05	4.31 0.00
8	5.10~ 5.42	40.53 42.14	23.52 23.52	64.05 73.62	0.00 -7.96

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.30 m (GL -5.10 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.85			
Section efficiency	μ	=	1.00			
Young's modulus	E	=	200000 N/mm^2			
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)			
	I	=	130900 cm^4 (after reduction by corrosion and section)			
Inertia sectional moment	EI	=	200000 x 10^3 x 130900 x 10^{-8} = 2.618 x 10^5			

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	2.42	2
5	3.42	3
6	4.42	5
7	5.42	6
8	6.42	19
9	7.42	20
10	8.42	26

	Depth (m)	N-value
11	9.42	24
12	10.42	26
13	11.42	30
14	12.42	33
15	13.42	50
16	20.00	50

5-2 Normal Condition

K_h = 18704 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.366 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.74 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.39) to 2.74 m depth (GL -7.12m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	4.39	0.03	4.9	5.0	0.16
2	4.42	1.00	5.0	6.0	5.50
3	5.42	1.00	6.0	19.0	12.50
4	6.42	0.70	19.0	19.7	13.63
L = Σh = 2.74					ΣA = 31.78

A: (upper N-value + lower N-value) × h/2

1.159

$$\text{Average N-value} = \frac{\Sigma A}{L} = \frac{31.78}{2.74} = 11.62$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 11.62^{0.406} = 18704 \text{ kN/m}^3$$

Kh (normal condition) = 18704 kN/m^3

5-3 Seismic Condition

K_h = 20964 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}} = 0.376 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.66 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.10 m) to 2.66 m depth (GL -7.75 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	5.10	0.32	5.7	6.0	1.89
2	5.42	1.00	6.0	19.0	12.50
3	6.42	1.00	19.0	20.0	19.50
4	7.42	0.33	20.0	22.0	7.02
	L = Σh = 2.66				ΣA = 40.91

A (upper N-value + lower N-value) × h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{40.91}{2.66} = 15.39$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 15.39^{0.406} = 20964 \text{ kN/m}^3$$

K_h (seismic condition) = 20964 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.95 37.91	11.50 39.81	3.69 2.99	42.42 118.97
2	2.10~ 2.42	0.32	53.63 59.33	8.58 9.49	2.18 2.08	18.72 19.70
3	2.42~ 2.80	0.38	53.52 58.77	10.17 11.17	1.84 1.72	18.73 19.15
4	2.80~ 2.90	0.10	22.77 22.55	1.14 1.13	1.56 1.52	1.77 1.72
5	2.90~ 3.42	0.52	22.55 20.47	5.86 5.32	1.32 1.14	7.71 6.08
6	3.42~ 4.39	0.97	31.03 0.00	15.03 0.00	0.65 0.32	9.71 0.00
				ΣP = 119.19		ΣM = 264.68

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	5.1 kN/m
depth to acting position	H_t	=	-0.66 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.59 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 25.75 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{290.43}{124.29} = 2.34 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	14.88 44.85	15.62 47.10	4.40 3.70	68.66 174.05
2	2.10~ 2.40	0.30	66.37 72.81	9.95 10.92	2.90 2.80	28.82 30.53
3	2.40~ 2.42	0.02	72.81 73.05	0.73 0.73	2.69 2.68	1.96 1.96
4	2.42~ 2.80	0.38	58.21 62.18	11.06 11.81	2.55 2.42	28.19 28.62
5	2.80~ 3.42	0.62	26.18 27.75	8.11 8.60	2.09 1.88	16.95 16.19
6	3.42~ 4.92	1.50	41.09 4.31	30.82 3.23	1.18 0.68	36.23 2.18
7	4.92~ 5.10	0.18	4.31 0.00	0.38 0.00	0.12 0.06	0.04 0.00
				ΣP = 159.07		ΣM = 434.40

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	12.9 kN/m
depth to acting position	H_t	=	-0.48 m
moment	M_m	=	4.7 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.80 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.30 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 76.63 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.40~ 2.80	0.40	0.0 0.7	0.00 0.14	2.56 2.43	0.00 0.33
				ΣPdw = 0.14		ΣM dw = 0.33

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{511.36}{172.11} = 2.97 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	130900 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 130900 x 10^{-8}		=	2.618 x 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	18704 kN/m^3
calculated value	β	=	0.36557 m^{-1}
resultant earth force (lateral)	P_0	=	124.29 kN/m
height of acting position of load	h_0	=	2.34 m
moment	M_0	=	290.43 kN·m/m

in consideration of ϕ_m = 1.187,

maximum moment	M_{max}	=	344.59 kN·m/m
depth of generated position of M_{max}	l_m	=	0.968 m
depth of 1st fixed point	l_i	=	3.116 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	20964 kN/m^3
calculated value	β	=	0.37615 m^{-1}
resultant earth force (lateral)	P_0	=	172.11 kN/m
height of acting position of load	h_0	=	2.97 m
moment	M_0	=	511.36 kN·m/m

in consideration of ϕ_m = 1.123,

maximum moment	M_{max}	=	574.02 kN·m/m
depth of generated position of M_{max}	l_m	=	0.797 m
depth of 1st fixed point	l_i	=	2.885 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	4160 cm^3 (original condition)
	Z	=	3619 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{344.59\times10^6}{3619\times10^3} = 95\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2 \quad (ok)$$

6-5-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{574.02\times10^6}{3619\times10^3} = 159\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2 \quad (ok)$$

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.69 2.99	0.841 0.681	0.254 0.179	11.50 39.81	2.924 7.135
2	2.10~ 2.42	2.18 2.08	0.497 0.473	0.103 0.094	8.58 9.49	0.885 0.894
3	2.42~ 2.80	1.84 1.72	0.420 0.391	0.076 0.066	10.17 11.17	0.770 0.742
4	2.80~ 2.90	1.56 1.52	0.354 0.347	0.055 0.053	1.14 1.13	0.063 0.060
5	2.90~ 3.42	1.32 1.14	0.300 0.260	0.040 0.031	5.86 5.32	0.237 0.165
6	3.42~ 4.39	0.65 0.32	0.147 0.074	0.010 0.003	15.03 0.00	0.155 0.000
						ΣQ = 14.029

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

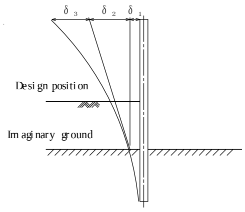
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3656\times2.34)\times124.29}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3656^3} = 0.00901\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3656\times2.34)\times124.29}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3656^2}\times(2.80+1.59) = 0.02111\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{14.03\times(2.80+1.59)^3}{2.00\times10^8\times130900\times10^{-8}} = 0.00453\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00067 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.39 m
Horizontal load: P = 5.10
Moment: M = 3.37

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00901 + 0.02111 + 0.00520
= 0.03532 m
= 35.32 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-5-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	4.40 3.70	0.863 0.725	0.265 0.199	15.62 47.10	4.141 9.392
2	2.10~ 2.40	2.90 2.80	0.568 0.549	0.131 0.123	9.95 10.92	1.303 1.343
3	2.40~ 2.42	2.69 2.68	0.528 0.526	0.115 0.114	0.73 0.73	0.084 0.083
4	2.42~ 2.80	2.55 2.42	0.500 0.475	0.104 0.095	11.06 11.81	1.153 1.123
5	2.80~ 3.42	2.09 1.88	0.410 0.369	0.073 0.060	8.11 8.60	0.589 0.515
6	3.42~ 4.92	1.18 0.68	0.231 0.133	0.025 0.008	30.82 3.23	0.757 0.027
7	4.92~ 5.10	0.12 0.06	0.023 0.011	0.000 0.000	0.38 0.00	0.000 0.000
						ΣQ = 20.510

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

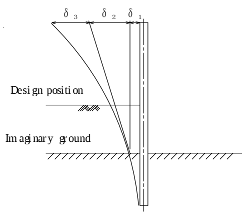
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.40~ 2.80	2.56 2.43	0.503 0.477	0.105 0.096	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below:
Q = 20.510 + 0.013 = 20.523

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3762\times2.97)\times172.11}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3762^3} = 0.01308\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3762\times2.97)\times172.11}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3762^2}\times(2.80+2.30) = 0.03830\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{20.52\times(2.80+2.30)^3}{2.00\times10^8\times130900\times10^{-8}} = 0.01037\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00248 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.10 m
Horizontal load: P = 12.90
Moment: M = 6.19

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=5.10\ m、h=L-H_m、H_m=0.80\ m、\quad h\leqq L)$$

$$= \frac{4.70\times4.30}{2\times2.00\times10^8\times130900\times10^{-8}}\times(2\times5.10-4.30) = 0.00023\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01308 + 0.03830 + 0.01308
= 0.06446 m
= 64.46 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	154000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 154000 \times 10^{-8}$		=	3.080×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 18704$ kN/m^3

Calculated value $\beta = 0.35102$ m^{-1}

Penetration length of SSP $D = 1.59 + \frac{3}{0.351} = 10.14$ m

Whole length of SSP $L = 2.80 - 0.40 + 10.14 = 12.54$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 20964$ kN/m^3

Calculated value $\beta = 0.36117$ m^{-1}

Penetration length of SSP $D = 2.30 + \frac{3}{0.361} = 10.60$ m

Whole length of SSP $L = 2.80 - 0.40 + 10.60 = 13.00$ m

Therefore, whole length of SSP is set as 13.50 m in consideration of round unit of SSP length.

8 Calculation Result

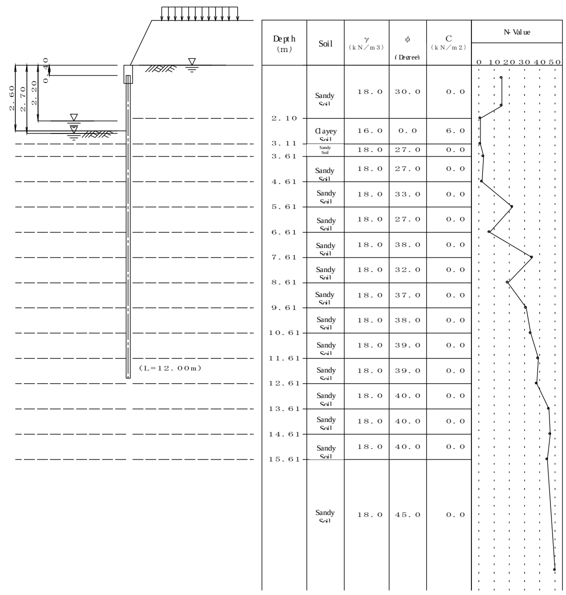
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	154000		
Section modulus	Z (cm^3)	4160		
Maximum bending moment	M_{max} (kN·m/m)		344.59	574.02
Stress intensity	σ (N/mm^2)		95 (185)	159 (278)
Lateral displacement	δ (mm)		35.32 (50.0)	64.46 (75.0)
Penetration depth	D (m)		10.14	10.60
Whole length of SSP	L (m)	13.50		

－Steel Sheet Pile Design Calculation－

Left Bank No. 22_STA 15+965 - 16+150

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	9.6 kNm (Normal Condition)
		P_t'	=	20.7 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.95 m (Normal Condition)
		H_t'	=	-0.77 m (Seismic Condition)
	Moment	M_m	=	0.5 kN-m/m (Normal Condition)
		M_m'	=	18.2 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m (Seismic Condition)
		H_m	=	0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \dfrac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	1
4	3.11	1
5	3.61	3
6	4.61	2
7	5.61	22
8	6.61	7
9	7.61	35
10	8.61	19

No	Depth (m)	N-Value
11	9.61	31
12	10.61	34
13	11.61	39
14	12.61	38
15	13.61	46
16	14.61	47
17	15.61	45
18	20.00	50

1.163

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

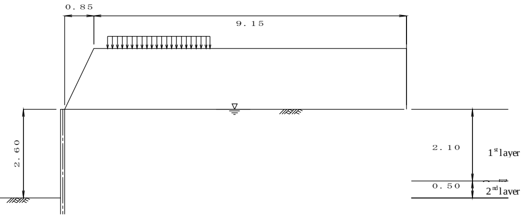
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.11	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	3.61	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.61	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.61	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
6	6.61	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	7.61	S	35.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
8	8.61	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
9	9.61	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
10	10.61	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
11	11.61	S	39.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
12	12.61	S	38.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
13	13.61	S	46.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
14	14.61	S	47.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
15	15.61	S	45.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
16	20.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kNm³)	φ (degree)	C (kNm²)	Normal	Seismic
1	Sandy soil	0.00	0.85	10.00	10.00	1.78	4.5	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	1.25	4.25	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	114000 cm⁴
Sectional factor	Z_0	=	3250 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0)	η	=	0.84
Corrosion rate (to Z_0)	η	=	0.87
Section efficiency (to I_0)	μ	=	1.00
Section efficiency (to Z_0)	μ	=	1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 Nmm² (Normal)
σ_a' = 278 Nmm² (Seismic)

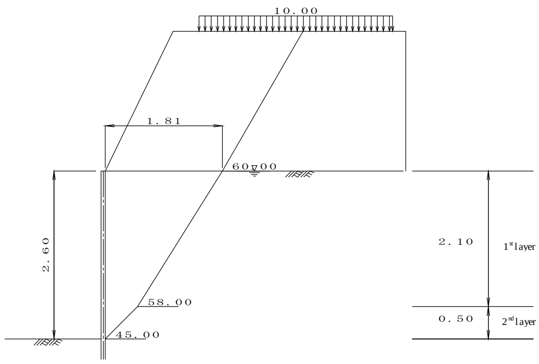
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam: calculated as distributed load of each layer

Reduction of material modulus:
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kNm³)	Σγh (kNm³)	Q (kNm³)	γwhw (kNm³)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	9.0	6.0	25.00	17.18	25.48	45.00
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	17.18	20.58	58.00
3		Embankment	30.0	——	0.0	8.01	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where.
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	58.00	2.10	0.50	0.50	1.81	2.60
3	60.00	1.78	1.81	2.60	2.84	4.38

Therefore, width of acting load shall be set as 1.81 m

2-1-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	4.5	3.38	15.23
Σ			15.23

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

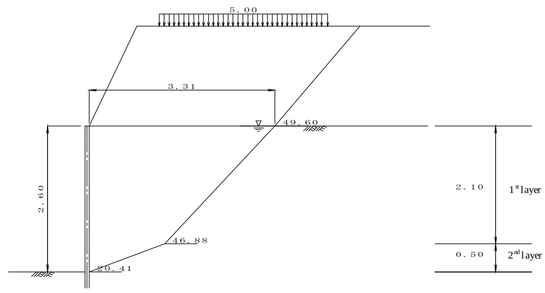
No	Q (kNm²)	l (m)	Q X l (kNm)
1	10.0	1.59	15.90
Σ			15.90

Q surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$
$$= \frac{15.23 + 15.90 + 0.00}{1.81}$$
$$= 17.18 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kNm³)	Σγh (kNm³)	Q (kNm³)	γwhw (kNm³)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	9.0	6.0	25.00	13.35	25.48	0.200	11.31	20.41
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	13.35	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	8.01	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	20.41	0.50	0.00	0.00	1.34	0.50
2	46.88	2.10	1.34	0.50	3.31	2.60
3	49.60	1.78	3.31	2.60	4.82	4.38

Therefore, width of acting load shall be set as 3.31 m

2-2-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	4.5	6.48	29.18
Σ			29.18

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kNm²)	l (m)	Q X l (kNm)
1	5.0	3.00	15.00
Σ			15.00

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

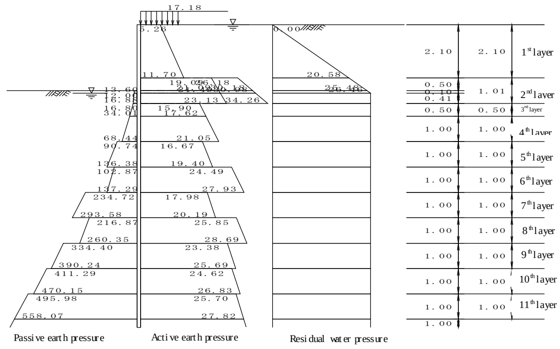
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{29.18 + 15.00 + 0.00}{3.31}$$

$$= 13.35 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	17.176 38.176	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.60	Clayey soil	8.0	—	6.0 6.0	38.176 42.176	—— ——	—— ——
3	2.60~ 2.70	Clayey soil	8.0	—	6.0 6.0	42.176 42.976	—— ——	—— ——
4	2.70~ 3.11	Clayey soil	8.0	—	6.0 6.0	42.976 46.256	—— ——	—— ——
5	3.11~ 3.61	Sandy soil	10.0	27.0	—— ——	46.256 51.256	0.34800 0.34800	0.34371 0.34371
6	3.61~ 4.61	Sandy soil	10.0	27.0	—— ——	51.256 61.256	0.34800 0.34800	0.34371 0.34371
7	4.61~ 5.61	Sandy soil	10.0	33.0	—— ——	61.256 71.256	0.27561 0.27561	0.27222 0.27222
8	5.61~ 6.61	Sandy soil	10.0	27.0	—— ——	71.256 81.256	0.34800 0.34800	0.34371 0.34371
9	6.61~ 7.61	Sandy soil	10.0	38.0	—— ——	81.256 91.256	0.22404 0.22404	0.22128 0.22128
10	7.61~ 8.61	Sandy soil	10.0	32.0	—— ——	91.256 101.256	0.28683 0.28683	0.28330 0.28330
11	8.61~ 9.61	Sandy soil	10.0	37.0	—— ——	101.256 111.256	0.23377 0.23377	0.23089 0.23089
12	9.61~ 10.61	Sandy soil	10.0	38.0	—— ——	111.256 121.256	0.22404 0.22404	0.22128 0.22128
13	10.61~ 11.61	Sandy soil	10.0	39.0	—— ——	121.256 131.256	0.21458 0.21458	0.21193 0.21193

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	11.61~ 12.61	Sandy soil	10.0	39.0	—— ——	131.256 141.256	0.21458 0.21458	0.21193 0.21193
15	12.61~ 13.61	Sandy soil	10.0	40.0	—— ——	141.256 151.256	0.20538 0.20538	0.20285 0.20285
16	13.61~ 14.61	Sandy soil	10.0	40.0	—— ——	151.256 161.256	0.20538 0.20538	0.20285 0.20285
17	14.61~ 15.61	Sandy soil	10.0	40.0	—— ——	161.256 171.256	0.20538 0.20538	0.20285 0.20285
18	15.61~ 20.00	Sandy soil	10.0	45.0	—— ——	171.256 215.156	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 9.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Clayey soil	16.0	0.0	6.0 6.0	0.000 1.600	—— ——	—— ——
4	2.70~ 3.11	Clayey soil	8.0	0.0	6.0 6.0	1.600 4.880	—— ——	—— ——
5	3.11~ 3.61	Sandy soil	10.0	27.0	—— ——	4.880 9.880	3.48553 3.48553	3.44261 3.44261
6	3.61~ 4.61	Sandy soil	10.0	27.0	—— ——	9.880 19.880	3.48553 3.48553	3.44261 3.44261
7	4.61~ 5.61	Sandy soil	10.0	33.0	—— ——	19.880 29.880	4.62104 4.62104	4.56415 4.56415
8	5.61~ 6.61	Sandy soil	10.0	27.0	—— ——	29.880 39.880	3.48553 3.48553	3.44261 3.44261
9	6.61~ 7.61	Sandy soil	10.0	38.0	—— ——	39.880 49.880	5.95910 5.95910	5.88573 5.88573
10	7.61~ 8.61	Sandy soil	10.0	32.0	—— ——	49.880 59.880	4.40199 4.40199	4.34780 4.34780
11	8.61~ 9.61	Sandy soil	10.0	37.0	—— ——	59.880 69.880	5.65410 5.65410	5.58449 5.58449
12	9.61~ 10.61	Sandy soil	10.0	38.0	—— ——	69.880 79.880	5.95910 5.95910	5.88573 5.88573
13	10.61~ 11.61	Sandy soil	10.0	39.0	—— ——	79.880 89.880	6.28642 6.28642	6.20903 6.20903
14	11.61~ 12.61	Sandy soil	10.0	39.0	—— ——	89.880 99.880	6.28642 6.28642	6.20903 6.20903
15	12.61~ 13.61	Sandy soil	10.0	40.0	—— ——	99.880 109.880	6.63830 6.63830	6.55657 6.55657

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
16	13.61~ 14.61	Sandy soil	10.0	40.0	—— ——	109.880 119.880	6.63830 6.63830	6.55657 6.55657
17	14.61~ 15.61	Sandy soil	10.0	40.0	—— ——	119.880 129.880	6.63830 6.63830	6.55657 6.55657
18	15.61~ 20.00	Sandy soil	10.0	45.0	—— ——	129.880 173.780	8.86593 8.86593	8.75678 8.75678

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -9.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta) \cdot \sin(\phi+\beta-\theta)}{\cos(\delta-\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	5.26 11.70	—— ——	5.26 11.70	0.00 20.58	—— ——
2	2.10~ 2.60	26.18 30.18	19.09 21.09	26.18 30.18	20.58 25.48	—— ——
3	2.60~ 2.70	30.18 30.98	21.09 21.49	30.18 30.98	25.48 26.46	12.00 13.60
4	2.70~ 3.11	30.98 34.26	21.49 23.13	30.98 34.26	26.46 26.46	13.60 16.88
5	3.11~ 3.61	15.90 17.62	—— ——	15.90 17.62	26.46 26.46	16.80 34.01
6	3.61~ 4.61	17.62 21.05	—— ——	17.62 21.05	26.46 26.46	34.01 68.44
7	4.61~ 5.61	16.67 19.40	—— ——	16.67 19.40	26.46 26.46	90.74 136.38
8	5.61~ 6.61	24.49 27.93	—— ——	24.49 27.93	26.46 26.46	102.87 137.29
9	6.61~ 7.61	17.98 20.19	—— ——	17.98 20.19	26.46 26.46	234.72 293.58
10	7.61~ 8.61	25.85 28.69	—— ——	25.85 28.69	26.46 26.46	216.87 260.35
11	8.61~ 9.61	23.38 25.69	—— ——	23.38 25.69	26.46 26.46	334.40 390.24
12	9.61~ 10.61	24.62 26.83	—— ——	24.62 26.83	26.46 26.46	411.29 470.15
13	10.61~ 11.61	25.70 27.82	—— ——	25.70 27.82	26.46 26.46	495.98 558.07
14	11.61~ 12.61	27.82 29.94	—— ——	27.82 29.94	26.46 26.46	558.07 620.16
15	12.61~ 13.61	28.65 30.68	—— ——	28.65 30.68	26.46 26.46	654.87 720.44
16	13.61~ 14.61	30.68 32.71	—— ——	30.68 32.71	26.46 26.46	720.44 786.00
17	14.61~ 15.61	32.71 34.74	—— ——	32.71 34.74	26.46 26.46	786.00 851.57
18	15.61~ 20.00	27.61 34.69	—— ——	27.61 34.69	26.46 26.46	1137.33 1521.75

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

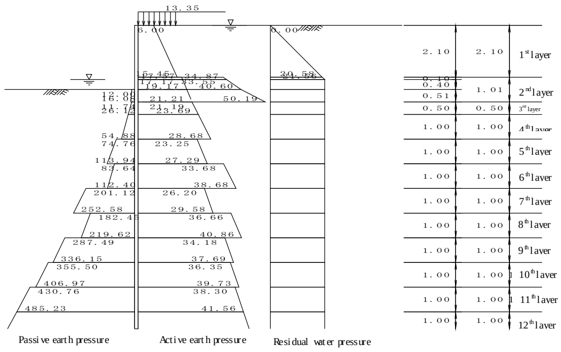
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	13.35 34.35	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10~ 2.20	Clayey Soil	8.0	—	6.0 6.0	34.35 35.15	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	24.37 23.65
3	2.20~ 2.60	Clayey Soil	8.0	—	6.0 6.0	35.15 38.35	21.56 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	23.65 20.41
4	2.60~ 3.11	Clayey Soil	8.0	—	6.0 6.0	38.35 42.43	25.48 30.48	0.200 0.200	11.31 11.31	—— ——	—— ——	20.41 14.87
5	3.11~ 3.61	Sandy Soil	10.0	27.0	—— ——	42.43 47.43	30.48 35.38	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——

Case: Left Bank No. 22_STA 15+965_16+150

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	3.61~ 4.61	Sandy Soil	10.0	27.0	—— ——	47.43 57.43	35.38 45.18	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
7	4.61~ 5.61	Sandy Soil	10.0	33.0	—— ——	57.43 67.43	45.18 54.98	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——
8	5.61~ 6.61	Sandy Soil	10.0	27.0	—— ——	67.43 77.43	54.98 64.78	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
9	6.61~ 7.61	Sandy Soil	10.0	38.0	—— ——	77.43 87.43	64.78 74.58	0.200 0.200	11.31 11.31	0.34256 0.34256	0.33834 0.33834	—— ——
10	7.61~ 8.61	Sandy Soil	10.0	32.0	—— ——	87.43 97.43	74.58 84.38	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
11	8.61~ 9.61	Sandy Soil	10.0	37.0	—— ——	97.43 107.43	84.38 94.18	0.200 0.200	11.31 11.31	0.35524 0.35524	0.35087 0.35087	—— ——
12	9.61~ 10.61	Sandy Soil	10.0	38.0	—— ——	107.43 117.43	94.18 103.98	0.200 0.200	11.31 11.31	0.34256 0.34256	0.33834 0.33834	—— ——
13	10.61~ 11.61	Sandy Soil	10.0	39.0	—— ——	117.43 127.43	103.98 113.78	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
14	11.61~ 12.61	Sandy Soil	10.0	39.0	—— ——	127.43 137.43	113.78 123.58	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
15	12.61~ 13.61	Sandy Soil	10.0	40.0	—— ——	137.43 147.43	123.58 133.38	0.200 0.200	11.31 11.31	0.31824 0.31824	0.31432 0.31432	—— ——
16	13.61~ 14.61	Sandy Soil	10.0	40.0	—— ——	147.43 157.43	133.38 143.18	0.200 0.200	11.31 11.31	0.31824 0.31824	0.31432 0.31432	—— ——
17	14.61~ 15.61	Sandy Soil	10.0	40.0	—— ——	157.43 167.43	143.18 152.98	0.200 0.200	11.31 11.31	0.31824 0.31824	0.31432 0.31432	—— ——
18	15.61~ 20.00	Sandy Soil	10.0	45.0	—— ——	167.43 211.33	152.98 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a=\frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta=\tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 3.11	Clayey Soil	8.00	0.0	6.0 6.0	0.000 4.080	0.00 5.00	0.200 0.200	11.31 11.31	—— ——	—— ——
5	3.11~ 3.61	Sandy Soil	10.00	27.0	—— ——	4.080 9.080	5.00 9.90	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	3.61~ 4.61	Sandy Soil	10.00	27.0	—— ——	9.080 19.080	9.90 19.70	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626

Case: Left Bank No. 22_STA 15+965_16+150

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
7	4.61~ 5.61	Sandy Soil	10.00	33.0	—— ——	19.080 29.080	19.70 29.50	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819
8	5.61~ 6.61	Sandy Soil	10.00	27.0	—— ——	29.080 39.080	29.50 39.30	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
9	6.61~ 7.61	Sandy Soil	10.00	38.0	—— ——	39.080 49.080	39.30 49.10	0.200 0.200	11.31 11.31	5.21042 5.21042	5.14627 5.14627
10	7.61~ 8.61	Sandy Soil	10.00	32.0	—— ——	49.080 59.080	49.10 58.90	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
11	8.61~ 9.61	Sandy Soil	10.00	37.0	—— ——	59.080 69.080	58.90 68.70	0.200 0.200	11.31 11.31	4.92675 4.92675	4.86609 4.86609
12	9.61~ 10.61	Sandy Soil	10.00	38.0	—— ——	69.080 79.080	68.70 78.50	0.200 0.200	11.31 11.31	5.21042 5.21042	5.14627 5.14627
13	10.61~ 11.61	Sandy Soil	10.00	39.0	—— ——	79.080 89.080	78.50 88.30	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
14	11.61~ 12.61	Sandy Soil	10.00	39.0	—— ——	89.080 99.080	88.30 98.10	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
15	12.61~ 13.61	Sandy Soil	10.00	40.0	—— ——	99.080 109.080	98.10 107.90	0.200 0.200	11.31 11.31	5.84277 5.84277	5.77084 5.77084
16	13.61~ 14.61	Sandy Soil	10.00	40.0	—— ——	109.080 119.080	107.90 117.70	0.200 0.200	11.31 11.31	5.84277 5.84277	5.77084 5.77084
17	14.61~ 15.61	Sandy Soil	10.00	40.0	—— ——	119.080 129.080	117.70 127.50	0.200 0.200	11.31 11.31	5.84277 5.84277	5.77084 5.77084
18	15.61~ 20.00	Sandy Soil	10.00	45.0	—— ——	129.080 172.980	127.50 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p=\frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	6.00 15.45	—— ——	6.00 15.45	0.00 20.58	—— ——
2	2.10~ 2.20	33.55 34.87	17.17 17.57	33.55 34.87	20.58 21.56	—— ——
3	2.20~ 2.60	34.87 40.60	17.57 19.17	34.87 40.60	21.56 21.56	—— ——
4	2.60~ 3.11	40.60 50.19	19.17 21.21	40.60 50.19	21.56 21.56	12.00 16.08
5	3.11~ 3.61	21.19 23.69	—— ——	21.19 23.69	21.56 21.56	11.74 26.12
6	3.61~ 4.61	23.69 28.68	—— ——	23.69 28.68	21.56 21.56	26.12 54.88
7	4.61~ 5.61	23.25 27.29	—— ——	23.25 27.29	21.56 21.56	74.76 113.94

Case: Left Bank No. 22_STA 15+965_16+150

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
8	5.61~ 6.61	33.68 38.68	—— ——	33.68 38.68	21.56 21.56	83.64 112.40
9	6.61~ 7.61	26.20 29.58	—— ——	26.20 29.58	21.56 21.56	201.12 252.58
10	7.61~ 8.61	36.66 40.86	—— ——	36.66 40.86	21.56 21.56	182.45 219.62
11	8.61~ 9.61	34.18 37.69	—— ——	34.18 37.69	21.56 21.56	287.49 336.15
12	9.61~ 10.61	36.35 39.73	—— ——	36.35 39.73	21.56 21.56	355.50 406.97
13	10.61~ 11.61	38.30 41.56	—— ——	38.30 41.56	21.56 21.56	430.76 485.23
14	11.61~ 12.61	41.56 44.82	—— ——	41.56 44.82	21.56 21.56	485.23 539.70
15	12.61~ 13.61	43.20 46.34	—— ——	43.20 46.34	21.56 21.56	571.77 629.48
16	13.61~ 14.61	46.34 49.48	—— ——	46.34 49.48	21.56 21.56	629.48 687.19
17	14.61~ 15.61	49.48 52.63	—— ——	49.48 52.63	21.56 21.56	687.19 744.90
18	15.61~ 20.00	43.50 54.90	—— ——	43.50 54.90	21.56 21.56	1010.07 1353.59

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

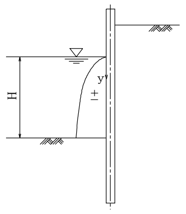
Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

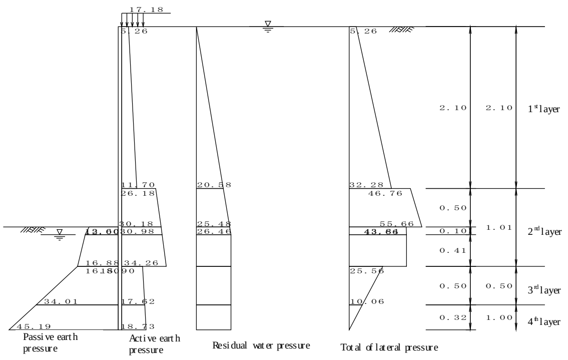
Where,
k_{hs}: design seismic coefficient
γ_w: unit weight of water
H: water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

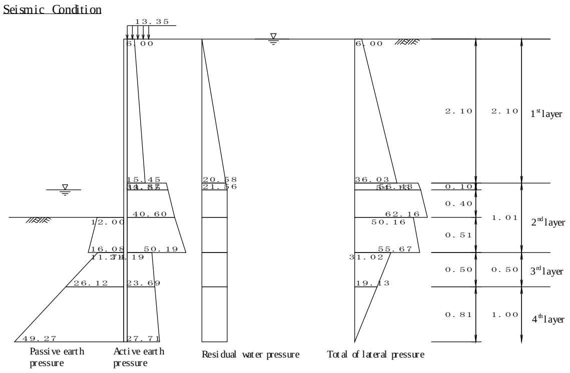


	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	5.26 11.70	0.00 20.58	—— ——	5.26 32.28
2	2.10~ 2.60	26.18 30.18	20.58 25.48	—— ——	46.76 55.66
3	2.60~ 2.70	30.18 30.98	25.48 26.46	12.00 13.60	43.66 43.84
4	2.70~ 3.11	30.98 34.26	26.46 26.46	13.60 16.88	43.84 43.84
5	3.11~ 3.61	15.90 17.62	26.46 26.46	16.80 34.01	25.56 10.06
6	3.61~ 3.94	17.62 18.73	26.46 26.46	34.01 45.19	10.06 0.00
7	3.94~ 4.61	18.73 21.05	26.46 26.46	45.19 68.44	0.00 -20.92

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.34 m (GL -3.94 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	6.00 15.45	0.00 20.58	—— ——	6.00 36.03
2	2.10~ 2.20	33.55 34.87	20.58 21.56	—— ——	54.13 56.43
3	2.20~ 2.60	34.87 40.60	21.56 21.56	—— ——	56.43 62.16
4	2.60~ 3.11	40.60 50.19	21.56 21.56	12.00 16.08	50.16 55.67
5	3.11~ 3.61	21.19 23.69	21.56 21.56	11.74 26.12	31.02 19.13
6	3.61~ 4.42	23.69 27.71	21.56 21.56	26.12 49.27	19.13 0.00
7	4.42~ 4.61	27.71 28.68	21.56 21.56	49.27 54.88	0.00 -4.63

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.82 m (GL -4.42 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 95760 \times 10^{-8} = 1.915 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	1
4	3.11	1
5	3.61	3
6	4.61	2
7	5.61	22
8	6.61	7
9	7.61	35
10	8.61	19

	Depth (m)	N-value
11	9.61	31
12	10.61	34
13	11.61	39
14	12.61	38
15	13.61	46
16	14.61	47
17	15.61	45
18	20.00	50

5-2 Normal Condition

K_h = 18033 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.392 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.55 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) to 2.55 m depth (GL -6.49 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	3.93	0.68	2.7	2.0	1.58
2	4.61	1.00	2.0	22.0	12.00
3	5.61	0.88	22.0	8.8	13.53
L = Σh = 2.55					ΣA = 27.11

A: (upper N-value + lower N-value) × h/2

1.167

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{27.11}{2.55}$

$= 10.62$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.62^{0.406} = 18033$ kN/m³

Kh (normal condition) = 18033 kNm³

5-3 Seismic Condition

K_h = 19056 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.397$ m⁻¹

$$L = \frac{1}{\beta} = 2.52 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.42 m) to 2.52 m depth (GL -6.93 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.42	0.19	2.2	2.0	0.41
2	4.61	1.00	2.0	22.0	12.00
3	5.61	1.00	22.0	7.0	14.50
4	6.61	0.32	7.0	16.0	3.72
	L = Σh = 2.52				ΣA = 30.63

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{30.63}{2.52}$

$= 12.16$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 12.16^{0.406} = 19056$ kN/m³

Kh (seismic condition) = 19056 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	5.26 32.28	5.53 33.89	3.23 2.53	17.88 85.91
2	2.10~ 2.60	0.50	46.76 55.66	11.69 13.91	1.67 1.50	19.50 20.89
3	2.60~ 2.70	0.10	43.66 43.84	2.18 2.19	1.30 1.27	2.84 2.78
4	2.70~ 3.11	0.41	43.84 43.84	8.99 8.99	1.10 0.96	9.87 8.64
5	3.11~ 3.61	0.50	25.56 10.06	6.39 2.52	0.66 0.49	4.21 1.24
6	3.61~ 3.93	0.32	10.06 0.00	1.63 0.00	0.22 0.11	0.35 0.00
				ΣP = 97.91		ΣM = 174.10

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.6 kNm
depth to acting position	H	=	-0.95 m
moment	M_m	=	0.5 kN·m/m
depth to acting position	H_t	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.33 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 47.39$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{221.49}{107.51} = 2.06 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	6.00 36.03	6.30 37.83	3.72 3.02	23.42 114.06
2	2.10~ 2.20	0.10	54.13 56.43	2.71 2.82	2.28 2.25	6.18 6.34
3	2.20~ 2.60	0.40	56.43 62.16	11.29 12.43	2.08 1.95	23.49 24.22

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
4	2.60~ 3.11	0.51	50.16 55.67	12.79 14.20	1.65 1.48	21.04 20.94
5	3.11~ 3.61	0.50	31.02 19.13	7.75 4.78	1.14 0.97	8.83 4.65
6	3.61~ 4.42	0.81	19.13 0.00	7.70 0.00	0.54 0.27	4.13 0.00
				ΣP = 120.60		ΣM = 257.30

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	20.7 kNm
depth to acting position	H	=	-0.77 m
moment	M_m	=	18.2 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.82 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 125.53$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.08 1.95	0.00 0.27
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.27

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{383.10}{141.44} = 2.71 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 95760 x 10⁻⁸		=	1.915 x 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	18033 kNm³
calculated value	β	=	0.39170 m⁻¹
resultant earth force (lateral)	P_0	=	107.51 kNm
height of acting position of load	h_0	=	2.06 m
moment	M_0	=	221.49 kN·m/m

in consideration of ψ_h = 1.203,

maximum moment	M_{max}	=	266.53 kN·m/m
depth of generated position of M_{max}	l_m	=	0.933 m
depth of 1st fixed point	l_i	=	2.938 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	19056 kNm³
calculated value	β	=	0.39714 m⁻¹
resultant earth force (lateral)	P_0	=	141.44 kNm
height of acting position of load	h_0	=	2.71 m
moment	M_0	=	383.10 kN·m/m

in consideration of ψ_h = 1.130,

maximum moment	M_{max}	=	432.99 kN·m/m
depth of generated position of M_{max}	l_m	=	0.774 m
depth of 1st fixed point	l_i	=	2.751 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm^3 (original condition)
	Z	=	2828 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{266.53\times10^6}{2828\times10^3} = 94\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{432.99\times10^6}{2828\times10^3} = 153\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.23 2.53	0.822 0.644	0.245 0.163	5.53 33.89	1.356 5.522
2	2.10~ 2.60	1.67 1.50	0.424 0.382	0.077 0.064	11.69 13.91	0.902 0.884
3	2.60~ 2.70	1.30 1.27	0.331 0.322	0.049 0.046	2.18 2.19	0.106 0.102
4	2.70~ 3.11	1.10 0.96	0.279 0.244	0.035 0.027	8.99 8.99	0.317 0.246
5	3.11~ 3.61	0.66 0.49	0.167 0.125	0.013 0.007	6.39 2.52	0.084 0.019
6	3.61~ 3.93	0.22 0.11	0.055 0.028	0.001 0.000	1.63 0.00	0.002 0.000
						ΣQ = 9.542

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

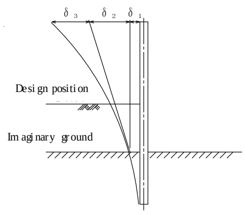
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3917\times2.06)\times107.51}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3917^3} = 0.00844\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3917\times2.06)\times107.51}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3917^2}\times(2.60+1.33) = 0.01882\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.54\times(2.60+1.33)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00304\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00139 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.93 m
Horizontal load: P = 9.60
Moment: M = 9.12

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=3.93\ m,\ h=L-H_m,\ H_m=0.00\ m,\quad h\leqq L)$$

$$= \frac{0.50\times3.93}{2\times2.00\times10^8\times95760\times10^{-8}}\times(2\times3.93-3.93) = 0.00002\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00844 + 0.01882 + 0.00444
= 0.03170 m
= 31.70 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.72 3.02	0.841 0.683	0.255 0.180	6.30 37.83	1.606 6.813
2	2.10~ 2.20	2.28 2.25	0.517 0.509	0.111 0.108	2.71 2.82	0.299 0.304
3	2.20~ 2.60	2.08 1.95	0.472 0.441	0.094 0.083	11.29 12.43	1.057 1.032
4	2.60~ 3.11	1.65 1.48	0.373 0.334	0.061 0.050	12.79 14.20	0.778 0.704
5	3.11~ 3.61	1.14 0.97	0.258 0.220	0.030 0.022	7.75 4.78	0.236 0.107
6	3.61~ 4.42	0.54 0.27	0.122 0.061	0.007 0.002	7.70 0.00	0.055 0.000
						ΣQ = 12.991

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

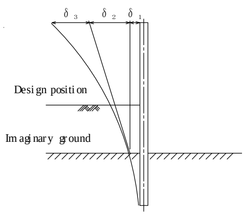
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	2.08 1.95	0.472 0.441	0.094 0.083	0.00 0.14	0.000 0.011
						ΣQdw = 0.011

Therefore, modulus of deformation Q is calculated as below:
Q = 12.991 + 0.011 = 13.002

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3971\times2.71)\times141.44}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3971^3} = 0.01224\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3971\times2.71)\times141.44}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3971^2}\times(2.60+1.82) = 0.03257\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.00\times(2.60+1.82)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00584\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00391 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.42 m
Horizontal load: P = 20.70
Moment: M = 15.94

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01224 + 0.03257 + 0.01065
= 0.05546 m
= 55.46 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)
	I	=	114000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 114000 \times 10^{-8}$		=	2.280×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 18033\ kN/m^3$

Calculated value $\beta = 0.37499\ m^{-1}$

Penetration length of SSP $D = 1.33 + \frac{3}{0.375} = 9.33\ m$

Whole length of SSP $L = 2.60 - 0.40 + 9.33 = 11.53\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 19056\ kN/m^3$

Calculated value $\beta = 0.38020\ m^{-1}$

Penetration length of SSP $D = 1.82 + \frac{3}{0.380} = 9.71\ m$

Whole length of SSP $L = 2.60 - 0.40 + 9.71 = 11.91\ m$

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

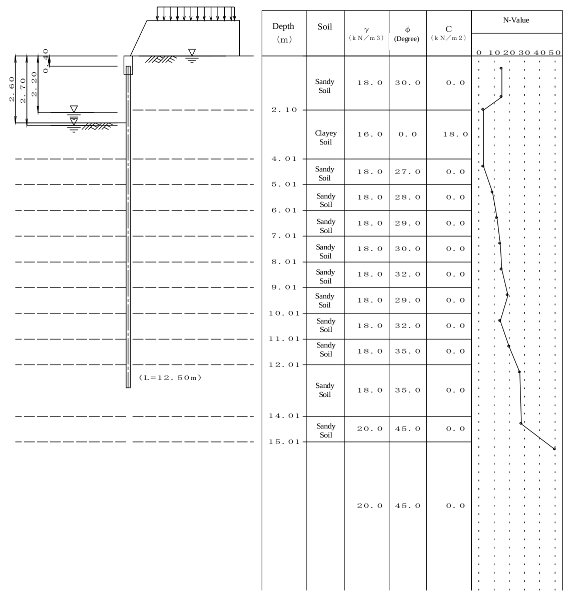
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		266.53	432.99
Stress intensity	σ (Nmm^2)		94 (185)	153 (278)
Lateral displacement	δ (mm)		31.70 (50.0)	55.46 (75.0)
Penetration depth	D (m)		9.33	9.71
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 23_STA. 16+150 - 16+200

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wb}	=	2.70 m (Normal Condition)
	L_{wb}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	4.7 kNm (Normal Condition)
		Pt'	=	12.5 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.63 m (Normal Condition)
		Ht'	=	-0.48 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	2.7 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	3
4	4.31	3
5	5.31	9
6	6.31	12
7	7.31	14
8	8.31	15
9	9.31	19
10	10.31	14

No	Depth (m)	N-Value
11	11.31	20
12	12.31	27
13	14.31	28
14	15.31	50
15	20.00	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ (kN/m³)	γ' (kN/m³)	ϕ	C (kN/m²)	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m³) normal	kh(kN/m³) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.01	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
3	5.01	S	9.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	6.01	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
5	7.01	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
6	8.01	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
7	9.01	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
8	10.01	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
9	11.01	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
10	12.01	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
11	14.01	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
12	15.01	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
13	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

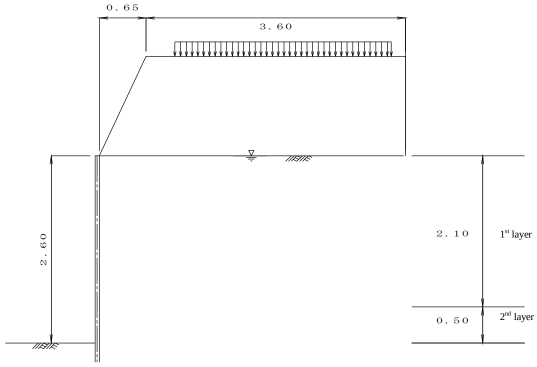
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1.171

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.65	4.25	4.25	1.38	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.05	4.05	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

Case: Left Bank No. 23_STA 16+150_16+200

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 11400 cm^4
Sectional factor Z_0 = 3250 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.84
Corrosion rate (to Z_0) η = 0.87
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 N/mm^2 (Normal)
σ_a' = 278 N/mm^2 (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

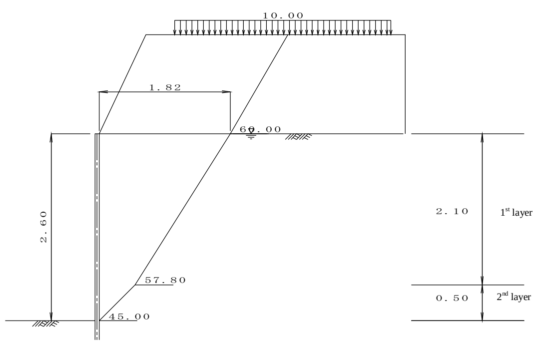
Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

Case: Left Bank No. 23_STA 16+150_16+200

2 Calculation of Acting Load

2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	18.0	25.00	34.45	25.48	45.00
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	34.45	20.58	57.80
3		Embankment	30.0	——	0.0	24.84	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^o since $\theta=0^o$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00^o$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

Case: Left Bank No. 23_STA 16+150_16+200

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	1.38	1.82	2.60	2.62	3.98

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.62	47.09
Σ			47.09

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.57	15.69
Σ			15.69

Q surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

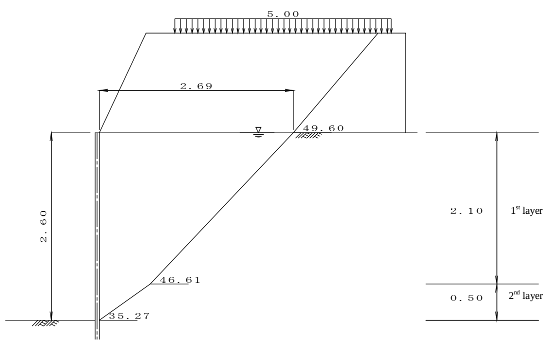
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{47.09 + 15.69 + 0.00}{1.82}$$

$$= 34.45\ kN/m^2$$

1.172

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	18.0	25.00	32.49	25.48	0.200	11.31	35.27
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	32.49	20.58	0.200	11.31	46.61
3		embankment	30.0	—	0.0	24.84	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00^{0}$)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^{-3}) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^{-2})
C cohesive force of soil (kNm^{-2})

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	35.27	0.50	0.00	0.00	0.71	0.50
2	46.61	2.10	0.71	0.50	2.69	2.60
3	49.60	1.38	2.69	2.60	3.87	3.98

Therefore, width of acting load shall be set as 2.69 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.08	73.39
Σ			73.39

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.82	14.08
Σ			14.08

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

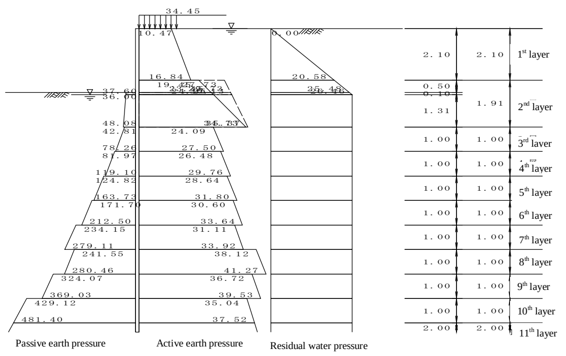
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{73.39 + 14.08 + 0.00}{2.69}$$

$$= 32.49 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	— —	34.450 55.450	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Clayey soil	8.0	—	18.0 18.0	55.450 59.450	— —	— —
3	2.60~ 2.70	Clayey soil	8.0	—	18.0 18.0	59.450 60.250	— —	— —
4	2.70~ 4.01	Clayey soil	8.0	—	18.0 18.0	60.250 70.730	— —	— —
5	4.01~ 5.01	Sandy soil	10.0	27.0	— —	70.730 80.730	0.34585 0.34585	0.34060 0.34060
6	5.01~ 6.01	Sandy soil	10.0	28.0	— —	80.730 90.730	0.33303 0.33303	0.32798 0.32798
7	6.01~ 7.01	Sandy soil	10.0	29.0	— —	90.730 100.730	0.32058 0.32058	0.31571 0.31571
8	7.01~ 8.01	Sandy soil	10.0	30.0	— —	100.730 110.730	0.30847 0.30847	0.30378 0.30378
9	8.01~ 9.01	Sandy soil	10.0	32.0	— —	110.730 120.730	0.28525 0.28525	0.28092 0.28092
10	9.01~ 10.01	Sandy soil	10.0	29.0	— —	120.730 130.730	0.32058 0.32058	0.31571 0.31571
11	10.01~ 11.01	Sandy soil	10.0	32.0	— —	130.730 140.730	0.28525 0.28525	0.28092 0.28092
12	11.01~ 12.01	Sandy soil	10.0	35.0	— —	140.730 150.730	0.25279 0.25279	0.24895 0.24895
13	12.01~ 14.01	Sandy soil	10.0	35.0	— —	150.730 170.730	0.25279 0.25279	0.24895 0.24895

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	14.01~ 15.01	Sandy soil	10.0	45.0	— —	170.730 180.730	0.16262 0.16262	0.16015 0.16015
15	15.01~ 20.00	Sandy soil	10.0	45.0	— —	180.730 230.630	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Clayey soil	16.0	0.0	18.0 18.0	0.000 1.600	— —	— —
4	2.70~ 4.01	Clayey soil	8.0	0.0	18.0 18.0	1.600 12.080	— —	— —
5	4.01~ 5.01	Sandy soil	10.0	27.0	— —	12.080 22.080	3.59892 3.59892	3.54425 3.54425
6	5.01~ 6.01	Sandy soil	10.0	28.0	— —	22.080 32.080	3.76978 3.76978	3.71251 3.71251
7	6.01~ 7.01	Sandy soil	10.0	29.0	— —	32.080 42.080	3.95096 3.95096	3.89093 3.89093
8	7.01~ 8.01	Sandy soil	10.0	30.0	— —	42.080 52.080	4.14330 4.14330	4.08035 4.08035
9	8.01~ 9.01	Sandy soil	10.0	32.0	— —	52.080 62.080	4.56530 4.56530	4.49594 4.49594
10	9.01~ 10.01	Sandy soil	10.0	29.0	— —	62.080 72.080	3.95096 3.95096	3.89093 3.89093
11	10.01~ 11.01	Sandy soil	10.0	32.0	— —	72.080 82.080	4.56530 4.56530	4.49594 4.49594
12	11.01~ 12.01	Sandy soil	10.0	35.0	— —	82.080 92.080	5.30876 5.30876	5.22810 5.22810
13	12.01~ 14.01	Sandy soil	10.0	35.0	— —	92.080 112.080	5.30876 5.30876	5.22810 5.22810
14	14.01~ 15.01	Sandy soil	10.0	45.0	— —	112.080 122.080	9.34548 9.34548	9.20351 9.20351
15	15.01~ 20.00	Sandy soil	10.0	45.0	— —	122.080 171.980	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	10.47 16.84	—— ——	10.47 16.84	0.00 20.58	—— ——
2	2.10~ 2.60	19.45 23.45	27.73 29.73	27.73 29.73	20.58 25.48	—— ——
3	2.60~ 2.70	23.45 24.25	29.73 30.13	29.73 30.13	25.48 26.46	36.00 37.60
4	2.70~ 4.01	24.25 34.73	30.13 35.37	30.13 35.37	26.46 26.46	37.60 48.08
5	4.01~ 5.01	24.09 27.50	—— ——	24.09 27.50	26.46 26.46	42.81 78.26
6	5.01~ 6.01	26.48 29.76	—— ——	26.48 29.76	26.46 26.46	81.97 119.10
7	6.01~ 7.01	28.64 31.80	—— ——	28.64 31.80	26.46 26.46	124.82 163.73
8	7.01~ 8.01	30.60 33.64	—— ——	30.60 33.64	26.46 26.46	171.70 212.50
9	8.01~ 9.01	31.11 33.92	—— ——	31.11 33.92	26.46 26.46	234.15 279.11
10	9.01~ 10.01	38.12 41.27	—— ——	38.12 41.27	26.46 26.46	241.55 280.46
11	10.01~ 11.01	36.72 39.53	—— ——	36.72 39.53	26.46 26.46	324.07 369.03
12	11.01~ 12.01	35.04 37.52	—— ——	35.04 37.52	26.46 26.46	429.12 481.40
13	12.01~ 14.01	37.52 42.50	—— ——	37.52 42.50	26.46 26.46	481.40 585.97
14	14.01~ 15.01	27.34 28.94	—— ——	27.34 28.94	26.46 26.46	1031.53 1123.56
15	15.01~ 20.00	28.94 36.94	—— ——	28.94 36.94	26.46 26.46	1123.56 1582.82

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

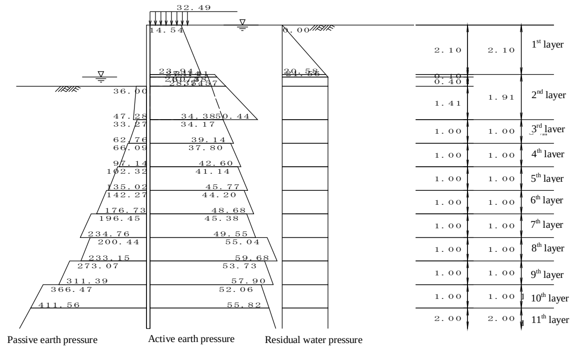
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	32.49 53.49	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Clayey Soil	8.0	—	18.0 18.0	53.49 54.29	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	35.86 35.74
3	2.20~ 2.60	Clayey Soil	8.0	—	18.0 18.0	54.29 57.49	21.56 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	35.74 35.27
4	2.60~ 4.01	Clayey Soil	8.0	—	18.0 18.0	57.49 68.77	25.48 39.30	0.200 0.200	11.31 11.31	—— ——	—— ——	35.27 33.48
5	4.01~ 5.01	Sandy Soil	10.0	27.0	—— ——	68.77 78.77	39.30 49.10	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	5.01~ 6.01	Sandy Soil	10.0	28.0	—— ——	78.77 88.77	49.10 58.90	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
7	6.01~ 7.01	Sandy Soil	10.0	29.0	—— ——	88.77 98.77	58.90 68.70	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
8	7.01~ 8.01	Sandy Soil	10.0	30.0	—— ——	98.77 108.77	68.70 78.50	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
9	8.01~ 9.01	Sandy Soil	10.0	32.0	—— ——	108.77 118.77	78.50 88.30	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
10	9.01~ 10.01	Sandy Soil	10.0	29.0	—— ——	118.77 128.77	88.30 98.10	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
11	10.01~ 11.01	Sandy Soil	10.0	32.0	—— ——	128.77 138.77	98.10 107.90	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
12	11.01~ 12.01	Sandy Soil	10.0	35.0	—— ——	138.77 148.77	107.90 117.70	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
13	12.01~ 14.01	Sandy Soil	10.0	35.0	—— ——	148.77 168.77	117.70 137.30	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
14	14.01~ 15.01	Sandy Soil	10.0	45.0	—— ——	168.77 178.77	137.30 147.10	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
15	15.01~ 20.00	Sandy Soil	10.0	45.0	—— ——	178.77 228.67	147.10 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta= 10.00$, $\beta= 0.00$, $\theta= \tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 4.01	Clayey Soil	8.00	0.0	18.0 18.0	0.000 11.280	0.00 13.82	0.200 0.200	11.31 11.31	—— ——	—— ——
5	4.01~ 5.01	Sandy Soil	10.00	27.0	—— ——	11.280 21.280	13.82 23.62	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	5.01~ 6.01	Sandy Soil	10.00	28.0	—— ——	21.280 31.280	23.62 33.42	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
7	6.01~ 7.01	Sandy Soil	10.00	29.0	—— ——	31.280 41.280	33.42 43.22	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
8	7.01~ 8.01	Sandy Soil	10.00	30.0	—— ——	41.280 51.280	43.22 53.02	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
9	8.01~ 9.01	Sandy Soil	10.00	32.0	—— ——	51.280 61.280	53.02 62.82	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
10	9.01~ 10.01	Sandy Soil	10.00	29.0	—— ——	61.280 71.280	62.82 72.62	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
11	10.01~ 11.01	Sandy Soil	10.00	32.0	—— ——	71.280 81.280	72.62 82.42	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
12	11.01~ 12.01	Sandy Soil	10.00	35.0	—— ——	81.280 91.280	82.42 92.22	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
13	12.01~ 14.01	Sandy Soil	10.00	35.0	—— ——	91.280 111.280	92.22 111.82	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
14	14.01~ 15.01	Sandy Soil	10.00	45.0	—— ——	111.280 121.280	111.82 121.62	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
15	15.01~ 20.00	Sandy Soil	10.00	45.0	—— ——	121.280 171.180	121.62 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta= -10.00$, $\beta= 0.00$, $\theta= \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	14.54 23.94	—— ——	14.54 23.94	0.00 20.58	—— ——
2	2.10~ 2.20	30.38 31.41	26.74 27.14	30.38 31.41	20.58 21.56	—— ——
3	2.20~ 2.60	31.41 35.57	27.14 28.74	31.41 35.57	21.56 21.56	—— ——
4	2.60~ 4.01	35.57 50.44	28.74 34.38	35.57 50.44	21.56 21.56	36.00 47.28
5	4.01~ 5.01	34.17 39.14	—— ——	34.17 39.14	21.56 21.56	33.27 62.76
6	5.01~ 6.01	37.80 42.60	—— ——	37.80 42.60	21.56 21.56	66.09 97.14
7	6.01~ 7.01	41.14 45.77	—— ——	41.14 45.77	21.56 21.56	102.32 135.02
8	7.01~ 8.01	44.20 48.68	—— ——	44.20 48.68	21.56 21.56	142.27 176.73
9	8.01~ 9.01	45.38 49.55	—— ——	45.38 49.55	21.56 21.56	196.45 234.76
10	9.01~ 10.01	55.04 59.68	—— ——	55.04 59.68	21.56 21.56	200.44 233.15
11	10.01~ 11.01	53.73 57.90	—— ——	53.73 57.90	21.56 21.56	273.07 311.39
12	11.01~ 12.01	52.06 55.82	—— ——	52.06 55.82	21.56 21.56	366.47 411.56
13	12.01~ 14.01	55.82 63.32	—— ——	55.82 63.32	21.56 21.56	411.56 501.73
14	14.01~ 15.01	43.67 46.25	—— ——	43.67 46.25	21.56 21.56	912.88 994.91
15	15.01~ 20.00	46.25 59.16	—— ——	46.25 59.16	21.56 21.56	994.91 1404.27

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

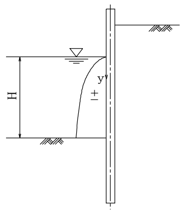
Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m^2)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

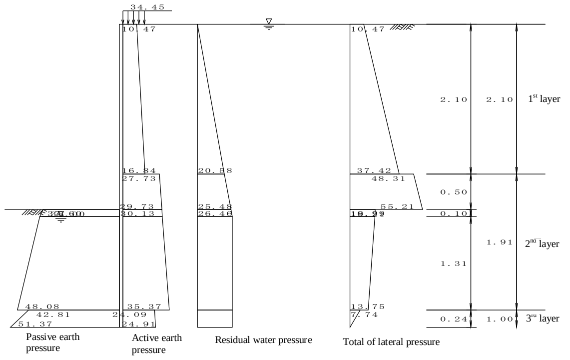
Where,
k_{hs}: design seismic coefficient
γ_w: unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

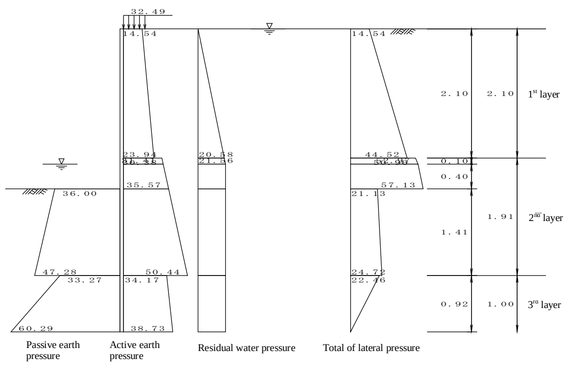


	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	10.47 16.84	0.00 20.58	—— ——	10.47 37.42
2	2.10~ 2.60	27.73 29.73	20.58 25.48	—— ——	48.31 55.21
3	2.60~ 2.70	29.73 30.13	25.48 26.46	36.00 37.60	19.21 18.99
4	2.70~ 4.01	30.13 35.37	26.46 26.46	37.60 48.08	18.99 13.75
5	4.01~ 4.25	24.09 24.91	26.46 26.46	42.81 51.37	7.74 0.00
6	4.25~ 5.01	24.91 27.50	26.46 26.46	51.37 78.26	0.00 -24.30

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.65 m (GL -4.25 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	14.54 23.94	0.00 20.58	—— ——	14.54 44.52
2	2.10~ 2.20	30.38 31.41	20.58 21.56	—— ——	50.96 52.97
3	2.20~ 2.60	31.41 35.57	21.56 21.56	—— ——	52.97 57.13
4	2.60~ 4.01	35.57 50.44	21.56 21.56	36.00 47.28	21.13 24.72
5	4.01~ 4.93	34.17 38.73	21.56 21.56	33.27 60.29	22.46 0.00
6	4.93~ 5.01	38.73 39.14	21.56 21.56	60.29 62.76	0.00 -2.06

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.33 m (GL -4.93 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m	
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84	
Section efficiency	μ	=	1.00	
Young's modulus	E	=	200000 N/mm^2	
Inertia sectional moment	I_0	=	114000 cm^4(original condition)	
	I	=	95760 cm^4(after reduction by corrosion and section)	
Inertia sectional moment	EI	=	200000 x 10^{3}x95760 x 10^{-8} = 1.915x 10^5	

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	3
4	4.31	3
5	5.31	9
6	6.31	12
7	7.31	14
8	8.31	15
9	9.31	19
10	10.31	14

	Depth (m)	N-value
11	11.31	20
12	12.31	27
13	14.31	28
14	15.31	50
15	20.00	50

5-2 Normal Condition

K_h = 16876 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.385 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.60 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.25 m) to 2.60 m depth (GL -6.85 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.25	0.06	3.0	3.0	0.18
2	4.31	1.00	3.0	9.0	6.00
3	5.31	1.00	9.0	12.0	10.50
4	6.31	0.54	12.0	13.1	6.73
	L = Σh = 2.60				ΣA = 23.41

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{23.41}{2.60} = 9.02$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 9.02^{0.406} = 16876$ kN/m³

Kh (normal condition) = 16876 kN/m³

5-3 Seismic Condition

K_h = 18494 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.394 \ m^{-1}$$

$$L = \frac{1}{\beta} = 2.54 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.93 m) to 2.54 m depth (GL -7.46 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.93	0.38	6.7	9.0	3.01
2	5.31	1.00	9.0	12.0	10.50
3	6.31	1.00	12.0	14.0	13.00
4	7.31	0.15	14.0	14.2	2.15
	L = Σh = 2.54				ΣA = 28.67

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{28.67}{2.54} = 11.30$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 11.30^{0.406} = 18494$ kN/m³

Kh (seismic condition) = 18494 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.47 37.42	10.99 39.30	3.55 2.85	39.03 112.05
2	2.10~ 2.60	0.50	48.31 55.21	12.08 13.80	1.98 1.82	23.97 25.09
3	2.60~ 2.70	0.10	19.21 18.99	0.96 0.95	1.62 1.58	1.55 1.50
4	2.70~ 4.01	1.31	18.99 13.75	12.44 9.00	1.11 0.68	13.86 6.11
5	4.01~ 4.25	0.24	7.74 0.00	0.93 0.00	0.16 0.08	0.15 0.00
				ΣP = 100.44		ΣM = 223.32

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	4.7 kN/m
depth to acting position	H_t	=	-0.63 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.65 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 22.94$ kN·m

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{246.26}{105.14} = 2.34 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	14.54 44.52	15.27 46.74	4.23 3.53	64.52 164.82
2	2.10~ 2.20	0.10	50.96 52.97	2.55 2.65	2.79 2.76	7.12 7.31
3	2.20~ 2.60	0.40	52.97 57.13	10.59 11.43	2.59 2.46	27.47 28.10
4	2.60~ 4.01	1.41	21.13 24.72	14.89 17.43	1.86 1.39	27.64 24.16

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
5	4.01~ 4.93	0.92	22.46 0.00	10.29 0.00	0.61 0.31	6.28 0.00
				ΣP = 131.84		ΣM = 357.40

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	12.5 kN/m
depth to acting position	H_t	=	-0.48 m
moment	M_m	=	2.7 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.33 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 70.27$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.59 2.46	0.00 0.34
				ΣPdw = 0.14		ΣMdw = 0.34

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{428.02}{144.48} = 2.96 \ m$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 95760 x 10⁻⁸		=	1.915 x 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	16876 kN/m³
calculated value	β	=	0.38526 m⁻¹
resultant earth force (lateral)	P_0	=	105.14 kN/m
height of acting position of load	h_0	=	2.34 m
moment	M_0	=	246.26 kN·m/m

in consideration of ϕ_m = 1.171,

maximum moment	M_{max}	=	288.48 kN·m/m
depth of generated position of M_{max}	l_m	=	0.889 m
depth of 1st fixed point	l_i	=	2.928 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	18494 kN/m³
calculated value	β	=	0.39417 m⁻¹
resultant earth force (lateral)	P_0	=	144.48 kN/m
height of acting position of load	h_0	=	2.96 m
moment	M_0	=	428.05 kN·m/m

in consideration of ϕ_m = 1.114,

maximum moment	M_{max}	=	476.93 kN·m/m
depth of generated position of M_{max}	l_m	=	0.739 m
depth of 1st fixed point	l_i	=	2.731 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm³ (original condition)
	Z	=	2828 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{288.48\times10^6}{2828\times10^3} = 102\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{476.93\times10^6}{2828\times10^3} = 169\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2$$

6-4 Displacement

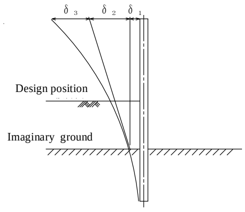
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.55 2.85	0.835 0.671	0.252 0.175	10.99 39.30	2.766 6.862
2	2.10~ 2.60	1.98 1.82	0.467 0.428	0.092 0.078	12.08 13.80	1.111 1.082
3	2.60~ 2.70	1.62 1.58	0.381 0.373	0.063 0.061	0.96 0.95	0.061 0.058
4	2.70~ 4.01	1.11 0.68	0.262 0.160	0.031 0.012	12.44 9.00	0.390 0.108
5	4.01~ 4.25	0.16 0.08	0.038 0.019	0.001 0.000	0.93 0.00	0.001 0.000
						ΣQ = 12.440

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.3853\times2.34)\times105.14}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3853^3} = 0.00913\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$
$$= \frac{(1+2\times0.3853\times2.34)\times105.14}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3853^2}\times(2.60+1.65) = 0.02205\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{12.44\times(2.60+1.65)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00499\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00077 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.25 m
Horizontal load: P = 4.70
Moment: M = 2.96

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00913＋0.02205＋0.00576
= 0.03694 m
= 36.94 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	4.23 3.53	0.858 0.716	0.263 0.195	15.27 46.74	4.011 9.118
2	2.10~ 2.20	2.79 2.76	0.567 0.560	0.130 0.128	2.55 2.65	0.332 0.338
3	2.20~ 2.60	2.59 2.46	0.526 0.499	0.114 0.104	10.59 11.43	1.210 1.187
4	2.60~ 4.01	1.86 1.39	0.377 0.281	0.062 0.036	14.89 17.43	0.924 0.625
5	4.01~ 4.93	0.61 0.31	0.124 0.062	0.007 0.002	10.29 0.00	0.076 0.000
						ΣQ = 17.821

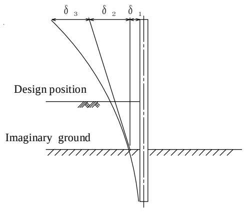
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	2.59 2.46	0.526 0.499	0.114 0.104	0.00 0.14	0.000 0.014
						ΣQdw = 0.014

Therefore, modulus of deformation Q is calculated as below:
Q = 17.821＋0.014 = 17.836

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.3942\times2.96)\times144.48}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3942^3} = 0.01335\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$
$$= \frac{(1+2\times0.3942\times2.96)\times144.48}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3942^2}\times(2.60+2.33) = 0.03989\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{17.84\times(2.60+2.33)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.01113\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00298 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.93 m
Horizontal load: P = 12.50
Moment: M = 6.00

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.93\ m、h=L-H_m、H_m=0.00\ m、\quad h\leqq L)$$
$$= \frac{2.70\times4.13}{2\times2.00\times10^8\times95760\times10^{-8}}\times(2\times4.93-4.13) = 0.00017\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01335＋0.03989＋0.01428
= 0.06752 m
= 67.52 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm ^{2}
Inertia sectional moment	I_0	=	114000 cm ^{4} (original condition)
	I	=	114000 cm ^{4} (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 114000 \times 10^{-8}$		=	2.280×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 16876$ kN/m^3
Calculated value	$\beta = 0.36882$ m^{-1}
Penetration length of SSP	$D = 1.65 + \frac{3}{0.369} = 9.79$ m
Whole length of SSP	$L = 2.60 - 0.40 + 9.79 = 11.99$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 18494$ kN/m^3
Calculated value	$\beta = 0.37736$ m^{-1}
Penetration length of SSP	$D = 2.33 + \frac{3}{0.377} = 10.28$ m
Whole length of SSP	$L = 2.60 - 0.40 + 10.28 = 12.48$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		288.48	476.93
Stress intensity	σ (N/mm^2)		102 (185)	169 (278)
Lateral displacement	δ (mm)		36.94 (50.0)	67.52 (75.0)
Penetration depth	D (m)		9.79	10.28
Whole length of SSP	L (m)	12.50		

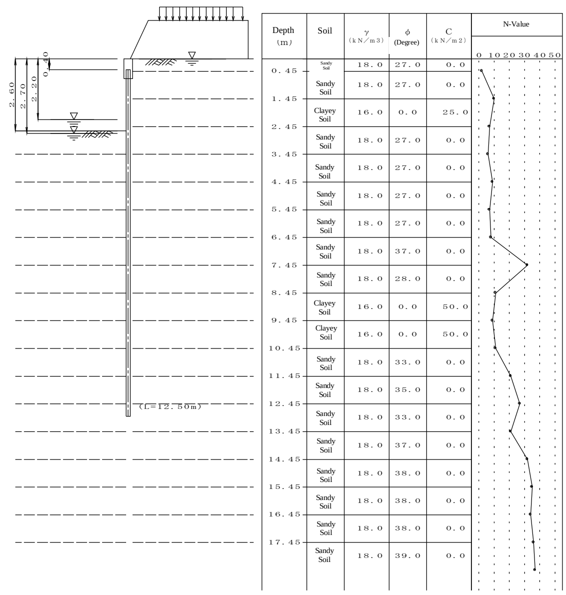
－Steel Sheet Pile　Design Calculation－

Left Bank No. 24_STA. 16+200_16+300

Case: Left Bank No. 24_STA. 16+200_16+300

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

Case: Left Bank No. 24_STA. 16+200_16+300

1-3 Applied Formula

Formula for generated stress　Chang's formula

Penetration depths　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　$\gamma_w = 9.8$ kN/m^3

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake
considered as distributed load

Arbitrary load	Horizontal load	Pt	=	4.7 kN/m (Normal Condition)
		Pt'	=	12.5 kN/m (Seismic Condition)
	Depth of acting point	Ht	=	-0.63 m (Normal Condition)
		Ht'	=	-0.48 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	2.8 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　$\zeta_0 = 10$ degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　$K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N'^{0.406}$

Average N-value　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.45	2	11	10.45	11
2	1.45	10	12	11.45	21
3	2.45	7	13	12.45	27
4	3.45	6	14	13.45	21
5	4.45	9	15	14.45	32
6	5.45	7	16	15.45	35
7	6.45	8	17	16.45	34
8	7.45	32	18	17.45	36
9	8.45	11	19	18.45	37
10	9.45	9			

Case: Left Bank No. 24_STA. 16+200_16+300

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ (kN/m^3)	γ' (kN/m^3)	φ	C (kN/m^2)	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	0.45	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
2	1.45	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
3	2.45	C	7.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	———	———
4	3.45	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
5	4.45	S	9.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
6	5.45	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
7	6.45	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
8	7.45	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	———	———
9	8.45	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	———	———
10	9.45	C	9.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	———	———
11	10.45	C	11.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	———	———
12	11.45	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	———	———
13	12.45	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	———	———
14	13.45	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	———	———
15	14.45	S	32.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	———	———
16	15.45	S	35.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	———	———
17	16.45	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	———	———
18	17.45	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	———	———
19	18.45	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	———	———

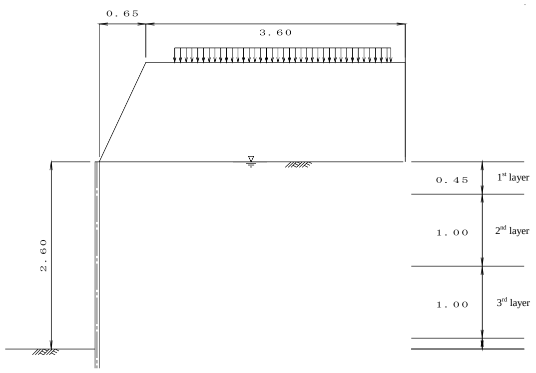
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1.179

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	0.65	4.25	4.25	1.38	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	1.05	4.05	10.0	5.0

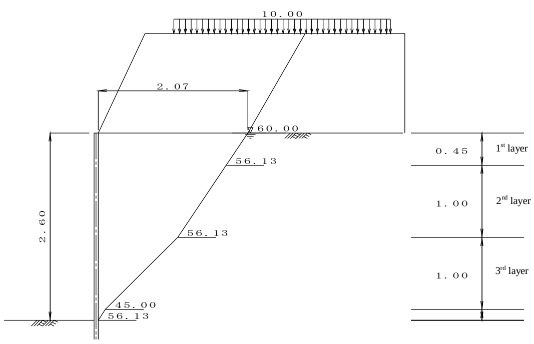
Angle of rapture in embankment   calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm^2			
Inertia sectional moment	I_0	=	114000 cm^4			
Sectional factor	Z_0	=	3250 cm^3			
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2	=	1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.84			
Corrosion rate (to Z_0)	η	=	0.88			
Section efficiency (to I_0)	μ	=	1.00			
Section efficiency (to Z_0)	μ	=	1.00			
Round unit of SSP length			0.50 m			
Allowable stress	σ_a	=	185 N/mm^2 (Normal)			
	σ_a'	=	278 N/mm^2 (Seismic)			
Allowable displacement	δ_a	=	50.0 mm (Normal)			
	δ_a'	=	75.0 mm (Seismic)			
Bending of cantilever beam			calculated as distributed load of each layer			
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction			
			Not reduced: I_0 applied to calculation of penetration depth			
			Reduced: I_0 applied to calculation of section forces and displacement			
			Reduced: Z_0 applied to calculation of stresses			

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	Angle of rupture Z (degree)
1	2.60~ 2.45	Sandy Soil	27.0	9.0	0.0	24.00	34.50	25.48	56.13
2	2.45~ 1.45	Clayey Soil	0.0	9.0	25.0	22.50	34.50	24.01	45.00
3	1.45~ 0.45	Sandy Soil	27.0	9.0	0.0	14.50	34.50	14.21	56.13
4	0.45~ 0.00	Sandy Soil	27.0	9.0	0.0	4.50	34.50	4.41	56.13
5		Embankment	30.0	——	0.0	24.84	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m^2)
- C : cohesive force of soil (kN/m^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.15	0.00	0.00	0.10	0.15
2	45.00	1.00	0.10	0.15	1.10	1.15
3	56.13	1.00	1.10	1.15	1.77	2.15
4	56.13	0.45	1.77	2.15	2.07	2.60
5	60.00	1.38	2.07	2.60	2.87	3.98

Therefore, width of acting load shall be set as 2.07 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	2.96	53.34
Σ			53.34

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	10.0	1.82	18.21
Σ			18.21

Q: surcharge load
l : width of surcharge load set by line of active rupture

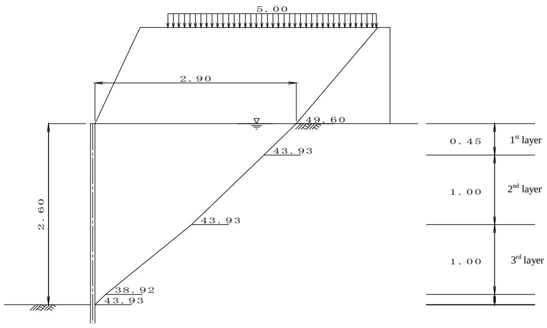
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{53.34 + 18.21 + 0.00}{2.07}$$

$$= 34.50 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.45	Sandy Soil	27.0	9.0	0.0	24.00	32.26	25.48	0.200	11.31	43.93
2	2.45~ 1.45	Clayey Soil	0.0	9.0	25.0	22.50	32.26	24.01	0.200	11.31	38.92
3	1.45~ 0.45	Sandy Soil	27.0	9.0	0.0	14.50	32.26	14.21	0.200	11.31	43.93
4	0.45~ 0.00	Sandy Soil	27.0	9.0	0.0	4.50	32.26	4.41	0.200	11.31	43.93
5		Embankment	30.0	——	0.0	24.84	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m^2)
- C cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	0.15	0.00	0.00	0.16	0.15
2	38.92	1.00	0.16	0.15	1.39	1.15
3	43.93	1.00	1.39	1.15	2.43	2.15
4	43.93	0.45	2.43	2.15	2.90	2.60
5	49.60	1.38	2.90	2.60	4.07	3.98

Therefore, width of acting load shall be set as 2.90 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.36	78.54
Σ			78.54

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

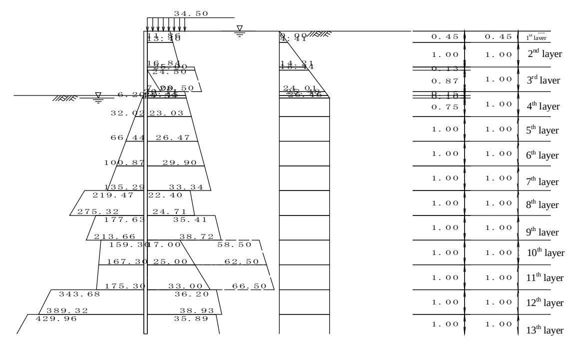
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{78.54 + 15.00 + 0.00}{2.90}$$

$$= 32.26\ kN/m^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 0.45	Sandy soil	10.0	27.0	—— ——	34.498 38.998	0.34800 0.34800	0.34371 0.34371
2	0.45~ 1.45	Sandy soil	10.0	27.0	—— ——	38.998 48.998	0.34800 0.34800	0.34371 0.34371
3	1.45~ 1.58	Clayey soil	8.0	—	25.0 25.0	48.998 50.000	—— ——	—— ——
4	1.58~ 2.45	Clayey soil	8.0	—	25.0 25.0	50.000 56.998	—— ——	—— ——
5	2.45~ 2.60	Sandy soil	10.0	27.0	—— ——	56.998 58.498	0.34800 0.34800	0.34371 0.34371
6	2.60~ 2.70	Sandy soil	10.0	27.0	—— ——	58.498 59.498	0.34800 0.34800	0.34371 0.34371
7	2.70~ 3.45	Sandy soil	10.0	27.0	—— ——	59.498 66.998	0.34800 0.34800	0.34371 0.34371
8	3.45~ 4.45	Sandy soil	10.0	27.0	—— ——	66.998 76.998	0.34800 0.34800	0.34371 0.34371
9	4.45~ 5.45	Sandy soil	10.0	27.0	—— ——	76.998 86.998	0.34800 0.34800	0.34371 0.34371
10	5.45~ 6.45	Sandy soil	10.0	27.0	—— ——	86.998 96.998	0.34800 0.34800	0.34371 0.34371
11	6.45~ 7.45	Sandy soil	10.0	37.0	—— ——	96.998 106.998	0.23377 0.23377	0.23089 0.23089
12	7.45~ 8.45	Sandy soil	10.0	28.0	—— ——	106.998 116.998	0.33506 0.33506	0.33093 0.33093
13	8.45~ 9.45	Clayey soil	8.0	—	50.0 50.0	116.998 124.998	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	9.45~ 10.45	Clayey soil	8.0	—	50.0 50.0	124.998 132.998	—— ——	—— ——
15	10.45~ 11.45	Sandy soil	10.0	33.0	—— ——	132.998 142.998	0.27561 0.27561	0.27222 0.27222
16	11.45~ 12.45	Sandy soil	10.0	35.0	—— ——	142.998 152.998	0.25410 0.25410	0.25097 0.25097
17	12.45~ 13.45	Sandy soil	10.0	33.0	—— ——	152.998 162.998	0.27561 0.27561	0.27222 0.27222
18	13.45~ 14.45	Sandy soil	10.0	37.0	—— ——	162.998 172.998	0.23377 0.23377	0.23089 0.23089
19	14.45~ 15.45	Sandy soil	10.0	38.0	—— ——	172.998 182.998	0.22404 0.22404	0.22128 0.22128
20	15.45~ 16.45	Sandy soil	10.0	38.0	—— ——	182.998 192.998	0.22404 0.22404	0.22128 0.22128
21	16.45~ 17.45	Sandy soil	10.0	38.0	—— ——	192.998 202.998	0.22404 0.22404	0.22128 0.22128
22	17.45~ 18.45	Sandy soil	10.0	39.0	—— ——	202.998 212.998	0.21458 0.21458	0.21193 0.21193

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
6	2.60~ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.48553 3.48553	3.44261 3.44261
7	2.70~ 3.45	Sandy soil	10.0	27.0	—— ——	1.800 9.300	3.48553 3.48553	3.44261 3.44261
8	3.45~ 4.45	Sandy soil	10.0	27.0	—— ——	9.300 19.300	3.48553 3.48553	3.44261 3.44261
9	4.45~ 5.45	Sandy soil	10.0	27.0	—— ——	19.300 29.300	3.48553 3.48553	3.44261 3.44261

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
10	5.45~ 6.45	Sandy soil	10.0	27.0	—— ——	29.300 39.300	3.48553 3.48553	3.44261 3.44261
11	6.45~ 7.45	Sandy soil	10.0	37.0	—— ——	39.300 49.300	5.65410 5.65410	5.58449 5.58449
12	7.45~ 8.45	Sandy soil	10.0	28.0	—— ——	49.300 59.300	3.64796 3.64796	3.60305 3.60305
13	8.45~ 9.45	Clayey soil	8.0	0.0	50.0 50.0	59.300 67.300	—— ——	—— ——
14	9.45~ 10.45	Clayey soil	8.0	0.0	50.0 50.0	67.300 75.300	—— ——	—— ——
15	10.45~ 11.45	Sandy soil	10.0	33.0	—— ——	75.300 85.300	4.62104 4.62104	4.56415 4.56415
16	11.45~ 12.45	Sandy soil	10.0	35.0	—— ——	85.300 95.300	5.10344 5.10344	5.04061 5.04061
17	12.45~ 13.45	Sandy soil	10.0	33.0	—— ——	95.300 105.300	4.62104 4.62104	4.56415 4.56415
18	13.45~ 14.45	Sandy soil	10.0	37.0	—— ——	105.300 115.300	5.65410 5.65410	5.58449 5.58449
19	14.45~ 15.45	Sandy soil	10.0	38.0	—— ——	115.300 125.300	5.95910 5.95910	5.88573 5.88573
20	15.45~ 16.45	Sandy soil	10.0	38.0	—— ——	125.300 135.300	5.95910 5.95910	5.88573 5.88573
21	16.45~ 17.45	Sandy soil	10.0	38.0	—— ——	135.300 145.300	5.95910 5.95910	5.88573 5.88573
22	17.45~ 18.45	Sandy soil	10.0	39.0	—— ——	145.300 155.300	6.28642 6.28642	6.20903 6.20903

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -9.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 0.45	11.86 13.40	—— ——	11.86 13.40	0.00 4.41	—— ——
2	0.45~ 1.45	13.40 16.84	—— ——	13.40 16.84	4.41 14.21	—— ——
3	1.45~ 1.58	-1.00 0.00	24.50 25.00	24.50 25.00	14.21 15.44	—— ——
4	1.58~ 2.45	0.00 7.00	25.00 28.50	25.00 28.50	15.44 24.01	—— ——
5	2.45~ 2.60	19.59 20.11	—— ——	19.59 20.11	24.01 25.48	—— ——
6	2.60~ 2.70	20.11 20.45	—— ——	20.11 20.45	25.48 26.46	0.00 6.20
7	2.70~ 3.45	20.45 23.03	—— ——	20.45 23.03	26.46 26.46	6.20 32.02

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
8	3.45~ 4.45	23.03 26.47	—— ——	23.03 26.47	26.46 26.46	32.02 66.44
9	4.45~ 5.45	26.47 29.90	—— ——	26.47 29.90	26.46 26.46	66.44 100.87
10	5.45~ 6.45	29.90 33.34	—— ——	29.90 33.34	26.46 26.46	100.87 135.29
11	6.45~ 7.45	22.40 24.71	—— ——	22.40 24.71	26.46 26.46	219.47 275.32
12	7.45~ 8.45	35.41 38.72	—— ——	35.41 38.72	26.46 26.46	177.63 213.66
13	8.45~ 9.45	17.00 25.00	58.50 62.50	58.50 62.50	26.46 26.46	159.30 167.30
14	9.45~ 10.45	25.00 33.00	62.50 66.50	62.50 66.50	26.46 26.46	167.30 175.30
15	10.45~ 11.45	36.20 38.93	—— ——	36.20 38.93	26.46 26.46	343.68 389.32
16	11.45~ 12.45	35.89 38.40	—— ——	35.89 38.40	26.46 26.46	429.96 480.37
17	12.45~ 13.45	41.65 44.37	—— ——	41.65 44.37	26.46 26.46	434.96 480.60
18	13.45~ 14.45	37.64 39.94	—— ——	37.64 39.94	26.46 26.46	588.05 643.89
19	14.45~ 15.45	38.28 40.49	—— ——	38.28 40.49	26.46 26.46	678.62 737.48
20	15.45~ 16.45	40.49 42.71	—— ——	40.49 42.71	26.46 26.46	737.48 796.34
21	16.45~ 17.45	42.71 44.92	—— ——	42.71 44.92	26.46 26.46	796.34 855.20
22	17.45~ 18.45	43.02 45.14	—— ——	43.02 45.14	26.46 26.46	902.17 964.26

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

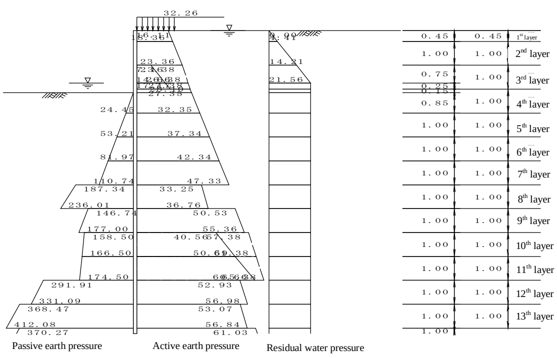
Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$
Clayey soil $P_p = \Sigma\gamma h + Q + 2C$
Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 0.45	Sandy Soil	10.0	27.0	—— ——	32.26 36.76	0.00 4.41	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
2	0.45~ 1.45	Sandy Soil	10.0	27.0	—— ——	36.76 46.76	4.41 14.21	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	1.45~ 2.20	Clayey Soil	8.0	——	25.0 25.0	46.76 52.76	14.21 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	39.59 39.09
4	2.20~ 2.45	Clayey Soil	8.0	——	25.0 25.0	52.76 54.76	21.56 24.01	0.200 0.200	11.31 11.31	—— ——	—— ——	39.09 38.92
5	2.45~ 2.60	Sandy Soil	10.0	27.0	—— ——	54.76 56.26	24.01 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	2.60~ 3.45	Sandy Soil	10.0	27.0	—— ——	56.26 64.76	25.48 33.81	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
7	3.45~ 4.45	Sandy Soil	10.0	27.0	—— ——	64.76 74.76	33.81 43.61	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
8	4.45~ 5.45	Sandy Soil	10.0	27.0	—— ——	74.76 84.76	43.61 53.41	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
9	5.45~ 6.45	Sandy Soil	10.0	27.0	—— ——	84.76 94.76	53.41 63.21	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
10	6.45~ 7.45	Sandy Soil	10.0	37.0	—— ——	94.76 104.76	63.21 73.01	0.200 0.200	11.31 11.31	0.35524 0.35524	0.35087 0.35087	—— ——
11	7.45~ 8.45	Sandy Soil	10.0	28.0	—— ——	104.76 114.76	73.01 82.81	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——
12	8.45~ 9.45	Clayey Soil	8.0	——	50.0 50.0	114.76 122.76	82.81 92.61	0.200 0.200	11.31 11.31	—— ——	—— ——	40.04 39.71
13	9.45~ 10.45	Clayey Soil	8.0	——	50.0 50.0	122.76 130.76	92.61 102.41	0.200 0.200	11.31 11.31	—— ——	—— ——	39.71 39.38
14	10.45~ 11.45	Sandy Soil	10.0	33.0	—— ——	130.76 140.76	102.41 112.21	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——

15	11.45~ 12.45	Sandy Soil	10.0	35.0	—— ——	140.76 150.76	112.21 122.01	0.200 0.200	11.31 11.31	0.38174 0.38174	0.37704 0.37704	—— ——
16	12.45~ 13.45	Sandy Soil	10.0	33.0	—— ——	150.76 160.76	122.01 131.81	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——
17	13.45~ 14.45	Sandy Soil	10.0	37.0	—— ——	160.76 170.76	131.81 141.61	0.200 0.200	11.31 11.31	0.35524 0.35524	0.35087 0.35087	—— ——
18	14.45~ 15.45	Sandy Soil	10.0	38.0	—— ——	170.76 180.76	141.61 151.41	0.200 0.200	11.31 11.31	0.34256 0.34256	0.33834 0.33834	—— ——
19	15.45~ 16.45	Sandy Soil	10.0	38.0	—— ——	180.76 190.76	151.41 161.21	0.200 0.200	11.31 11.31	0.34256 0.34256	0.33834 0.33834	—— ——
20	16.45~ 17.45	Sandy Soil	10.0	38.0	—— ——	190.76 200.76	161.21 171.01	0.200 0.200	11.31 11.31	0.34256 0.34256	0.33834 0.33834	—— ——
21	17.45~ 18.45	Sandy Soil	10.0	39.0	—— ——	200.76 210.76	171.01 180.81	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 9.00$, $\beta = 0.00$, $\theta = \tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
6	2.60~ 3.45	Sandy Soil	10.00	27.0	—— ——	0.000 8.500	0.00 8.33	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	3.45~ 4.45	Sandy Soil	10.00	27.0	—— ——	8.500 18.500	8.33 18.13	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	4.45~ 5.45	Sandy Soil	10.00	27.0	—— ——	18.500 28.500	18.13 27.93	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
9	5.45~ 6.45	Sandy Soil	10.00	27.0	—— ——	28.500 38.500	27.93 37.73	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
10	6.45~ 7.45	Sandy Soil	10.00	37.0	—— ——	38.500 48.500	37.73 47.53	0.200 0.200	11.31 11.31	4.92675 4.92675	4.86609 4.86609
11	7.45~ 8.45	Sandy Soil	10.00	28.0	—— ——	48.500 58.500	47.53 57.33	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
12	8.45~ 9.45	Clayey Soil	8.00	0.0	50.0 50.0	58.500 66.500	57.33 67.13	0.200 0.200	11.31 11.31	—— ——	—— ——
13	9.45~ 10.45	Clayey Soil	8.00	0.0	50.0 50.0	66.500 74.500	67.13 76.93	0.200 0.200	11.31 11.31	—— ——	—— ——
14	10.45~ 11.45	Sandy Soil	10.00	33.0	—— ——	74.500 84.500	76.93 86.73	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819
15	11.45~ 12.45	Sandy Soil	10.00	35.0	—— ——	84.500 94.500	86.73 96.53	0.200 0.200	11.31 11.31	4.41499 4.41499	4.36064 4.36064
16	12.45~ 13.45	Sandy Soil	10.00	33.0	—— ——	94.500 104.500	96.53 106.33	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
17	13.45~ 14.45	Sandy Soil	10.00	37.0	—— ——	104.500 114.500	106.33 116.13	0.200 0.200	11.31 11.31	4.92675 4.92675	4.86609 4.86609
18	14.45~ 15.45	Sandy Soil	10.00	38.0	—— ——	114.500 124.500	116.13 125.93	0.200 0.200	11.31 11.31	5.21042 5.21042	5.14627 5.14627
19	15.45~ 16.45	Sandy Soil	10.00	38.0	—— ——	124.500 134.500	125.93 135.73	0.200 0.200	11.31 11.31	5.21042 5.21042	5.14627 5.14627
20	16.45~ 17.45	Sandy Soil	10.00	38.0	—— ——	134.500 144.500	135.73 145.53	0.200 0.200	11.31 11.31	5.21042 5.21042	5.14627 5.14627
21	17.45~ 18.45	Sandy Soil	10.00	39.0	—— ——	144.500 154.500	145.53 155.33	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -9.00$, $\beta = 0.00$, $\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side Pa1 (kN/m²)	Active side Pa2 (kN/m²)	Active side Pa (kN/m²)	Residual water pressure Pw (kN/m²)	Passive side Pp (kN/m²)
1	0.00~ 0.45	16.11 18.36	—— ——	16.11 18.36	0.00 4.41	—— ——
2	0.45~ 1.45	18.36 23.36	—— ——	18.36 23.36	4.41 14.21	—— ——
3	1.45~ 2.20	7.16 14.66	23.38 26.38	23.38 26.38	14.21 21.56	—— ——
4	2.20~ 2.45	14.66 17.17	26.38 27.38	26.38 27.38	21.56 21.56	—— ——
5	2.45~ 2.60	27.35 28.10	—— ——	27.35 28.10	21.56 21.56	—— ——
6	2.60~ 3.45	28.10 32.35	—— ——	28.10 32.35	21.56 21.56	0.00 24.45
7	3.45~ 4.45	32.35 37.34	—— ——	32.35 37.34	21.56 21.56	24.45 53.21
8	4.45~ 5.45	37.34 42.34	—— ——	37.34 42.34	21.56 21.56	53.21 81.97
9	5.45~ 6.45	42.34 47.33	—— ——	42.34 47.33	21.56 21.56	81.97 110.74
10	6.45~ 7.45	33.25 36.76	—— ——	33.25 36.76	21.56 21.56	187.34 236.01
11	7.45~ 8.45	50.53 55.36	—— ——	50.53 55.36	21.56 21.56	146.74 177.00
12	8.45~ 9.45	40.56 50.59	57.38 61.38	57.38 61.38	21.56 21.56	158.50 166.50
13	9.45~ 10.45	50.59 60.66	61.38 65.38	61.38 65.38	21.56 21.56	166.50 174.50
14	10.45~ 11.45	52.93 56.98	—— ——	52.93 56.98	21.56 21.56	291.91 331.09

No	Depth (m)	Active side Pa1 (kN/m²)	Active side Pa2 (kN/m²)	Active side Pa (kN/m²)	Residual water pressure Pw (kN/m²)	Passive side Pp (kN/m²)
15	11.45~ 12.45	53.07 56.84	—— ——	53.07 56.84	21.56 21.56	368.47 412.08
16	12.45~ 13.45	61.03 65.08	—— ——	61.03 65.08	21.56 21.56	370.27 409.45
17	13.45~ 14.45	56.41 59.91	—— ——	56.41 59.91	21.56 21.56	508.51 557.17
18	14.45~ 15.45	57.77 61.16	—— ——	57.77 61.16	21.56 21.56	589.25 640.71
19	15.45~ 16.45	61.16 64.54	—— ——	61.16 64.54	21.56 21.56	640.71 692.17
20	16.45~ 17.45	64.54 67.92	—— ——	64.54 67.92	21.56 21.56	692.17 743.64
21	17.45~ 18.45	65.48 68.74	—— ——	65.48 68.74	21.56 21.56	787.11 841.59

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

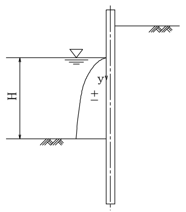
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,
k_{hs}: design seismic coefficient

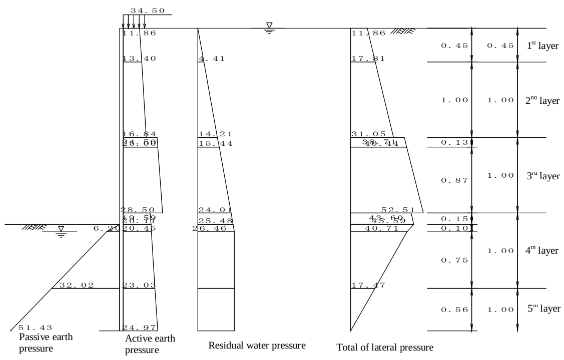
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

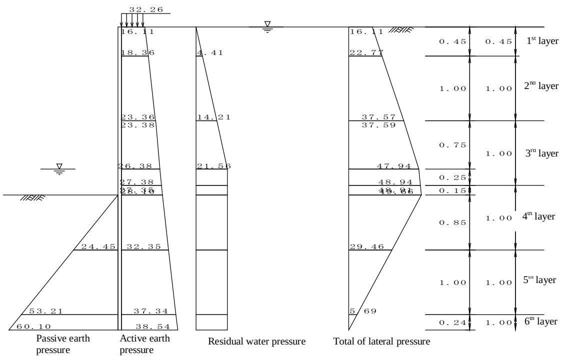


	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 0.45	11.86 13.40	0.00 4.41	—— ——	11.86 17.81
2	0.45~ 1.45	13.40 16.84	4.41 14.21	—— ——	17.81 31.05
3	1.45~ 1.58	24.50 25.00	14.21 15.44	—— ——	38.71 40.44
4	1.58~ 2.45	25.00 28.50	15.44 24.01	—— ——	40.44 52.51
5	2.45~ 2.60	19.59 20.11	24.01 25.48	—— ——	43.60 45.59
6	2.60~ 2.70	20.11 20.45	25.48 26.46	0.00 6.20	45.59 40.71
7	2.70~ 3.45	20.45 23.03	26.46 26.46	6.20 32.02	40.71 17.47
8	3.45~ 4.01	23.03 24.97	26.46 26.46	32.02 51.43	17.47 0.00
9	4.01~ 4.45	24.97 26.47	26.46 26.46	51.43 66.44	0.00 -13.52

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.41 m (GL -4.01 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 0.45	16.11 18.36	0.00 4.41	—— ——	16.11 22.77
2	0.45~ 1.45	18.36 23.36	4.41 14.21	—— ——	22.77 37.57
3	1.45~ 2.20	23.38 26.38	14.21 21.56	—— ——	37.59 47.94
4	2.20~ 2.45	26.38 27.38	21.56 21.56	—— ——	47.94 48.94
5	2.45~ 2.60	27.35 28.10	21.56 21.56	—— ——	48.91 49.66
6	2.60~ 3.45	28.10 32.35	21.56 21.56	0.00 24.45	49.66 29.46
7	3.45~ 4.45	32.35 37.34	21.56 21.56	24.45 53.21	29.46 5.69
8	4.45~ 4.69	37.34 38.54	21.56 21.56	53.21 60.10	5.69 0.00
9	4.69~ 5.45	38.54 42.34	21.56 21.56	60.10 81.97	0.00 -18.08

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.09 m (GL -4.69 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m		
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	= 1.00 mm (passive side)
Corrosion rate	η	=	0.84		
Section efficiency	μ	=	1.00		
Young's modulus	E	=	200000 N/mm^2		
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)		
	I	=	95760 cm^4 (after reduction by corrosion and section)		
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 95760 \times 10^{-8} = 1.915 \times 10^5$		

	Depth (m)	N-value
1	0.45	2
2	1.45	10
3	2.45	7
4	3.45	6
5	4.45	9
6	5.45	7
7	6.45	8
8	7.45	32
9	8.45	11
10	9.45	9

	Depth (m)	N-value
11	10.45	11
12	11.45	21
13	12.45	27
14	13.45	21
15	14.45	32
16	15.45	35
17	16.45	34
18	17.45	36
19	18.45	37

5-2 Normal Condition

K_h = 16100 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.381 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.63 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.01 m) to 2.63 m depth (GL -6.64 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.01	0.44	7.7	9.0	3.64
2	4.45	1.00	9.0	7.0	8.00
3	5.45	1.00	7.0	8.0	7.50
4	6.45	0.19	8.0	12.6	1.96
	L = Σh = 2.63				ΣA = 21.10

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{21.10}{2.63}$$

$$= 8.03$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 8.03^{0.406} = 16100 \ kN/m^3$$

Kh (normal condition) = 16100 kN/m^3

5-3 Seismic Condition

K_h = 18072 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.392 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.55 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.69 m) to 2.55 m depth (GL -7.24 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.69	0.76	8.5	7.0	5.90
2	5.45	1.00	7.0	8.0	7.50
3	6.45	0.79	8.0	27.0	13.84
	L = Σh = 2.55				ΣA = 27.24

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{27.24}{2.55}$$

$$= 10.68$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 10.68^{0.406} = 18072 \ kN/m^3$$

Kh (seismic condition) = 18072 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 0.45	0.45	11.86 17.81	2.67 4.01	3.86 3.71	10.31 14.89
2	0.45~ 1.45	1.00	17.81 31.05	8.91 15.53	3.23 2.90	28.77 44.98
3	1.45~ 1.58	0.13	38.71 40.44	2.42 2.53	2.52 2.48	6.12 6.28
4	1.58~ 2.45	0.87	40.44 52.51	17.69 22.96	2.15 1.86	37.97 42.61
5	2.45~ 2.60	0.15	43.60 45.59	3.27 3.42	1.51 1.46	4.95 5.00
6	2.60~ 2.70	0.10	45.59 40.71	2.28 2.04	1.38 1.35	3.15 2.74
7	2.70~ 3.45	0.75	40.71 17.47	15.27 6.55	1.06 0.81	16.24 5.33
8	3.45~ 4.01	0.56	17.47 0.00	4.93 0.00	0.38 0.19	1.85 0.00
				ΣP = 114.47		ΣM = 231.19

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	4.7 kN/m
depth to acting position	H_t	=	-0.63 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.41 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 21.83 \ kN \cdot m$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{253.02}{119.17} = 2.12 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 0.45	0.45	16.11 22.77	3.63 5.12	4.54 4.39	16.46 22.49
2	0.45~ 1.45	1.00	22.77 37.57	11.39 18.78	3.91 3.57	44.47 67.11
3	1.45~ 2.20	0.75	37.59 47.94	14.10 17.98	2.99 2.74	42.14 49.25
4	2.20~ 2.45	0.25	47.94 48.94	5.99 6.12	2.41 2.32	14.42 14.21
5	2.45~ 2.60	0.15	48.91 49.66	3.67 3.72	2.19 2.14	8.03 7.97
6	2.60~ 3.45	0.85	49.66 29.46	21.11 12.52	1.81 1.52	38.12 19.07
7	3.45~ 4.45	1.00	29.46 5.69	14.73 2.85	0.91 0.57	13.35 1.63
8	4.45~ 4.69	0.24	5.69 0.00	0.68 0.00	0.16 0.08	0.11 0.00
				ΣP = 142.38		ΣM = 358.82

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	12.5 kN/m
depth to acting position	H_t	=	-0.48 m
moment	M_m	=	2.8 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.09 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 67.42$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.36 2.22	0.00 0.31
				ΣPdw = 0.14		ΣMdw = 0.31

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{426.55}{155.02} = 2.75 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 95760 x 10⁻⁸		=	1.915 x 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	16100 kN/m³
calculated value	β	=	0.38075 m⁻¹
resultant earth force (lateral)	P_0	=	119.17 kN/m
height of acting position of load	h_0	=	2.12 m
moment	M_0	=	253.02 kN·m/m

in consideration of ϕ_m = 1.203,

maximum moment	M_{max}	=	304.33 kN·m/m
depth of generated position of M_{max}	l_m	=	0.959 m
depth of 1st fixed point	l_i	=	3.021 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	18072 kN/m³
calculated value	β	=	0.39191 m⁻¹
resultant earth force (lateral)	P_0	=	155.02 kN/m
height of acting position of load	h_0	=	2.75 m
moment	M_0	=	426.55 kN·m/m

in consideration of ϕ_m = 1.130,

maximum moment	M_{max}	=	481.88 kN·m/m
depth of generated position of M_{max}	l_m	=	0.783 m
depth of 1st fixed point	l_i	=	2.787 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm³ (original condition)
	Z	=	2860 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{304.33\times10^6}{2860\times10^3} = 106 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{481.88\times10^6}{2860\times10^3} = 168 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 0.45	3.86 3.71	0.963 0.925	0.315 0.296	2.67 4.01	0.839 1.187
2	0.45~ 1.45	3.23 2.90	0.805 0.722	0.237 0.198	8.91 15.53	2.111 3.071
3	1.45~ 1.58	2.52 2.48	0.628 0.618	0.156 0.152	2.42 2.53	0.378 0.384
4	1.58~ 2.45	2.15 1.86	0.535 0.462	0.118 0.090	17.69 22.96	2.079 2.075
5	2.45~ 2.60	1.51 1.46	0.377 0.365	0.062 0.058	3.27 3.42	0.203 0.200
6	2.60~ 2.70	1.38 1.35	0.344 0.336	0.052 0.050	2.28 2.04	0.119 0.102
7	2.70~ 3.45	1.06 0.81	0.265 0.203	0.032 0.019	15.27 6.55	0.489 0.126
8	3.45~ 4.01	0.38 0.19	0.094 0.047	0.004 0.001	4.93 0.00	0.021 0.000
						ΣQ = 13.385

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

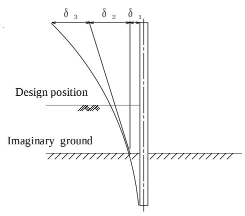
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3808\times2.12)\times119.17}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3808^3} = 0.01019 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3808\times2.12)\times119.17}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3808^2}\times(2.60+1.41) = 0.02254 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.38\times(2.60+1.41)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00452 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00065 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.01 m
Horizontal load: P = 4.70
Moment: M = 2.96

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01019＋0.02254＋0.00517
= 0.03791 m
= 37.91 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 0.45	4.54 4.39	0.968 0.936	0.317 0.301	3.63 5.12	1.151 1.544
2	0.45~ 1.45	3.91 3.57	0.833 0.762	0.251 0.217	11.39 18.78	2.853 4.067
3	1.45~ 2.20	2.99 2.74	0.637 0.584	0.160 0.137	14.10 17.98	2.256 2.470
4	2.20~ 2.45	2.41 2.32	0.513 0.495	0.109 0.102	5.99 6.12	0.654 0.627
5	2.45~ 2.60	2.19 2.14	0.467 0.456	0.092 0.088	3.67 3.72	0.338 0.329
6	2.60~ 3.45	1.81 1.52	0.385 0.325	0.065 0.047	21.11 12.52	1.364 0.589
7	3.45~ 4.45	0.91 0.57	0.193 0.122	0.017 0.007	14.73 2.85	0.257 0.020
8	4.45~ 4.69	0.16 0.08	0.034 0.017	0.001 0.000	0.68 0.00	0.000 0.000
						ΣQ= 18.519

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

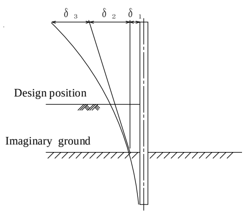
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	2.36 2.22	0.502 0.474	0.105 0.095	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below:

Q = 18.519＋0.013 ＝ 18.532

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3919\times2.75)\times155.02}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3919^3} = 0.01397\ \mathrm{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3919\times2.75)\times155.02}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3919^2}\times(2.60+2.09) = 0.03901\ \mathrm{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{18.53\times(2.60+2.09)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00998\ \mathrm{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00259 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.69 m

Horizontal load: P = 12.50

Moment: M = 6.00

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI}\times(2L-h) \qquad (L=4.69\ \mathrm{m},\ h=L-H_m,\ H_m=0.80\ \mathrm{m}, \qquad h\leqq L)$$

$$= \frac{2.80\times3.89}{2\times2.00\times10^8\times95760\times10^{-8}}\times(2\times4.69-3.89) = 0.00016\ \mathrm{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01397＋0.03901＋0.01272

= 0.06570 m

= 65.70 ≦ δ_a = 75.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)
	I	=	114000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 114000 x 10^{-8}		=	2.280 x 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction Calculated value

K_h = 16100 kN/m^3

β = 0.36451 m^{-1}

Penetration length of SSP — $D = 1.41 + \dfrac{3}{0.365} = 9.64$ m

Whole length of SSP — $L = 2.60 - 0.40 + 9.64 = 11.84$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction Calculated value

K_h = 18072 kN/m^3

β = 0.37519 m^{-1}

Penetration length of SSP — $D = 2.09 + \dfrac{3}{0.375} = 10.09$ m

Whole length of SSP — $L = 2.60 - 0.40 + 10.09 = 12.29$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

8 Calculation Result

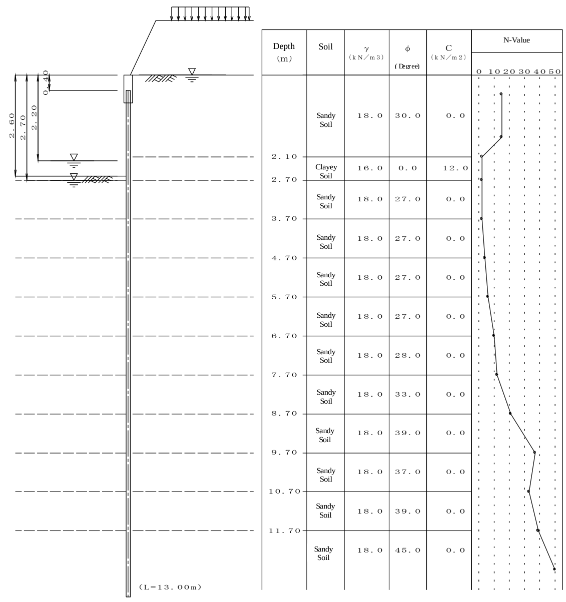
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		304.33	481.88
Stress intensity	σ (N/mm^2)		106 (185)	168 (278)
Lateral displacement	δ (mm)		37.91 (50.0)	65.70 (75.0)
Penetration depth	D (m)		9.64	10.09
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

Left Bank No. 25_STA. 16+300 - 16+450

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	4.7 kNm (Normal Condition)
		P_t'	=	12.6 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.64 m (Normal Condition)
		H_t'	=	-0.48 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	2.9 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m (Seismic Condition)
		H_m	=	0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	2
4	2.70	2
5	3.70	2
6	4.70	4
7	5.70	6
8	6.70	10
9	7.70	12
10	8.70	21

No	Depth (m)	N-Value
11	9.70	37
12	10.70	33
13	11.70	39
14	12.70	50

1.187

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

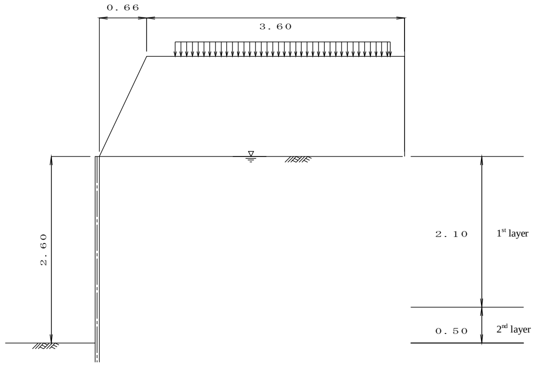
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.70	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	3.70	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.70	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.70	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	6.70	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	7.70	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
8	8.70	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
9	9.70	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
10	10.70	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
11	11.70	S	39.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
12	12.70	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_0 : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	0.66	4.26	4.26	1.40	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	1.06	4.06	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

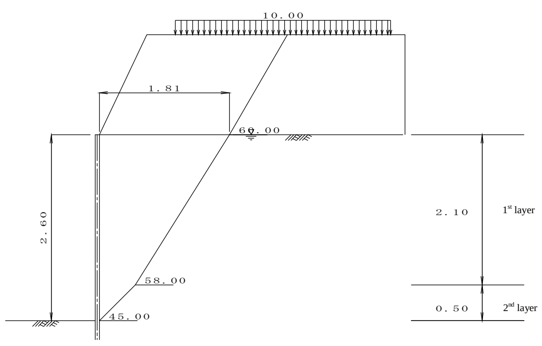
Young's modulus	E	=	200000 Nmm^2	
Inertia sectional moment	I_0	=	114000cm^4	
Sectional factor	Z_0	=	3250 cm^3	
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.84	
Corrosion rate (to Z_0)	η	=	0.88	
Section efficiency (to I_0)	μ	=	1.00	
Section efficiency (to Z_0)	μ	=	1.00	
Round unit of SSP length			0.50 m	
Allowable stress	σ_a	=	185 Nmm^2(Normal)	
	σ_a'	=	278 Nmm^2(Seismic)	
Allowable displacement	δ_a	=	50.0 mm (Normal)	
	δ_a'	=	75.0 mm (Seismic)	

Bending of cantilever beam: calculated as distributed load of each layer

Reduction of material modulus:
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	9.0	12.0	25.00	34.84	25.48	45.00
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	34.84	20.58	58.00
3		Embankment	30.0	——	0.0	25.20	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where.
- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm^2)
- C : cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	58.00	2.10	0.50	0.50	1.81	2.60
3	60.00	1.40	1.81	2.60	2.62	4.00

Therefore, width of acting load shall be set as 1.81 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	2.64	47.54
Σ			47.54

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	10.0	1.56	15.61
Σ			15.61

Q surcharge load
l : width of surcharge load set by line of active rupture

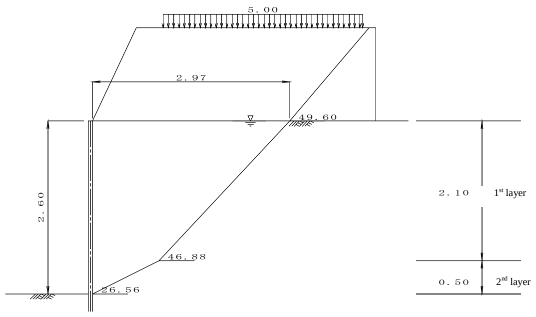
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{47.54 + 15.61 + 0.00}{1.81}$$

$$= 34.84 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	9.0	12.0	25.00	32.51	25.48	0.200	11.31	26.56
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	32.51	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	25.20	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  θ=tan⁻¹k or θ=tan⁻¹k'
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	26.56	0.50	0.00	0.00	1.00	0.50
2	46.88	2.10	1.00	0.50	2.97	2.60
3	49.60	1.40	2.97	2.60	4.16	4.00

Therefore, width of acting load shall be set as 2.97 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.53	81.46
Σ			81.46

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

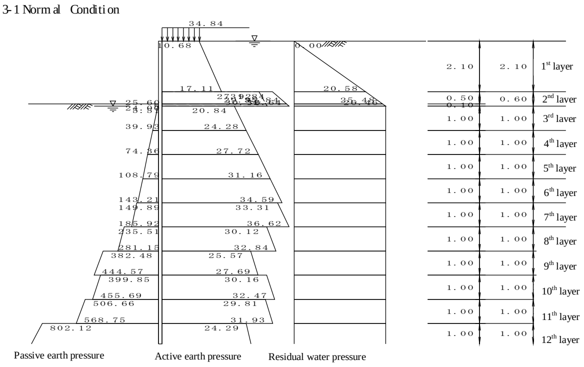
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{81.46 + 15.00 + 0.00}{2.97}$$

$$= 32.51 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	34.842 55.842	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.60	Clayey soil	8.0	——	12.0 12.0	55.842 59.842	—— ——	—— ——
3	2.60~ 2.70	Clayey soil	8.0	——	12.0 12.0	59.842 60.642	—— ——	—— ——
4	2.70~ 3.70	Sandy soil	10.0	27.0	—— ——	60.642 70.642	0.34800 0.34800	0.34371 0.34371
5	3.70~ 4.70	Sandy soil	10.0	27.0	—— ——	70.642 80.642	0.34800 0.34800	0.34371 0.34371
6	4.70~ 5.70	Sandy soil	10.0	27.0	—— ——	80.642 90.642	0.34800 0.34800	0.34371 0.34371
7	5.70~ 6.70	Sandy soil	10.0	27.0	—— ——	90.642 100.642	0.34800 0.34800	0.34371 0.34371
8	6.70~ 7.70	Sandy soil	10.0	28.0	—— ——	100.642 110.642	0.33506 0.33506	0.33093 0.33093
9	7.70~ 8.70	Sandy soil	10.0	33.0	—— ——	110.642 120.642	0.27561 0.27561	0.27222 0.27222
10	8.70~ 9.70	Sandy soil	10.0	39.0	—— ——	120.642 130.642	0.21458 0.21458	0.21193 0.21193
11	9.70~ 10.70	Sandy soil	10.0	37.0	—— ——	130.642 140.642	0.23377 0.23377	0.23089 0.23089
12	10.70~ 11.70	Sandy soil	10.0	39.0	—— ——	140.642 150.642	0.21458 0.21458	0.21193 0.21193
13	11.70~ 12.70	Sandy soil	10.0	45.0	—— ——	150.642 160.642	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Clayey soil	16.0	0.0	12.0 12.0	0.000 1.600	—— ——	—— ——
4	2.70~ 3.70	Sandy soil	10.0	27.0	—— ——	1.600 11.600	3.48553 3.48553	3.44261 3.44261
5	3.70~ 4.70	Sandy soil	10.0	27.0	—— ——	11.600 21.600	3.48553 3.48553	3.44261 3.44261
6	4.70~ 5.70	Sandy soil	10.0	27.0	—— ——	21.600 31.600	3.48553 3.48553	3.44261 3.44261
7	5.70~ 6.70	Sandy soil	10.0	27.0	—— ——	31.600 41.600	3.48553 3.48553	3.44261 3.44261
8	6.70~ 7.70	Sandy soil	10.0	28.0	—— ——	41.600 51.600	3.64796 3.64796	3.60305 3.60305
9	7.70~ 8.70	Sandy soil	10.0	33.0	—— ——	51.600 61.600	4.62104 4.62104	4.56415 4.56415
10	8.70~ 9.70	Sandy soil	10.0	39.0	—— ——	61.600 71.600	6.28642 6.28642	6.20903 6.20903
11	9.70~ 10.70	Sandy soil	10.0	37.0	—— ——	71.600 81.600	5.65410 5.65410	5.58449 5.58449
12	10.70~ 11.70	Sandy soil	10.0	39.0	—— ——	81.600 91.600	6.28642 6.28642	6.20903 6.20903
13	11.70~ 12.70	Sandy soil	10.0	45.0	—— ——	91.600 101.600	8.86593 8.86593	8.75678 8.75678

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -9.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	10.68 17.11	—— ——	10.68 17.11	0.00 20.58	—— ——
2	2.10~ 2.60	31.84 35.84	27.92 29.92	31.84 35.84	20.58 25.48	—— ——
3	2.60~ 2.70	35.84 36.64	29.92 30.32	35.84 36.64	25.48 26.46	24.00 25.60
4	2.70~ 3.70	20.84 24.28	—— ——	20.84 24.28	26.46 26.46	5.51 39.93

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
5	3.70~ 4.70	24.28 27.72	—— ——	24.28 27.72	26.46 26.46	39.93 74.36
6	4.70~ 5.70	27.72 31.16	—— ——	27.72 31.16	26.46 26.46	74.36 108.79
7	5.70~ 6.70	31.16 34.59	—— ——	31.16 34.59	26.46 26.46	108.79 143.21
8	6.70~ 7.70	33.31 36.62	—— ——	33.31 36.62	26.46 26.46	149.89 185.92
9	7.70~ 8.70	30.12 32.84	—— ——	30.12 32.84	26.46 26.46	235.51 281.15
10	8.70~ 9.70	25.57 27.69	—— ——	25.57 27.69	26.46 26.46	382.48 444.57
11	9.70~ 10.70	30.16 32.47	—— ——	30.16 32.47	26.46 26.46	399.85 455.69
12	10.70~ 11.70	29.81 31.93	—— ——	29.81 31.93	26.46 26.46	506.66 568.75
13	11.70~ 12.70	24.29 25.90	—— ——	24.29 25.90	26.46 26.46	802.12 889.69

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

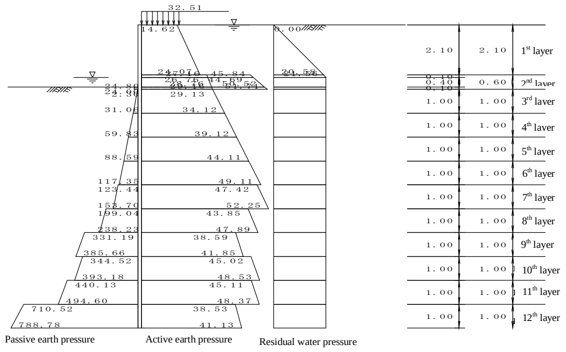
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	32.51 53.51	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10~ 2.20	Clayey Soil	8.0	—	12.0 12.0	53.51 54.31	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	28.02 27.74
3	2.20~ 2.60	Clayey Soil	8.0	—	12.0 12.0	54.31 57.51	21.56 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	27.74 26.56
4	2.60~ 2.70	Clayey Soil	8.0	—	12.0 12.0	57.51 58.31	25.48 26.46	0.200 0.200	11.31 11.31	—— ——	—— ——	26.56 26.25
5	2.70~ 3.70	Sandy Soil	10.0	27.0	—— ——	58.31 68.31	26.46 36.26	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	3.70~ 4.70	Sandy Soil	10.0	27.0	—— ——	68.31 78.31	36.26 46.06	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
7	4.70~ 5.70	Sandy Soil	10.0	27.0	—— ——	78.31 88.31	46.06 55.86	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
8	5.70~ 6.70	Sandy Soil	10.0	27.0	—— ——	88.31 98.31	55.86 65.66	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
9	6.70~ 7.70	Sandy Soil	10.0	28.0	—— ——	98.31 108.31	65.66 75.46	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——
10	7.70~ 8.70	Sandy Soil	10.0	33.0	—— ——	108.31 118.31	75.46 85.26	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——
11	8.70~ 9.70	Sandy Soil	10.0	39.0	—— ——	118.31 128.31	85.26 95.06	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
12	9.70~ 10.70	Sandy Soil	10.0	37.0	—— ——	128.31 138.31	95.06 104.86	0.200 0.200	11.31 11.31	0.35524 0.35524	0.35087 0.35087	—— ——
13	10.70~ 11.70	Sandy Soil	10.0	39.0	—— ——	138.31 148.31	104.86 114.66	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
14	11.70~ 12.70	Sandy Soil	10.0	45.0	—— ——	148.31 158.31	114.66 124.46	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 2.70	Clayey Soil	8.00	0.0	12.0 12.0	0.000 0.800	0.00 0.98	0.200 0.200	11.31 11.31	—— ——	—— ——
5	2.70~ 3.70	Sandy Soil	10.00	27.0	—— ——	0.800 10.800	0.98 10.78	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	3.70~ 4.70	Sandy Soil	10.00	27.0	—— ——	10.800 20.800	10.78 20.58	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	4.70~ 5.70	Sandy Soil	10.00	27.0	—— ——	20.800 30.800	20.58 30.38	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	5.70~ 6.70	Sandy Soil	10.00	27.0	—— ——	30.800 40.800	30.38 40.18	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
9	6.70~ 7.70	Sandy Soil	10.00	28.0	—— ——	40.800 50.800	40.18 49.98	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
10	7.70~ 8.70	Sandy Soil	10.00	33.0	—— ——	50.800 60.800	49.98 59.78	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819
11	8.70~ 9.70	Sandy Soil	10.00	39.0	—— ——	60.800 70.800	59.78 69.58	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
12	9.70~ 10.70	Sandy Soil	10.00	37.0	—— ——	70.800 80.800	69.58 79.38	0.200 0.200	11.31 11.31	4.92675 4.92675	4.86609 4.86609
13	10.70~ 11.70	Sandy Soil	10.00	39.0	—— ——	80.800 90.800	79.38 89.18	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
14	11.70~ 12.70	Sandy Soil	10.00	45.0	—— ——	90.800 100.800	89.18 98.98	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	14.62 24.07	—— ——	14.62 24.07	0.00 20.58	—— ——
2	2.10~ 2.20	44.69 45.84	26.76 27.16	44.69 45.84	20.58 21.56	—— ——
3	2.20~ 2.60	45.84 50.52	27.16 28.76	45.84 50.52	21.56 21.56	—— ——
4	2.60~ 2.70	50.52 51.71	28.76 29.16	50.52 51.71	21.56 21.56	24.00 24.80
5	2.70~ 3.70	29.13 34.12	—— ——	29.13 34.12	21.56 21.56	2.30 31.06
6	3.70~ 4.70	34.12 39.12	—— ——	34.12 39.12	21.56 21.56	31.06 59.83
7	4.70~ 5.70	39.12 44.11	—— ——	39.12 44.11	21.56 21.56	59.83 88.59
8	5.70~ 6.70	44.11 49.11	—— ——	44.11 49.11	21.56 21.56	88.59 117.35
9	6.70~ 7.70	47.42 52.25	—— ——	47.42 52.25	21.56 21.56	123.44 153.70
10	7.70~ 8.70	43.85 47.89	—— ——	43.85 47.89	21.56 21.56	199.04 238.23
11	8.70~ 9.70	38.59 41.85	—— ——	38.59 41.85	21.56 21.56	331.19 385.66
12	9.70~ 10.70	45.02 48.53	—— ——	45.02 48.53	21.56 21.56	344.52 393.18
13	10.70~ 11.70	45.11 48.37	—— ——	45.11 48.37	21.56 21.56	440.13 494.60
14	11.70~ 12.70	38.53 41.13	—— ——	38.53 41.13	21.56 21.56	710.52 788.78

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

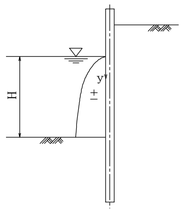
Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

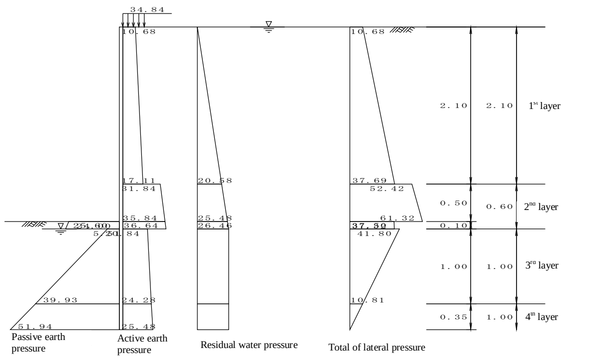
Where,
- k_{hs}: design seismic coefficient
- γ_w: unit weight of water
- H : water depth of riverside
- y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

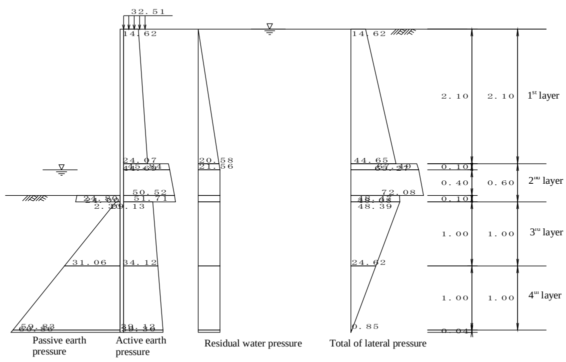


	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 2.10	10.68 17.11	0.00 20.58	—— ——	10.68 37.69
2	2.10~ 2.60	31.84 35.84	20.58 25.48	—— ——	52.42 61.32
3	2.60~ 2.70	35.84 36.64	25.48 26.46	24.00 25.60	37.32 37.50
4	2.70~ 3.70	20.84 24.28	26.46 26.46	5.51 39.93	41.80 10.81
5	3.70~ 4.05	24.28 25.48	26.46 26.46	39.93 51.94	10.81 0.00
6	4.05~ 4.70	25.48 27.72	26.46 26.46	51.94 74.36	0.00 -20.18

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.45 m (GL -4.05 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 2.10	14.62 24.07	0.00 20.58	—— ——	14.62 44.65
2	2.10~ 2.20	44.69 45.84	20.58 21.56	—— ——	65.27 67.40
3	2.20~ 2.60	45.84 50.52	21.56 21.56	—— ——	67.40 72.08
4	2.60~ 2.70	50.52 51.71	21.56 21.56	24.00 24.80	48.08 48.47
5	2.70~ 3.70	29.13 34.12	21.56 21.56	2.30 31.06	48.39 24.62
6	3.70~ 4.70	34.12 39.12	21.56 21.56	31.06 59.83	24.62 0.85
7	4.70~ 4.74	39.12 39.30	21.56 21.56	59.83 60.86	0.85 0.00
8	4.74~ 5.70	39.30 44.11	21.56 21.56	60.86 88.59	0.00 -22.92

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.14 m (GL -4.74 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 95760 \times 10^{-8} = 1.915 \times 10^5$

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	9.70	37
2	1.60	15	12	10.70	33
3	2.10	2	13	11.70	39
4	2.70	2	14	12.70	50
5	3.70	2			
6	4.70	4			
7	5.70	6			
8	6.70	10			
9	7.70	12			
10	8.70	21			

5-2 Normal Condition

K_h = 14131 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.369 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.71 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.05 m) to 2.71 m depth (GL -6.76 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.05	0.65	2.7	4.0	2.18
2	4.70	1.00	4.0	6.0	5.00
3	5.70	1.00	6.0	10.0	8.00
4	6.70	0.06	10.0	10.1	0.63
	L = Σh = 2.71				ΣA = 15.81

A (upper N-value + lower N-value) × h/2

1.191

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{15.81}{2.71}$

$= 5.82$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 5.82^{0.406} = 14131\ kN/m^3$

Kh (normal condition) = 14131 kN/m ^{3}

5-3 Seismic Condition

K_h = 15746 kN/m ^{3} is set tentatively.

$\beta = \sqrt[4]{\dfrac{Kh \cdot B}{4EI}}$

$= 0.379\ m^{-1}$

$L = \dfrac{1}{\beta} = 2.64\ m$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.74 m) to 2.64 m depth (GL -7.38 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	4.74	0.96	4.1	6.0	4.86
2	5.70	1.00	6.0	10.0	8.00
3	6.70	0.68	10.0	11.4	7.23
L = Σh= 2.64				ΣA = 20.08	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{20.08}{2.64}$

$= 7.60$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.60^{0.406} = 15746\ kN/m^3$

Kh (seismic condition) = 15746 kN/m ^{3}

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m ^{2})	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.68 37.69	11.21 39.58	3.35 2.65	37.54 104.83
2	2.10~ 2.60	0.50	52.42 61.32	13.11 15.33	1.78 1.62	23.35 24.76
3	2.60~ 2.70	0.10	37.32 37.50	1.87 1.88	1.42 1.38	2.64 2.59
4	2.70~ 3.70	1.00	41.80 10.81	20.90 5.40	1.02 0.68	21.22 3.69
5	3.70~ 4.05	0.35	10.81 0.00	1.88 0.00	0.23 0.12	0.44 0.00
				ΣP = 111.15		ΣM = 221.07

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	4.7 kN/m
depth to acting position	H_t	=	-0.64 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.45 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 22.04\ kN \cdot m$

h_0 Height of acting position of P_0 from imaginary riverbed

$h_0 = \dfrac{M_0}{P_0} = \dfrac{\Sigma M + M_t}{\Sigma P + P_t}$

$= \dfrac{243.10}{115.85} = 2.10\ m$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m ^{2})	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	14.62 44.65	15.36 46.88	4.04 3.34	61.97 156.40
2	2.10~ 2.20	0.10	65.27 67.40	3.26 3.37	2.60 2.57	8.49 8.66
3	2.20~ 2.60	0.40	67.40 72.08	13.48 14.42	2.40 2.27	32.39 32.71
4	2.60~ 2.70	0.10	48.08 48.47	2.40 2.42	2.10 2.07	5.05 5.01
5	2.70~ 3.70	1.00	48.39 24.62	24.19 12.31	1.70 1.37	41.19 16.85
6	3.70~ 4.70	1.00	24.62 0.85	12.31 0.43	0.70 0.37	8.65 0.16
7	4.70~ 4.74	0.04	0.85 0.00	0.02 0.00	0.02 0.01	0.00 0.00
				ΣP = 150.85		ΣM = 377.53

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	12.6 kN/m
depth to acting position	H_t	=	-0.48 m
moment	M_m	=	2.9 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.14 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 68.62\ kN \cdot m$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m ^{2})	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.40 2.27	0.00 0.31
				ΣPdw = 0.14		ΣM dw = 0.31

h_0 Height of acting position of P_0 from imaginary riverbed

$h_0 = \dfrac{M_0}{P_0} = \dfrac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$

$= \dfrac{446.46}{163.59} = 2.73\ m$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm ^{2}
Inertia sectional moment	I_0	=	114000 cm ^{4} (original condition)
	I	=	95760 cm ^{4} (after reduction by corrosion and section)
EI = 200000 x 10^3 x 95760 x 10^{-8}		=	1.915 x 10^5

$\beta = \sqrt[4]{\dfrac{K_h \cdot B}{4EI}}$

$\phi_m = \dfrac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1}\dfrac{1}{1+2\beta h_0})$

$M_{max} = M_0 \cdot \phi_m$

$l_m = \dfrac{1}{\beta} \times \tan^{-1}\dfrac{1}{1+2\beta h_0}$

$l_i = \dfrac{1}{\beta} \times \tan^{-1}\dfrac{1+\beta h_0}{\beta h_0}$

$M_{(x)} = \dfrac{P_0}{\beta} \times \exp^{-\beta x}\ (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	14131 kN/m ^{3}
calculated value	β	=	0.36853 m^{-1}
resultant earth force (lateral)	P_0	=	115.85 kN/m
height of acting position of load	h_0	=	2.10 m
moment	M_0	=	243.10 kN·m/m

in consideration of ψ_m = 1.217,

maximum moment	M_{max}	=	295.80 kN·m/m
depth of generated position of M_{max}	l_m	=	1.015 m
depth of 1st fixed point	l_i	=	3.146 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	15746 kN/m ^{3}
calculated value	β	=	0.37864 m^{-1}
resultant earth force (lateral)	P_0	=	163.59 kN/m
height of acting position of load	h_0	=	2.73 m
moment	M_0	=	446.46 kN·m/m

in consideration of ψ_m = 1.139,

maximum moment	M_{max}	=	508.42 kN·m/m
depth of generated position of M_{max}	l_m	=	0.832 m
depth of 1st fixed point	l_i	=	2.907 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm^3 (original condition)
	Z	=	2860 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{295.80\times10^6}{2860\times10^3} = 103\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{508.42\times10^6}{2860\times10^3} = 178\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.35 2.65	0.827 0.654	0.248 0.167	11.21 39.58	2.777 6.622
2	2.10~ 2.60	1.78 1.62	0.440 0.399	0.083 0.069	13.11 15.33	1.083 1.058
3	2.60~ 2.70	1.42 1.38	0.350 0.341	0.054 0.052	1.87 1.88	0.101 0.097
4	2.70~ 3.70	1.02 0.68	0.251 0.168	0.029 0.013	20.90 5.40	0.602 0.072
5	3.70~ 4.05	0.23 0.12	0.057 0.029	0.002 0.000	1.88 0.00	0.003 0.000
						ΣQ = 12.416

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

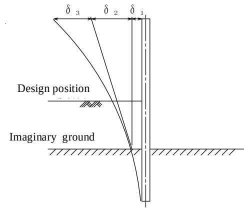
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3685\times2.10)\times115.85}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3685^3} = 0.01072\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3685\times2.10)\times115.85}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3685^2}\times(2.60+1.45) = 0.02296\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.42\times(2.60+1.45)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00430\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00067 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.05 m

Horizontal load: P = 4.70

Moment: M = 3.01

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01072 + 0.02296 + 0.00497

= 0.03865 m

= 38.65 ≦ δa = 50.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	4.04 3.34	0.852 0.704	0.260 0.190	15.36 46.88	3.992 8.900
2	2.10~ 2.20	2.60 2.57	0.550 0.542	0.123 0.121	3.26 3.37	0.402 0.406
3	2.20~ 2.60	2.40 2.27	0.507 0.479	0.107 0.096	13.48 14.42	1.441 1.391
4	2.60~ 2.70	2.10 2.07	0.444 0.437	0.084 0.082	2.40 2.42	0.202 0.198
5	2.70~ 3.70	1.70 1.37	0.359 0.289	0.057 0.038	24.19 12.31	1.376 0.465
6	3.70~ 4.70	0.70 0.37	0.148 0.078	0.010 0.003	12.31 0.43	0.129 0.001
7	4.70~ 4.74	0.02 0.01	0.005 0.003	0.000 0.000	0.02 0.00	0.000 0.000
						ΣQ = 18.903

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

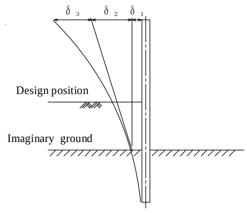
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	2.40 2.27	0.507 0.479	0.107 0.096	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below:

Q = 18.903 + 0.013 = 18.916

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3786\times2.73)\times163.59}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3786^3} = 0.01600\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3786\times2.73)\times163.59}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3786^2}\times(2.60+2.14) = 0.04326\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{18.92\times(2.60+2.14)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.01049\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00268 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.74 m

Horizontal load: P = 12.60

Moment: M = 6.05

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.74\ m、h=L-H_m、H_m=0.80\ m、\quad h\leqq L)$$

$$= \frac{2.90\times3.94}{2\times2.00\times10^8\times95760\times10^{-8}}\times(2\times4.74-3.94) = 0.00016\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01600 + 0.04326 + 0.01334

= 0.07260 m

= 72.60 ≦ δ_a = 75.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)
	I	=	114000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 114000 \times 10^{-8}$		=	2.280×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $\quad K_h = 14131\ kN/m^3$

Calculated value $\quad \beta = 0.35282\ m^{-1}$

Penetration length of SSP $\quad D = 1.45 + \frac{3}{0.353} = 9.95\ m$

Whole length of SSP $\quad L = 2.60 - 0.40 + 9.95 = 12.15\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $\quad K_h = 15746\ kN/m^3$

Calculated value $\quad \beta = 0.36249\ m^{-1}$

Penetration length of SSP $\quad D = 2.14 + \frac{3}{0.362} = 10.41\ m$

Whole length of SSP $\quad L = 2.60 - 0.40 + 10.41 = 12.61\ m$

Therefore, whole length of SSP is set as 13.00 m in consideration of round unit of SSP length.

8 Calculation Result

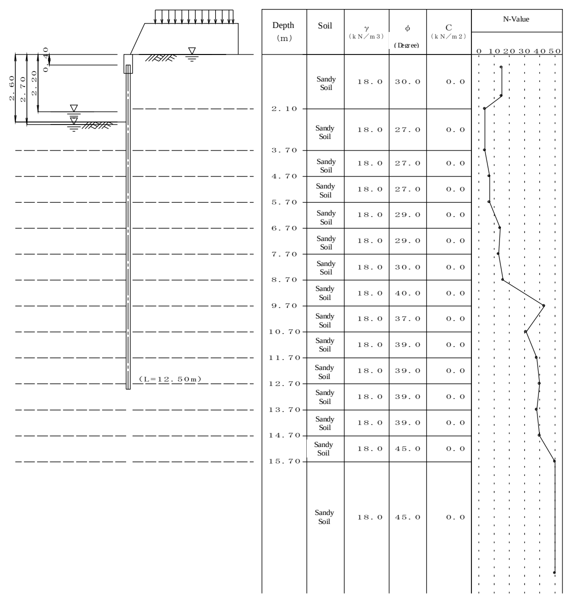
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		295.80	508.42
Stress intensity	σ (N/mm^2)		103 (185)	178 (278)
Lateral displacement	δ (mm)		38.65 (50.0)	72.60 (75.0)
Penetration depth	D (m)		9.95	10.41
Whole length of SSP	L (m)	13.00		

－Steel Sheet Pile Design Calculation－

Left Bank No. 26_STA. 16+450 - 16+552

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake
considered as distributed load

Arbitrary load	Horizontal load	P_t	=	3.8 kNm (Normal Condition)
		P_t'	=	11.1 kNm (Seismic Condition)
	Depth of acting point	H	=	-0.56 m (Normal Condition)
		H'	=	-0.41 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	0.4 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00m (Seismic Condition)
		H_m	=	0.80m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_ζ = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N- Value
1	0.50	15
2	1.60	15
3	2.10	4
4	3.70	4
5	4.70	7
6	5.70	7
7	6.70	14
8	7.70	13
9	8.70	16
10	9.70	43

No	Depth (m)	N- Value
11	10.70	31
12	11.70	38
13	12.70	40
14	13.70	38
15	14.70	40
16	15.70	50
17	20.00	50

1.195

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

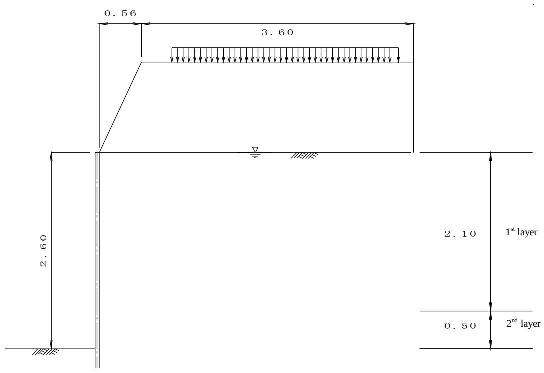
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.70	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	4.70	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	5.70	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	6.70	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
6	7.70	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
7	8.70	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
8	9.70	S	43.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
9	10.70	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
10	11.70	S	38.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
11	12.70	S	40.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
12	13.70	S	38.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
13	14.70	S	40.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
14	15.70	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
15	20.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.56	4.16	4.16	1.20	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.96	3.96	10.0	5.0

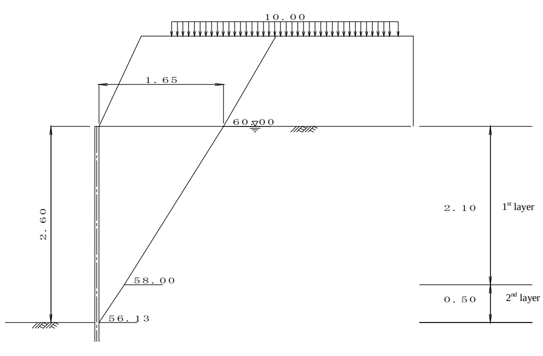
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm^2			
Inertia sectional moment	I_0	=	114000 cm^4			
Sectional factor	Z_0	=	3250 cm^3			
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2	=	1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.84			
Corrosion rate (to Z_0)	η	=	0.87			
Section efficiency (to I_0)	μ	=	1.00			
Section efficiency (to Z_0)	μ	=	1.00			
Round unit of SSP length			0.50 m			
Allowable stress	σ_a	=	185 N/mm^2 (Normal)			
	σ_a'	=	278 N/mm^2 (Seismic)			
Allowable displacement	δ_a	=	50.0 mm (Normal)			
	δ_a'	=	75.0 mm (Seismic)			
Bending of cantilever beam			calculated as distributed load of each layer			
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction			
			Not reduced: I_0 applied to calculation of penetration depth			
			Reduced: I_0 applied to calculation of section forces and displacement			
			Reduced: Z_0 applied to calculation of stresses			

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	30.85	25.48	56.13
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	30.85	20.58	58.00
3		Embankment	30.0	——	0.0	21.60	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m^2)
- C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.50	0.00	0.00	0.34	0.50
2	58.00	2.10	0.34	0.50	1.65	2.60
3	60.00	1.20	1.65	2.60	2.34	3.80

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.06	37.03
Σ			37.03

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.38	13.81
Σ			13.81

Q surcharge load

l : width of surcharge load set by line of active rupture

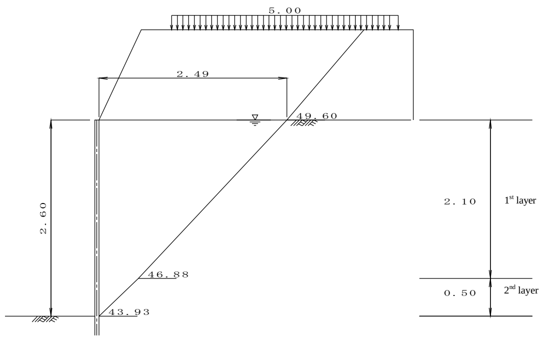
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{37.03 + 13.81 + 0.00}{1.65}$$

$$= 30.85 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	28.73	25.48	0.200	11.31	43.93
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	28.73	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	21.60	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{0}$)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	0.50	0.00	0.00	0.52	0.50
2	46.88	2.10	0.52	0.50	2.49	2.60
3	49.60	1.20	2.49	2.60	3.51	3.80

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.26	58.67
Σ			58.67

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.55	12.73
Σ			12.73

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

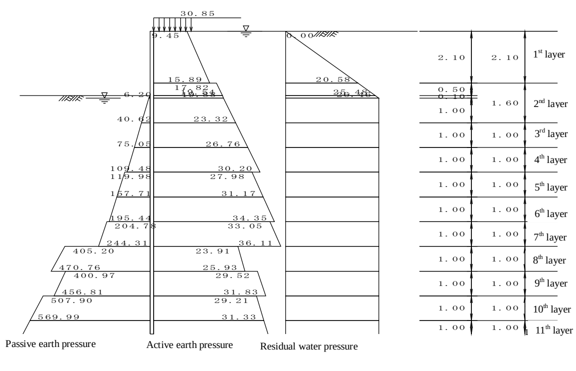
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{58.67 + 12.73 + 0.00}{2.49}$$

$$= 28.73 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	30.849 51.849	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	51.849 56.849	0.34800 0.34800	0.34371 0.34371
3	2.60~ 2.70	Sandy soil	10.0	27.0	—— ——	56.849 57.849	0.34800 0.34800	0.34371 0.34371
4	2.70~ 3.70	Sandy soil	10.0	27.0	—— ——	57.849 67.849	0.34800 0.34800	0.34371 0.34371
5	3.70~ 4.70	Sandy soil	10.0	27.0	—— ——	67.849 77.849	0.34800 0.34800	0.34371 0.34371
6	4.70~ 5.70	Sandy soil	10.0	27.0	—— ——	77.849 87.849	0.34800 0.34800	0.34371 0.34371
7	5.70~ 6.70	Sandy soil	10.0	29.0	—— ——	87.849 97.849	0.32248 0.32248	0.31851 0.31851
8	6.70~ 7.70	Sandy soil	10.0	29.0	—— ——	97.849 107.849	0.32248 0.32248	0.31851 0.31851
9	7.70~ 8.70	Sandy soil	10.0	30.0	—— ——	107.849 117.849	0.31026 0.31026	0.30644 0.30644
10	8.70~ 9.70	Sandy soil	10.0	40.0	—— ——	117.849 127.849	0.20538 0.20538	0.20285 0.20285
11	9.70~ 10.70	Sandy soil	10.0	37.0	—— ——	127.849 137.849	0.23377 0.23377	0.23089 0.23089
12	10.70~ 11.70	Sandy soil	10.0	39.0	—— ——	137.849 147.849	0.21458 0.21458	0.21193 0.21193

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
13	11.70~ 12.70	Sandy soil	10.0	39.0	—— ——	147.849 157.849	0.21458 0.21458	0.21193 0.21193
14	12.70~ 13.70	Sandy soil	10.0	39.0	—— ——	157.849 167.849	0.21458 0.21458	0.21193 0.21193
15	13.70~ 14.70	Sandy soil	10.0	39.0	—— ——	167.849 177.849	0.21458 0.21458	0.21193 0.21193
16	14.70~ 15.70	Sandy soil	10.0	45.0	—— ——	177.849 187.849	0.16323 0.16323	0.16122 0.16122
17	15.70~ 20.00	Sandy soil	10.0	45.0	—— ——	187.849 230.849	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.48553 3.48553	3.44261 3.44261
4	2.70~ 3.70	Sandy soil	10.0	27.0	—— ——	1.800 11.800	3.48553 3.48553	3.44261 3.44261
5	3.70~ 4.70	Sandy soil	10.0	27.0	—— ——	11.800 21.800	3.48553 3.48553	3.44261 3.44261
6	4.70~ 5.70	Sandy soil	10.0	27.0	—— ——	21.800 31.800	3.48553 3.48553	3.44261 3.44261
7	5.70~ 6.70	Sandy soil	10.0	29.0	—— ——	31.800 41.800	3.82002 3.82002	3.77299 3.77299
8	6.70~ 7.70	Sandy soil	10.0	29.0	—— ——	41.800 51.800	3.82002 3.82002	3.77299 3.77299
9	7.70~ 8.70	Sandy soil	10.0	30.0	—— ——	51.800 61.800	4.00247 4.00247	3.95319 3.95319
10	8.70~ 9.70	Sandy soil	10.0	40.0	—— ——	61.800 71.800	6.63830 6.63830	6.55657 6.55657
11	9.70~ 10.70	Sandy soil	10.0	37.0	—— ——	71.800 81.800	5.65410 5.65410	5.58449 5.58449
12	10.70~ 11.70	Sandy soil	10.0	39.0	—— ——	81.800 91.800	6.28642 6.28642	6.20903 6.20903
13	11.70~ 12.70	Sandy soil	10.0	39.0	—— ——	91.800 101.800	6.28642 6.28642	6.20903 6.20903
14	12.70~ 13.70	Sandy soil	10.0	39.0	—— ——	101.800 111.800	6.28642 6.28642	6.20903 6.20903
15	13.70~ 14.70	Sandy soil	10.0	39.0	—— ——	111.800 121.800	6.28642 6.28642	6.20903 6.20903

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
16	14.70~ 15.70	Sandy soil	10.0	45.0	—— ——	121.800 131.800	8.86593 8.86593	8.75678 8.75678
17	15.70~ 20.00	Sandy soil	10.0	45.0	—— ——	131.800 174.800	8.86593 8.86593	8.75678 8.75678

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -9.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	9.45 15.89	—— ——	9.45 15.89	0.00 20.58	—— ——
2	2.10~ 2.60	17.82 19.54	—— ——	17.82 19.54	20.58 25.48	—— ——
3	2.60~ 2.70	19.54 19.88	—— ——	19.54 19.88	25.48 26.46	0.00 6.20
4	2.70~ 3.70	19.88 23.32	—— ——	19.88 23.32	26.46 26.46	6.20 40.62
5	3.70~ 4.70	23.32 26.76	—— ——	23.32 26.76	26.46 26.46	40.62 75.05
6	4.70~ 5.70	26.76 30.20	—— ——	26.76 30.20	26.46 26.46	75.05 109.48
7	5.70~ 6.70	27.98 31.17	—— ——	27.98 31.17	26.46 26.46	119.98 157.71
8	6.70~ 7.70	31.17 34.35	—— ——	31.17 34.35	26.46 26.46	157.71 195.44
9	7.70~ 8.70	33.05 36.11	—— ——	33.05 36.11	26.46 26.46	204.78 244.31
10	8.70~ 9.70	23.91 25.93	—— ——	23.91 25.93	26.46 26.46	405.20 470.76
11	9.70~ 10.70	29.52 31.83	—— ——	29.52 31.83	26.46 26.46	400.97 456.81
12	10.70~ 11.70	29.21 31.33	—— ——	29.21 31.33	26.46 26.46	507.90 569.99
13	11.70~ 12.70	31.33 33.45	—— ——	31.33 33.45	26.46 26.46	569.99 632.08
14	12.70~ 13.70	33.45 35.57	—— ——	33.45 35.57	26.46 26.46	632.08 694.17
15	13.70~ 14.70	35.57 37.69	—— ——	35.57 37.69	26.46 26.46	694.17 756.26
16	14.70~ 15.70	28.67 30.29	—— ——	28.67 30.29	26.46 26.46	1066.58 1154.14
17	15.70~ 20.00	30.29 37.22	—— ——	30.29 37.22	26.46 26.46	1154.14 1530.68

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

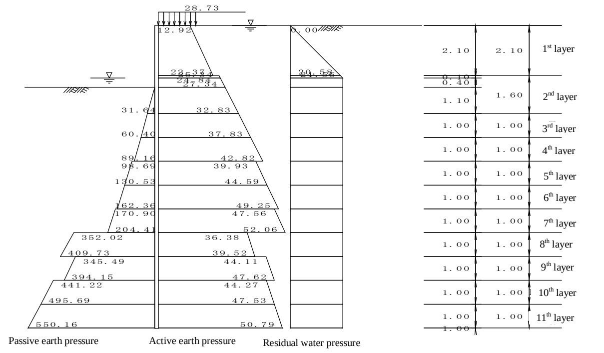
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	28.73 49.73	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	27.0	—— ——	49.73 50.73	20.58 21.56	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.20~ 2.60	Sandy Soil	10.0	27.0	—— ——	50.73 54.73	21.56 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	2.60~ 3.70	Sandy Soil	10.0	27.0	—— ——	54.73 65.73	25.48 36.26	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	3.70~ 4.70	Sandy Soil	10.0	27.0	—— ——	65.73 75.73	36.26 46.06	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	4.70~ 5.70	Sandy Soil	10.0	27.0	—— ——	75.73 85.73	46.06 55.86	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
7	5.70~ 6.70	Sandy Soil	10.0	29.0	—— ——	85.73 95.73	55.86 65.66	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
8	6.70~ 7.70	Sandy Soil	10.0	29.0	—— ——	95.73 105.73	65.66 75.46	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
9	7.70~ 8.70	Sandy Soil	10.0	30.0	—— ——	105.73 115.73	75.46 85.26	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
10	8.70~ 9.70	Sandy Soil	10.0	40.0	—— ——	115.73 125.73	85.26 95.06	0.200 0.200	11.31 11.31	0.31824 0.31824	0.31432 0.31432	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
11	9.70~ 10.70	Sandy Soil	10.0	37.0	—— ——	125.73 135.73	95.06 104.86	0.200 0.200	11.31 11.31	0.35524 0.35524	0.35087 0.35087	—— ——
12	10.70~ 11.70	Sandy Soil	10.0	39.0	—— ——	135.73 145.73	104.86 114.66	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
13	11.70~ 12.70	Sandy Soil	10.0	39.0	—— ——	145.73 155.73	114.66 124.46	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
14	12.70~ 13.70	Sandy Soil	10.0	39.0	—— ——	155.73 165.73	124.46 134.26	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
15	13.70~ 14.70	Sandy Soil	10.0	39.0	—— ——	165.73 175.73	134.26 144.06	0.200 0.200	11.31 11.31	0.33023 0.33023	0.32616 0.32616	—— ——
16	14.70~ 15.70	Sandy Soil	10.0	45.0	—— ——	175.73 185.73	144.06 153.86	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——
17	15.70~ 20.00	Sandy Soil	10.0	45.0	—— ——	185.73 228.73	153.86 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp × cosδ
4	2.60~ 3.70	Sandy Soil	10.00	27.0	—— ——	0.000 11.000	0.00 10.78	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	3.70~ 4.70	Sandy Soil	10.00	27.0	—— ——	11.000 21.000	10.78 20.58	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	4.70~ 5.70	Sandy Soil	10.00	27.0	—— ——	21.000 31.000	20.58 30.38	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	5.70~ 6.70	Sandy Soil	10.00	29.0	—— ——	31.000 41.000	30.38 40.18	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
8	6.70~ 7.70	Sandy Soil	10.00	29.0	—— ——	41.000 51.000	40.18 49.98	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
9	7.70~ 8.70	Sandy Soil	10.00	30.0	—— ——	51.000 61.000	49.98 59.78	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
10	8.70~ 9.70	Sandy Soil	10.00	40.0	—— ——	61.000 71.000	59.78 69.58	0.200 0.200	11.31 11.31	5.84277 5.84277	5.77084 5.77084
11	9.70~ 10.70	Sandy Soil	10.00	37.0	—— ——	71.000 81.000	69.58 79.38	0.200 0.200	11.31 11.31	4.92675 4.92675	4.86609 4.86609
12	10.70~ 11.70	Sandy Soil	10.00	39.0	—— ——	81.000 91.000	79.38 89.18	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
13	11.70~ 12.70	Sandy Soil	10.00	39.0	—— ——	91.000 101.000	89.18 98.98	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp × cosδ
14	12.70~ 13.70	Sandy Soil	10.00	39.0	—— ——	101.000 111.000	98.98 108.78	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
15	13.70~ 14.70	Sandy Soil	10.00	39.0	—— ——	111.000 121.000	108.78 118.58	0.200 0.200	11.31 11.31	5.51506 5.51506	5.44716 5.44716
16	14.70~ 15.70	Sandy Soil	10.00	45.0	—— ——	121.000 131.000	118.58 128.38	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515
17	15.70~ 20.00	Sandy Soil	10.00	45.0	—— ——	131.000 174.000	128.38 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -9.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	12.92 22.37	—— ——	12.92 22.37	0.00 20.58	—— ——
2	2.10~ 2.20	24.84 25.34	—— ——	24.84 25.34	20.58 21.56	—— ——
3	2.20~ 2.60	25.34 27.34	—— ——	25.34 27.34	21.56 21.56	—— ——
4	2.60~ 3.70	27.34 32.83	—— ——	27.34 32.83	21.56 21.56	0.00 31.64
5	3.70~ 4.70	32.83 37.83	—— ——	32.83 37.83	21.56 21.56	31.64 60.40
6	4.70~ 5.70	37.83 42.82	—— ——	37.83 42.82	21.56 21.56	60.40 89.16
7	5.70~ 6.70	39.93 44.59	—— ——	39.93 44.59	21.56 21.56	98.69 130.53
8	6.70~ 7.70	44.59 49.25	—— ——	44.59 49.25	21.56 21.56	130.53 162.36
9	7.70~ 8.70	47.56 52.06	—— ——	47.56 52.06	21.56 21.56	170.90 204.41
10	8.70~ 9.70	36.38 39.52	—— ——	36.38 39.52	21.56 21.56	352.02 409.73
11	9.70~ 10.70	44.11 47.62	—— ——	44.11 47.62	21.56 21.56	345.49 394.15
12	10.70~ 11.70	44.27 47.53	—— ——	44.27 47.53	21.56 21.56	441.22 495.69
13	11.70~ 12.70	47.53 50.79	—— ——	47.53 50.79	21.56 21.56	495.69 550.16
14	12.70~ 13.70	50.79 54.05	—— ——	50.79 54.05	21.56 21.56	550.16 604.63

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
15	13.70~ 14.70	54.05 57.32	—— ——	54.05 57.32	21.56 21.56	604.63 659.11
16	14.70~ 15.70	45.65 48.25	—— ——	45.65 48.25	21.56 21.56	946.84 1025.09
17	15.70~ 20.00	48.25 59.42	—— ——	48.25 59.42	21.56 21.56	1025.09 1361.58

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

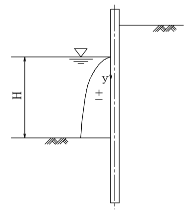
Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

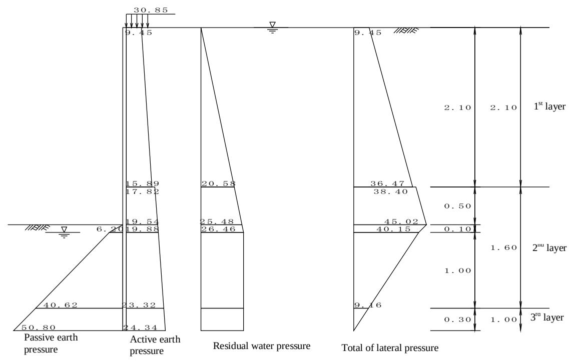
Where,
k_h : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

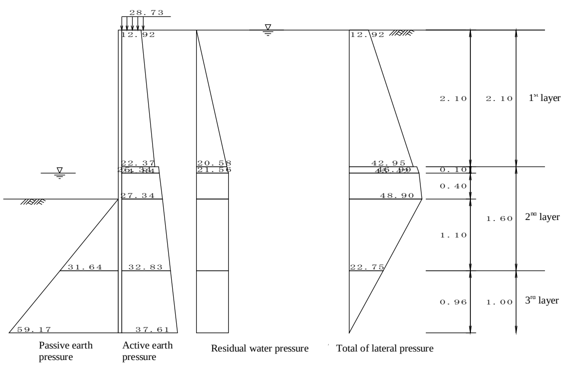


	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	9.45 15.89	0.00 20.58	—— ——	9.45 36.47
2	2.10~ 2.60	17.82 19.54	20.58 25.48	—— ——	38.40 45.02
3	2.60~ 2.70	19.54 19.88	25.48 26.46	0.00 6.20	45.02 40.15
4	2.70~ 3.70	19.88 23.32	26.46 26.46	6.20 40.62	40.15 9.16
5	3.70~ 4.00	23.32 24.34	26.46 26.46	40.62 50.80	9.16 0.00
6	4.00~ 4.70	24.34 26.76	26.46 26.46	50.80 75.05	0.00 -21.83

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.40 m (GL -4.00 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	12.92 22.37	0.00 20.58	—— ——	12.92 42.95
2	2.10~ 2.20	24.84 25.34	20.58 21.56	—— ——	45.42 46.90
3	2.20~ 2.60	25.34 27.34	21.56 21.56	—— ——	46.90 48.90
4	2.60~ 3.70	27.34 32.83	21.56 21.56	0.00 31.64	48.90 22.75
5	3.70~ 4.66	32.83 37.61	21.56 21.56	31.64 59.17	22.75 0.00
6	4.66~ 4.70	37.61 37.83	21.56 21.56	59.17 60.40	0.00 -1.02

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.06 m (GL -4.66 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.84			
Section efficiency	μ	=	1.00			
Young's modulus	E	=	200000 Nmm^2			
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)			
	I	=	95760 cm^4 (after reduction by corrosion and section)			
Inertia sectional moment	EI	=	200000 x 10^3 x 95760 x 10^{-8} =1.915 x 10^5			

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	10.70	31
2	1.60	15	12	11.70	38
3	2.10	4	13	12.70	40
4	3.70	4	14	13.70	38
5	4.70	7	15	14.70	40
6	5.70	7	16	15.70	50
7	6.70	14	17	20.00	50
8	7.70	13			
9	8.70	16			
10	9.70	43			

5-2 Normal Condition

K_h = 15960 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.380 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.63 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.00 m) to 2.63 m depth (GL -6.63 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	4.00	0.70	4.9	7.0	4.19
2	4.70	1.00	7.0	7.0	7.00
3	5.70	0.93	7.0	13.5	9.51
L = Σh = 2.63					ΣA = 20.69

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{20.69}{2.63}$

$= 7.86$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.86^{0.406} = 15960$ kN/m³

Kh (normal condition) = 15960 kN/m³

5-3 Seismic Condition

K_h = 17419 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.388$ m^{-1}

$$L = \frac{1}{\beta} = 2.58 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.66 m) to 2.58 m depth (GL -7.23 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.66	0.04	6.9	7.0	0.30
2	4.70	1.00	7.0	7.0	7.00
3	5.70	1.00	7.0	14.0	10.50
4	6.70	0.53	14.0	13.5	7.31
	L= Σh = 2.58				ΣA = 25.11

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{25.11}{2.58}$

$= 9.75$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 9.75^{0.406} = 17419$ kN/m³

Kh (seismic condition) = 17419 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.45 36.47	9.93 38.29	3.30 2.60	32.71 99.39
2	2.10~ 2.60	0.50	38.40 45.02	9.60 11.25	1.73 1.56	16.60 17.58
3	2.60~ 2.70	0.10	45.02 40.15	2.25 2.01	1.36 1.33	3.07 2.67
4	2.70~ 3.70	1.00	40.15 9.16	20.07 4.58	0.96 0.63	19.31 2.88
5	3.70~ 4.00	0.30	9.16 0.00	1.35 0.00	0.20 0.10	0.27 0.00
				ΣP = 99.34		ΣM = 194.47

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.8 kN/m
depth to acting position	H_t	=	-0.56 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.40 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 17.31$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{211.79}{103.14} = 2.05 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	12.92 42.95	13.57 45.10	3.96 3.26	53.69 146.89
2	2.10~ 2.20	0.10	45.42 46.90	2.27 2.34	2.52 2.49	5.73 5.84

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
3	2.20~ 2.60	0.40	46.90 48.90	9.38 9.78	2.32 2.19	21.80 21.42
4	2.60~ 3.70	1.10	48.90 22.75	26.89 12.51	1.69 1.32	45.47 16.57
5	3.70~ 4.66	0.96	22.75 0.00	10.89 0.00	0.64 0.32	6.95 0.00
				ΣP = 132.74		ΣM = 324.36

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	11.1 kN/m
depth to acting position	H_t	=	-0.41 m
moment	M_m	=	0.4 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.06 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 56.65$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.32 2.19	0.00 0.30
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.30

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{381.31}{143.97} = 2.65 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 95760 x 10⁻⁸		=	1.915 x 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	15960 kN/m³
calculated value	β	=	0.37992 m⁻¹
resultant earth force (lateral)	P_0	=	103.14 kN/m
height of acting position of load	h_0	=	2.05 m
moment	M_0	=	211.79 kN·m/m

in consideration of ϕ_m = 1.214,

maximum moment	M_{max}	=	257.10 kN·m/m
depth of generated position of M_{max}	l_m	=	0.980 m
depth of 1st fixed point	l_i	=	3.047 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	17419 kN/m³
calculated value	β	=	0.38832 m⁻¹
resultant earth force (lateral)	P_0	=	143.97 kN/m
height of acting position of load	h_0	=	2.65 m
moment	M_0	=	381.31 kN·m/m

in consideration of ϕ_m = 1.140,

maximum moment	M_{max}	=	434.62 kN·m/m
depth of generated position of M_{max}	l_m	=	0.814 m
depth of 1st fixed point	l_i	=	2.837 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm³ (original condition)
	Z	=	2828 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{257.10\times10^6}{2828\times10^3} = 91\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{434.62\times10^6}{2828\times10^3} = 154\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.30 2.60	0.825 0.650	0.247 0.165	9.93 38.29	2.448 6.330
2	2.10~ 2.60	1.73 1.56	0.433 0.391	0.080 0.066	9.60 11.25	0.769 0.748
3	2.60~ 2.70	1.36 1.33	0.341 0.333	0.052 0.049	2.25 2.01	0.116 0.099
4	2.70~ 3.70	0.96 0.63	0.241 0.157	0.027 0.012	20.07 4.58	0.535 0.054
5	3.70~ 4.00	0.20 0.10	0.049 0.025	0.001 0.000	1.35 0.00	0.002 0.000
						ΣQ = 11.101

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

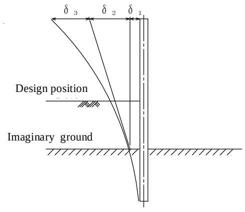
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3799\times2.05)\times103.14}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3799^3} = 0.00874\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3799\times2.05)\times103.14}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3799^2}\times(2.60+1.40) = 0.01908\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.10\times(2.60+1.40)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00370\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00051 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.00 m

Horizontal load: P = 3.80

Moment: M = 2.13

δ = δ_1 + δ_2 + δ_3

= 0.00874＋0.01908＋0.00421

= 0.03203 m

= 32.03 ≦ δa = 50.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.96 3.26	0.850 0.699	0.259 0.188	13.57 45.10	3.511 8.458
2	2.10~ 2.20	2.52 2.49	0.542 0.535	0.120 0.118	2.27 2.34	0.273 0.276
3	2.20~ 2.60	2.32 2.19	0.499 0.470	0.104 0.093	9.38 9.78	0.974 0.912
4	2.60~ 3.70	1.69 1.32	0.363 0.284	0.058 0.037	26.89 12.51	1.557 0.458
5	3.70~ 4.66	0.64 0.32	0.137 0.069	0.009 0.002	10.89 0.00	0.098 0.000
						ΣQ = 16.516

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

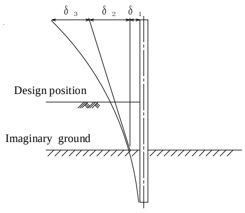
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	2.32 2.19	0.499 0.470	0.104 0.093	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below:

Q = 16.516＋0.013 ＝ 16.529

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3883\times2.65)\times143.97}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3883^3} = 0.01302\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3883\times2.65)\times143.97}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3883^2}\times(2.60+2.06) = 0.03549\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{16.53\times(2.60+2.06)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00872\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00221 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.66 m

Horizontal load: P = 11.10

Moment: M = 4.55

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.66\ m、h=L-H_m、H_m=0.80\ m、\quad h\leqq L)$$

$$= \frac{0.40\times3.86}{2\times2.00\times10^8\times95760\times10^{-8}}\times(2\times4.66-3.86) = 0.00002\ m$$

δ = δ_1 + δ_2 + δ_3

= 0.01302＋0.03549＋0.01095

= 0.05946 m

= 59.46 ≦ δ_a = 75.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)
	I	=	114000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 114000 \times 10^{-8}$		=	2.280×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 15960$ kN/m³

Calculated value $\beta = 0.36372$ m^{-1}

Penetration length of SSP $D = 1.40 + \dfrac{3}{0.364} = 9.64$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.64 = 11.84$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 17419$ kN/m³

Calculated value $\beta = 0.37175$ m^{-1}

Penetration length of SSP $D = 2.06 + \dfrac{3}{0.372} = 10.13$ m

Whole length of SSP $L = 2.60 - 0.40 + 10.13 = 12.33$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

8 Calculation Result

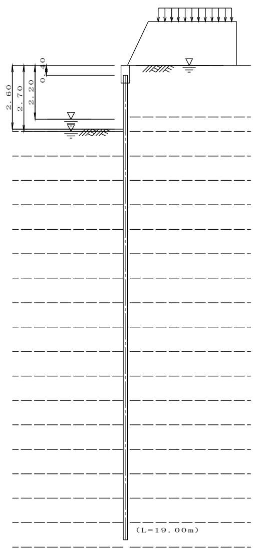
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		257.10	434.62
Stress intensity	σ (N/mm^2)		91 (185)	154 (278)
Lateral displacement	δ (mm)		32.03 (50.0)	59.46 (75.0)
Penetration depth	D (m)		9.64	10.13
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

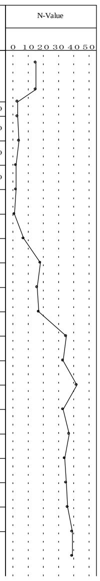
Left Bank No. 27_STA. 16+552 - 16+564

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
	Sandy Soil	18.0	30.0	0.0
2.10	Clayey Soil	16.0	0.0	18.0
2.70	Clayey Soil	16.0	0.0	24.0
3.70	Clayey Soil	16.0	0.0	12.0
4.70	Clayey Soil	16.0	0.0	12.0
5.70	Clayey Soil	16.0	0.0	6.0
6.70	Sandy Soil	18.0	27.0	0.0
7.70	Sandy Soil	18.0	31.0	0.0
8.70	Sandy Soil	18.0	30.0	0.0
9.70	Sandy Soil	18.0	31.0	0.0
10.70	Sandy Soil	18.0	38.0	0.0
11.70	Sandy Soil	18.0	37.0	0.0
12.70	Sandy Soil	18.0	41.0	0.0
13.70	Sandy Soil	18.0	37.0	0.0
14.70	Sandy Soil	18.0	39.0	0.0
15.70	Sandy Soil	18.0	38.0	0.0
16.70	Sandy Soil	18.0	38.0	0.0
17.70	Sandy Soil	18.0	38.0	0.0
18.70	Sandy Soil	18.0	39.0	0.0
19.70	Sandy Soil	18.0	39.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake
considered as distributed load

Arbitrary load	Horizontal load	P_t	=	7.1 kNm (Normal Condition)
		P_t'	=	16.5 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.80 m (Normal Condition)
		H_t'	=	-0.63 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	9.6 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00m (Seismic Condition)
		H_m	=	0.80m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.70	16	21	19.70	39
2	1.60	15	12	10.70	17	22	20.70	39
3	2.10	3	13	11.70	35			
4	2.70	3	14	12.70	33			
5	3.70	4	15	13.70	42			
6	4.70	2	16	14.70	33			
7	5.70	2	17	15.70	37			
8	6.70	1	18	16.70	34			
9	7.70	7	19	17.70	35			
10	8.70	18	20	18.70	36			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.70	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
3	3.70	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
4	4.70	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
5	5.70	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
6	6.70	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
7	7.70	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	8.70	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
9	9.70	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
10	10.70	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
11	11.70	S	35.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
12	12.70	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
13	13.70	S	42.0	18.00	10.00	41.0	0.0	0.0	0.200	auto	auto	——	——
14	14.70	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
15	15.70	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
16	16.70	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
17	17.70	S	35.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
18	18.70	S	36.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
19	19.70	S	39.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
20	20.70	S	39.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——

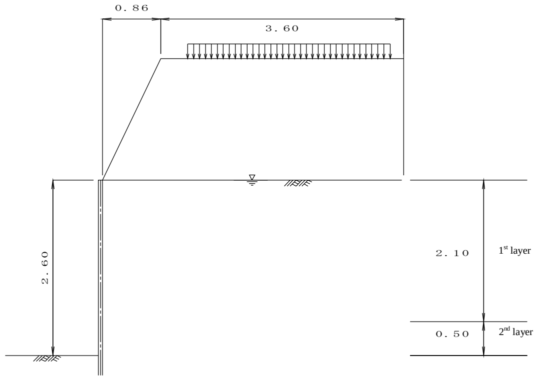
Note) depth : from top of coping to bottom of the layer
soil : sandy (S), clayey (C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active passive	10.00° -10.00°	10.00° -10.00°

1.203

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.86	4.46	4.46	1.80	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.26	4.26	10.0	5.0

Angle of rapture in embankment   calculated in consideration of embankment conditions

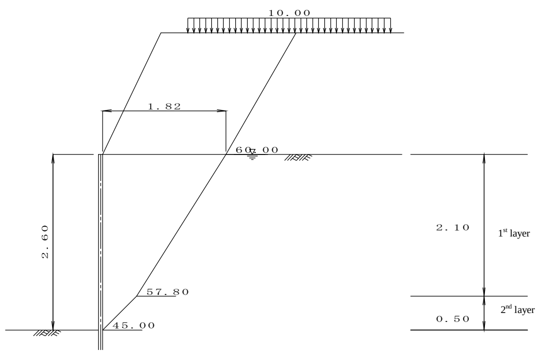
1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	709000 cm⁴
Sectional factor	Z_0	=	11400 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.88
Corrosion rate (to Z_0)	η	=	0.89
Section efficiency (to I_0)	μ	=	1.00
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	185 N/mm² (Normal)
	σ_a'	=	278 N/mm² (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～2.10	Clayey Soil	0.0	10.0	18.0	25.00	42.78	25.48	45.00
2	2.10～0.00	Sandy Soil	30.0	10.0	0.0	21.00	42.78	20.58	57.80
3		Embankment	30.0	——	0.0	32.40	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where.
- ζ : angle of active rupture (degree, ζ≥10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C : cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	1.80	1.82	2.60	2.86	4.40

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.44	61.95
Σ			61.95

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.60	16.02
Σ			16.02

Q surcharge load
l : width of surcharge load set by line of active rupture

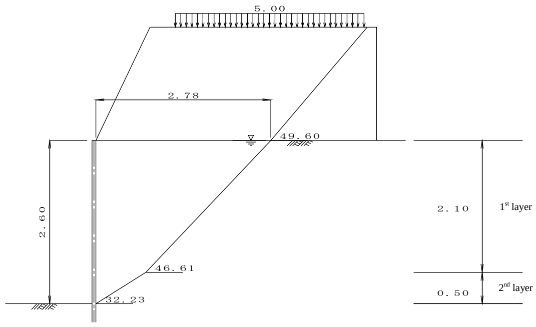
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{61.95 + 16.02 + 0.00}{1.82}$$

$$= 42.78 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	18.0	25.00	41.72	25.48	0.200	11.31	32.23
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	41.72	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	32.40	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  θ=tan⁻¹k or θ=tan⁻¹k'
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C : cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	32.23	0.50	0.00	0.00	0.79	0.50
2	46.61	2.10	0.79	0.50	2.78	2.60
3	49.60	1.80	2.78	2.60	4.31	4.40

Therefore, width of acting load shall be set as 2.78 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.61	100.90
Σ			100.90

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

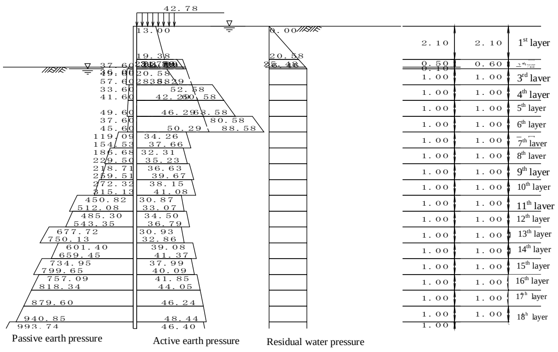
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{100.90 + 15.00 + 0.00}{2.78}$$

$$= 41.72 \ \text{kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	42.782 63.782	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Clayey soil	8.0	—	18.0 18.0	63.782 67.782	—— ——	—— ——
3	2.60~ 2.70	Clayey soil	8.0	—	18.0 18.0	67.782 68.582	—— ——	—— ——
4	2.70~ 3.70	Clayey soil	8.0	—	24.0 24.0	68.582 76.582	—— ——	—— ——
5	3.70~ 4.70	Clayey soil	8.0	—	12.0 12.0	76.582 84.582	—— ——	—— ——
6	4.70~ 5.70	Clayey soil	8.0	—	12.0 12.0	84.582 92.582	—— ——	—— ——
7	5.70~ 6.70	Clayey soil	8.0	—	6.0 6.0	92.582 100.582	—— ——	—— ——
8	6.70~ 7.70	Sandy soil	10.0	27.0	—— ——	100.582 110.582	0.34585 0.34585	0.34060 0.34060
9	7.70~ 8.70	Sandy soil	10.0	31.0	—— ——	110.582 120.582	0.29669 0.29669	0.29219 0.29219
10	8.70~ 9.70	Sandy soil	10.0	30.0	—— ——	120.582 130.582	0.30847 0.30847	0.30378 0.30378
11	9.70~ 10.70	Sandy soil	10.0	31.0	—— ——	130.582 140.582	0.29669 0.29669	0.29219 0.29219
12	10.70~ 11.70	Sandy soil	10.0	38.0	—— ——	140.582 150.582	0.22298 0.22298	0.21959 0.21959

1.205

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
13	11.70~ 12.70	Sandy soil	10.0	37.0	—— ——	150.582 160.582	0.23264 0.23264	0.22910 0.22910
14	12.70~ 13.70	Sandy soil	10.0	41.0	—— ——	160.582 170.582	0.19561 0.19561	0.19264 0.19264
15	13.70~ 14.70	Sandy soil	10.0	37.0	—— ——	170.582 180.582	0.23264 0.23264	0.22910 0.22910
16	14.70~ 15.70	Sandy soil	10.0	39.0	—— ——	180.582 190.582	0.21359 0.21359	0.21035 0.21035
17	15.70~ 16.70	Sandy soil	10.0	38.0	—— ——	190.582 200.582	0.22298 0.22298	0.21959 0.21959
18	16.70~ 17.70	Sandy soil	10.0	38.0	—— ——	200.582 210.582	0.22298 0.22298	0.21959 0.21959
19	17.70~ 18.70	Sandy soil	10.0	38.0	—— ——	210.582 220.582	0.22298 0.22298	0.21959 0.21959
20	18.70~ 19.70	Sandy soil	10.0	39.0	—— ——	220.582 230.582	0.21359 0.21359	0.21035 0.21035
21	19.70~ 20.70	Sandy soil	10.0	39.0	—— ——	230.582 240.582	0.21359 0.21359	0.21035 0.21035

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Clayey soil	16.0	0.0	18.0 18.0	0.000 1.600	—— ——	—— ——
4	2.70~ 3.70	Clayey soil	8.0	0.0	24.0 24.0	1.600 9.600	—— ——	—— ——
5	3.70~ 4.70	Clayey soil	8.0	0.0	12.0 12.0	9.600 17.600	—— ——	—— ——
6	4.70~ 5.70	Clayey soil	8.0	0.0	12.0 12.0	17.600 25.600	—— ——	—— ——
7	5.70~ 6.70	Clayey soil	8.0	0.0	6.0 6.0	25.600 33.600	—— ——	—— ——
8	6.70~ 7.70	Sandy soil	10.0	27.0	—— ——	33.600 43.600	3.59892 3.59892	3.54425 3.54425
9	7.70~ 8.70	Sandy soil	10.0	31.0	—— ——	43.600 53.600	4.34774 4.34774	4.28169 4.28169

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
10	8.70~ 9.70	Sandy soil	10.0	30.0	—— ——	53.600 63.600	4.14330 4.14330	4.08035 4.08035
11	9.70~ 10.70	Sandy soil	10.0	31.0	—— ——	63.600 73.600	4.34774 4.34774	4.28169 4.28169
12	10.70~ 11.70	Sandy soil	10.0	38.0	—— ——	73.600 83.600	6.21981 6.21981	6.12532 6.12532
13	11.70~ 12.70	Sandy soil	10.0	37.0	—— ——	83.600 93.600	5.89457 5.89457	5.80501 5.80501
14	12.70~ 13.70	Sandy soil	10.0	41.0	—— ——	93.600 103.600	7.35235 7.35235	7.24065 7.24065
15	13.70~ 14.70	Sandy soil	10.0	37.0	—— ——	103.600 113.600	5.89457 5.89457	5.80501 5.80501
16	14.70~ 15.70	Sandy soil	10.0	39.0	—— ——	113.600 123.600	6.56948 6.56948	6.46967 6.46967
17	15.70~ 16.70	Sandy soil	10.0	38.0	—— ——	123.600 133.600	6.21981 6.21981	6.12532 6.12532
18	16.70~ 17.70	Sandy soil	10.0	38.0	—— ——	133.600 143.600	6.21981 6.21981	6.12532 6.12532
19	17.70~ 18.70	Sandy soil	10.0	38.0	—— ——	143.600 153.600	6.21981 6.21981	6.12532 6.12532
20	18.70~ 19.70	Sandy soil	10.0	39.0	—— ——	153.600 163.600	6.56948 6.56948	6.46967 6.46967
21	19.70~ 20.70	Sandy soil	10.0	39.0	—— ——	163.600 173.600	6.56948 6.56948	6.46967 6.46967

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	13.00 19.38	—— ——	13.00 19.38	0.00 20.58	—— ——
2	2.10~ 2.60	27.78 31.78	31.89 33.89	31.89 33.89	20.58 25.48	—— ——
3	2.60~ 2.70	31.78 32.58	33.89 34.29	33.89 34.29	25.48 26.46	36.00 37.60
4	2.70~ 3.70	20.58 28.58	34.29 38.29	34.29 38.29	26.46 26.46	49.60 57.60
5	3.70~ 4.70	52.58 60.58	38.29 42.29	52.58 60.58	26.46 26.46	33.60 41.60
6	4.70~ 5.70	60.58 68.58	42.29 46.29	60.58 68.58	26.46 26.46	41.60 49.60
7	5.70~ 6.70	80.58 88.58	46.29 50.29	80.58 88.58	26.46 26.46	37.60 45.60
8	6.70~ 7.70	34.26 37.66	—— ——	34.26 37.66	26.46 26.46	119.09 154.53
9	7.70~ 8.70	32.31 35.23	—— ——	32.31 35.23	26.46 26.46	186.68 229.50

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
10	8.70~ 9.70	36.63 39.67	—— ——	36.63 39.67	26.46 26.46	218.71 259.51
11	9.70~ 10.70	38.15 41.08	—— ——	38.15 41.08	26.46 26.46	272.32 315.13
12	10.70~ 11.70	30.87 33.07	—— ——	30.87 33.07	26.46 26.46	450.82 512.08
13	11.70~ 12.70	34.50 36.79	—— ——	34.50 36.79	26.46 26.46	485.30 543.35
14	12.70~ 13.70	30.93 32.86	—— ——	30.93 32.86	26.46 26.46	677.72 750.13
15	13.70~ 14.70	39.08 41.37	—— ——	39.08 41.37	26.46 26.46	601.40 659.45
16	14.70~ 15.70	37.99 40.09	—— ——	37.99 40.09	26.46 26.46	734.95 799.65
17	15.70~ 16.70	41.85 44.05	—— ——	41.85 44.05	26.46 26.46	757.09 818.34
18	16.70~ 17.70	44.05 46.24	—— ——	44.05 46.24	26.46 26.46	818.34 879.60
19	17.70~ 18.70	46.24 48.44	—— ——	46.24 48.44	26.46 26.46	879.60 940.85
20	18.70~ 19.70	46.40 48.50	—— ——	46.40 48.50	26.46 26.46	993.74 1058.44
21	19.70~ 20.70	48.50 50.61	—— ——	48.50 50.61	26.46 26.46	1058.44 1123.13

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c: Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

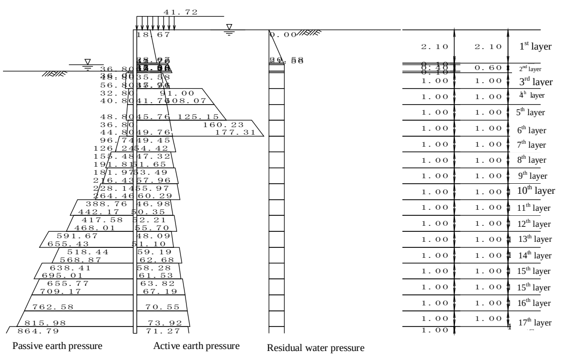
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k)	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	41.72 62.72	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Clayey Soil	8.0	—	18.0 18.0	62.72 63.52	20.58 21.56	0.200 0.200	11.31 11.31	——	——	32.94 32.80
3	2.20~ 2.60	Clayey Soil	8.0	—	18.0 18.0	63.52 66.72	21.56 25.48	0.200 0.200	11.31 11.31	——	——	32.80 32.23
4	2.60~ 2.70	Clayey Soil	8.0	—	18.0 18.0	66.72 67.52	25.48 26.46	0.200 0.200	11.31 11.31	——	——	32.23 32.09
5	2.70~ 3.70	Clayey Soil	8.0	—	24.0 24.0	67.52 75.52	26.46 36.26	0.200 0.200	11.31 11.31	——	——	36.43 35.57
6	3.70~ 4.70	Clayey Soil	8.0	—	12.0 12.0	75.52 83.52	36.26 46.06	0.200 0.200	11.31 11.31	——	——	10.00 10.00
7	4.70~ 5.70	Clayey Soil	8.0	—	12.0 12.0	83.52 91.52	46.06 55.86	0.200 0.200	11.31 11.31	——	——	10.00 10.00
8	5.70~ 6.70	Clayey Soil	8.0	—	6.0 6.0	91.52 99.52	55.86 65.66	0.200 0.200	11.31 11.31	——	——	10.00 10.00
9	6.70~ 7.70	Sandy Soil	10.0	27.0	—— ——	99.52 109.52	65.66 75.46	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
10	7.70~ 8.70	Sandy Soil	10.0	31.0	—— ——	109.52 119.52	75.46 85.26	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
11	8.70~ 9.70	Sandy Soil	10.0	30.0	—— ——	119.52 129.52	85.26 95.06	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
12	9.70~ 10.70	Sandy Soil	10.0	31.0	—— ——	129.52 139.52	95.06 104.86	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
13	10.70~ 11.70	Sandy Soil	10.0	38.0	—— ——	139.52 149.52	104.86 114.66	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	11.70~ 12.70	Sandy Soil	10.0	37.0	—— ——	149.52 159.52	114.66 124.46	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
15	12.70~ 13.70	Sandy Soil	10.0	41.0	—— ——	159.52 169.52	124.46 134.26	0.200 0.200	11.31 11.31	0.30610 0.30610	0.30145 0.30145	—— ——
16	13.70~ 14.70	Sandy Soil	10.0	37.0	—— ——	169.52 179.52	134.26 144.06	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
17	14.70~ 15.70	Sandy Soil	10.0	39.0	—— ——	179.52 189.52	144.06 153.86	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
18	15.70~ 16.70	Sandy Soil	10.0	38.0	—— ——	189.52 199.52	153.86 163.66	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
19	16.70~ 17.70	Sandy Soil	10.0	38.0	—— ——	199.52 209.52	163.66 173.46	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
20	17.70~ 18.70	Sandy Soil	10.0	38.0	—— ——	209.52 219.52	173.46 183.26	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
21	18.70~ 19.70	Sandy Soil	10.0	39.0	—— ——	219.52 229.52	183.26 193.06	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
22	19.70~ 20.70	Sandy Soil	10.0	39.0	—— ——	229.52 239.52	193.06 202.86	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta=\tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k)	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 2.70	Clayey Soil	8.00	0.0	18.0 18.0	0.000 0.800	0.00 0.98	0.200 0.200	11.31 11.31	—— ——	—— ——
5	2.70~ 3.70	Clayey Soil	8.00	0.0	24.0 24.0	0.800 8.800	0.98 10.78	0.200 0.200	11.31 11.31	—— ——	—— ——
6	3.70~ 4.70	Clayey Soil	8.00	0.0	12.0 12.0	8.800 16.800	10.78 20.58	0.200 0.200	11.31 11.31	—— ——	—— ——
7	4.70~ 5.70	Clayey Soil	8.00	0.0	12.0 12.0	16.800 24.800	20.58 30.38	0.200 0.200	11.31 11.31	—— ——	—— ——
8	5.70~ 6.70	Clayey Soil	8.00	0.0	6.0 6.0	24.800 32.800	30.38 40.18	0.200 0.200	11.31 11.31	—— ——	—— ——
9	6.70~ 7.70	Sandy Soil	10.00	27.0	—— ——	32.800 42.800	40.18 49.98	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
10	7.70~ 8.70	Sandy Soil	10.00	31.0	—— ——	42.800 52.800	49.98 59.78	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
11	8.70~ 9.70	Sandy Soil	10.00	30.0	—— ——	52.800 62.800	59.78 69.58	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
12	9.70~ 10.70	Sandy Soil	10.00	31.0	—— ——	62.800 72.800	69.58 79.38	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
13	10.70~ 11.70	Sandy Soil	10.00	38.0	—— ——	72.800 82.800	79.38 89.18	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
14	11.70~ 12.70	Sandy Soil	10.00	37.0	—— ——	82.800 92.800	89.18 98.98	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
15	12.70~ 13.70	Sandy Soil	10.00	41.0	—— ——	92.800 102.800	98.98 108.78	0.200 0.200	11.31 11.31	6.47409 6.47409	6.37573 6.37573
16	13.70~ 14.70	Sandy Soil	10.00	37.0	—— ——	102.800 112.800	108.78 118.58	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
17	14.70~ 15.70	Sandy Soil	10.00	39.0	—— ——	112.800 122.800	118.58 128.38	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
18	15.70~ 16.70	Sandy Soil	10.00	38.0	—— ——	122.800 132.800	128.38 138.18	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
19	16.70~ 17.70	Sandy Soil	10.00	38.0	—— ——	132.800 142.800	138.18 147.98	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
20	17.70~ 18.70	Sandy Soil	10.00	38.0	—— ——	142.800 152.800	147.98 157.78	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
21	18.70~ 19.70	Sandy Soil	10.00	39.0	—— ——	152.800 162.800	157.78 167.58	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
22	19.70~ 20.70	Sandy Soil	10.00	39.0	—— ——	162.800 172.800	167.58 177.38	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	18.67 28.07	—— ——	18.67 28.07	0.00 20.58	—— ——
2	2.10~ 2.20	42.63 43.70	31.36 31.76	42.63 43.70	20.58 21.56	—— ——
3	2.20~ 2.60	43.70 47.98	31.76 33.36	43.70 47.98	21.56 21.56	—— ——
4	2.60~ 2.70	47.98 49.06	33.36 33.76	47.98 49.06	21.56 21.56	36.00 36.80
5	2.70~ 3.70	35.58 45.91	33.76 37.76	35.58 45.91	21.56 21.56	48.80 56.80
6	3.70~ 4.70	91.00 108.07	37.76 41.76	91.00 108.07	21.56 21.56	32.80 40.80
7	4.70~ 5.70	108.07 125.15	41.76 45.76	108.07 125.15	21.56 21.56	40.80 48.80

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
8	5.70~ 6.70	160.23 177.31	45.76 49.76	160.23 177.31	21.56 21.56	36.80 44.80
9	6.70~ 7.70	49.45 54.42	—— ——	49.45 54.42	21.56 21.56	96.74 126.24
10	7.70~ 8.70	47.32 51.65	—— ——	47.32 51.65	21.56 21.56	155.48 191.81
11	8.70~ 9.70	53.49 57.96	—— ——	53.49 57.96	21.56 21.56	181.97 216.43
12	9.70~ 10.70	55.97 60.29	—— ——	55.97 60.29	21.56 21.56	228.14 264.46
13	10.70~ 11.70	46.98 50.35	—— ——	46.98 50.35	21.56 21.56	388.76 442.17
14	11.70~ 12.70	52.21 55.70	—— ——	52.21 55.70	21.56 21.56	417.58 468.01
15	12.70~ 13.70	48.09 51.10	—— ——	48.09 51.10	21.56 21.56	591.67 655.43
16	13.70~ 14.70	59.19 62.68	—— ——	59.19 62.68	21.56 21.56	518.44 568.87
17	14.70~ 15.70	58.28 61.53	—— ——	58.28 61.53	21.56 21.56	638.41 695.01
18	15.70~ 16.70	63.82 67.19	—— ——	63.82 67.19	21.56 21.56	655.77 709.17
19	16.70~ 17.70	67.19 70.55	—— ——	67.19 70.55	21.56 21.56	709.17 762.58
20	17.70~ 18.70	70.55 73.92	—— ——	70.55 73.92	21.56 21.56	762.58 815.98
21	18.70~ 19.70	71.27 74.51	—— ——	71.27 74.51	21.56 21.56	864.79 921.39
22	19.70~ 20.70	74.51 77.76	—— ——	74.51 77.76	21.56 21.56	921.39 977.99

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

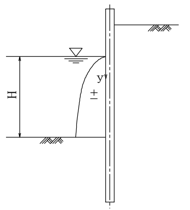
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

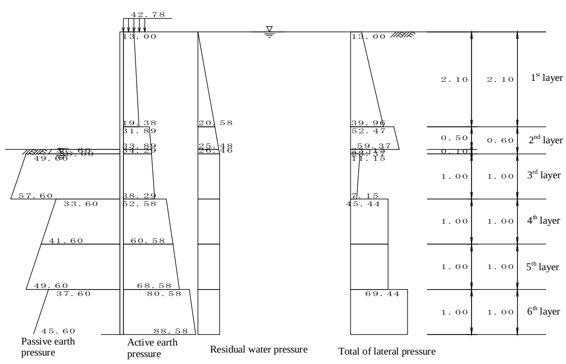
Where,
k_{hs}: design seismic coefficient
γ_w: unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

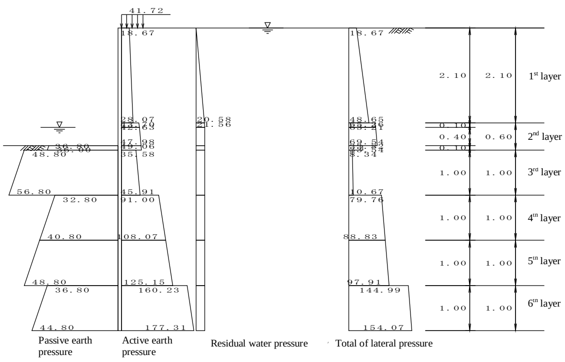


	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	13.00 19.38	0.00 20.58	—— ——	13.00 39.96
2	2.10~ 2.60	31.89 33.89	20.58 25.48	—— ——	52.47 59.37
3	2.60~ 2.70	33.89 34.29	25.48 26.46	36.00 37.60	23.37 23.15
4	2.70~ 3.70	34.29 38.29	26.46 26.46	49.60 57.60	11.15 7.15
5	3.70~ 4.70	52.58 60.58	26.46 26.46	33.60 41.60	45.44 45.44
6	4.70~ 5.70	60.58 68.58	26.46 26.46	41.60 49.60	45.44 45.44
7	5.70~ 6.70	80.58 88.58	26.46 26.46	37.60 45.60	69.44 69.44
8	6.70~ 7.70	34.26 37.66	26.46 26.46	119.09 154.53	-58.37 -90.41

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 4.10 m (GL -6.70 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	18.67 28.07	0.00 20.58	—— ——	18.67 48.65
2	2.10~ 2.20	42.63 43.70	20.58 21.56	—— ——	63.21 65.26
3	2.20~ 2.60	43.70 47.98	21.56 21.56	—— ——	65.26 69.54
4	2.60~ 2.70	47.98 49.06	21.56 21.56	36.00 36.80	33.54 33.82
5	2.70~ 3.70	35.58 45.91	21.56 21.56	48.80 56.80	8.34 10.67
6	3.70~ 4.70	91.00 108.07	21.56 21.56	32.80 40.80	79.76 88.83
7	4.70~ 5.70	108.07 125.15	21.56 21.56	40.80 48.80	88.83 97.91
8	5.70~ 6.70	160.23 177.31	21.56 21.56	36.80 44.80	144.99 154.07
9	6.70~ 7.70	49.45 54.42	21.56 21.56	96.74 126.24	-25.73 -50.25

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 4.10 m (GL -6.70 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m		
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 =	1.00 mm (passive side)
Corrosion rate	η	=	0.88		
Section efficiency	μ	=	1.00		
Young's modulus	E	=	200000 N/mm^2		
Inertia sectional moment	I_0	=	709000 cm^4 (original condition)		
	I	=	623920 cm^4 (after reduction by corrosion and section)		
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 623920 \times 10^{-8} = 1.248 \times 10^6$		

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	3
4	2.70	3
5	3.70	4
6	4.70	2
7	5.70	2
8	6.70	1
9	7.70	7
10	8.70	18
11	9.70	16
12	10.70	17
13	11.70	35
14	12.70	33
15	13.70	42
16	14.70	33
17	15.70	37
18	16.70	34
19	17.70	35
20	18.70	36
21	19.70	39
22	20.70	39

5-2 Normal Condition

K_h = 19276 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.249 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 4.01 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.70 m) to 4.01 m depth (GL -10.71 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	6.70	1.00	1.0	7.0	4.00
2	7.70	1.00	7.0	18.0	12.50
3	8.70	1.00	18.0	16.0	17.00
4	9.70	1.00	16.0	17.0	16.50
5	10.70	0.01	17.0	17.2	0.20
	L = Σh = 4.01				ΣA = 50.20

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{50.20}{4.01}$$

$$= 12.51$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 12.51^{0.406} = 19276 \text{ kN/m}^3$$

Kh (normal condition) = 19276 kN/m^3

5-3 Seismic Condition

K_h = 19276 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.249 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 4.01 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.70 m) to 4.01 m depth (GL -10.71 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	6.70	1.00	1.0	7.0	4.00
2	7.70	1.00	7.0	18.0	12.50
3	8.70	1.00	18.0	16.0	17.00
4	9.70	1.00	16.0	17.0	16.50
5	10.70	0.01	17.0	17.2	0.20
	L = Σh = 4.01				ΣA = 50.20

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{50.20}{4.01}$$

$$= 12.51$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 12.51^{0.406} = 19276 \text{ kN/m}^3$$

Kh (seismic condition) = 19276 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	13.00 39.96	13.65 41.95	6.00 5.30	81.88 222.35
2	2.10~ 2.60	0.50	52.47 59.37	13.12 14.84	4.43 4.27	58.16 63.33
3	2.60~ 2.70	0.10	23.37 23.15	1.17 1.16	4.07 4.03	4.75 4.67
4	2.70~ 3.70	1.00	11.15 7.15	5.58 3.58	3.67 3.33	20.44 11.92
5	3.70~ 4.70	1.00	45.44 45.44	22.72 22.72	2.67 2.33	60.59 53.02
6	4.70~ 5.70	1.00	45.44 45.44	22.72 22.72	1.67 1.33	37.87 30.29
7	5.70~ 6.70	1.00	69.44 69.44	34.72 34.72	0.67 0.33	23.15 11.57
				ΣP = 255.36		ΣM = 683.98

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	7.1 kN/m
depth to acting position	H_t	=	-0.80 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	4.10 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 53.25 \text{ kN·m}$$

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{737.23}{262.46} = 2.81 \text{ m}$$

6.1.2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	18.67 48.65	19.60 51.08	6.00 5.30	117.61 270.72
2	2.10~ 2.20	0.10	63.21 65.26	3.16 3.26	4.57 4.53	14.43 14.79
3	2.20~ 2.60	0.40	65.26 69.54	13.05 13.91	4.37 4.23	56.99 58.88
4	2.60~ 2.70	0.10	33.54 33.82	1.68 1.69	4.07 4.03	6.82 6.82
5	2.70~ 3.70	1.00	8.34 10.67	4.17 5.34	3.67 3.33	15.29 17.78
6	3.70~ 4.70	1.00	79.76 88.83	39.88 44.42	2.67 2.33	106.34 103.64
7	4.70~ 5.70	1.00	88.83 97.91	44.42 48.95	1.67 1.33	74.03 65.27
8	5.70~ 6.70	1.00	144.99 154.07	72.50 77.03	0.67 0.33	48.33 25.68
				ΣP = 444.13		ΣM = 1003.42

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	16.5 kN/m
depth to acting position	H_t	=	-0.63 m
moment	M_m	=	9.6 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	4.10 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 130.55 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	4.37 4.23	0.00 0.58
				ΣPdw = 0.14		ΣM dw = 0.58

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{1134.55}{460.77} = 2.46 \text{ m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	709000 cm^4 (original condition)
	I	=	623920 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 623920 x 10^{-8}		=	1.248×10^6

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\ (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	19276 kN/m^3
calculated value	β	=	0.24929 m^{-1}
resultant earth force (lateral)	P_0	=	262.46 kN/m
height of acting position of load	h_0	=	2.81 m
moment	M_0	=	737.23 kN·m/m

in consideration of ϕ_m = 1.251,

maximum moment	M_{max}	=	922.47 kN·m/m
depth of generated position of M_{max}	l_m	=	1.583 m
depth of 1st fixed point	l_i	=	4.734 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	19276 kN/m^3
calculated value	β	=	0.24929 m^{-1}
resultant earth force (lateral)	P_0	=	460.77 kN/m
height of acting position of load	h_0	=	2.46 m
moment	M_0	=	1134.55 kN·m/m

in consideration of ϕ_m = 1.304,

maximum moment	M_{max}	=	1479.84 kN·m/m
depth of generated position of M_{max}	l_m	=	1.693 m
depth of 1st fixed point	l_i	=	4.843 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	11400 cm^3 (original condition)
	Z	=	10146 cm^3 (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{922.47\times10^6}{10146\times10^3} = 91 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2$$

6.3.2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{1479.84\times10^6}{10146\times10^3} = 146 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2$$

6.4 Displacement

6.4.1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	6.00 5.30	0.896 0.791	0.281 0.230	13.65 41.95	3.838 9.665
2	2.10~ 2.60	4.43 4.27	0.662 0.637	0.171 0.160	13.12 14.84	2.238 2.371
3	2.60~ 2.70	4.07 4.03	0.607 0.602	0.147 0.145	1.17 1.16	0.172 0.168
4	2.70~ 3.70	3.67 3.33	0.547 0.498	0.122 0.103	5.58 3.58	0.683 0.369
5	3.70~ 4.70	2.67 2.33	0.398 0.348	0.069 0.054	22.72 22.72	1.561 1.218
6	4.70~ 5.70	1.67 1.33	0.249 0.199	0.028 0.018	22.72 22.72	0.645 0.420
7	5.70~ 6.70	0.67 0.33	0.100 0.050	0.005 0.001	34.72 34.72	0.166 0.042
						ΣQ = 23.556

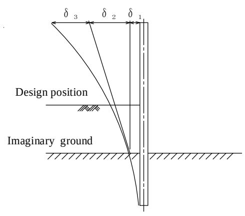
Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.2493\times2.81)\times262.46}{2\times2.00\times10^8\times623920\times10^{-8}\times0.2493^3} = 0.01154 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.2493\times2.81)\times262.46}{2\times2.00\times10^8\times623920\times10^{-8}\times0.2493^2}\times(2.60+4.10) = 0.02722 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{23.56\times(2.60+4.10)^3}{2.00\times10^8\times623920\times10^{-8}} = 0.00568 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00067 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 6.70 m
Horizontal load: P = 7.10
Moment: M = 5.68

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= 0.01154 + 0.02722 + 0.00635$$
$$= 0.04511 \text{ m}$$
$$= 45.11 \leqq \delta a = 50.00 \text{ mm}$$

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6.4.2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	6.00 5.30	0.896 0.791	0.281 0.230	19.60 51.08	5.514 11.767
2	2.10~ 2.20	4.57 4.53	0.682 0.677	0.180 0.177	3.16 3.26	0.567 0.578
3	2.20~ 2.60	4.37 4.23	0.652 0.632	0.166 0.158	13.05 13.91	2.170 2.191
4	2.60~ 2.70	4.07 4.03	0.607 0.602	0.147 0.145	1.68 1.69	0.246 0.245
5	2.70~ 3.70	3.67 3.33	0.547 0.498	0.122 0.103	4.17 5.34	0.510 0.551
6	3.70~ 4.70	2.67 2.33	0.398 0.348	0.069 0.054	39.88 44.42	2.740 2.381
7	4.70~ 5.70	1.67 1.33	0.249 0.199	0.028 0.018	44.42 48.95	1.260 0.905
8	5.70~ 6.70	0.67 0.33	0.100 0.050	0.005 0.001	72.50 77.03	0.347 0.094
						ΣQ = 32.067

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

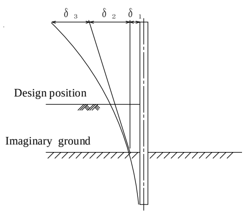
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	4.37 4.23	0.652 0.632	0.166 0.158	0.00 0.14	0.000 0.022
						ΣQ_{dw} = 0.022

Therefore, modulus of deformation Q is calculated as below:

Q = 32.067 + 0.022 = 32.089

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.2493\times 2.46)\times 460.77}{2\times 2.00\times 10^8\times 623920\times 10^{-8}\times 0.2493^3} = 0.01923 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.2493\times 2.46)\times 460.77}{2\times 2.00\times 10^8\times 623920\times 10^{-8}\times 0.2493^2}\times(2.60+4.10) = 0.04434 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{32.09\times(2.60+4.10)^3}{2.00\times 10^8\times 623920\times 10^{-8}} = 0.00773 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00151 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 6.70 m

Horizontal load: P = 16.50

Moment: M = 10.40

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=6.70 \text{ m},\ h=L-H_m,\ H_m=0.80 \text{ m},\ h\leqq L)$$

$$= \frac{9.60\times 5.90}{2\times 2.00\times 10^8\times 623920\times 10^{-8}}\times(2\times 6.70-5.90) = 0.00017 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01923 + 0.04434 + 0.00942

= 0.07299 m

= 72.99 ≦ δ_a = 75.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	709000 cm^4 (original condition)
	I	=	709000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 709000 x 10^{-8}		=	1.418x 10^5

7.4 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7.4.1 Normal Condition

Modules of lateral subgrade reaction K_h = 19276 kN/m^3

Calculated value β = 0.24144 m^{-1}

Penetration length of SSP $D = 4.10 + \dfrac{3}{0.241} = 16.53$ m

Whole length of SSP $L = 2.60 - 0.40 + 16.53 = 18.73$ m

7.4.2 Seismic Condition

Modules of lateral subgrade reaction K_h = 19276 kN/m^3

Calculated value β = 0.24144 m^{-1}

Penetration length of SSP $D = 4.10 + \dfrac{3}{0.241} = 16.53$ m

Whole length of SSP $L = 2.60 - 0.40 + 16.53 = 18.73$ m

Therefore, whole length of SSP is set as 19.00 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	709000		
Section modulus	Z (cm^3)	11400		
Maximum bending moment	M_{max} (kN·m/m)		922.47	1479.84
Stress intensity	σ (N/mm^2)		91 (185)	146 (278)
Lateral displacement	δ (mm)		45.11 (50.0)	72.99 (75.0)
Penetration depth	D (m)		16.53	16.53
Whole length of SSP	L (m)	19.00		

CHAPTER 2 STEEL SHEET PILE (SSP) REVETMENT (RIGHT BANK)

Table R 3.1.1 Design Results of SSP Revetment in Each Section (Right Bank)

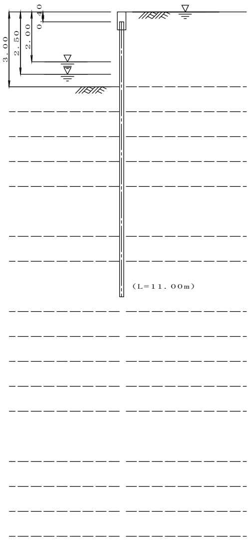
No.	Section			EL. of Design Riverbed (EL. m)	Designed SSP Revetment			Result of Design Calculation			
	from	to	Bank		Type	Z_0 (cm^3)	Length (m)	Stress (N/mm^2) Normal (acceptable)	Stress (N/mm^2) Seismic (acceptable)	Dsiplacement (mm) Normal (50)	Dsiplacement (mm) Seismic (75)
1	3+649	3+753	R	9.6	IV_W	2700	11.0	84 (180)	105 (270)	44.85	59.20
2	5+046	5+100	R	10.0	V_L	3150	12.0	62 (180)	94 (270)	38.92	64.94
3	5+100	5+223	R	10.0	VI_L	3820	12.5	66 (180)	90 (270)	41.86	61.62
4	5+262	5+340	R	10.0	VI_L	3820	13.0	53 (180)	81 (270)	36.53	61.33
5	5+340	5+414	R	10.0	VI_L	3820	13.0	60 (180)	92 (270)	38.83	65.28
6	5+545	5+639	R	10.0	10H + 450x200x12x25	902+2320	14.0	97 (185)	148 (278)	45.02	69.06
7	6+337	6+510	R	10.1	V_L	3150	12.0	65 (180)	88 (270)	43.3	62.39
8	8+222	8+250	R	10.1	10H + 550x250x12x28	902+3940	15.0	90 (185)	112 (278)	43.66	54.73
9	8+250	8+400	R	10.1	VI_L	3820	12.0	66 (180)	99 (270)	39.39	63.44
10	8+400	8+510	R	10.1	10H + 450x250x9x22	902+2490	13.5	110 (185)	151 (278)	44.71	61.74
11	8+510	8+650	R	10.1	VI_L	3820	12.5	63 (180)	96 (270)	39.34	65.21
12	8+650	8+800	R	10.1	10H + 400x200x9x22	902+1760	13.0	112 (185)	139 (278)	46.89	58.09
13	8+800	8+900	R	10.1	VI_L	3820	11.5	78 (180)	119 (270)	44.53	71.14
14	8+900	9+000	R	10.1	VI_L	3820	12.0	73 (180)	107 (270)	43.87	68.49
15	9+000	9+150	R	10.1	VI_L	3820	12.0	63 (180)	96 (270)	36.81	60.07
16	9+150	9+200	R	8.1	10H + 650x250x12x28	902+4850	16.5	100 (185)	127 (278)	47.39	64.03
17	9+200	9+341	R	10.1	IV_W	2700	10.5	81 (180)	121 (270)	39.29	64.16
18	9+430	9+550	R	10.1	VI_L	3820	12.5	64 (180)	98 (270)	40.83	66.06
19	9+550	9+650	R	10.1	VI_L	3820	12.0	64 (180)	98 (270)	38.59	61.89
20	9+650	9+723	R	10.1	VI_L	3820	12.0	64 (180)	98 (270)	40.10	63.28
21	9+723	9+750	R	10.1	10H + 400x200x9x22	902+1760	12.5	104 (185)	161 (278)	37.00	60.18
22	9+750	9+770	R	10.1	VI_L	3820	12.0	67 (180)	103 (270)	38.99	64.46
23	9+770	9+830	R	8.1	10H + 600x250x12x28	902+4390	15.5	105 (185)	127 (278)	47.65	60.19
24	9+830	9+947	R	10.1	VI_L	3820	12.0	64 (180)	99 (270)	38.87	64.22
25	10+956	11+050	R	8.2	10H + 500x200x12x25	902+2650	14.0	117 (185)	156 (278)	46.91	65.65
26	11+050	11+150	R	8.2	10H + 750x250x12x25	902+5390	18.0	97 (185)	147 (278)	42.57	70.16
27	11+150	11+263	R	8.2	10H + 650x200x12x28	902+4020	15.0	115 (185)	138 (278)	46.55	56.42
28	11+610	11+653	R	10.2	IV_W	2700	11.0	77 (180)	124 (270)	41.21	72.72
29	11+788	11+803	R	10.2	VI_L	3820	11.5	71 (180)	112 (270)	39.41	68.30
30	13+578	13+700	R	10.2	IV_W	2700	11.0	70 (180)	121 (270)	36.40	67.54
31	13+700	13+802	R	10.2	IV_W	2700	10.0	73 (180)	122 (270)	33.63	60.37
32	13+802	13+900	R	10.2	VI_L	3820	11.5	75 (180)	100 (270)	44.81	60.35
33	13+900	14+000	R	10.2	VI_L	3820	12.0	59 (180)	109 (270)	32.76	69.21
34	14+000	14+100	R	10.2	IV_W	2700	10.0	67 (180)	109 (270)	29.52	50.95
35	14+100	14+200	R	10.2	III_W	1800	8.5	105 (180)	162 (270)	43.44	69.47
36	14+200	14+300	R	10.2	V_L	3150	10.0	74 (180)	126 (270)	35.00	65.18
37	14+300	14+350	R	10.2	10H + 400x200x9x22	902+1760	12.0	76 (185)	203 (278)	23.24	69.65
38	14+350	14+395	R	10.2	10H + 500x250x12x28	902+3500	13.5	91 (185)	166 (278)	32.88	66.13
39	14+835	14+943	R	10.2	IV_W	2700	10.0	72 (180)	114 (270)	31.55	52.44
40	14+983	15+075	R	10.2	10H + 400x200x9x22	902+1760	11.5	97 (185)	178 (278)	30.17	58.36
41	15+409	15+441	R	10.2	10H + 450x250x9x22	902+2490	11.5	76 (185)	208 (278)	21.20	63.73
42	15+476	15+494	R	10.2	IV_W	2700	9.5	82 (180)	142 (270)	33.58	61.28
43	16+667	16+724	R	10.2	VI_L	3820	11.0	69 (180)	121 (270)	36.07	69.50
44	16+760	16+840	R	10.2	10H + 450x250x9x22	902+2490	13.0	79 (185)	158 (278)	26.14	61.14

－Steel Sheet Pile Design Calculation－

Right Bank No. 01_STA 3+649 - 3+753

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)	N-Value (0 10 20 30 40 50)
	Sandy Soil	18.0	27.0	0.0	
2.99	Sandy Soil	18.0	27.0	0.0	
3.99	Sandy Soil	18.0	28.0	0.0	
4.99	Sandy Soil	18.0	31.0	0.0	
5.99	Sandy Soil	18.0	33.0	0.0	
6.99	Sandy Soil	18.0	32.0	0.0	
8.99	Sandy Soil	18.0	33.0	0.0	
9.99	Clayey Soil	16.0	0.0	100.0	
11.99	Clayey Soil	16.0	0.0	100.0	
12.99	Clayey Soil	16.0	0.0	100.0	
13.99	Clayey Soil	16.0	0.0	12.0	
14.99	Clayey Soil	16.0	0.0	18.0	
15.99	Clayey Soil	16.0	0.0	25.0	
17.99	Clayey Soil	16.0	0.0	25.0	
18.99	Clayey Soil	16.0	0.0	100.0	
19.99	Clayey Soil	16.0	0.0	100.0	
20.99	Clayey Soil	16.0	0.0	100.0	

1-2 Dimensions of Structure

Depth from coping top to riverbed　H = 3.00 m
Depth from coping top to rear side ground　H_h = 0.00 m
Depth from coping top to SSP top　H_t = 0.40 m
Landside WL　L_{wa} = 0.00 m (Normal Condition)
L_{wa}' = 0.00 m (Seismic Condition)
Riverside WL　L_{wp} = 2.50 m (Normal Condition)
L_{wp}' = 2.00 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　Chang's formula
Penetration depths　$L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　γ_w = 9.8 kNm^3

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case　- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load
- Horizontal load　P_t = 0.0 kN/m (Normal Condition); P_t' = 4.1 kN/m (Seismic Condition)
- Depth of acting point　H_t = 0.00 m (Normal Condition); H_t' = 0.26 m (Seismic Condition)
- Moment　M_m = 0.0 kN·m/m (Normal Condition); M_m' = 2.2 kN·m/m (Seismic Condition)
- Depth of acting point　H_m' = 0.00 m (Seismic Condition); H_m = 0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　ζ_0 = 10 degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1-\dfrac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression　K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N'^{0.406}$
Average N-value　calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	4	11	13.99	16
2	2.99	4	12	14.99	2
3	3.99	5	13	15.99	3
4	4.99	11	14	17.99	5
5	5.99	18	15	18.99	6
6	6.99	21	16	19.99	19
7	8.99	19	17	20.99	20
8	9.99	21	18	21.99	21
9	11.99	18			
10	12.99	20			

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ(degree) normal	ζ(degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	2.99	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
2	3.99	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
3	4.99	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	――	――
4	5.99	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	――	――
5	6.99	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	――	――
6	8.99	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	――	――
7	9.99	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	――	――
8	11.99	C	18.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	――	――
9	12.99	C	20.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	――	――
10	13.99	C	16.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	――	――
11	14.99	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	――	――
12	15.99	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
13	17.99	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	――	――
14	18.99	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	――	――
15	19.99	C	19.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	――	――
16	20.99	C	20.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	――	――
17	21.99	C	16.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	――	――

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

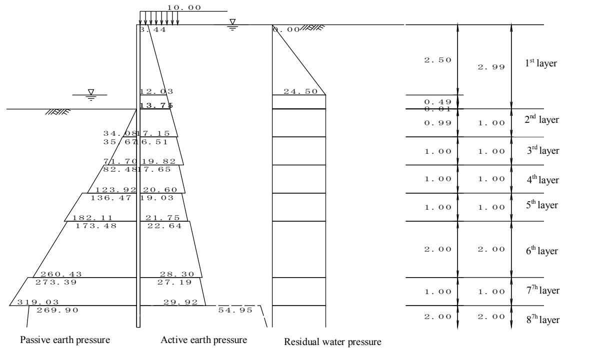
2.2

1-8 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm^2	
Inertia sectional moment	I_0	=	56700 cm^4	
Sectional factor	Z_0	=	2700 cm^3	
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.88	
Corrosion rate (to Z_0)	η	=	0.88	
Section efficiency (to I_0)	μ	=	0.80	
Section efficiency (to Z_0)	μ	=	1.00	
Round unit of SSP length			0.50 m	
Allowable stress	σ_a	=	180 Nmm (Normal)	
	σ_a'	=	270 Nmm (Seismic)	
Allowable displacement	δ_a	=	50.0 mm (Normal)	
	δ_a'	=	75.0 mm (Seismic)	
Bending of cantilever beam			calculated as distributed load of each layer	
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction Not reduced: I_0 applied to calculation of penetration depth Reduced: I_0 applied to calculation of section forces and displacement Reduced: Z_0 applied to calculation of stresses	

2 Lateral Pressure

2-1 Normal Condition



2-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C kNm^2	Σγh+Qa (kNm^2)	Ka	Ka ×cosδ
1	0.00～ 2.50	Sandy soil	10.0	27.0	—— ——	10.000 35.000	0.34800 0.34800	0.34371 0.34371
2	2.50～ 2.99	Sandy soil	10.0	27.0	—— ——	35.000 39.900	0.34800 0.34800	0.34371 0.34371
3	2.99～ 3.00	Sandy soil	10.0	27.0	—— ——	39.900 40.000	0.34800 0.34800	0.34371 0.34371
4	3.00～ 3.99	Sandy soil	10.0	27.0	—— ——	40.000 49.900	0.34800 0.34800	0.34371 0.34371
5	3.99～ 4.99	Sandy soil	10.0	28.0	—— ——	49.900 59.900	0.33506 0.33506	0.33093 0.33093
6	4.99～ 5.99	Sandy soil	10.0	31.0	—— ——	59.900 69.900	0.29838 0.29838	0.29471 0.29471
7	5.99～ 6.99	Sandy soil	10.0	33.0	—— ——	69.900 79.900	0.27561 0.27561	0.27222 0.27222
8	6.99～ 8.99	Sandy soil	10.0	32.0	—— ——	79.900 99.900	0.28683 0.28683	0.28330 0.28330
9	8.99～ 9.99	Sandy soil	10.0	33.0	—— ——	99.900 109.900	0.27561 0.27561	0.27222 0.27222
10	9.99～ 11.99	Clayey soil	8.0	—	100.0 100.0	109.900 125.900	—— ——	—— ——
11	11.99～ 12.99	Clayey soil	8.0	—	100.0 100.0	125.900 133.900	—— ——	—— ——
12	12.99～ 13.99	Clayey soil	8.0	—	100.0 100.0	133.900 141.900	—— ——	—— ——
13	13.99～ 14.99	Clayey soil	8.0	—	12.0 12.0	141.900 149.900	—— ——	—— ——

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C kNm^2	Σγh+Qa (kNm^2)	Ka	Ka ×cosδ
14	14.99～ 15.99	Clayey soil	8.0	—	18.0 18.0	149.900 157.900	—— ——	—— ——
15	15.99～ 17.99	Clayey soil	8.0	—	25.0 25.0	157.900 173.900	—— ——	—— ——
16	17.99～ 18.99	Clayey soil	8.0	—	25.0 25.0	173.900 181.900	—— ——	—— ——
17	18.99～ 19.99	Clayey soil	8.0	—	100.0 100.0	181.900 189.900	—— ——	—— ——
18	19.99～ 20.99	Clayey soil	8.0	—	100.0 100.0	189.900 197.900	—— ——	—— ——
19	20.99～ 21.25	Clayey soil	8.0	—	100.0 100.0	197.900 200.000	—— ——	—— ——
20	21.25～ 21.99	Clayey soil	8.0	—	100.0 100.0	200.000 205.900	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

2-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C kNm^2	Σγh+Qp (kNm^2)	Kp	Kp ×cosδ
4	3.00～ 3.99	Sandy soil	10.0	27.0	—— ——	0.000 9.900	3.48553 3.48553	3.44261 3.44261
5	3.99～ 4.99	Sandy soil	10.0	28.0	—— ——	9.900 19.900	3.64796 3.64796	3.60305 3.60305
6	4.99～ 5.99	Sandy soil	10.0	31.0	—— ——	19.900 29.900	4.19615 4.19615	4.14448 4.14448
7	5.99～ 6.99	Sandy soil	10.0	33.0	—— ——	29.900 39.900	4.62104 4.62104	4.56415 4.56415
8	6.99～ 8.99	Sandy soil	10.0	32.0	—— ——	39.900 59.900	4.40199 4.40199	4.34780 4.34780
9	8.99～ 9.99	Sandy soil	10.0	33.0	—— ——	59.900 69.900	4.62104 4.62104	4.56415 4.56415
10	9.99～ 11.99	Clayey soil	8.0	0.0	100.0 100.0	69.900 85.900	—— ——	—— ——
11	11.99～ 12.99	Clayey soil	8.0	0.0	100.0 100.0	85.900 93.900	—— ——	—— ——
12	12.99～ 13.99	Clayey soil	8.0	0.0	100.0 100.0	93.900 101.900	—— ——	—— ——
13	13.99～ 14.99	Clayey soil	8.0	0.0	12.0 12.0	101.900 109.900	—— ——	—— ——
14	14.99～ 15.99	Clayey soil	8.0	0.0	18.0 18.0	109.900 117.900	—— ——	—— ——
15	15.99～ 17.99	Clayey soil	8.0	0.0	25.0 25.0	117.900 133.900	—— ——	—— ——
16	17.99～ 18.99	Clayey soil	8.0	0.0	25.0 25.0	133.900 141.900	—— ——	—— ——
17	18.99～ 19.99	Clayey soil	8.0	0.0	100.0 100.0	141.900 149.900	—— ——	—— ——

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C kNm^2	Σγh+Qp (kNm^2)	Kp	Kp ×cosδ
18	19.99～ 20.99	Clayey soil	8.0	0.0	100.0 100.0	149.900 157.900	—— ——	—— ——
19	20.99～ 21.25	Clayey soil	8.0	0.0	100.0 100.0	157.900 160.000	—— ——	—— ——
20	21.25～ 21.99	Clayey soil	8.0	0.0	100.0 100.0	160.000 165.900	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

2-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm^2	Pa2 kNm^2	Pa kNm^2	Pw kNm^2	Pp kNm^2
1	0.00～ 2.50	3.44 12.03	—— ——	3.44 12.03	0.00 24.50	—— ——
2	2.50～ 2.99	12.03 13.71	—— ——	12.03 13.71	24.50 24.50	—— ——
3	2.99～ 3.00	13.71 13.75	—— ——	13.71 13.75	24.50 24.50	—— ——
4	3.00～ 3.99	13.75 17.15	—— ——	13.75 17.15	24.50 24.50	0.00 34.08
5	3.99～ 4.99	16.51 19.82	—— ——	16.51 19.82	24.50 24.50	35.67 71.70
6	4.99～ 5.99	17.65 20.60	—— ——	17.65 20.60	24.50 24.50	82.48 123.92
7	5.99～ 6.99	19.03 21.75	—— ——	19.03 21.75	24.50 24.50	136.47 182.11
8	6.99～ 8.99	22.64 28.30	—— ——	22.64 28.30	24.50 24.50	173.48 260.43
9	8.99～ 9.99	27.19 29.92	—— ——	27.19 29.92	24.50 24.50	273.39 319.03
10	9.99～ 11.99	-90.10 -74.10	54.95 62.95	54.95 62.95	24.50 24.50	269.90 285.90
11	11.99～ 12.99	-74.10 -66.10	62.95 66.95	62.95 66.95	24.50 24.50	285.90 293.90
12	12.99～ 13.99	-66.10 -58.10	66.95 70.95	66.95 70.95	24.50 24.50	293.90 301.90
13	13.99～ 14.99	117.90 125.90	70.95 74.95	117.90 125.90	24.50 24.50	125.90 133.90
14	14.99～ 15.99	113.90 121.90	74.95 78.95	113.90 121.90	24.50 24.50	145.90 153.90
15	15.99～ 17.99	107.90 123.90	78.95 86.95	107.90 123.90	24.50 24.50	167.90 183.90
16	17.99～ 18.99	123.90 131.90	86.95 90.95	123.90 131.90	24.50 24.50	183.90 191.90
17	18.99～ 19.99	-18.10 -10.10	90.95 94.95	90.95 94.95	24.50 24.50	341.90 349.90
18	19.99～ 20.99	-10.10 -2.10	94.95 98.95	94.95 98.95	24.50 24.50	349.90 357.90
19	20.99～ 21.25	-2.10 0.00	98.95 100.00	98.95 100.00	24.50 24.50	357.90 360.00
20	21.25～ 21.99	0.00 5.90	100.00 102.95	100.00 102.95	24.50 24.50	360.00 365.90

2.3

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

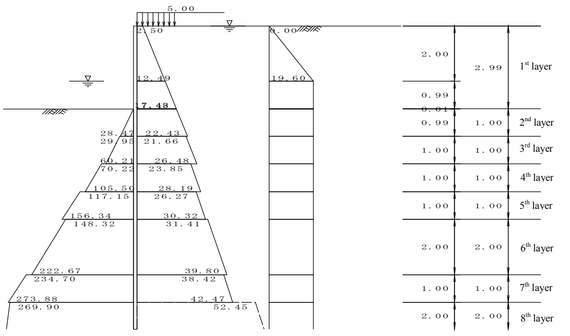
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

2-2 Seismic Condition



Passive earth pressure Active earth pressure Residual water pressure

2-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.00	Sandy Soil	10.0	27.0	—— ——	5.00 25.00	0.00 19.60	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
2	2.00~ 2.99	Sandy Soil	10.0	27.0	—— ——	25.00 34.90	19.60 29.30	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.99~ 3.00	Sandy Soil	10.0	27.0	—— ——	34.90 35.00	29.30 29.40	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	3.00~ 3.99	Sandy Soil	10.0	27.0	—— ——	35.00 44.90	29.40 39.10	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	3.99~ 4.99	Sandy Soil	10.0	28.0	—— ——	44.90 54.90	39.10 48.90	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	4.99~ 5.99	Sandy Soil	10.0	31.0	—— ——	54.90 64.90	48.90 58.70	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	—— ——
7	5.99~ 6.99	Sandy Soil	10.0	33.0	—— ——	64.90 74.90	58.70 68.50	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——
8	6.99~ 8.99	Sandy Soil	10.0	32.0	—— ——	74.90 94.90	68.50 88.10	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
9	8.99~ 9.99	Sandy Soil	10.0	33.0	—— ——	94.90 104.90	88.10 97.90	0.200 0.200	11.31 11.31	0.40986 0.40986	0.40481 0.40481	—— ——
10	9.99~ 11.99	Clayey Soil	8.0	—	100.0 100.0	104.90 120.90	97.90 117.50	0.200 0.200	11.31 11.31	—— ——	—— ——	43.33 43.07
11	11.99~ 12.99	Clayey Soil	8.0	—	100.0 100.0	120.90 128.90	117.50 127.30	0.200 0.200	11.31 11.31	—— ——	—— ——	43.07 42.94
12	12.99~ 13.99	Clayey Soil	8.0	—	100.0 100.0	128.90 136.90	127.30 137.10	0.200 0.200	11.31 11.31	—— ——	—— ——	42.94 42.81
13	13.99~ 14.99	Clayey Soil	8.0	—	12.0 12.0	136.90 144.90	137.10 146.90	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
14	14.99~ 15.99	Clayey Soil	8.0	—	18.0 18.0	144.90 152.90	146.90 156.70	0.200 0.200	11.31 11.31	—— ——	—— ——	22.24 19.31
15	15.99~ 17.99	Clayey Soil	8.0	—	25.0 25.0	152.90 168.90	156.70 176.30	0.200 0.200	11.31 11.31	—— ——	—— ——	31.26 28.89
16	17.99~ 18.99	Clayey Soil	8.0	—	25.0 25.0	168.90 176.90	176.30 186.10	0.200 0.200	11.31 11.31	—— ——	—— ——	28.89 27.56
17	18.99~ 19.99	Clayey Soil	8.0	—	100.0 100.0	176.90 184.90	186.10 195.90	0.200 0.200	11.31 11.31	—— ——	—— ——	42.13 41.99
18	19.99~ 20.99	Clayey Soil	8.0	—	100.0 100.0	184.90 192.90	195.90 205.70	0.200 0.200	11.31 11.31	—— ——	—— ——	41.99 41.85
19	20.99~ 21.99	Clayey Soil	8.0	—	100.0 100.0	192.90 200.90	205.70 215.50	0.200 0.200	11.31 11.31	—— ——	—— ——	41.85 41.70

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$$

2-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	3.00~ 3.99	Sandy soil	10.00	27.0	—— ——	0.000 9.900	0.00 9.70	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	3.99~ 4.99	Sandy soil	10.00	28.0	—— ——	9.900 19.900	9.70 19.50	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
6	4.99~ 5.99	Sandy soil	10.00	31.0	—— ——	19.900 29.900	19.50 29.30	0.200 0.200	11.31 11.31	3.57258 3.57258	3.52859 3.52859
7	5.99~ 6.99	Sandy soil	10.00	33.0	—— ——	29.900 39.900	29.30 39.10	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819

Passive earth pressure Active earth pressure Residual water pressure

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
8	6.99~ 8.99	Sandy soil	10.00	32.0	—— ——	39.900 59.900	39.10 58.70	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
9	8.99~ 9.99	Clayey soil	10.00	33.0	—— ——	59.900 69.900	58.70 68.50	0.200 0.200	11.31 11.31	3.96703 3.96703	3.91819 3.91819
10	9.99~ 11.99	Clayey soil	8.00	0.0	100.0 100.0	69.900 85.900	68.50 88.10	0.200 0.200	11.31 11.31	—— ——	—— ——
11	11.99~ 12.99	Clayey soil	8.00	0.0	100.0 100.0	85.900 93.900	88.10 97.90	0.200 0.200	11.31 11.31	—— ——	—— ——
12	12.99~ 13.99	Clayey soil	8.00	0.0	100.0 100.0	93.900 101.900	97.90 107.70	0.200 0.200	11.31 11.31	—— ——	—— ——
13	13.99~ 14.99	Clayey soil	8.00	0.0	12.0 12.0	101.900 109.900	107.70 117.50	0.200 0.200	11.31 11.31	—— ——	—— ——
14	14.99~ 15.99	Clayey soil	8.00	0.0	18.0 18.0	109.900 117.900	117.50 127.30	0.200 0.200	11.31 11.31	—— ——	—— ——
15	15.99~ 17.99	Clayey soil	8.00	0.0	25.0 25.0	117.900 133.900	127.30 146.90	0.200 0.200	11.31 11.31	—— ——	—— ——
16	17.99~ 18.99	Clayey soil	8.00	0.0	25.0 25.0	133.900 141.900	146.90 156.70	0.200 0.200	11.31 11.31	—— ——	—— ——
17	18.99~ 19.99	Clayey soil	8.00	0.0	100.0 100.0	141.900 149.900	156.70 166.50	0.200 0.200	11.31 11.31	—— ——	—— ——
18	19.99~ 20.99	Clayey soil	8.00	0.0	100.0 100.0	149.900 157.900	166.50 176.30	0.200 0.200	11.31 11.31	—— ——	—— ——
19	20.99~ 21.99	Clayey soil	8.00	0.0	100.0 100.0	157.900 165.900	176.30 186.10	0.200 0.200	11.31 11.31	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,

$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}}\right]^2}$$

2-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.00	2.50 12.49	—— ——	2.50 12.49	0.00 19.60	—— ——
2	2.00~ 2.99	12.49 17.43	—— ——	12.49 17.43	19.60 19.60	—— ——
3	2.99~ 3.00	17.43 17.48	—— ——	17.43 17.48	19.60 19.60	—— ——
4	3.00~ 3.99	17.48 22.43	—— ——	17.48 22.43	19.60 19.60	0.00 28.47
5	3.99~ 4.99	21.66 26.48	—— ——	21.66 26.48	19.60 19.60	29.95 60.21
6	4.99~ 5.99	23.85 28.19	—— ——	23.85 28.19	19.60 19.60	70.22 105.50
7	5.99~ 6.99	26.27 30.32	—— ——	26.27 30.32	19.60 19.60	117.15 156.34

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
8	6.99~ 8.99	31.41 39.80	—— ——	31.41 39.80	19.60 19.60	148.32 222.67
9	8.99~ 9.99	38.42 42.47	—— ——	38.42 42.47	19.60 19.60	234.70 273.88
10	9.99~ 11.99	-73.20 -53.69	52.45 60.45	52.45 60.45	19.60 19.60	269.90 285.90
11	11.99~ 12.99	-53.69 -43.92	60.45 64.45	60.45 64.45	19.60 19.60	285.90 293.90
12	12.99~ 13.99	-43.92 -34.13	64.45 68.45	64.45 68.45	19.60 19.60	293.90 301.90
13	13.99~ 14.99	222.01 239.08	68.45 72.45	222.01 239.08	19.60 19.60	125.90 133.90
14	14.99~ 15.99	164.39 182.50	72.45 76.45	164.39 182.50	19.60 19.60	145.90 153.90
15	15.99~ 17.99	146.92 171.02	76.45 84.45	146.92 171.02	19.60 19.60	167.90 183.90
16	17.99~ 18.99	171.02 183.74	84.45 88.45	171.02 183.74	19.60 19.60	183.90 191.90
17	18.99~ 19.99	15.01 24.88	88.45 92.45	88.45 92.45	19.60 19.60	341.90 349.90
18	19.99~ 20.99	24.88 34.76	92.45 96.45	92.45 96.45	19.60 19.60	349.90 357.90
19	20.99~ 21.99	34.76 44.66	96.45 100.45	96.45 100.45	19.60 19.60	357.90 365.90

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

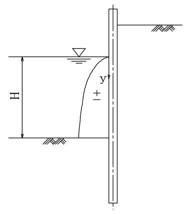
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

2-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	2.00	0.00	0.00
2	3.00	1.00	1.72

Where,

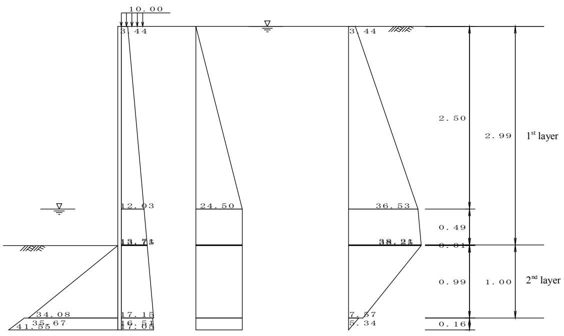
k_{hs} : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



3 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

3-1 Normal Condition



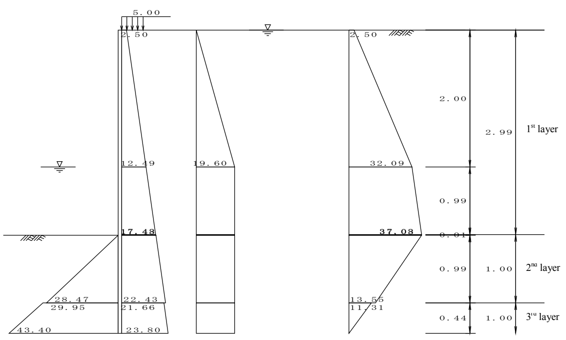
Passive earth pressure | Active earth pressure | Residual water pressure | Total of lateral pressure

	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00~ 2.50	3.44 12.03	0.00 24.50	—— ——	3.44 36.53
2	2.50~ 2.99	12.03 13.71	24.50 24.50	—— ——	36.53 38.21
3	2.99~ 3.00	13.71 13.75	24.50 24.50	—— ——	38.21 38.25
4	3.00~ 3.99	13.75 17.15	24.50 24.50	0.00 34.08	38.25 7.57
5	3.99~ 4.15	16.51 17.05	24.50 24.50	35.67 41.55	5.34 0.00
6	4.15~ 4.99	17.05 19.82	24.50 24.50	41.55 71.70	0.00 -27.38

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.15 m (GL -4.15 m)

3-2 Seismic Condition



Passive earth pressure | Active earth pressure | Residual water pressure | Total of lateral pressure

	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00~ 2.00	2.50 12.49	0.00 19.60	—— ——	2.50 32.09
2	2.00~ 2.99	12.49 17.43	19.60 19.60	—— ——	32.09 37.03
3	2.99~ 3.00	17.43 17.48	19.60 19.60	—— ——	37.03 37.08
4	3.00~ 3.99	17.48 22.43	19.60 19.60	0.00 28.47	37.08 13.55
5	3.99~ 4.44	21.66 23.80	19.60 19.60	29.95 43.40	11.31 0.00
6	4.44~ 4.99	23.80 26.48	19.60 19.60	43.40 60.21	0.00 -14.13

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.44 m (GL -4.44 m)

4 Modulus of Lateral Subgrade Reaction

4-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	4	11	13.99	16
2	2.99	4	12	14.99	2
3	3.99	5	13	15.99	3
4	4.99	11	14	17.99	5
5	5.99	18	15	18.99	6
6	6.99	21	16	19.99	19
7	8.99	19	17	20.99	20
8	9.99	21	18	21.99	21
9	11.99	18			
10	12.99	20			

4-2 Normal Condition

K_h = 19175 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.495 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.02 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.15 m) to 2.02 m depth (GL -6.17 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.15	0.84	6.0	11.0	7.10
2	4.99	1.00	11.0	18.0	14.50
3	5.99	0.18	18.0	18.6	3.35
	L = Σh = 2.02			ΣA = 24.96	

A (upper N-value + lower N-value) × h/2

2.5

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{24.96}{2.02}$

$= 12.35$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 12.35^{0.406} = 19175$ kN/m³

Kh (normal condition) = 19175 kNm³

4-3 Seismic Condition

K_h = 20162 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.501$ m⁻¹

$$L = \frac{1}{\beta} = 1.99 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.43 m) and 1.99 m depth (GL -6.43 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.43	0.56	7.7	11.0	5.18
2	4.99	1.00	11.0	18.0	14.50
3	5.99	0.44	18.0	19.3	8.20
	L = Σh = 1.99			ΣA = 27.88	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{27.88}{1.99}$

$= 13.98$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 13.98^{0.406} = 20162$ kN/m³

Kh (seismic condition) = 20162 kNm³

5 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

5-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

5-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.50	2.50	3.44 36.53	4.30 45.66	3.32 2.49	14.26 113.55
2	2.50~ 2.99	0.49	36.53 38.21	8.95 9.36	1.49 1.33	13.34 12.42
3	2.99~ 3.00	0.01	38.21 38.25	0.19 0.19	1.16 1.16	0.22 0.22
4	3.00~ 3.99	0.99	38.25 7.57	18.93 3.75	0.82 0.49	15.59 1.85
5	3.99~ 4.15	0.16	5.34 0.00	0.44 0.00	0.11 0.05	0.05 0.00
				ΣP = 91.77		ΣM = 171.49

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	0.0 kNm
depth to acting position	H_t	=	0.00 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	3.00 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.15 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 00.00$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{171.49}{91.77} = 1.87 \text{ m}$$

5-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.00	2.00	2.50 32.09	2.50 32.09	3.77 3.10	9.41 99.51
2	2.00~ 2.99	0.99	32.09 37.03	15.88 18.33	2.10 1.77	33.43 32.53
3	2.99~ 3.00	0.01	37.03 37.08	0.19 0.19	1.44 1.44	0.27 0.27
4	3.00~ 3.99	0.99	37.08 13.55	18.36 6.71	1.10 0.77	20.27 5.20
5	3.99~ 4.43	0.44	11.31 0.00	2.51 0.00	0.30 0.15	0.74 0.00
				ΣP = 96.75		ΣM = 201.63

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	4.1 kNm
depth to acting position	H_t	=	0.26 m
moment	M_m	=	2.2 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	3.00 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.43 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 19.32$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00~ 3.00	1.00	0.0 1.7	0.00 0.86	2.10 1.77	0.00 1.52
				ΣPdw = 0.86		ΣMdw = 1.52

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{222.46}{101.71} = 2.19 \text{ m}$$

5-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	56700 cm⁴ (original condition)
	I	=	39917 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 39917 × 10⁻⁸		=	7.983 × 10⁴

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

5-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	19175 kNm³
calculated value	β	=	0.49502 m⁻¹
resultant earth force (lateral)	P_0	=	91.77 kNm
height of acting position of load	h_0	=	1.87 m
moment	M_0	=	171.49 kN·m/m

in consideration of ψ_m = 1.165,

maximum moment	M_{max}	=	199.79 kN·m/m
depth of generated position of M_{max}	l_m	=	0.682 m
depth of 1st fixed point	l_i	=	2.268 m

5-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	20162 kNm³
calculated value	β	=	0.50127 m⁻¹
resultant earth force (lateral)	P_0	=	101.71 kNm
height of acting position of load	h_0	=	2.19 m
moment	M_0	=	222.46 kN·m/m

in consideration of ψ_m = 1.126,

maximum moment	M_{max}	=	250.57 kN·m/m
depth of generated position of M_{max}	l_m	=	0.606 m
depth of 1st fixed point	l_i	=	2.172 m

5-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm^3 (original condition)
	Z	=	2376 cm^3 (after reduction by corrosion and section)

5-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{199.79\times10^6}{2376\times10^3} = 84\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad (ok)$$

5-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{250.57\times10^6}{2376\times10^3} = 105\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad (ok)$$

5-4 Displacement

5-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.50	3.32 2.49	0.799 0.599	0.234 0.143	4.30 45.66	1.007 6.551
2	2.50~ 2.99	1.49 1.33	0.359 0.319	0.057 0.046	8.95 9.36	0.507 0.427
3	2.99~ 3.00	1.16 1.16	0.279 0.278	0.035 0.035	0.19 0.19	0.007 0.007
4	3.00~ 3.99	0.82 0.49	0.198 0.119	0.018 0.007	18.93 3.75	0.347 0.025
5	3.99~ 4.15	0.11 0.05	0.026 0.013	0.000 0.000	0.44 0.00	0.000 0.000
						ΣQ = 8.878

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

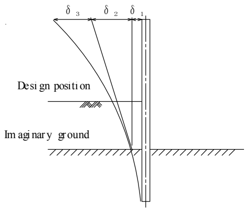
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4950\times1.87)\times91.77}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4950^3} = 0.00912\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4950\times1.87)\times91.77}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4950^2}\times(3.00+1.15) = 0.02776\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{8.88\times(3.00+1.15)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00797\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00912 + 0.02776 + 0.00797
= 0.04485 m
= 44.85 $\leqq$ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

5-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.00	3.77 3.10	0.850 0.699	0.259 0.188	2.50 32.09	0.646 6.017
2	2.00~ 2.99	2.10 1.77	0.475 0.400	0.095 0.069	15.88 18.33	1.506 1.272
3	2.99~ 3.00	1.44 1.44	0.325 0.324	0.047 0.047	0.19 0.19	0.009 0.009
4	3.00~ 3.99	1.10 0.77	0.249 0.175	0.028 0.014	18.36 6.71	0.522 0.096
5	3.99~ 4.43	0.30 0.15	0.067 0.033	0.002 0.001	2.51 0.00	0.005 0.000
						ΣQ = 10.083

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

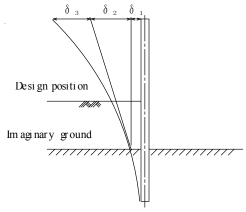
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.00~ 3.00	2.10 1.77	0.474 0.399	0.095 0.069	0.00 0.86	0.000 0.059
						$ΣQ_{dw}$ = 0.059

Therefore, modulus of deformation Q is calculated as below

Q = 11.329 + 0.059 = 11.388

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5013\times2.19)\times101.71}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5013^3} = 0.01060\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5013\times2.19)\times101.71}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5013^2}\times(3.00+1.43) = 0.03589\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.39\times(3.00+1.43)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.01244\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$$= \frac{2.20\times3.63}{2\times2.00\times10^8\times39917\times10^{-8}}\times(2\times4.43-3.63) = 0.00026\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01060 + 0.03589 + 0.01270
= 0.05920 m
= 59.20 $\leqq \delta_a$ = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 56700 \times 10^{-8}$		=	1.134×10^5

6-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

6-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 19175$ kN/m³
Calculated value $\beta = 0.45344$ m⁻¹

Penetration length of SSP $D = 1.15 + \dfrac{3}{0.453} = 7.77$ m
Whole length of SSP $L = 3.00 - 0.40 + 7.77 = 10.37$ m

6-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 20162$ kN/m³
Calculated value $\beta = 0.45916$ m⁻¹

Penetration length of SSP $D = 1.43 + \dfrac{3}{0.459} = 7.97$ m
Whole length of SSP $L = 3.00 - 0.40 + 7.97 = 10.57$ m

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

Case: Right Bank No. 01_STA 3+649 - 3+753

7 Calculation Result

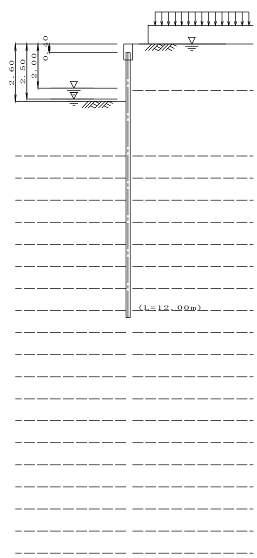
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		199.79	250.57
Stress intensity	σ (N/mm^2)		84 (180)	105 (270)
Lateral displacement	δ (mm)		44.85 (50.0)	59.20 (75.0)
Penetration depth	D (m)		7.77	7.97
Whole length of SSP	L (m)	11.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 02_STA 5+046 - 5+100

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)	N-Value (0 10 20 30 40 50)
2.10	Sandy Soil	18.0	30.0	0.0	
5.08	Sandy Soil	18.0	27.0	0.0	
6.08	Sandy Soil	18.0	27.0	0.0	
7.08	Clayey Soil	16.0	0.0	12.0	
8.08	Clayey Soil	16.0	0.0	24.0	
9.08	Clayey Soil	16.0	0.0	24.0	
10.08	Clayey Soil	16.0	0.0	25.0	
11.08	Clayey Soil	16.0	0.0	24.0	
12.08	Clayey Soil	16.0	0.0	18.0	
13.08	Clayey Soil	16.0	0.0	24.0	
14.08	Clayey Soil	16.0	0.0	24.0	
15.08	Clayey Soil	16.0	0.0	25.0	
16.08	Clayey Soil	16.0	0.0	24.0	
17.08	Clayey Soil	16.0	0.0	24.0	
18.08	Clayey Soil	16.0	0.0	24.0	
19.08	Sandy Soil	18.0	27.0	0.0	
20.08	Sandy Soil	18.0	27.0	0.0	
21.08	Clayey Soil	16.0	0.0	25.0	
22.08	Clayey Soil	16.0	0.0	24.0	
23.08	Clayey Soil	16.0	0.0	24.0	
	Clayey Soil	16.0	0.0	25.0	

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.50 m (Normal Condition)
	L_{wn}'	=	2.00 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load					
	Horizontal load	P_t	=	0.0 kN/m	(Normal Condition)
		P_t'	=	2.7 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	0.00 m	(Normal Condition)
		H_t'	=	0.40 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	1.1 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	12.08	3	21	22.08	4
2	1.60	15	12	13.08	4	22	23.08	4
3	2.10	4	13	14.08	4	23	24.08	5
4	5.08	4	14	15.08	5			
5	6.08	4	15	16.08	4			
6	7.08	2	16	17.08	4			
7	8.08	4	17	18.08	4			
8	9.08	4	18	19.08	5			
9	10.08	5	19	20.08	5			
10	11.08	4	20	21.08	5			

2.9

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

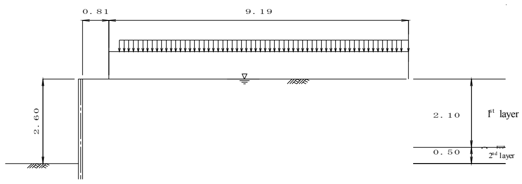
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh (kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	5.08	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	6.08	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	7.08	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
5	8.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
6	9.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
7	10.08	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
8	11.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
9	12.08	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
10	13.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
11	14.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
12	15.08	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
13	16.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
14	17.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
15	18.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
16	19.08	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
17	20.08	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
18	21.08	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
19	22.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
20	23.08	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
21	24.08	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.81	0.81	10.00	10.00	0.84	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	1.13	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 63000 cm⁴
Sectional factor Z_0 = 3150 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.92
Corrosion rate (to Z_0) η = 0.92
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

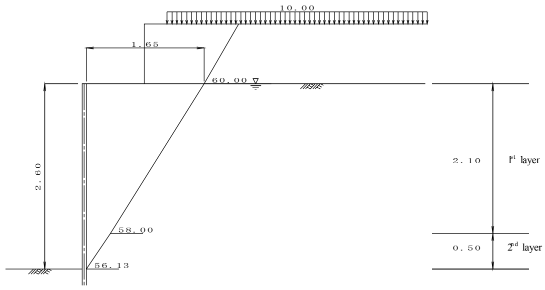
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	16.00	25.48	56.13
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	16.00	20.58	58.00
3		Embankment	30.0	——	0.0	15.12	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where.
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.50	0.00	0.00	0.34	0.50
2	58.00	2.10	0.34	0.50	1.65	2.60
3	60.00	0.84	1.65	2.60	2.13	3.44

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.91	16.34
Σ			16.34

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.00	10.03
Σ			10.03

Q surcharge load
l : width of surcharge load set by line of active rupture

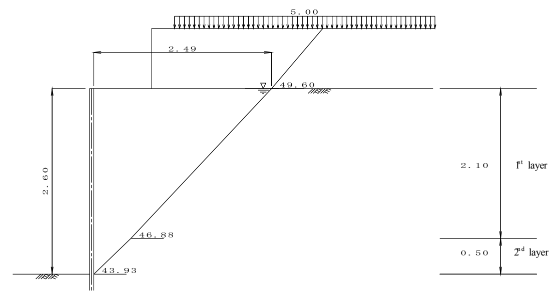
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{16.34 + 10.03 + 0.00}{1.65}$$

$$= 16.00 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	16.53	25.48	0.200	11.31	43.93
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	16.53	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	15.12	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where.
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	0.50	0.00	0.00	0.52	0.50
2	46.88	2.10	0.52	0.50	2.49	2.60
3	49.60	0.84	2.49	2.60	3.20	3.44

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.71	30.74
Σ			30.74

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.07	10.35
Σ			10.35

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

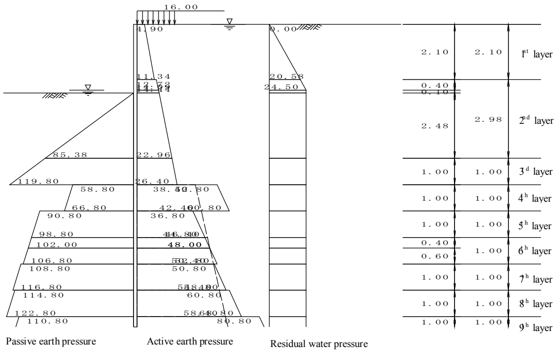
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{30.74 + 10.35 + 0.00}{2.49}$$

$$= 16.53 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	15.999 36.999	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.50	Sandy soil	10.0	27.0	—— ——	36.999 40.999	0.34800 0.34800	0.34371 0.34371
3	2.50~ 2.60	Sandy soil	10.0	27.0	—— ——	40.999 41.999	0.34800 0.34800	0.34371 0.34371
4	2.60~ 5.08	Sandy soil	10.0	27.0	—— ——	41.999 66.799	0.34800 0.34800	0.34371 0.34371
5	5.08~ 6.08	Sandy soil	10.0	27.0	—— ——	66.799 76.799	0.34800 0.34800	0.34371 0.34371
6	6.08~ 7.08	Clayey soil	8.0	—	12.0 12.0	76.799 84.799	—— ——	—— ——
7	7.08~ 8.08	Clayey soil	8.0	—	24.0 24.0	84.799 92.799	—— ——	—— ——
8	8.08~ 8.48	Clayey soil	8.0	—	24.0 24.0	92.799 96.000	—— ——	—— ——
9	8.48~ 9.08	Clayey soil	8.0	—	24.0 24.0	96.000 100.799	—— ——	—— ——
10	9.08~ 10.08	Clayey soil	8.0	—	25.0 25.0	100.799 108.799	—— ——	—— ——
11	10.08~ 11.08	Clayey soil	8.0	—	24.0 24.0	108.799 116.799	—— ——	—— ——
12	11.08~ 12.08	Clayey soil	8.0	—	18.0 18.0	116.799 124.799	—— ——	—— ——
13	12.08~ 13.08	Clayey soil	8.0	—	24.0 24.0	124.799 132.799	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	13.08~ 14.08	Clayey soil	8.0	—	24.0 24.0	132.799 140.799	—— ——	—— ——
15	14.08~ 15.08	Clayey soil	8.0	—	25.0 25.0	140.799 148.799	—— ——	—— ——
16	15.08~ 16.08	Clayey soil	8.0	—	24.0 24.0	148.799 156.799	—— ——	—— ——
17	16.08~ 17.08	Clayey soil	8.0	—	24.0 24.0	156.799 164.799	—— ——	—— ——
18	17.08~ 18.08	Clayey soil	8.0	—	24.0 24.0	164.799 172.799	—— ——	—— ——
19	18.08~ 19.08	Sandy soil	10.0	27.0	—— ——	172.799 182.799	0.34800 0.34800	0.34371 0.34371
20	19.08~ 20.08	Sandy soil	10.0	27.0	—— ——	182.799 192.799	0.34800 0.34800	0.34371 0.34371
21	20.08~ 21.08	Clayey soil	8.0	—	25.0 25.0	192.799 200.799	—— ——	—— ——
22	21.08~ 22.08	Clayey soil	8.0	—	24.0 24.0	200.799 208.799	—— ——	—— ——
23	22.08~ 23.08	Clayey soil	8.0	—	24.0 24.0	208.799 216.799	—— ——	—— ——
24	23.08~ 24.08	Clayey soil	8.0	—	25.0 25.0	216.799 224.799	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60~ 5.08	Sandy soil	10.0	27.0	—— ——	0.000 24.800	3.48553 3.48553	3.44261 3.44261
5	5.08~ 6.08	Sandy soil	10.0	27.0	—— ——	24.800 34.800	3.48553 3.48553	3.44261 3.44261
6	6.08~ 7.08	Clayey soil	8.0	0.0	12.0 12.0	34.800 42.800	—— ——	—— ——
7	7.08~ 8.08	Clayey soil	8.0	0.0	24.0 24.0	42.800 50.800	—— ——	—— ——
8	8.08~ 8.48	Clayey soil	8.0	0.0	24.0 24.0	50.800 54.001	—— ——	—— ——
9	8.48~ 9.08	Clayey soil	8.0	0.0	24.0 24.0	54.001 58.800	—— ——	—— ——
10	9.08~ 10.08	Clayey soil	8.0	0.0	25.0 25.0	58.800 66.800	—— ——	—— ——
11	10.08~ 11.08	Clayey soil	8.0	0.0	24.0 24.0	66.800 74.800	—— ——	—— ——
12	11.08~ 12.08	Clayey soil	8.0	0.0	18.0 18.0	74.800 82.800	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
13	12.08~ 13.08	Clayey soil	8.0	0.0	24.0 24.0	82.800 90.800	—— ——	—— ——
14	13.08~ 14.08	Clayey soil	8.0	0.0	24.0 24.0	90.800 98.800	—— ——	—— ——
15	14.08~ 15.08	Clayey soil	8.0	0.0	25.0 25.0	98.800 106.800	—— ——	—— ——
16	15.08~ 16.08	Clayey soil	8.0	0.0	24.0 24.0	106.800 114.800	—— ——	—— ——
17	16.08~ 17.08	Clayey soil	8.0	0.0	24.0 24.0	114.800 122.800	—— ——	—— ——
18	17.08~ 18.08	Clayey soil	8.0	0.0	24.0 24.0	122.800 130.800	—— ——	—— ——
19	18.08~ 19.08	Sandy soil	10.0	27.0	—— ——	130.800 140.800	3.48553 3.48553	3.44261 3.44261
20	19.08~ 20.08	Sandy soil	10.0	27.0	—— ——	140.800 150.800	3.48553 3.48553	3.44261 3.44261
21	20.08~ 21.08	Clayey soil	8.0	0.0	25.0 25.0	150.800 158.800	—— ——	—— ——
22	21.08~ 22.08	Clayey soil	8.0	0.0	24.0 24.0	158.800 166.800	—— ——	—— ——
23	22.08~ 23.08	Clayey soil	8.0	0.0	24.0 24.0	166.800 174.800	—— ——	—— ——
24	23.08~ 24.08	Clayey soil	8.0	0.0	25.0 25.0	174.800 182.800	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	4.90 11.34	—— ——	4.90 11.34	0.00 20.58	—— ——
2	2.10~ 2.50	12.72 14.09	—— ——	12.72 14.09	20.58 24.50	—— ——
3	2.50~ 2.60	14.09 14.44	—— ——	14.09 14.44	24.50 24.50	—— ——
4	2.60~ 5.08	14.44 22.96	—— ——	14.44 22.96	24.50 24.50	0.00 85.38
5	5.08~ 6.08	22.96 26.40	—— ——	22.96 26.40	24.50 24.50	85.38 119.80
6	6.08~ 7.08	52.80 60.80	38.40 42.40	52.80 60.80	24.50 24.50	58.80 66.80
7	7.08~ 8.08	36.80 44.80	42.40 46.40	42.40 46.40	24.50 24.50	90.80 98.80
8	8.08~ 8.48	44.80 48.00	46.40 48.00	46.40 48.00	24.50 24.50	98.80 102.00
9	8.48~ 9.08	48.00 52.80	48.00 50.40	48.00 52.80	24.50 24.50	102.00 106.80

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm^2	Pa2 kNm^2	Pa kNm^2	Pw kNm^2	Pp kNm^2
10	9.08～ 10.08	50.80 58.80	50.40 54.40	50.80 58.80	24.50 24.50	108.80 116.80
11	10.08～ 11.08	60.80 68.80	54.40 58.40	60.80 68.80	24.50 24.50	114.80 122.80
12	11.08～ 12.08	80.80 88.80	58.40 62.40	80.80 88.80	24.50 24.50	110.80 118.80
13	12.08～ 13.08	76.80 84.80	62.40 66.40	76.80 84.80	24.50 24.50	130.80 138.80
14	13.08～ 14.08	84.80 92.80	66.40 70.40	84.80 92.80	24.50 24.50	138.80 146.80
15	14.08～ 15.08	90.80 98.80	70.40 74.40	90.80 98.80	24.50 24.50	148.80 156.80
16	15.08～ 16.08	100.80 108.80	74.40 78.40	100.80 108.80	24.50 24.50	154.80 162.80
17	16.08～ 17.08	108.80 116.80	78.40 82.40	108.80 116.80	24.50 24.50	162.80 170.80
18	17.08～ 18.08	116.80 124.80	82.40 86.40	116.80 124.80	24.50 24.50	170.80 178.80
19	18.08～ 19.08	59.39 62.83	—— ——	59.39 62.83	24.50 24.50	450.29 484.72
20	19.08～ 20.08	62.83 66.27	—— ——	62.83 66.27	24.50 24.50	484.72 519.15
21	20.08～ 21.08	142.80 150.80	96.40 100.40	142.80 150.80	24.50 24.50	200.80 208.80
22	21.08～ 22.08	152.80 160.80	100.40 104.40	152.80 160.80	24.50 24.50	206.80 214.80
23	22.08～ 23.08	160.80 168.80	104.40 108.40	160.80 168.80	24.50 24.50	214.80 222.80
24	23.08～ 24.08	166.80 174.80	108.40 112.40	166.80 174.80	24.50 24.50	224.80 232.80

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

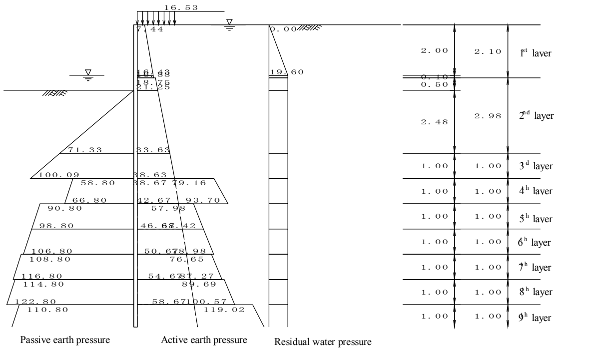
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C kNm^2	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.00	Sandy Soil	10.0	30.0	—— ——	16.53 36.53	0.00 19.60	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	36.53 37.53	19.60 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
3	2.10～ 2.60	Sandy Soil	10.0	27.0	—— ——	37.53 42.53	20.58 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	2.60～ 5.08	Sandy Soil	10.0	27.0	—— ——	42.53 67.33	25.48 49.78	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	5.08～ 6.08	Sandy Soil	10.0	27.0	—— ——	67.33 77.33	49.78 59.58	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	6.08～ 7.08	Clayey Soil	8.0	—	12.0 12.0	77.33 85.33	59.58 69.38	0.200 0.200	11.31 11.31	—— ——	—— ——	25.02 21.24
7	7.08～ 8.08	Clayey Soil	8.0	—	24.0 24.0	85.33 93.33	69.38 79.18	0.200 0.200	11.31 11.31	—— ——	—— ——	37.19 36.37
8	8.08～ 9.08	Clayey Soil	8.0	—	24.0 24.0	93.33 101.33	79.18 88.98	0.200 0.200	11.31 11.31	—— ——	—— ——	36.37 35.50
9	9.08～ 10.08	Clayey Soil	8.0	—	25.0 25.0	101.33 109.33	88.98 98.78	0.200 0.200	11.31 11.31	—— ——	—— ——	36.02 35.17
10	10.08～ 11.08	Clayey Soil	8.0	—	24.0 24.0	109.33 117.33	98.78 108.58	0.200 0.200	11.31 11.31	—— ——	—— ——	34.59 33.62
11	11.08～ 12.08	Clayey Soil	8.0	—	18.0 18.0	117.33 125.33	108.58 118.38	0.200 0.200	11.31 11.31	—— ——	—— ——	26.85 24.72
12	12.08～ 13.08	Clayey Soil	8.0	—	24.0 24.0	125.33 133.33	118.38 128.18	0.200 0.200	11.31 11.31	—— ——	—— ——	32.60 31.50
13	13.08～ 14.08	Clayey Soil	8.0	—	24.0 24.0	133.33 141.33	128.18 137.98	0.200 0.200	11.31 11.31	—— ——	—— ——	31.50 30.33
14	14.08～ 15.08	Clayey Soil	8.0	—	25.0 25.0	141.33 149.33	137.98 147.78	0.200 0.200	11.31 11.31	—— ——	—— ——	31.26 30.12

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C kNm^2	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	15.08～ 16.08	Clayey Soil	8.0	—	24.0 24.0	149.33 157.33	147.78 157.58	0.200 0.200	11.31 11.31	—— ——	—— ——	29.06 27.70
16	16.08～ 17.08	Clayey Soil	8.0	—	24.0 24.0	157.33 165.33	157.58 167.38	0.200 0.200	11.31 11.31	—— ——	—— ——	27.70 26.21
17	17.08～ 18.08	Clayey Soil	8.0	—	24.0 24.0	165.33 173.33	167.38 177.18	0.200 0.200	11.31 11.31	—— ——	—— ——	26.21 24.56
18	18.08～ 19.08	Sandy Soil	10.0	27.0	—— ——	173.33 183.33	177.18 186.98	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
19	19.08～ 20.08	Sandy Soil	10.0	27.0	—— ——	183.33 193.33	186.98 196.78	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
20	20.08～ 21.08	Clayey Soil	8.0	—	25.0 25.0	193.33 201.33	196.78 206.58	0.200 0.200	11.31 11.31	—— ——	—— ——	21.84 19.72
21	21.08～ 22.08	Clayey Soil	8.0	—	24.0 24.0	201.33 209.33	206.58 216.38	0.200 0.200	11.31 11.31	—— ——	—— ——	16.89 13.64
22	22.08～ 23.08	Clayey Soil	8.0	—	24.0 24.0	209.33 217.33	216.38 226.18	0.200 0.200	11.31 11.31	—— ——	—— ——	13.64 10.00
23	23.08～ 24.08	Clayey Soil	8.0	—	25.0 25.0	217.33 225.33	226.18 235.98	0.200 0.200	11.31 11.31	—— ——	—— ——	14.25 10.23

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C} \cdot \tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C kNm^2	Σγh+Qp (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 5.08	Sandy soil	10.00	27.0	—— ——	0.000 24.800	0.00 24.30	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	5.08～ 6.08	Clayey soil	10.00	27.0	—— ——	24.800 34.800	24.30 34.10	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	6.08～ 7.08	Clayey soil	8.00	0.0	12.0 12.0	34.800 42.800	34.10 43.90	0.200 0.200	11.31 11.31	—— ——	—— ——
7	7.08～ 8.08	Clayey soil	8.00	0.0	24.0 24.0	42.800 50.800	43.90 53.70	0.200 0.200	11.31 11.31	—— ——	—— ——
8	8.08～ 9.08	Clayey soil	8.00	0.0	24.0 24.0	50.800 58.800	53.70 63.50	0.200 0.200	11.31 11.31	—— ——	—— ——
9	9.08～ 10.08	Clayey soil	8.00	0.0	25.0 25.0	58.800 66.800	63.50 73.30	0.200 0.200	11.31 11.31	—— ——	—— ——
10	10.08～ 11.08	Clayey soil	8.00	0.0	24.0 24.0	66.800 74.800	73.30 83.10	0.200 0.200	11.31 11.31	—— ——	—— ——
11	11.08～ 12.08	Clayey soil	8.00	0.0	18.0 18.0	74.800 82.800	83.10 92.90	0.200 0.200	11.31 11.31	—— ——	—— ——
12	12.08～ 13.08	Clayey soil	8.00	0.0	24.0 24.0	82.800 90.800	92.90 102.70	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C kNm^2	Σγh+Qp (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
13	13.08～ 14.08	Clayey soil	8.00	0.0	24.0 24.0	90.800 98.800	102.70 112.50	0.200 0.200	11.31 11.31	—— ——	—— ——
14	14.08～ 15.08	Clayey soil	8.00	0.0	25.0 25.0	98.800 106.800	112.50 122.30	0.200 0.200	11.31 11.31	—— ——	—— ——
15	15.08～ 16.08	Clayey soil	8.00	0.0	24.0 24.0	106.800 114.800	122.30 132.10	0.200 0.200	11.31 11.31	—— ——	—— ——
16	16.08～ 17.08	Clayey soil	8.00	0.0	24.0 24.0	114.800 122.800	132.10 141.90	0.200 0.200	11.31 11.31	—— ——	—— ——
17	17.08～ 18.08	Clayey soil	8.00	0.0	24.0 24.0	122.800 130.800	141.90 151.70	0.200 0.200	11.31 11.31	—— ——	—— ——
18	18.08～ 19.08	Sandy soil	10.00	27.0	—— ——	130.800 140.800	151.70 161.50	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
19	19.08～ 20.08	Sandy soil	10.00	27.0	—— ——	140.800 150.800	161.50 171.30	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
20	20.08～ 21.08	Clayey soil	8.00	0.0	25.0 25.0	150.800 158.800	171.30 181.10	0.200 0.200	11.31 11.31	—— ——	—— ——
21	21.08～ 22.08	Clayey soil	8.00	0.0	24.0 24.0	158.800 166.800	181.10 190.90	0.200 0.200	11.31 11.31	—— ——	—— ——
22	22.08～ 23.08	Clayey soil	8.00	0.0	24.0 24.0	166.800 174.800	190.90 200.70	0.200 0.200	11.31 11.31	—— ——	—— ——
23	23.08～ 24.08	Clayey soil	8.00	0.0	25.0 25.0	174.800 182.800	200.70 210.50	0.200 0.200	11.31 11.31	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below

$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta) \cdot \sin(\phi+\beta-\theta)}{\cos(\delta-\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm^2	Pa2 kNm^2	Pa kNm^2	Pw kNm^2	Pp kNm^2
1	0.00～ 2.00	7.44 16.43	—— ——	7.44 16.43	0.00 19.60	—— ——
2	2.00～ 2.10	16.43 16.88	—— ——	16.43 16.88	19.60 19.60	—— ——
3	2.10～ 2.60	18.75 21.25	—— ——	18.75 21.25	19.60 19.60	—— ——
4	2.60～ 5.08	21.25 33.63	—— ——	21.25 33.63	19.60 19.60	0.00 71.33
5	5.08～ 6.08	33.63 38.63	—— ——	33.63 38.63	19.60 19.60	71.33 100.09
6	6.08～ 7.08	79.16 93.70	38.67 42.67	79.16 93.70	19.60 19.60	58.80 66.80
7	7.08～ 8.08	57.98 68.42	42.67 46.67	57.98 68.42	19.60 19.60	90.80 98.80
8	8.08～ 9.08	68.42 78.98	46.67 50.67	68.42 78.98	19.60 19.60	98.80 106.80

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm^2	Pa2 kNm^2	Pa kNm^2	Pw kNm^2	Pp kNm^2
9	9.08～ 10.08	76.65 87.27	50.67 54.67	76.65 87.27	19.60 19.60	108.80 116.80
10	10.08～ 11.08	89.69 100.57	54.67 58.67	89.69 100.57	19.60 19.60	114.80 122.80
11	11.08～ 12.08	119.02 132.40	58.67 62.67	119.02 132.40	19.60 19.60	110.80 118.80
12	12.08～ 13.08	111.65 122.97	62.67 66.67	111.65 122.97	19.60 19.60	130.80 138.80
13	13.08～ 14.08	122.97 134.58	66.67 70.67	122.97 134.58	19.60 19.60	138.80 146.80
14	14.08～ 15.08	131.54 143.22	70.67 74.67	131.54 143.22	19.60 19.60	148.80 156.80
15	15.08～ 16.08	146.55 158.96	74.67 78.67	146.55 158.96	19.60 19.60	154.80 162.80
16	16.08～ 17.08	158.96 171.94	78.67 82.67	158.96 171.94	19.60 19.60	162.80 170.80
17	17.08～ 18.08	171.94 185.70	82.67 86.67	171.94 185.70	19.60 19.60	170.80 178.80
18	18.08～ 19.08	86.58 91.58	—— ——	86.58 91.58	19.60 19.60	376.21 404.98
19	19.08～ 20.08	91.58 96.57	—— ——	91.58 96.57	19.60 19.60	404.98 433.74
20	20.08～ 21.08	217.42 234.95	96.67 100.67	217.42 234.95	19.60 19.60	200.80 208.80
21	21.08～ 22.08	247.60 277.12	100.67 104.67	247.60 277.12	19.60 19.60	206.80 214.80
22	22.08～ 23.08	277.12 323.50	104.67 108.67	277.12 323.50	19.60 19.60	214.80 222.80
23	23.08～ 24.08	283.67 332.05	108.67 112.67	283.67 332.05	19.60 19.60	224.80 232.80

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	2.00	0.00	0.00
2	2.60	0.60	1.03

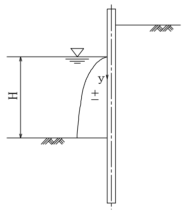
Where,

k_{hs} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

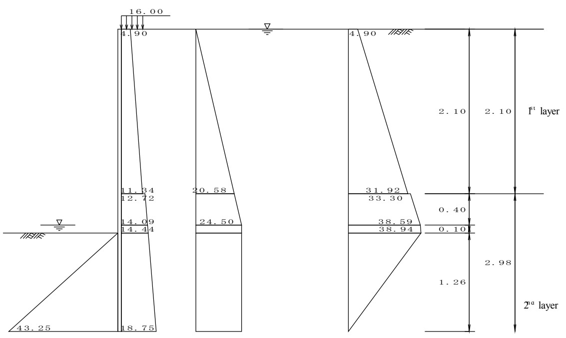
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



Passive earth pressure　Active earth pressure　Residual water pressure　Total of lateral pressure

	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.10	4.90 11.34	0.00 20.58	—— ——	4.90 31.92
2	2.10～ 2.50	12.72 14.09	20.58 24.50	—— ——	33.30 38.59
3	2.50～ 2.60	14.09 14.44	24.50 24.50	—— ——	38.59 38.94
4	2.60～ 3.86	14.44 18.75	24.50 24.50	0.00 43.25	38.94 0.00
5	3.86～ 5.08	18.75 22.96	24.50 24.50	43.25 85.38	0.00 -37.92

P_a : Active earth pressure

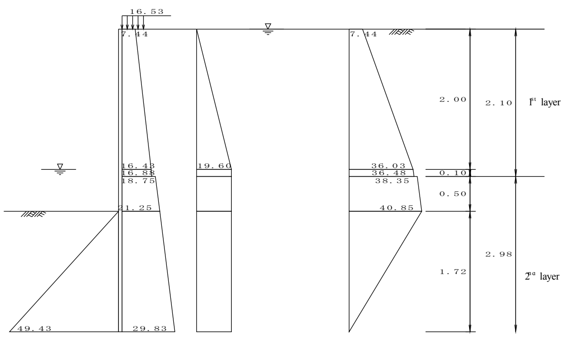
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.26 m (GL -3.86 m)

4-2 Seismic Condition



Passive earth pressure　Active earth pressure　Residual water pressure　Total of lateral pressure

	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.00	7.44 16.43	0.00 19.60	—— ——	7.44 36.03
2	2.00～ 2.10	16.43 16.88	19.60 19.60	—— ——	36.03 36.48
3	2.10～ 2.60	18.75 21.25	19.60 19.60	—— ——	38.35 40.85
4	2.60～ 4.32	21.25 29.83	19.60 19.60	0.00 49.43	40.85 0.00
5	4.32～ 5.08	29.83 33.63	19.60 19.60	49.43 71.33	0.00 -18.10

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.72 m (GL -4.32 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	46368 cm^4 (after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 46368 \times 10^{-8} = 9.274 \times 10^4$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	4
4	5.08	4
5	6.08	4
6	7.08	2
7	8.08	4
8	9.08	4
9	10.08	5
10	11.08	4

	Depth (m)	N-value
11	12.08	3
12	13.08	4
13	14.08	4
14	15.08	5
15	16.08	4
16	17.08	4
17	18.08	4
18	19.08	5
19	20.08	5
20	21.08	5

	Depth (m)	N-value
21	22.08	4
22	23.08	4
23	24.08	5

5-2 Normal Condition

K_h = 12123 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.425 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.35 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.86 m) to 2.35 m depth (GL -6.21 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.86	1.22	4.0	4.0	4.89
2	5.08	1.00	4.0	4.0	4.00
3	6.08	0.13	4.0	3.7	0.50
L = Σh = 2.35				ΣA = 9.39	

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{9.39}{2.35} = 3.99$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 3.99^{0.406} = 12123$ kN/m^3

Kh (normal condition) = 12123 kN/m^3

5-3 Seismic Condition

K_h = 11942 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.424 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.36 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.32 m) and 2.36 m depth (GL -6.68 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.32	0.76	4.0	4.0	3.05
2	5.08	1.00	4.0	4.0	4.00
3	6.08	0.60	4.0	2.8	2.04
L = Σh = 2.36				ΣA = 9.08	

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{9.08}{2.36} = 3.85$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 3.85^{0.406} = 11942$ kN/m^3

Kh (seismic condition) = 11942 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	4.90 31.92	5.15 33.51	3.16 2.46	16.25 82.32
2	2.10~ 2.50	0.40	33.30 38.59	6.66 7.72	1.62 1.49	10.81 11.50
3	2.50~ 2.60	0.10	38.59 38.94	1.93 1.95	1.32 1.29	2.55 2.51
4	2.60~ 3.86	1.26	38.94 0.00	24.46 0.00	0.84 0.42	20.49 0.00
				ΣP = 81.38		ΣM = 146.43

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	0.0 kN/m
depth to acting position	H_t	=	0.00 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.26 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 00.00 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{146.43}{81.38} = 1.80 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.00	2.00	7.44 36.03	7.44 36.03	3.65 2.99	27.16 107.57
2	2.00~ 2.10	0.10	36.03 36.48	1.80 1.82	2.29 2.25	4.12 4.11
3	2.10~ 2.60	0.50	38.35 40.85	9.59 10.21	2.05 1.89	19.67 19.25
4	2.60~ 4.32	1.72	40.85 0.00	35.10 0.00	1.15 0.57	40.21 0.00
				ΣP = 101.99		ΣM = 222.08

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.7 kN/m
depth to acting position	H_t	=	0.40 m
moment	M_m	=	1.1 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.72 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 11.68 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00~ 2.60	0.60	0.0 1.0	0.00 0.31	2.12 1.92	0.00 0.59
				ΣP_{dw} = 0.31		ΣM_{dw} = 0.59

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{234.35}{105.00} = 2.23 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	46368 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 46368 \times 10^{-8}$		=	9.274×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	12123 kNm^3
calculated value	β	=	0.42518 m^{-1}
resultant earth force (lateral)	P_0	=	81.38 kNm
height of acting position of load	h_0	=	1.80 m
moment	M_0	=	146.43 kN·m/m

in consideration of ψ_m = 1.220,

maximum moment	M_{max}	=	178.69 kN·m/m
depth of generated position of M_{max}	l_m	=	0.885 m
depth of 1st fixed point	l_i	=	2.732 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	11942 kNm^3
calculated value	β	=	0.42358 m^{-1}
resultant earth force (lateral)	P_0	=	105.00 kNm
height of acting position of load	h_0	=	2.23 m
moment	M_0	=	234.35 kN·m/m

in consideration of ψ_m = 1.160,

maximum moment	M_{max}	=	271.73 kN·m/m
depth of generated position of M_{max}	l_m	=	0.786 m
depth of 1st fixed point	l_i	=	2.640 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3150 cm^3 (original condition)
	Z	=	2898 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{178.69\times10^6}{2898\times10^3} = 62\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{271.73\times10^6}{2898\times10^3} = 94\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.16 2.46	0.818 0.637	0.244 0.160	5.15 33.51	1.254 5.355
2	2.10~ 2.50	1.62 1.49	0.421 0.386	0.076 0.065	6.66 7.72	0.507 0.502
3	2.50~ 2.60	1.32 1.29	0.343 0.334	0.052 0.050	1.93 1.95	0.101 0.097
4	2.60~ 3.86	0.84 0.42	0.217 0.109	0.022 0.006	24.46 0.00	0.535 0.000
						ΣQ = 8.350

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

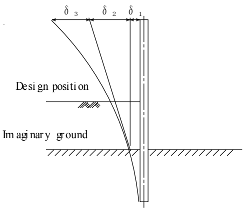
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4252\times1.80)\times81.38}{2\times2.00\times10^8\times46368\times10^{-8}\times0.4252^3} = 0.01008\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4252\times1.80)\times81.38}{2\times2.00\times10^8\times46368\times10^{-8}\times0.4252^2}\times(2.60+1.26) = 0.02368\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{8.35\times(2.60+1.26)^3}{2.00\times10^8\times46368\times10^{-8}} = 0.00516\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01008 + 0.02368 + 0.00516
= 0.03892 m
= 38.92 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.00	3.65 2.99	0.846 0.691	0.257 0.184	7.44 36.03	1.909 6.625
2	2.00~ 2.10	2.29 2.25	0.529 0.521	0.115 0.112	1.80 1.82	0.208 0.205
3	2.10~ 2.60	2.05 1.89	0.475 0.437	0.095 0.081	9.59 10.21	0.911 0.831
4	2.60~ 4.32	1.15 0.57	0.265 0.133	0.032 0.008	35.10 0.00	1.126 0.000
						ΣQ = 11.815

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

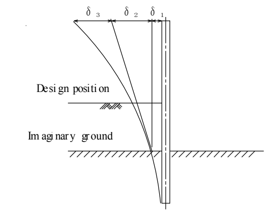
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.00~ 2.60	2.12 1.92	0.491 0.444	0.101 0.084	0.00 0.31	0.000 0.026
						ΣQ_{dw} = 0.026

Therefore, modulus of deformation Q is calculated as below
Q = 12.590 + 0.026 = 12.616

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4236\times 2.23)\times 105.00}{2\times 2.00\times 10^8\times 46368\times 10^{-8}\times 0.4236^3} = 0.01449 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4236\times 2.23)\times 105.00}{2\times 2.00\times 10^8\times 46368\times 10^{-8}\times 0.4236^2}\times(2.60+1.72) = 0.03939 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.62\times(2.60+1.72)^3}{2.00\times 10^8\times 46368\times 10^{-8}} = 0.01096 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$$= \frac{1.10\times 3.52}{2\times 2.00\times 10^8\times 46368\times 10^{-8}}\times(2\times 4.32-3.52) = 0.00011 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01449 + 0.03939 + 0.01106$
$= 0.06494$ m
$= 64.94 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm ^{2}
Inertia sectional moment	I_0	=	63000 cm ^{4} (original condition)
	I	=	63000 cm ^{4} (after reduction by corrosion and section)
EI = 200000 × 10^3 × 63000 × 10^{8}		=	1.260 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction — $K_h = 12123$ kN/m^3
Calculated value — $\beta = 0.39382$ m^{-1}

Penetration length of SSP — $D = 1.26 + \frac{3}{0.394} = 8.87$ m
Whole length of SSP — $L = 2.60 - 0.40 + 8.87 = 11.07$ m

7-1-2 Seismic Conditic

Modules of lateral subgrade reaction — $K_h = 11942$ kN/m^3
Calculated value — $\beta = 0.39234$ m^{-1}

Penetration length of SSP — $D = 1.72 + \frac{3}{0.392} = 9.37$ m
Whole length of SSP — $L = 2.60 - 0.40 + 9.37 = 11.57$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

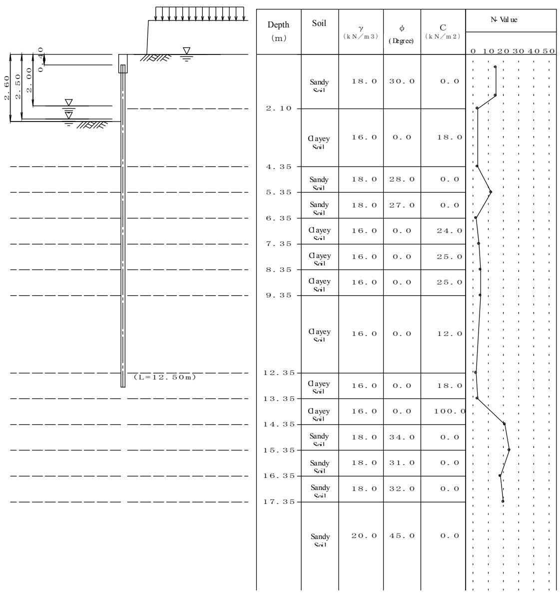
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	63000		
Section modulus	Z (cm^3)	3150		
Maximum bending moment	M_{max} (kN·m/m)		178.69	271.73
Stress intensity	σ (Nmm^2)		62 (180)	94 (270)
Lateral displacement	δ (mm)		38.92 (50.0)	64.94 (75.0)
Penetration depth	D (m)		8.87	9.37
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 03_STA_5+100 - 5+223

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.50 m (Normal Condition)
	L_{wp}'	=	2.00 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	0.0 kN/m	(Normal Condition)
		Pt'	=	2.7 kN/m	(Seismic Condition)
	Depth of acting point	H	=	0.00 m	(Normal Condition)
		H'	=	0.40 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN·m/m	(Normal Condition)
		Mm'	=	1.1 kN·m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\dfrac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	13.35	3
2	1.60	15	12	14.35	21
3	2.10	3	13	15.35	24
4	4.35	3	14	16.35	18
5	5.35	12	15	17.35	20
6	6.35	2	16	20.00	40
7	7.35	4			
8	8.35	5			
9	9.35	5			
10	12.35	2			

2.17

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

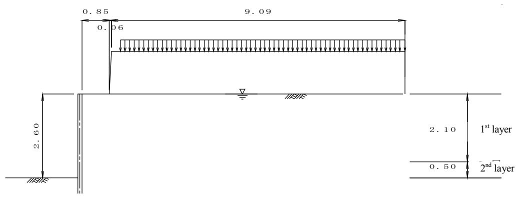
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	ϕ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kN/m^3) normal	kh (kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.35	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
3	5.35	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
4	6.35	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	7.35	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
6	8.35	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
7	9.35	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
8	12.35	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
9	13.35	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
10	14.35	C	21.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	——	——
11	15.35	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
12	16.35	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
13	17.35	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
14	20.00	S	40.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.85	0.91	10.00	10.00	1.32	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	1.19	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 86000 cm⁴
Sectional factor Z_0 = 3820 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.92
Corrosion rate (to Z_0) η = 0.92
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

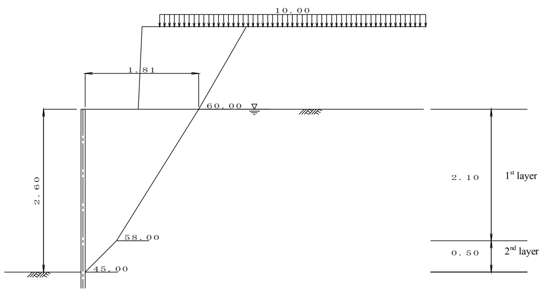
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	9.0	18.0	25.00	24.86	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	24.86	20.58	58.00
3		Embankment	30.0	——	0.0	23.76	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	58.00	2.10	0.50	0.50	1.81	2.60
3	60.00	1.32	1.81	2.60	2.57	3.92

Therefore, width of acting load shall be set as 1.81 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.73	31.21
Σ			31.21

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.38	13.84
Σ			13.84

Q surcharge load
l : width of surcharge load set by line of active rupture

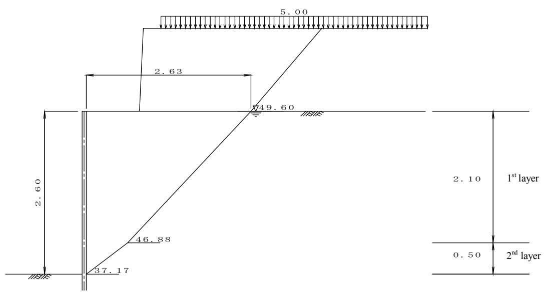
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{31.21 + 13.84 + 0.00}{1.81}$$

$$= 24.86 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	9.0	18.0	25.00	25.75	25.48	0.200	11.31	37.17
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	25.75	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	23.76	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	37.17	0.50	0.00	0.00	0.66	0.50
2	46.88	2.10	0.66	0.50	2.63	2.60
3	49.60	1.32	2.63	2.60	3.75	3.92

Therefore, width of acting load shall be set as 2.63 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.05	54.83
Σ			54.83

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.56	12.80
Σ			12.80

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

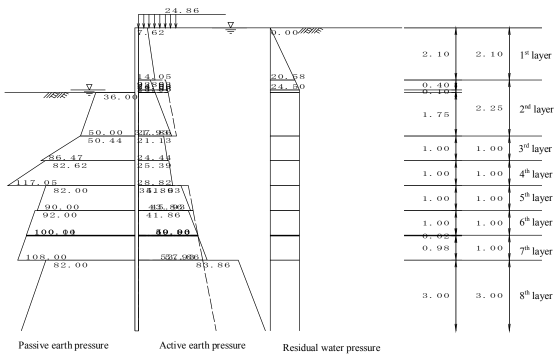
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{54.83 + 12.80 + 0.00}{2.63}$$

$$= 25.75 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	―― ――	24.858 45.858	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.50	Clayey soil	8.0	―	18.0 18.0	45.858 49.058	―― ――	―― ――
3	2.50~ 2.60	Clayey soil	8.0	―	18.0 18.0	49.058 49.858	―― ――	―― ――
4	2.60~ 4.35	Clayey soil	8.0	―	18.0 18.0	49.858 63.858	―― ――	―― ――
5	4.35~ 5.35	Sandy soil	10.0	28.0	―― ――	63.858 73.858	0.33506 0.33506	0.33093 0.33093
6	5.35~ 6.35	Sandy soil	10.0	27.0	―― ――	73.858 83.858	0.34800 0.34800	0.34371 0.34371
7	6.35~ 7.35	Clayey soil	8.0	―	24.0 24.0	83.858 91.858	―― ――	―― ――
8	7.35~ 8.35	Clayey soil	8.0	―	25.0 25.0	91.858 99.858	―― ――	―― ――
9	8.35~ 8.37	Clayey soil	8.0	―	25.0 25.0	99.858 100.000	―― ――	―― ――
10	8.37~ 9.35	Clayey soil	8.0	―	25.0 25.0	100.000 107.858	―― ――	―― ――
11	9.35~ 12.35	Clayey soil	8.0	―	12.0 12.0	107.858 131.858	―― ――	―― ――
12	12.35~ 13.35	Clayey soil	8.0	―	18.0 18.0	131.858 139.858	―― ――	―― ――
13	13.35~ 14.35	Clayey soil	8.0	―	100.0 100.0	139.858 147.858	―― ――	―― ――

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	14.35~ 15.35	Sandy soil	10.0	34.0	―― ――	147.858 157.858	0.26470 0.26470	0.26144 0.26144
15	15.35~ 16.35	Sandy soil	10.0	31.0	―― ――	157.858 167.858	0.29838 0.29838	0.29471 0.29471
16	16.35~ 17.35	Sandy soil	10.0	32.0	―― ――	167.858 177.858	0.28683 0.28683	0.28330 0.28330
17	17.35~ 20.00	Sandy soil	10.0	45.0	―― ――	177.858 204.358	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60~ 4.35	Clayey soil	8.0	0.0	18.0 18.0	0.000 14.000	―― ――	―― ――
5	4.35~ 5.35	Sandy soil	10.0	28.0	―― ――	14.000 24.000	3.64796 3.64796	3.60305 3.60305
6	5.35~ 6.35	Sandy soil	10.0	27.0	―― ――	24.000 34.000	3.48553 3.48553	3.44261 3.44261
7	6.35~ 7.35	Clayey soil	8.0	0.0	24.0 24.0	34.000 42.000	―― ――	―― ――
8	7.35~ 8.35	Clayey soil	8.0	0.0	25.0 25.0	42.000 50.000	―― ――	―― ――
9	8.35~ 8.37	Clayey soil	8.0	0.0	25.0 25.0	50.000 50.142	―― ――	―― ――
10	8.37~ 9.35	Clayey soil	8.0	0.0	25.0 25.0	50.142 58.000	―― ――	―― ――
11	9.35~ 12.35	Clayey soil	8.0	0.0	12.0 12.0	58.000 82.000	―― ――	―― ――
12	12.35~ 13.35	Clayey soil	8.0	0.0	18.0 18.0	82.000 90.000	―― ――	―― ――
13	13.35~ 14.35	Clayey soil	8.0	0.0	100.0 100.0	90.000 98.000	―― ――	―― ――
14	14.35~ 15.35	Sandy soil	10.0	34.0	―― ――	98.000 108.000	4.85443 4.85443	4.79467 4.79467
15	15.35~ 16.35	Sandy soil	10.0	31.0	―― ――	108.000 118.000	4.19615 4.19615	4.14448 4.14448
16	16.35~ 17.35	Sandy soil	10.0	32.0	―― ――	118.000 128.000	4.40199 4.40199	4.34780 4.34780
17	17.35~ 20.00	Sandy soil	10.0	45.0	―― ――	128.000 154.500	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	7.62 14.05	―― ――	7.62 14.05	0.00 20.58	―― ――
2	2.10~ 2.50	9.86 13.06	22.93 24.53	22.93 24.53	20.58 24.50	―― ――
3	2.50~ 2.60	13.06 13.86	24.53 24.93	24.53 24.93	24.50 24.50	―― ――
4	2.60~ 4.35	13.86 27.86	24.93 31.93	24.93 31.93	24.50 24.50	36.00 50.00
5	4.35~ 5.35	21.13 24.44	―― ――	21.13 24.44	24.50 24.50	50.44 86.47
6	5.35~ 6.35	25.39 28.82	―― ――	25.39 28.82	24.50 24.50	82.62 117.05
7	6.35~ 7.35	35.86 43.86	41.93 45.93	41.93 45.93	24.50 24.50	82.00 90.00
8	7.35~ 8.35	41.86 49.86	45.93 49.93	45.93 49.93	24.50 24.50	92.00 100.00
9	8.35~ 8.37	49.86 50.00	49.93 50.00	49.93 50.00	24.50 24.50	100.00 100.14
10	8.37~ 9.35	50.00 57.86	50.00 53.93	50.00 57.86	24.50 24.50	100.14 108.00
11	9.35~ 12.35	83.86 107.86	53.93 65.93	83.86 107.86	24.50 24.50	82.00 106.00
12	12.35~ 13.35	95.86 103.86	65.93 69.93	95.86 103.86	24.50 24.50	118.00 126.00
13	13.35~ 14.35	-60.14 -52.14	69.93 73.93	69.93 73.93	24.50 24.50	290.00 298.00
14	14.35~ 15.35	38.66 41.27	―― ――	38.66 41.27	24.50 24.50	469.88 517.82
15	15.35~ 16.35	46.52 49.47	―― ――	46.52 49.47	24.50 24.50	447.60 489.05
16	16.35~ 17.35	47.55 50.39	―― ――	47.55 50.39	24.50 24.50	513.04 556.52
17	17.35~ 20.00	28.67 32.95	―― ――	28.67 32.95	24.50 24.50	1120.87 1352.92

2.19

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

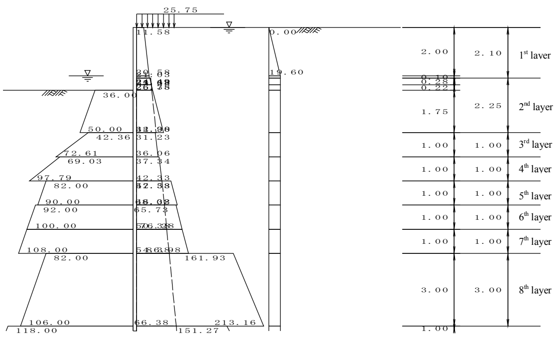
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



Passive earth pressure   Active earth pressure   Residual water pressure

3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.00	Sandy Soil	10.0	30.0	—— ——	25.75 45.75	0.00 19.60	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	45.75 46.75	19.60 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
3	2.10~ 2.38	Clayey Soil	8.0	—	18.0 18.0	46.75 48.98	20.58 ——	0.200 ——	11.31 ——	—— ——	—— ——	37.70 ——
4	2.38~ 2.60	Clayey Soil	8.0	—	18.0 18.0	48.98 50.75	—— 25.48	—— 0.200	—— 11.31	—— ——	—— ——	—— 37.17
5	2.60~ 4.35	Clayey Soil	8.0	—	18.0 18.0	50.75 64.75	25.48 42.63	0.200 0.200	11.31 11.31	—— ——	—— ——	37.17 35.19

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	4.35~ 5.35	Sandy Soil	10.0	28.0	—— ——	64.75 74.75	42.63 52.43	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——
7	5.35~ 6.35	Sandy Soil	10.0	27.0	—— ——	74.75 84.75	52.43 62.23	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
8	6.35~ 7.35	Clayey Soil	8.0	—	24.0 24.0	84.75 92.75	62.23 72.03	0.200 0.200	11.31 11.31	—— ——	—— ——	36.30 35.43
9	7.35~ 8.35	Clayey Soil	8.0	—	25.0 25.0	92.75 100.75	72.03 81.83	0.200 0.200	11.31 11.31	—— ——	—— ——	35.95 35.10
10	8.35~ 9.35	Clayey Soil	8.0	—	25.0 25.0	100.75 108.75	81.83 91.63	0.200 0.200	11.31 11.31	—— ——	—— ——	35.10 34.20
11	9.35~ 12.35	Clayey Soil	8.0	—	12.0 12.0	108.75 132.75	91.63 121.03	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
12	12.35~ 13.35	Clayey Soil	8.0	—	18.0 18.0	132.75 140.75	121.03 130.83	0.200 0.200	11.31 11.31	—— ——	—— ——	19.06 15.31
13	13.35~ 14.35	Clayey Soil	8.0	—	100.0 100.0	140.75 148.75	130.83 140.63	0.200 0.200	11.31 11.31	—— ——	—— ——	42.39 42.26
14	14.35~ 15.35	Sandy Soil	10.0	34.0	—— ——	148.75 158.75	140.63 150.43	0.200 0.200	11.31 11.31	0.39559 0.39559	0.39072 0.39072	—— ——
15	15.35~ 16.35	Sandy Soil	10.0	31.0	—— ——	158.75 168.75	150.43 160.23	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	—— ——
16	16.35~ 17.35	Sandy Soil	10.0	32.0	—— ——	168.75 178.75	160.23 170.03	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
17	17.35~ 20.00	Sandy Soil	10.0	45.0	—— ——	178.75 205.25	170.03 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60~ 4.35	Clayey soil	8.00	0.0	18.0 18.0	0.000 14.000	0.00 17.15	0.200 0.200	11.31 11.31	—— ——	—— ——
6	4.35~ 5.35	Sandy soil	10.00	28.0	—— ——	14.000 24.000	17.15 26.95	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
7	5.35~ 6.35	Sandy soil	10.00	27.0	—— ——	24.000 34.000	26.95 36.75	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	6.35~ 7.35	Clayey soil	8.00	0.0	24.0 24.0	34.000 42.000	36.75 46.55	0.200 0.200	11.31 11.31	—— ——	—— ——
9	7.35~ 8.35	Clayey soil	8.00	0.0	25.0 25.0	42.000 50.000	46.55 56.35	0.200 0.200	11.31 11.31	—— ——	—— ——
10	8.35~ 9.35	Clayey soil	8.00	0.0	25.0 25.0	50.000 58.000	56.35 66.15	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
11	9.35~ 12.35	Clayey soil	8.00	0.0	12.0 12.0	58.000 82.000	66.15 95.55	0.200 0.200	11.31 11.31	—— ——	—— ——
12	12.35~ 13.35	Clayey soil	8.00	0.0	18.0 18.0	82.000 90.000	95.55 105.35	0.200 0.200	11.31 11.31	—— ——	—— ——
13	13.35~ 14.35	Clayey soil	8.00	0.0	100.0 100.0	90.000 98.000	105.35 115.15	0.200 0.200	11.31 11.31	—— ——	—— ——
14	14.35~ 15.35	Sandy soil	10.00	34.0	—— ——	98.000 108.000	115.15 124.95	0.200 0.200	11.31 11.31	4.18373 4.18373	4.13222 4.13222
15	15.35~ 16.35	Sandy soil	10.00	31.0	—— ——	108.000 118.000	124.95 134.75	0.200 0.200	11.31 11.31	3.57258 3.57258	3.52859 3.52859
16	16.35~ 17.35	Sandy soil	10.00	32.0	—— ——	118.000 128.000	134.75 144.55	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
17	17.35~ 20.00	Sandy soil	10.00	45.0	—— ——	128.000 154.500	144.55 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.

$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.00	11.58 20.58	—— ——	11.58 20.58	0.00 19.60	—— ——
2	2.00~ 2.10	20.58 21.03	—— ——	20.58 21.03	19.60 19.60	—— ——
3	2.10~ 2.38	21.65 24.49	23.38 24.49	23.38 24.49	19.60 19.60	—— ——
4	2.38~ 2.60	24.49 26.75	24.49 25.38	24.49 26.75	19.60 19.60	—— ——
5	2.60~ 4.35	26.75 44.90	25.38 32.38	26.75 44.90	19.60 19.60	36.00 50.00
6	4.35~ 5.35	31.23 36.06	—— ——	31.23 36.06	19.60 19.60	42.36 72.61
7	5.35~ 6.35	37.34 42.33	—— ——	37.34 42.33	19.60 19.60	69.03 97.79
8	6.35~ 7.35	57.53 68.02	42.38 46.38	57.53 68.02	19.60 19.60	82.00 90.00
9	7.35~ 8.35	65.73 76.28	46.38 50.38	65.73 76.28	19.60 19.60	92.00 100.00
10	8.35~ 9.35	76.28 86.98	50.38 54.38	76.28 86.98	19.60 19.60	100.00 108.00
11	9.35~ 12.35	161.93 213.16	54.38 66.38	161.93 213.16	19.60 19.60	82.00 106.00
12	12.35~ 13.35	151.27 172.89	66.38 70.38	151.27 172.89	19.60 19.60	118.00 126.00

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
13	13.35~ 14.35	-29.24 -19.42	70.38 74.38	70.38 74.38	19.60 19.60	290.00 298.00
14	14.35~ 15.35	58.12 62.03	—— ——	58.12 62.03	19.60 19.60	404.96 446.28
15	15.35~ 16.35	68.95 73.30	—— ——	68.95 73.30	19.60 19.60	381.09 416.37
16	16.35~ 17.35	70.77 74.96	—— ——	70.77 74.96	19.60 19.60	438.65 475.82
17	17.35~ 20.00	46.44 53.32	—— ——	46.44 53.32	19.60 19.60	1001.62 1208.99

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

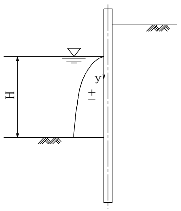
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.00 2.60	0.00 0.60	0.00 1.03

$$p_{dw} = \pm \frac{7}{8}\, k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

k_{hs} : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated

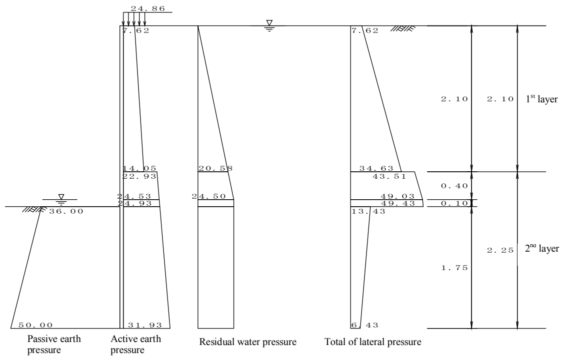


Passive earth pressure | Active earth pressure | Residual water pressure | Total of lateral pressure

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

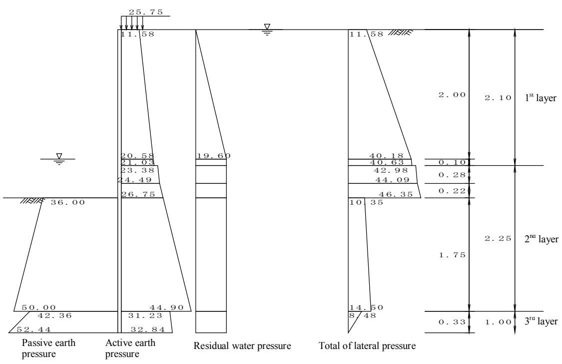


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	7.62 14.05	0.00 20.58	—— ——	7.62 34.63
2	2.10～ 2.50	22.93 24.53	20.58 24.50	—— ——	43.51 49.03
3	2.50～ 2.60	24.53 24.93	24.50 24.50	—— ——	49.03 49.43
4	2.60～ 4.35	24.93 31.93	24.50 24.50	36.00 50.00	13.43 6.43
5	4.35～ 5.35	21.13 24.44	24.50 24.50	50.44 86.47	-4.81 -37.53

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.75 m (GL -4.35 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.00	11.58 20.58	0.00 19.60	—— ——	11.58 40.18
2	2.00～ 2.10	20.58 21.03	19.60 19.60	—— ——	40.18 40.63
3	2.10～ 2.38	23.38 24.49	19.60 19.60	—— ——	42.98 44.09
4	2.38～ 2.60	24.49 26.75	19.60 19.60	—— ——	44.09 46.35
5	2.60～ 4.35	26.75 44.90	19.60 19.60	36.00 50.00	10.35 14.50
6	4.35～ 4.68	31.23 32.84	19.60 19.60	42.36 52.44	8.48 0.00
7	4.68～ 5.35	32.84 36.06	19.60 19.60	52.44 72.61	0.00 -16.96

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.08 m (GL -4.68 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below.

$$K_h = 6910 \times N'^{\,0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	86000 cm⁴(original condition)
	I	=	63296 cm⁴(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	3
4	4.35	3
5	5.35	12
6	6.35	2
7	7.35	4
8	8.35	5
9	9.35	5
10	12.35	2

	Depth (m)	N-value
11	13.35	3
12	14.35	21
13	15.35	24
14	16.35	18
15	17.35	20
16	20.00	40

5-2 Normal Condition

K_h = 14689 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.413 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.42 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.35 m) to 2.42 m depth (GL -6.77 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.35	1.00	3.0	12.0	7.50
2	5.35	1.00	12.0	2.0	7.00
3	6.35	0.42	2.0	2.8	1.03
L = Σh = 2.42			ΣA = 15.53		

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{15.53}{2.42}$

$= 6.41$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 6.41^{0.406} = 14689$ kN/m³

Kh (normal condition) = 14689 kN/m³

5-3 Seismic Condition

K_h = 14510 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.411$ m⁻¹

$$L = \frac{1}{\beta} = 2.43 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.68 m) and 2.43 m depth (GL -7.11 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.68	0.67	6.0	12.0	6.00
2	5.35	1.00	12.0	2.0	7.00
3	6.35	0.76	2.0	3.5	2.11
	L = Σh = 2.43			ΣA = 15.11	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{15.11}{2.43}$

$= 6.22$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 6.22^{0.406} = 14510$ kN/m³

Kh (seismic condition) = 14510 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.62 34.63	8.00 36.36	3.65 2.95	29.19 107.27
2	2.10~ 2.50	0.40	43.51 49.03	8.70 9.81	2.12 1.98	18.42 19.45
3	2.50~ 2.60	0.10	49.03 49.43	2.45 2.47	1.82 1.78	4.45 4.41
4	2.60~ 4.35	1.75	13.43 6.43	11.75 5.63	1.17 0.58	13.71 3.28
				ΣP = 85.17		ΣM = 200.19

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 0.0 kN/m
depth to acting position H_t = 0.00 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.75 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 00.00 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{200.19}{85.17} = 2.35 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.00	2.00	11.58 40.18	11.58 40.18	4.02 3.35	46.53 134.60
2	2.00~ 2.10	0.10	40.18 40.63	2.01 2.03	2.65 2.62	5.32 5.32
3	2.10~ 2.38	0.28	42.98 44.09	5.98 6.14	2.49 2.40	14.89 14.71
4	2.38~ 2.60	0.22	44.09 46.35	4.89 5.14	2.23 2.16	10.90 11.08

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
5	2.60~ 4.35	1.75	10.35 14.50	9.06 12.69	1.50 0.92	13.59 11.63
6	4.35~ 4.68	0.33	8.48 0.00	1.41 0.00	0.22 0.11	0.31 0.00
				ΣP = 101.10		ΣM = 268.89

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 2.7 kN/m
depth to acting position H_t = 0.40 m
moment M_m = 1.1 kN·m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 2.08 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 12.66 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00~ 2.60	0.60	0.0 1.0	0.00 0.31	2.48 2.28	0.00 0.70
				ΣPdw = 0.31		ΣMdw = 0.70

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{282.26}{104.11} = 2.71 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.92
Section efficiency μ = 0.80
Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 86000 cm⁴ (original condition)
I = 63296 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 14689 kN/m³
calculated value β = 0.41269 m⁻¹
resultant earth force (lateral) P_0 = 85.17 kN/m
height of acting position of load h_0 = 2.35 m
moment M_0 = 200.19 kN·m/m

in consideration of ψ = 1.153,
maximum moment M_{max} = 230.87 kN·m/m
depth of generated position of M_{max} l_m = 0.794 m
depth of 1st fixed point l_i = 2.698 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 14510 kN/m³
calculated value β = 0.41144 m⁻¹
resultant earth force (lateral) P_0 = 104.11 kN/m
height of acting position of load h_0 = 2.71 m
moment M_0 = 282.26 kN·m/m

in consideration of ψ = 1.123,
maximum moment M_{max} = 316.96 kN·m/m
depth of generated position of M_{max} l_m = 0.730 m
depth of 1st fixed point l_i = 2.638 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.92
Section efficiency μ = 1.00
Module of section Z_0 = 3820 cm³ (original condition)
Z = 3514 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{230.87\times10^6}{3514\times10^3} = 66\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{316.96\times10^6}{3514\times10^3} = 90\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.65 2.95	0.839 0.678	0.254 0.178	8.00 36.36	2.028 6.472
2	2.10~ 2.50	2.12 1.98	0.487 0.456	0.099 0.088	8.70 9.81	0.863 0.864
3	2.50~ 2.60	1.82 1.78	0.418 0.410	0.075 0.073	2.45 2.47	0.184 0.179
4	2.60~ 4.35	1.17 0.58	0.268 0.134	0.033 0.009	11.75 5.63	0.385 0.048
						ΣQ = 11.024

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

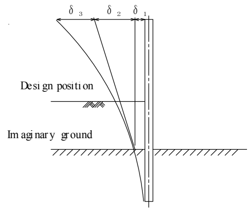
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4127\times2.35)\times85.17}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4127^3} = 0.00943\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4127\times2.35)\times85.17}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4127^2}\times(2.60+1.75) = 0.02526\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.02\times(2.60+1.75)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00717\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00943 + 0.02526 + 0.00717
= 0.04186 m
= 41.86 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.00	4.02 3.35	0.858 0.715	0.263 0.195	11.58 40.18	3.042 7.828
2	2.00~ 2.10	2.65 2.62	0.566 0.559	0.130 0.127	2.01 2.03	0.261 0.258
3	2.10~ 2.38	2.49 2.40	0.532 0.512	0.116 0.109	5.98 6.14	0.696 0.667
4	2.38~ 2.60	2.23 2.16	0.476 0.461	0.095 0.090	4.89 5.14	0.466 0.461
5	2.60~ 4.35	1.50 0.92	0.320 0.196	0.046 0.018	9.06 12.69	0.415 0.227
6	4.35~ 4.68	0.22 0.11	0.047 0.024	0.001 0.000	1.41 0.00	0.002 0.000
						ΣQ = 14.324

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

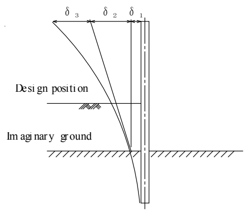
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.00~ 2.60	2.48 2.28	0.530 0.488	0.116 0.100	0.00 0.31	0.000 0.031
						ΣQ_{dw} = 0.031

Therefore, modulus of deformation Q is calculated as below
Q = 15.109 + 0.031 = 15.140

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4114\times2.71)\times104.11}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4114^3} = 0.01249\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4114\times2.71)\times104.11}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4114^2}\times(2.60+2.08) = 0.03676\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.14\times(2.60+2.08)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.01228\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$$= \frac{1.10\times3.88}{2\times2.00\times10^8\times63296\times10^{-8}}\times(2\times4.68-3.88) = 0.00009\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01249 + 0.03676 + 0.01238
= 0.06162 m
= 61.62 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

2.23

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 86000 \times 10^{-8}$		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 14689$ kN/m^3

Calculated value $\beta = 0.38225$ m^{-1}

Penetration length of SSP $D = 1.75 + \frac{3}{0.382} = 9.60$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.60 = 11.80$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 14510$ kN/m^3

Calculated value $\beta = 0.38109$ m^{-1}

Penetration length of SSP $D = 2.08 + \frac{3}{0.381} = 9.96$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.96 = 12.16$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

Case: Right Bank No. 03_STA_5+100 - 5+223

8 Calculation Result

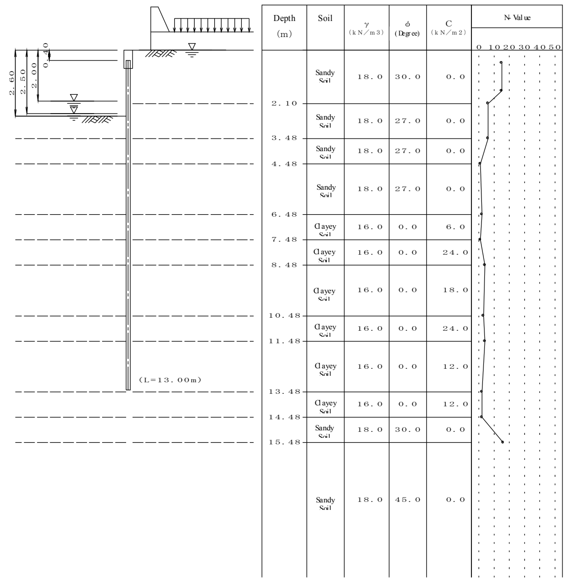
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		230.87	316.96
Stress intensity	σ (N/mm^2)		66 (180)	90 (270)
Lateral displacement	δ (mm)		41.86 (50.0)	61.62 (75.0)
Penetration depth	D (m)		9.60	9.96
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 04_STA 5+262 - 5+340

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wn}	=	2.50 m (Normal Condition)
	L_{wn}'	=	2.00 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	0.0 kNm (Normal Condition)
		P_t'	=	2.7 kNm (Seismic Condition)
	Depth of acting point	H_t	=	0.00 m (Normal Condition)
		H_t'	=	0.40 m (Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m (Normal Condition)
		M_m'	=	1.1 kN·m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m (Seismic Condition)
		H_m	=	0.80 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	6
4	3.48	6
5	4.48	1
6	6.48	2
7	7.48	1
8	8.48	4
9	10.48	3
10	11.48	4

No	Depth (m)	N-Value
11	13.48	2
12	14.48	2
13	15.48	16
14	20.00	20

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

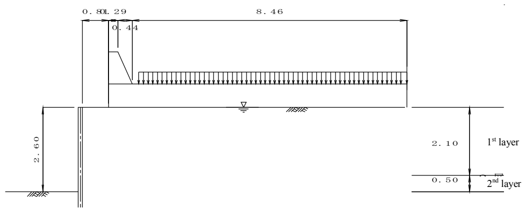
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.48	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	4.48	S	1.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	6.48	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	7.48	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
6	8.48	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
7	10.48	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
8	11.48	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
9	13.48	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
10	14.48	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
11	15.48	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
12	20.00	S	20.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note) depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.81	0.81	10.00	10.00	0.72	18.0	30.0	0.0	auto	auto
2	Sandy soil	0.81	0.81	1.10	1.54	0.99	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	1.74	10.00	10.0	5.0

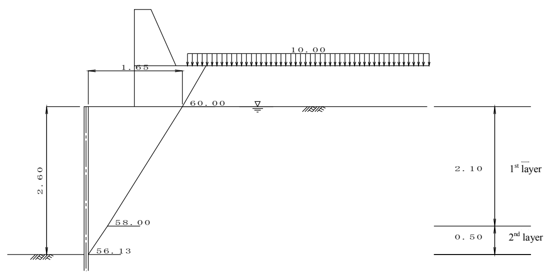
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	86000 cm⁴
Sectional factor	Z_0	=	3820 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 Nmm² (Normal)
	σ_a'	=	270 Nmm² (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kNm²)	Σγh (kNm²)	Q (kNm²)	γwhw (kNm²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	15.70	25.48	56.13
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	15.70	20.58	58.00
3		Embankment	30.0	——	0.0	30.78	0.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.50	0.00	0.00	0.34	0.50
2	58.00	2.10	0.34	0.50	1.65	2.60
3	60.00	0.72	1.65	2.60	2.06	3.32

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.75	13.55
2	18.0	0.50	9.09
Σ			22.64

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	0.32	3.24
Σ			3.24

Q surcharge load

l : width of surcharge load set by line of active rupture

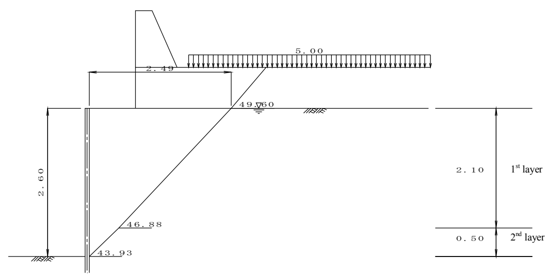
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{22.64 + 3.24 + 0.00}{1.65}$$

$$= 15.70 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	16.72	25.48	0.200	11.31	43.93
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	16.72	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	30.78	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.93	0.50	0.00	0.00	0.52	0.50
2	46.88	2.10	0.52	0.50	2.49	2.60
3	49.60	0.72	2.49	2.60	3.10	3.32

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.43	25.69
2	18.0	0.50	9.09
Σ			34.78

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	1.36	6.79
Σ			6.79

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

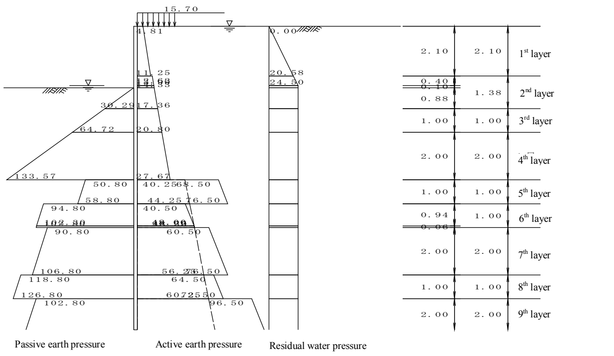
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{34.78 + 6.79 + 0.00}{2.49}$$

$$= 16.72 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	15.703 36.703	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.50	Sandy soil	10.0	27.0	—— ——	36.703 40.703	0.34800 0.34800	0.34371 0.34371
3	2.50~ 2.60	Sandy soil	10.0	27.0	—— ——	40.703 41.703	0.34800 0.34800	0.34371 0.34371
4	2.60~ 3.48	Sandy soil	10.0	27.0	—— ——	41.703 50.503	0.34800 0.34800	0.34371 0.34371
5	3.48~ 4.48	Sandy soil	10.0	27.0	—— ——	50.503 60.503	0.34800 0.34800	0.34371 0.34371
6	4.48~ 6.48	Sandy soil	10.0	27.0	—— ——	60.503 80.503	0.34800 0.34800	0.34371 0.34371
7	6.48~ 7.48	Clayey soil	8.0	—	6.0 6.0	80.503 88.503	—— ——	—— ——
8	7.48~ 8.42	Clayey soil	8.0	—	24.0 24.0	88.503 96.000	—— ——	—— ——
9	8.42~ 8.48	Clayey soil	8.0	—	24.0 24.0	96.000 96.503	—— ——	—— ——
10	8.48~ 10.48	Clayey soil	8.0	—	18.0 18.0	96.503 112.503	—— ——	—— ——
11	10.48~ 11.48	Clayey soil	8.0	—	24.0 24.0	112.503 120.503	—— ——	—— ——
12	11.48~ 13.48	Clayey soil	8.0	—	12.0 12.0	120.503 136.503	—— ——	—— ——
13	13.48~ 14.48	Clayey soil	8.0	—	12.0 12.0	136.503 144.503	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	14.48~ 15.48	Sandy soil	10.0	30.0	—— ——	144.503 154.503	0.31026 0.31026	0.30644 0.30644
15	15.48~ 20.00	Sandy soil	10.0	45.0	—— ——	154.503 199.703	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.

δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60~ 3.48	Sandy soil	10.0	27.0	—— ——	0.000 8.800	3.48553 3.48553	3.44261 3.44261
5	3.48~ 4.48	Sandy soil	10.0	27.0	—— ——	8.800 18.800	3.48553 3.48553	3.44261 3.44261
6	4.48~ 6.48	Sandy soil	10.0	27.0	—— ——	18.800 38.800	3.48553 3.48553	3.44261 3.44261
7	6.48~ 7.48	Clayey soil	8.0	0.0	6.0 6.0	38.800 46.800	—— ——	—— ——
8	7.48~ 8.42	Clayey soil	8.0	0.0	24.0 24.0	46.800 54.297	—— ——	—— ——
9	8.42~ 8.48	Clayey soil	8.0	0.0	24.0 24.0	54.297 54.800	—— ——	—— ——
10	8.48~ 10.48	Clayey soil	8.0	0.0	18.0 18.0	54.800 70.800	—— ——	—— ——
11	10.48~ 11.48	Clayey soil	8.0	0.0	24.0 24.0	70.800 78.800	—— ——	—— ——
12	11.48~ 13.48	Clayey soil	8.0	0.0	12.0 12.0	78.800 94.800	—— ——	—— ——
13	13.48~ 14.48	Clayey soil	8.0	0.0	12.0 12.0	94.800 102.800	—— ——	—— ——
14	14.48~ 15.48	Sandy soil	10.0	30.0	—— ——	102.800 112.800	4.00247 4.00247	3.95319 3.95319
15	15.48~ 20.00	Sandy soil	10.0	45.0	—— ——	112.800 158.000	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.

δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side Pa1 kN/m²	Active side Pa2 kN/m²	Active side Pa kN/m²	Residual water pressure Pw kN/m²	Passive side Pp kN/m²
1	0.00~ 2.10	4.81 11.25	—— ——	4.81 11.25	0.00 20.58	—— ——
2	2.10~ 2.50	12.62 13.99	—— ——	12.62 13.99	20.58 24.50	—— ——
3	2.50~ 2.60	13.99 14.33	—— ——	13.99 14.33	24.50 24.50	—— ——
4	2.60~ 3.48	14.33 17.36	—— ——	14.33 17.36	24.50 24.50	0.00 30.29
5	3.48~ 4.48	17.36 20.80	—— ——	17.36 20.80	24.50 24.50	30.29 64.72
6	4.48~ 6.48	20.80 27.67	—— ——	20.80 27.67	24.50 24.50	64.72 133.57
7	6.48~ 7.48	68.50 76.50	40.25 44.25	68.50 76.50	24.50 24.50	50.80 58.80
8	7.48~ 8.42	40.50 48.00	44.25 48.00	44.25 48.00	24.50 24.50	94.80 102.30
9	8.42~ 8.48	48.00 48.50	48.00 48.25	48.00 48.50	24.50 24.50	102.30 102.80
10	8.48~ 10.48	60.50 76.50	48.25 56.25	60.50 76.50	24.50 24.50	90.80 106.80
11	10.48~ 11.48	64.50 72.50	56.25 60.25	64.50 72.50	24.50 24.50	118.80 126.80
12	11.48~ 13.48	96.50 112.50	60.25 68.25	96.50 112.50	24.50 24.50	102.80 118.80
13	13.48~ 14.48	112.50 120.50	68.25 72.25	112.50 120.50	24.50 24.50	118.80 126.80
14	14.48~ 15.48	44.28 47.35	—— ——	44.28 47.35	24.50 24.50	406.39 445.92
15	15.48~ 20.00	24.91 32.20	—— ——	24.91 32.20	24.50 24.50	987.76 1383.57

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

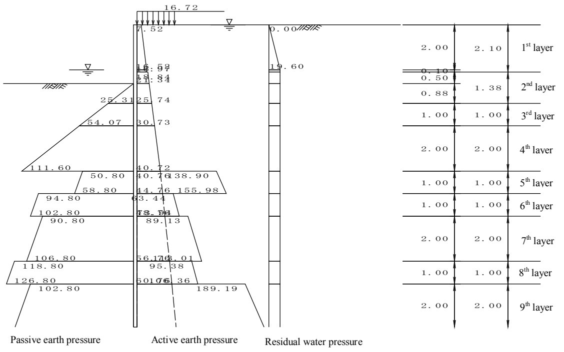
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.00	Sandy Soil	10.0	30.0	— —	16.72 36.72	0.00 19.60	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	— —
2	2.00～ 2.10	Sandy Soil	10.0	30.0	— —	36.72 37.72	19.60 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	— —
3	2.10～ 2.60	Sandy Soil	10.0	27.0	— —	37.72 42.72	20.58 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	— —
4	2.60～ 3.48	Sandy Soil	10.0	27.0	— —	42.72 51.52	25.48 34.10	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	— —
5	3.48～ 4.48	Sandy Soil	10.0	27.0	— —	51.52 61.52	34.10 43.90	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	— —
6	4.48～ 6.48	Sandy Soil	10.0	27.0	— —	61.52 81.52	43.90 63.50	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	— —
7	6.48～ 7.48	Clayey Soil	8.0	—	6.0 6.0	81.52 89.52	63.50 73.30	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
8	7.48～ 8.48	Clayey Soil	8.0	—	24.0 24.0	89.52 97.52	73.30 83.10	0.200 0.200	11.31 11.31	— —	— —	36.74 35.90
9	8.48～ 10.48	Clayey Soil	8.0	—	18.0 18.0	97.52 113.52	83.10 102.70	0.200 0.200	11.31 11.31	— —	— —	31.15 27.73
10	10.48～ 11.48	Clayey Soil	8.0	—	24.0 24.0	113.52 121.52	102.70 112.50	0.200 0.200	11.31 11.31	— —	— —	34.07 33.07
11	11.48～ 13.48	Clayey Soil	8.0	—	12.0 12.0	121.52 137.52	112.50 132.10	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
12	13.48～ 14.48	Clayey Soil	8.0	—	12.0 12.0	137.52 145.52	132.10 141.90	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
13	14.48～ 15.48	Sandy Soil	10.0	30.0	— —	145.52 155.52	141.90 151.70	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	— —
14	15.48～ 20.00	Sandy Soil	10.0	45.0	— —	155.52 200.72	151.70 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.

δ = 9.00、 β = 0.00、 θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 3.48	Sandy soil	10.00	27.0	— —	0.000 8.800	0.00 8.62	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	3.48～ 4.48	Sandy soil	10.00	27.0	— —	8.800 18.800	8.62 18.42	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	4.48～ 6.48	Sandy soil	10.00	27.0	— —	18.800 38.800	18.42 38.02	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	6.48～ 7.48	Clayey soil	8.00	0.0	6.0 6.0	38.800 46.800	38.02 47.82	0.200 0.200	11.31 11.31	— —	— —
8	7.48～ 8.48	Clayey soil	8.00	0.0	24.0 24.0	46.800 54.800	47.82 57.62	0.200 0.200	11.31 11.31	— —	— —
9	8.48～ 10.48	Clayey soil	8.00	0.0	18.0 18.0	54.800 70.800	57.62 77.22	0.200 0.200	11.31 11.31	— —	— —
10	10.48～ 11.48	Clayey soil	8.00	0.0	24.0 24.0	70.800 78.800	77.22 87.02	0.200 0.200	11.31 11.31	— —	— —
11	11.48～ 13.48	Clayey soil	8.00	0.0	12.0 12.0	78.800 94.800	87.02 106.62	0.200 0.200	11.31 11.31	— —	— —
12	13.48～ 14.48	Clayey soil	8.00	0.0	12.0 12.0	94.800 102.800	106.62 116.42	0.200 0.200	11.31 11.31	— —	— —
13	14.48～ 15.48	Sandy soil	10.00	30.0	— —	102.800 112.800	116.42 126.22	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
14	15.48～ 20.00	Sandy soil	10.00	45.0	— —	112.800 158.000	126.22 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.

δ = -9.00、 β = 0.00、 θ = tan⁻¹k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.00	7.52 16.52	— —	7.52 16.52	0.00 19.60	— —
2	2.00～ 2.10	16.52 16.97	— —	16.52 16.97	19.60 19.60	— —
3	2.10～ 2.60	18.84 21.34	— —	18.84 21.34	19.60 19.60	— —
4	2.60～ 3.48	21.34 25.74	— —	21.34 25.74	19.60 19.60	0.00 25.31
5	3.48～ 4.48	25.74 30.73	— —	25.74 30.73	19.60 19.60	25.31 54.07
6	4.48～ 6.48	30.73 40.72	— —	30.73 40.72	19.60 19.60	54.07 111.60
7	6.48～ 7.48	138.90 155.98	40.76 44.76	138.90 155.98	19.60 19.60	50.80 58.80
8	7.48～ 8.48	63.44 73.94	44.76 48.76	63.44 73.94	19.60 19.60	94.80 102.80
9	8.48～ 10.48	89.13 113.01	48.76 56.76	89.13 113.01	19.60 19.60	90.80 106.80
10	10.48～ 11.48	95.38 106.36	56.76 60.76	95.38 106.36	19.60 19.60	118.80 126.80
11	11.48～ 13.48	189.19 223.34	60.76 68.76	189.19 223.34	19.60 19.60	102.80 118.80
12	13.48～ 14.48	223.34 240.41	68.76 72.76	223.34 240.41	19.60 19.60	118.80 126.80
13	14.48～ 15.48	65.46 69.96	— —	65.46 69.96	19.60 19.60	344.48 377.99
14	15.48～ 20.00	40.41 52.15	— —	40.41 52.15	19.60 19.60	882.68 1236.37

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.00 2.60	0.00 0.60	0.00 1.03

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

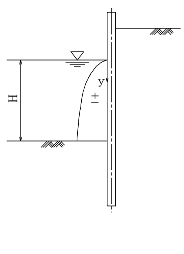
Where,

k_{hs} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

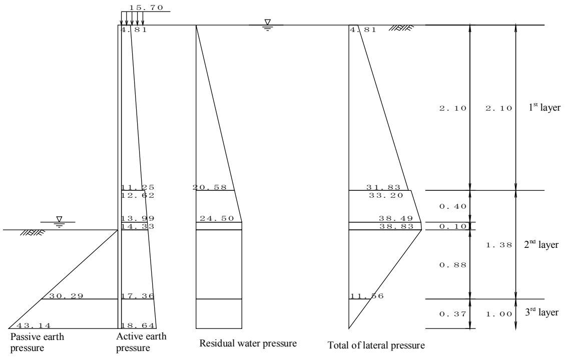
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

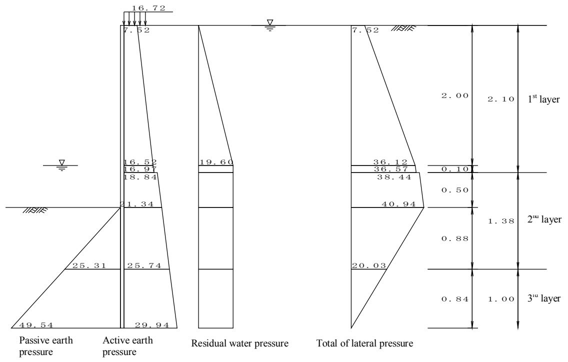


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	4.81 11.25	0.00 20.58	―― ――	4.81 31.83
2	2.10～ 2.50	12.62 13.99	20.58 24.50	―― ――	33.20 38.49
3	2.50～ 2.60	13.99 14.33	24.50 24.50	―― ――	38.49 38.83
4	2.60～ 3.48	14.33 17.36	24.50 24.50	0.00 30.29	38.83 11.56
5	3.48～ 3.85	17.36 18.64	24.50 24.50	30.29 43.14	11.56 0.00
6	3.85～ 4.48	18.64 20.80	24.50 24.50	43.14 64.72	0.00 -19.43

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.25 m (GL -3.85 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.00	7.52 16.52	0.00 19.60	―― ――	7.52 36.12
2	2.00～ 2.10	16.52 16.97	19.60 19.60	―― ――	36.12 36.57
3	2.10～ 2.60	18.84 21.34	19.60 19.60	―― ――	38.44 40.94
4	2.60～ 3.48	21.34 25.74	19.60 19.60	0.00 25.31	40.94 20.03
5	3.48～ 4.32	25.74 29.94	19.60 19.60	25.31 49.54	20.03 0.00
6	4.32～ 4.48	29.94 30.73	19.60 19.60	49.54 54.07	0.00 -3.74

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.72 m (GL -4.32 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below.

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m		
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 =	1.00 mm (passive side)
Corrosion rate	η	=	0.92		
Section efficiency	μ	=	0.80		
Young's modulus	E	=	200000 Nmm²		
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)		
	I	=	63296 cm⁴ (after reduction by corrosion and section)		
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$		

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	13.48	2
2	1.60	15	12	14.48	2
3	2.10	6	13	15.48	16
4	3.48	6	14	20.00	20
5	4.48	1			
6	6.48	2			
7	7.48	1			
8	8.48	4			
9	10.48	3			
10	11.48	4			

5-2 Normal Condition

K_h = 8699 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.362 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.76 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.85 m) to 2.76 m depth (GL -6.62 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.85	0.63	4.1	1.0	1.61
2	4.48	2.00	1.0	2.0	3.00
3	6.48	0.14	2.0	1.9	0.26
L = Σh = 2.76			ΣA = 4.87		

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{4.87}{2.76}$$

$$= 1.76$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following.

$K_h = 6910 \times N'^{0.406} = 6910 \times 1.76^{0.406} = 8699$ kN/m³

Kh (normal condition) = 8699 kNm³

5-3 Seismic Condition

K_h = 8223 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.357 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.80 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.32 m) and 2.80 m depth (GL -7.12 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.32	0.16	1.8	1.0	0.22
2	4.48	2.00	1.0	2.0	3.00
3	6.48	0.64	2.0	1.4	1.08
L = Σh = 2.80			ΣA = 4.30		

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{4.30}{2.80}$$

$$= 1.53$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following.

$K_h = 6910 \times N'^{0.406} = 6910 \times 1.53^{0.406} = 8223$ kN/m³

Kh (seismic condition) = 8223 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	4.81 31.83	5.05 33.42	3.15 2.45	15.93 81.98
2	2.10~ 2.50	0.40	33.20 38.49	6.64 7.70	1.62 1.49	10.75 11.44
3	2.50~ 2.60	0.10	38.49 38.83	1.92 1.94	1.32 1.29	2.54 2.50
4	2.60~ 3.48	0.88	38.83 11.56	17.09 5.09	0.96 0.67	16.40 3.39
5	3.48~ 3.85	0.37	11.56 0.00	2.16 0.00	0.25 0.12	0.54 0.00
				ΣP = 81.01		ΣM = 145.48

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	0.0 kN/m
depth to acting position	H_t	=	0.00 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.25 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 0.00$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{145.48}{81.01} = 1.80 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.00	2.00	7.52 36.12	7.52 36.12	3.66 2.99	27.50 107.97
2	2.00~ 2.10	0.10	36.12 36.57	1.81 1.83	2.29 2.26	4.13 4.12
3	2.10~ 2.60	0.50	38.44 40.94	9.61 10.24	2.06 1.89	19.76 19.34

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
4	2.60~ 3.48	0.88	40.94 20.03	18.01 8.81	1.43 1.14	25.75 10.01
5	3.48~ 4.32	0.84	20.03 0.00	8.44 0.00	0.56 0.28	4.74 0.00
				ΣP = 102.38		ΣM = 223.31

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.7 kN/m
depth to acting position	H_t	=	0.40 m
moment	M_m	=	1.1 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.72 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 11.69$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00~ 2.60	0.60	0.0 1.0	0.00 0.31	2.12 1.92	0.00 0.59
				ΣPdw = 0.31		ΣMdw = 0.59

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{235.60}{105.39} = 2.24 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266x 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	8699 kN/m^3
calculated value	β	=	0.36204 m^{-1}
resultant earth force (lateral)	P_0	=	81.01 kN/m
height of acting position of load	h_0	=	1.80 m
moment	M_0	=	145.48 kN·m/m

in consideration of ϕ_m = 1.280,

maximum moment	M_{max}	=	186.22 kN·m/m
depth of generated position of M_{max}	l_m	=	1.133 m
depth of 1st fixed point	l_i	=	3.302 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	8223 kN/m^3
calculated value	β	=	0.35698 m^{-1}
resultant earth force (lateral)	P_0	=	105.39 kN/m
height of acting position of load	h_0	=	2.24 m
moment	M_0	=	235.60 kN·m/m

in consideration of ϕ_m = 1.207,

maximum moment	M_{max}	=	284.31 kN·m/m
depth of generated position of M_{max}	l_m	=	1.030 m
depth of 1st fixed point	l_i	=	3.230 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{186.22\times10^6}{3514\times10^3} = 53 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{284.31\times10^6}{3514\times10^3} = 81 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

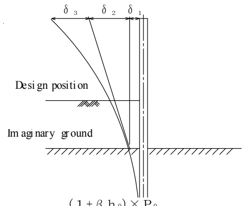
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.15 2.45	0.818 0.637	0.244 0.160	5.05 33.42	1.230 5.336
2	2.10~ 2.50	1.62 1.49	0.420 0.386	0.076 0.065	6.64 7.70	0.504 0.499
3	2.50~ 2.60	1.32 1.29	0.343 0.334	0.052 0.050	1.92 1.94	0.100 0.096
4	2.60~ 3.48	0.96 0.67	0.249 0.173	0.028 0.014	17.09 5.09	0.486 0.072
5	3.48~ 3.85	0.25 0.12	0.065 0.032	0.002 0.001	2.16 0.00	0.004 0.000
						ΣQ = 8.328

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3620\times 1.80)\times 81.01}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3620^3} = 0.01113 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3620\times 1.80)\times 81.01}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3620^2}\times(2.60+1.25) = 0.02164 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{8.33\times(2.60+1.25)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00376 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01113 + 0.02164 + 0.00376$
$= 0.03653$ m
$= 36.53 \leqq \delta a = 50.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

Case: Right Bank No. 04_STA 5+262-5+340

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.00	3.66 2.99	0.846 0.692	0.257 0.184	7.52 36.12	1.932 6.646
2	2.00~ 2.10	2.29 2.26	0.530 0.522	0.115 0.112	1.81 1.83	0.209 0.206
3	2.10~ 2.60	2.06 1.89	0.476 0.437	0.095 0.082	9.61 10.24	0.915 0.835
4	2.60~ 3.48	1.43 1.14	0.331 0.263	0.049 0.032	18.01 8.81	0.876 0.278
5	3.48~ 4.32	0.56 0.28	0.130 0.065	0.008 0.002	8.44 0.00	0.068 0.000
						ΣQ = 11.964

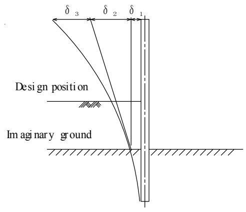
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	P_{dw} (kN)	Q_{dw} (kN)
1	2.00~ 2.60	2.12 1.92	0.491 0.445	0.101 0.084	0.00 0.31	0.000 0.026
						ΣQ_{dw} = 0.026

Therefore, modulus of deformation Q is calculated as below
Q = 12.739 + 0.026 = 12.765

Displacement



Case: Right Bank No. 04_STA 5+262-5+340

$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3570\times 2.24)\times 105.39}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3570^3} = 0.01645 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3570\times 2.24)\times 105.39}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3570^2}\times(2.60+1.72) = 0.03666 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.76\times(2.60+1.72)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00814 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01645 + 0.03666 + 0.00822$
$= 0.06133$ m
$= 61.33 \leqq \delta a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

Case: Right Bank No. 04_STA 5+262-5+340

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720x 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 8699 kN/m³
Calculated value β = 0.33533 m⁻¹

Penetration length of SSP $D = 1.25 + \frac{3}{0.335} = 10.20$ m
Whole length of SSP $L = 2.60 - 0.40 + 10.20 = 12.40$ m

7-1-2 Seismic (

Modules of lateral subgrade reaction K_h = 8223 kN/m³
Calculated value β = 0.33064 m⁻¹

Penetration length of SSP $D = 1.72 + \frac{3}{0.331} = 10.80$ m
Whole length of SSP $L = 2.60 - 0.40 + 10.80 = 13.00$ m

Therefore, whole length of SSP is set as 13.00m in consideration of round unit of SSP length.

8 Calculation Result

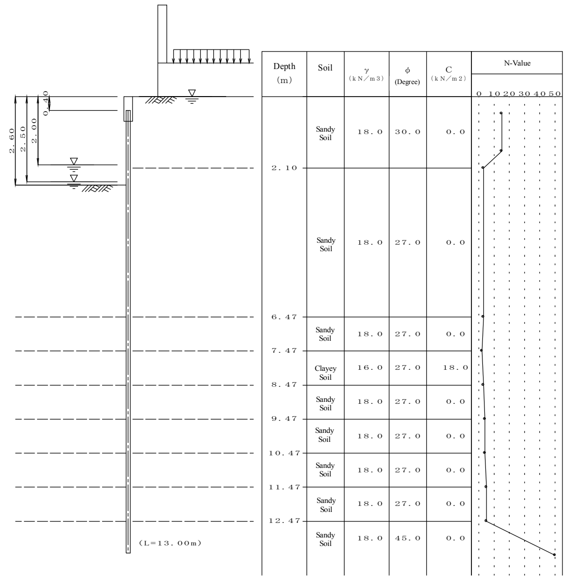
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		186.22	284.31
Stress intensity	σ (N/mm^2)		53 (180)	81 (270)
Lateral displacement	δ (mm)		36.53 (50.0)	61.33 (75.0)
Penetration depth	D (m)		10.20	10.80
Whole length of SSP	L (m)	13.00		

－Steel Sheet Pile　Design Calculation－

Right Bank No. 05_STA 5+340 - 5+414

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wn}	=	2.50 m (Normal Condition)
	L_{wn}'	=	2.00 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　$\gamma_w = 9.8$ kN/m³

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load

Horizontal load	Pt	=	0.0 kNm	(Normal Condition)
	Pt'	=	2.7 kNm	(Seismic Condition)
Depth of acting point	Ht	=	0.00 m	(Normal Condition)
	Ht'	=	0.40 m	(Seismic Condition)
Moment	Mm	=	0.0 kN·m/m	(Normal Condition)
	Mm'	=	1.1 kN·m/m	(Seismic Condition)
Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
	Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　$\zeta_0 = 10$ degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1 - \dfrac{\Sigma\gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression　　$K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	3
4	6.47	3
5	7.47	2
6	8.47	3
7	9.47	4
8	10.47	4
9	11.47	5
10	12.47	5

No	Depth (m)	N-Value
11	13.47	50
12	20.00	50

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

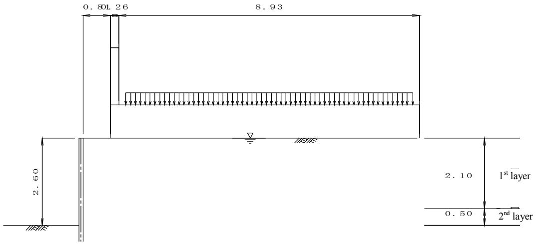
No	Depth (m)	Soil	N-value	γ kN/m³	γ' kN/m³	φ	C kN/m²	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m³) normal	kh(kN/m³) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	6.47	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	7.47	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	8.47	C	3.0	16.00	8.00	27.0	18.0	0.0	0.200	auto	auto	——	——
5	9.47	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	10.47	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	11.47	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	12.47	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
9	13.47	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.81	0.81	10.00	10.00	0.99	18.0	30.0	0.0	auto	auto
2	Sandy soil	0.81	0.81	1.07	1.07	1.70	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.27	9.80	10.0	5.0

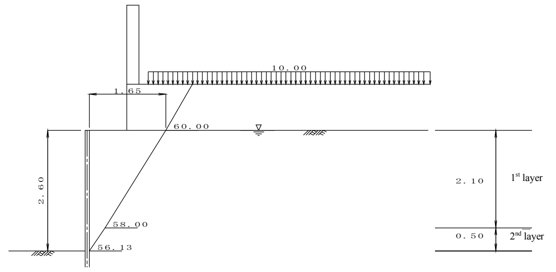
Angle of rupture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4
Sectional factor	Z_0	=	3820 cm^3
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 Nmm^2 (Normal)
	σ_a'	=	270 Nmm^2 (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not Reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	22.74	25.48	56.13
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	22.74	20.58	58.00
3		Embankment	30.0	——	0.0	48.42	0.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where,
- ζ : angle of active rupture (degree, ζ≥10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm^2)
- C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.50	0.00	0.00	0.34	0.50
2	58.00	2.10	0.34	0.50	1.65	2.60
3	60.00	0.99	1.65	2.60	2.22	3.59

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.11	20.02
2	18.0	0.44	7.96
Σ			27.98

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

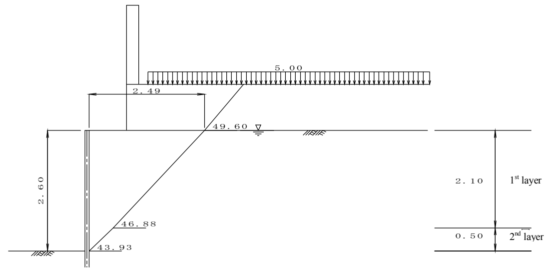
No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	0.95	9.49
Σ			9.49

Q surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L} = \frac{27.98+9.49+0.00}{1.65} = 22.74\ \text{kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	22.37	25.48	0.200	11.31	43.93
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	22.37	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	48.42	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,
- ζ : angle of active rupture (degree, ζ≥10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm^2)
- C cohesive force of soil (kNm^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	0.50	0.00	0.00	0.52	0.50
2	46.88	2.10	0.52	0.50	2.49	2.60
3	49.60	0.99	2.49	2.60	3.33	3.59

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.08	37.37
2	18.0	0.44	7.96
Σ			45.32

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.06	10.29
Σ			10.29

Q surcharge load
L : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

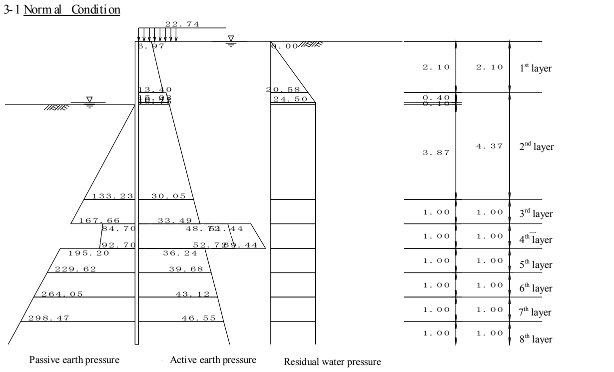
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{45.32 + 10.29 + 0.00}{2.49}$$

$$= 22.37 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	22.741 43.741	0.31026 0.31026	0.30644 0.30644
2	2.10～ 2.50	Sandy soil	10.0	27.0	—— ——	43.741 47.741	0.34800 0.34800	0.34371 0.34371
3	2.50～ 2.60	Sandy soil	10.0	27.0	—— ——	47.741 48.741	0.34800 0.34800	0.34371 0.34371
4	2.60～ 6.47	Sandy soil	10.0	27.0	—— ——	48.741 87.441	0.34800 0.34800	0.34371 0.34371
5	6.47～ 7.47	Sandy soil	10.0	27.0	—— ——	87.441 97.441	0.34800 0.34800	0.34371 0.34371
6	7.47～ 8.47	Clayey soil	8.0	—	18.0 18.0	97.441 105.441	—— ——	—— ——
7	8.47～ 9.47	Sandy soil	10.0	27.0	—— ——	105.441 115.441	0.34800 0.34800	0.34371 0.34371
8	9.47～ 10.47	Sandy soil	10.0	27.0	—— ——	115.441 125.441	0.34800 0.34800	0.34371 0.34371
9	10.47～ 11.47	Sandy soil	10.0	27.0	—— ——	125.441 135.441	0.34800 0.34800	0.34371 0.34371
10	11.47～ 12.47	Sandy soil	10.0	27.0	—— ——	135.441 145.441	0.34800 0.34800	0.34371 0.34371
11	12.47～ 13.47	Sandy soil	10.0	45.0	—— ——	145.441 155.441	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60～ 6.47	Sandy soil	10.0	27.0	—— ——	0.000 38.700	3.48553 3.48553	3.44261 3.44261
5	6.47～ 7.47	Sandy soil	10.0	27.0	—— ——	38.700 48.700	3.48553 3.48553	3.44261 3.44261
6	7.47～ 8.47	Clayey soil	8.0	27.0	18.0 18.0	48.700 56.700	—— ——	—— ——
7	8.47～ 9.47	Sandy soil	10.0	27.0	—— ——	56.700 66.700	3.48553 3.48553	3.44261 3.44261
8	9.47～ 10.47	Sandy soil	10.0	27.0	—— ——	66.700 76.700	3.48553 3.48553	3.44261 3.44261
9	10.47～ 11.47	Sandy soil	10.0	27.0	—— ——	76.700 86.700	3.48553 3.48553	3.44261 3.44261
10	11.47～ 12.47	Sandy soil	10.0	27.0	—— ——	86.700 96.700	3.48553 3.48553	3.44261 3.44261
11	12.47～ 13.47	Sandy soil	10.0	45.0	—— ——	96.700 106.700	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	6.97 13.40	—— ——	6.97 13.40	0.00 20.58	—— ——
2	2.10～ 2.50	15.03 16.41	—— ——	15.03 16.41	20.58 24.50	—— ——
3	2.50～ 2.60	16.41 16.75	—— ——	16.41 16.75	24.50 24.50	—— ——
4	2.60～ 6.47	16.75 30.05	—— ——	16.75 30.05	24.50 24.50	0.00 133.23
5	6.47～ 7.47	30.05 33.49	—— ——	30.05 33.49	24.50 24.50	133.23 167.66
6	7.47～ 8.47	61.44 69.44	48.72 52.72	61.44 69.44	24.50 24.50	84.70 92.70
7	8.47～ 9.47	36.24 39.68	—— ——	36.24 39.68	24.50 24.50	195.20 229.62
8	9.47～ 10.47	39.68 43.12	—— ——	39.68 43.12	24.50 24.50	229.62 264.05
9	10.47～ 11.47	43.12 46.55	—— ——	43.12 46.55	24.50 24.50	264.05 298.47

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
10	11.47～ 12.47	46.55 49.99	—— ——	46.55 49.99	24.50 24.50	298.47 332.90
11	12.47～ 13.47	23.45 25.06	—— ——	23.45 25.06	24.50 24.50	846.78 934.35

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

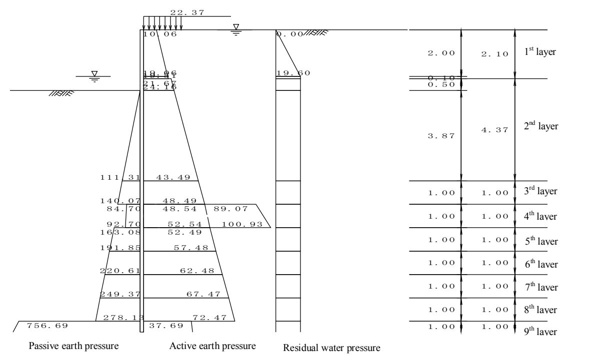
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



2.35

3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.00	Sandy Soil	10.0	30.0	―― ――	22.37 42.37	0.00 19.60	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	―― ――
2	2.00～ 2.10	Sandy Soil	10.0	30.0	―― ――	42.37 43.37	19.60 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	―― ――
3	2.10～ 2.60	Sandy Soil	10.0	27.0	―― ――	43.37 48.37	20.58 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
4	2.60～ 6.47	Sandy Soil	10.0	27.0	―― ――	48.37 87.07	25.48 63.41	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
5	6.47～ 7.47	Sandy Soil	10.0	27.0	―― ――	87.07 97.07	63.41 73.21	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
6	7.47～ 8.47	Clayey Soil	8.0	―	18.0 18.0	97.07 105.07	73.21 83.01	0.200 0.200	11.31 11.31	―― ――	―― ――	30.11 28.38
7	8.47～ 9.47	Sandy Soil	10.0	27.0	―― ――	105.07 115.07	83.01 92.81	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
8	9.47～ 10.47	Sandy Soil	10.0	27.0	―― ――	115.07 125.07	92.81 102.61	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
9	10.47～ 11.47	Sandy Soil	10.0	27.0	―― ――	125.07 135.07	102.61 112.41	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
10	11.47～ 12.47	Sandy Soil	10.0	27.0	―― ――	135.07 145.07	112.41 122.21	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
11	12.47～ 13.47	Sandy Soil	10.0	45.0	―― ――	145.07 155.07	122.21 132.01	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	―― ――

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 6.47	Sandy soil	10.00	27.0	―― ――	0.000 38.700	0.00 37.93	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	6.47～ 7.47	Sandy soil	10.00	27.0	―― ――	38.700 48.700	37.93 47.73	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	7.47～ 8.47	Clayey soil	8.00	27.0	18.0 18.0	48.700 56.700	47.73 57.53	0.200 0.200	11.31 11.31	―― ――	―― ――
7	8.47～ 9.47	Sandy soil	10.00	27.0	―― ――	56.700 66.700	57.53 67.33	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	9.47～ 10.47	Sandy soil	10.00	27.0	―― ――	66.700 76.700	67.33 77.13	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
9	10.47～ 11.47	Sandy soil	10.00	27.0	―― ――	76.700 86.700	77.13 86.93	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626

Case: Right Bank No. 05_STA 5+340 - 5+414

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
10	11.47～ 12.47	Sandy soil	10.00	27.0	―― ――	86.700 96.700	86.93 96.73	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
11	12.47～ 13.47	Sandy soil	10.00	45.0	―― ――	96.700 106.700	96.73 106.53	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.00	10.06 19.06	―― ――	10.06 19.06	0.00 19.60	―― ――
2	2.00～ 2.10	19.06 19.51	―― ――	19.06 19.51	19.60 19.60	―― ――
3	2.10～ 2.60	21.67 24.16	―― ――	21.67 24.16	19.60 19.60	―― ――
4	2.60～ 6.47	24.16 43.49	―― ――	24.16 43.49	19.60 19.60	0.00 111.31
5	6.47～ 7.47	43.49 48.49	―― ――	43.49 48.49	19.60 19.60	111.31 140.07
6	7.47～ 8.47	89.07 100.93	48.54 52.54	89.07 100.93	19.60 19.60	84.70 92.70
7	8.47～ 9.47	52.49 57.48	―― ――	52.49 57.48	19.60 19.60	163.08 191.85
8	9.47～ 10.47	57.48 62.48	―― ――	57.48 62.48	19.60 19.60	191.85 220.61
9	10.47～ 11.47	62.48 67.47	―― ――	62.48 67.47	19.60 19.60	220.61 249.37
10	11.47～ 12.47	67.47 72.47	―― ――	67.47 72.47	19.60 19.60	249.37 278.13
11	12.47～ 13.47	37.69 40.29	―― ――	37.69 40.29	19.60 19.60	756.69 834.94

Case: Right Bank No. 05_STA 5+340 - 5+414

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

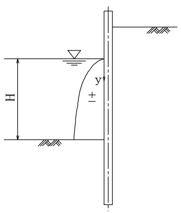
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.00 2.60	0.00 0.60	0.00 1.03

$$p_{dw} = \pm\frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated

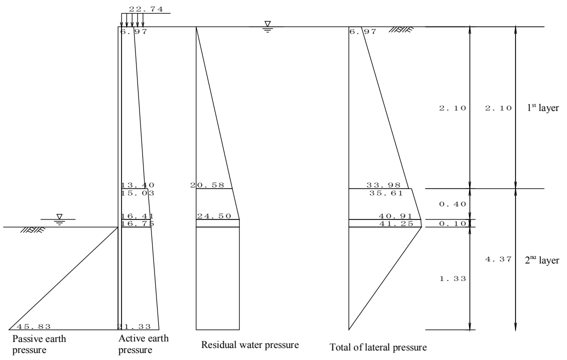


Case: Right Bank No. 05_STA 5+340 - 5+414

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

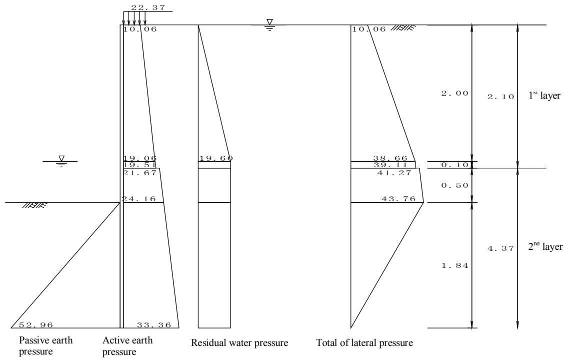


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	6.97 13.40	0.00 20.58	―― ――	6.97 33.98
2	2.10～ 2.50	15.03 16.41	20.58 24.50	―― ――	35.61 40.91
3	2.50～ 2.60	16.41 16.75	24.50 24.50	―― ――	40.91 41.25
4	2.60～ 3.93	16.75 21.33	24.50 24.50	0.00 45.83	41.25 0.00
5	3.93～ 6.47	21.33 30.05	24.50 24.50	45.83 133.23	0.00 -78.67

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.33 m (GL -3.93 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.00	10.06 19.06	0.00 19.60	—— ——	10.06 38.66
2	2.00～ 2.10	19.06 19.51	19.60 19.60	—— ——	38.66 39.11
3	2.10～ 2.60	21.67 24.16	19.60 19.60	—— ——	41.27 43.76
4	2.60～ 4.44	24.16 33.36	19.60 19.60	0.00 52.96	43.76 0.00
5	4.44～ 6.47	33.36 43.49	19.60 19.60	52.96 111.31	0.00 -48.22

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.84 m (GL -4.44 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.92			
Section efficiency	μ	=	0.80			
Young's modulus	E	=	200000 Nmm²			
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)			
	I	=	63296 cm⁴ (after reduction by corrosion and section)			
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$			

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	3
4	6.47	3
5	7.47	2
6	8.47	3
7	9.47	4
8	10.47	4
9	11.47	5
10	12.47	5

	Depth (m)	N-value
11	13.47	50
12	20.00	50

5-2 Normal Condition

K_h = 10792 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.382 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.62 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) to 2.62 m depth (GL -6.55 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.93	2.54	3.0	3.0	7.62
2	6.47	0.08	3.0	2.9	0.23
	L = Σh = 2.62			ΣA = 7.85	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{7.85}{2.62}$$

$$= 3.00$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$K_h = 6910 \times N'^{0.406} = 6910 \times 3.00^{0.406} = 10792$ kN/m³

Kh (normal condition) = 10792 kNm³

5-3 Seismic Condition

K_h = 10695 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.381 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.62 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.44 m) and 2.62 m depth (GL -7.06 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.44	2.03	3.0	3.0	6.09
2	6.47	0.59	3.0	2.4	1.61
	L = Σh = 2.62			ΣA = 7.69	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{7.69}{2.62}$$

$$= 2.93$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following;

$K_h = 6910 \times N'^{0.406} = 6910 \times 2.93^{0.406} = 10695$ kN/m³

Kh (seismic condition) = 10695 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	6.97 33.98	7.32 35.68	3.23 2.53	23.64 90.32
2	2.10～ 2.50	0.40	35.61 40.91	7.12 8.18	1.70 1.56	12.09 12.80
3	2.50～ 2.60	0.10	40.91 41.25	2.05 2.06	1.40 1.36	2.86 2.81
4	2.60～ 3.93	1.33	41.25 0.00	27.46 0.00	0.89 0.44	24.37 0.00
				ΣP = 89.87	ΣM =	168.90

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load		P_t	=	0.0 kNm
	depth to acting position	H_t	=	0.00 m
	moment	M_m	=	0.0 kN-m/m
	depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping		H	=	2.60 m
Depth of Imaginary riverbed from riverbed		L_k	=	1.33 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 0.00$ kN-m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{168.90}{89.87} = 1.88 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.00	2.00	10.06 38.66	10.06 38.66	3.77 3.11	37.99 120.16
2	2.00～ 2.10	0.10	38.66 39.11	1.93 1.96	2.41 2.37	4.65 4.64
3	2.10～ 2.60	0.50	41.27 43.76	10.32 10.94	2.17 2.01	22.43 21.97
				ΣP = 114.16		ΣM = 261.30

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.7 kN/m
depth to acting position	H_t	=	0.40 m
moment	M_m	=	1.1 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.84 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 12.01 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00～ 2.60	0.60	0.0 1.0	0.00 0.31	2.24 2.04	0.00 0.63
					ΣP_{dw} = 0.31	ΣM_{dw} = 0.63

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{273.95}{117.17} = 2.34 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266 x 10^5

$$\beta = \sqrt[4]{K_h \cdot B}$$

$$\sigma = \frac{M_{max}}{Z} = \frac{285.33 \times 10^6}{3514 \times 10^3} = 81 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2$$

$2\beta h_0$ $1+2\beta h_0$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	10792 kN/m³
calculated value	β	=	0.38209 m⁻¹
resultant earth force (lateral)	P_0	=	89.87 kN/m
height of acting position of load	h_0	=	1.88 m
moment	M_0	=	168.90 kN·m/m

in consideration of ϕ_m = 1.242,

maximum moment	M_{max}	=	209.79 kN·m/m
depth of generated position of M_{max}	l_m	=	1.019 m
depth of 1st fixed point	l_i	=	3.075 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	10695 kN/m³
calculated value	β	=	0.38122 m⁻¹
resultant earth force (lateral)	P_0	=	117.17 kN/m
height of acting position of load	h_0	=	2.34 m
moment	M_0	=	273.95 kN·m/m

in consideration of ϕ_m = 1.175,

maximum moment	M_{max}	=	321.81 kN·m/m
depth of generated position of M_{max}	l_m	=	0.905 m
depth of 1st fixed point	l_i	=	2.965 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm³ (original condition)
	Z	=	3514 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{209.79 \times 10^6}{3514 \times 10^3} = 60 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{321.81 \times 10^6}{3514 \times 10^3} = 92 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

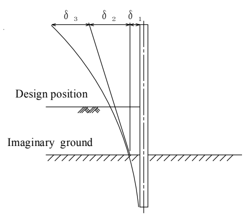
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.23 2.53	0.822 0.644	0.245 0.163	7.32 35.68	1.795 5.809
2	2.10～ 2.50	1.70 1.56	0.432 0.398	0.080 0.069	7.12 8.18	0.569 0.562
3	2.50～ 2.60	1.40 1.36	0.356 0.347	0.056 0.053	2.05 2.06	0.114 0.110
4	2.60～ 3.93	0.89 0.44	0.226 0.113	0.024 0.006	27.46 0.00	0.647 0.000
					ΣQ =	9.605

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha) \times \alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2EI\beta^3} = \frac{(1+0.3821 \times 1.88) \times 89.87}{2 \times 2.00 \times 10^8 \times 63296 \times 10^{-8} \times 0.3821^3} = 0.01093 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2EI\beta^2} \times (H+L_k) = \frac{(1+2 \times 0.3821 \times 1.88) \times 89.87}{2 \times 2.00 \times 10^8 \times 63296 \times 10^{-8} \times 0.3821^2} \times (2.60+1.33) = 0.02329 \text{ m}$$

$$\delta_3 = \frac{Q \times (H+L_k)^3}{EI} = \frac{9.61 \times (2.60+1.33)^3}{2.00 \times 10^8 \times 63296 \times 10^{-8}} = 0.00461 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= 0.01093 + 0.02329 + 0.00461$$
$$= 0.03883 \text{ m}$$
$$= 38.83 \leqq \delta a = 50.00 \text{ mm (ok)}$$

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.00	3.77 3.11	0.850 0.700	0.259 0.188	10.06 38.66	2.605 7.258
2	2.00～ 2.10	2.41 2.37	0.542 0.535	0.120 0.117	1.93 1.96	0.233 0.230
3	2.10～ 2.60	2.17 2.01	0.490 0.452	0.100 0.087	10.32 10.94	1.035 0.950
4	2.60～ 4.44	1.23 0.61	0.276 0.138	0.035 0.009	40.29 0.00	1.397 0.000
						ΣQ = 13.707

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

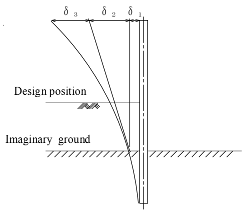
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.00～ 2.60	2.24 2.04	0.505 0.460	0.106 0.089	0.00 0.31	0.000 0.028
						EQ_{dw} = 0.028

Therefore, modulus of deformation Q is calculated as below

Q = 14.486 + 0.028 = 14.514

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3812\times2.34)\times117.17}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3812^3} = 0.01580 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3812\times2.34)\times117.17}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3812^2}\times(2.60+1.84) = 0.03935 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{14.51\times(2.60+1.84)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.01004 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01580 + 0.03935 + 0.01013

= 0.06528 m

= 65.28 ≦ δa = 75.00 mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720 x 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 10792 kN/m^3

Calculated value β = 0.35390 m^{-1}

Penetration length of SSP $D = 1.33 + \dfrac{3}{0.354} = 9.81$ m

Whole length of SSP L = 2.60 − 0.40 + 9.81 = 12.01 m

7-1-2 Seismic Co

Modules of lateral subgrade reaction K_h = 10695 kN/m^3

Calculated value β = 0.35310 m^{-1}

Penetration length of SSP $D = 1.84 + \dfrac{3}{0.353} = 10.34$ m

Whole length of SSP L = 2.60 − 0.40 + 10.34 = 12.54 m

Therefore, whole length of SSP is set as 13.00 m in consideration of round unit of SSP length.

8 Calculation Result

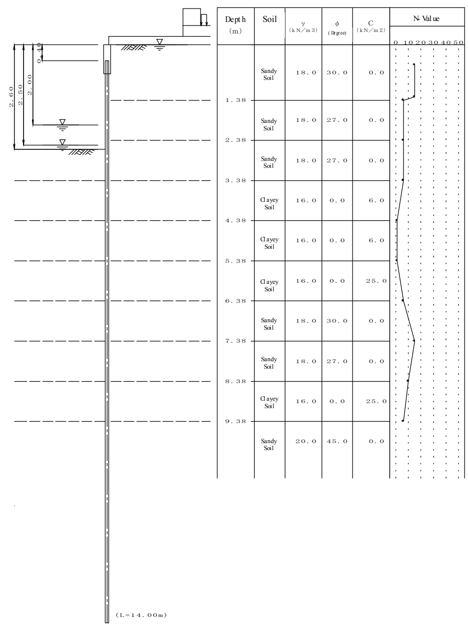
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		209.79	321.81
Stress intensity	σ (N/mm^2)		60 (180)	92 (270)
Lateral displacement	δ (mm)		38.83 (50.0)	65.28 (75.0)
Penetration depth	D (m)		9.81	10.34
Whole length of SSP	L (m)	13.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 06_STA 5+545 - 5+639

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.50 m (Normal Condition)
	L_{wp}'	=	2.00 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.1 kNm	(Normal Condition)
		Pt'	=	6.2 kNm	(Seismic Condition)
	Depth of acting point	H	=	-0.22 m	(Normal Condition)
		H'	=	-0.01 m	(Seismic Condition)
	Moment	M_m	=	0.5 kN·m/m	(Normal Condition)
		M_m'	=	5.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.30	15
3	1.38	6
4	2.38	6
5	3.38	6
6	4.38	1
7	5.38	1
8	6.38	6
9	7.38	15
10	8.38	10

No	Depth (m)	N-Value
11	9.38	6
12	10.38	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

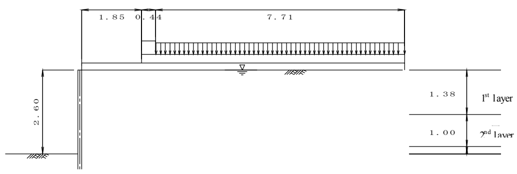
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	1.38	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.38	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	3.38	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.38	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
5	5.38	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
6	6.38	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
7	7.38	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
8	8.38	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
9	9.38	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
10	10.38	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kNm³)	φ (degree)	C (kNm²)	Normal	Seismic
1	Sandy soil	0.00	0.00	10.00	10.00	0.21	18.0	30.0	0.0	auto	auto
2	Sandy soil	1.85	1.85	10.00	10.00	0.27	18.0	30.0	0.0	auto	auto
3	Sandy soil	1.85	1.85	2.29	2.29	0.42	24.0	45.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	2.30	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Youne's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 145000 cm^4
Sectional factor Z_0 = 4070 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP lenth 0.50 m

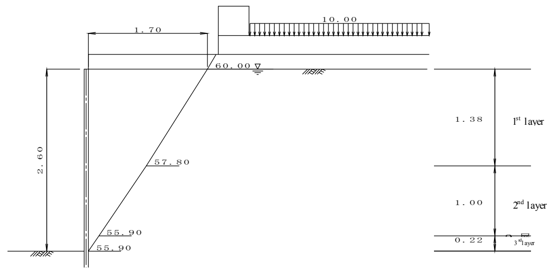
Allowable stress σ_a = 185 Nmm (Normal)
σ_a' = 278 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kNm²)	Σγh (kNm²)	Q (kNm²)	γwhw (kNm²)	Angle of rupture Z (degree)
1	2.60～ 2.38	Sandy Soil	27.0	10.0	0.0	26.00	3.92	25.48	55.90
2	2.38～ 1.38	Sandy Soil	27.0	10.0	0.0	23.80	3.92	23.32	55.90
3	1.38～ 0.00	Sandy Soil	30.0	10.0	0.0	13.80	3.92	13.52	57.80
4		Embankment	30.0	——	0.0	18.72	0.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.22	0.00	0.00	0.15	0.22
2	55.90	1.00	0.15	0.22	0.83	1.22
3	57.80	1.38	0.83	1.22	1.70	2.60
4	60.00	0.21	1.70	2.60	1.82	2.81

Therefore, width of acting load shall be set as 1.70 m

2-1-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	18.0	0.37	6.64
Σ			6.64

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

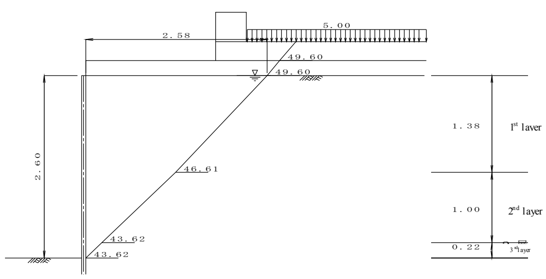
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{6.64 + 0.00 + 0.00}{1.70}$$

$$= 3.92\ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kNm²)	Σγh (kNm²)	Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.38	Sandy Soil	27.0	10.0	0.0	26.00	8.90	25.48	0.200	11.31	43.62
2	2.38～ 1.38	Sandy Soil	27.0	10.0	0.0	23.80	8.90	23.32	0.200	11.31	43.62
3	1.38～ 0.00	Sandy Soil	30.0	10.0	0.0	13.80	8.90	13.52	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	18.72	0.00	0.00	0.200	11.31	49.60
5		Embankment	30.0	——	0.0	14.94	0.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.22	0.00	0.00	0.23	0.22
2	43.62	1.00	0.23	0.22	1.28	1.22
3	46.61	1.38	1.28	1.22	2.58	2.60
4	49.60	0.21	2.58	2.60	2.76	2.81
5	49.60	0.27	2.76	2.81	2.99	3.08

Therefore, width of acting load shall be set as 2.58 m

2-2-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	18.0	0.56	10.11
2	18.0	0.28	5.00
3	24.0	0.18	4.44
Σ			19.54

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kNm²)	l (m)	Q X l (kNm)
1	5.0	0.69	3.47
Σ			3.47

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

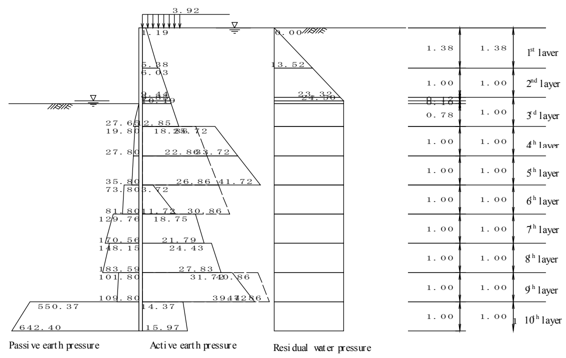
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{19.54 + 3.47 + 0.00}{2.58}$$

$$= 8.90 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 1.38	Sandy soil	10.0	30.0	—— ——	3.915 17.715	0.30847 0.30847	0.30378 0.30378
2	1.38~ 2.38	Sandy soil	10.0	27.0	—— ——	17.715 27.715	0.34585 0.34585	0.34060 0.34060
3	2.38~ 2.50	Sandy soil	10.0	27.0	—— ——	27.715 28.915	0.34585 0.34585	0.34060 0.34060
4	2.50~ 2.60	Sandy soil	10.0	27.0	—— ——	28.915 29.915	0.34585 0.34585	0.34060 0.34060
5	2.60~ 3.38	Sandy soil	10.0	27.0	—— ——	29.915 37.715	0.34585 0.34585	0.34060 0.34060
6	3.38~ 4.38	Clayey soil	8.0	—	6.0 6.0	37.715 45.715	—— ——	—— ——
7	4.38~ 5.38	Clayey soil	8.0	—	6.0 6.0	45.715 53.715	—— ——	—— ——
8	5.38~ 6.38	Clayey soil	8.0	—	25.0 25.0	53.715 61.715	—— ——	—— ——
9	6.38~ 7.38	Sandy soil	10.0	30.0	—— ——	61.715 71.715	0.30847 0.30847	0.30378 0.30378
10	7.38~ 8.38	Sandy soil	10.0	27.0	—— ——	71.715 81.715	0.34585 0.34585	0.34060 0.34060
11	8.38~ 9.38	Clayey soil	8.0	—	25.0 25.0	81.715 89.715	—— ——	—— ——
12	9.38~ 10.38	Sandy soil	10.0	45.0	—— ——	89.715 99.715	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
5	2.60~ 3.38	Sandy soil	10.0	27.0	—— ——	0.000 7.800	3.59892 3.59892	3.54425 3.54425
6	3.38~ 4.38	Clayey soil	8.0	0.0	6.0 6.0	7.800 15.800	—— ——	—— ——
7	4.38~ 5.38	Clayey soil	8.0	0.0	6.0 6.0	15.800 23.800	—— ——	—— ——
8	5.38~ 6.38	Clayey soil	8.0	0.0	25.0 25.0	23.800 31.800	—— ——	—— ——
9	6.38~ 7.38	Sandy soil	10.0	30.0	—— ——	31.800 41.800	4.14330 4.14330	4.08035 4.08035
10	7.38~ 8.38	Sandy soil	10.0	27.0	—— ——	41.800 51.800	3.59892 3.59892	3.54425 3.54425
11	8.38~ 9.38	Clayey soil	8.0	0.0	25.0 25.0	51.800 59.800	—— ——	—— ——
12	9.38~ 10.38	Sandy soil	10.0	45.0	—— ——	59.800 69.800	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 1.38	1.19 5.38	—— ——	1.19 5.38	0.00 13.52	—— ——
2	1.38~ 2.38	6.03 9.44	—— ——	6.03 9.44	13.52 23.32	—— ——
3	2.38~ 2.50	9.44 9.85	—— ——	9.44 9.85	23.32 24.50	—— ——
4	2.50~ 2.60	9.85 10.19	—— ——	9.85 10.19	24.50 24.50	—— ——
5	2.60~ 3.38	10.19 12.85	—— ——	10.19 12.85	24.50 24.50	0.00 27.65
6	3.38~ 4.38	25.72 33.72	18.86 22.86	25.72 33.72	24.50 24.50	19.80 27.80
7	4.38~ 5.38	33.72 41.72	22.86 26.86	33.72 41.72	24.50 24.50	27.80 35.80
8	5.38~ 6.38	3.72 11.72	26.86 30.86	26.86 30.86	24.50 24.50	73.80 81.80
9	6.38~ 7.38	18.75 21.79	—— ——	18.75 21.79	24.50 24.50	129.76 170.56
10	7.38~ 8.38	24.43 27.83	—— ——	24.43 27.83	24.50 24.50	148.15 183.59

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
11	8.38~ 9.38	31.72 39.72	40.86 44.86	40.86 44.86	24.50 24.50	101.80 109.80
12	9.38~ 10.38	14.37 15.97	—— ——	14.37 15.97	24.50 24.50	550.37 642.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

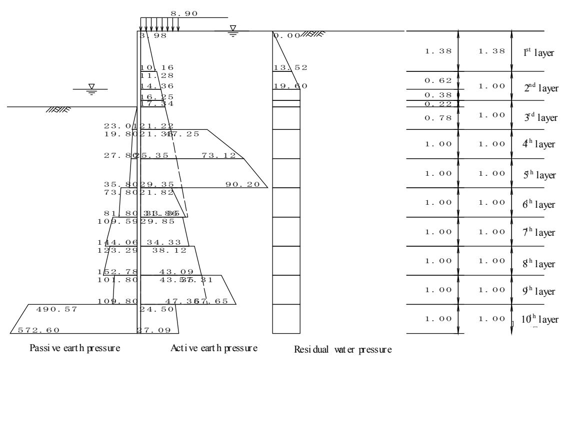
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



2.42

3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 1.38	Sandy Soil	10.0	30.0	— —	8.90 22.70	0.00 13.52	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
2	1.38~ 2.00	Sandy Soil	10.0	27.0	— —	22.70 28.90	13.52 19.60	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
3	2.00~ 2.38	Sandy Soil	10.0	27.0	— —	28.90 32.70	19.60 23.32	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
4	2.38~ 2.60	Sandy Soil	10.0	27.0	— —	32.70 34.90	23.32 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
5	2.60~ 3.38	Sandy Soil	10.0	27.0	— —	34.90 42.70	25.48 33.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
6	3.38~ 4.38	Clayey Soil	8.0	—	6.0 6.0	42.70 50.70	33.12 42.92	0.200 0.200	11.31 11.31	— —	— —	20.51 10.00
7	4.38~ 5.38	Clayey Soil	8.0	—	6.0 6.0	50.70 58.70	42.92 52.72	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
8	5.38~ 6.38	Clayey Soil	8.0	—	25.0 25.0	58.70 66.70	52.72 62.52	0.200 0.200	11.31 11.31	— —	— —	40.50 39.87
9	6.38~ 7.38	Sandy Soil	10.0	30.0	— —	66.70 76.70	62.52 72.32	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
10	7.38~ 8.38	Sandy Soil	10.0	27.0	— —	76.70 86.70	72.32 82.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
11	8.38~ 9.38	Clayey Soil	8.0	—	25.0 25.0	86.70 94.70	82.12 91.92	0.200 0.200	11.31 11.31	— —	— —	38.16 37.42
12	9.38~ 10.38	Sandy Soil	10.0	45.0	— —	94.70 104.70	91.92 101.72	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below
$\delta = 10.00$、 $\beta = 0.00$、 $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60~ 3.38	Sandy soil	10.00	27.0	— —	0.000 7.800	0.00 7.64	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	3.38~ 4.38	Clayey soil	8.00	0.0	6.0 6.0	7.800 15.800	7.64 17.44	0.200 0.200	11.31 11.31	— —	— —
7	4.38~ 5.38	Clayey soil	8.00	0.0	6.0 6.0	15.800 23.800	17.44 27.24	0.200 0.200	11.31 11.31	— —	— —
8	5.38~ 6.38	Clayey soil	8.00	0.0	25.0 25.0	23.800 31.800	27.24 37.04	0.200 0.200	11.31 11.31	— —	— —
9	6.38~ 7.38	Sandy soil	10.00	30.0	— —	31.800 41.800	37.04 46.84	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
10	7.38~ 8.38	Sandy soil	10.00	27.0	— —	41.800 51.800	46.84 56.64	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
11	8.38~ 9.38	Clayey soil	8.00	0.0	25.0 25.0	51.800 59.800	56.64 66.44	0.200 0.200	11.31 11.31	— —	— —
12	9.38~ 10.38	Sandy soil	10.00	45.0	— —	59.800 69.800	66.44 76.24	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$、 $\beta = 0.00$、 $\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 1.38	3.98 10.16	— —	3.98 10.16	0.00 13.52	— —
2	1.38~ 2.00	11.28 14.36	— —	11.28 14.36	13.52 19.60	— —
3	2.00~ 2.38	14.36 16.25	— —	14.36 16.25	19.60 19.60	— —
4	2.38~ 2.60	16.25 17.34	— —	16.25 17.34	19.60 19.60	— —
5	2.60~ 3.38	17.34 21.22	— —	17.34 21.22	19.60 19.60	0.00 23.01
6	3.38~ 4.38	47.25 73.12	21.35 25.35	47.25 73.12	19.60 19.60	19.80 27.80
7	4.38~ 5.38	73.12 90.20	25.35 29.35	73.12 90.20	19.60 19.60	27.80 35.80
8	5.38~ 6.38	21.82 31.86	29.35 33.35	29.35 33.35	19.60 19.60	73.80 81.80
9	6.38~ 7.38	29.85 34.33	— —	29.85 34.33	19.60 19.60	109.59 144.06
10	7.38~ 8.38	38.12 43.09	— —	38.12 43.09	19.60 19.60	123.29 152.78
11	8.38~ 9.38	57.31 67.65	43.35 47.35	57.31 67.65	19.60 19.60	101.80 109.80
12	9.38~ 10.38	24.50 27.09	— —	24.50 27.09	19.60 19.60	490.57 572.60

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

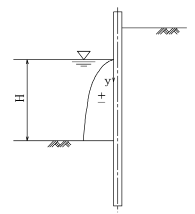
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.00	0.00	0.00
2	2.60	0.60	1.03

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where, Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

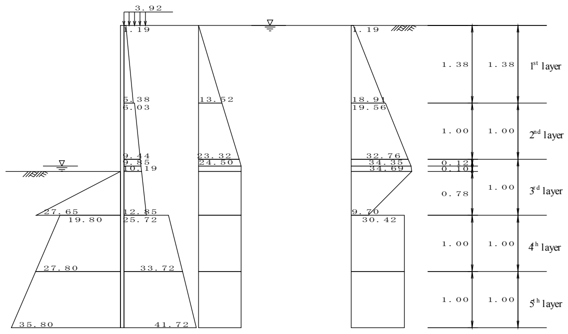
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

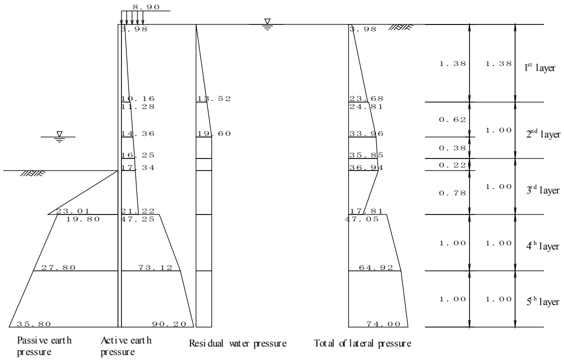


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 1.38	1.19 5.38	0.00 13.52	— —	1.19 18.91
2	1.38~ 2.38	6.03 9.44	13.52 23.32	— —	19.56 32.76
3	2.38~ 2.50	9.44 9.85	23.32 24.50	— —	32.76 34.35
4	2.50~ 2.60	9.85 10.19	24.50 24.50	— —	34.35 34.69
5	2.60~ 3.38	10.19 12.85	24.50 24.50	0.00 27.65	34.69 9.70
6	3.38~ 4.38	25.72 33.72	24.50 24.50	19.80 27.80	30.42 30.42
7	4.38~ 5.38	33.72 41.72	24.50 24.50	27.80 35.80	30.42 30.42
8	5.38~ 6.38	26.86 30.86	24.50 24.50	73.80 81.80	-22.44 -26.44

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.78 m (GL -5.38 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 1.38	3.98 10.16	0.00 13.52	―― ――	3.98 23.68
2	1.38～ 2.00	11.28 14.36	13.52 19.60	―― ――	24.81 33.96
3	2.00～ 2.38	14.36 16.25	19.60 19.60	―― ――	33.96 35.85
4	2.38～ 2.60	16.25 17.34	19.60 19.60	―― ――	35.85 36.94
5	2.60～ 3.38	17.34 21.22	19.60 19.60	0.00 23.01	36.94 17.81
6	3.38～ 4.38	47.25 73.12	19.60 19.60	19.80 27.80	47.05 64.92
7	4.38～ 5.38	73.12 90.20	19.60 19.60	27.80 35.80	64.92 74.00
8	5.38～ 6.38	29.35 33.35	19.60 19.60	73.80 81.80	-24.85 -28.85

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.78 m (GL -5.38 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	145000 cm⁴ (original condition)
	I	=	127600 cm⁴ (after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 127600 \times 10^{8} = 2.552 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.30	15
3	1.38	6
4	2.38	6
5	3.38	6
6	4.38	1
7	5.38	1
8	6.38	6
9	7.38	15
10	8.38	10

	Depth (m)	N-value
11	9.38	6
12	10.38	50

5-2 Normal Condition

K_h = 16641 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.357 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.80 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.38 m) to 2.80 m depth (GL -8.18 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	5.38	1.00	1.0	6.0	3.50
2	6.38	1.00	6.0	15.0	10.50
3	7.38	0.80	15.0	11.0	10.38
	L = Σh = 2.80				ΣA = 24.38

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{24.38}{2.80} = 8.71$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 8.71^{0.406} = 16641$ kN/m³
Kh (normal condition) = 16641 kNm³

5-3 Seismic Condition

K_h = 16641 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.357 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.80 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.38 m) and 2.80 m depth (GL -8.18 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	5.38	1.00	1.0	6.0	3.50
2	6.38	1.00	6.0	15.0	10.50
3	7.38	0.80	15.0	11.0	10.38
	L = Σh = 2.80				ΣA = 24.38

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{24.38}{2.80} = 8.71$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 8.71^{0.406} = 16641$ kN/m³
Kh (seismic condition) = 16641 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 1.38	1.38	1.19 18.91	0.82 13.04	4.92 4.46	4.04 58.18
2	1.38～ 2.38	1.00	19.56 32.76	9.78 16.38	3.67 3.33	35.86 54.61
3	2.38～ 2.50	0.12	32.76 34.35	1.97 2.06	2.96 2.92	5.82 6.02
4	2.50～ 2.60	0.10	34.35 34.69	1.72 1.73	2.85 2.81	4.89 4.88
5	2.60～ 3.38	0.78	34.69 9.70	13.53 3.78	2.52 2.26	34.09 8.55
6	3.38～ 4.38	1.00	30.42 30.42	15.21 15.21	1.67 1.33	25.35 20.28
7	4.38～ 5.38	1.00	30.42 30.42	15.21 15.21	0.67 0.33	10.14 5.07
				ΣP = 125.65		ΣM = 277.76

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.1 kNm
depth to acting position	H_t	=	-0.22 m
moment	M_m	=	0.5 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.78 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 12.26$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{290.02}{127.75} = 2.27 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 1.38	1.38	3.98 23.68	2.75 16.34	4.92 4.46	13.52 72.88
2	1.38~ 2.00	0.62	24.81 33.96	7.69 10.53	3.79 3.59	29.17 37.76
3	2.00~ 2.38	0.38	33.96 35.85	6.45 6.81	3.25 3.13	20.99 21.30
4	2.38~ 2.60	0.22	35.85 36.94	3.94 4.06	2.93 2.85	11.54 11.60
5	2.60~ 3.38	0.78	36.94 17.81	14.41 6.95	2.52 2.26	36.31 15.70
6	3.38~ 4.38	1.00	47.05 64.92	23.52 32.46	1.67 1.33	39.21 43.28
7	4.38~ 5.38	1.00	64.92 74.00	32.46 37.00	0.67 0.33	21.64 12.33
				ΣP = 205.38		ΣM = 387.24

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	6.2 kN/m
depth to acting position	H	=	-0.01 m
moment	M_m	=	5.0 kN·m/m
depth to acting position	H_t	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.78 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 38.42 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.00~ 2.60	0.60	0.0 1.0	0.00 0.31	3.18 2.98	0.00 0.92
				ΣP_{dw} = 0.31		ΣM_{dw} = 0.92

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{426.58}{211.89} = 2.01 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	145000 cm^4 (original condition)
	I	=	127600 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 127600 \times 10^{-8}$		=	2.552×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	16641 kN/m^3
calculated value	β	=	0.35732 m^{-1}
resultant earth force (lateral)	P_0	=	127.75 kN/m
height of acting position of load	h_0	=	2.27 m
moment	M_0	=	290.02 kN·m/m

in consideration of ψ_m = 1.202,

maximum moment	M_{max}	=	348.52 kN·m/m
depth of generated position of M_{max}	l_m	=	1.020 m
depth of 1st fixed point	l_i	=	3.218 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	16641 kN/m^3
calculated value	β	=	0.35732 m^{-1}
resultant earth force (lateral)	P_0	=	211.89 kN/m
height of acting position of load	h_0	=	2.01 m
moment	M_0	=	426.58 kN·m/m

in consideration of ψ_m = 1.241,

maximum moment	M_{max}	=	529.58 kN·m/m
depth of generated position of M_{max}	l_m	=	1.089 m
depth of 1st fixed point	l_i	=	3.287 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	4070 cm^3 (original condition)
	Z	=	3582 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{348.52\times10^6}{3582\times10^3} = 97 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{529.58\times10^6}{3582\times10^3} = 148 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

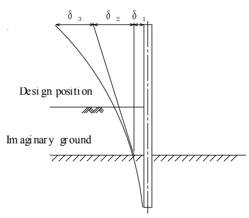
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 1.38	4.92 4.46	0.915 0.829	0.291 0.249	0.82 13.04	0.239 3.244
2	1.38~ 2.38	3.67 3.33	0.682 0.620	0.179 0.152	9.78 16.38	1.755 2.495
3	2.38~ 2.50	2.96 2.92	0.550 0.543	0.124 0.121	1.97 2.06	0.243 0.249
4	2.50~ 2.60	2.85 2.81	0.529 0.523	0.115 0.113	1.72 1.73	0.198 0.196
5	2.60~ 3.38	2.52 2.26	0.468 0.420	0.093 0.076	13.53 3.78	1.252 0.287
6	3.38~ 4.38	1.67 1.33	0.310 0.248	0.043 0.028	15.21 15.21	0.654 0.428
7	4.38~ 5.38	0.67 0.33	0.124 0.062	0.007 0.002	15.21 15.21	0.112 0.029
						ΣQ = 11.381

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3573\times2.27)\times127.75}{2\times2.00\times10^8\times127600\times10^{-8}\times0.3573^3} = 0.00994 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.3573\times2.27)\times127.75}{2\times2.00\times10^8\times127600\times10^{-8}\times0.3573^2} \times (2.60+2.78) = 0.02766 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.38\times(2.60+2.78)^3}{2.00\times10^8\times127600\times10^{-8}} = 0.00694 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI} \times (2L-h) \qquad (L=5.38 \text{ m、} h=L-H_m\text{、} H_m=0.00 \text{ m、ただし} h \leqq L)$$

$$= \frac{0.50\times5.38}{2\times2.00\times10^8\times127600\times10^{-8}} \times (2\times5.38-5.38) = 0.00003 \text{ m}$$

δ_3' is calculated as 0.00045 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.38 m
Horizontal load: P = 2.10
Moment: M = 0.46

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.00994 + 0.02766 + 0.00743$
$= 0.04502$ m
$= 45.02 \leqq \delta a = 50.00$ mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 1.38	4.92 4.46	0.915 0.829	0.291 0.249	2.75 16.34	0.799 4.064
2	1.38~ 2.00	3.79 3.59	0.705 0.667	0.190 0.173	7.69 10.53	1.462 1.820
3	2.00~ 2.38	3.25 3.13	0.605 0.581	0.146 0.136	6.45 6.81	0.942 0.927
4	2.38~ 2.60	2.93 2.85	0.544 0.530	0.121 0.116	3.94 4.06	0.478 0.471
5	2.60~ 3.38	2.52 2.26	0.468 0.420	0.093 0.076	14.41 6.95	1.334 0.527
6	3.38~ 4.38	1.67 1.33	0.310 0.248	0.043 0.028	23.52 32.46	1.012 0.915
7	4.38~ 5.38	0.67 0.33	0.124 0.062	0.007 0.002	32.46 37.00	0.239 0.070
						ΣQ = 15.058

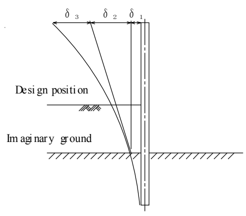
Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.00~ 2.60	3.18 2.98	0.591 0.554	0.140 0.125	0.00 0.31	0.000 0.039
						ΣQ_{dw} = 0.039

Therefore, modulus of deformation Q is calculated as below
$Q = 15.058 + 0.039 = 15.097$

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3573\times 2.01)\times 211.89}{2\times 2.00\times 10^8\times 127600\times 10^{-8}\times 0.3573^3} = 0.01565 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3573\times 2.01)\times 211.89}{2\times 2.00\times 10^8\times 127600\times 10^{-8}\times 0.3573^2}\times(2.60+2.78) = 0.04266 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.10\times(2.60+2.78)^3}{2.00\times 10^8\times 127600\times 10^{-8}} = 0.00921 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00126 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.38 m
Horizontal load: P = 6.20
Moment: M = 0.06

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=5.38 \text{ m、} h=L-H_m\text{、}H_m=0.80 \text{ m、ただし} h\leqq L)$$

$$= \frac{5.00\times 4.58}{2\times 2.00\times 10^8\times 127600\times 10^{-8}}\times(2\times 5.38-4.58) = 0.00028 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01565 + 0.04266 + 0.01075$
$= 0.06906$ m
$= 69.06 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	145000 cm^4 (original condition)
	I	=	145000 cm^4 (after reduction by corrosion and section)
EI = $200000\times 10^3\times 145000\times 10^{-8}$		=	2.900×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 16641$ kN/m^3
Calculated value $\beta = 0.34609$ m^{-1}

Penetration length of SSP $D = 2.78 + \dfrac{3}{0.346} = 11.45$ m
Whole length of SSP $L = 2.60 - 0.40 + 11.45 = 13.65$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 16641$ kN/m^3
Calculated value $\beta = 0.34609$ m^{-1}

Penetration length of SSP $D = 2.78 + \dfrac{3}{0.346} = 11.45$ m
Whole length of SSP $L = 2.60 - 0.40 + 11.45 = 13.65$ m

Therefore, whole length of SSP is set as 14.00 m in consideration of round unit of SSP length.

8 Calculation Result

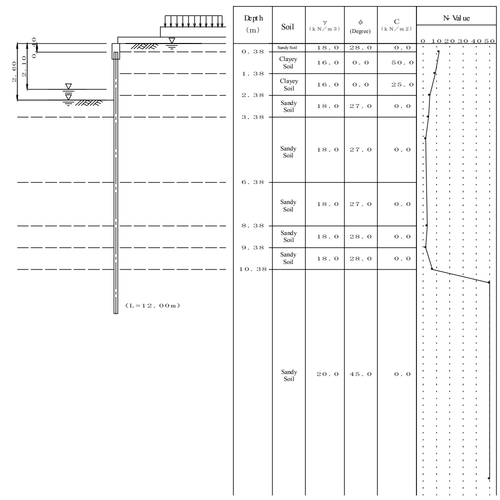
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	145000		
Section modulus	Z (cm^3)	4070		
Maximum bending moment	M_{max} (kN·m/m)		348.52	529.58
Stress intensity	σ (N/mm^2)		97 (185)	148 (278)
Lateral displacement	δ (mm)		45.02 (50.0)	69.06 (75.0)
Penetration depth	D (m)		11.45	11.45
Whole length of SSP	L (m)	14.00		

－Steel Sheet Pile　Design Calculation－

Right Bank No. 07 STA_6+337 - 6+510

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.60 m (Normal Condition)
	L_{wn}'	=	2.10 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

Sandy

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　γ_w = 9.8 kNm^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	1.2 kNm	(Normal Condition)
		P_t'	=	5.4 kNm	(Seismic Condition)
	Depth of acting point	H	=	-0.14 m	(Normal Condition)
		H'	=	0.08 m	(Seismic Condition)
	Moment	M_m	=	0.2 kN·m/m	(Normal Condition)
		M_m'	=	3.9 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　ζ_0 = 10 degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　　K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.38	12			
2	1.38	9			
3	2.38	5			
4	3.38	4			
5	4.38	2			
6	8.38	3			
7	9.38	2			
8	10.38	7			
9	11.00	50			
10	20.00	50			

2.48

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

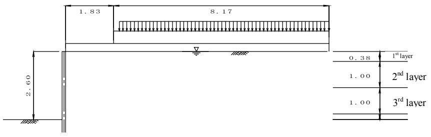
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	0.38	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
2	1.38	C	9.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
3	2.38	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
4	3.38	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	6.38	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	8.38	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	9.38	S	2.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
8	10.38	S	7.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
9	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.00	10.00	10.00	0.30	18.0	30.0	0.0	auto	auto
2	Sandy soil	1.83	1.83	10.00	10.00	0.47	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	2.04	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 63000 cm⁴
Sectional factor Z_0 = 3150 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.91
Corrosion rate (to Z_0) η = 0.91
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

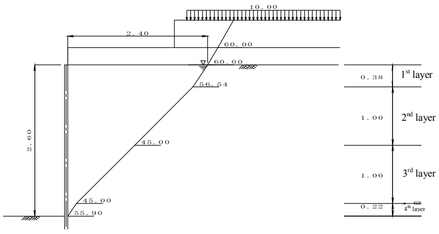
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.38	Sandy Soil	27.0	10.0	0.0	22.00	12.05	25.48	55.90
2	2.38～ 1.38	Clayey Soil	0.0	10.0	25.0	19.80	12.05	23.32	45.00
3	1.38～ 0.38	Clayey Soil	0.0	10.0	50.0	11.80	12.05	13.52	45.00
4	0.38～ 0.00	Sandy Soil	28.0	10.0	0.0	3.80	12.05	3.72	56.54
5		Embankment	30.0	——	0.0	13.86	10.00	0.00	60.00
6		Embankment	30.0	——	0.0	8.46	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.22	0.00	0.00	0.15	0.22
2	45.00	1.00	0.15	0.22	1.15	1.22
3	45.00	1.00	1.15	1.22	2.15	2.22
4	56.54	0.38	2.15	2.22	2.40	2.60
5	60.00	0.30	2.40	2.60	2.57	2.90
6	60.00	0.47	2.57	2.90	2.84	3.37

Therefore, width of acting load shall be set as 2.40 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.75	13.43
2	18.0	0.41	7.44
Σ			20.86

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	0.80	8.05
Σ			8.05

Q surcharge load
l : width of surcharge load set by line of active rupture

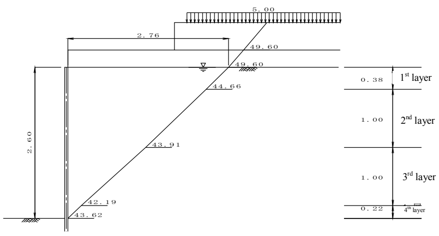
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{20.86 + 8.05 + 0.00}{2.40}$$

$= 12.05$ kN/m²

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.38	Sandy Soil	27.0	10.0	0.0	22.00	12.38	25.48	0.200	11.31	43.62
2	2.38～ 1.38	Clayey Soil	0.0	10.0	25.0	19.80	12.38	23.32	0.200	11.31	42.19
3	1.38～ 0.38	Clayey Soil	0.0	10.0	50.0	11.80	12.38	13.52	0.200	11.31	43.91
4	0.38～ 0.00	Sandy Soil	28.0	10.0	0.0	3.80	12.38	3.72	0.200	11.31	44.66
5		Embankment	30.0	——	0.0	13.86	5.00	0.00	0.200	11.31	49.60
6		Embankment	30.0	——	0.0	8.46	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where.
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.22	0.00	0.00	0.23	0.22
2	42.19	1.00	0.23	0.22	1.33	1.22
3	43.91	1.00	1.33	1.22	2.37	2.22
4	44.66	0.38	2.37	2.22	2.76	2.60
5	49.60	0.30	2.76	2.60	3.01	2.90
6	49.60	0.47	3.01	2.90	3.41	3.37

Therefore, width of acting load shall be set as 2.76 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	0.87	15.58
2	18.0	0.65	11.70
Σ			27.27

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	1.37	6.86
Σ			6.86

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

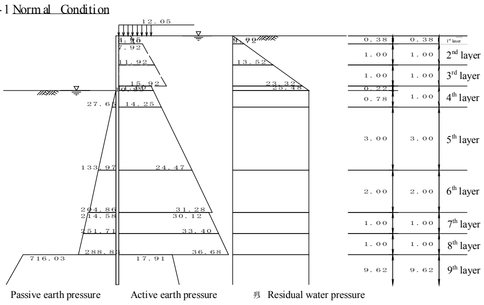
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{27.27 + 6.86 + 0.00}{2.76}$$

$$= 12.38 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 0.38	Sandy soil	10.0	28.0	—— ——	12.046 15.846	0.33303 0.33303	0.32798 0.32798
2	0.38~ 1.38	Clayey soil	8.0	—	50.0 50.0	15.846 23.846	—— ——	—— ——
3	1.38~ 2.38	Clayey soil	8.0	—	25.0 25.0	23.846 31.846	—— ——	—— ——
4	2.38~ 2.60	Sandy soil	10.0	27.0	—— ——	31.846 34.046	0.34585 0.34585	0.34060 0.34060
5	2.60~ 3.38	Sandy soil	10.0	27.0	—— ——	34.046 41.846	0.34585 0.34585	0.34060 0.34060
6	3.38~ 6.38	Sandy soil	10.0	27.0	—— ——	41.846 71.846	0.34585 0.34585	0.34060 0.34060
7	6.38~ 8.38	Sandy soil	10.0	27.0	—— ——	71.846 91.846	0.34585 0.34585	0.34060 0.34060
8	8.38~ 9.38	Sandy soil	10.0	28.0	—— ——	91.846 101.846	0.33303 0.33303	0.32798 0.32798
9	9.38~ 10.38	Sandy soil	10.0	28.0	—— ——	101.846 111.846	0.33303 0.33303	0.32798 0.32798
10	10.38~ 20.00	Sandy soil	10.0	45.0	—— ——	111.846 208.046	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
5	2.60~ 3.38	Sandy soil	10.0	27.0	—— ——	0.000 7.800	3.59892 3.59892	3.54425 3.54425
6	3.38~ 6.38	Sandy soil	10.0	27.0	—— ——	7.800 37.800	3.59892 3.59892	3.54425 3.54425
7	6.38~ 8.38	Sandy soil	10.0	27.0	—— ——	37.800 57.800	3.59892 3.59892	3.54425 3.54425
8	8.38~ 9.38	Sandy soil	10.0	28.0	—— ——	57.800 67.800	3.76978 3.76978	3.71251 3.71251
9	9.38~ 10.38	Sandy soil	10.0	28.0	—— ——	67.800 77.800	3.76978 3.76978	3.71251 3.71251
10	10.38~ 20.00	Sandy soil	10.0	45.0	—— ——	77.800 174.000	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 0.38	3.95 5.20	—— ——	3.95 5.20	0.00 3.72	—— ——
2	0.38~ 1.38	-84.15 -76.15	7.92 11.92	7.92 11.92	3.72 13.52	—— ——
3	1.38~ 2.38	-26.15 -18.15	11.92 15.92	11.92 15.92	13.52 23.32	—— ——
4	2.38~ 2.60	10.85 11.60	—— ——	10.85 11.60	23.32 25.48	—— ——
5	2.60~ 3.38	11.60 14.25	—— ——	11.60 14.25	25.48 25.48	0.00 27.65
6	3.38~ 6.38	14.25 24.47	—— ——	14.25 24.47	25.48 25.48	27.65 133.97
7	6.38~ 8.38	24.47 31.28	—— ——	24.47 31.28	25.48 25.48	133.97 204.86
8	8.38~ 9.38	30.12 33.40	—— ——	30.12 33.40	25.48 25.48	214.58 251.71
9	9.38~ 10.38	33.40 36.68	—— ——	33.40 36.68	25.48 25.48	251.71 288.83
10	10.38~ 20.00	17.91 33.32	—— ——	17.91 33.32	25.48 25.48	716.03 1601.41

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = \left[K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}\right] \cdot \cos\delta$

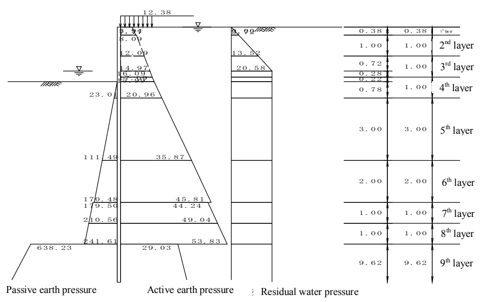
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = \left[K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}\right] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 0.38	Sandy Soil	10.0	28.0	—— ——	12.38 16.18	0.00 3.72	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
2	0.38~ 1.38	Clayey Soil	8.0	—	50.0 50.0	16.18 24.18	3.72 13.52	0.200 0.200	11.31 11.31	—— ——	—— ——	44.16 43.91
3	1.38~ 2.10	Clayey Soil	8.0	—	25.0 25.0	24.18 29.94	13.52 20.58	0.200 0.200	11.31 11.31	—— ——	—— ——	42.74 42.35
4	2.10~ 2.38	Clayey Soil	8.0	—	25.0 25.0	29.94 32.18	20.58 23.32	0.200 0.200	11.31 11.31	—— ——	—— ——	42.35 42.19
5	2.38~ 2.60	Sandy Soil	10.0	27.0	—— ——	32.18 34.38	23.32 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	2.60~ 3.38	Sandy Soil	10.0	27.0	—— ——	34.38 42.18	25.48 33.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	3.38~ 6.38	Sandy Soil	10.0	27.0	—— ——	42.18 72.18	33.12 62.52	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
8	6.38～ 8.38	Sandy Soil	10.0	27.0	—— ——	72.18 92.18	62.52 82.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
9	8.38～ 9.38	Sandy Soil	10.0	28.0	—— ——	92.18 102.18	82.12 91.92	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
10	9.38～ 10.38	Sandy Soil	10.0	28.0	—— ——	102.18 112.18	91.92 101.72	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
11	10.38～ 20.00	Sandy Soil	10.0	45.0	—— ——	112.18 208.38	101.72 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
6	2.60～ 3.38	Sandy soil	10.00	27.0	—— ——	0.000 7.800	0.00 7.64	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	3.38～ 6.38	Sandy soil	10.00	27.0	—— ——	7.800 37.800	7.64 37.04	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
8	6.38～ 8.38	Sandy soil	10.00	27.0	—— ——	37.800 57.800	37.04 56.64	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
9	8.38～ 9.38	Sandy soil	10.00	28.0	—— ——	57.800 67.800	56.64 66.44	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
10	9.38～ 10.38	Sandy soil	10.00	28.0	—— ——	67.800 77.800	66.44 76.24	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
11	10.38～ 20.00	Sandy soil	10.00	45.0	—— ——	77.800 174.000	76.24 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 0.38	5.94 7.77	—— ——	5.94 7.77	0.00 3.72	—— ——
2	0.38～ 1.38	-80.53 -70.87	8.09 12.09	8.09 12.09	3.72 13.52	—— ——

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
3	1.38～ 2.10	-20.74 -13.70	12.09 14.97	12.09 14.97	13.52 20.58	—— ——
4	2.10～ 2.38	-13.70 -10.96	14.97 16.09	14.97 16.09	20.58 20.58	—— ——
5	2.38～ 2.60	15.99 17.09	—— ——	15.99 17.09	20.58 20.58	—— ——
6	2.60～ 3.38	17.09 20.96	—— ——	17.09 20.96	20.58 20.58	0.00 23.01
7	3.38～ 6.38	20.96 35.87	—— ——	20.96 35.87	20.58 20.58	23.01 111.49
8	6.38～ 8.38	35.87 45.81	—— ——	35.87 45.81	20.58 20.58	111.49 170.48
9	8.38～ 9.38	44.24 49.04	—— ——	44.24 49.04	20.58 20.58	179.50 210.56
10	9.38～ 10.38	49.04 53.83	—— ——	49.04 53.83	20.58 20.58	210.56 241.61
11	10.38～ 20.00	29.03 53.92	—— ——	29.03 53.92	20.58 20.58	638.23 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

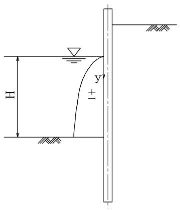
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



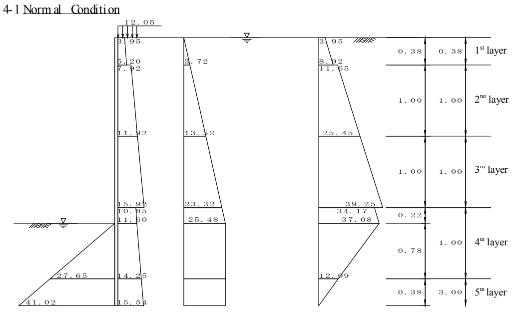
Passive earth pressure   Active earth pressure   Residual water pressure   Total of lateral pressure

2.51

4 Imaginary Riverbed

Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



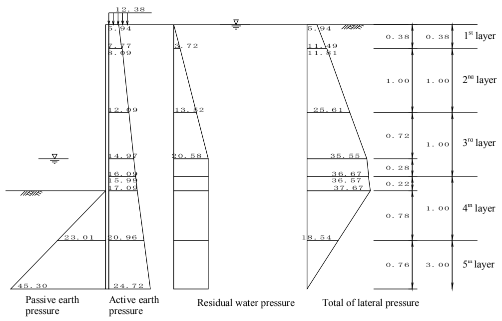
Passive earth pressure   Active earth pressure   Residual water pressure   Total of lateral pressure

	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 0.38	3.95 5.20	0.00 3.72	—— ——	3.95 8.92
2	0.38～ 1.38	7.92 11.92	3.72 13.52	—— ——	11.65 25.45
3	1.38～ 2.38	11.92 15.92	13.52 23.32	—— ——	25.45 39.25
4	2.38～ 2.60	10.85 11.60	23.32 25.48	—— ——	34.17 37.08
5	2.60～ 3.38	11.60 14.25	25.48 25.48	0.00 27.65	37.08 12.09
6	3.38～ 3.76	14.25 15.54	25.48 25.48	27.65 41.02	12.09 0.00
7	3.76～ 6.38	15.54 24.47	25.48 25.48	41.02 133.97	0.00 -84.02

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.16 m (GL -3.76 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 0.38	5.94 7.77	0.00 3.72	—— ——	5.94 11.49
2	0.38~ 1.38	8.09 12.09	3.72 13.52	—— ——	11.81 25.61
3	1.38~ 2.10	12.09 14.97	13.52 20.58	—— ——	25.61 35.55
4	2.10~ 2.38	14.97 16.09	20.58 20.58	—— ——	35.55 36.67
5	2.38~ 2.60	15.99 17.09	20.58 20.58	—— ——	36.57 37.67
6	2.60~ 3.38	17.09 20.96	20.58 20.58	0.00 23.01	37.67 18.54
7	3.38~ 4.14	20.96 24.72	20.58 20.58	23.01 45.30	18.54 0.00
8	4.14~ 6.38	24.72 35.87	20.58 20.58	45.30 111.49	0.00 -55.04

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.54 m (GL -4.14 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	63000 cm⁴(original condition)
	I	=	45864 cm⁴(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 45864 \times 10^{-8} = 9.173 \times 10^4$

	Depth (m)	N-value
1	0.38	12
2	1.38	9
3	2.38	5
4	3.38	4
5	4.38	2
6	8.38	3
7	9.38	2
8	10.38	7
9	11.00	50
10	20.00	50

5-2 Normal Condition

K_h = 9741 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.404\ m^{-1}$

$$L = \frac{1}{\beta} = 2.48\ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.76 m) to 2.48 m depth (GL -6.23 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.76	0.62	3.2	2.0	1.63
2	4.38	1.85	2.0	2.5	4.14
	L = Σh = 2.48				ΣA = 5.77

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{5.77}{2.48}$

$= 2.33$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 2.33^{0.406} = 9741\ kN/m^3$$

Kh (normal condition) = 9741 kNm³

5-3 Seismic Condition

K_h = 9649 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.403\ m^{-1}$

$$L = \frac{1}{\beta} = 2.48\ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.14 m) and 2.48 m depth (GL -6.62 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.14	0.24	2.5	2.0	0.55
2	4.38	2.24	2.0	2.6	5.10
	L = Σh = 2.48				ΣA = 5.65

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{5.65}{2.48}$

$= 2.28$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 2.28^{0.406} = 9649\ kN/m^3$$

Kh (seismic condition) = 9649 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 0.38	0.38	3.95 8.92	0.75 1.69	3.63 3.50	2.73 5.94
2	0.38~ 1.38	1.00	11.65 25.45	5.82 12.72	3.04 2.71	17.73 34.49
3	1.38~ 2.38	1.00	25.45 39.25	12.72 19.62	2.04 1.71	26.01 33.57
4	2.38~ 2.60	0.22	34.17 37.08	3.76 4.08	1.30 1.23	4.90 5.02
5	2.60~ 3.38	0.78	37.08 12.09	14.46 4.71	0.90 0.64	12.97 3.00
6	3.38~ 3.76	0.38	12.09 0.00	2.28 0.00	0.25 0.13	0.57 0.00
				ΣP = 82.63		ΣM = 146.93

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	1.2 kNm
depth to acting position	H_t	=	-0.14 m
moment	M_m	=	0.2 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.16 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 4.88$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{151.80}{83.83} = 1.81\ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 0.38	0.38	5.94 11.49	1.13 2.18	4.01 3.88	4.53 8.48
2	0.38~ 1.38	1.00	11.81 25.61	5.91 12.81	3.42 3.09	20.22 39.56
3	1.38~ 2.10	0.72	25.61 35.55	9.22 12.80	2.52 2.28	23.20 29.13

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
4	2.10～ 2.38	0.28	35.55 36.67	4.98 5.13	1.94 1.85	9.67 9.49
5	2.38～ 2.60	0.22	36.57 37.67	4.02 4.14	1.68 1.61	6.77 6.67
6	2.60～ 3.38	0.78	37.67 18.54	14.69 7.23	1.28 1.02	18.74 7.34
7	3.38～ 4.14	0.76	18.54 0.00	7.00 0.00	0.50 0.25	3.53 0.00
				ΣP = 91.25		ΣM = 187.31

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	5.4 kN/m
depth to acting position	H	=	0.08 m
moment	M_m	=	3.9 kN·m/m
depth to acting position	H_t	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.54 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 25.80$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10～ 2.60	0.50	0.0 0.9	0.00 0.21	1.87 1.70	0.00 0.37
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.37

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{213.48}{96.86} = 2.20 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	45864 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 45864 \times 10^{-8}$		=	9.173×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	9741 kN/m^3
calculated value	β	=	0.40366 m^{-1}
resultant earth force (lateral)	P_0	=	83.83 kN/m
height of acting position of load	h_0	=	1.81 m
moment	M_0	=	151.80 kN·m/m

in consideration of $\psi_m = 1.236$,

maximum moment	M_{max}	=	187.60 kN·m/m
depth of generated position of M_{max}	l_m	=	0.956 m
depth of 1st fixed point	l_i	=	2.902 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	9649 kN/m^3
calculated value	β	=	0.40270 m^{-1}
resultant earth force (lateral)	P_0	=	96.86 kN/m
height of acting position of load	h_0	=	2.20 m
moment	M_0	=	213.48 kN·m/m

in consideration of $\psi_m = 1.176$,

maximum moment	M_{max}	=	251.02 kN·m/m
depth of generated position of M_{max}	l_m	=	0.859 m
depth of 1st fixed point	l_i	=	2.809 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	1.00
Module of section	Z_0	=	31500 cm^3 (original condition)
	Z	=	2867 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{187.60\times10^6}{2867\times10^3} = 65 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{251.02\times10^6}{2867\times10^3} = 88 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

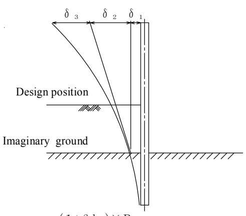
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.38	3.63 3.50	0.966 0.933	0.316 0.300	0.75 1.69	0.238 0.508
2	0.38～ 1.38	3.04 2.71	0.810 0.721	0.240 0.198	5.82 12.72	1.395 2.515
3	1.38～ 2.38	2.04 1.71	0.544 0.455	0.121 0.088	12.72 19.62	1.541 1.725
4	2.38～ 2.60	1.30 1.23	0.347 0.328	0.053 0.048	3.76 4.08	0.200 0.195
5	2.60～ 3.38	0.90 0.64	0.239 0.170	0.026 0.014	14.46 4.71	0.380 0.064
6	3.38～ 3.76	0.25 0.13	0.067 0.033	0.002 0.001	2.28 0.00	0.005 0.000
						ΣQ = 8.765

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3} = \frac{(1+0.4037\times1.81)\times83.83}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4037^3} = 0.01203 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k) = \frac{(1+2\times0.4037\times1.81)\times83.83}{2\times2.00\times10^8\times45864\times10^{-8}\times0.4037^2}\times(2.60+1.16) = 0.02594 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI} = \frac{8.77\times(2.60+1.16)^3}{2.00\times10^8\times45864\times10^{-8}} = 0.00507 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00024 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.76 m
Horizontal load: P = 1.20
Moment: M = 0.17

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI}\times(2L-h) \qquad (L=4.27\text{ m、}h=L-H_m\text{、}H_m=0.80\text{ m、ただし }h\leqq L)$$

$$= \frac{2.20\times3.47}{2\times2.00\times10^8\times39917\times10^{-8}}\times(2\times4.27-3.47) = 0.00024 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01203 + 0.02594 + 0.00533$
$= 0.04330$ m
$= 43.30 \leqq \delta a = 50.00$ mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.38	4.01 3.88	0.969 0.939	0.318 0.303	1.13 2.18	0.359 0.661
2	0.38～ 1.38	3.42 3.09	0.828 0.747	0.248 0.210	5.91 12.81	1.465 2.683
3	1.38～ 2.10	2.52 2.28	0.608 0.550	0.148 0.124	9.22 12.80	1.360 1.582
4	2.10～ 2.38	1.94 1.85	0.470 0.447	0.093 0.085	4.98 5.13	0.463 0.437
5	2.38～ 2.60	1.68 1.61	0.407 0.389	0.072 0.066	4.02 4.14	0.288 0.273
6	2.60～ 3.38	1.28 1.02	0.308 0.246	0.043 0.028	14.69 7.23	0.627 0.200
7	3.38～ 4.14	0.50 0.25	0.122 0.061	0.007 0.002	7.00 0.00	0.050 0.000
					ΣQ =	10.447

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

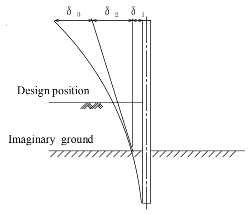
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10～ 2.60	1.87 1.70	0.452 0.412	0.087 0.073	0.00 0.21	0.000 0.016
					ΣQ_{dw} =	0.016

Therefore, modulus of deformation Q is calculated as below

$Q = 12.195 + 0.016 = 12.211$

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4027\times 2.20)\times 96.86}{2\times 2.00\times 10^8\times 45864\times 10^{-8}\times 0.4027^3} = 0.01526\ \mathrm{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4027\times 2.20)\times 96.86}{2\times 2.00\times 10^8\times 45864\times 10^{-8}\times 0.4027^2}\times(2.60+1.54) = 0.03737\ \mathrm{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.21\times(2.60+1.54)^3}{2.00\times 10^8\times 45864\times 10^{-8}} = 0.00942\ \mathrm{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m \cdot h}{2EI}\times(2L-h) \qquad (L=4.27\ \mathrm{m}、h=L-H_m、H_m=0.80\ \mathrm{m}、ただし h \leqq L)$$

$$= \frac{2.20\times 3.47}{2\times 2.00\times 10^8\times 39917\times 10^{-8}}\times(2\times 4.27-3.47) = 0.00024\ \mathrm{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$

$= 0.01526 + 0.03737 + 0.00977$

$= 0.06239$ m

$= 62.39 \leqq \delta_a = 75.00$ mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	63000 cm^4 (after reduction by corrosion and section)
$EI = 200000\times 10^3\times 63000\times 10^{-8}$		=	1.260×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction
Calculated value

$K_h = 9741\ \mathrm{kN/m^3}$

$\beta = 0.37286\ \mathrm{m^{-1}}$

Penetration length of SSP　$D = 1.16 + \frac{3}{0.373} = 9.20$ m

Whole length of SSP　$L = 2.60 - 0.40 + 9.20 = 11.40$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction
Calculated value

$K_h = 9649\ \mathrm{kN/m^3}$

$\beta = 0.37198\ \mathrm{m^{-1}}$

Penetration length of SSP　$D = 1.54 + \frac{3}{0.372} = 9.60$ m

Whole length of SSP　$L = 2.60 - 0.40 + 9.60 = 11.80$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

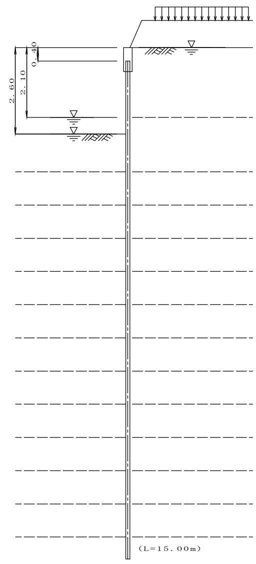
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	63000		
Section modulus	Z (cm^3)	3150		
Maximum bending moment	M_{max} (kN·m/m)		187.60	251.02
Stress intensity	σ (N/mm^2)		65 (180)	88 (270)
Lateral displacement	δ (mm)		43.30 (50.0)	62.39 (75.0)
Penetration depth	D (m)		9.20	9.60
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

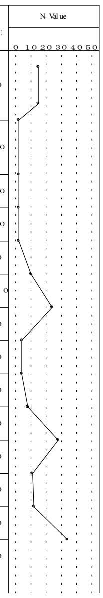
Right Bank No. 8_STA 8+222 - 8+250

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
3.74	Clayey Soil	16.0	0.0	12.0
4.74	Clayey Soil	16.0	0.0	12.0
5.74	Clayey Soil	16.0	0.0	12.0
6.74	Sandy Soil	18.0	27.0	0.0
7.74	Clayey Soil	16.0	0.0	100.0
8.74	Sandy Soil	18.0	27.0	0.0
9.74	Sandy Soil	18.0	27.0	0.0
10.74	Sandy Soil	18.0	27.0	0.0
11.74	Sandy Soil	18.0	35.0	0.0
12.74	Sandy Soil	18.0	28.0	0.0
13.74	Sandy Soil	18.0	28.0	0.0
14.74	Sandy Soil	18.0	38.0	0.0
	Sandy Soil	18.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm³

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.1 kNm (Normal Condition)
		P_t'	=	5.9 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.39 m (Normal Condition)
		H_t'	=	-0.50 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	H_h'	=	0.00 m (Seismic Condition)
		H_h	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\dfrac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_s = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	10.74	8
2	1.60	15	12	11.74	28
3	2.10	2	13	12.74	11
4	3.74	2	14	13.74	12
5	4.74	2	15	14.74	34
6	5.74	2	16	15.74	50
7	6.74	10			
8	7.74	24			
9	8.74	4			
10	9.74	4			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ (kNm³)	γ' (kNm³)	φ	C (kNm²)	a	k'	ζ (degree)		kh(kNm³)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.74	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	4.74	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
4	5.74	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
5	6.74	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	7.74	C	24.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	——	——
7	8.74	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	9.74	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
9	10.74	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
10	11.74	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
11	12.74	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
12	13.74	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
13	14.74	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
14	15.74	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

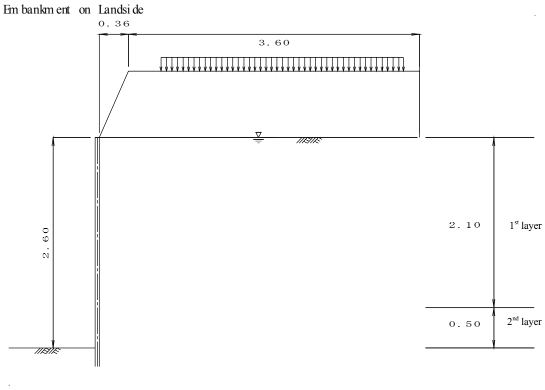
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

2.55

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate 1 (m)	2 (m)	3 (m)	4 (m)	Embankment height h (m)	Wet unit weight γ (kN/m³)	Internal friction angle φ (degree)	Cohesive force C (kN/m²)	Angle of rupture Normal	Seismic
1	Sandy soil	0.00	0.36	3.96	3.96	0.82	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period from (m)	to (m)	Load Normal (kN/m²)	Seismic (kN/m²)
1	0.76	3.76	10.0	5.0

Angle of rapture in embankment   calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

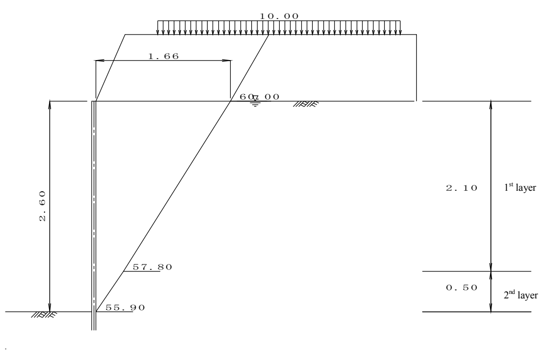
Young's modulus	E	=	200000 N/mm²	
Inertia sectional moment	I_0	=	252000 cm⁴	
Sectional factor	Z_0	=	6090 cm³	
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.86	
Corrosion rate (to Z_0)	η	=	0.89	
Section efficiency (to I_0)	μ	=	1.00	
Section efficiency (to Z_0)	μ	=	1.00	
Round unit of SSP length			0.50 m	
Allowable stress	σ_a	=	185 N/mm² (Normal)	
	σ_a'	=	278 N/mm² (Seismic)	
Allowable displacement	δ_a	=	50.0 mm (Normal)	
	δ_a'	=	75.0 mm (Seismic)	

Bending of cantilever beam   calculated as distributed load of each layer

Reduction of material modulus   Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60 ~ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	23.65	25.48	45.00
2	2.10 ~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	23.65	20.58	57.80
3		Embankment	30.0	——	0.0	14.76	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where,
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C   cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Y (m)	Coordinate of upper end X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	0.82	1.82	2.60	2.30	3.42

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.54	27.74
Σ			27.74

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.54	15.36
Σ			15.36

Q   surcharge load
l : width of surcharge load set by line of active rupture

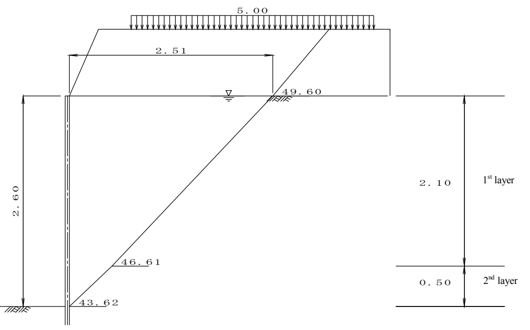
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{27.74 + 15.36 + 0.00}{1.82}$$

$$= 23.65 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60 ~ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	20.56	25.48	0.200	11.31	33.83
2	2.10 ~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	20.56	20.58	0.200	11.31	46.61
3		Embankment	30.0	—	0.0	14.76	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{o}$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	33.83	0.50	0.00	0.00	0.75	0.50
2	46.61	2.10	0.75	0.50	2.73	2.60
3	49.60	0.82	2.73	2.60	3.43	3.42

Therefore, width of acting load shall be set as 2.73 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.38	42.81
Σ			42.81

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.67	13.35
Σ			13.35

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

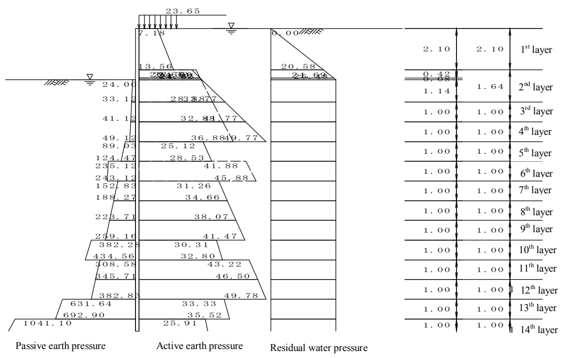
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{42.81 + 13.35 + 0.00}{2.73}$$

$$= 20.56 \ kN/m^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	— —	23.647 44.647	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.52	Clayey soil	8.0	—	12.0 12.0	44.647 48.000	— —	— —
3	2.52~ 2.60	Clayey soil	8.0	—	12.0 12.0	48.000 48.647	— —	— —
4	2.60~ 3.74	Clayey soil	8.0	—	12.0 12.0	48.647 57.767	— —	— —
5	3.74~ 4.74	Clayey soil	8.0	—	12.0 12.0	57.767 65.767	— —	— —
6	4.74~ 5.74	Clayey soil	8.0	—	12.0 12.0	65.767 73.767	— —	— —
7	5.74~ 6.74	Sandy soil	10.0	27.0	— —	73.767 83.767	0.34585 0.34585	0.34060 0.34060
8	6.74~ 7.74	Clayey soil	8.0	—	100.0 100.0	83.767 91.767	— —	— —
9	7.74~ 8.74	Sandy soil	10.0	27.0	— —	91.767 101.767	0.34585 0.34585	0.34060 0.34060
10	8.74~ 9.74	Sandy soil	10.0	27.0	— —	101.767 111.767	0.34585 0.34585	0.34060 0.34060
11	9.74~ 10.74	Sandy soil	10.0	27.0	— —	111.767 121.767	0.34585 0.34585	0.34060 0.34060
12	10.74~ 11.74	Sandy soil	10.0	35.0	— —	121.767 131.767	0.25279 0.25279	0.24895 0.24895
13	11.74~ 12.74	Sandy soil	10.0	28.0	— —	131.767 141.767	0.33303 0.33303	0.32798 0.32798

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	12.74~ 13.74	Sandy soil	10.0	28.0	— —	141.767 151.767	0.33303 0.33303	0.32798 0.32798
15	13.74~ 14.74	Sandy soil	10.0	38.0	— —	151.767 161.767	0.22298 0.22298	0.21959 0.21959
16	14.74~ 15.74	Sandy soil	10.0	45.0	— —	161.767 171.767	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta= 10.00,\ \beta= 0.00,\ \theta= 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60~ 3.74	Clayey soil	8.0	0.0	12.0 12.0	0.000 9.120	— —	— —
5	3.74~ 4.74	Clayey soil	8.0	0.0	12.0 12.0	9.120 17.120	— —	— —
6	4.74~ 5.74	Clayey soil	8.0	0.0	12.0 12.0	17.120 25.120	— —	— —
7	5.74~ 6.74	Sandy soil	10.0	27.0	— —	25.120 35.120	3.59892 3.59892	3.54425 3.54425
8	6.74~ 7.74	Clayey soil	8.0	0.0	100.0 100.0	35.120 43.120	— —	— —
9	7.74~ 8.74	Sandy soil	10.0	27.0	— —	43.120 53.120	3.59892 3.59892	3.54425 3.54425
10	8.74~ 9.74	Sandy soil	10.0	27.0	— —	53.120 63.120	3.59892 3.59892	3.54425 3.54425
11	9.74~ 10.74	Sandy soil	10.0	27.0	— —	63.120 73.120	3.59892 3.59892	3.54425 3.54425
12	10.74~ 11.74	Sandy soil	10.0	35.0	— —	73.120 83.120	5.30876 5.30876	5.22810 5.22810
13	11.74~ 12.74	Sandy soil	10.0	28.0	— —	83.120 93.120	3.76978 3.76978	3.71251 3.71251
14	12.74~ 13.74	Sandy soil	10.0	28.0	— —	93.120 103.120	3.76978 3.76978	3.71251 3.71251
15	13.74~ 14.74	Sandy soil	10.0	38.0	— —	103.120 113.120	6.21981 6.21981	6.12532 6.12532
16	14.74~ 15.74	Sandy soil	10.0	45.0	— —	113.120 123.120	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta= -10.00,\ \beta= 0.00,\ \theta= 0.00$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
1	0.00~ 2.10	7.18 13.56	—— ——	7.18 13.56	0.00 20.58	—— ——
2	2.10~ 2.52	20.65 24.00	22.32 24.00	22.32 24.00	20.58 24.69	—— ——
3	2.52~ 2.60	24.00 24.65	24.00 24.32	24.00 24.65	24.69 25.48	—— ——
4	2.60~ 3.74	24.65 33.77	24.32 28.88	24.65 33.77	25.48 25.48	24.00 33.12
5	3.74~ 4.74	33.77 41.77	28.88 32.88	33.77 41.77	25.48 25.48	33.12 41.12
6	4.74~ 5.74	41.77 49.77	32.88 36.88	41.77 49.77	25.48 25.48	41.12 49.12
7	5.74~ 6.74	25.12 28.53	—— ——	25.12 28.53	25.48 25.48	89.03 124.47
8	6.74~ 7.74	-116.23 -108.23	41.88 45.88	41.88 45.88	25.48 25.48	235.12 243.12
9	7.74~ 8.74	31.26 34.66	—— ——	31.26 34.66	25.48 25.48	152.83 188.27
10	8.74~ 9.74	34.66 38.07	—— ——	34.66 38.07	25.48 25.48	188.27 223.71
11	9.74~ 10.74	38.07 41.47	—— ——	38.07 41.47	25.48 25.48	223.71 259.16
12	10.74~ 11.74	30.31 32.80	—— ——	30.31 32.80	25.48 25.48	382.28 434.56
13	11.74~ 12.74	43.22 46.50	—— ——	43.22 46.50	25.48 25.48	308.58 345.71
14	12.74~ 13.74	46.50 49.78	—— ——	46.50 49.78	25.48 25.48	345.71 382.83
15	13.74~ 14.74	33.33 35.52	—— ——	33.33 35.52	25.48 25.48	631.64 692.90
16	14.74~ 15.74	25.91 27.51	—— ——	25.91 27.51	25.48 25.48	1041.10 1133.14

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

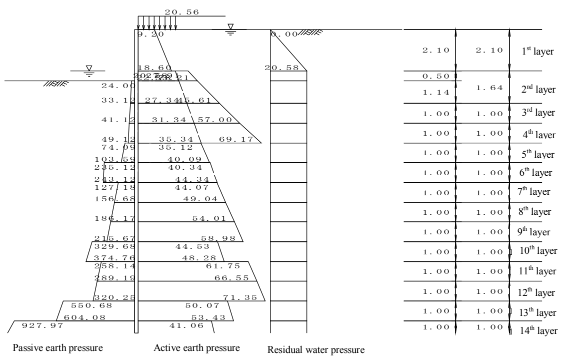
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	20.56 41.56	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Clayey Soil	8.0	—	12.0 12.0	41.56 45.56	20.58 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	34.78 33.83
3	2.60~ 3.74	Clayey Soil	8.0	—	12.0 12.0	45.56 54.68	25.48 36.65	0.200 0.200	11.31 11.31	—— ——	—— ——	33.83 31.41
4	3.74~ 4.74	Clayey Soil	8.0	—	12.0 12.0	54.68 62.68	36.65 46.45	0.200 0.200	11.31 11.31	—— ——	—— ——	31.41 28.96
5	4.74~ 5.74	Clayey Soil	8.0	—	12.0 12.0	62.68 70.68	46.45 56.25	0.200 0.200	11.31 11.31	—— ——	—— ——	28.96 26.09
6	5.74~ 6.74	Sandy Soil	10.0	27.0	—— ——	70.68 80.68	56.25 66.05	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	6.74~ 7.74	Clayey Soil	8.0	—	100.0 100.0	80.68 88.68	66.05 75.85	0.200 0.200	11.31 11.31	—— ——	—— ——	43.47 43.34
8	7.74~ 8.74	Sandy Soil	10.0	27.0	—— ——	88.68 98.68	75.85 85.65	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
9	8.74~ 9.74	Sandy Soil	10.0	27.0	—— ——	98.68 108.68	85.65 95.45	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
10	9.74~ 10.74	Sandy Soil	10.0	27.0	—— ——	108.68 118.68	95.45 105.25	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
11	10.74~ 11.74	Sandy Soil	10.0	35.0	—— ——	118.68 128.68	105.25 115.05	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
12	11.74~ 12.74	Sandy Soil	10.0	28.0	—— ——	128.68 138.68	115.05 124.85	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k)	θ (degree)	Ka	Ka ×cosδ	θ (degree)
13	12.74~ 13.74	Sandy Soil	10.0	28.0	—— ——	138.68 148.68	124.85 134.65	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
14	13.74~ 14.74	Sandy Soil	10.0	38.0	—— ——	148.68 158.68	134.65 144.45	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
15	14.74~ 15.74	Sandy Soil	10.0	45.0	—— ——	158.68 168.68	144.45 154.25	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 10.00$, $\beta = 0.00$, $\theta = \tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Qp (kNm^2)	γwhw (kNm^2)	k (k)	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 3.74	Clayey soil	8.00	0.0	12.0 12.0	0.000 9.120	0.00 11.17	0.200 0.200	11.31 11.31	—— ——	—— ——
4	3.74~ 4.74	Clayey soil	8.00	0.0	12.0 12.0	9.120 17.120	11.17 20.97	0.200 0.200	11.31 11.31	—— ——	—— ——
5	4.74~ 5.74	Clayey soil	8.00	0.0	12.0 12.0	17.120 25.120	20.97 30.77	0.200 0.200	11.31 11.31	—— ——	—— ——
6	5.74~ 6.74	Sandy soil	10.00	27.0	—— ——	25.120 35.120	30.77 40.57	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	6.74~ 7.74	Clayey soil	8.00	0.0	100.0 100.0	35.120 43.120	40.57 50.37	0.200 0.200	11.31 11.31	—— ——	—— ——
8	7.74~ 8.74	Sandy soil	10.00	27.0	—— ——	43.120 53.120	50.37 60.17	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
9	8.74~ 9.74	Sandy soil	10.00	27.0	—— ——	53.120 63.120	60.17 69.97	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
10	9.74~ 10.74	Sandy soil	10.00	27.0	—— ——	63.120 73.120	69.97 79.77	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
11	10.74~ 11.74	Sandy soil	10.00	35.0	—— ——	73.120 83.120	79.77 89.57	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
12	11.74~ 12.74	Sandy soil	10.00	28.0	—— ——	83.120 93.120	89.57 99.37	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
13	12.74~ 13.74	Sandy soil	10.00	28.0	—— ——	93.120 103.120	99.37 109.17	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
14	13.74~ 14.74	Sandy soil	10.00	38.0	—— ——	103.120 113.120	109.17 118.97	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
15	14.74~ 15.74	Sandy soil	10.00	45.0	—— ——	113.120 123.120	118.97 128.77	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
1	0.00~ 2.10	9.20 18.60	—— ——	9.20 18.60	0.00 20.58	—— ——
2	2.10~ 2.60	27.91 33.21	20.78 22.78	27.91 33.21	20.58 20.58	—— ——
3	2.60~ 3.74	33.21 45.61	22.78 27.34	33.21 45.61	20.58 20.58	24.00 33.12
4	3.74~ 4.74	45.61 57.00	27.34 31.34	45.61 57.00	20.58 20.58	33.12 41.12
5	4.74~ 5.74	57.00 69.17	31.34 35.34	57.00 69.17	20.58 20.58	41.12 49.12
6	5.74~ 6.74	35.12 40.09	—— ——	35.12 40.09	20.58 20.58	74.09 103.59
7	6.74~ 7.74	-102.59 -92.86	40.34 44.34	40.34 44.34	20.58 20.58	235.12 243.12
8	7.74~ 8.74	44.07 49.04	—— ——	44.07 49.04	20.58 20.58	127.18 156.68
9	8.74~ 9.74	49.04 54.01	—— ——	49.04 54.01	20.58 20.58	156.68 186.17
10	9.74~ 10.74	54.01 58.98	—— ——	54.01 58.98	20.58 20.58	186.17 215.67
11	10.74~ 11.74	44.53 48.28	—— ——	44.53 48.28	20.58 20.58	329.68 374.76
12	11.74~ 12.74	61.75 66.55	—— ——	61.75 66.55	20.58 20.58	258.14 289.19
13	12.74~ 13.74	66.55 71.35	—— ——	66.55 71.35	20.58 20.58	289.19 320.25
14	13.74~ 14.74	50.07 53.43	—— ——	50.07 53.43	20.58 20.58	550.68 604.08
15	14.74~ 15.74	41.06 43.64	—— ——	41.06 43.64	20.58 20.58	927.97 1010.01

2.58

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

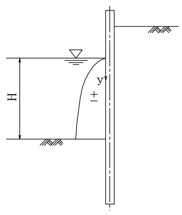
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

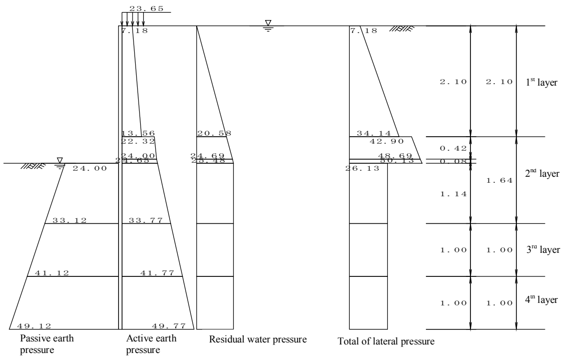
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	7.18 13.56	0.00 20.58	—— ——	7.18 34.14
2	2.10~ 2.52	22.32 24.00	20.58 24.69	—— ——	42.90 48.69
3	2.52~ 2.60	24.00 24.65	24.69 25.48	—— ——	48.69 50.13
4	2.60~ 3.74	24.65 33.77	25.48 25.48	24.00 33.12	26.13 26.13
5	3.74~ 4.74	33.77 41.77	25.48 25.48	33.12 41.12	26.13 26.13
6	4.74~ 5.74	41.77 49.77	25.48 25.48	41.12 49.12	26.13 26.13
7	5.74~ 6.74	25.12 28.53	25.48 25.48	89.03 124.47	-38.43 -70.46

P_a : Active earth pressure

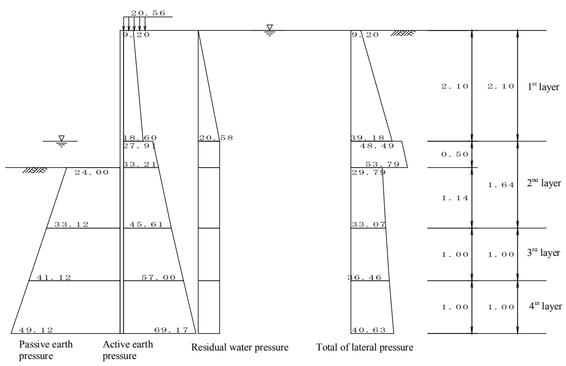
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 3.14 m (GL -5.74 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	9.20 18.60	0.00 20.58	—— ——	9.20 39.18
2	2.10~ 2.60	27.91 33.21	20.58 20.58	—— ——	48.49 53.79
3	2.60~ 3.74	33.21 45.61	20.58 20.58	24.00 33.12	29.79 33.07
4	3.74~ 4.74	45.61 57.00	20.58 20.58	33.12 41.12	33.07 36.46
5	4.74~ 5.74	57.00 69.17	20.58 20.58	41.12 49.12	36.46 40.63
6	5.74~ 6.74	35.12 40.09	20.58 20.58	74.09 103.59	-18.39 -42.91

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 3.14 m (GL -5.74 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.86			
Section efficiency	μ	=	1.00			
Young's modulus	E	=	200000 Nmm^2			
Inertia sectional moment	I_0	=	252000 cm^4 (original condition)			
	I	=	216720 cm^4 (after reduction by corrosion and)			
Inertia sectional moment	EI	=	200000 x 10^3 x 216720x 10^{-8} = 4.334 × 10^5			

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	10.74	8
2	1.60	15	12	11.74	28
3	2.10	2	13	12.74	11
4	3.74	2	14	13.74	12
5	4.74	2	15	14.74	34
6	5.74	2	16	15.74	50
7	6.74	10			
8	7.74	24			
9	8.74	4			
10	9.74	4			

5-2 Normal Condition

K_h = 19008 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.324 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.09 \text{ m}$$

Therefore, average N-value is calculated on the actual N value from imaginary riverbed (GL -5.74 m) to 3.09 m depth (GL -8.83 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	5.74	1.00	2.0	10.0	6.00
2	6.74	1.00	10.0	24.0	17.00
3	7.74	1.00	24.0	4.0	14.00
4	8.74	0.09	4.0	4.0	0.36
	L = Σh = 3.09				ΣA = 37.36

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{37.36}{3.09}$$

$$= 12.09$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 12.09^{0.406} = 19008 \text{ kN/m}^3$$

K_h (normal condition) = 19008 kN/m^3

5-3 Seismic Condition

K_h = 19008 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.324 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.09 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.74 m) to 3.09 m depth (GL -8.83 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	5.74	1.00	2.0	10.0	6.00
2	6.74	1.00	10.0	24.0	17.00
3	7.74	1.00	24.0	4.0	14.00
4	8.74	0.09	4.0	4.0	0.36
	L = Σh = 3.09				ΣA = 37.36

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{37.36}{3.09}$$

$$= 12.09$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 12.09^{0.406} = 19008 \text{ kN/m}^3$$

K_h (seismic condition) = 19008 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.18 34.14	7.54 35.85	5.04 4.34	38.01 155.59
2	2.10~ 2.52	0.42	42.90 48.69	8.99 10.20	3.50 3.36	31.47 34.29
3	2.52~ 2.60	0.08	48.69 50.13	1.97 2.03	3.19 3.17	6.29 6.42
4	2.60~ 3.74	1.14	26.13 26.13	14.89 14.89	2.76 2.38	41.10 35.44
5	3.74~ 4.74	1.00	26.13 26.13	13.06 13.06	1.67 1.33	21.77 17.42
6	4.74~ 5.74	1.00	26.13 26.13	13.06 13.06	0.67 0.33	8.71 4.35
				ΣP = 148.62		ΣM = 400.87

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.1 kN/m
depth to acting position	H	=	-0.39 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_t	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	3.14 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 12.87 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{413.74}{150.72} = 2.75 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.20 39.18	9.66 41.14	5.04 4.34	48.69 178.54
2	2.10~ 2.60	0.50	48.49 53.79	12.12 13.45	3.47 3.31	42.11 44.46

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
3	2.60~ 3.74	1.14	29.79 33.07	16.98 18.85	2.76 2.38	46.86 44.86
4	3.74~ 4.74	1.00	33.07 36.46	16.53 18.23	1.67 1.33	27.56 24.31
5	4.74~ 5.74	1.00	36.46 40.63	18.23 20.31	0.67 0.33	12.15 6.77
				ΣP = 185.51		ΣM = 476.31

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	5.9 kN/m
depth to acting position	H	=	-0.50 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_t	=	0.0 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	3.14 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 36.82 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	3.47 3.31	0.00 0.71
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.71

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{513.83}{191.62} = 2.68 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	252000 cm^4 (original condition)
	I	=	216720 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 216720 x 10^{-8}		=	4.334×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	19008 kN/m^3
calculated value	β	=	0.32358 m^{-1}
resultant earth force (lateral)	P_0	=	150.72 kN/m
height of acting position of load	h_0	=	2.75 m
moment	M_0	=	413.74 kN·m/m

in consideration of ω = 1.176,

maximum moment	M_{max}	=	486.42 kN·m/m
depth of generated position of M_{max}	l_m	=	1.068 m
depth of 1st fixed point	l_i	=	3.496 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	19008 kN/m^3
calculated value	β	=	0.32358 m^{-1}
resultant earth force (lateral)	P_0	=	191.62 kN/m
height of acting position of load	h_0	=	2.68 m
moment	M_0	=	513.83 kN·m/m

in consideration of ω = 1.182

maximum moment	M_{max}	=	607.39 kN·m/m
depth of generated position of M_{max}	l_m	=	1.083 m
depth of 1st fixed point	l_i	=	3.510 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	6090 cm^3 (original condition)
	Z	=	5420 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{486.42\times10^6}{5420\times10^3} = 90\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{607.39\times10^6}{5420\times10^3} = 112\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2$$

6-4 Displacement

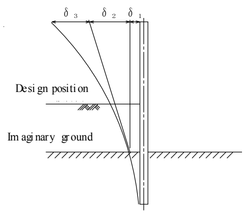
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	5.04 4.34	0.878 0.756	0.273 0.214	7.54 35.85	2.057 7.665
2	2.10~ 2.52	3.50 3.36	0.610 0.585	0.148 0.138	8.99 10.20	1.332 1.407
3	2.52~ 2.60	3.19 3.17	0.556 0.552	0.126 0.124	1.97 2.03	0.248 0.252
4	2.60~ 3.74	2.76 2.38	0.481 0.415	0.097 0.074	14.89 14.89	1.446 1.103
5	3.74~ 4.74	1.67 1.33	0.290 0.232	0.038 0.025	13.06 13.06	0.497 0.325
6	4.74~ 5.74	0.67 0.33	0.116 0.058	0.006 0.002	13.06 13.06	0.085 0.022
						ΣQ = 16.438

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3236\times2.75)\times150.72}{2\times2.00\times10^8\times216720\times10^{-8}\times0.3236^3} = 0.00969\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3236\times2.75)\times150.72}{2\times2.00\times10^8\times216720\times10^{-8}\times0.3236^2}\times(2.60+3.14) = 0.02646\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{16.44\times(2.60+3.14)^3}{2.00\times10^8\times216720\times10^{-8}} = 0.00717\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00034 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.74 m
Horizontal load: P = 2.10
Moment: M = 0.82

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00969 + 0.02646 + 0.00751
= 0.04366 m
= 43.66 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	5.04 4.34	0.878 0.756	0.273 0.214	9.66 41.14	2.634 8.795
2	2.10~ 2.60	3.47 3.31	0.605 0.576	0.146 0.134	12.12 13.45	1.772 1.803
3	2.60~ 3.74	2.76 2.38	0.481 0.415	0.097 0.074	16.98 18.85	1.648 1.396
4	3.74~ 4.74	1.67 1.33	0.290 0.232	0.038 0.025	16.53 18.23	0.630 0.454
5	4.74~ 5.74	0.67 0.33	0.116 0.058	0.006 0.002	18.23 20.31	0.118 0.034
						ΣQ = 19.283

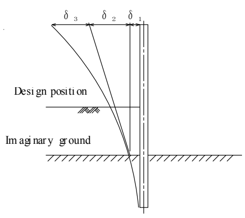
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	3.47 3.31	0.605 0.576	0.146 0.134	0.00 0.21	0.000 0.029
					ΣQ_{dw} =	0.029

Therefore, modulus of deformation Q is calculated as below
Q = 19.283 + 0.029 = 19.312

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3236\times2.68)\times191.62}{2\times2.00\times10^8\times216720\times10^{-8}\times0.3236^3} = 0.01219\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3236\times2.68)\times191.62}{2\times2.00\times10^8\times216720\times10^{-8}\times0.3236^2}\times(2.60+3.14) = 0.03315\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{19.31\times(2.60+3.14)^3}{2.00\times10^8\times216720\times10^{-8}} = 0.00843\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00097 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.74 m
Horizontal load: P = 5.90
Moment: M = 2.95

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01219 + 0.03315 + 0.00940
= 0.05473 m
= 54.73 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	252000 cm^4 (original condition)
	I	=	252000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 252000 \times 10^{-8}$		=	5.040×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 19008\ kN/m^3$
Calculated value	$\beta = 0.31161\ m^{-1}$
Penetration length of SSP	$D = 3.14 + \frac{3}{0.312} = 12.77$ m
Whole length of SSP	$L = 2.60 - 0.40 + 12.77 = 14.97$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 19008\ kN/m^3$
Calculated value	$\beta = 0.31161\ m^{-1}$
Penetration length of SSP	$D = 3.14 + \frac{3}{0.312} = 12.77$ m
Whole length of SSP	$L = 2.60 - 0.40 + 12.77 = 14.97$ m

Therefore, whole length of SSP is set as 15.00 m in consideration of round unit of SSP length.

8 Calculation Result

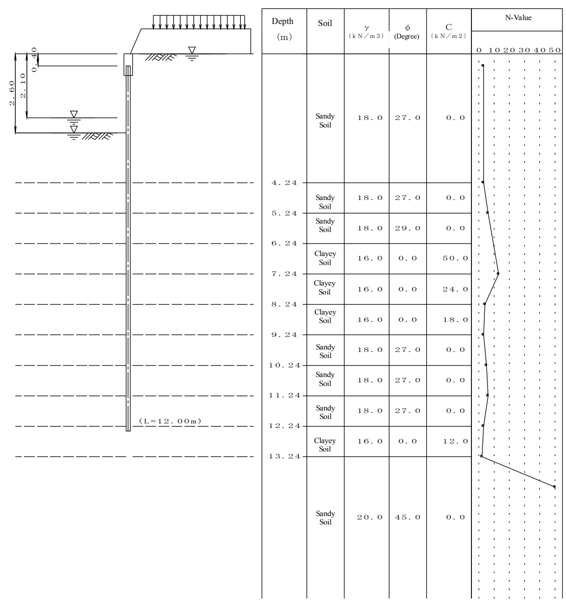
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	252000		
Section modulus	Z (cm^3)	6090		
Maximum bending moment	M_{max} (kN·m/m)		486.42	607.39
Stress intensity	σ (N/mm^2)		90 (185)	112 (278)
Lateral displacement	δ (mm)		43.66 (50.0)	54.73 (75.0)
Penetration depth	D (m)		12.77	12.77
Whole length of SSP	L (m)	15.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 9_STA_8+250 - 8+400

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.2 kNm (Normal Condition)
		Pt'	=	8.3 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.40 m (Normal Condition)
		Ht'	=	-0.22 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00m (Seismic Condition)
		Hm	=	0.00m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression $K_e = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.40	3
2	4.24	3
3	5.24	6
4	7.24	13
5	8.24	4
6	9.24	3
7	10.24	5
8	11.24	6
9	12.24	3
10	13.24	2

No	Depth (m)	N-Value
11	14.24	50
12	17.24	50

2.63

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

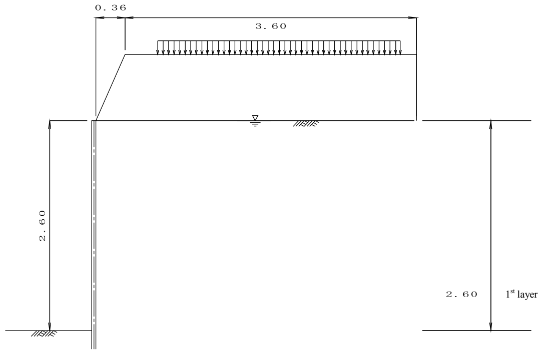
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^3)	a	k'	ζ (degree		kh(kNm^3)	
										normal	seismic	normal	seismic
1	4.24	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
2	5.24	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	6.24	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
4	7.24	C	13.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
5	8.24	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
6	9.24	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
7	10.24	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	11.24	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
9	12.24	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
10	13.24	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
11	17.24	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.36	3.96	3.96	0.82	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.76	3.76	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

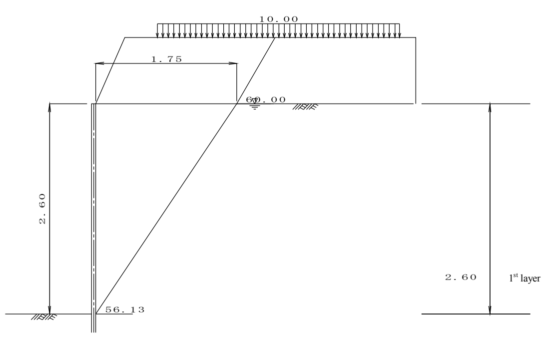
1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4
Sectional factor	Z_0	=	3820 cm^3
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 Nmm^2 (Normal)
	σ_a'	=	270 Nmm^2 (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60 ~ 0.00	Sandy Soil	27.0	9.0	0.0	26.00	23.60	25.48	56.13
2		Embankment	30.0	——	0.0	14.76	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm^2)
- C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	2.60	0.00	0.00	1.75	2.60
2	60.00	0.82	1.75	2.60	2.22	3.42

Therefore, width of acting load shall be set as 1.75 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.48	26.60
Σ			26.60

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.46	14.59
Σ			14.59

Q surcharge load

l : width of surcharge load set by line of active rupture

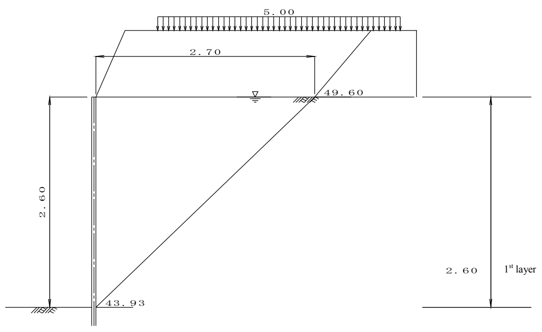
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{26.60 + 14.59 + 0.00}{1.75}$$

$$= 23.60\ \text{kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60 ~ 0.00	Sandy Soil	27.0	9.0	0.0	26.00	20.57	25.48	0.200	11.31	43.93
2		Embankment	30.0	——	0.0	14.76	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Where.
- ζ : angle of active rupture (degree, ζ≥10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  θ=tan⁻¹k or θ=tan⁻¹k'
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.93	2.60	0.00	0.00	2.70	2.60
2	49.60	0.82	2.70	2.60	3.40	3.42

Therefore, width of acting load shall be set as 2.70 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.35	42.33
Σ			42.33

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.64	13.19
Σ			13.19

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

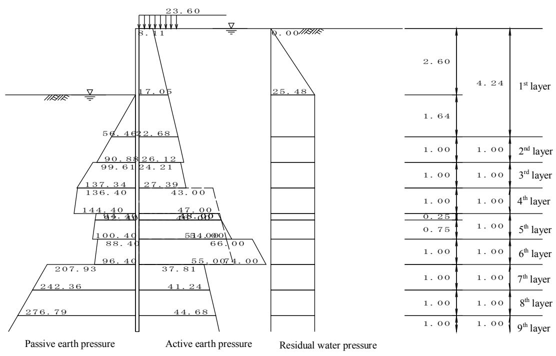
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{42.33 + 13.19 + 0.00}{2.70}$$

$$= 20.57 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm³)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.60	Sandy soil	10.0	27.0	—— ——	23.598 49.598	0.34800 0.34800	0.34371 0.34371
2	2.60~ 4.24	Sandy soil	10.0	27.0	—— ——	49.598 65.998	0.34800 0.34800	0.34371 0.34371
3	4.24~ 5.24	Sandy soil	10.0	27.0	—— ——	65.998 75.998	0.34800 0.34800	0.34371 0.34371
4	5.24~ 6.24	Sandy soil	10.0	29.0	—— ——	75.998 85.998	0.32248 0.32248	0.31851 0.31851
5	6.24~ 7.24	Clayey soil	8.0	—	50.0 50.0	85.998 93.998	—— ——	—— ——
6	7.24~ 7.49	Clayey soil	8.0	—	24.0 24.0	93.998 96.000	—— ——	—— ——
7	7.49~ 8.24	Clayey soil	8.0	—	24.0 24.0	96.000 101.998	—— ——	—— ——
8	8.24~ 9.24	Clayey soil	8.0	—	18.0 18.0	101.998 109.998	—— ——	—— ——
9	9.24~ 10.24	Sandy soil	10.0	27.0	—— ——	109.998 119.998	0.34800 0.34800	0.34371 0.34371
10	10.24~ 11.24	Sandy soil	10.0	27.0	—— ——	119.998 129.998	0.34800 0.34800	0.34371 0.34371
11	11.24~ 12.24	Sandy soil	10.0	27.0	—— ——	129.998 139.998	0.34800 0.34800	0.34371 0.34371
12	12.24~ 13.24	Clayey soil	8.0	—	12.0 12.0	139.998 147.998	—— ——	—— ——
13	13.24~ 17.24	Sandy soil	10.0	45.0	—— ——	147.998 187.998	0.16323 0.16323	0.16122 0.16122

2.65

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 9.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm³)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
2	2.60~ 4.24	Sandy soil	10.0	27.0	—— ——	0.000 16.400	3.48553 3.48553	3.44261 3.44261
3	4.24~ 5.24	Sandy soil	10.0	27.0	—— ——	16.400 26.400	3.48553 3.48553	3.44261 3.44261
4	5.24~ 6.24	Sandy soil	10.0	29.0	—— ——	26.400 36.400	3.82002 3.82002	3.77299 3.77299
5	6.24~ 7.24	Clayey soil	8.0	0.0	50.0 50.0	36.400 44.400	—— ——	—— ——
6	7.24~ 7.49	Clayey soil	8.0	0.0	24.0 24.0	44.400 46.402	—— ——	—— ——
7	7.49~ 8.24	Clayey soil	8.0	0.0	24.0 24.0	46.402 52.400	—— ——	—— ——
8	8.24~ 9.24	Clayey soil	8.0	0.0	18.0 18.0	52.400 60.400	—— ——	—— ——
9	9.24~ 10.24	Sandy soil	10.0	27.0	—— ——	60.400 70.400	3.48553 3.48553	3.44261 3.44261
10	10.24~ 11.24	Sandy soil	10.0	27.0	—— ——	70.400 80.400	3.48553 3.48553	3.44261 3.44261
11	11.24~ 12.24	Sandy soil	10.0	27.0	—— ——	80.400 90.400	3.48553 3.48553	3.44261 3.44261
12	12.24~ 13.24	Clayey soil	8.0	0.0	12.0 12.0	90.400 98.400	—— ——	—— ——
13	13.24~ 17.24	Sandy soil	10.0	45.0	—— ——	98.400 138.400	8.86593 8.86593	8.75678 8.75678

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -9.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side Pa1 (kNm²)	Active side Pa2 (kNm²)	Active side Pa (kNm²)	Residual water pressure Pw (kNm²)	Passive side Pp (kNm²)
1	0.00~ 2.60	8.11 17.05	—— ——	8.11 17.05	0.00 25.48	—— ——
2	2.60~ 4.24	17.05 22.68	—— ——	17.05 22.68	25.48 25.48	0.00 56.46
3	4.24~ 5.24	22.68 26.12	—— ——	22.68 26.12	25.48 25.48	56.46 90.88
4	5.24~ 6.24	24.21 27.39	—— ——	24.21 27.39	25.48 25.48	99.61 137.34
5	6.24~ 7.24	-14.00 -6.00	43.00 47.00	43.00 47.00	25.48 25.48	136.40 144.40

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm³)	Pa2 (kNm³)	Pa (kNm³)	Pw (kNm³)	Pp (kNm³)
6	7.24~ 7.49	46.00 48.00	47.00 48.00	47.00 48.00	25.48 25.48	92.40 94.40
7	7.49~ 8.24	48.00 54.00	48.00 51.00	48.00 54.00	25.48 25.48	94.40 100.40
8	8.24~ 9.24	66.00 74.00	51.00 55.00	66.00 74.00	25.48 25.48	88.40 96.40
9	9.24~ 10.24	37.81 41.24	—— ——	37.81 41.24	25.48 25.48	207.93 242.36
10	10.24~ 11.24	41.24 44.68	—— ——	41.24 44.68	25.48 25.48	242.36 276.79
11	11.24~ 12.24	44.68 48.12	—— ——	44.68 48.12	25.48 25.48	276.79 311.21
12	12.24~ 13.24	116.00 124.00	70.00 74.00	116.00 124.00	25.48 25.48	114.40 122.40
13	13.24~ 17.24	23.86 30.31	—— ——	23.86 30.31	25.48 25.48	861.67 1211.94

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

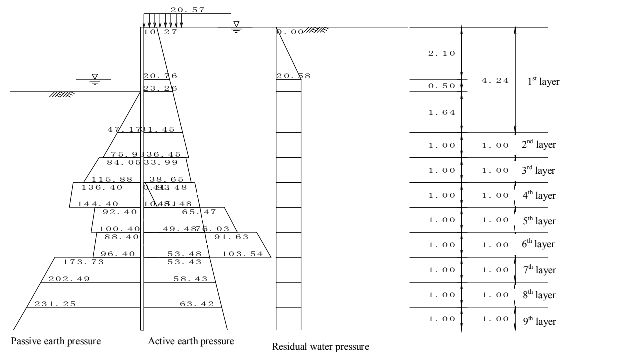
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm³)	Σγh+Q (kNm³)	γwhw (kNm³)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	27.0	—— ——	20.57 41.57	0.00 20.58	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	27.0	—— ——	41.57 46.57	20.58 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.60~ 4.24	Sandy Soil	10.0	27.0	—— ——	46.57 62.97	25.48 41.55	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	4.24~ 5.24	Sandy Soil	10.0	27.0	—— ——	62.97 72.97	41.55 51.35	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	5.24~ 6.24	Sandy Soil	10.0	29.0	—— ——	72.97 82.97	51.35 61.15	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
6	6.24~ 7.24	Clayey Soil	8.0	—	50.0 50.0	82.97 90.97	61.15 70.95	0.200 0.200	11.31 11.31	—— ——	—— ——	41.68 41.39
7	7.24~ 8.24	Clayey Soil	8.0	—	24.0 24.0	90.97 98.97	70.95 80.75	0.200 0.200	11.31 11.31	—— ——	—— ——	36.19 35.32
8	8.24~ 9.24	Clayey Soil	8.0	—	18.0 18.0	98.97 106.97	80.75 90.55	0.200 0.200	11.31 11.31	—— ——	—— ——	30.10 28.36
9	9.24~ 10.24	Sandy Soil	10.0	27.0	—— ——	106.97 116.97	90.55 100.35	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
10	10.24~ 11.24	Sandy Soil	10.0	27.0	—— ——	116.97 126.97	100.35 110.15	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
11	11.24~ 12.24	Sandy Soil	10.0	27.0	—— ——	126.97 136.97	110.15 119.95	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
12	12.24~ 13.24	Clayey Soil	8.0	—	12.0 12.0	136.97 144.97	119.95 129.75	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
13	13.24~ 17.24	Sandy Soil	10.0	45.0	—— ——	144.97 184.97	129.75 168.95	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta= 9.00$, $\beta= 0.00$, $\theta= \tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm³)	Σγh+Qp (kNm³)	γwhw (kNm³)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 4.24	Sandy soil	10.00	27.0	—— ——	0.000 16.400	0.00 16.07	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
4	4.24~ 5.24	Sandy soil	10.00	27.0	—— ——	16.400 26.400	16.07 25.87	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	5.24~ 6.24	Sandy soil	10.00	29.0	—— ——	26.400 36.400	25.87 35.67	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
6	6.24~ 7.24	Clayey soil	8.00	0.0	50.0 50.0	36.400 44.400	35.67 45.47	0.200 0.200	11.31 11.31	—— ——	—— ——
7	7.24~ 8.24	Clayey soil	8.00	0.0	24.0 24.0	44.400 52.400	45.47 55.27	0.200 0.200	11.31 11.31	—— ——	—— ——
8	8.24~ 9.24	Clayey soil	8.00	0.0	18.0 18.0	52.400 60.400	55.27 65.07	0.200 0.200	11.31 11.31	—— ——	—— ——
9	9.24~ 10.24	Sandy soil	10.00	27.0	—— ——	60.400 70.400	65.07 74.87	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
10	10.24~ 11.24	Sandy soil	10.00	27.0	—— ——	70.400 80.400	74.87 84.67	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
11	11.24~ 12.24	Sandy soil	10.00	27.0	—— ——	80.400 90.400	84.67 94.47	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
12	12.24~ 13.24	Clayey soil	8.00	0.0	12.0 12.0	90.400 98.400	94.47 104.27	0.200 0.200	11.31 11.31	—— ——	—— ——
13	13.24~ 17.24	Sandy soil	10.00	45.0	—— ——	98.400 138.400	104.27 143.47	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta= -9.00$, $\beta= 0.00$, $\theta= \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm³)	Pa2 (kNm³)	Pa (kNm³)	Pw (kNm³)	Pp (kNm³)
1	0.00~ 2.10	10.27 20.76	—— ——	10.27 20.76	0.00 20.58	—— ——
2	2.10~ 2.60	20.76 23.26	—— ——	20.76 23.26	20.58 20.58	—— ——
3	2.60~ 4.24	23.26 31.45	—— ——	23.26 31.45	20.58 20.58	0.00 47.17
4	4.24~ 5.24	31.45 36.45	—— ——	31.45 36.45	20.58 20.58	47.17 75.93
5	5.24~ 6.24	33.99 38.65	—— ——	33.99 38.65	20.58 20.58	84.05 115.88
6	6.24~ 7.24	0.93 10.81	41.48 45.48	41.48 45.48	20.58 20.58	136.40 144.40
7	7.24~ 8.24	65.47 76.03	45.48 49.48	65.47 76.03	20.58 20.58	92.40 100.40
8	8.24~ 9.24	91.63 103.54	49.48 53.48	91.63 103.54	20.58 20.58	88.40 96.40
9	9.24~ 10.24	53.43 58.43	—— ——	53.43 58.43	20.58 20.58	173.73 202.49
10	10.24~ 11.24	58.43 63.42	—— ——	58.43 63.42	20.58 20.58	202.49 231.25
11	11.24~ 12.24	63.42 68.42	—— ——	63.42 68.42	20.58 20.58	231.25 260.01
12	12.24~ 13.24	222.15 239.23	68.48 72.48	222.15 239.23	20.58 20.58	114.40 122.40
13	13.24~ 17.24	37.66 48.06	—— ——	37.66 48.06	20.58 20.58	769.99 1083.00

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

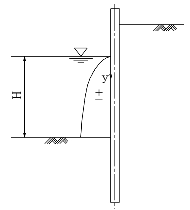
Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.10 2.60	0.00 0.50	0.00 0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

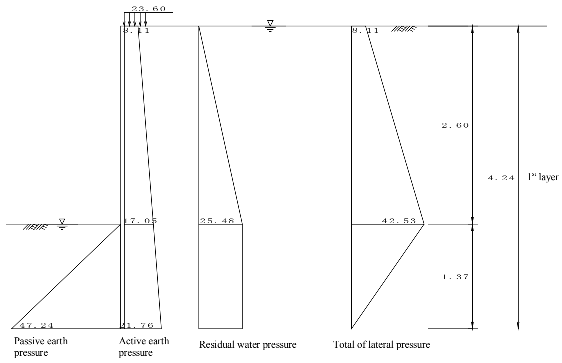
Where,
k_{hs}: design seismic coefficient
γ_w: unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

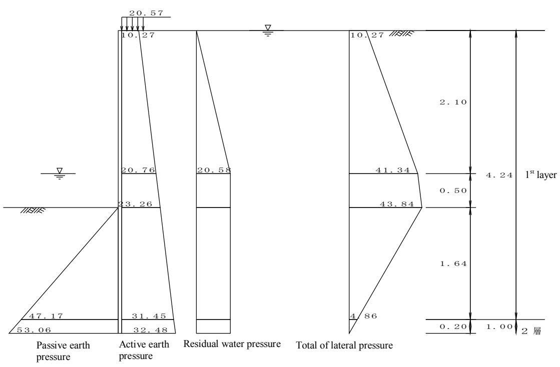


	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.60	8.11 17.05	0.00 25.48	—— ——	8.11 42.53
2	2.60~ 3.97	17.05 21.76	25.48 25.48	0.00 47.24	42.53 0.00
3	3.97~ 4.24	21.76 22.68	25.48 25.48	47.24 56.46	0.00 -8.29

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.37 m (GL -3.97 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	10.27 20.76	0.00 20.58	—— ——	10.27 41.34
2	2.10~ 2.60	20.76 23.26	20.58 20.58	—— ——	41.34 43.84
3	2.60~ 4.24	23.26 31.45	20.58 20.58	0.00 47.17	43.84 4.86
4	4.24~ 4.45	31.45 32.48	20.58 20.58	47.17 53.06	4.86 0.00
5	4.45~ 5.24	32.48 36.45	20.58 20.58	53.06 75.93	0.00 -18.90

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.85 m (GL -4.45 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.92			
Section efficiency	μ	=	0.80			
Young's modulus	E	=	200000 Nmm²			
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)			
	I	=	63296 cm⁴ (after reduction by corrosion and section)			
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$			

	Depth (m)	N-value
1	0.40	3
2	4.24	3
3	5.24	6
4	7.24	13
5	8.24	4
6	9.24	3
7	10.24	5
8	11.24	6
9	12.24	3
10	13.24	2

	Depth (m)	N-value
11	14.24	50
12	17.24	50

5-2 Normal Condition

K_h = 14339 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.410 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.44 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.97 m) to 2.44 m depth (GL -6.41 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.97	0.27	3.0	3.0	0.80
2	4.24	1.00	3.0	6.0	4.50
3	5.24	1.17	6.0	10.1	9.42
L = Σh = 2.44					ΣA = 14.72

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{14.72}{2.44} = 6.04$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 6.04^{0.406} = 14339$ kN/m³

K_h (normal condition) = 14339 kN/m³

5-3 Seismic Condition

K_h = 15623 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.419 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.39 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.44 m) to 2.39 m depth (GL -6.83 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.44	0.80	3.6	6.0	3.82
2	5.24	1.59	6.0	11.6	13.97
L = Σh = 2.39					ΣA = 17.79

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{17.79}{2.39} = 7.46$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.46^{0.406} = 15623$ kN/m³

K_h (seismic condition) = 15623 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.60	2.60	8.11 42.53	10.54 55.29	3.11 2.24	32.75 123.78
2	2.60~ 3.97	1.37	42.53 0.00	29.18 0.00	0.91 0.46	26.70 0.00
				ΣP = 95.01		ΣM = 183.23

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.2 kN/m
depth to acting position	H_t	=	-0.40 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.37 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 9.62$ kN·m

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{192.85}{97.21} = 1.98 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.27 41.34	10.79 43.41	3.74 3.04	40.40 132.17
2	2.10~ 2.60	0.50	41.34 43.84	10.34 10.96	2.18 2.01	22.51 22.04
3	2.60~ 4.24	1.64	43.84 4.86	35.95 3.99	1.30 0.75	46.66 3.00
4	4.24~ 4.44	0.20	4.86 0.00	0.50 0.00	0.14 0.07	0.07 0.00
				ΣP = 115.93		ΣM = 266.84

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.3 kN/m
depth to acting position	H_t	=	-0.22 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.84 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 38.72$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.18 2.01	0.00 0.43
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.43

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{305.99}{124.44} = 2.46 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2= 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	14339 kN/m³
calculated value	β	=	0.41022 m^{-1}
resultant earth force (lateral)	P_0	=	97.21 kN/m
height of acting position of load	h_0	=	1.98 m
moment	M_0	=	192.85 kN·m/m

in consideration of ψ_m= 1.201,

maximum moment	M_{max}	=	231.56 kN·m/m
depth of generated position of M_{max}	l_m	=	0.886 m
depth of 1st fixed point	l_i	=	2.801 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	15623 kN/m³
calculated value	β	=	0.41911 m^{-1}
resultant earth force (lateral)	P_0	=	124.44 kN/m
height of acting position of load	h_0	=	2.46 m
moment	M_0	=	305.99 kN·m/m

in consideration of ψ_m= 1.139,

maximum moment	M_{max}	=	348.64 kN·m/m
depth of generated position of M_{max}	l_m	=	0.753 m
depth of 1st fixed point	l_i	=	2.627 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2= 1.00 mm (passive side)
Corrosion rate	n	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3(original condition)
	Z	=	3514 cm^3(after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{231.56\times10^6}{3514\times10^3} = 66\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2$$

6-3-2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{348.64\times10^6}{3514\times10^3} = 99\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.60	3.11 2.24	0.782 0.564	0.226 0.129	10.54 55.29	2.383 7.132
2	2.60~ 3.97	0.91 0.46	0.230 0.115	0.024 0.006	29.18 0.00	0.715 0.000
						ΣQ= 10.229

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

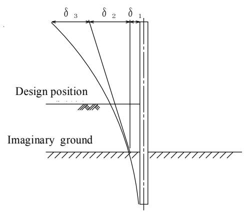
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4102\times1.98)\times97.21}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4102^3} = 0.01009\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4102\times1.98)\times97.21}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4102^2}\times(2.60+1.37) = 0.02382\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.23\times(2.60+1.37)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00507\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00042 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.97 m
Horizontal load: P = 2.20
Moment: M = 0.88

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01009 + 0.02382 + 0.00548$
$= 0.03939$ m
$= 39.39 \leqq \delta a = 50.00$ mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.74 3.04	0.843 0.685	0.255 0.181	10.79 43.41	2.753 7.859
2	2.10~ 2.60	2.18 2.01	0.490 0.453	0.100 0.087	10.34 10.96	1.038 0.953
3	2.60~ 4.24	1.30 0.75	0.292 0.169	0.038 0.013	35.95 3.99	1.384 0.054
4	4.24~ 4.44	0.14 0.07	0.031 0.015	0.000 0.000	0.50 0.00	0.000 0.000
						ΣQ = 14.042

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

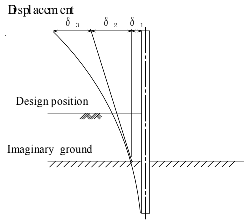
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.18 2.01	0.490 0.453	0.100 0.087	0.00 0.21	0.000 0.019
						ΣQ_{dw} = 0.019

Therefore, modulus of deformation Q is calculated as below
Q = 14.042 + 0.019 = 14.060

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4191\times2.46)\times124.44}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4191^3} = 0.01356\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4191\times2.46)\times124.44}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4191^2}\times(2.60+1.84) = 0.03807\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{14.06\times(2.60+1.84)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00975\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00206 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.44 m
Horizontal load: P = 8.30
Moment: M = 1.83

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01356 + 0.03807 + 0.01181$
$= 0.06344$ m
$= 63.44 \leqq \delta_a = 75.00$ mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 86000 \times 10^{-8}$		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 14339$ kN/m^3
Calculated value	$\beta = 0.37995$ m^{-1}
Penetration length of SSP	$D = 1.37 + \frac{3}{0.380} = 9.27$ m
Whole length of SSP	$L = 2.60 - 0.40 + 9.27 = 11.47$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 15623$ kN/m^3
Calculated value	$\beta = 0.38819$ m^{-1}
Penetration length of SSP	$D = 1.84 + \frac{3}{0.388} = 9.57$ m
Whole length of SSP	$L = 2.60 - 0.40 + 9.57 = 11.77$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

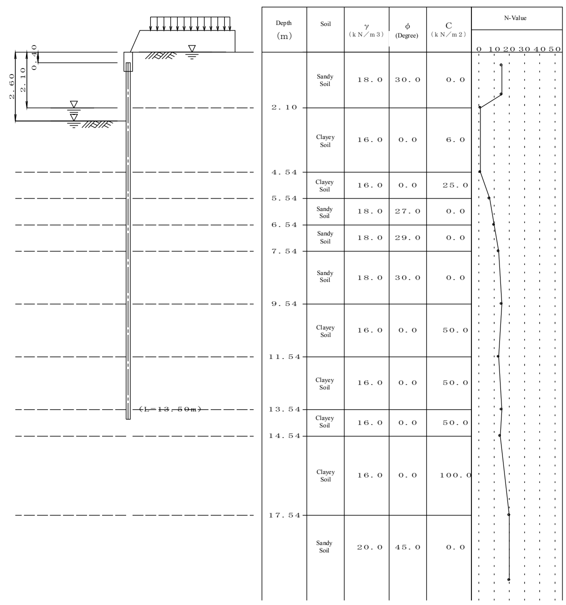
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		231.56	348.64
Stress intensity	σ (N/mm^2)		66 (180)	99 (270)
Lateral displacement	δ (mm)		39.39 (50.0)	63.44 (75.0)
Penetration depth	D (m)		9.27	9.57
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 10_STA_8+400 - 8+510

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed   calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress   Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8\ kN/m^3$

Type of water pressure   trapezoidal water pressure

Lateral pressure   calculated in consideration of site conditions

Study case   - Normal Condition
- Seismic Condition

Design earthquake intensity   k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.2 kN/m (Normal Condition)
		Pt'	=	8.3 kN/m (Seismic Condition)
	Depth of acting point	Ht	=	-0.40 m (Normal Condition)
		Ht'	=	-0.22 m (Seismic Condition)
	Moment	Mm	=	0.0 kN･m/m (Normal Condition)
		Mm'	=	0.0 kN･m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load   not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope   not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value   calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	1
4	4.54	1
5	5.54	7
6	6.54	10
7	7.54	13
8	9.54	15
9	11.54	13
10	13.54	15

No	Depth (m)	N-Value
11	14.54	14
12	17.54	20
13	20.00	20

2.71

1-6 Vertical Load

Vertical load on landside   calculated in consideration of embankment shape on landside

Vertical load on riverside   not considered

1-7 Soil Modulus

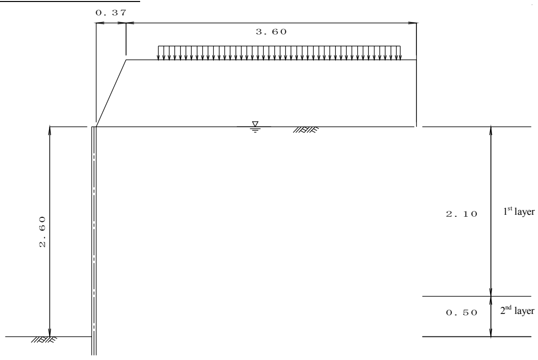
No	Depth (m)	Soil	N-value	γ (kN/m³)	γ' (kN/m³)	ϕ	C (kN/m²)	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m³) normal	kh(kN/m³) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.54	C	1.0	16.00	6.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	5.54	C	7.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
4	6.54	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	7.54	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
6	9.54	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
7	11.54	C	13.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
8	13.54	C	15.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
9	14.54	C	14.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
10	17.54	C	20.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	——	——
11	20.00	S	20.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.37	3.97	3.97	0.83	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.77	3.77	10.0	5.0

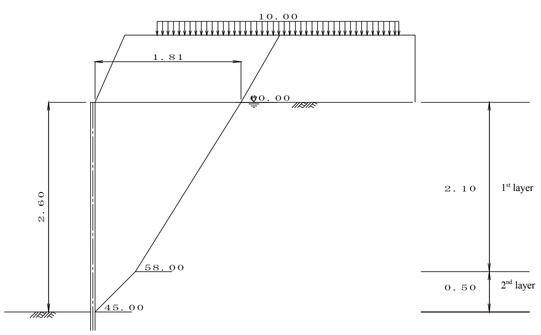
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	154000 cm⁴
Sectional factor	Z_0	=	4160 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.85
Corrosion rate (to Z_0)	η	=	0.87
Section efficiency (to I_0)	μ	=	1.00
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	185 N/mm² (Normal)
	σ_a'	=	275 N/mm² (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	9.0	6.0	24.00	23.79	25.48	45.00
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	23.79	20.58	58.00
3		Embankment	30.0	——	0.0	14.94	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where,

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	58.00	2.10	0.50	0.50	1.81	2.60
3	60.00	0.83	1.81	2.60	2.29	3.43

Therefore, width of acting load shall be set as 1.81m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.55	27.89
Σ			27.89

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

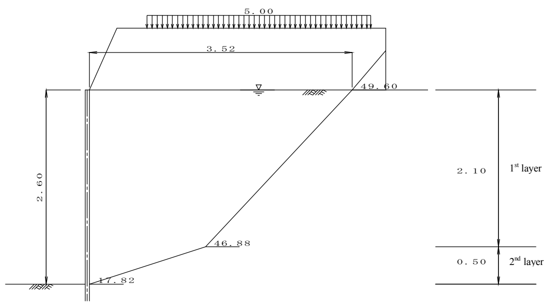
No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.52	15.22
Σ			15.22

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L} = \frac{27.89 + 15.22 + 0.00}{1.81} = 23.79\ \text{kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	9.0	6.0	24.00	19.71	25.48	0.200	11.31	17.82
2	2.10~ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	19.71	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	14.94	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	17.82	0.50	0.00	0.00	1.56	0.50
2	46.88	2.10	1.56	0.50	3.52	2.60
3	49.60	0.53	3.52	2.60	3.97	3.13

Therefore, width of acting load shall be set as 3.52 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.02	54.42
Σ			54.42

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

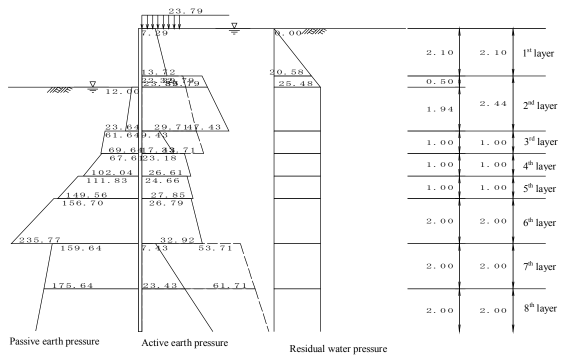
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{54.42 + 15.00 + 0.00}{3.52}$$

$= 19.71$ kN/m²

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	23.786 44.786	0.31026 0.31026	0.30644 0.30644
2	2.10~ 2.60	Clayey soil	6.0	—	6.0 6.0	44.786 47.786	—— ——	—— ——
3	2.60~ 4.54	Clayey soil	6.0	—	6.0 6.0	47.786 59.426	—— ——	—— ——
4	4.54~ 5.54	Clayey soil	8.0	—	25.0 25.0	59.426 67.426	—— ——	—— ——
5	5.54~ 6.54	Sandy soil	10.0	27.0	—— ——	67.426 77.426	0.34800 0.34800	0.34371 0.34371
6	6.54~ 7.54	Sandy soil	10.0	29.0	—— ——	77.426 87.426	0.32248 0.32248	0.31851 0.31851
7	7.54~ 9.54	Sandy soil	10.0	30.0	—— ——	87.426 107.426	0.31026 0.31026	0.30644 0.30644
8	9.54~ 11.54	Clayey soil	8.0	—	50.0 50.0	107.426 123.426	—— ——	—— ——
9	11.54~ 13.54	Clayey soil	8.0	—	50.0 50.0	123.426 139.426	—— ——	—— ——
10	13.54~ 14.54	Clayey soil	8.0	—	50.0 50.0	139.426 147.426	—— ——	—— ——
11	14.54~ 17.54	Clayey soil	8.0	—	100.0 100.0	147.426 171.426	—— ——	—— ——
12	17.54~ 20.00	Sandy soil	10.0	45.0	—— ——	171.426 196.026	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 9.00, β = 0.00, θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 4.54	Clayey soil	6.0	0.0	6.0 6.0	0.000 11.640	—— ——	—— ——
4	4.54~ 5.54	Clayey soil	8.0	0.0	25.0 25.0	11.640 19.640	—— ——	—— ——
5	5.54~ 6.54	Sandy soil	10.0	27.0	—— ——	19.640 29.640	3.48553 3.48553	3.44261 3.44261
6	6.54~ 7.54	Sandy soil	10.0	29.0	—— ——	29.640 39.640	3.82002 3.82002	3.77299 3.77299
7	7.54~ 9.54	Sandy soil	10.0	30.0	—— ——	39.640 59.640	4.00247 4.00247	3.95319 3.95319
8	9.54~ 11.54	Clayey soil	8.0	0.0	50.0 50.0	59.640 75.640	—— ——	—— ——
9	11.54~ 13.54	Clayey soil	8.0	0.0	50.0 50.0	75.640 91.640	—— ——	—— ——
10	13.54~ 14.54	Clayey soil	8.0	0.0	50.0 50.0	91.640 99.640	—— ——	—— ——
11	14.54~ 17.54	Clayey soil	8.0	0.0	100.0 100.0	99.640 123.640	—— ——	—— ——
12	17.54~ 20.00	Sandy soil	10.0	45.0	—— ——	123.640 148.240	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = -9.00, β = 0.00, θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.29 13.72	—— ——	7.29 13.72	0.00 20.58	—— ——
2	2.10~ 2.60	32.79 35.79	22.39 23.89	32.79 35.79	20.58 25.48	—— ——
3	2.60~ 4.54	35.79 47.43	23.89 29.71	35.79 47.43	25.48 25.48	12.00 23.64
4	4.54~ 5.54	9.43 17.43	29.71 33.71	29.71 33.71	25.48 25.48	61.64 69.64
5	5.54~ 6.54	23.18 26.61	—— ——	23.18 26.61	25.48 25.48	67.61 102.04
6	6.54~ 7.54	24.66 27.85	—— ——	24.66 27.85	25.48 25.48	111.83 149.56

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
7	7.54~ 9.54	26.79 32.92	—— ——	26.79 32.92	25.48 25.48	156.70 235.77
8	9.54~ 11.54	7.43 23.43	53.71 61.71	53.71 61.71	25.48 25.48	159.64 175.64
9	11.54~ 13.54	23.43 39.43	61.71 69.71	61.71 69.71	25.48 25.48	175.64 191.64
10	13.54~ 14.54	39.43 47.43	69.71 73.71	69.71 73.71	25.48 25.48	191.64 199.64
11	14.54~ 17.54	-52.57 -28.57	73.71 85.71	73.71 85.71	25.48 25.48	299.64 323.64
12	17.54~ 20.00	27.64 31.60	—— ——	27.64 31.60	25.48 25.48	1082.69 1298.10

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

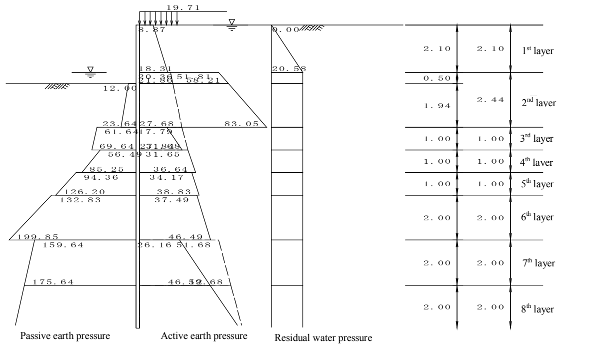
Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$
Clayey soil $P_p = \Sigma \gamma h + Q + 2C$
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	19.71 40.71	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10~ 2.60	Clayey Soil	6.0	——	6.0 6.0	40.71 43.71	20.58 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
3	2.60~ 4.54	Clayey Soil	6.0	——	6.0 6.0	43.71 55.35	25.48 44.49	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
4	4.54~ 5.54	Clayey Soil	8.0	——	25.0 25.0	55.35 63.35	44.49 54.29	0.200 0.200	11.31 11.31	—— ——	—— ——	39.91 39.25
5	5.54~ 6.54	Sandy Soil	10.0	27.0	—— ——	63.35 73.35	54.29 64.09	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	6.54~ 7.54	Sandy Soil	10.0	29.0	—— ——	73.35 83.35	64.09 73.89	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
7	7.54~ 9.54	Sandy Soil	10.0	30.0	—— ——	83.35 103.35	73.89 93.49	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
8	9.54~ 11.54	Clayey Soil	8.0	——	50.0 50.0	103.35 119.35	93.49 113.09	0.200 0.200	11.31 11.31	—— ——	—— ——	40.97 40.35
9	11.54~ 13.54	Clayey Soil	8.0	——	50.0 50.0	119.35 135.35	113.09 132.69	0.200 0.200	11.31 11.31	—— ——	—— ——	40.35 39.71
10	13.54~ 13.78	Clayey Soil	8.0	——	50.0 50.0	135.35 137.26	132.69 ——	0.200 ——	11.31 ——	—— ——	—— ——	39.71
11	13.78~ 14.54	Clayey Soil	8.0	——	50.0 50.0	137.26 143.35	—— 142.49	—— 0.200	—— 11.31	—— ——	—— ——	39.38
12	14.54~ 17.19	Clayey Soil	8.0	——	100.0 100.0	143.35 164.59	142.49 ——	0.200 ——	11.31 ——	—— ——	—— ——	42.45
13	17.19~ 17.54	Clayey Soil	8.0	——	100.0 100.0	164.59 167.35	—— 171.89	—— 0.200	—— 11.31	—— ——	—— ——	42.04
14	17.54~ 20.00	Sandy Soil	10.0	45.0	—— ——	167.35 191.95	171.89 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 9.00, β = 0.00, θ = 0.00

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Qp (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 4.54	Clayey soil	6.00	0.0	6.0 6.0	0.000 11.640	0.00 19.01	0.200 0.200	11.31 11.31	—— ——	—— ——
4	4.54~ 5.54	Clayey soil	8.00	0.0	25.0 25.0	11.640 19.640	19.01 28.81	0.200 0.200	11.31 11.31	—— ——	—— ——
5	5.54~ 6.54	Sandy soil	10.00	27.0	—— ——	19.640 29.640	28.81 38.61	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	6.54~ 7.54	Sandy soil	10.00	29.0	—— ——	29.640 39.640	38.61 48.41	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
7	7.54~ 9.54	Sandy soil	10.00	30.0	—— ——	39.640 59.640	48.41 68.01	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
8	9.54~ 11.54	Clayey soil	8.00	0.0	50.0 50.0	59.640 75.640	68.01 87.61	0.200 0.200	11.31 11.31	—— ——	—— ——
9	11.54~ 13.54	Clayey soil	8.00	0.0	50.0 50.0	75.640 91.640	87.61 107.21	0.200 0.200	11.31 11.31	—— ——	—— ——
10	13.54~ 13.78	Clayey soil	8.00	0.0	50.0 50.0	91.640 93.552	107.21 ——	0.200 ——	11.31 ——	—— ——	—— ——
11	13.78~ 14.54	Clayey soil	8.00	0.0	50.0 50.0	93.552 99.640	—— 117.01	—— 0.200	—— 11.31	—— ——	—— ——
12	14.54~ 17.19	Clayey soil	8.00	0.0	100.0 100.0	99.640 120.873	117.01 ——	0.200 ——	11.31 ——	—— ——	—— ——
13	17.19~ 17.54	Clayey soil	8.00	0.0	100.0 100.0	120.873 123.640	—— 146.41	—— 0.200	—— 11.31	—— ——	—— ——
14	17.54~ 20.00	Sandy soil	10.00	45.0	—— ——	123.640 148.240	146.41 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ = -9.00, β = 0.00, θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
1	0.00~ 2.10	8.87 18.31	—— ——	8.87 18.31	0.00 20.58	—— ——

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
2	2.10~ 2.60	51.81 58.21	20.36 21.86	51.81 58.21	20.58 20.58	—— ——
3	2.60~ 4.54	58.21 83.05	21.86 27.68	58.21 83.05	20.58 20.58	12.00 23.64
4	4.54~ 5.54	17.79 27.84	27.68 31.68	27.68 31.68	20.58 20.58	61.64 69.64
5	5.54~ 6.54	31.65 36.64	—— ——	31.65 36.64	20.58 20.58	56.49 85.25
6	6.54~ 7.54	34.17 38.83	—— ——	34.17 38.83	20.58 20.58	94.36 126.20
7	7.54~ 9.54	37.49 46.49	—— ——	37.49 46.49	20.58 20.58	132.83 199.85
8	9.54~ 11.54	26.16 46.12	51.68 59.68	51.68 59.68	20.58 20.58	159.64 175.64
9	11.54~ 13.54	46.12 66.22	59.68 67.68	59.68 67.68	20.58 20.58	175.64 191.64
10	13.54~ 13.78	66.22 68.63	67.68 68.63	67.68 68.63	20.58 20.58	191.64 193.55
11	13.78~ 14.54	68.63 76.32	68.63 71.68	68.63 76.32	20.58 20.58	193.55 199.64
12	14.54~ 17.19	-26.10 0.00	71.68 82.29	71.68 82.29	20.58 20.58	299.64 320.87
13	17.19~ 17.54	0.00 3.40	82.29 83.68	82.29 83.68	20.58 20.58	320.87 323.64
14	17.54~ 20.00	43.48 49.87	—— ——	43.48 49.87	20.58 20.58	967.50 1160.00

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$
Clayey soil $P_p = \Sigma \gamma h + Q + 2C$
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

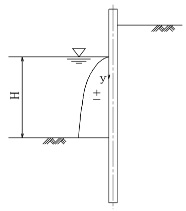
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

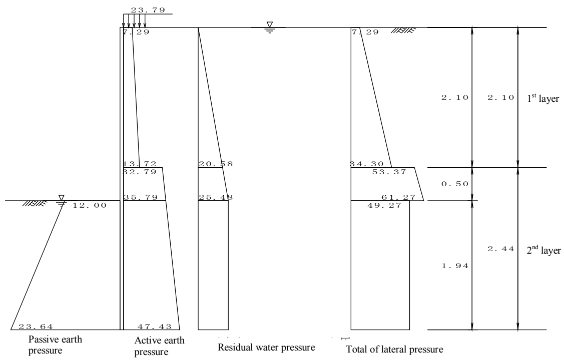
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

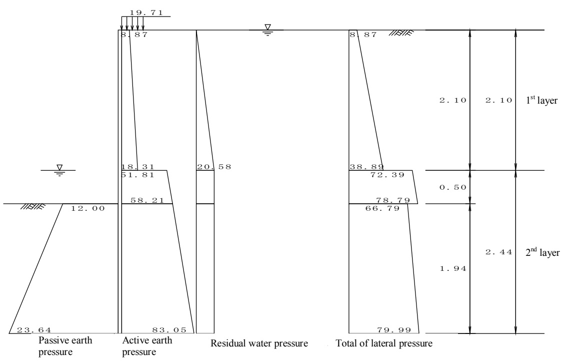


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00~ 2.10	7.29 13.72	0.00 20.58	—— ——	7.29 34.30
2	2.10~ 2.60	32.79 35.79	20.58 25.48	—— ——	53.37 61.27
3	2.60~ 4.54	35.79 47.43	25.48 25.48	12.00 23.64	49.27 49.27
4	4.54~ 5.54	29.71 33.71	25.48 25.48	61.64 69.64	-6.45 -10.45

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.94 m (GL -4.54 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00~ 2.10	8.87 18.31	0.00 20.58	—— ——	8.87 38.89
2	2.10~ 2.60	51.81 58.21	20.58 20.58	—— ——	72.39 78.79
3	2.60~ 4.54	58.21 83.05	20.58 20.58	12.00 23.64	66.79 79.99
4	4.54~ 5.54	27.68 31.68	20.58 20.58	61.64 69.64	-13.38 -17.38

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.94 m (GL -4.54 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	= 1.0000 m	
Corrosion margin	t_1	= 1.00 mm (active side)	t_2 = 1.00 mm (passive side)
Corrosion rate	η	= 0.85	
Section efficiency	μ	= 1.00	
Young's modulus	E	= 200000 N/mm²	
Inertia sectional moment	I_0	= 154000 cm⁴ (original condition)	
	I	= 130900 cm⁴ (after reduction by corrosion and section)	
Inertia sectional moment	EI	= $200000 \times 10^3 \times 130900 \times 10^{-8} = 2.618 \times 10^5$	

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	1
4	4.54	1
5	5.54	7
6	6.54	10
7	7.54	13
8	9.54	15
9	11.54	13
10	13.54	15

	Depth (m)	N-value
11	14.54	14
12	17.54	20
13	20.00	20

5-2 Normal Condition

K_h = 15867 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.351 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.85 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.54 m) to 2.85 m depth (GL -7.39 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	4.54	1.00	1.0	7.0	4.00
2	5.54	1.00	7.0	10.0	8.50
3	6.54	0.85	10.0	12.6	9.59
L = Σh = 2.85			ΣA = 22.09		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{22.09}{2.85}$

$= 7.75$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.75^{0.406} = 15867$ kN/m³

K_h (normal condition) = 15867 kN/m³

5-3 Seismic Condition

K_h = 15867 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.351$ m⁻¹

$$L = \frac{1}{\beta} = 2.85 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.54 m) and 2.85 m depth (GL -7.39 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.54	1.00	1.0	7.0	4.00
2	5.54	1.00	7.0	10.0	8.50
3	6.54	0.85	10.0	12.6	9.59
L = Σh = 2.85					ΣA = 22.09

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{22.09}{2.85}$

$= 7.75$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.75^{0.406} = 15867$ kN/m³

K_h (seismic condition) = 15867 kN/m³

Case: Right Bank No. 10_STA 8+400 - 8+510

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.29 34.30	7.65 36.02	3.84 3.14	29.39 113.10
2	2.10~ 2.60	0.50	53.37 61.27	13.34 15.32	2.27 2.11	30.33 32.27
3	2.60~ 4.54	1.94	49.27 49.27	47.79 47.79	1.29 0.65	61.81 30.90
				ΣP = 167.91		ΣM = 297.79

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 2.2 kN/m
depth to acting position H_t = -0.40 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.94 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.87$ kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{308.66}{170.11} = 1.81 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.87 38.89	9.31 40.84	3.84 3.14	35.75 128.23
2	2.10~ 2.60	0.50	72.39 78.79	18.10 19.70	2.27 2.11	41.14 41.50
3	2.60~ 4.54	1.94	66.79 79.99	64.78 77.59	1.29 0.65	83.79 50.18
				ΣP = 230.32		ΣM = 380.58

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Case: Right Bank No. 10_STA 8+400 - 8+510

Arbitrary load lateral load P_t = 8.3 kN/m
depth to acting position H_t = 0.22 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.94 m
Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 39.51$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.27 2.11	0.00 0.45
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.45

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{420.54}{238.83} = 1.76 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	154000 cm⁴ (original condition)
	I	=	130900 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 130900 \times 10^{-8}$		=	2.618×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

Case: Right Bank No. 10_STA 8+400 - 8+510

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	15867 kN/m³
calculated value	β	=	0.35085 m⁻¹
resultant earth force (lateral)	P_0	=	170.11 kN/m
height of acting position of load	h_0	=	1.81 m
moment	M_0	=	308.66 kN·m/m
in consideration of ψ_m = 1.289,			
maximum moment	M_{max}	=	397.78 kN·m/m
depth of generated position of M_{max}	l_m	=	1.181 m
depth of 1st fixed point	l_i	=	3.420 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	15867 kN/m³
calculated value	β	=	0.35085 m⁻¹
resultant earth force (lateral)	P_0	=	238.83 kN/m
height of acting position of load	h_0	=	1.76 m
moment	M_0	=	420.54 kN·m/m
in consideration of ψ_m = 1.302,			
maximum moment	M_{max}	=	547.35 kN·m/m
depth of generated position of M_{max}	l_m	=	1.199 m
depth of 1st fixed point	l_i	=	3.437 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	4160 cm³ (original condition)
	Z	=	3619 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{397.78 \times 10^6}{3619 \times 10^3} = 110 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{547.35 \times 10^6}{3619 \times 10^3} = 151 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.84 3.14	0.846 0.692	0.257 0.184	7.65 36.02	1.966 6.629
2	2.10~ 2.60	2.27 2.11	0.501 0.464	0.104 0.091	13.34 15.32	1.393 1.394
3	2.60~ 4.54	1.29 0.65	0.285 0.142	0.037 0.010	47.79 47.79	1.755 0.462
						ΣQ = 13.599

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

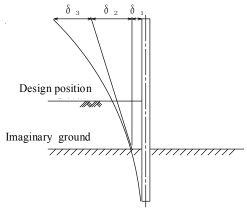
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3509\times 1.81)\times 170.11}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3509^3} = 0.01231 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3509\times 1.81)\times 170.11}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3509^2}\times(2.60+1.94) = 0.02724 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.60\times(2.60+1.94)^3}{2.00\times 10^8\times 130900\times 10^{-8}} = 0.00486 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00030 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.54 m
Horizontal load: P = 2.20
Moment: M = 0.88

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01231＋0.02724＋0.00516
= 0.04471 m
= 44.71 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.84 3.14	0.846 0.692	0.257 0.184	9.31 40.84	2.391 7.516
2	2.10~ 2.60	2.27 2.11	0.501 0.464	0.104 0.091	18.10 19.70	1.890 1.793
3	2.60~ 4.54	1.29 0.65	0.285 0.142	0.037 0.010	64.78 77.59	2.379 0.750
						ΣQ = 16.719

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

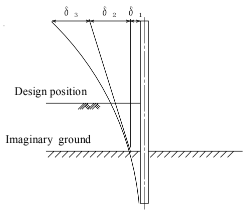
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.27 2.11	0.501 0.464	0.104 0.091	0.00 0.21	0.000 0.020
						ΣQ_{dw} = 0.020

Therefore, modulus of deformation Q is calculated as below:
Q = 16.719＋0.020 = 16.738

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3509\times 1.76)\times 238.83}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3509^3} = 0.01709 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3509\times 1.76)\times 238.83}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3509^2}\times(2.60+1.94) = 0.03761 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{16.74\times(2.60+1.94)^3}{2.00\times 10^8\times 130900\times 10^{-8}} = 0.00598 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00106 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.54 m
Horizontal load: P = 8.30
Moment: M = 1.83

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01709＋0.03761＋0.00704
= 0.06174 m
= 61.74 ≦ δa = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	154000 cm^4 (after reduction by corrosion and section)
$EI = 200000\times10^3\times154000\times10^{-8}$		=	3.080×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 15867\ kN/m^3$
Calculated value	$\beta = 0.33688\ m^{-1}$
Penetration length of SSP	$D = 1.94 + \frac{3}{0.337} = 10.85\ m$
Whole length of SSP	$L = 2.60 - 0.40 + 10.85 = 13.05\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 15867\ kN/m^3$
Calculated value	$\beta = 0.33688\ m^{-1}$
Penetration length of SSP	$D = 1.94 + \frac{3}{0.337} = 10.85\ m$
Whole length of SSP	$L = 2.60 - 0.40 + 10.85 = 13.05\ m$

Therefore, whole length of SSP is set as 13.50 m in consideration of round unit of SSP length.

8 Calculation Result

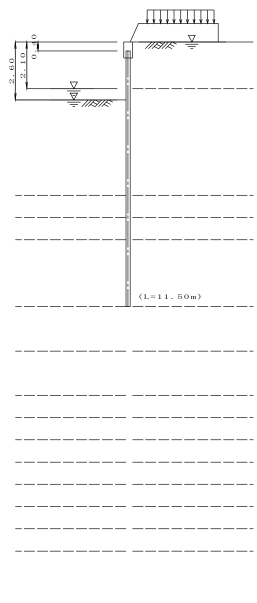
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	154000		
Section modulus	Z (cm^3)	4160		
Maximum bending moment	M_{max} (kN·m/m)		397.78	547.35
Stress intensity	σ (N/mm^2)		110 (185)	151 (278)
Lateral displacement	δ (mm)		44.71 (50.0)	61.74 (75.0)
Penetration depth	D (m)		10.85	10.85
Whole length of SSP	L (m)	13.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 11_STA 8+510 - 8+650

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (degree)	C (kN/m2)	N-Value (0 10 20 30 40 50)
	Sandy Soil	18.0	30.0	0.0	
2.10	Sandy Soil	18.0	27.0	0.0	
6.90	Clayey Soil	16.0	0.0	25.0	
7.90	Clayey Soil	16.0	0.0	6.0	
8.90	Clayey Soil	16.0	0.0	12.0	
11.90	Clayey Soil	16.0	0.0	24.0	
13.90	Clayey Soil	16.0	0.0	30.0	
15.90	Clayey Soil	16.0	0.0	24.0	
16.90	Clayey Soil	16.0	0.0	25.0	
17.90	Clayey Soil	16.0	0.0	25.0	
18.90	Clayey Soil	16.0	0.0	25.0	
19.90	Clayey Soil	16.0	0.0	50.0	
20.90	Clayey Soil	16.0	0.0	100.0	
21.90	Clayey Soil	16.0	0.0	50.0	
22.90	Clayey Soil	16.0	0.0	50.0	

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depth $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.2 kN/m (Normal Condition)
		Pt'	=	8.4 kN/m (Seismic Condition)
	Depth of acting point	Ht	=	-0.40 m (Normal Condition)
		Ht'	=	-0.22 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \dfrac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	4
4	6.90	4
5	7.90	7
6	8.90	1
7	11.90	2
8	13.90	4
9	15.90	6
10	16.90	4

No	Depth (m)	N-Value
11	17.90	5
12	18.90	6
13	19.90	5
14	20.90	11
15	21.90	16
16	22.90	12
17	23.90	13

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

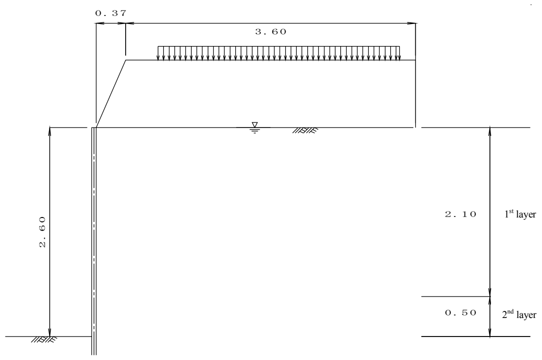
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh (kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	6.90	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	7.90	C	7.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
4	8.90	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
5	11.90	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
6	13.90	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
7	15.90	C	6.0	16.00	8.00	0.0	30.0	0.0	0.200	auto	auto	——	——
8	16.90	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
9	17.90	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
10	18.90	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
11	19.90	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
12	20.90	C	11.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
13	21.90	C	16.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	——	——
14	22.90	C	12.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
15	23.90	C	13.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——

Note)
depth : from top of coping to bottom of the layer
soil : sandy (S), clayey (C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.37	3.97	3.97	0.84	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.77	3.77	10.0	5.0

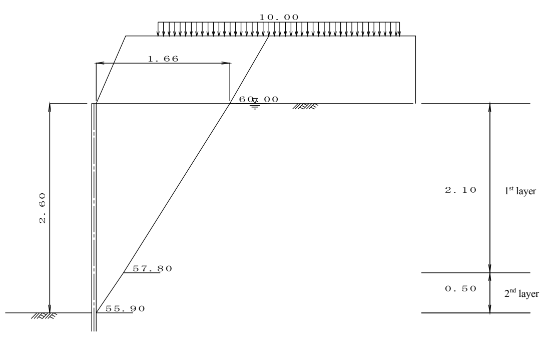
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	86000 cm⁴
Sectional factor	Z_0	=	3820 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 Nmm^2 (Normal)
	σ_a'	=	270 Nmm^2 (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	23.93	25.48	55.90
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	23.93	20.58	57.80
3		Embankment	30.0	——	0.0	15.12	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where,
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C : cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	0.84	1.66	2.60	2.15	3.44

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.44	25.98
Σ			25.98

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.38	13.76
Σ			13.76

Q : surcharge load
l : width of surcharge load set by line of active rupture

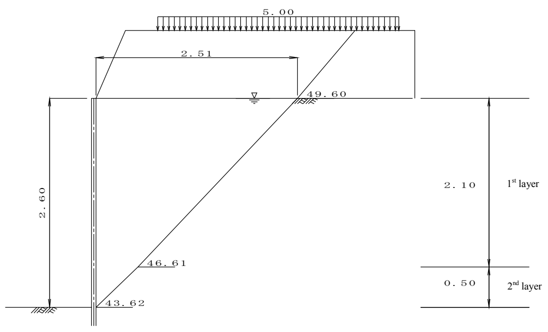
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{25.98 + 13.76 + 0.00}{1.66}$$

$$= 23.93 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	21.05	25.48	0.200	11.31	43.62
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	21.05	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	15.12	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C} \cdot \tan\theta}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C : cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	0.84	2.51	2.60	3.22	3.44

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.25	40.56
Σ			40.56

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.45	12.27
Σ			12.27

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

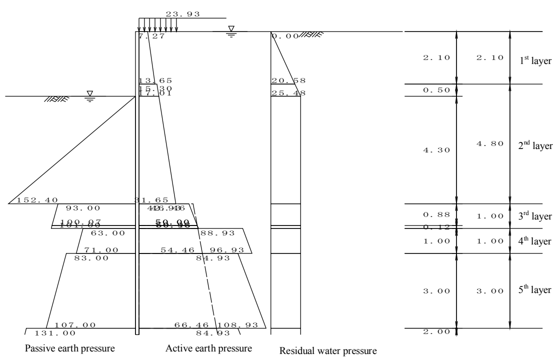
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{40.56 + 12.27 + 0.00}{2.51}$$

$$= 21.05 \ kN/m^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	23.927 44.927	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	44.927 49.927	0.34585 0.34585	0.34060 0.34060
3	2.60~ 6.90	Sandy soil	10.0	27.0	—— ——	49.927 92.927	0.34585 0.34585	0.34060 0.34060
4	6.90~ 7.78	Clayey soil	8.0	—	25.0 25.0	92.927 100.000	—— ——	—— ——
5	7.78~ 7.90	Clayey soil	8.0	—	25.0 25.0	100.000 100.927	—— ——	—— ——
6	7.90~ 8.90	Clayey soil	8.0	—	6.0 6.0	100.927 108.927	—— ——	—— ——
7	8.90~ 11.90	Clayey soil	8.0	—	12.0 12.0	108.927 132.927	—— ——	—— ——
8	11.90~ 13.90	Clayey soil	8.0	—	24.0 24.0	132.927 148.927	—— ——	—— ——
9	13.90~ 15.90	Clayey soil	8.0	—	30.0 30.0	148.927 164.927	—— ——	—— ——
10	15.90~ 16.90	Clayey soil	8.0	—	24.0 24.0	164.927 172.927	—— ——	—— ——
11	16.90~ 17.90	Clayey soil	8.0	—	25.0 25.0	172.927 180.927	—— ——	—— ——
12	17.90~ 18.90	Clayey soil	8.0	—	25.0 25.0	180.927 188.927	—— ——	—— ——
13	18.90~ 19.90	Clayey soil	8.0	—	25.0 25.0	188.927 196.927	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	19.90~ 20.28	Clayey soil	8.0	—	50.0 50.0	196.927 200.000	—— ——	—— ——
15	20.28~ 20.90	Clayey soil	8.0	—	50.0 50.0	200.000 204.927	—— ——	—— ——
16	20.90~ 21.90	Clayey soil	8.0	—	100.0 100.0	204.927 212.927	—— ——	—— ——
17	21.90~ 22.90	Clayey soil	8.0	—	50.0 50.0	212.927 220.927	—— ——	—— ——
18	22.90~ 23.90	Clayey soil	8.0	—	50.0 50.0	220.927 228.927	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 10.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60~ 6.90	Sandy soil	10.0	27.0	—— ——	0.000 43.000	3.59892 3.59892	3.54425 3.54425
4	6.90~ 7.78	Clayey soil	8.0	0.0	25.0 25.0	43.000 50.073	—— ——	—— ——
5	7.78~ 7.90	Clayey soil	8.0	0.0	25.0 25.0	50.073 51.000	—— ——	—— ——
6	7.90~ 8.90	Clayey soil	8.0	0.0	6.0 6.0	51.000 59.000	—— ——	—— ——
7	8.90~ 11.90	Clayey soil	8.0	0.0	12.0 12.0	59.000 83.000	—— ——	—— ——
8	11.90~ 13.90	Clayey soil	8.0	0.0	24.0 24.0	83.000 99.000	—— ——	—— ——
9	13.90~ 15.90	Clayey soil	8.0	0.0	30.0 30.0	99.000 115.000	—— ——	—— ——
10	15.90~ 16.90	Clayey soil	8.0	0.0	24.0 24.0	115.000 123.000	—— ——	—— ——
11	16.90~ 17.90	Clayey soil	8.0	0.0	25.0 25.0	123.000 131.000	—— ——	—— ——
12	17.90~ 18.90	Clayey soil	8.0	0.0	25.0 25.0	131.000 139.000	—— ——	—— ——
13	18.90~ 19.90	Clayey soil	8.0	0.0	25.0 25.0	139.000 147.000	—— ——	—— ——
14	19.90~ 20.28	Clayey soil	8.0	0.0	50.0 50.0	147.000 150.073	—— ——	—— ——
15	20.28~ 20.90	Clayey soil	8.0	0.0	50.0 50.0	150.073 155.000	—— ——	—— ——
16	20.90~ 21.90	Clayey soil	8.0	0.0	100.0 100.0	155.000 163.000	—— ——	—— ——
17	21.90~ 22.90	Clayey soil	8.0	0.0	50.0 50.0	163.000 171.000	—— ——	—— ——
18	22.90~ 23.90	Clayey soil	8.0	0.0	50.0 50.0	171.000 179.000	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	7.27 13.65	—— ——	7.27 13.65	0.00 20.58	—— ——
2	2.10~ 2.60	15.30 17.01	—— ——	15.30 17.01	20.58 25.48	—— ——
3	2.60~ 6.90	17.01 31.65	—— ——	17.01 31.65	25.48 25.48	0.00 152.40
4	6.90~ 7.78	42.93 50.00	46.46 50.00	46.46 50.00	25.48 25.48	93.00 100.07
5	7.78~ 7.90	50.00 50.93	50.00 50.46	50.00 50.93	25.48 25.48	100.07 101.00
6	7.90~ 8.90	88.93 96.93	50.46 54.46	88.93 96.93	25.48 25.48	63.00 71.00
7	8.90~ 11.90	84.93 108.93	54.46 66.46	84.93 108.93	25.48 25.48	83.00 107.00
8	11.90~ 13.90	84.93 100.93	66.46 74.46	84.93 100.93	25.48 25.48	131.00 147.00
9	13.90~ 15.90	88.93 104.93	74.46 82.46	88.93 104.93	25.48 25.48	159.00 175.00
10	15.90~ 16.90	116.93 124.93	82.46 86.46	116.93 124.93	25.48 25.48	163.00 171.00
11	16.90~ 17.90	122.93 130.93	86.46 90.46	122.93 130.93	25.48 25.48	173.00 181.00
12	17.90~ 18.90	130.93 138.93	90.46 94.46	130.93 138.93	25.48 25.48	181.00 189.00
13	18.90~ 19.90	138.93 146.93	94.46 98.46	138.93 146.93	25.48 25.48	189.00 197.00
14	19.90~ 20.28	96.93 100.00	98.46 100.00	98.46 100.00	25.48 25.48	247.00 250.07
15	20.28~ 20.90	100.00 104.93	100.00 102.46	100.00 104.93	25.48 25.48	250.07 255.00
16	20.90~ 21.90	4.93 12.93	102.46 106.46	102.46 106.46	25.48 25.48	355.00 363.00
17	21.90~ 22.90	112.93 120.93	106.46 110.46	112.93 120.93	25.48 25.48	263.00 271.00
18	22.90~ 23.90	120.93 128.93	110.46 114.46	120.93 128.93	25.48 25.48	271.00 279.00

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$
$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

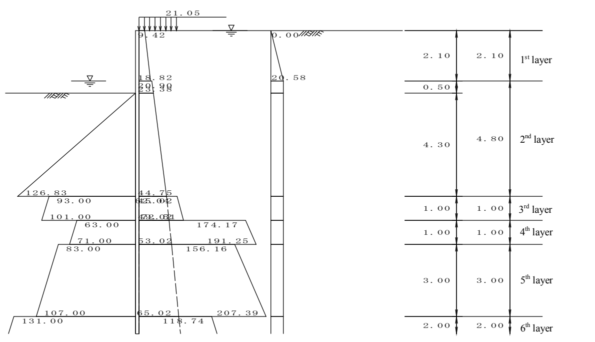
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	ζ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	21.05 42.05	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	27.0	—— ——	42.05 47.05	20.58 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.60~ 6.90	Sandy Soil	10.0	27.0	—— ——	47.05 90.05	25.48 67.62	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	6.90~ 7.90	Clayey Soil	8.0	—	25.0 25.0	90.05 98.05	67.62 77.42	0.200 0.200	11.31 11.31	—— ——	—— ——	36.70 35.89
5	7.90~ 8.90	Clayey Soil	8.0	—	6.0 6.0	98.05 106.05	77.42 87.22	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
6	8.90~ 11.90	Clayey Soil	8.0	—	12.0 12.0	106.05 130.05	87.22 116.62	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
7	11.90~ 13.90	Clayey Soil	8.0	—	24.0 24.0	130.05 146.05	116.62 136.22	0.200 0.200	11.31 11.31	—— ——	—— ——	31.33 28.86
8	13.90~ 15.90	Clayey Soil	8.0	—	30.0 30.0	146.05 162.05	136.22 155.82	0.200 0.200	11.31 11.31	—— ——	—— ——	33.65 31.97
9	15.90~ 16.90	Clayey Soil	8.0	—	24.0 24.0	162.05 170.05	155.82 165.62	0.200 0.200	11.31 11.31	—— ——	—— ——	25.96 24.29
10	16.90~ 17.90	Clayey Soil	8.0	—	25.0 25.0	170.05 178.05	165.62 175.42	0.200 0.200	11.31 11.31	—— ——	—— ——	25.89 24.29
11	17.90~ 18.90	Clayey Soil	8.0	—	25.0 25.0	178.05 186.05	175.42 185.22	0.200 0.200	11.31 11.31	—— ——	—— ——	24.29 22.50
12	18.90~ 19.90	Clayey Soil	8.0	—	25.0 25.0	186.05 194.05	185.22 195.02	0.200 0.200	11.31 11.31	—— ——	—— ——	22.50 20.49
13	19.90~ 20.90	Clayey Soil	8.0	—	50.0 50.0	194.05 202.05	195.02 204.82	0.200 0.200	11.31 11.31	—— ——	—— ——	37.05 36.66

2.82

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	ζ (degree)
14	20.90~ 21.90	Clayey Soil	8.0	—	100.0 100.0	202.05 210.05	204.82 214.62	0.200 0.200	11.31 11.31	—— ——	—— ——	41.39 41.25
15	21.90~ 22.90	Clayey Soil	8.0	—	50.0 50.0	210.05 218.05	214.62 224.42	0.200 0.200	11.31 11.31	—— ——	—— ——	36.25 35.84
16	22.90~ 23.90	Clayey Soil	8.0	—	50.0 50.0	218.05 226.05	224.42 234.22	0.200 0.200	11.31 11.31	—— ——	—— ——	35.84 35.42

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= tan⁻¹k

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta=\tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 6.90	Sandy soil	10.00	27.0	—— ——	0.000 43.000	0.00 42.14	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
4	6.90~ 7.90	Clayey soil	8.00	0.0	25.0 25.0	43.000 51.000	42.14 51.94	0.200 0.200	11.31 11.31	—— ——	—— ——
5	7.90~ 8.90	Clayey soil	8.00	0.0	6.0 6.0	51.000 59.000	51.94 61.74	0.200 0.200	11.31 11.31	—— ——	—— ——
6	8.90~ 11.90	Clayey soil	8.00	0.0	12.0 12.0	59.000 83.000	61.74 91.14	0.200 0.200	11.31 11.31	—— ——	—— ——
7	11.90~ 13.90	Clayey soil	8.00	0.0	24.0 24.0	83.000 99.000	91.14 110.74	0.200 0.200	11.31 11.31	—— ——	—— ——
8	13.90~ 15.90	Clayey soil	8.00	0.0	30.0 30.0	99.000 115.000	110.74 130.34	0.200 0.200	11.31 11.31	—— ——	—— ——
9	15.90~ 16.90	Clayey soil	8.00	0.0	24.0 24.0	115.000 123.000	130.34 140.14	0.200 0.200	11.31 11.31	—— ——	—— ——
10	16.90~ 17.90	Clayey soil	8.00	0.0	25.0 25.0	123.000 131.000	140.14 149.94	0.200 0.200	11.31 11.31	—— ——	—— ——
11	17.90~ 18.90	Clayey soil	8.00	0.0	25.0 25.0	131.000 139.000	149.94 159.74	0.200 0.200	11.31 11.31	—— ——	—— ——
12	18.90~ 19.90	Clayey soil	8.00	0.0	25.0 25.0	139.000 147.000	159.74 169.54	0.200 0.200	11.31 11.31	—— ——	—— ——
13	19.90~ 20.90	Clayey soil	8.00	0.0	50.0 50.0	147.000 155.000	169.54 179.34	0.200 0.200	11.31 11.31	—— ——	—— ——
14	20.90~ 21.90	Clayey soil	8.00	0.0	100.0 100.0	155.000 163.000	179.34 189.14	0.200 0.200	11.31 11.31	—— ——	—— ——
15	21.90~ 22.90	Clayey soil	8.00	0.0	50.0 50.0	163.000 171.000	189.14 198.94	0.200 0.200	11.31 11.31	—— ——	—— ——
16	22.90~ 23.90	Clayey soil	8.00	0.0	50.0 50.0	171.000 179.000	198.94 208.74	0.200 0.200	11.31 11.31	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.
δ= -10.00, β= 0.00, θ= tan⁻¹k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	9.42 18.82	—— ——	9.42 18.82	0.00 20.58	—— ——
2	2.10~ 2.60	20.90 23.38	—— ——	20.90 23.38	20.58 20.58	—— ——
3	2.60~ 6.90	23.38 44.75	—— ——	23.38 44.75	20.58 20.58	0.00 126.83
4	6.90~ 7.90	62.04 72.51	45.02 49.02	62.04 72.51	20.58 20.58	93.00 101.00
5	7.90~ 8.90	174.17 191.25	49.02 53.02	174.17 191.25	20.58 20.58	63.00 71.00
6	8.90~ 11.90	156.16 207.39	53.02 65.02	156.16 207.39	20.58 20.58	83.00 107.00
7	11.90~ 13.90	118.74 142.27	65.02 73.02	118.74 142.27	20.58 20.58	131.00 147.00
8	13.90~ 15.90	124.89 147.18	73.02 81.02	124.89 147.18	20.58 20.58	159.00 175.00
9	15.90~ 16.90	167.63 181.39	81.02 85.02	167.63 181.39	20.58 20.58	163.00 171.00
10	16.90~ 17.90	176.47 190.28	85.02 89.02	176.47 190.28	20.58 20.58	173.00 181.00
11	17.90~ 18.90	190.28 205.17	89.02 93.02	190.28 205.17	20.58 20.58	181.00 189.00
12	18.90~ 19.90	205.17 221.67	93.02 97.02	205.17 221.67	20.58 20.58	189.00 197.00
13	19.90~ 20.90	141.48 151.95	97.02 101.02	141.48 151.95	20.58 20.58	247.00 255.00
14	20.90~ 21.90	46.30 56.23	101.02 105.02	101.02 105.02	20.58 20.58	355.00 363.00
15	21.90~ 22.90	162.49 173.08	105.02 109.02	162.49 173.08	20.58 20.58	263.00 271.00
16	22.90~ 23.90	173.08 183.75	109.02 113.02	173.08 183.75	20.58 20.58	271.00 279.00

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

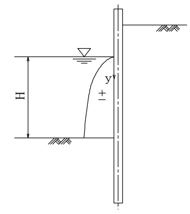
Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.10 2.60	0.00 0.50	0.00 0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

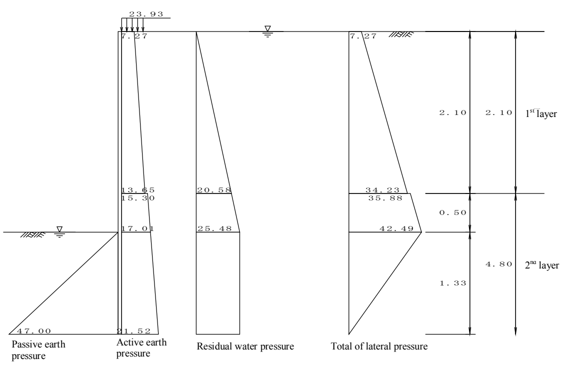
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

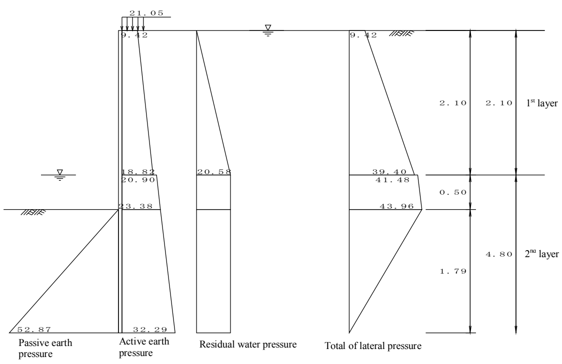


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.10	7.27 13.65	0.00 20.58	—— ——	7.27 34.23
2	2.10~ 2.60	15.30 17.01	20.58 25.48	—— ——	35.88 42.49
3	2.60~ 3.93	17.01 21.52	25.48 25.48	0.00 47.00	42.49 0.00
4	3.93~ 6.90	21.52 31.65	25.48 25.48	47.00 152.40	0.00 -95.27

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.33 m (GL -3.93 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.10	9.42 18.82	0.00 20.58	—— ——	9.42 39.40
2	2.10~ 2.60	20.90 23.38	20.58 20.58	—— ——	41.48 43.96
3	2.60~ 4.39	23.38 32.29	20.58 20.58	0.00 52.87	43.96 0.00
4	4.39~ 6.90	32.29 44.75	20.58 20.58	52.87 126.83	0.00 -61.50

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.79 m (GL -4.39 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} = 1.266×10^5

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	17.90	5
2	1.60	15	12	18.90	6
3	2.10	4	13	19.90	5
4	6.90	4	14	20.90	11
5	7.90	7	15	21.90	16
6	8.90	1	16	22.90	12
7	11.90	2	17	23.90	13
8	13.90	4			
9	15.90	6			
10	16.90	4			

5-2 Normal Condition

K_h = 12131 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.393 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.54 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) to 2.54 m depth (GL -6.47 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.93	2.54	4.0	4.0	10.17
	L = Σh = 2.54				ΣA = 10.17

A (upper N-value + lower N-value) × h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{10.17}{2.54} = 4.00$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 4.00^{0.406} = 12131 \text{ kN/m}^3$$

K_h (normal condition) = 12131 kNm^3

5-3 Seismic Condition

K_h = 12132 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.393 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.54 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.39 m) to 2.34 m depth (GL -6.74 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.39	2.51	4.0	4.0	10.03
2	6.90	0.03	4.0	4.1	0.14
	L = Σh = 2.54				ΣA = 10.17

A (upper N-value + lower N-value) × h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{10.17}{2.54} = 4.00$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 4.00^{0.406} = 12132 \text{ kN/m}^3$$

K_h (seismic condition) = 12132 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.27 34.23	7.63 35.94	3.23 2.53	24.62 90.79
2	2.10~ 2.60	0.50	35.88 42.49	8.97 10.62	1.66 1.49	14.89 15.86
3	2.60~ 3.93	1.33	42.49 0.00	28.17 0.00	0.88 0.44	24.91 0.00
				ΣP = 91.33		ΣM = 171.06

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.2 kNm
depth to acting position	H_t	=	-0.40 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.33 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 9.52 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{180.58}{93.53} = 1.93 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.42 39.40	9.89 41.37	3.69 2.99	36.52 123.79
2	2.10~ 2.60	0.50	41.48 43.96	10.37 10.99	2.13 1.96	22.04 21.53
3	2.60~ 4.39	1.79	43.96 0.00	39.40 0.00	1.19 0.60	47.08 0.00
				ΣP = 112.02		ΣM = 250.96

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.4 kNm
depth to acting position	H_t	=	-0.22 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.79 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 38.74 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.13 1.96	0.00 0.42
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.42

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{290.13}{120.63} = 2.41 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63296 \times 10^{-8}$		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	12132 kN/m^3
calculated value	β	=	0.39343 m^{-1}
resultant earth force (lateral)	P_0	=	93.53 kN/m
height of acting position of load	h_0	=	1.93 m
moment	M_0	=	180.58 kN·m/m

in consideration of ψ_m = 1.223,

maximum moment	M_{max}	=	220.79 kN·m/m
depth of generated position of M_{max}	l_m	=	0.961 m
depth of 1st fixed point	l_i	=	2.957 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	12132 kN/m^3
calculated value	β	=	0.39343 m^{-1}
resultant earth force (lateral)	P_0	=	120.63 kN/m
height of acting position of load	h_0	=	2.41 m
moment	M_0	=	290.13 kN·m/m

in consideration of ψ_m = 1.159,

maximum moment	M_{max}	=	336.35 kN·m/m
depth of generated position of M_{max}	l_m	=	0.846 m
depth of 1st fixed point	l_i	=	2.842 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{220.79\times10^6}{3514\times10^3} = 63\ \text{N/mm}^2 \leqq \sigma_a = 180\ \text{N/mm}^2$$

6-3-2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{336.35\times10^6}{3514\times10^3} = 96\ \text{N/mm}^2 \leqq \sigma_a = 270\ \text{N/mm}^2$$

6-4 Displacement

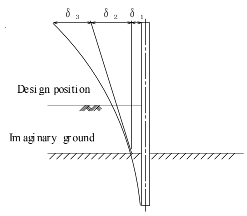
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.23 2.53	0.822 0.643	0.245 0.163	7.63 35.94	1.871 5.844
2	2.10~ 2.60	1.66 1.49	0.423 0.380	0.077 0.063	8.97 10.62	0.688 0.670
3	2.60~ 3.93	0.88 0.44	0.225 0.113	0.023 0.006	28.17 0.00	0.661 0.000
						ΣQ = 9.734

- Y : Height from imaginary riverbed to acting position
- α : $\alpha = \dfrac{Y}{H+L_k}$
- ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
- Q : $\zeta \times P$
- P : Lateral force
- H : Depth to design position
- L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3934\times1.93)\times93.53}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3934^3} = 0.01067\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3934\times1.93)\times93.53}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3934^2}\times(2.60+1.33) = 0.02361\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.73\times(2.60+1.33)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00465\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00040 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.93 m
Horizontal load: P = 2.20
Moment: M = 0.88

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01067 + 0.02361 + 0.00506$
$= 0.03934$ m
$= 39.34 \leqq \delta_a = 50.00$ mm

Where,
- δ_1 : Displacement at imaginary ground
- δ_2 : Displacement by angle of inclination slope at imaginary ground
- δ_3 : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

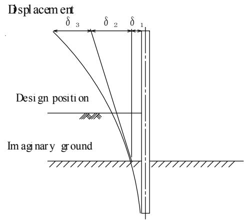
	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.69 2.99	0.841 0.681	0.254 0.179	9.89 41.37	2.515 7.420
2	2.10~ 2.60	2.13 1.96	0.484 0.446	0.098 0.085	10.37 10.99	1.018 0.931
3	2.60~ 4.39	1.19 0.60	0.272 0.136	0.034 0.009	39.40 0.00	1.326 0.000
						ΣQ = 13.210

- Y : Height from imaginary riverbed to acting position
- α : $\alpha = \dfrac{Y}{H+L_k}$
- ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
- Q : $\zeta \times P$
- P : Lateral force
- H : Depth to design position
- L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.13 1.96	0.484 0.446	0.098 0.085	0.00 0.21	0.000 0.018
						ΣQ_{dw} = 0.018

Therefore, modulus of deformation Q is calculated as below
$Q = 13.210 + 0.018 = 13.228$



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3934\times 2.41)\times 120.63}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3934^3} = 0.01523\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3934\times 2.41)\times 120.63}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3934^2}\times(2.60+1.79) = 0.03911\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.23\times(2.60+1.79)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00886\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00202 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.39 m
Horizontal load: P = 8.40
Moment: M = 1.85

$\delta = \delta_1 + \delta_2 + \delta_3$
= 00.01523 + 0.03911 + 0.01087
= 0.06521 m
= 65.21 $\leqq \delta_a$ = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 12131 kN/m^3
Calculated value β = 0.36440 m^{-1}

Penetration length of SSP $D = 1.33 + \frac{3}{0.364} = 9.56$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.56 = 11.76$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 12132 kN/m^3
Calculated value β = 0.36441 m^{-1}

Penetration length of SSP $D = 1.79 + \frac{3}{0.364} = 10.03$ m
Whole length of SSP $L = 2.60 - 0.40 + 10.03 = 12.23$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

8 Calculation Result

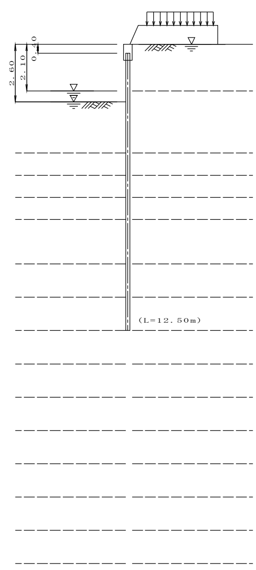
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		220.79	336.35
Stress intensity	σ (N/mm^2)		63 (180)	96 (270)
Lateral displacement	δ (mm)		39.34 (50.0)	65.21 (75.0)
Penetration depth	D (m)		9.56	10.03
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 12_STA 8+650 - 8+800

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	N-Value
	Sandy Soil	18.0	30.0	0.0
2.10	Clayey Soil	16.0	0.0	15.0
4.90	Sandy Soil	18.0	27.0	0.0
5.90	Sandy Soil	18.0	27.0	0.0
6.90	Sandy Soil	18.0	28.0	0.0
7.90	Sandy Soil	18.0	27.0	0.0
9.90	Sandy Soil	18.0	27.0	0.0
11.40	Clayey Soil	16.0	0.0	24.0
12.90	Clayey Soil	16.0	0.0	24.0
14.40	Clayey Soil	16.0	0.0	18.0
15.90	Clayey Soil	16.0	0.0	24.0
17.40	Clayey Soil	16.0	0.0	18.0
18.90	Clayey Soil	16.0	0.0	24.0
20.40	Clayey Soil	16.0	0.0	24.0
21.90	Clayey Soil	16.0	0.0	25.0
23.40	Clayey Soil	16.0	0.0	25.0

N値: 0 10 20 30 40 50

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wn}	=	2.60 m (Normal Condition)
	L_{wn}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depth $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.2 kNm (Normal Condition)
		Pt'	=	8.4 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.41 m (Normal Condition)
		Ht'	=	-0.23 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression $K_e = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	2
4	4.90	2
5	5.90	7
6	6.90	10
7	7.90	11
8	11.40	2
9	12.90	4
10	14.40	4

No	Depth (m)	N-Value
11	15.90	3
12	17.40	4
13	18.90	3
14	20.40	4
15	21.90	4
16	23.40	5
17	23.90	6

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.90	C	2.0	16.00	8.00	0.0	15.0	0.0	0.200	auto	auto	——	——
3	5.90	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	6.90	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	7.90	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
6	9.90	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	11.40	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	12.90	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
9	14.40	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
10	15.90	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
11	17.40	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
12	18.90	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
13	20.40	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
14	21.90	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
15	23.40	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
16	23.90	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——

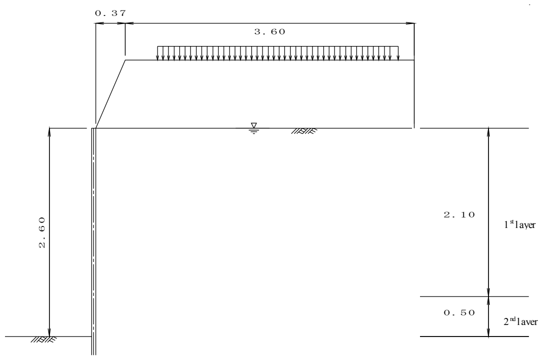
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ ': saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

2.87

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m³)	Normal	Seismic
1	Sandy soil	0.00	0.37	3.97	3.97	0.85	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m³)	Seismic (kN/m³)
1	0.77	3.77	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

Case: Right Bank No. 12_STA 8+650 – 8+800

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 114000 cm⁴
Sectional factor Z_0 = 3250 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.84
Corrosion rate (to Z_0) η = 0.87
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 N/mm² (Normal)
σ_a' = 278 N/mm² (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

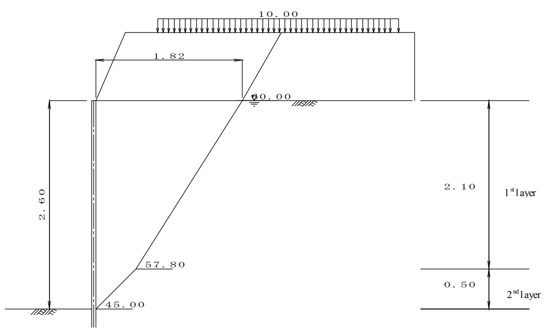
Bending of cantilever beam: calculated as distributed load of each layer

Reduction of material modulus:
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

Case: Right Bank No. 12_STA 8+650 – 8+800

2 Calculation of Acting Load
2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m³)	$\Sigma\gamma h$ (kN/m³)	Q (kN/m³)	$\gamma_w h_w$ (kN/m³)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	15.0	25.00	24.27	25.48	45.00
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	24.27	20.58	57.80
3		Embankment	30.0	——	0.0	15.30	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C : cohesive force of soil (kN/m²)

Case: Right Bank No. 12_STA 8+650 – 8+800

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	0.85	1.82	2.60	2.31	3.45

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.60	28.81
Σ			28.81

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m³)	l (m)	Q X l (kN/m)
1	10.0	1.54	15.43
Σ			15.43

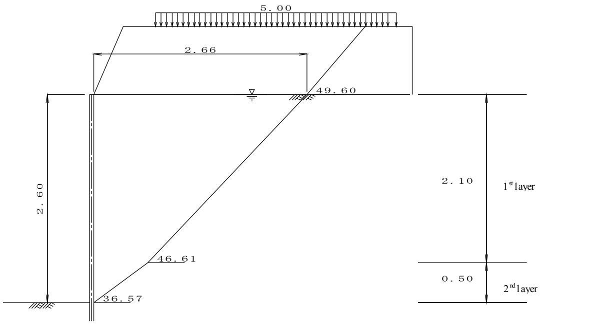
Q : surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{28.81 + 15.43 + 0.00}{1.82}$$

$$= 24.27 \text{ kN/m}^2$$



2-2 Earthquake Condition

2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m³)	Σγh (kN/m³)	Q (kN/m³)	γwhw (kN/m³)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	15.0	25.00	21.23	25.48	0.200	11.31	36.57
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	21.23	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	15.30	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{0}$)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C : cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	36.57	0.50	0.00	0.00	0.67	0.50
2	46.61	2.10	0.67	0.50	2.66	2.60
3	49.60	0.85	2.66	2.60	3.38	3.45

Therefore, width of acting load shall be set as 2.66 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.41	43.39
Σ			43.39

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.61	13.06
Σ			13.06

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

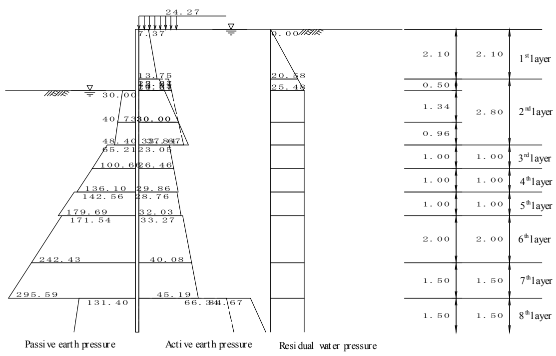
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{43.39 + 13.06 + 0.00}{2.66}$$

$$= 21.23 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	24.275 45.275	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Clayey soil	8.0	—	15.0 15.0	45.275 49.275	—— ——	—— ——
3	2.60~ 3.94	Clayey soil	8.0	—	15.0 15.0	49.275 60.000	—— ——	—— ——
4	3.94~ 4.90	Clayey soil	8.0	—	15.0 15.0	60.000 67.675	—— ——	—— ——
5	4.90~ 5.90	Sandy soil	10.0	27.0	—— ——	67.675 77.675	0.34585 0.34585	0.34060 0.34060
6	5.90~ 6.90	Sandy soil	10.0	27.0	—— ——	77.675 87.675	0.34585 0.34585	0.34060 0.34060
7	6.90~ 7.90	Sandy soil	10.0	28.0	—— ——	87.675 97.675	0.33303 0.33303	0.32798 0.32798
8	7.90~ 9.90	Sandy soil	10.0	27.0	—— ——	97.675 117.675	0.34585 0.34585	0.34060 0.34060
9	9.90~ 11.40	Sandy soil	10.0	27.0	—— ——	117.675 132.675	0.34585 0.34585	0.34060 0.34060
10	11.40~ 12.90	Clayey soil	8.0	—	24.0 24.0	132.675 144.675	—— ——	—— ——
11	12.90~ 14.40	Clayey soil	8.0	—	24.0 24.0	144.675 156.675	—— ——	—— ——
12	14.40~ 15.90	Clayey soil	8.0	—	18.0 18.0	156.675 168.675	—— ——	—— ——
13	15.90~ 17.40	Clayey soil	8.0	—	24.0 24.0	168.675 180.675	—— ——	—— ——
14	17.40~ 18.90	Clayey soil	8.0	—	18.0 18.0	180.675 192.675	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
15	18.90~ 20.40	Clayey soil	8.0	—	24.0 24.0	192.675 204.675	—— ——	—— ——
16	20.40~ 21.90	Clayey soil	8.0	—	24.0 24.0	204.675 216.675	—— ——	—— ——
17	21.90~ 23.40	Clayey soil	8.0	—	25.0 25.0	216.675 228.675	—— ——	—— ——
18	23.40~ 23.90	Clayey soil	8.0	—	25.0 25.0	228.675 232.675	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 10.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60~ 3.94	Clayey soil	8.0	0.0	15.0 15.0	0.000 10.725	—— ——	—— ——
4	3.94~ 4.90	Clayey soil	8.0	0.0	15.0 15.0	10.725 18.400	—— ——	—— ——
5	4.90~ 5.90	Sandy soil	10.0	27.0	—— ——	18.400 28.400	3.59892 3.59892	3.54425 3.54425
6	5.90~ 6.90	Sandy soil	10.0	27.0	—— ——	28.400 38.400	3.59892 3.59892	3.54425 3.54425
7	6.90~ 7.90	Sandy soil	10.0	28.0	—— ——	38.400 48.400	3.76978 3.76978	3.71251 3.71251
8	7.90~ 9.90	Sandy soil	10.0	27.0	—— ——	48.400 68.400	3.59892 3.59892	3.54425 3.54425
9	9.90~ 11.40	Sandy soil	10.0	27.0	—— ——	68.400 83.400	3.59892 3.59892	3.54425 3.54425
10	11.40~ 12.90	Clayey soil	8.0	0.0	24.0 24.0	83.400 95.400	—— ——	—— ——
11	12.90~ 14.40	Clayey soil	8.0	0.0	24.0 24.0	95.400 107.400	—— ——	—— ——
12	14.40~ 15.90	Clayey soil	8.0	0.0	18.0 18.0	107.400 119.400	—— ——	—— ——
13	15.90~ 17.40	Clayey soil	8.0	0.0	24.0 24.0	119.400 131.400	—— ——	—— ——
14	17.40~ 18.90	Clayey soil	8.0	0.0	18.0 18.0	131.400 143.400	—— ——	—— ——
15	18.90~ 20.40	Clayey soil	8.0	0.0	24.0 24.0	143.400 155.400	—— ——	—— ——
16	20.40~ 21.90	Clayey soil	8.0	0.0	24.0 24.0	155.400 167.400	—— ——	—— ——
17	21.90~ 23.40	Clayey soil	8.0	0.0	25.0 25.0	167.400 179.400	—— ——	—— ——
18	23.40~ 23.90	Clayey soil	8.0	0.0	25.0 25.0	179.400 183.400	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m^2)	Pa2 (kN/m^2)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)
1	0.00~ 2.10	7.37 13.75	—— ——	7.37 13.75	0.00 20.58	—— ——
2	2.10~ 2.60	15.27 19.27	22.64 24.64	22.64 24.64	20.58 25.48	—— ——
3	2.60~ 3.94	19.27 30.00	24.64 30.00	24.64 30.00	25.48 25.48	30.00 40.73
4	3.94~ 4.90	30.00 37.67	30.00 33.84	30.00 37.67	25.48 25.48	40.73 48.40
5	4.90~ 5.90	23.05 26.46	—— ——	23.05 26.46	25.48 25.48	65.21 100.66
6	5.90~ 6.90	26.46 29.86	—— ——	26.46 29.86	25.48 25.48	100.66 136.10
7	6.90~ 7.90	28.76 32.03	—— ——	28.76 32.03	25.48 25.48	142.56 179.69
8	7.90~ 9.90	33.27 40.08	—— ——	33.27 40.08	25.48 25.48	171.54 242.43
9	9.90~ 11.40	40.08 45.19	—— ——	40.08 45.19	25.48 25.48	242.43 295.59
10	11.40~ 12.90	84.67 96.67	66.34 72.34	84.67 96.67	25.48 25.48	131.40 143.40
11	12.90~ 14.40	96.67 108.67	72.34 78.34	96.67 108.67	25.48 25.48	143.40 155.40
12	14.40~ 15.90	120.67 132.67	78.34 84.34	120.67 132.67	25.48 25.48	143.40 155.40
13	15.90~ 17.40	120.67 132.67	84.34 90.34	120.67 132.67	25.48 25.48	167.40 179.40
14	17.40~ 18.90	144.67 156.67	90.34 96.34	144.67 156.67	25.48 25.48	167.40 179.40
15	18.90~ 20.40	144.67 156.67	96.34 102.34	144.67 156.67	25.48 25.48	191.40 203.40
16	20.40~ 21.90	156.67 168.67	102.34 108.34	156.67 168.67	25.48 25.48	203.40 215.40
17	21.90~ 23.40	166.67 178.67	108.34 114.34	166.67 178.67	25.48 25.48	217.40 229.40
18	23.40~ 23.90	178.67 182.67	114.34 116.34	178.67 182.67	25.48 25.48	229.40 233.40

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$
$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

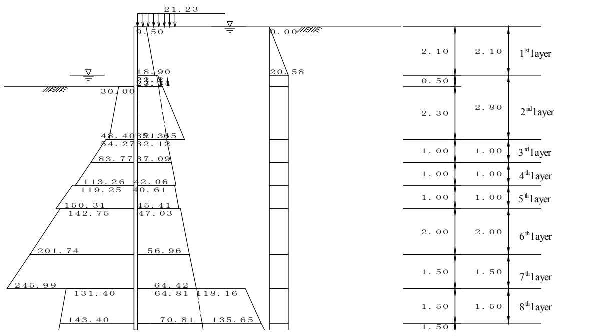
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Σγh+Q (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	21.23 42.23	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Clayey Soil	8.0	—	15.0 15.0	42.23 46.23	20.58 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	37.22 36.57
3	2.60~ 4.90	Clayey Soil	8.0	—	15.0 15.0	46.23 64.63	25.48 48.02	0.200 0.200	11.31 11.31	—— ——	—— ——	36.57 33.18
4	4.90~ 5.90	Sandy Soil	10.0	27.0	—— ——	64.63 74.63	48.02 57.82	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	5.90~ 6.90	Sandy Soil	10.0	27.0	—— ——	74.63 84.63	57.82 67.62	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	6.90~ 7.90	Sandy Soil	10.0	28.0	—— ——	84.63 94.63	67.62 77.42	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
7	7.90~ 9.90	Sandy Soil	10.0	27.0	—— ——	94.63 114.63	77.42 97.02	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
8	9.90~ 11.40	Sandy Soil	10.0	27.0	—— ——	114.63 129.63	97.02 111.72	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
9	11.40~ 12.90	Clayey Soil	8.0	—	24.0 24.0	129.63 141.63	111.72 126.42	0.200 0.200	11.31 11.31	—— ——	—— ——	31.36 29.55
10	12.90~ 14.40	Clayey Soil	8.0	—	24.0 24.0	141.63 153.63	126.42 141.12	0.200 0.200	11.31 11.31	—— ——	—— ——	29.55 27.52

	Depth (m)	Soil	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Σγh+Q (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
11	14.40~ 15.90	Clayey Soil	8.0	—	18.0 18.0	153.63 165.63	141.12 155.82	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
12	15.90~ 17.40	Clayey Soil	8.0	—	24.0 24.0	165.63 177.63	155.82 170.52	0.200 0.200	11.31 11.31	—— ——	—— ——	25.20 22.49
13	17.40~ 18.90	Clayey Soil	8.0	—	18.0 18.0	177.63 189.63	170.52 185.22	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
14	18.90~ 20.40	Clayey Soil	8.0	—	24.0 24.0	189.63 201.63	185.22 199.92	0.200 0.200	11.31 11.31	—— ——	—— ——	19.21 14.96
15	20.40~ 21.90	Clayey Soil	8.0	—	24.0 24.0	201.63 213.63	199.92 214.62	0.200 0.200	11.31 11.31	—— ——	—— ——	14.96 10.00
16	21.90~ 23.40	Clayey Soil	8.0	—	25.0 25.0	213.63 225.63	214.62 229.32	0.200 0.200	11.31 11.31	—— ——	—— ——	13.83 10.00
17	23.40~ 23.90	Clayey Soil	8.0	—	25.0 25.0	225.63 229.63	229.32 234.22	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= -10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta=\tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Σγh+Qp (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 4.90	Clayey soil	8.00	0.0	15.0 15.0	0.000 18.400	0.00 22.54	0.200 0.200	11.31 11.31	—— ——	—— ——
4	4.90~ 5.90	Sandy soil	10.00	27.0	—— ——	18.400 28.400	22.54 32.34	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	5.90~ 6.90	Sandy soil	10.00	27.0	—— ——	28.400 38.400	32.34 42.14	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	6.90~ 7.90	Sandy soil	10.00	28.0	—— ——	38.400 48.400	42.14 51.94	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
7	7.90~ 9.90	Sandy soil	10.00	27.0	—— ——	48.400 68.400	51.94 71.54	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
8	9.90~ 11.40	Sandy soil	10.00	27.0	—— ——	68.400 83.400	71.54 86.24	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
9	11.40~ 12.90	Clayey soil	8.00	0.0	24.0 24.0	83.400 95.400	86.24 100.94	0.200 0.200	11.31 11.31	—— ——	—— ——
10	12.90~ 14.40	Clayey soil	8.00	0.0	24.0 24.0	95.400 107.400	100.94 115.64	0.200 0.200	11.31 11.31	—— ——	—— ——
11	14.40~ 15.90	Clayey soil	8.00	0.0	18.0 18.0	107.400 119.400	115.64 130.34	0.200 0.200	11.31 11.31	—— ——	—— ——
12	15.90~ 17.40	Clayey soil	8.00	0.0	24.0 24.0	119.400 131.400	130.34 145.04	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Σγh+Qp (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
13	17.40~ 18.90	Clayey soil	8.00	0.0	18.0 18.0	131.400 143.400	145.04 159.74	0.200 0.200	11.31 11.31	—— ——	—— ——
14	18.90~ 20.40	Clayey soil	8.00	0.0	24.0 24.0	143.400 155.400	159.74 174.44	0.200 0.200	11.31 11.31	—— ——	—— ——
15	20.40~ 21.90	Clayey soil	8.00	0.0	24.0 24.0	155.400 167.400	174.44 189.14	0.200 0.200	11.31 11.31	—— ——	—— ——
16	21.90~ 23.40	Clayey soil	8.00	0.0	25.0 25.0	167.400 179.400	189.14 203.84	0.200 0.200	11.31 11.31	—— ——	—— ——
17	23.40~ 23.90	Clayey soil	8.00	0.0	25.0 25.0	179.400 183.400	203.84 208.74	0.200 0.200	11.31 11.31	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m^2)	Pa2 (kN/m^2)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)
1	0.00~ 2.10	9.50 18.90	—— ——	9.50 18.90	0.00 20.58	—— ——
2	2.10~ 2.60	22.21 27.34	21.11 23.11	22.21 27.34	20.58 20.58	—— ——
3	2.60~ 4.90	27.34 51.65	23.11 32.31	27.34 51.65	20.58 20.58	30.00 48.40
4	4.90~ 5.90	32.12 37.09	—— ——	32.12 37.09	20.58 20.58	54.27 83.77
5	5.90~ 6.90	37.09 42.06	—— ——	37.09 42.06	20.58 20.58	83.77 113.26
6	6.90~ 7.90	40.61 45.41	—— ——	40.61 45.41	20.58 20.58	119.25 150.31
7	7.90~ 9.90	47.03 56.96	—— ——	47.03 56.96	20.58 20.58	142.75 201.74
8	9.90~ 11.40	56.96 64.42	—— ——	56.96 64.42	20.58 20.58	201.74 245.99
9	11.40~ 12.90	118.16 135.65	64.81 70.81	118.16 135.65	20.58 20.58	131.40 143.40
10	12.90~ 14.40	135.65 154.03	70.81 76.81	135.65 154.03	20.58 20.58	143.40 155.40
11	14.40~ 15.90	222.63 248.24	76.81 82.81	222.63 248.24	20.58 20.58	143.40 155.40
12	15.90~ 17.40	173.73 195.53	82.81 88.81	173.73 195.53	20.58 20.58	167.40 179.40
13	17.40~ 18.90	273.85 299.46	88.81 94.81	273.85 299.46	20.58 20.58	167.40 179.40
14	18.90~ 20.40	221.23 256.30	94.81 100.81	221.23 256.30	20.58 20.58	191.40 203.40

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
15	20.40~ 21.90	256.30 315.60	100.81 106.81	256.30 315.60	20.58 20.58	203.40 215.40
16	21.90~ 23.40	279.50 335.36	106.81 112.81	279.50 335.36	20.58 20.58	217.40 229.40
17	23.40~ 23.90	335.36 343.90	112.81 114.81	335.36 343.90	20.58 20.58	229.40 233.40

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

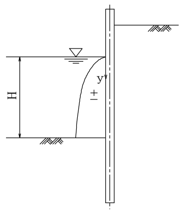
Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1 2	2.10 2.60	0.00 0.50	0.00 0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

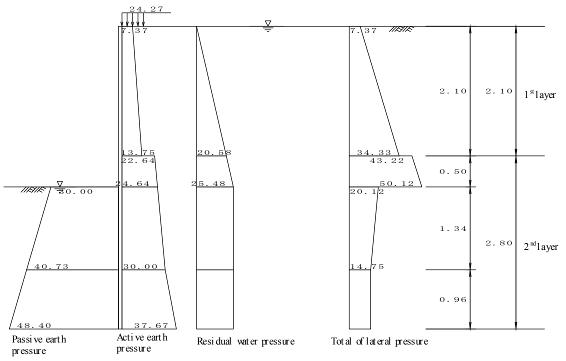
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

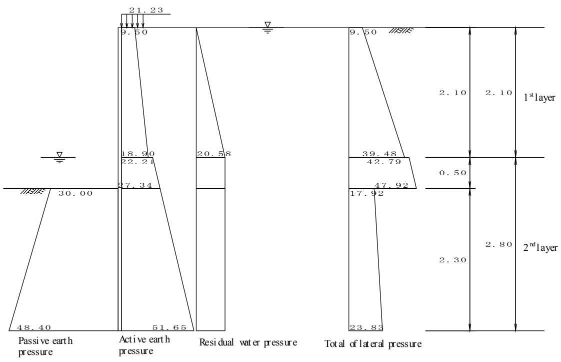


	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	7.37 13.75	0.00 20.58	—— ——	7.37 34.33
2	2.10~ 2.60	22.64 24.64	20.58 25.48	—— ——	43.22 50.12
3	2.60~ 3.94	24.64 30.00	25.48 25.48	30.00 40.73	20.12 14.75
4	3.94~ 4.90	30.00 37.67	25.48 25.48	40.73 48.40	14.75 14.75
5	4.90~ 5.90	23.05 26.46	25.48 25.48	65.21 100.66	-16.68 -48.72

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.30 m (GL -4.90 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	9.50 18.90	0.00 20.58	—— ——	9.50 39.48
2	2.10~ 2.60	22.21 27.34	20.58 20.58	—— ——	42.79 47.92
3	2.60~ 4.90	27.34 51.65	20.58 20.58	30.00 48.40	17.92 23.83
4	4.90~ 5.90	32.12 37.09	20.58 20.58	54.27 83.77	-1.57 -26.10

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.30 m (GL -4.90 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.84			
Section efficiency	μ	=	1.00			
Young's modulus	E	=	200000 Nmm^2			
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)			
	I	=	95760 cm^4 (after reduction by corrosion and section)			
Inertia sectional moment	EI	=	200000 x 10^3 x95760x 10^{-8} =1.915×10^5			

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	4.90	2
5	5.90	7
6	6.90	10
7	7.90	11
8	11.40	2
9	12.90	4
10	14.40	4

	Depth (m)	N-value
11	15.90	3
12	17.40	4
13	18.90	3
14	20.40	4
15	21.90	4
16	23.40	5
17	23.90	6

5-2 Normal Condition

K_h = 15603 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.378 \ m^{-1}$

$$L = \frac{1}{\beta} = 2.65 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.90 m) to 2.65 m depth (GL -7.55 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.90	1.00	2.0	7.0	4.50
2	5.90	1.00	7.0	10.0	8.50
3	6.90	0.65	10.0	10.6	6.68
L = Σh = 2.65					ΣA = 19.68

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{19.68}{2.65} = 7.43$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.43^{0.406} = 15603$ kN/m³

K_h (normal condition) = 15603 kN/m³

5-3 Seismic Condition

K_h = 15603 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.378 \ m^{-1}$$

$$L = \frac{1}{\beta} = 2.65 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.90 m) to 2.65 m depth (GL -7.55 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.90	1.00	2.0	7.0	4.50
2	5.90	1.00	7.0	10.0	8.50
3	6.90	0.65	10.0	10.6	6.68
L = Σh = 2.65					ΣA = 19.68

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{19.68}{2.65} = 7.43$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.43^{0.406} = 15603$ kN/m³

K_h (seismic condition) = 15603 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.37 34.33	7.74 36.05	4.20 3.50	32.52 126.18
2	2.10~ 2.60	0.50	43.22 50.12	10.80 12.53	2.63 2.47	28.45 30.91
3	2.60~ 3.94	1.34	20.12 14.75	13.49 9.89	1.85 1.41	24.99 13.91
4	3.94~ 4.90	0.96	14.75 14.75	7.08 7.08	0.64 0.32	4.53 2.26
				ΣP = 104.66		ΣM = 263.74

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.2 kN/m
depth to acting position	H_t	=	-0.41 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.30 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 11.68 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{275.42}{106.86} = 2.58 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.50 39.48	9.98 41.45	4.20 3.50	41.90 145.08
2	2.10~ 2.60	0.50	42.79 47.92	10.70 11.98	2.63 2.47	28.17 29.55
3	2.60~ 4.90	2.30	17.92 23.83	20.61 27.40	1.53 0.77	31.61 21.01
				ΣP = 122.12		ΣM = 297.31

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.4 kN/m
depth to acting position	H_t	=	-0.23 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.30 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 43.09 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.63 2.47	0.00 0.53
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.53

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{340.93}{130.73} = 2.61 \ m$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 95760 x 10⁻⁸		=	1.915×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	15603 kN/m³
calculated value	β	=	0.37778 m⁻¹
resultant earth force (lateral)	P_0	=	106.86 kN/m
height of acting position of load	h_0	=	2.58 m
moment	M_0	=	275.42 kN·m/m

in consideration of ψ_m = 1.152,

maximum moment	M_{max}	=	317.38 kN·m/m
depth of generated position of M_{max}	l_m	=	0.866 m
depth of 1st fixed point	l_i	=	2.945 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	15603 kN/m³
calculated value	β	=	0.37778 m⁻¹
resultant earth force (lateral)	P_0	=	130.73 kN/m
height of acting position of load	h_0	=	2.61 m
moment	M_0	=	340.93 kN·m/m

in consideration of ψ_m = 1.150,

maximum moment	M_{max}	=	391.93 kN·m/m
depth of generated position of M_{max}	l_m	=	0.860 m
depth of 1st fixed point	l_i	=	2.939 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm^3 (original condition)
	Z	=	2828 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{317.38\times10^6}{2828\times10^3} = 112\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2$$

6-3-2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{391.93\times10^6}{2828\times10^3} = 139\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	4.20 3.50	0.857 0.714	0.262 0.194	7.74 36.05	2.032 7.007
2	2.10~ 2.60	2.63 2.47	0.537 0.503	0.119 0.105	10.80 12.53	1.281 1.321
3	2.60~ 3.94	1.85 1.41	0.378 0.287	0.063 0.037	13.49 9.89	0.843 0.368
4	3.94~ 4.90	0.64 0.32	0.131 0.065	0.008 0.002	7.08 7.08	0.058 0.015
						ΣQ = 12.924

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

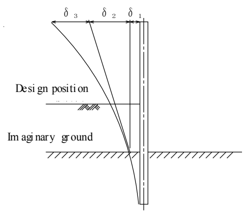
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3778\times2.58)\times106.86}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3778^3} = 0.01021\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3778\times2.58)\times106.86}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3778^2}\times(2.60+2.30) = 0.02823\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.92\times(2.60+2.30)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00794\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00051 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.90 m
Horizontal load: P = 2.20
Moment: M = 0.90

δ = δ_1 + δ_2 + δ_3
= 0.01021 + 0.02823 + 0.00845
= 0.04689 m
= 46.89 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	4.20 3.50	0.857 0.714	0.262 0.194	9.98 41.45	2.617 8.057
2	2.10~ 2.60	2.63 2.47	0.537 0.503	0.119 0.105	10.70 11.98	1.268 1.263
3	2.60~ 4.90	1.53 0.77	0.313 0.156	0.044 0.012	20.61 27.40	0.904 0.318
						ΣQ = 14.427

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

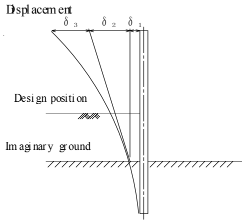
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.63 2.47	0.537 0.503	0.119 0.105	0.00 0.21	0.000 0.023
						ΣQ_{dw} = 0.023

Therefore, modulus of deformation Q is calculated as below.
Q = 14.427 + 0.023 = 14.450

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3778\times2.61)\times130.73}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3778^3} = 0.01257\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3778\times2.61)\times130.73}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3778^2}\times(2.60+2.30) = 0.03481\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{14.45\times(2.60+2.30)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00888\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00184 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.90 m
Horizontal load: P = 8.40
Moment: M = 1.93

δ = δ_1 + δ_2 + δ_3
= 0.01257 + 0.03481 + 0.01072
= 0.05809 m
= 58.09 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)
	I	=	114000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 114000 \times 10^{-8}$		=	2.280×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 15603\ kN/m^3$
Calculated value $\beta = 0.36166\ m^{-1}$

Penetration length of SSP $D = 2.30 + \frac{3}{0.362} = 10.60\ m$
Whole length of SSP $L = 2.60 - 0.40 + 10.60 = 12.80\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 15603\ kN/m^3$
Calculated value $\beta = 0.36166\ m^{-1}$

Penetration length of SSP $D = 2.30 + \frac{3}{0.362} = 10.60\ m$
Whole length of SSP $L = 2.60 - 0.40 + 10.60 = 12.80\ m$

Therefore, whole length of SSP is set as 13.00 m in consideration of round unit of SSP length.

8 Calculation Result

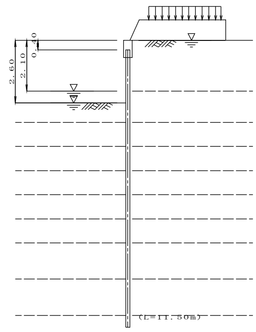
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		317.38	391.93
Stress intensity	σ (Nmm^2)		112 (185)	139 (278)
Lateral displacement	δ (mm)		46.89 (50.0)	58.09 (75.0)
Penetration depth	D (m)		10.60	10.60
Whole length of SSP	L (m)	13.00		

－Steel Sheet Pile Design Calculation－

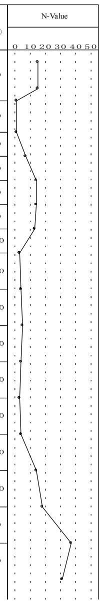
Right Bank No. 13_STA 8+800 - 8+900

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
	Sandy Soil	18.0	30.0	0.0
2.10	Clayey Soil	16.0	0.0	6.0
3.40	Sandy Soil	18.0	27.0	0.0
4.40	Sandy Soil	18.0	29.0	0.0
5.40	Sandy Soil	18.0	29.0	0.0
6.40	Sandy Soil	18.0	29.0	0.0
7.40	Clayey Soil	16.0	0.0	18.0
8.40	Clayey Soil	16.0	0.0	24.0
9.90	Clayey Soil	16.0	0.0	25.0
11.40	Clayey Soil	16.0	0.0	24.0
12.90	Clayey Soil	16.0	0.0	18.0
14.40	Clayey Soil	16.0	0.0	24.0
15.90	Clayey Soil	16.0	0.0	50.0
17.40	Clayey Soil	16.0	0.0	50.0
18.90	Sandy Soil	18.0	39.0	0.0
20.40	Sandy Soil	18.0	37.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{ww}	=	0.00 m (Normal Condition)
	L_{ww}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wn}	=	2.60 m (Normal Condition)
	L_{wn}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.3 kNm (Normal Condition)
		Pt'	=	8.5 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.41 m (Normal Condition)
		Ht'	=	-0.23 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression $K_e = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	1
4	3.40	1
5	4.40	7
6	5.40	14
7	6.40	14
8	7.40	13
9	8.40	3
10	9.90	4

No	Depth (m)	N-Value
11	11.40	5
12	12.90	4
13	14.40	3
14	15.90	4
15	17.40	14
16	18.90	18
17	20.40	37
18	21.90	31

2.95

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

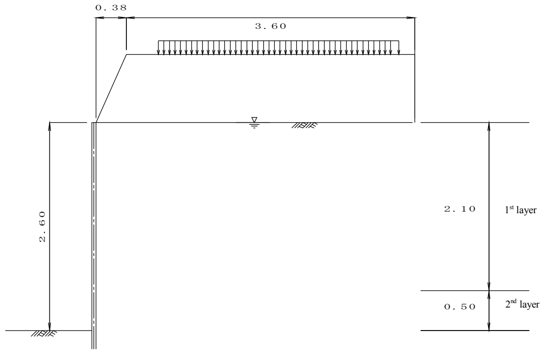
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3)	
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.40	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	4.40	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	5.40	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
5	6.40	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
6	7.40	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
7	8.40	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
8	9.90	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
9	11.40	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
10	12.90	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
11	14.40	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
12	15.90	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
13	17.40	C	14.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
14	18.90	C	16.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
15	20.40	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
16	21.90	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.38	3.98	3.98	0.85	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.78	3.78	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 86000 cm^4
Sectional factor Z_0 = 3820 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.92
Corrosion rate (to Z_0) η = 0.92
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

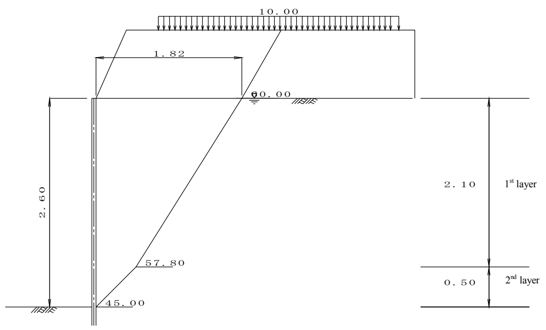
Allowable stress σ_a = 180 N/mm^2 (Normal)
σ_a' = 270 N/mm^2 (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	24.18	25.48	45.00
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	24.18	20.58	57.80
3		Embankment	30.0	——	0.0	15.30	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	0.85	1.82	2.60	2.31	3.45

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.60	28.73
Σ			28.73

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.53	15.33
Σ			15.33

Q surcharge load
l : width of surcharge load set by line of active rupture

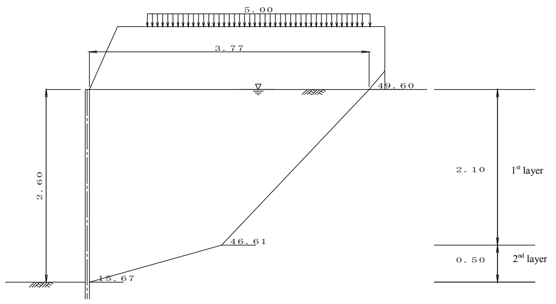
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{28.73 + 15.33 + 0.00}{1.82}$$

$$= 24.18 \ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	19.24	25.48	0.200	11.31	15.67
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	19.24	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	15.30	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	15.67	0.50	0.00	0.00	1.78	0.50
2	46.61	2.10	1.78	0.50	3.77	2.60
3	49.60	0.25	3.77	2.60	3.98	2.85

Therefore, width of acting load shall be set as 3.77 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.20	57.51
Σ			57.51

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

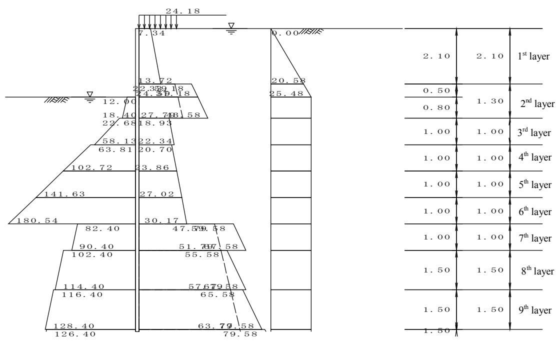
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{57.51 + 15.00 + 0.00}{3.77}$$

$$= 19.24 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



Passive earth pressure Active earth pressure Residual water pressure

3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	24.178 45.178	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Clayey soil	8.0	—	6.0 6.0	45.178 49.178	—— ——	—— ——
3	2.60~ 3.40	Clayey soil	8.0	—	6.0 6.0	49.178 55.578	—— ——	—— ——
4	3.40~ 4.40	Sandy soil	10.0	27.0	—— ——	55.578 65.578	0.34585 0.34585	0.34060 0.34060
5	4.40~ 5.40	Sandy soil	10.0	29.0	—— ——	65.578 75.578	0.32058 0.32058	0.31571 0.31571
6	5.40~ 6.40	Sandy soil	10.0	29.0	—— ——	75.578 85.578	0.32058 0.32058	0.31571 0.31571
7	6.40~ 7.40	Sandy soil	10.0	29.0	—— ——	85.578 95.578	0.32058 0.32058	0.31571 0.31571
8	7.40~ 8.40	Clayey soil	8.0	—	18.0 18.0	95.578 103.578	—— ——	—— ——
9	8.40~ 9.90	Clayey soil	8.0	—	24.0 24.0	103.578 115.578	—— ——	—— ——
10	9.90~ 11.40	Clayey soil	8.0	—	25.0 25.0	115.578 127.578	—— ——	—— ——
11	11.40~ 12.90	Clayey soil	8.0	—	24.0 24.0	127.578 139.578	—— ——	—— ——
12	12.90~ 14.40	Clayey soil	8.0	—	18.0 18.0	139.578 151.578	—— ——	—— ——
13	14.40~ 15.90	Clayey soil	8.0	—	24.0 24.0	151.578 163.578	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	15.90~ 17.40	Clayey soil	8.0	—	50.0 50.0	163.578 175.578	—— ——	—— ——
15	17.40~ 18.90	Clayey soil	8.0	—	50.0 50.0	175.578 187.578	—— ——	—— ——
16	18.90~ 20.40	Sandy soil	10.0	39.0	—— ——	187.578 202.578	0.21359 0.21359	0.21035 0.21035
17	20.40~ 21.90	Sandy soil	10.0	37.0	—— ——	202.578 217.578	0.23264 0.23264	0.22910 0.22910

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 3.40	Clayey soil	8.0	0.0	6.0 6.0	0.000 6.400	—— ——	—— ——
4	3.40~ 4.40	Sandy soil	10.0	27.0	—— ——	6.400 16.400	3.59892 3.59892	3.54425 3.54425
5	4.40~ 5.40	Sandy soil	10.0	29.0	—— ——	16.400 26.400	3.95096 3.95096	3.89093 3.89093
6	5.40~ 6.40	Sandy soil	10.0	29.0	—— ——	26.400 36.400	3.95096 3.95096	3.89093 3.89093
7	6.40~ 7.40	Sandy soil	10.0	29.0	—— ——	36.400 46.400	3.95096 3.95096	3.89093 3.89093
8	7.40~ 8.40	Clayey soil	8.0	0.0	18.0 18.0	46.400 54.400	—— ——	—— ——
9	8.40~ 9.90	Clayey soil	8.0	0.0	24.0 24.0	54.400 66.400	—— ——	—— ——
10	9.90~ 11.40	Clayey soil	8.0	0.0	25.0 25.0	66.400 78.400	—— ——	—— ——
11	11.40~ 12.90	Clayey soil	8.0	0.0	24.0 24.0	78.400 90.400	—— ——	—— ——
12	12.90~ 14.40	Clayey soil	8.0	0.0	18.0 18.0	90.400 102.400	—— ——	—— ——
13	14.40~ 15.90	Clayey soil	8.0	0.0	24.0 24.0	102.400 114.400	—— ——	—— ——
14	15.90~ 17.40	Clayey soil	8.0	0.0	50.0 50.0	114.400 126.400	—— ——	—— ——
15	17.40~ 18.90	Clayey soil	8.0	0.0	50.0 50.0	126.400 138.400	—— ——	—— ——
16	18.90~ 20.40	Sandy soil	10.0	39.0	—— ——	138.400 153.400	6.56948 6.56948	6.46967 6.46967
17	20.40~ 21.90	Sandy soil	10.0	37.0	—— ——	153.400 168.400	5.89457 5.89457	5.80501 5.80501

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.34 13.72	— —	7.34 13.72	0.00 20.58	— —
2	2.10~ 2.60	33.18 37.18	22.59 24.59	33.18 37.18	20.58 25.48	— —
3	2.60~ 3.40	37.18 43.58	24.59 27.79	37.18 43.58	25.48 25.48	12.00 18.40
4	3.40~ 4.40	18.93 22.34	— —	18.93 22.34	25.48 25.48	22.68 58.13
5	4.40~ 5.40	20.70 23.86	— —	20.70 23.86	25.48 25.48	63.81 102.72
6	5.40~ 6.40	23.86 27.02	— —	23.86 27.02	25.48 25.48	102.72 141.63
7	6.40~ 7.40	27.02 30.17	— —	27.02 30.17	25.48 25.48	141.63 180.54
8	7.40~ 8.40	59.58 67.58	47.79 51.79	59.58 67.58	25.48 25.48	82.40 90.40
9	8.40~ 9.90	55.58 67.58	51.79 57.79	55.58 67.58	25.48 25.48	102.40 114.40
10	9.90~ 11.40	65.58 77.58	57.79 63.79	65.58 77.58	25.48 25.48	116.40 128.40
11	11.40~ 12.90	79.58 91.58	63.79 69.79	79.58 91.58	25.48 25.48	126.40 138.40
12	12.90~ 14.40	103.58 115.58	69.79 75.79	103.58 115.58	25.48 25.48	126.40 138.40
13	14.40~ 15.90	103.58 115.58	75.79 81.79	103.58 115.58	25.48 25.48	150.40 162.40
14	15.90~ 17.40	63.58 75.58	81.79 87.79	81.79 87.79	25.48 25.48	214.40 226.40
15	17.40~ 18.90	75.58 87.58	87.79 93.79	87.79 93.79	25.48 25.48	226.40 238.40
16	18.90~ 20.40	39.46 42.61	— —	39.46 42.61	25.48 25.48	895.40 992.45
17	20.40~ 21.90	46.41 49.85	— —	46.41 49.85	25.48 25.48	890.49 977.56

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

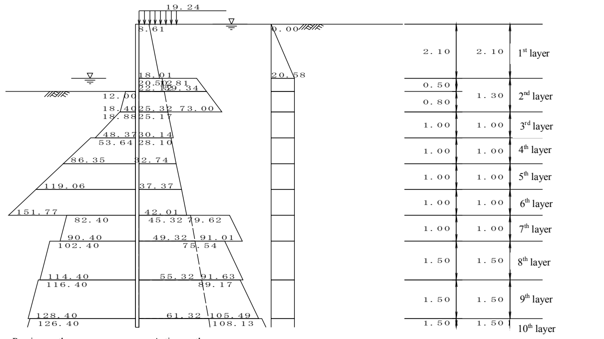
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	— —	19.25 40.25	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
2	2.10~ 2.60	Clayey Soil	8.0	—	6.0 6.0	40.25 44.25	20.58 25.48	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
3	2.60~ 3.40	Clayey Soil	8.0	—	6.0 6.0	44.25 50.65	25.48 33.32	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
4	3.40~ 4.40	Sandy Soil	10.0	27.0	— —	50.65 60.65	33.32 43.12	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
5	4.40~ 5.40	Sandy Soil	10.0	29.0	— —	60.65 70.65	43.12 52.92	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	— —
6	5.40~ 6.40	Sandy Soil	10.0	29.0	— —	70.65 80.65	52.92 62.72	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	— —
7	6.40~ 7.40	Sandy Soil	10.0	29.0	— —	80.65 90.65	62.72 72.52	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	— —
8	7.40~ 8.40	Clayey Soil	8.0	—	18.0 18.0	90.65 98.65	72.52 82.32	0.200 0.200	11.31 11.31	— —	— —	31.97 30.43
9	8.40~ 9.90	Clayey Soil	8.0	—	24.0 24.0	98.65 110.65	82.32 97.02	0.200 0.200	11.31 11.31	— —	— —	35.50 34.11
10	9.90~ 11.40	Clayey Soil	8.0	—	25.0 25.0	110.65 122.65	97.02 111.72	0.200 0.200	11.31 11.31	— —	— —	34.73 33.33
11	11.40~ 12.90	Clayey Soil	8.0	—	24.0 24.0	122.65 134.65	111.72 126.42	0.200 0.200	11.31 11.31	— —	— —	32.59 30.92
12	12.90~ 14.40	Clayey Soil	8.0	—	18.0 18.0	134.65 146.65	126.42 141.12	0.200 0.200	11.31 11.31	— —	— —	20.85 15.64
13	14.40~ 15.90	Clayey Soil	8.0	—	24.0 24.0	146.65 158.65	141.12 155.82	0.200 0.200	11.31 11.31	— —	— —	29.06 26.96

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	15.90~ 17.40	Clayey Soil	8.0	—	50.0 50.0	158.65 170.65	155.82 170.52	0.200 0.200	11.31 11.31	— —	— —	38.75 38.22
15	17.40~ 18.90	Clayey Soil	8.0	—	50.0 50.0	170.65 182.65	170.52 185.22	0.200 0.200	11.31 11.31	— —	— —	38.22 37.67
16	18.90~ 20.40	Sandy Soil	10.0	39.0	— —	182.65 197.65	185.22 199.92	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	— —
17	20.40~ 21.90	Sandy Soil	10.0	37.0	— —	197.65 212.65	199.92 214.62	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta= 10.00,\ \beta= 0.00,\ \theta= \tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 3.40	Sandy soil	8.00	0.0	6.0 6.0	0.000 6.400	0.00 7.84	0.200 0.200	11.31 11.31	— —	— —
4	3.40~ 4.40	Clayey soil	10.00	27.0	— —	6.400 16.400	7.84 17.64	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	4.40~ 5.40	Sandy soil	10.00	29.0	— —	16.400 26.400	17.64 27.44	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
6	5.40~ 6.40	Sandy soil	10.00	29.0	— —	26.400 36.400	27.44 37.24	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
7	6.40~ 7.40	Sandy soil	10.00	29.0	— —	36.400 46.400	37.24 47.04	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
8	7.40~ 8.40	Clayey soil	8.00	0.0	18.0 18.0	46.400 54.400	47.04 56.84	0.200 0.200	11.31 11.31	— —	— —
9	8.40~ 9.90	Clayey soil	8.00	0.0	24.0 24.0	54.400 66.400	56.84 71.54	0.200 0.200	11.31 11.31	— —	— —
10	9.90~ 11.40	Clayey soil	8.00	0.0	25.0 25.0	66.400 78.400	71.54 86.24	0.200 0.200	11.31 11.31	— —	— —
11	11.40~ 12.90	Clayey soil	8.00	0.0	24.0 24.0	78.400 90.400	86.24 100.94	0.200 0.200	11.31 11.31	— —	— —
12	12.90~ 14.40	Clayey soil	8.00	0.0	18.0 18.0	90.400 102.400	100.94 115.64	0.200 0.200	11.31 11.31	— —	— —
13	14.40~ 15.90	Clayey soil	8.00	0.0	24.0 24.0	102.400 114.400	115.64 130.34	0.200 0.200	11.31 11.31	— —	— —
14	15.90~ 17.40	Clayey soil	8.00	0.0	50.0 50.0	114.400 126.400	130.34 145.04	0.200 0.200	11.31 11.31	— —	— —
15	17.40~ 18.90	Clayey soil	8.00	0.0	50.0 50.0	126.400 138.400	145.04 159.74	0.200 0.200	11.31 11.31	— —	— —
16	18.90~ 20.40	Sandy soil	10.00	39.0	— —	138.400 153.400	159.74 174.44	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
17	20.40~ 21.90	Sandy soil	10.00	37.0	— —	153.400 168.400	174.44 189.14	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta= -10.00,\ \beta= 0.00,\ \theta= \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
1	0.00~ 2.10	8.61 18.01	—— ——	8.61 18.01	0.00 20.58	—— ——
2	2.10~ 2.60	50.81 59.34	20.12 22.12	50.81 59.34	20.58 20.58	—— ——
3	2.60~ 3.40	59.34 73.00	22.12 25.32	59.34 73.00	20.58 20.58	12.00 18.40
4	3.40~ 4.40	25.17 30.14	—— ——	25.17 30.14	20.58 20.58	18.88 48.37
5	4.40~ 5.40	28.10 32.74	—— ——	28.10 32.74	20.58 20.58	53.64 86.35
6	5.40~ 6.40	32.74 37.37	—— ——	32.74 37.37	20.58 20.58	86.35 119.06
7	6.40~ 7.40	37.37 42.01	—— ——	37.37 42.01	20.58 20.58	119.06 151.77
8	7.40~ 8.40	79.62 91.01	45.32 49.32	79.62 91.01	20.58 20.58	82.40 90.40
9	8.40~ 9.90	75.54 91.63	49.32 55.32	75.54 91.63	20.58 20.58	102.40 114.40
10	9.90~ 11.40	89.17 105.49	55.32 61.32	89.17 105.49	20.58 20.58	116.40 128.40
11	11.40~ 12.90	108.13 125.16	61.32 67.32	108.13 125.16	20.58 20.58	126.40 138.40
12	12.90~ 14.40	151.23 182.07	67.32 73.32	151.23 182.07	20.58 20.58	126.40 138.40
13	14.40~ 15.90	142.90 161.63	73.32 79.32	142.90 161.63	20.58 20.58	150.40 162.40
14	15.90~ 17.40	95.75 111.12	79.32 85.32	95.75 111.12	20.58 20.58	214.40 226.40
15	17.40~ 18.90	111.12 126.59	85.32 91.32	111.12 126.59	20.58 20.58	226.40 238.40
16	18.90~ 20.40	59.30 64.17	—— ——	59.30 64.17	20.58 20.58	783.30 868.19
17	20.40~ 21.90	69.02 74.25	—— ——	69.02 74.25	20.58 20.58	773.62 849.27

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

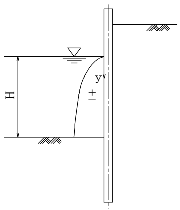
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

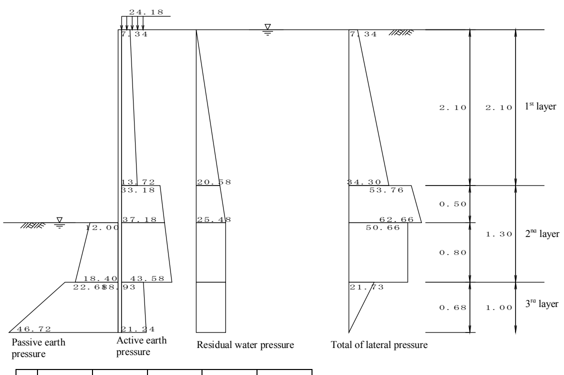
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	7.34 13.72	0.00 20.58	—— ——	7.34 34.30
2	2.10~ 2.60	33.18 37.18	20.58 25.48	—— ——	53.76 62.66
3	2.60~ 3.40	37.18 43.58	25.48 25.48	12.00 18.40	50.66 50.66
4	3.40~ 4.08	18.93 21.24	25.48 25.48	22.68 46.72	21.73 0.00
5	4.08~ 4.40	21.24 22.34	25.48 25.48	46.72 58.13	0.00 -10.31

P_a : Active earth pressure

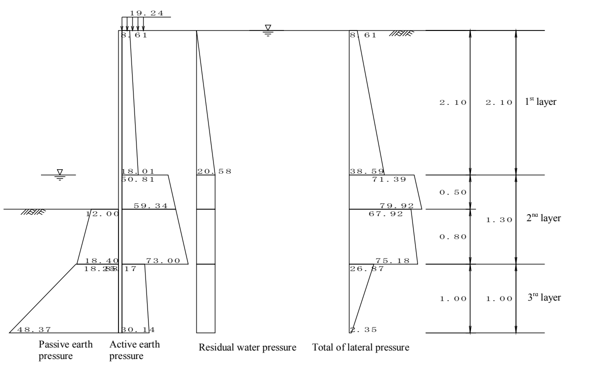
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.48 m (GL -4.08 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	8.61 18.01	0.00 20.58	—— ——	8.61 38.59
2	2.10~ 2.60	50.81 59.34	20.58 20.58	—— ——	71.39 79.92
3	2.60~ 3.40	59.34 73.00	20.58 20.58	12.00 18.40	67.92 75.18
4	3.40~ 4.40	25.17 30.14	20.58 20.58	18.88 48.37	26.87 2.35
5	4.40~ 5.40	28.10 32.74	20.58 20.58	53.64 86.35	-4.96 -33.03

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.80 m (GL -4.40 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.82
Young's modulus	E	=	200000 Nmm ^{2}
Inertia sectional moment	I_0	=	86000 cm ^{4}(original condition)
	I	=	63296 cm ^{4}(after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} = 1.266×10^5

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	11.40	5
2	1.60	15	12	12.90	4
3	2.10	1	13	14.40	3
4	3.40	1	14	15.90	4
5	4.40	7	15	17.40	14
6	5.40	14	16	18.90	18
7	6.40	14	17	20.40	37
8	7.40	13	18	21.90	31
9	8.40	3			
10	9.90	4			

5-2 Normal Condition

K_h = 18526 kNm ^{3} is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.437 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.29 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.08 m) to 2.29 m depth (GL -6.36 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.08	0.32	5.1	7.0	1.94
2	4.40	1.00	7.0	14.0	10.50
3	5.40	0.96	14.0	14.0	13.51
	L = Σh = 2.29				ΣA = 25.95

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{25.95}{2.29} = 11.35$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 11.35^{0.406} = 18526 \text{ kN/m}^3$$

K_h (normal condition) = 18526 kNm ^{3}

5-3 Seismic Condition

K_h = 19229 kNm ^{3} is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.441 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.27 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.40 m) to 2.27 m depth (GL -6.67 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.40	1.00	7.0	14.0	10.50
2	5.40	1.00	14.0	14.0	14.00
3	6.40	0.27	14.0	13.7	3.68
	L = Σh = 2.27				ΣA = 28.18

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{28.18}{2.27} = 12.44$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 12.44^{0.406} = 19229 \text{ kN/m}^3$$

K_h (seismic condition) = 19229 kNm ^{3}

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm ^{2})	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.34 34.30	7.71 36.02	3.38 2.68	26.05 96.47
2	2.10~ 2.60	0.50	53.76 62.66	13.44 15.66	1.81 1.64	24.35 25.77
3	2.60~ 3.40	0.80	50.66 50.66	20.26 20.26	1.21 0.94	24.55 19.15
4	3.40~ 4.08	0.68	21.73 0.00	7.37 0.00	0.45 0.23	3.33 0.00
				ΣP = 120.73		ΣM = 219.66

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.3 kNm
depth to acting position	H_t	=	-0.41 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.48 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.32 \text{ kN·m}$$

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{229.98}{123.03} = 1.87 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm ^{2})	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.61 38.59	9.04 40.52	3.70 3.00	33.46 121.56
2	2.10~ 2.60	0.50	71.39 79.92	17.85 19.98	2.13 1.97	38.07 39.30
3	2.60~ 3.40	0.80	67.92 75.18	27.17 30.07	1.53 1.27	41.66 38.09
4	3.40~ 4.40	1.00	26.87 2.35	13.44 1.17	0.67 0.33	8.96 0.39
				ΣP = 159.24		ΣM = 321.49

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.5 kNm
depth to acting position	H_t	=	-0.23 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.80 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 39.36 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm ^{2})	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.13 1.97	0.00 0.42
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.42

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{361.27}{167.96} = 2.15 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm ^{2}
Inertia sectional moment	I_0	=	86000 cm ^{4}(original condition)
	I	=	63296 cm ^{4}(after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	= 18526 kN/m^3
calculated value	β	= 0.43735 m^{-1}
resultant earth force (lateral)	P_0	= 123.03 kN/m
height of acting position of load	h_0	= 1.87 m
moment	M_0	= 229.98 kN·m/m

in consideration of ψ_m = 1.199,

maximum moment	M_{max}	= 275.83 kN·m/m
depth of generated position of M_{max}	l_m	= 0.829 m
depth of 1st fixed point	l_i	= 2.625 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	= 19229 kN/m^3
calculated value	β	= 0.44144 m^{-1}
resultant earth force (lateral)	P_0	= 167.96 kN/m
height of acting position of load	h_0	= 2.15 m
moment	M_0	= 361.27 kN·m/m

in consideration of ψ_m = 1.158,

maximum moment	M_{max}	= 418.51 kN·m/m
depth of generated position of M_{max}	l_m	= 0.752 m
depth of 1st fixed point	l_i	= 2.532 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{275.83\times10^6}{3514\times10^3} = 78\ \text{N/mm}^2 \leqq \sigma_a = 180\ \text{N/mm}^2$$

6-3-2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{418.51\times10^6}{3514\times10^3} = 119\ \text{N/mm}^2 \leqq \sigma_a = 270\ \text{N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.38 2.68	0.828 0.657	0.248 0.168	7.71 36.02	1.915 6.067
2	2.10~ 2.60	1.81 1.64	0.444 0.403	0.084 0.070	13.44 15.66	1.130 1.103
3	2.60~ 3.40	1.21 0.94	0.297 0.232	0.040 0.025	20.26 20.26	0.806 0.502
4	3.40~ 4.08	0.45 0.23	0.111 0.055	0.006 0.002	7.37 0.00	0.044 0.000
						ΣQ = 11.565

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

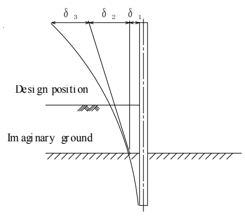
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4374\times1.87)\times123.03}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4374^3} = 0.01056\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4374\times1.87)\times123.03}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4374^2}\times(2.60+1.48) = 0.02730\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.57\times(2.60+1.48)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00620\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00047 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.08 m

Horizontal load: P = 2.30

Moment: M = 0.94

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01056 + 0.02730 + 0.00667

= 0.04453 m

= 44.53 ≦ δa = 50.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.18 2.48	0.820 0.639	0.244 0.161	9.99 41.46	2.438 6.665
2	2.10~ 2.60	1.61 1.45	0.416 0.373	0.074 0.061	9.87 10.43	0.735 0.635
3	2.60~ 3.88	0.85 0.43	0.220 0.110	0.022 0.006	26.71 2.14	0.599 0.012
4	3.40~ 4.40	0.67 0.33	0.152 0.076	0.011 0.003	13.44 1.17	0.146 0.003
						ΣQ = 15.771

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

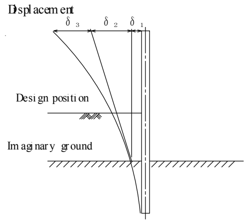
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.13 1.97	0.485 0.447	0.099 0.085	0.00 0.21	0.000 0.018
						ΣQ_{dw} = 0.018

Therefore, modulus of deformation Q is calculated as below.

Q = 15.771 + 0.018 = 15.789

2.101



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4414\times 2.15)\times 167.96}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4414^3} = 0.01503 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4414\times 2.15)\times 167.96}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4414^2}\times(2.60+1.80) = 0.04342 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.79\times(2.60+1.80)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.01062 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00206 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.40 m

Horizontal load: P = 8.50

Moment: M = 1.96

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01503 + 0.04342 + 0.01268

= 0.07114 m

= 71.14 ≦ δ_a = 75.00 mm

Where,

- δ_1 : Displacement at imaginary ground
- δ_2 : Displacement by angle of inclination slope at imaginary ground
- δ_3 : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm ^{2}
Inertia sectional moment	I_0	=	86000 cm ^{4} (original condition)
	I	=	86000 cm ^{4} (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 18526 kN/m^3

Calculated value β = 0.40509 m^{-1}

Penetration length of SSP $D = 1.48 + \frac{3}{0.405} = 8.88$ m

Whole length of SSP $L = 2.60 - 0.40 + 8.88 = 11.08$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 19229 kN/m^3

Calculated value β = 0.40888 m^{-1}

Penetration length of SSP $D = 1.80 + \frac{3}{0.409} = 9.14$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.14 = 11.34$ m

Therefore, whole length of SSP is set as 11.50 m in consideration of round unit of SSP length.

8 Calculation Result

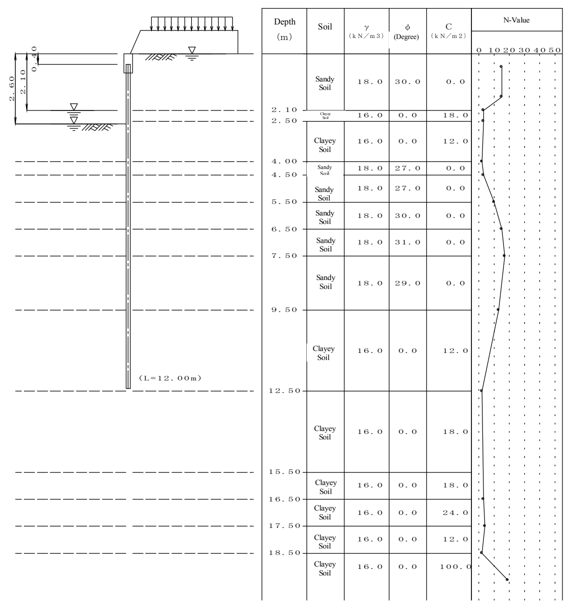
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		275.83	418.51
Stress intensity	σ (Nmm^2)		78 (180)	119 (270)
Lateral displacement	δ (mm)		44.53 (50.0)	71.14 (75.0)
Penetration depth	D (m)		8.88	9.14
Whole length of SSP	L (m)	11.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 14_STA 8+900 - 9+000

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_g	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.3 kN/m (Normal Condition)
		Pt'	=	8.5 kN/m (Seismic Condition)
	Depth of acting point	Ht	=	-0.41 m (Normal Condition)
		Ht'	=	-0.23 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	3
4	2.50	3
5	4.00	2
6	4.50	3
7	5.50	10
8	6.50	15
9	7.50	17
10	9.50	13

No	depth (m)	N-Value
11	12.50	2
12	16.50	3
13	17.50	4
14	18.50	2
15	19.50	19

2.103

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on front side not considered

1-7 Soil Modulus

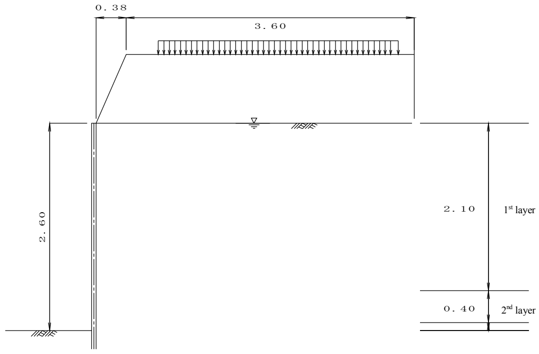
No	depth (m)	Soil	N-value	γ (kN/m^3)	γ' (kN/m^3)	φ	C (kN/m^2)	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	———	———
2	2.50	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	———	———
3	4.00	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	———	———
4	4.50	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
5	5.50	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
6	6.50	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	———	———
7	7.50	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	———	———
8	9.50	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	———	———
9	12.50	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	———	———
10	15.50	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	———	———
11	16.50	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	———	———
12	17.50	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	———	———
13	18.50	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	———	———
14	19.50	C	19.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	———	———

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.38	3.98	3.98	0.86	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.78	3.78	10.0	5.0

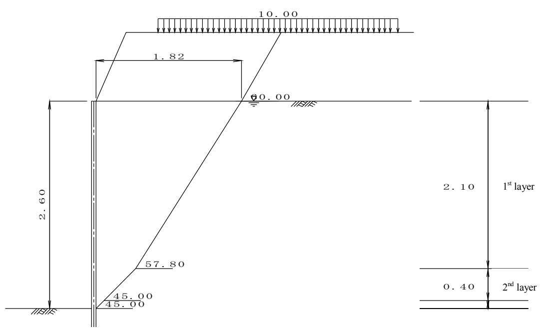
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴
Sectional factor	Z_0	=	3820 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 N/mm² (Normal)
	σ_a'	=	270 N/mm² (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction Not reduced: I_0 applied to calculation of penetration depth Reduced: I_0 applied to calculation of section forces and displacement Reduced: Z0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.50	Clayey Soil	0.0	10.0	12.0	25.00	24.42	25.48	45.00
2	2.50~ 2.10	Clayey Soil	0.0	10.0	18.0	24.20	24.42	24.50	45.00
3	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	24.42	20.58	57.80
4		Embankment	30.0	——	0.0	15.48	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where,

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	45.00	0.10	0.00	0.00	0.10	0.10
2	45.00	0.40	0.10	0.10	0.50	0.50
3	57.80	2.10	0.50	0.50	1.82	2.60
4	60.00	0.86	1.82	2.60	2.32	3.46

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.62	29.11
Σ			29.11

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.54	15.39
Σ			15.39

Q: surcharge load

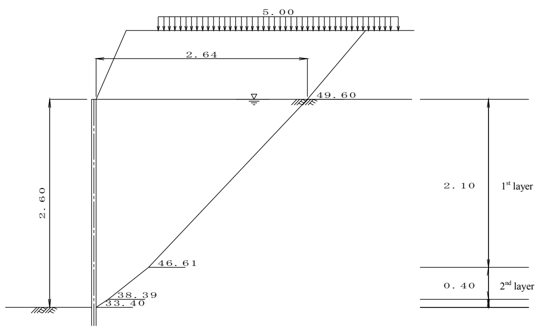
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L} = \frac{29.11+15.39+0.00}{1.82}$$

$$= 24.42 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m^2)	Σγh (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.50	Clayey Soil	0.0	10.0	12.0	25.00	21.42	25.48	0.200	11.31	33.40
2	2.50~ 2.10	Clayey Soil	0.0	10.0	18.0	24.20	21.42	24.50	0.200	11.31	38.39
3	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	21.42	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	15.48	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where,

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m^2)
- C cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	33.40	0.10	0.00	0.00	0.15	0.10
2	38.39	0.40	0.15	0.10	0.66	0.50
3	46.61	2.10	0.66	0.50	2.64	2.60
4	49.60	0.86	2.64	2.60	3.37	3.46

Therefore, width of acting load shall be set as 2.64 m

2-2-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	2.42	43.62
Σ			43.62

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	5.0	2.59	12.97
Σ			12.97

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

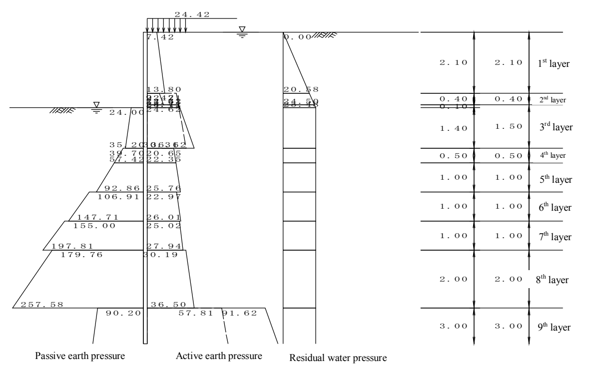
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{43.62 + 12.97 + 0.00}{2.64}$$

$$= 21.42\ kN/m^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m^3)	φ (degree)	C (kN/m^2)	Σγh+Qa (kN/m^2)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	24.419 45.419	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.50	Clayey soil	8.0	—	18.0 18.0	45.419 48.619	—— ——	—— ——
3	2.50~ 2.60	Clayey soil	8.0	—	12.0 12.0	48.619 49.419	—— ——	—— ——
4	2.60~ 4.00	Clayey soil	8.0	—	12.0 12.0	49.419 60.619	—— ——	—— ——
5	4.00~ 4.50	Sandy soil	10.0	27.0	—— ——	60.619 65.619	0.34585 0.34585	0.34060 0.34060
6	4.50~ 5.50	Sandy soil	10.0	27.0	—— ——	65.619 75.619	0.34585 0.34585	0.34060 0.34060
7	5.50~ 6.50	Sandy soil	10.0	30.0	—— ——	75.619 85.619	0.30847 0.30847	0.30378 0.30378
8	6.50~ 7.50	Sandy soil	10.0	31.0	—— ——	85.619 95.619	0.29669 0.29669	0.29219 0.29219
9	7.50~ 9.50	Sandy soil	10.0	29.0	—— ——	95.619 115.619	0.32058 0.32058	0.31571 0.31571
10	9.50~ 12.50	Clayey soil	8.0	—	12.0 12.0	115.619 139.619	—— ——	—— ——
11	12.50~ 15.50	Clayey soil	8.0	—	18.0 18.0	139.619 163.619	—— ——	—— ——
12	15.50~ 16.50	Clayey soil	8.0	—	18.0 18.0	163.619 171.619	—— ——	—— ——
13	16.50~ 17.50	Clayey soil	8.0	—	24.0 24.0	171.619 179.619	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m^3)	φ (degree)	C (kN/m^2)	Σγh+Qa (kN/m^2)	Ka	Ka ×cosδ
14	17.50~ 18.50	Clayey soil	8.0	—	12.0 12.0	179.619 187.619	—— ——	—— ——
15	18.50~ 19.50	Clayey soil	8.0	—	100.0 100.0	187.619 195.619	—— ——	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m^3)	φ (degree)	C kN/m^2	Σγh+Qp (kN/m^2)	Kp	Kp ×cosδ
4	2.60~ 4.00	Clayey soil	8.0	0.0	12.0 12.0	0.000 11.200	—— ——	—— ——
5	4.00~ 4.50	Sandy soil	10.0	27.0	—— ——	11.200 16.200	3.59892 3.59892	3.54425 3.54425
6	4.50~ 5.50	Sandy soil	10.0	27.0	—— ——	16.200 26.200	3.59892 3.59892	3.54425 3.54425
7	5.50~ 6.50	Sandy soil	10.0	30.0	—— ——	26.200 36.200	4.14330 4.14330	4.08035 4.08035
8	6.50~ 7.50	Sandy soil	10.0	31.0	—— ——	36.200 46.200	4.34774 4.34774	4.28169 4.28169
9	7.50~ 9.50	Sandy soil	10.0	29.0	—— ——	46.200 66.200	3.95096 3.95096	3.89093 3.89093
10	9.50~ 12.50	Clayey soil	8.0	0.0	12.0 12.0	66.200 90.200	—— ——	—— ——
11	12.50~ 15.50	Clayey soil	8.0	0.0	18.0 18.0	90.200 114.200	—— ——	—— ——
12	15.50~ 16.50	Clayey soil	8.0	0.0	18.0 18.0	114.200 122.200	—— ——	—— ——
13	16.50~ 17.50	Clayey soil	8.0	0.0	24.0 24.0	122.200 130.200	—— ——	—— ——
14	17.50~ 18.50	Clayey soil	8.0	0.0	12.0 12.0	130.200 138.200	—— ——	—— ——
15	18.50~ 19.50	Clayey soil	8.0	0.0	100.0 100.0	138.200 146.200	—— ——	—— ——

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	7.42 13.80	— —	7.42 13.80	0.00 20.58	— —
2	2.10~ 2.50	9.42 12.62	22.71 24.31	22.71 24.31	20.58 24.50	— —
3	2.50~ 2.60	24.62 25.42	24.31 24.71	24.62 25.42	24.50 25.48	— —
4	2.60~ 4.00	25.42 36.62	24.71 30.31	25.42 36.62	25.48 25.48	24.00 35.20
5	4.00~ 4.50	20.65 22.35	— —	20.65 22.35	25.48 25.48	39.70 57.42
6	4.50~ 5.50	22.35 25.76	— —	22.35 25.76	25.48 25.48	57.42 92.86
7	5.50~ 6.50	22.97 26.01	— —	22.97 26.01	25.48 25.48	106.91 147.71
8	6.50~ 7.50	25.02 27.94	— —	25.02 27.94	25.48 25.48	155.00 197.81
9	7.50~ 9.50	30.19 36.50	— —	30.19 36.50	25.48 25.48	179.76 257.58
10	9.50~ 12.50	91.62 115.62	57.81 69.81	91.62 115.62	25.48 25.48	90.20 114.20
11	12.50~ 15.50	103.62 127.62	69.81 81.81	103.62 127.62	25.48 25.48	126.20 150.20
12	15.50~ 16.50	127.62 135.62	81.81 85.81	127.62 135.62	25.48 25.48	150.20 158.20
13	16.50~ 17.50	123.62 131.62	85.81 89.81	123.62 131.62	25.48 25.48	170.20 178.20
14	17.50~ 18.50	155.62 163.62	89.81 93.81	155.62 163.62	25.48 25.48	154.20 162.20
15	18.50~ 19.50	-12.38 -4.38	93.81 97.81	93.81 97.81	25.48 25.48	338.20 346.20

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

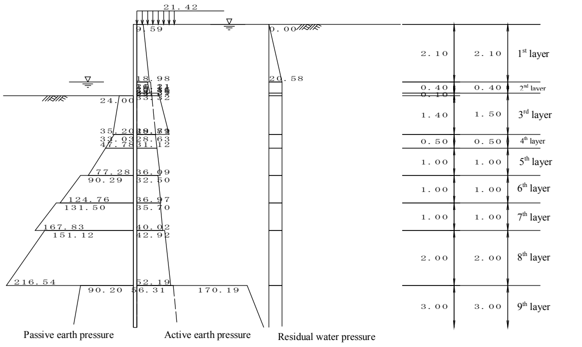
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	— —	21.42 42.42	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
2	2.10~ 2.50	Clayey Soil	8.0	—	18.0 18.0	42.42 45.62	20.58 24.50	0.200 0.200	11.31 11.31	— —	— —	38.78 38.39
3	2.50~ 2.60	Clayey Soil	8.0	—	12.0 12.0	45.62 46.42	24.50 25.48	0.200 0.200	11.31 11.31	— —	— —	33.60 33.40
4	2.60~ 4.00	Clayey Soil	8.0	—	12.0 12.0	46.42 57.62	25.48 39.20	0.200 0.200	11.31 11.31	— —	— —	33.40 30.30
5	4.00~ 4.50	Sandy Soil	10.0	27.0	— —	57.62 62.62	39.20 44.10	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
6	4.50~ 5.50	Sandy Soil	10.0	27.0	— —	62.62 72.62	44.10 53.90	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	— —
7	5.50~ 6.50	Sandy Soil	10.0	30.0	— —	72.62 82.62	53.90 63.70	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
8	6.50~ 7.50	Sandy Soil	10.0	31.0	— —	82.62 92.62	63.70 73.50	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	— —
9	7.50~ 9.50	Sandy Soil	10.0	29.0	— —	92.62 112.62	73.50 93.10	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	— —
10	9.50~ 12.50	Clayey Soil	8.0	—	12.0 12.0	112.62 136.62	93.10 122.50	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
11	12.50~ 15.50	Clayey Soil	8.0	—	18.0 18.0	136.62 160.62	122.50 151.90	0.200 0.200	11.31 11.31	— —	— —	19.25 10.00
12	15.50~ 16.50	Clayey Soil	8.0	—	18.0 18.0	160.62 168.62	151.90 161.70	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
13	16.50~ 17.50	Clayey Soil	8.0	—	24.0 24.0	168.62 176.62	161.70 171.50	0.200 0.200	11.31 11.31	— —	— —	24.53 22.69
14	17.50~ 18.50	Clayey Soil	8.0	—	12.0 12.0	176.62 184.62	171.50 181.30	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	18.50~ 19.50	Clayey Soil	8.0	—	100.0 100.0	184.62 192.62	181.30 191.10	0.200 0.200	11.31 11.31	— —	— —	41.70 41.56

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C} \cdot \tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 4.00	Clayey soil	8.00	0.0	12.0 12.0	0.000 11.200	0.00 13.72	0.200 0.200	11.31 11.31	— —	— —
5	4.00~ 4.50	Sandy soil	10.00	27.0	— —	11.200 16.200	13.72 18.62	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	4.50~ 5.50	Sandy soil	10.00	27.0	— —	16.200 26.200	18.62 28.42	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	5.50~ 6.50	Sandy soil	10.00	30.0	— —	26.200 36.200	28.42 38.22	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
8	6.50~ 7.50	Sandy soil	10.00	31.0	— —	36.200 46.200	38.22 48.02	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
9	7.50~ 9.50	Sandy soil	10.00	29.0	— —	46.200 66.200	48.02 67.62	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
10	9.50~ 12.50	Clayey soil	8.00	0.0	12.0 12.0	66.200 90.200	67.62 97.02	0.200 0.200	11.31 11.31	— —	— —
11	12.50~ 15.50	Clayey soil	8.00	0.0	18.0 18.0	90.200 114.200	97.02 126.42	0.200 0.200	11.31 11.31	— —	— —
12	15.50~ 16.50	Clayey soil	8.00	0.0	18.0 18.0	114.200 122.200	126.42 136.22	0.200 0.200	11.31 11.31	— —	— —
13	16.50~ 17.50	Clayey soil	8.00	0.0	24.0 24.0	122.200 130.200	136.22 146.02	0.200 0.200	11.31 11.31	— —	— —
14	17.50~ 18.50	Clayey soil	8.00	0.0	12.0 12.0	130.200 138.200	146.02 155.82	0.200 0.200	11.31 11.31	— —	— —
15	18.50~ 19.50	Clayey soil	8.00	0.0	100.0 100.0	138.200 146.200	155.82 165.62	0.200 0.200	11.31 11.31	— —	— —

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta) \cdot \sin(\phi+\beta-\theta)}{\cos(\delta-\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	9.59 18.98	— —	9.59 18.98	0.00 20.58	— —
2	2.10~ 2.50	16.11 20.16	21.21 22.81	21.21 22.81	20.58 20.58	— —
3	2.50~ 2.60	33.32 34.39	22.81 23.21	33.32 34.39	20.58 20.58	— —
4	2.60~ 4.00	34.39 49.79	23.21 28.81	34.39 49.79	20.58 20.58	24.00 35.20
5	4.00~ 4.50	28.63 31.12	— —	28.63 31.12	20.58 20.58	33.03 47.78
6	4.50~ 5.50	31.12 36.09	— —	31.12 36.09	20.58 20.58	47.78 77.28
7	5.50~ 6.50	32.50 36.97	— —	32.50 36.97	20.58 20.58	90.29 124.76
8	6.50~ 7.50	35.70 40.02	— —	35.70 40.02	20.58 20.58	131.50 167.83
9	7.50~ 9.50	42.92 52.19	— —	42.92 52.19	20.58 20.58	151.12 216.54
10	9.50~ 12.50	170.19 221.41	56.31 68.31	170.19 221.41	20.58 20.58	90.20 114.20
11	12.50~ 15.50	157.03 237.55	68.31 80.31	157.03 237.55	20.58 20.58	126.20 150.20
12	15.50~ 16.50	237.55 254.62	80.31 84.31	237.55 254.62	20.58 20.58	150.20 158.20
13	16.50~ 17.50	178.98 193.67	84.31 88.31	178.98 193.67	20.58 20.58	170.20 178.20
14	17.50~ 18.50	306.78 323.85	88.31 92.31	306.78 323.85	20.58 20.58	154.20 162.20
15	18.50~ 19.50	24.73 34.62	92.31 96.31	92.31 96.31	20.58 20.58	338.20 346.20

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

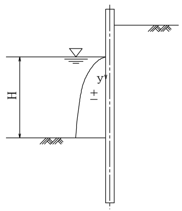
Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m^2)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

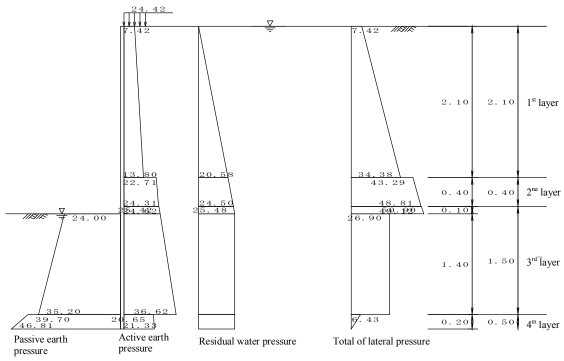
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

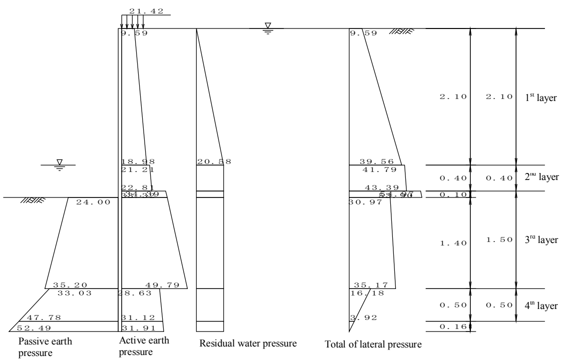


	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	7.42 13.80	0.00 20.58	—— ——	7.42 34.38
2	2.10~ 2.50	22.71 24.31	20.58 24.50	—— ——	43.29 48.81
3	2.50~ 2.60	24.62 25.42	24.50 25.48	—— ——	49.12 50.90
4	2.60~ 4.00	25.42 36.62	25.48 25.48	24.00 35.20	26.90 26.90
5	4.00~ 4.20	20.65 21.33	25.48 25.48	39.70 46.81	6.43 0.00
6	4.20~ 4.50	21.33 22.35	25.48 25.48	46.81 57.42	0.00 -9.59

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.60 m (GL -4.20 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	9.59 18.98	0.00 20.58	—— ——	9.59 39.56
2	2.10~ 2.50	21.21 22.81	20.58 20.58	—— ——	41.79 43.39
3	2.50~ 2.60	33.32 34.39	20.58 20.58	—— ——	53.90 54.97
4	2.60~ 4.00	34.39 49.79	20.58 20.58	24.00 35.20	30.97 35.17
5	4.00~ 4.50	28.63 31.12	20.58 20.58	33.03 47.78	16.18 3.92
6	4.50~ 4.66	31.12 31.91	20.58 20.58	47.78 52.49	3.92 0.00
7	4.66~ 5.50	31.91 36.09	20.58 20.58	52.49 77.28	0.00 -20.61

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 2.06 m (GL -4.66 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m		
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 =	1.00 mm (passive side)
Corrosion rate	η	=	0.92		
Section efficiency	μ	=	0.80		
Young's modulus	E	=	200000 N/mm^2		
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)		
	I	=	63296 cm^4 (after reduction by corrosion and section)		
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} = 1.266×10^5		

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	12.50	2
2	1.60	15	12	16.50	3
3	2.10	3	13	17.50	4
4	2.50	3	14	18.50	2
5	4.00	2	15	19.50	19
6	4.50	3			
7	5.50	10			
8	6.50	15			
9	7.50	17			
10	9.50	13			

5-2 Normal Condition

K_h = 16668 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.426 \ \mathrm{m^{-1}}$$

$$L = \frac{1}{\beta} = 2.35 \ \mathrm{m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.20 m) to 2.35 m depth (GL -6.55 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.20	0.30	2.4	3.0	0.81
2	4.50	1.00	3.0	10.0	6.50
3	5.50	1.00	10.0	15.0	12.50
4	6.50	0.05	15.0	15.1	0.73
	L = Σh = 2.35				ΣA = 20.54

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{20.54}{2.35} = 8.75$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 8.75^{0.406} = 16668$ kN/m³

K_h (normal condition) = 16668 kN/m³

5-3 Seismic Condition

K_h = 18351 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.436 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.29 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.66 m) to 2.29 m depth (GL -6.95 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.66	0.84	4.1	10.0	5.93
2	5.50	1.00	10.0	15.0	12.50
3	6.50	0.45	15.0	15.9	6.98
	L = Σh = 2.29				ΣA = 25.41

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{25.41}{2.29} = 11.09$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 11.09^{0.406} = 18351$ kN/m³

K_h (seismic condition) = 18351 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.42 / 34.38	7.79 / 36.10	3.50 / 2.80	27.27 / 101.10
2	2.10~ 2.50	0.40	43.29 / 48.81	8.66 / 9.76	1.97 / 1.83	17.03 / 17.90
3	2.50~ 2.60	0.10	49.12 / 50.90	2.46 / 2.54	1.67 / 1.63	4.10 / 4.16
4	2.60~ 4.00	1.40	26.90 / 26.90	18.83 / 18.83	1.13 / 0.67	21.35 / 12.57
5	4.00~ 4.20	0.20	6.43 / 0.00	0.65 / 0.00	0.13 / 0.07	0.09 / 0.00
				ΣP = 105.61		ΣM = 205.56

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.3 kN/m
depth to acting position	H_t	=	-0.41 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.60 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.60$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{216.17}{107.91} = 2.00 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.59 / 39.56	10.06 / 41.54	3.96 / 3.26	39.85 / 135.41
2	2.10~ 2.50	0.40	41.79 / 43.39	8.36 / 8.68	2.43 / 2.29	20.28 / 19.90
3	2.50~ 2.60	0.10	53.90 / 54.97	2.69 / 2.75	2.13 / 2.09	5.73 / 5.75
4	2.60~ 4.00	1.40	30.97 / 35.17	21.68 / 24.62	1.59 / 1.13	34.53 / 27.73
5	4.00~ 4.50	0.50	16.18 / 3.92	4.04 / 0.98	0.49 / 0.33	1.99 / 0.32

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
6	4.50~ 4.66	0.16	3.92 / 0.00	0.31 / 0.00	0.11 / 0.05	0.03 / 0.00
				ΣP = 125.72		ΣM = 291.54

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.5 kN/m
depth to acting position	H_t	=	-0.23 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.06 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 41.56$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 / 0.9	0.00 / 0.21	2.39 / 2.23	0.00 / 0.48
				ΣPdw = 0.21		ΣMdw = 0.48

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{333.58}{134.44} = 2.48 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 63296 x 10⁻⁸		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	16668 kN/m³
calculated value	β	=	0.42595 m⁻¹
resultant earth force (lateral)	P_0	=	107.91 kN/m
height of acting position of load	h_0	=	2.00 m
moment	M_0	=	216.17 kN·m/m
in consideration of ψ_m = 1.187, maximum moment	M_{max}	=	256.55 kN·m/m
depth of generated position of M_{max}	l_m	=	0.831 m
depth of 1st fixed point	l_i	=	2.675 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	18351 kN/m³
calculated value	β	=	0.43632 m⁻¹
resultant earth force (lateral)	P_0	=	134.44 kN/m
height of acting position of load	h_0	=	2.48 m
moment	M_0	=	333.58 kN·m/m
in consideration of ψ_m = 1.129, maximum moment	M_{max}	=	376.59 kN·m/m
depth of generated position of M_{max}	l_m	=	0.701 m
depth of 1st fixed point	l_i	=	2.501 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{256.55\times10^6}{3514\times10^3} = 73\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{376.59\times10^6}{3514\times10^3} = 107\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.50 2.80	0.833 0.667	0.251 0.173	7.79 36.10	1.953 6.240
2	2.10~ 2.50	1.97 1.83	0.468 0.437	0.093 0.081	8.66 9.76	0.801 0.795
3	2.50~ 2.60	1.67 1.63	0.397 0.389	0.068 0.066	2.46 2.54	0.168 0.168
4	2.60~ 4.00	1.13 0.67	0.270 0.159	0.033 0.012	18.83 18.83	0.624 0.225
5	4.00~ 4.20	0.13 0.07	0.032 0.016	0.001 0.000	0.65 0.00	0.000 0.000
						ΣQ = 10.975

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

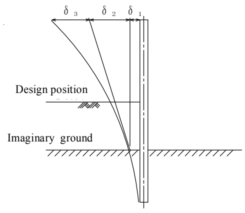
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4260\times2.00)\times107.91}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4260^3} = 0.01022\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4260\times2.00)\times107.91}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4260^2}\times(2.60+1.60) = 0.02671\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.97\times(2.60+1.60)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00643\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00051 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.20 m
Horizontal load: P = 2.30
Moment: M = 0.94

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01022 + 0.02671 + 0.00694
= 0.04387 m
= 43.87 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.96 3.26	0.850 0.700	0.259 0.188	10.06 41.54	2.605 7.794
2	2.10~ 2.50	2.43 2.29	0.521 0.492	0.112 0.101	8.36 8.68	0.936 0.878
3	2.50~ 2.60	2.13 2.09	0.456 0.449	0.088 0.086	2.69 2.75	0.238 0.236
4	2.60~ 4.00	1.59 1.13	0.342 0.242	0.052 0.027	21.68 24.62	1.122 0.661
5	4.00~ 4.50	0.49 0.33	0.106 0.070	0.005 0.002	4.04 0.98	0.022 0.002
6	4.50~ 4.66	0.11 0.05	0.023 0.011	0.000 0.000	0.31 0.00	0.000 0.000
						ΣQ = 14.496

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

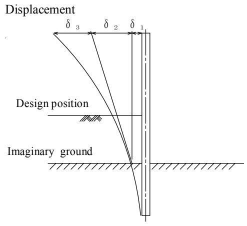
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.39 2.23	0.514 0.478	0.109 0.096	0.00 0.21	0.000 0.021
						ΣQ_{dw} = 0.021

Therefore, modulus of deformation Q is calculated as below:
Q = 14.496 + 0.021 = 14.516

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4363\times2.48)\times134.44}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4363^3} = 0.01331\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4363\times2.48)\times134.44}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4363^2}\times(2.60+2.06) = 0.04114\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{14.52\times(2.60+2.06)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.01160\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00243 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.66 m
Horizontal load: P = 8.50
Moment: M = 1.96

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01331 + 0.04114 + 0.01403
= 0.06849 m
= 68.49 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 86000 \times 10^{-8}$		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 16668$ kN/m^3

Calculated value $\beta = 0.39453$ m^{-1}

Penetration length of SSP $D = 1.60 + \dfrac{3}{0.395} = 9.20$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.20 = 11.40$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 18351$ kN/m^3

Calculated value $\beta = 0.40413$ m^{-1}

Penetration length of SSP $D = 2.06 + \dfrac{3}{0.404} = 9.48$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.48 = 11.68$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

Case: Right Bank No. 14_STA 8+900 – 9+000

8 Calculation Result

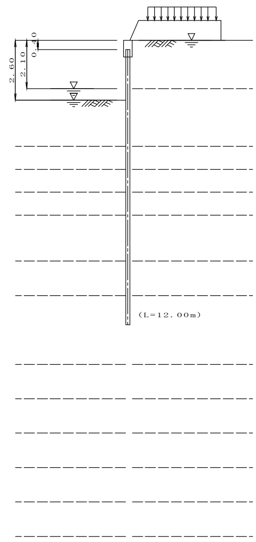
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		256.55	376.59
Stress intensity	σ (N/mm^2)		73 (180)	107 (270)
Lateral displacement	δ (mm)		43.87 (50.0)	68.49 (75.0)
Penetration depth	D (m)		9.20	9.48
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 15_STA 9+000 - 9+150

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
4.62	Sandy Soil	18.0	27.0	0.0
5.62	Sandy Soil	18.0	27.0	0.0
6.62	Sandy Soil	18.0	28.0	0.0
7.62	Clayey Soil	16.0	0.0	25.0
9.62	Clayey Soil	16.0	0.0	18.0
11.12	Clayey Soil	16.0	0.0	12.0
14.12	Clayey Soil	16.0	0.0	18.0
15.62	Clayey Soil	16.0	0.0	24.0
17.12	Clayey Soil	16.0	0.0	25.0
18.62	Sandy Soil	18.0	27.0	0.0
20.12	Sandy Soil	18.0	36.0	0.0
21.62	Sandy Soil	18.0	40.0	0.0
	Sandy Soil	18.0	41.0	0.0

N-Value: 0 10 20 30 40 50

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wn}	=	2.60 m (Normal Condition)
	L_{wn}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.3 kNm (Normal Condition)
		Pt'	=	8.6 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.41 m (Normal Condition)
		Ht'	=	-0.24 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	3
4	4.62	3
5	5.62	10
6	6.62	12
7	7.62	7
8	9.62	3
9	11.12	2
10	14.12	3

No	Depth (m)	N-Value
11	15.62	4
12	17.12	5
13	18.62	9
14	20.12	29
15	21.62	42
16	23.12	45

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1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

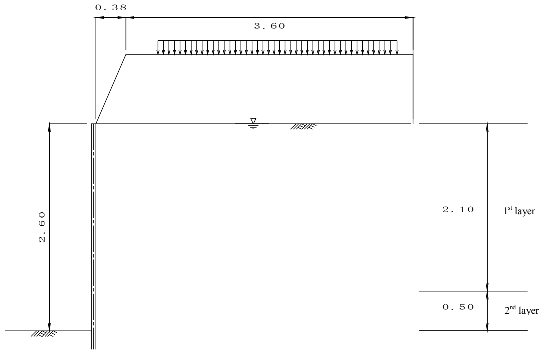
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.62	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	5.62	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	6.62	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
5	7.62	C	7.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
6	9.62	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
7	11.12	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
8	14.12	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
9	15.62	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
10	17.12	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
11	18.62	S	9.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
12	20.12	S	29.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
13	21.62	S	42.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
14	23.12	S	45.0	18.00	10.00	41.0	0.0	0.0	0.200	auto	auto	——	——

Note) depth : from top of coping to bottom of the layer
soil : sandy (S), clayey (C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.38	3.98	3.98	0.87	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.78	3.78	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 86000 cm⁴
Sectional factor Z_0 = 3820 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.92
Corrosion rate (to Z_0) η = 0.92
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

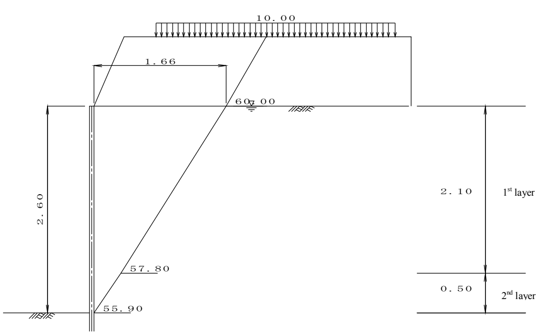
Allowable stress σ_a = 180 N/mm² (Normal)
σ_a' = 270 N/mm² (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	24.56	25.48	55.90
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	24.56	20.58	57.80
3		Embankment	30.0	——	0.0	15.66	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

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2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	0.87	1.66	2.60	2.16	3.47

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.50	26.97
Σ			26.97

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.38	13.83
Σ			13.83

Q surcharge load
l : width of surcharge load set by line of active rupture

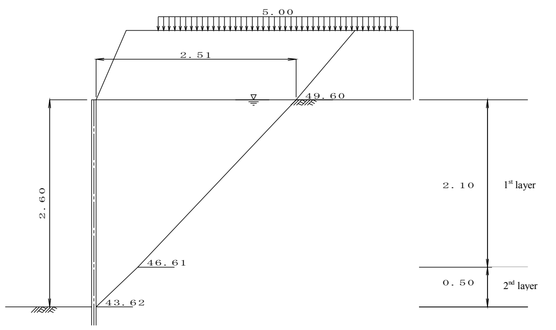
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{26.97 + 13.83 + 0.00}{1.66}$$

$$= 24.56 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	21.70	25.48	0.200	11.31	43.62
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	21.70	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	15.66	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{o}$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m^2)
- C cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	0.87	2.51	2.60	3.25	3.47

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.34	42.13
Σ			42.13

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.47	12.35
Σ			12.35

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

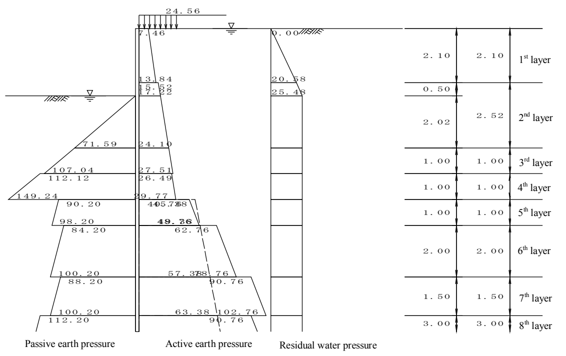
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{42.13 + 12.35 + 0.00}{2.51}$$

$$= 21.70 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	24.565 45.565	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	45.565 50.565	0.34585 0.34585	0.34060 0.34060
3	2.60~ 4.62	Sandy soil	10.0	27.0	—— ——	50.565 70.765	0.34585 0.34585	0.34060 0.34060
4	4.62~ 5.62	Sandy soil	10.0	27.0	—— ——	70.765 80.765	0.34585 0.34585	0.34060 0.34060
5	5.62~ 6.62	Sandy soil	10.0	28.0	—— ——	80.765 90.765	0.33303 0.33303	0.32798 0.32798
6	6.62~ 7.62	Clayey soil	8.0	—	25.0 25.0	90.765 98.765	—— ——	—— ——
7	7.62~ 9.62	Clayey soil	8.0	—	18.0 18.0	98.765 114.765	—— ——	—— ——
8	9.62~ 11.12	Clayey soil	8.0	—	12.0 12.0	114.765 126.765	—— ——	—— ——
9	11.12~ 14.12	Clayey soil	8.0	—	18.0 18.0	126.765 150.765	—— ——	—— ——
10	14.12~ 15.62	Clayey soil	8.0	—	24.0 24.0	150.765 162.765	—— ——	—— ——
11	15.62~ 17.12	Clayey soil	8.0	—	25.0 25.0	162.765 174.765	—— ——	—— ——
12	17.12~ 18.62	Sandy soil	10.0	27.0	—— ——	174.765 189.765	0.34585 0.34585	0.34060 0.34060
13	18.62~ 20.12	Sandy soil	10.0	36.0	—— ——	189.765 204.765	0.24257 0.24257	0.23889 0.23889

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	20.12~ 21.62	Sandy soil	10.0	40.0	—— ——	204.765 219.765	0.20447 0.20447	0.20137 0.20137
15	21.62~ 23.12	Sandy soil	10.0	41.0	—— ——	219.765 234.765	0.19561 0.19561	0.19264 0.19264

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60~ 4.62	Sandy soil	10.0	27.0	—— ——	0.000 20.200	3.59892 3.59892	3.54425 3.54425
4	4.62~ 5.62	Sandy soil	10.0	27.0	—— ——	20.200 30.200	3.59892 3.59892	3.54425 3.54425
5	5.62~ 6.62	Sandy soil	10.0	28.0	—— ——	30.200 40.200	3.76978 3.76978	3.71251 3.71251
6	6.62~ 7.62	Clayey soil	8.0	0.0	25.0 25.0	40.200 48.200	—— ——	—— ——
7	7.62~ 9.62	Clayey soil	8.0	0.0	18.0 18.0	48.200 64.200	—— ——	—— ——
8	9.62~ 11.12	Clayey soil	8.0	0.0	12.0 12.0	64.200 76.200	—— ——	—— ——
9	11.12~ 14.12	Clayey soil	8.0	0.0	18.0 18.0	76.200 100.200	—— ——	—— ——
10	14.12~ 15.62	Clayey soil	8.0	0.0	24.0 24.0	100.200 112.200	—— ——	—— ——
11	15.62~ 17.12	Clayey soil	8.0	0.0	25.0 25.0	112.200 124.200	—— ——	—— ——
12	17.12~ 18.62	Sandy soil	10.0	27.0	—— ——	124.200 139.200	3.59892 3.59892	3.54425 3.54425
13	18.62~ 20.12	Sandy soil	10.0	36.0	—— ——	139.200 154.200	5.59154 5.59154	5.50659 5.50659
14	20.12~ 21.62	Sandy soil	10.0	40.0	—— ——	154.200 169.200	6.94605 6.94605	6.84053 6.84053
15	21.62~ 23.12	Sandy soil	10.0	41.0	—— ——	169.200 184.200	7.35235 7.35235	7.24065 7.24065

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.46 13.84	—— ——	7.46 13.84	0.00 20.58	—— ——
2	2.10~ 2.60	15.52 17.22	—— ——	15.52 17.22	20.58 25.48	—— ——
3	2.60~ 4.62	17.22 24.10	—— ——	17.22 24.10	25.48 25.48	0.00 71.59
4	4.62~ 5.62	24.10 27.51	—— ——	24.10 27.51	25.48 25.48	71.59 107.04
5	5.62~ 6.62	26.49 29.77	—— ——	26.49 29.77	25.48 25.48	112.12 149.24
6	6.62~ 7.62	40.76 48.76	45.38 49.38	45.38 49.38	25.48 25.48	90.20 98.20
7	7.62~ 9.62	62.76 78.76	49.38 57.38	62.76 78.76	25.48 25.48	84.20 100.20
8	9.62~ 11.12	90.76 102.76	57.38 63.38	90.76 102.76	25.48 25.48	88.20 100.20
9	11.12~ 14.12	90.76 114.76	63.38 75.38	90.76 114.76	25.48 25.48	112.20 136.20
10	14.12~ 15.62	102.76 114.76	75.38 81.38	102.76 114.76	25.48 25.48	148.20 160.20
11	15.62~ 17.12	112.76 124.76	81.38 87.38	112.76 124.76	25.48 25.48	162.20 174.20
12	17.12~ 18.62	59.52 64.63	—— ——	59.52 64.63	25.48 25.48	440.20 493.36
13	18.62~ 20.12	45.33 48.92	—— ——	45.33 48.92	25.48 25.48	766.52 849.12
14	20.12~ 21.62	41.23 44.25	—— ——	41.23 44.25	25.48 25.48	1054.81 1157.42
15	21.62~ 23.12	42.33 45.22	—— ——	42.33 45.22	25.48 25.48	1225.12 1333.73

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

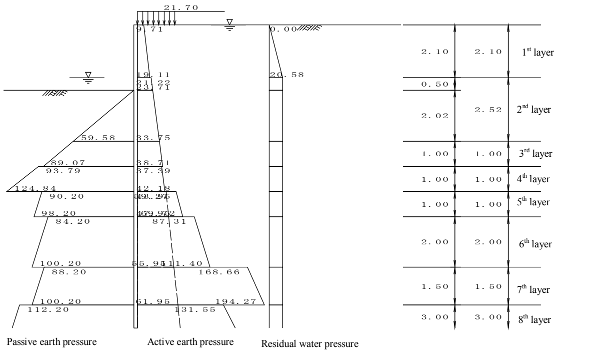
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	21.71 42.71	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	27.0	—— ——	42.71 47.71	20.58 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.60~ 4.62	Sandy Soil	10.0	27.0	—— ——	47.71 67.91	25.48 45.28	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	4.62~ 5.62	Sandy Soil	10.0	27.0	—— ——	67.91 77.91	45.28 55.08	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	5.62~ 6.62	Sandy Soil	10.0	28.0	—— ——	77.91 87.91	55.08 64.88	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
6	6.62~ 7.62	Clayey Soil	8.0	—	25.0 25.0	87.91 95.91	64.88 74.68	0.200 0.200	11.31 11.31	—— ——	—— ——	36.85 36.04
7	7.62~ 9.62	Clayey Soil	8.0	—	18.0 18.0	95.91 111.91	74.68 94.28	0.200 0.200	11.31 11.31	—— ——	—— ——	30.49 26.92
8	9.62~ 11.12	Clayey Soil	8.0	—	12.0 12.0	111.91 123.91	94.28 108.98	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
9	11.12~ 14.12	Clayey Soil	8.0	—	18.0 18.0	123.91 147.91	108.98 138.38	0.200 0.200	11.31 11.31	—— ——	—— ——	23.61 13.51
10	14.12~ 15.62	Clayey Soil	8.0	—	24.0 24.0	147.91 159.91	138.38 153.08	0.200 0.200	11.31 11.31	—— ——	—— ——	28.44 26.25
11	15.62~ 17.12	Clayey Soil	8.0	—	25.0 25.0	159.91 171.91	153.08 167.78	0.200 0.200	11.31 11.31	—— ——	—— ——	27.61 25.40
12	17.12~ 18.62	Sandy Soil	10.0	27.0	—— ——	171.91 186.91	167.78 182.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
13	18.62~ 20.12	Sandy Soil	10.0	36.0	—— ——	186.91 201.91	182.48 197.18	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—— ——
14	20.12~ 21.62	Sandy Soil	10.0	40.0	—— ——	201.91 216.91	197.18 211.88	0.200 0.200	11.31 11.31	0.31772 0.31772	0.31289 0.31289	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	21.62~ 23.12	Sandy Soil	10.0	41.0	—— ——	216.91 231.91	211.88 226.58	0.200 0.200	11.31 11.31	0.30610 0.30610	0.30145 0.30145	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta) \cdot \sin(\phi-\beta-\theta)}{\cos(\delta+\theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp × cosδ
3	2.60~ 4.62	Sandy soil	10.00	27.0	—— ——	0.000 20.200	0.00 19.80	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
4	4.62~ 5.62	Sandy soil	10.00	27.0	—— ——	20.200 30.200	19.80 29.60	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	5.62~ 6.62	Sandy soil	10.00	28.0	—— ——	30.200 40.200	29.60 39.40	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
6	6.62~ 7.62	Clayey soil	8.00	0.0	25.0 25.0	40.200 48.200	39.40 49.20	0.200 0.200	11.31 11.31	—— ——	—— ——
7	7.62~ 9.62	Clayey soil	8.00	0.0	18.0 18.0	48.200 64.200	49.20 68.80	0.200 0.200	11.31 11.31	—— ——	—— ——
8	9.62~ 11.12	Clayey soil	8.00	0.0	12.0 12.0	64.200 76.200	68.80 83.50	0.200 0.200	11.31 11.31	—— ——	—— ——
9	11.12~ 14.12	Clayey soil	8.00	0.0	18.0 18.0	76.200 100.200	83.50 112.90	0.200 0.200	11.31 11.31	—— ——	—— ——
10	14.12~ 15.62	Clayey soil	8.00	0.0	24.0 24.0	100.200 112.200	112.90 127.60	0.200 0.200	11.31 11.31	—— ——	—— ——
11	15.62~ 17.12	Clayey soil	8.00	0.0	25.0 25.0	112.200 124.200	127.60 142.30	0.200 0.200	11.31 11.31	—— ——	—— ——
12	17.12~ 18.62	Sandy soil	10.00	27.0	—— ——	124.200 139.200	142.30 157.00	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
13	18.62~ 20.12	Sandy soil	10.00	36.0	—— ——	139.200 154.200	157.00 171.70	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
14	20.12~ 21.62	Sandy soil	10.00	40.0	—— ——	154.200 169.200	171.70 186.40	0.200 0.200	11.31 11.31	6.09659 6.09659	6.00397 6.00397
15	21.62~ 23.12	Sandy soil	10.00	41.0	—— ——	169.200 184.200	186.40 201.10	0.200 0.200	11.31 11.31	6.47409 6.47409	6.37573 6.37573

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta) \cdot \sin(\phi+\beta-\theta)}{\cos(\delta-\theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
1	0.00~ 2.10	9.71 19.11	—— ——	9.71 19.11	0.00 20.58	—— ——
2	2.10~ 2.60	21.22 23.71	—— ——	21.22 23.71	20.58 20.58	—— ——
3	2.60~ 4.62	23.71 33.75	—— ——	23.71 33.75	20.58 20.58	0.00 59.58
4	4.62~ 5.62	33.75 38.71	—— ——	33.75 38.71	20.58 20.58	59.58 89.07
5	5.62~ 6.62	37.39 42.18	—— ——	37.39 42.18	20.58 20.58	93.79 124.84
6	6.62~ 7.62	59.27 69.72	43.95 47.95	59.27 69.72	20.58 20.58	90.20 98.20
7	7.62~ 9.62	87.31 111.40	47.95 55.95	87.31 111.40	20.58 20.58	84.20 100.20
8	9.62~ 11.12	168.66 194.27	55.95 61.95	168.66 194.27	20.58 20.58	88.20 100.20
9	11.12~ 14.12	131.55 191.78	61.95 73.95	131.55 191.78	20.58 20.58	112.20 136.20
10	14.12~ 15.62	145.21 164.25	73.95 79.95	145.21 164.25	20.58 20.58	148.20 160.20
11	15.62~ 17.12	160.18 179.78	79.95 85.95	160.18 179.78	20.58 20.58	162.20 174.20
12	17.12~ 18.62	85.43 92.88	—— ——	85.43 92.88	20.58 20.58	366.32 410.57
13	18.62~ 20.12	67.66 73.09	—— ——	67.66 73.09	20.58 20.58	663.52 735.02
14	20.12~ 21.62	63.17 67.87	—— ——	63.17 67.87	20.58 20.58	925.81 1015.87
15	21.62~ 23.12	65.39 69.91	—— ——	65.39 69.91	20.58 20.58	1078.77 1174.41

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1 2	2.10 2.60	0.00 0.50	0.00 0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

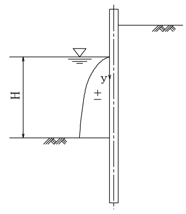
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

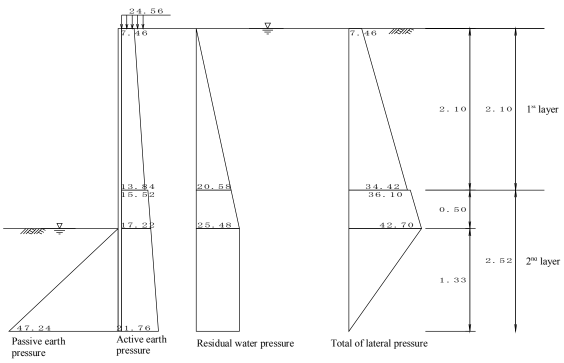
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level l_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

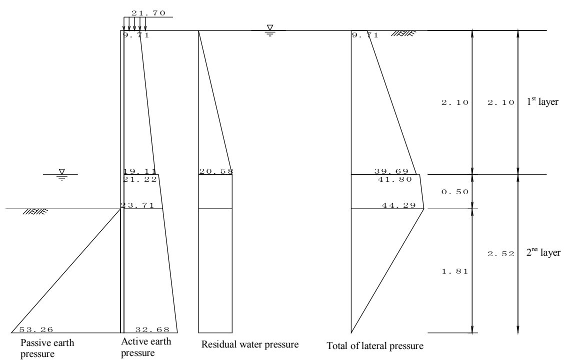


	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	7.46 13.84	0.00 20.58	—— ——	7.46 34.42
2	2.10~ 2.60	15.52 17.22	20.58 25.48	—— ——	36.10 42.70
3	2.60~ 3.93	17.22 21.76	25.48 25.48	0.00 47.24	42.70 0.00
4	3.93~ 4.62	21.76 24.10	25.48 25.48	47.24 71.59	0.00 -22.01

P_a ; Active earth pressure
P_w ; Residual water pressure
P_p ; Passive earth pressure
P_s ; Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed l_k: 1.33 m (GL -3.93 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	9.71 19.11	0.00 20.58	—— ——	9.71 39.69
2	2.10~ 2.60	21.22 23.71	20.58 20.58	—— ——	41.80 44.29
3	2.60~ 4.41	23.71 32.68	20.58 20.58	0.00 53.26	44.29 0.00
4	4.41~ 4.62	32.68 33.75	20.58 20.58	53.26 59.58	0.00 -5.25

P_a ; Active earth pressure
P_w ; Residual water pressure
P_p ; Passive earth pressure
P_s ; Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed l_k: 1.81 m (GL -4.41 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to $1/\beta$ depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} =1.266×10^5

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	3
4	4.62	3
5	5.62	10
6	6.62	12
7	7.62	7
8	9.62	3
9	11.12	2
10	14.12	3

	Depth (m)	N-value
11	15.62	4
12	17.12	5
13	18.62	9
14	20.12	29
15	21.62	42
16	23.12	45

5-2 Normal Condition

K_h = 15019 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.415 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.41 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) to 2.41 m depth (GL -6.34 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.93	0.69	3.0	3.0	2.06
2	4.62	1.00	3.0	10.0	6.50
3	5.62	0.72	10.0	11.4	7.75
	L = Σh = 2.41				ΣA = 16.31

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{16.31}{2.41}$$

$$= 6.77$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 6.77^{0.406} = 15019 \text{ kN/m}^3$$

K_h (normal condition) = 15019 kNm^3

5-3 Seismic Condition

K_h = 16399 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.424 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.36 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.41 m) to 2.36 m depth (GL -6.76 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.41	0.21	3.0	3.0	0.64
2	4.62	1.00	3.0	10.0	6.50
3	5.62	1.00	10.0	12.0	11.00
4	6.62	0.14	12.0	11.3	1.67
	L = Σh = 2.36				ΣA = 19.81

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{19.81}{2.36}$$

$$= 8.40$$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 8.40^{0.406} = 16399 \text{ kN/m}^3$$

K_h (seismic condition) = 16399 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.46 34.42	7.84 36.14	3.23 2.53	25.33 91.55
2	2.10~ 2.60	0.50	36.10 42.70	9.02 10.68	1.67 1.50	15.04 16.01
3	2.60~ 3.93	1.33	42.70 0.00	28.46 0.00	0.89 0.44	25.29 0.00
				ΣP = 92.14		ΣM = 173.21

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.3 kNm
depth to acting position	H_t	=	-0.41 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.33 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 9.99 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{183.20}{94.44} = 1.94 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.71 39.69	10.20 41.68	3.71 3.01	37.80 125.27
2	2.10~ 2.60	0.50	41.80 44.29	10.45 11.07	2.14 1.97	22.35 21.84
3	2.60~ 4.41	1.81	44.29 0.00	39.99 0.00	1.20 0.60	48.14 0.00
				ΣP = 113.38		ΣM = 255.39

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.6 kNm
depth to acting position	H_t	=	-0.24 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.81 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 39.95 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm^2)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.14 1.97	0.00 0.42
				ΣP_{dw}= 0.21		ΣM_{dw}= 0.42

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{295.77}{122.20} = 2.42 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 =1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266 × 10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	= 15019 kN/m^3
calculated value	β	= 0.41500 m^{-1}
resultant earth force (lateral)	P_0	= 94.44 kN/m
height of acting position of load	h_0	= 1.94 m
moment	M_0	= 183.20 kN·m/m

in consideration of ψ_h = 1.204,

maximum moment	M_{max}	= 220.59 kN·m/m
depth of generated position of M_{max}	l_m	= 0.882 m
depth of 1st fixed point	l_i	= 2.774 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	= 16399 kN/m^3
calculated value	β	= 0.42421 m^{-1}
resultant earth force (lateral)	P_0	= 122.20 kN/m
height of acting position of load	h_0	= 2.42 m
moment	M_0	= 295.77 kN·m/m

in consideration of ψ_h = 1.140,

maximum moment	M_{max}	= 337.23 kN·m/m
depth of generated position of M_{max}	l_m	= 0.746 m
depth of 1st fixed point	l_i	= 2.597 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{220.59\times10^6}{3514\times10^3} = 63\ \text{N/mm}^2 \leqq \sigma_a = 180\ \text{N/mm}^2$$

6-3-2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{337.23\times10^6}{3514\times10^3} = 96\ \text{N/mm}^2 \leqq \sigma_a = 270\ \text{N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.23 2.53	0.822 0.644	0.245 0.163	7.84 36.14	1.922 5.886
2	2.10~ 2.60	1.67 1.50	0.424 0.381	0.077 0.063	9.02 10.68	0.696 0.677
3	2.60~ 3.93	0.89 0.44	0.226 0.113	0.024 0.006	28.46 0.00	0.672 0.000
						ΣQ = 9.853

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

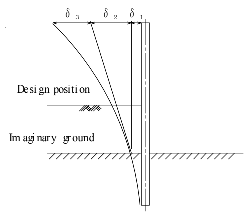
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4150\times1.94)\times94.44}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4150^3} = 0.00942\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4150\times1.94)\times94.44}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4150^2}\times(2.60+1.33) = 0.02223\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.85\times(2.60+1.33)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00473\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00043 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.93 m
Horizontal load: P = 2.30
Moment: M = 0.94

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00942 + 0.02223 + 0.00516
= 0.03681 m
= 36.81 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.71 3.01	0.841 0.682	0.255 0.180	10.20 41.68	2.596 7.493
2	2.10~ 2.60	2.14 1.97	0.486 0.448	0.099 0.085	10.45 11.07	1.032 0.944
3	2.60~ 4.41	1.20 0.60	0.273 0.137	0.034 0.009	39.99 0.00	1.357 0.000
						ΣQ = 13.423

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

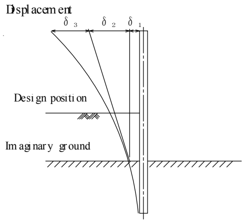
H : Depth to design position

L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.14 1.97	0.486 0.448	0.099 0.085	0.00 0.21	0.000 0.018
						ΣQ_{dw} = 0.018

Therefore, modulus of deformation Q is calculated as below
Q = 13.423 + 0.018 = 13.441



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4242\times 2.42)\times 122.20}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4242^3} = 0.01281 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4242\times 2.42)\times 122.20}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4242^2}\times(2.60+1.81) = 0.03608 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.44\times(2.60+1.81)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00908 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00209 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.41 m
Horizontal load: P = 8.60
Moment: M = 2.06

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01281 + 0.03608 + 0.01117
= 0.06007 m
= 60.07 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_1 + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 15019 kN/m^3
Calculated value β = 0.38438 m^{-1}

Penetration length of SSP $D = 1.33 + \frac{3}{0.384} = 9.14$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.14 = 11.34$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 16399 kN/m^3
Calculated value β = 0.39292 m^{-1}

Penetration length of SSP $D = 1.81 + \frac{3}{0.393} = 9.44$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.44 = 11.64$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		220.59	337.23
Stress intensity	σ (N/mm^2)		63 (180)	96 (270)
Lateral displacement	δ (mm)		36.81 (50.0)	60.07 (75.0)
Penetration depth	D (m)		9.14	9.44
Whole length of SSP	L (m)	12.00		

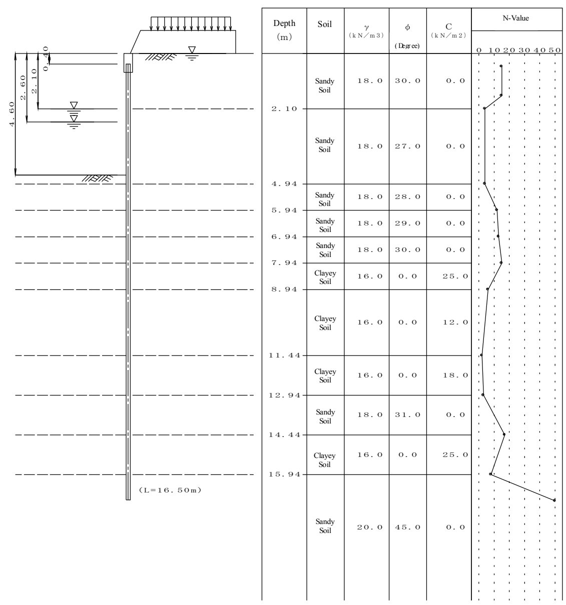
2.118

－Steel Sheet Pile Design Calculation－

Right Bank No. 16_STA 9+150 - 9+200

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	4.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.3 kNm (Normal Condition)
		Pt'	=	8.6 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.42 m (Normal Condition)
		Ht'	=	-0.24 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	14.44	17
2	1.60	15	12	15.94	8
3	2.10	4	13	16.94	50
4	4.94	4	14	20.00	50
5	5.94	12			
6	6.94	13			
7	7.94	15			
8	8.94	6			
9	11.44	2			
10	12.94	3			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on rierside not considered

1-7 Soil Modulus

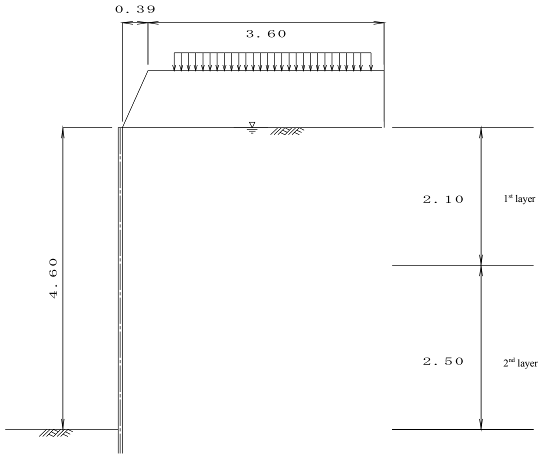
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.94	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	5.94	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
4	6.94	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
5	7.94	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
6	8.94	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
7	11.44	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
8	12.94	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
9	14.44	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
10	15.94	C	8.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
11	19.94	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate 1 (m)	2 (m)	3 (m)	4 (m)	Embankment height h (m)	Wet unit weight γ (kN/m³)	Internal friction angle ϕ (degree)	Cohesive force C (kN/m²)	Angle of rupture Normal	Seismic
1	Sandy soil	0.00	0.39	3.99	3.99	0.87	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period from (m)	to (m)	Load Normal (kN/m²)	Seismic (kN/m²)
1	0.79	3.79	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 342000 cm^4
Sectional factor Z_0 = 7200 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.87
Corrosion rate (to Z_0) η = 0.89
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 Nmm^2 (Normal)
σ_a' = 278 Nmm^2 (Seismic)

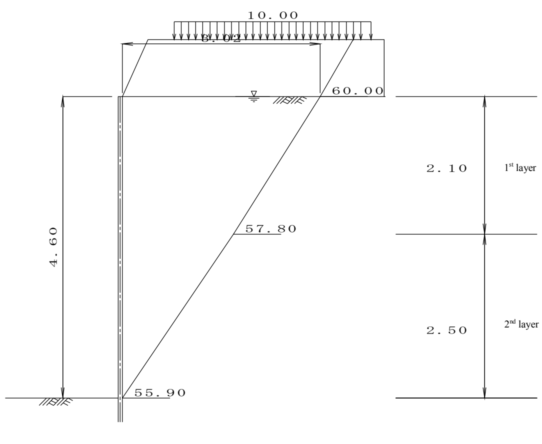
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	4.60~ 2.10	Sandy Soil	27.0	10.0	0.0	46.00	25.00	45.08	55.90
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.00	20.58	57.80
3		Embankment	30.0	——	0.0	15.66	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)

$\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Y (m)	Coordinate of upper end X (m)	Y (m)
1	55.90	2.50	0.00	0.00	1.69	2.50
2	57.80	2.10	1.69	2.50	3.02	4.60
3	60.00	0.87	3.02	4.60	3.52	5.47

Therefore, width of acting load shall be set as 3.02 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.67	48.10
Σ			48.10

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	2.73	27.27
Σ			27.27

Q surcharge load
l : width of surcharge load set by line of active rupture

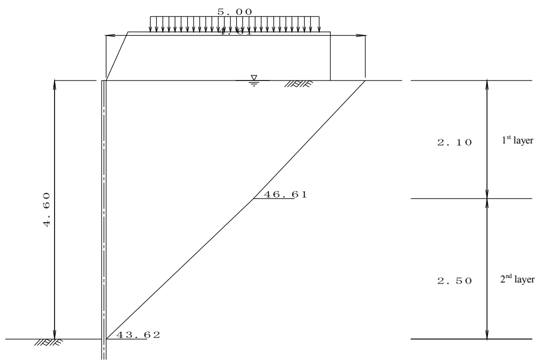
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{48.10 + 27.27 + 0.00}{3.02}$$

$$= 25.00\ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	4.60~ 2.10	Sandy Soil	27.0	10.0	0.0	46.00	16.15	45.08	0.200	11.31	43.62
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	16.15	20.58	0.200	11.31	46.61

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C : cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	2.50	0.00	0.00	2.62	2.50
2	46.61	2.10	2.62	2.50	4.61	4.60

Therefore, width of acting load shall be set as 4.61 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.30	59.43
Σ			59.43

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

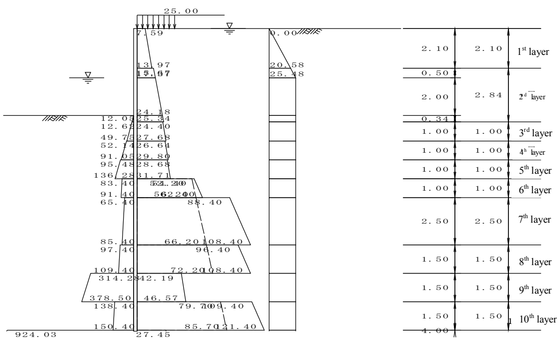
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{59.43 + 15.00 + 0.00}{4.61}$$

$$= 16.15\ \text{kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



Passive earth pressure Active earth pressure Residual water pressure

3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	24.997 45.997	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	45.997 50.997	0.34585 0.34585	0.34060 0.34060
3	2.60~ 4.60	Sandy soil	10.0	27.0	—— ——	50.997 70.997	0.34585 0.34585	0.34060 0.34060
4	4.60~ 4.94	Sandy soil	10.0	27.0	—— ——	70.997 74.397	0.34585 0.34585	0.34060 0.34060
5	4.94~ 5.94	Sandy soil	10.0	28.0	—— ——	74.397 84.397	0.33303 0.33303	0.32798 0.32798
6	5.94~ 6.94	Sandy soil	10.0	29.0	—— ——	84.397 94.397	0.32058 0.32058	0.31571 0.31571
7	6.94~ 7.94	Sandy soil	10.0	30.0	—— ——	94.397 104.397	0.30847 0.30847	0.30378 0.30378
8	7.94~ 8.94	Clayey soil	8.0	—	25.0 25.0	104.397 112.397	—— ——	—— ——
9	8.94~ 11.44	Clayey soil	8.0	—	12.0 12.0	112.397 132.397	—— ——	—— ——
10	11.44~ 12.94	Clayey soil	8.0	—	18.0 18.0	132.397 144.397	—— ——	—— ——
11	12.94~ 14.44	Sandy soil	10.0	31.0	—— ——	144.397 159.397	0.29669 0.29669	0.29219 0.29219
12	14.44~ 15.94	Clayey soil	8.0	—	25.0 25.0	159.397 171.397	—— ——	—— ——
13	15.94~ 19.94	Sandy soil	10.0	45.0	—— ——	171.397 211.397	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	4.60~ 4.94	Sandy soil	10.0	27.0	—— ——	0.000 3.400	3.59892 3.59892	3.54425 3.54425
5	4.94~ 5.94	Sandy soil	10.0	28.0	—— ——	3.400 13.400	3.76978 3.76978	3.71251 3.71251
6	5.94~ 6.94	Sandy soil	10.0	29.0	—— ——	13.400 23.400	3.95096 3.95096	3.89093 3.89093
7	6.94~ 7.94	Sandy soil	10.0	30.0	—— ——	23.400 33.400	4.14330 4.14330	4.08035 4.08035
8	7.94~ 8.94	Clayey soil	8.0	0.0	25.0 25.0	33.400 41.400	—— ——	—— ——
9	8.94~ 11.44	Clayey soil	8.0	0.0	12.0 12.0	41.400 61.400	—— ——	—— ——
10	11.44~ 12.94	Clayey soil	8.0	0.0	18.0 18.0	61.400 73.400	—— ——	—— ——
11	12.94~ 14.44	Sandy soil	10.0	31.0	—— ——	73.400 88.400	4.34774 4.34774	4.28169 4.28169
12	14.44~ 15.94	Clayey soil	8.0	0.0	25.0 25.0	88.400 100.400	—— ——	—— ——
13	15.94~ 19.94	Sandy soil	10.0	45.0	—— ——	100.400 140.400	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	7.59 13.97	—— ——	7.59 13.97	0.00 20.58	—— ——
2	2.10~ 2.60	15.67 17.37	—— ——	15.67 17.37	20.58 25.48	—— ——
3	2.60~ 4.60	17.37 24.18	—— ——	17.37 24.18	25.48 25.48	—— ——
4	4.60~ 4.94	24.18 25.34	—— ——	24.18 25.34	25.48 25.48	0.00 12.05
5	4.94~ 5.94	24.40 27.68	—— ——	24.40 27.68	25.48 25.48	12.62 49.75
6	5.94~ 6.94	26.64 29.80	—— ——	26.64 29.80	25.48 25.48	52.14 91.05
7	6.94~ 7.94	28.68 31.71	—— ——	28.68 31.71	25.48 25.48	95.48 136.28

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm^2	Pa2 kNm^2	Pa kNm^2	Pw kNm^2	Pp kNm^2
8	7.94~ 8.94	54.40 62.40	52.20 56.20	54.40 62.40	25.48 25.48	83.40 91.40
9	8.94~ 11.44	88.40 108.40	56.20 66.20	88.40 108.40	25.48 25.48	65.40 85.40
10	11.44~ 12.94	96.40 108.40	66.20 72.20	96.40 108.40	25.48 25.48	97.40 109.40
11	12.94~ 14.44	42.19 46.57	—— ——	42.19 46.57	25.48 25.48	314.28 378.50
12	14.44~ 15.94	109.40 121.40	79.70 85.70	109.40 121.40	25.48 25.48	138.40 150.40
13	15.94~ 19.94	27.45 33.86	—— ——	27.45 33.86	25.48 25.48	924.03 1292.17

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h + Q - 2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

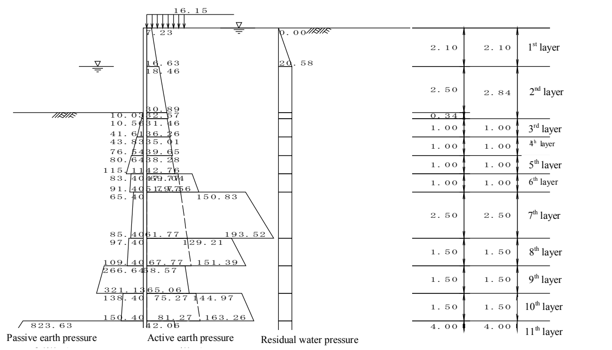
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h + Q + 2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C (kNm^2)	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	16.15 37.15	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 4.60	Sandy Soil	10.0	27.0	—— ——	37.15 62.15	20.58 45.08	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	4.60~ 4.94	Sandy Soil	10.0	27.0	—— ——	62.15 65.55	45.08 48.41	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	4.94~ 5.94	Sandy Soil	10.0	28.0	—— ——	65.55 75.55	48.41 58.21	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
5	5.94~ 6.94	Sandy Soil	10.0	29.0	—— ——	75.55 85.55	58.21 68.01	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
6	6.94~ 7.94	Sandy Soil	10.0	30.0	—— ——	85.55 95.55	68.01 77.81	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
7	7.94~ 8.94	Clayey Soil	8.0	—	25.0 25.0	95.55 103.55	77.81 87.61	0.200 0.200	11.31 11.31	—— ——	—— ——	36.64 35.83
8	8.94~ 11.44	Clayey Soil	8.0	—	12.0 12.0	103.55 123.55	87.61 112.11	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
9	11.44~ 12.94	Clayey Soil	8.0	—	18.0 18.0	123.55 135.55	112.11 126.81	0.200 0.200	11.31 11.31	—— ——	—— ——	25.32 21.63
10	12.94~ 14.44	Sandy Soil	10.0	31.0	—— ——	135.55 150.55	126.81 141.51	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
11	14.44~ 15.94	Clayey soil	8.0	—	25.0 25.0	150.55 162.55	141.51 156.21	0.200 0.200	11.31 11.31	—— ——	—— ——	30.00 28.10
12	15.94~ 19.94	Sandy Soil	10.0	45.0	—— ——	162.55 202.55	156.21 195.41	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C (kNm^2)	Σγh+Qp (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	4.60~ 4.94	Sandy soil	10.00	27.0	—— ——	0.000 3.400	0.00 3.33	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
4	4.94~ 5.94	Sandy soil	10.00	28.0	—— ——	3.400 13.400	3.33 13.13	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
5	5.94~ 6.94	Sandy soil	10.00	29.0	—— ——	13.400 23.400	13.13 22.93	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
6	6.94~ 7.94	Sandy soil	10.00	30.0	—— ——	23.400 33.400	22.93 32.73	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
7	7.94~ 8.94	Clayey soil	8.00	0.0	25.0 25.0	33.400 41.400	32.73 42.53	0.200 0.200	11.31 11.31	—— ——	—— ——
8	8.94~ 11.44	Clayey soil	8.00	0.0	12.0 12.0	41.400 61.400	42.53 67.03	0.200 0.200	11.31 11.31	—— ——	—— ——
9	11.44~ 12.94	Clayey soil	8.00	0.0	18.0 18.0	61.400 73.400	67.03 81.73	0.200 0.200	11.31 11.31	—— ——	—— ——
10	12.94~ 14.44	Sandy soil	10.00	31.0	—— ——	73.400 88.400	81.73 96.43	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
11	14.44~ 15.94	Clayey soil	8.00	0.0	25.0 25.0	88.400 100.400	96.43 111.13	0.200 0.200	11.31 11.31	—— ——	—— ——
12	15.94~ 19.94	Sandy soil	10.00	45.0	—— ——	100.400 140.400	111.13 150.33	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
1	0.00~ 2.10	7.23 16.63	—— ——	7.23 16.63	0.00 20.58	—— ——
2	2.10~ 4.60	18.46 30.89	—— ——	18.46 30.89	20.58 20.58	—— ——
3	4.60~ 4.94	30.89 32.57	—— ——	30.89 32.57	20.58 20.58	0.00 10.03
4	4.94~ 5.94	31.46 36.26	—— ——	31.46 36.26	20.58 20.58	10.56 41.61
5	5.94~ 6.94	35.01 39.65	—— ——	35.01 39.65	20.58 20.58	43.83 76.54
6	6.94~ 7.94	38.28 42.76	—— ——	38.28 42.76	20.58 20.58	80.64 115.11
7	7.94~ 8.94	69.04 79.56	47.77 51.77	69.04 79.56	20.58 20.58	83.40 91.40
8	8.94~ 11.44	150.83 193.52	51.77 61.77	150.83 193.52	20.58 20.58	65.40 85.40
9	11.44~ 12.94	129.21 151.39	61.77 67.77	129.21 151.39	20.58 20.58	97.40 109.40
10	12.94~ 14.44	58.57 65.06	—— ——	58.57 65.06	20.58 20.58	266.64 321.13
11	14.44~ 15.94	144.97 163.26	75.27 81.27	144.97 163.26	20.58 20.58	138.40 150.40
12	15.94~ 19.94	42.06 52.41	—— ——	42.06 52.41	20.58 20.58	823.63 1151.76

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h + Q - 2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h + Q + 2C$

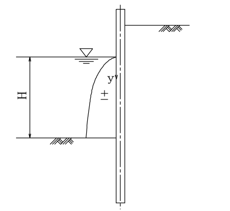
Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m^2)
1	2.10	0.00	0.00
2	3.10	1.00	2.71
3	4.10	2.00	3.83
4	4.60	2.50	4.29

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

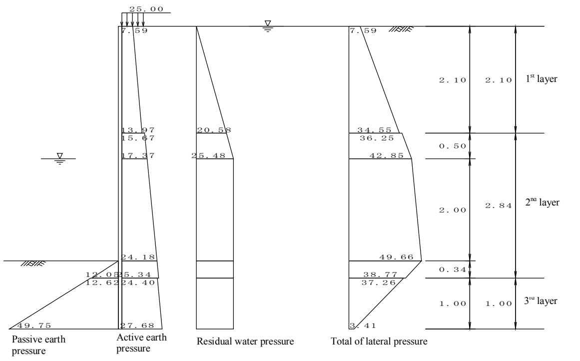
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level I_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

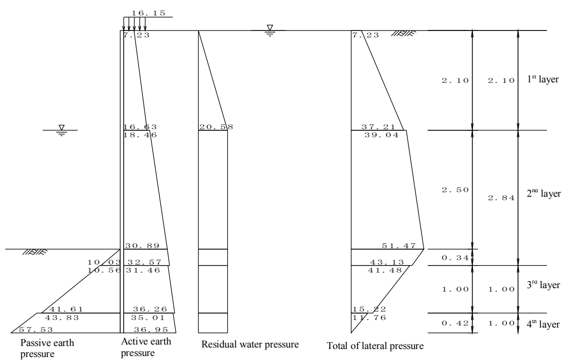


	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	7.59 13.97	0.00 20.58	—— ——	7.59 34.55
2	2.10~ 2.60	15.67 17.37	20.58 25.48	—— ——	36.25 42.85
3	2.60~ 4.60	17.37 24.18	25.48 25.48	—— ——	42.85 49.66
4	4.60~ 4.94	24.18 25.34	25.48 25.48	0.00 12.05	49.66 38.77
5	4.94~ 5.94	24.40 27.68	25.48 25.48	12.62 49.75	37.26 3.41
6	5.94~ 6.94	26.64 29.80	25.48 25.48	52.14 91.05	-0.01 -35.77

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed I_k: 1.34 m (GL -5.94 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	7.23 16.63	0.00 20.58	—— ——	7.23 37.21
2	2.10~ 4.60	18.46 30.89	20.58 20.58	—— ——	39.04 51.47
3	4.60~ 4.94	30.89 32.57	20.58 20.58	0.00 10.03	51.47 43.13
4	4.94~ 5.94	31.46 36.26	20.58 20.58	10.56 41.61	41.48 15.22
5	5.94~ 6.36	35.01 36.95	20.58 20.58	43.83 57.53	11.76 0.00
6	6.36~ 6.94	36.95 39.65	20.58 20.58	57.53 76.54	0.00 -16.31

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed I_k: 1.76 m (GL -6.36 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.87			
Section efficiency	μ	=	1.00			
Young's modulus	E	=	200000 N/mm^2			
Inertia sectional moment	I_0	=	342000 cm^4 (original condition)			
	I	=	297540 cm^4 (after reduction by corrosion and section)			
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 297540 \times 10^{-8} = 5.951 \times 10^5$			

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	14.44	17
2	1.60	15	12	15.94	8
3	2.10	4	13	16.94	50
4	4.94	4	14	20.00	50
5	5.94	12			
6	6.94	13			
7	7.94	15			
8	8.94	6			
9	11.44	2			
10	12.94	3			

5-2 Normal Condition

K_h = 18709 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.298 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.36 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.94 m) to 3.36m depth (GL -9.30 m).

2.123

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	5.94	1.00	12.0	13.0	12.50
2	6.94	1.00	13.0	15.0	14.00
3	7.94	1.00	15.0	6.0	10.50
4	8.94	0.36	6.0	5.4	2.05
	L = Σh = 3.36				ΣA = 39.05

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{39.05}{3.36}$

$= 11.63$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 11.63^{0.406} = 18709$ kN/m³

K_h (normal condition) = 18709 kN/m³

5-3 Seismic Condition

K_h = 18080 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.295 \ m^{-1}$

$$L = \frac{1}{\beta} = 3.39 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.36 m) to 3.39 m depth (GL -9.75 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m^2)
			upper	lower	
1	6.36	0.58	12.4	13.0	7.39
2	6.94	1.00	13.0	15.0	14.00
3	7.94	1.00	15.0	6.0	10.50
4	8.94	0.81	6.0	4.7	4.32
	L = Σh = 3.39				ΣA = 36.20

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{36.20}{3.39}$

$= 10.69$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.69^{0.406} = 18080$ kN/m³

K_h (seismic condition) = 18080 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.59 34.55	7.97 36.28	5.24 4.54	41.78 164.71
2	2.10~ 2.60	0.50	36.25 42.85	9.06 10.71	3.67 3.51	33.29 37.56
3	2.60~ 4.60	2.00	42.85 49.66	42.85 49.66	2.67 2.01	114.55 99.65
4	4.60~ 4.94	0.34	49.66 38.77	8.44 6.59	1.23 1.11	10.36 7.34
5	4.94~ 5.94	1.00	37.26 3.41	18.63 1.71	0.67 0.33	12.42 0.57
				ΣP = 191.91		ΣM = 522.23

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.3 kN/m
depth to acting position	H_t	=	-0.42 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.34 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 14.63$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{536.86}{194.21} = 2.76 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.23 37.21	7.59 39.07	5.66 4.96	42.94 193.72
2	2.10~ 4.60	2.50	39.04 51.47	48.80 64.33	3.43 2.59	167.17 166.76
3	4.60~ 4.94	0.34	51.47 43.13	8.75 7.33	1.65 1.53	14.40 11.23
4	4.94~ 5.94	1.00	41.48 15.22	20.74 7.61	1.09 0.75	22.51 5.72
5	5.94~ 6.36	0.42	11.76 0.00	2.46 0.00	0.28 0.14	0.69 0.00
				ΣP = 206.68		ΣM = 625.16

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.6 kN/m
depth to acting position	H_t	=	-0.24 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.76 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 56.75$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 3.10	1.00	0.0 2.7	0.00 1.36	3.93 3.59	0.00 4.87
2	3.10~ 4.10	1.00	2.7 3.8	1.36 1.92	2.93 2.59	3.97 4.97
3	4.10~ 4.60	0.50	3.8 4.3	0.96 1.07	2.09 1.93	2.01 2.06
				ΣP_{dw} = 6.66		ΣM_{dw} = 17.88

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{699.79}{221.94} = 3.15 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	342000 cm⁴ (original condition)
	I	=	297540 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 297540 x 10⁻⁸		=	5.951 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1}\frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	18709 kN/m³
calculated value	β	=	0.29775 m⁻¹
resultant earth force (lateral)	P_0	=	194.21 kN/m
height of acting position of load	h_0	=	2.76 m
moment	M_0	=	536.86 kN·m/m

in consideration of ψ_m = 1.197,

maximum moment	M_{max}	=	642.80 kN·m/m
depth of generated position of M_{max}	l_m	=	1.213 m
depth of 1st fixed point	l_i	=	3.851 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	18080 kN/m³
calculated value	β	=	0.29522 m⁻¹
resultant earth force (lateral)	P_0	=	221.94 kN/m
height of acting position of load	h_0	=	3.15 m
moment	M_0	=	699.79 kN·m/m

in consideration of ψ_m = 1.163,

maximum moment	M_{max}	=	814.14 kN·m/m
depth of generated position of M_{max}	l_m	=	1.139 m
depth of 1st fixed point	l_i	=	3.799 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	7200 cm^3 (original condition)
	Z	=	6408 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{642.80\times10^6}{6408\times10^3} = 100\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{814.14\times10^6}{6408\times10^3} = 127\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	5.24 4.54	0.882 0.764	0.275 0.218	7.97 36.28	2.190 7.897
2	2.10~ 2.60	3.67 3.51	0.618 0.590	0.152 0.140	9.06 10.71	1.376 1.499
3	2.60~ 4.60	2.67 2.01	0.450 0.338	0.086 0.051	42.85 49.66	3.689 2.515
4	4.60~ 4.94	1.23 1.11	0.207 0.187	0.020 0.016	8.44 6.59	0.168 0.109
5	4.94~ 5.94	0.67 0.33	0.112 0.056	0.006 0.002	18.63 1.71	0.113 0.003
						ΣQ = 19.557

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

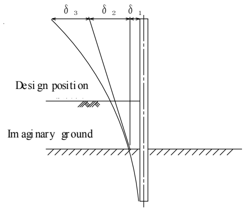
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.2978\times2.76)\times194.21}{2\times2.00\times10^8\times297540\times10^{-8}\times0.2978^3} = 0.01127\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.2978\times2.76)\times194.21}{2\times2.00\times10^8\times297540\times10^{-8}\times0.2978^2}\times(4.60+1.34) = 0.02893\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{19.56\times(4.60+1.34)^3}{2.00\times10^8\times297540\times10^{-8}} = 0.00689\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00030 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.94 m
Horizontal load: P = 2.30
Moment: M = 0.97

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01127 + 0.02893 + 0.00719
= 0.04739 m
= 47.39 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	5.66 4.96	0.890 0.780	0.279 0.225	7.59 39.07	2.114 8.791
2	2.10~ 4.60	3.43 2.59	0.539 0.408	0.119 0.072	48.80 64.33	5.810 4.619
3	4.60~ 4.94	1.65 1.53	0.259 0.241	0.031 0.027	8.75 7.33	0.268 0.196
4	4.94~ 5.94	1.09 0.75	0.171 0.118	0.014 0.007	20.74 7.61	0.285 0.051
5	5.94~ 6.36	0.28 0.14	0.044 0.022	0.001 0.000	2.46 0.00	0.002 0.000
						ΣQ = 22.135

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

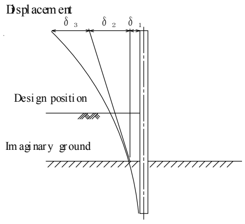
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 3.10	3.93 3.59	0.617 0.565	0.151 0.130	0.00 1.36	0.000 0.176
2	3.10~ 4.10	2.93 2.59	0.460 0.408	0.090 0.072	1.36 1.92	0.121 0.138
3	4.10~ 4.60	2.09 1.93	0.329 0.303	0.048 0.041	0.96 1.07	0.046 0.044
						ΣQ_{dw} = 0.525

Therefore, modulus of deformation Q is calculated as below.
Q = 22.135 + 0.525 = 22.660

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.2952\times3.15)\times221.94}{2\times2.00\times10^8\times297540\times10^{-8}\times0.2952^3} = 0.01399\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.2952\times3.15)\times221.94}{2\times2.00\times10^8\times297540\times10^{-8}\times0.2952^2}\times(4.60+1.76) = 0.03894\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{22.66\times(4.60+1.76)^3}{2.00\times10^8\times297540\times10^{-8}} = 0.00979\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00131 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 6.36 m
Horizontal load: P = 8.60
Moment: M = 2.06

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01399 + 0.03894 + 0.01110
= 0.06403 m
= 64.03 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	342000 cm^4 (original condition)
	I	=	342000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 342000 \times 10^{-8}$		=	6.840×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 18709\ kN/m^3$

Calculated value $\beta = 0.28756\ m^{-1}$

Penetration length of SSP $D = 1.34 + \frac{3}{0.288} = 11.77\ m$

Whole length of SSP $L = 4.60 - 0.40 + 11.77 = 15.97\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 18080\ kN/m^3$

Calculated value $\beta = 0.28512\ m^{-1}$

Penetration length of SSP $D = 1.76 + \frac{3}{0.285} = 12.28\ m$

Whole length of SSP $L = 4.60 - 0.40 + 12.28 = 16.48\ m$

Therefore, whole length of SSP is set as 16.50 m in consideration of round unit of SSP length.

8 Calculation Result

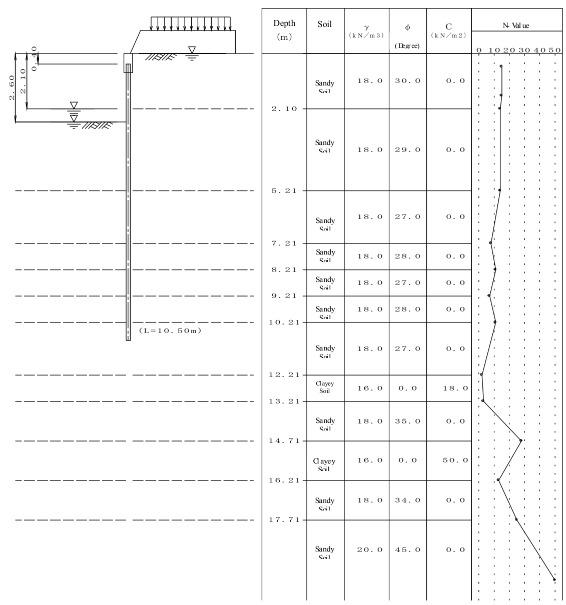
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	342000		
Section modulus	Z (cm^3)	7200		
Maximum bending moment	M_{max} (kN·m/m)		642.80	814.14
Stress intensity	σ (Nmm^2)		100 (185)	127 (278)
Lateral displacement	δ (mm)		47.39 (50.0)	64.03 (75.0)
Penetration depth	D (m)		11.77	12.28
Whole length of SSP	L (m)	16.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 17_STA 9+200 - 9+341

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wn}	=	2.60 m (Normal Condition)
	L_{wn}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kN/m³

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.4 kN/m (Normal Condition)
		Pt'	=	8.6 kN/m (Seismic Condition)
	Depth of acting point	Ht	=	-0.42 m (Normal Condition)
		Ht'	=	-0.24 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression $K_e = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	14
4	5.21	14
5	7.21	8
6	8.21	11
7	9.21	7
8	10.21	11
9	12.21	2
10	13.21	3

No	Depth (m)	N-Value
11	14.71	28
12	16.21	13
13	17.71	25
14	20.00	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ (kN/m³)	γ' (kN/m³)	φ	C (kN/m²)	a	k'	ζ (degree)		kh(kN/m³)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	5.21	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
3	7.21	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	8.21	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
5	9.21	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	10.21	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
7	12.21	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	13.21	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
9	14.71	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
10	16.21	C	13.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
11	17.71	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
12	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

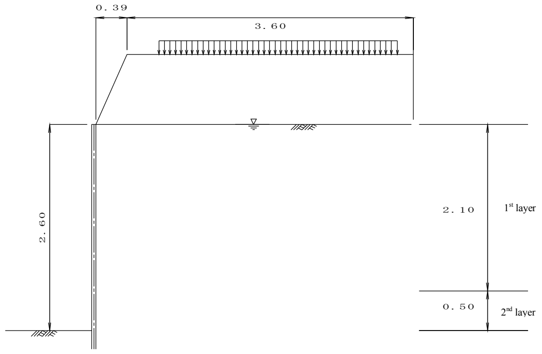
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

2.127

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.39	3.99	3.99	0.88	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.79	3.79	10.0	5.0

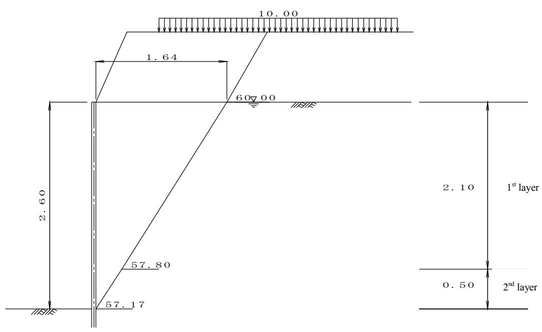
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm²		
Inertia sectional moment	I_0	=	56700 cm⁴		
Sectional factor	Z_0	=	2700 cm³		
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2 =	1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.88		
Corrosion rate (to Z_0)	η	=	0.88		
Section efficiency (to I_0)	μ	=	0.80		
Section efficiency (to Z_0)	μ	=	1.00		
Round unit of SSP length			0.50 m		
Allowable stress	σ_a	=	180 Nmm² (Normal)		
	σ_a'	=	270 Nmm² (Seismic)		
Allowable displacement	δ_a	=	50.0 mm (Normal)		
	δ_a'	=	75.0 mm (Seismic)		
Bending of cantilever beam			calculated as distributed load of each layer		
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction		
			Not reduced: I_0 applied to calculation of penetration depth		
			Reduced: I_0 applied to calculation of section forces and displacement		
			Reduced: Z_0 applied to calculation of stresses		

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	29.0	10.0	0.0	26.00	24.69	25.48	57.17
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	24.69	20.58	57.80
3		Embankment	30.0	——	0.0	15.84	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	57.17	0.50	0.00	0.00	0.32	0.50
2	57.80	2.10	0.32	0.50	1.64	2.60
3	60.00	0.88	1.64	2.60	2.15	3.48

Therefore, width of acting load shall be set as 1.64 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.50	26.99
Σ			26.99

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.36	13.63
Σ			13.63

Q surcharge load
l : width of surcharge load set by line of active rupture

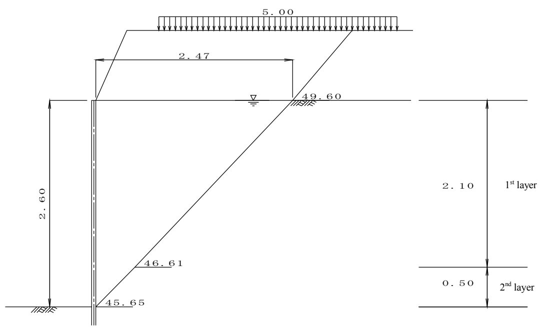
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{26.99 + 13.63 + 0.00}{1.64}$$

$$= 24.69 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	29.0	10.0	0.0	26.00	21.91	25.48	0.200	11.31	45.65
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	21.91	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	15.84	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Where.

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) θ=tan⁻¹k or θ=tan⁻¹k'
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	45.65	0.50	0.00	0.00	0.49	0.50
2	46.61	2.10	0.49	0.50	2.47	2.60
3	49.60	0.88	2.47	2.60	3.22	3.48

Therefore, width of acting load shall be set as 2.47 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.34	42.03
Σ			42.03

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.43	12.17
Σ			12.17

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

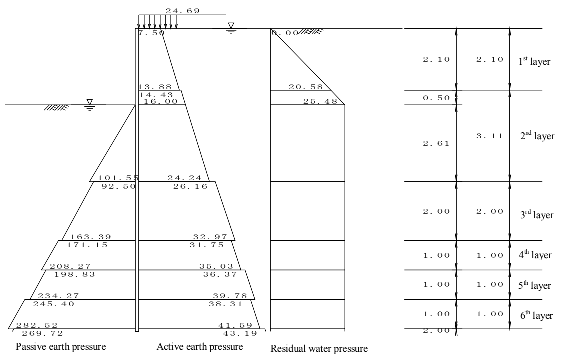
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{42.03 + 12.17 + 0.00}{2.47}$$

$$= 21.91 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	24.695 45.695	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	29.0	—— ——	45.695 50.695	0.32058 0.32058	0.31571 0.31571
3	2.60~ 5.21	Sandy soil	10.0	29.0	—— ——	50.695 76.795	0.32058 0.32058	0.31571 0.31571
4	5.21~ 7.21	Sandy soil	10.0	27.0	—— ——	76.795 96.795	0.34585 0.34585	0.34060 0.34060
5	7.21~ 8.21	Sandy soil	10.0	28.0	—— ——	96.795 106.795	0.33303 0.33303	0.32798 0.32798
6	8.21~ 9.21	Sandy soil	10.0	27.0	—— ——	106.795 116.795	0.34585 0.34585	0.34060 0.34060
7	9.21~ 10.21	Sandy soil	10.0	28.0	—— ——	116.795 126.795	0.33303 0.33303	0.32798 0.32798
8	10.21~ 12.21	Sandy soil	10.0	27.0	—— ——	126.795 146.795	0.34585 0.34585	0.34060 0.34060
9	12.21~ 13.21	Clayey soil	8.0	—	18.0 18.0	146.795 154.795	—— ——	—— ——
10	13.21~ 14.71	Sandy soil	10.0	35.0	—— ——	154.795 169.795	0.25279 0.25279	0.24895 0.24895
11	14.71~ 16.21	Clayey soil	8.0	—	50.0 50.0	169.795 181.795	—— ——	—— ——
12	16.21~ 17.71	Sandy soil	10.0	34.0	—— ——	181.795 196.795	0.26331 0.26331	0.25931 0.25931
13	17.71~ 20.00	Sandy soil	10.0	45.0	—— ——	171.397 211.397	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 5.21	Sandy soil	10.0	29.0	—— ——	0.000 26.100	3.95096 3.95096	3.89093 3.89093
4	5.21~ 7.21	Sandy soil	10.0	27.0	—— ——	26.100 46.100	3.59892 3.59892	3.54425 3.54425
5	7.21~ 8.21	Sandy soil	10.0	28.0	—— ——	46.100 56.100	3.76978 3.76978	3.71251 3.71251
6	8.21~ 9.21	Sandy soil	10.0	27.0	—— ——	56.100 66.100	3.59892 3.59892	3.54425 3.54425
7	9.21~ 10.21	Sandy soil	10.0	28.0	—— ——	66.100 76.100	3.76978 3.76978	3.71251 3.71251
8	10.21~ 12.21	Sandy soil	10.0	27.0	—— ——	76.100 96.100	3.59892 3.59892	3.54425 3.54425
9	12.21~ 13.21	Clayey soil	8.0	0.0	18.0 18.0	96.100 104.100	—— ——	—— ——
10	13.21~ 14.71	Sandy soil	10.0	35.0	—— ——	104.100 119.100	5.30876 5.30876	5.22810 5.22810
11	14.71~ 16.21	Clayey soil	8.0	0.0	50.0 50.0	119.100 131.100	—— ——	—— ——
12	16.21~ 17.71	Sandy soil	10.0	34.0	—— ——	131.100 146.100	5.04448 5.04448	4.96784 4.96784
13	17.71~ 20.00	Sandy soil	10.0	45.0	—— ——	146.100 169.000	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.50 13.88	—— ——	7.50 13.88	0.00 20.58	—— ——
2	2.10~ 2.60	14.43 16.00	—— ——	14.43 16.00	20.58 25.48	—— ——
3	2.60~ 5.21	16.00 24.24	—— ——	16.00 24.24	25.48 25.48	0.00 101.55
4	5.21~ 7.21	26.16 32.97	—— ——	26.16 32.97	25.48 25.48	92.50 163.39
5	7.21~ 8.21	31.75 35.03	—— ——	31.75 35.03	25.48 25.48	171.15 208.27
6	8.21~ 9.21	36.37 39.78	—— ——	36.37 39.78	25.48 25.48	198.83 234.27

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
7	9.21~ 10.21	38.31 41.59	—— ——	38.31 41.59	25.48 25.48	245.40 282.52
8	10.21~ 12.21	43.19 50.00	—— ——	43.19 50.00	25.48 25.48	269.72 340.60
9	12.21~ 13.21	110.79 118.79	73.40 77.40	110.79 118.79	25.48 25.48	132.10 140.10
10	13.21~ 14.71	38.54 42.27	—— ——	38.54 42.27	25.48 25.48	544.25 622.67
11	14.71~ 16.21	69.79 81.79	84.90 90.90	84.90 90.90	25.48 25.48	219.10 231.10
12	16.21~ 17.71	47.14 51.03	—— ——	47.14 51.03	25.48 25.48	651.28 725.80
13	17.71~ 20.00	31.52 35.18	—— ——	31.52 35.18	25.48 25.48	1344.63 1555.39

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

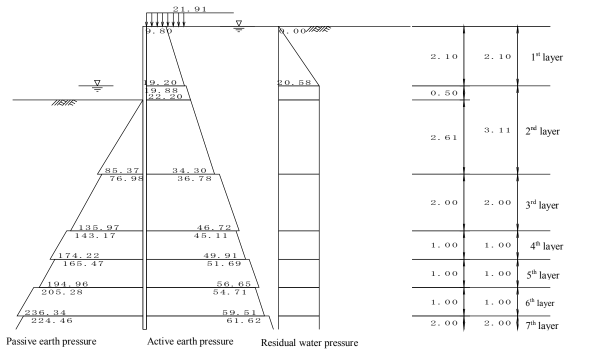
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	21.91 42.91	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	29.0	—— ——	42.91 47.91	20.58 25.48	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
3	2.60~ 5.21	Sandy Soil	10.0	29.0	—— ——	47.91 74.01	25.48 51.06	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
4	5.21~ 7.21	Sandy Soil	10.0	27.0	—— ——	74.01 94.01	51.06 70.66	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	7.21~ 8.21	Sandy Soil	10.0	28.0	—— ——	94.01 104.01	70.66 80.46	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
6	8.21~ 9.21	Sandy Soil	10.0	27.0	—— ——	104.01 114.01	80.46 90.26	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	9.21~ 10.21	Sandy Soil	10.0	28.0	—— ——	114.01 124.01	90.26 100.06	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
8	10.21~ 12.21	Sandy Soil	10.0	27.0	—— ——	124.01 144.01	100.06 119.66	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
9	12.21~ 13.21	Clayey Soil	8.0	—	18.0 18.0	144.01 152.01	119.66 129.46	0.200 0.200	11.31 11.31	—— ——	—— ——	15.63 10.42
10	13.21~ 14.71	Sandy Soil	10.0	35.0	—— ——	152.01 167.01	129.46 144.16	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
11	14.71~ 16.21	Clayey Soil	8.0	—	50.0 50.0	167.01 179.01	144.16 158.86	0.200 0.200	11.31 11.31	—— ——	—— ——	38.27 37.72
12	16.21~ 17.71	Sandy Soil	10.0	34.0	—— ——	179.01 194.01	158.86 173.56	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
13	17.71~ 20.00	Sandy Soil	10.0	45.0	—— ——	194.01 216.91	173.56 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= tan^{-1}k

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Qp (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 5.21	Sandy soil	10.00	29.0	—— ——	0.000 26.100	0.00 25.58	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
4	5.21~ 7.21	Sandy soil	10.00	27.0	—— ——	26.100 46.100	25.58 45.18	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	7.21~ 8.21	Sandy soil	10.00	28.0	—— ——	46.100 56.100	45.18 54.98	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
6	8.21~ 9.21	Sandy soil	10.00	27.0	—— ——	56.100 66.100	54.98 64.78	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	9.21~ 10.21	Sandy soil	10.00	28.0	—— ——	66.100 76.100	64.78 74.58	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
8	10.21~ 12.21	Sandy soil	10.00	27.0	—— ——	76.100 96.100	74.58 94.18	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
9	12.21~ 13.21	Clayey soil	8.00	0.0	18.0 18.0	96.100 104.100	94.18 103.98	0.200 0.200	11.31 11.31	—— ——	—— ——
10	13.21~ 14.71	Sandy soil	10.00	35.0	—— ——	104.100 119.100	103.98 118.68	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
11	14.71~ 16.21	Clayey soil	8.00	0.0	50.0 50.0	119.100 131.100	118.68 133.38	0.200 0.200	11.31 11.31	—— ——	—— ——
12	16.21~ 17.71	Sandy soil	10.00	34.0	—— ——	131.100 146.100	133.38 148.08	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
13	17.71~ 20.00	Sandy soil	10.00	45.0	—— ——	146.100 169.000	148.08 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= tan^{-1}k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm^2)	Pa2 (kNm^2)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)
1	0.00~ 2.10	9.80 19.20	—— ——	9.80 19.20	0.00 20.58	—— ——
2	2.10~ 2.60	19.88 22.20	—— ——	19.88 22.20	20.58 20.58	—— ——
3	2.60~ 5.21	22.20 34.30	—— ——	22.20 34.30	20.58 20.58	0.00 85.37
4	5.21~ 7.21	36.78 46.72	—— ——	36.78 46.72	20.58 20.58	76.98 135.97
5	7.21~ 8.21	45.11 49.91	—— ——	45.11 49.91	20.58 20.58	143.17 174.22
6	8.21~ 9.21	51.69 56.65	—— ——	51.69 56.65	20.58 20.58	165.47 194.96
7	9.21~ 10.21	54.71 59.51	—— ——	54.71 59.51	20.58 20.58	205.28 236.34
8	10.21~ 12.21	61.62 71.56	—— ——	61.62 71.56	20.58 20.58	224.46 283.44
9	12.21~ 13.21	177.58 216.12	72.00 76.00	177.58 216.12	20.58 20.58	132.10 140.10
10	13.21~ 14.71	57.03 62.66	—— ——	57.03 62.66	20.58 20.58	469.36 536.99
11	14.71~ 16.21	106.52 121.98	83.50 89.50	106.52 121.98	20.58 20.58	219.10 231.10
12	16.21~ 17.71	69.59 75.42	—— ——	69.59 75.42	20.58 20.58	559.50 623.52
13	17.71~ 20.00	50.20 56.12	—— ——	50.20 56.12	20.58 20.58	1198.52 1386.38

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

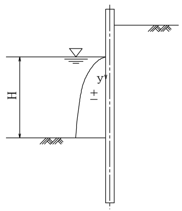
Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

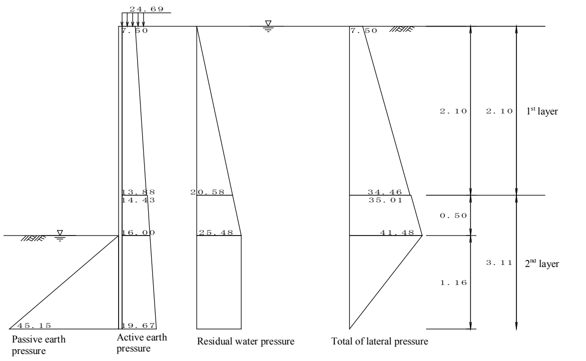
Where,
k_{hs} : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level l_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

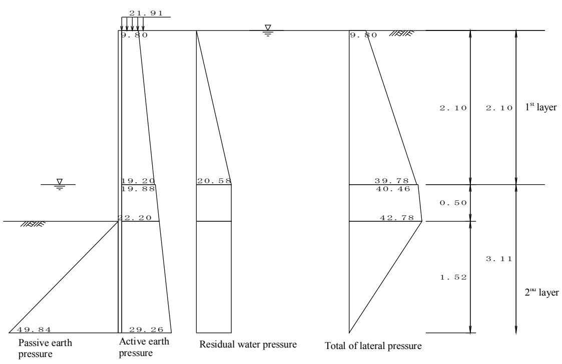


	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	7.50 13.88	0.00 20.58	—— ——	7.50 34.46
2	2.10~ 2.60	14.43 16.00	20.58 25.48	—— ——	35.01 41.48
3	2.60~ 3.76	16.00 19.67	25.48 25.48	0.00 45.15	41.48 0.00
4	3.76~ 5.21	19.67 24.24	25.48 25.48	45.15 101.55	0.00 -51.83

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.16 m (GL -3.76 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	9.80 19.20	0.00 20.58	—— ——	9.80 39.78
2	2.10~ 2.60	19.88 22.20	20.58 20.58	—— ——	40.46 42.78
3	2.60~ 4.12	22.20 29.26	20.58 20.58	0.00 49.84	42.78 0.00
4	4.12~ 5.21	29.26 34.30	20.58 20.58	49.84 85.37	0.00 -30.50

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.52 m (GL -4.12 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.88			
Section efficiency	μ	=	0.80			
Young's modulus	E	=	200000 Nmm^2			
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)			
	I	=	39917 cm^4 (after reduction by corrosion and joint)			
Inertia sectional moment	EI	=	200000 x 10^3 x 39917 x 10^8 =7.983×10^4			

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	14.71	28
2	1.60	15	12	16.21	13
3	2.10	14	13	17.71	25
4	5.21	14	14	20.00	50
5	7.21	8			
6	8.21	11			
7	9.21	7			
8	10.21	11			
9	12.21	2			
10	13.21	3			

5-2 Normal Condition

K_h = 20042 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.501 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.00 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.76 m) to 2.00 m depth (GL -5.76 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.76	1.45	14.0	14.0	20.30
2	5.21	0.55	14.0	12.4	7.23
	L = Σh = 2.00				ΣA = 27.52

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{27.52}{2.00}$

$= 13.77$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 13.77^{0.406} = 20042$ kN/m^3

K_h (normal condition) = 20042 kN/m^3

5-3 Seismic Condition

K_h = 19801 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.499$ m^{-1}

$L = \dfrac{1}{\beta} = 2.00$ m

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.12 m) to 2.00 m depth (GL -6.13 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.12	1.09	14.0	14.0	15.21
2	5.21	0.92	14.0	11.2	11.59
	L = Σh = 2.00				ΣA = 26.79

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$= \dfrac{26.79}{2.00}$

$= 13.37$

Calculated K_h is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 13.37^{0.406} = 19801$ kN/m^3

K_h (seismic condition) = 19801 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.50 34.46	7.88 36.18	3.06 2.36	24.11 85.41
2	2.10~ 2.60	0.50	35.01 41.48	8.75 10.37	1.49 1.33	13.07 13.76
3	2.60~ 3.76	1.16	41.48 0.00	24.07 0.00	0.77 0.39	18.62 0.00
				ΣP = 87.25		ΣM = 154.96

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.4 kN/m
depth to acting position	H_t	=	-0.42 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.16 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.03$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{165.00}{89.65} = 1.84 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.80 39.78	10.29 41.77	3.42 2.72	35.24 113.77
2	2.10~ 2.60	0.50	40.46 42.78	10.12 10.70	1.86 1.69	18.79 18.08
3	2.60~ 4.12	1.52	42.78 0.00	32.59 0.00	1.02 0.51	33.11 0.00
				ΣP = 105.47		ΣM = 218.99

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.6 kN/m
depth to acting position	H_t	=	-0.24 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.52 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 37.53$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} (kN)	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	1.86 1.69	0.00 0.36
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.36

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{256.88}{114.28} = 2.25 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 39917 x 10^{-8}		=	7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	20042 kN/m^3
calculated value	β	=	0.50052 m^{-1}
resultant earth force (lateral)	P_0	=	89.65 kN/m
height of acting position of load	h_0	=	1.84 m
moment	M_0	=	165.00 kN·m/m

in consideration of ψ_m = 1.166,

maximum moment	M_{max}	=	192.40 kN·m/m
depth of generated position of M_{max}	l_m	=	0.676 m
depth of 1st fixed point	l_i	=	2.245 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	19801 kN/m^3
calculated value	β	=	0.49901 m^{-1}
resultant earth force (lateral)	P_0	=	114.28 kN/m
height of acting position of load	h_0	=	2.25 m
moment	M_0	=	256.88 kN·m/m

in consideration of ψ_m = 1.122,

maximum moment	M_{max}	=	288.18 kN·m/m
depth of generated position of M_{max}	l_m	=	0.599 m
depth of 1st fixed point	l_i	=	2.173 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 =1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm^3 (original condition)
	Z	=	2376 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{192.40\times10^6}{2376\times10^3} = 81\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{288.18\times10^6}{2376\times10^3} = 121\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.06 2.36	0.814 0.628	0.241 0.156	7.88 36.18	1.901 5.637
2	2.10~ 2.60	1.49 1.33	0.397 0.353	0.068 0.055	8.75 10.37	0.599 0.570
3	2.60~ 3.76	0.77 0.39	0.206 0.103	0.020 0.005	24.07 0.00	0.474 0.000
						ΣQ = 9.181

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

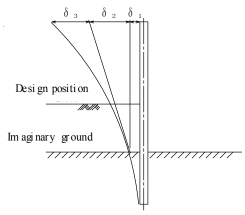
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5005\times1.84)\times89.65}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5005^3} = 0.00860\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5005\times1.84)\times89.65}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5005^2}\times(2.60+1.16) = 0.02396\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.18\times(2.60+1.16)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00611\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00062 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.76 m
Horizontal load: P = 2.40
Moment: M = 1.01

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00860 + 0.02396 + 0.00674
= 0.03929 m
= 39.29 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.42 2.72	0.830 0.661	0.249 0.170	10.29 41.77	2.566 7.105
2	2.10~ 2.60	1.86 1.69	0.450 0.410	0.086 0.073	10.12 10.70	0.872 0.776
3	2.60~ 4.12	1.02 0.51	0.246 0.123	0.028 0.007	32.59 0.00	0.908 0.000
						ΣQ = 12.227

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

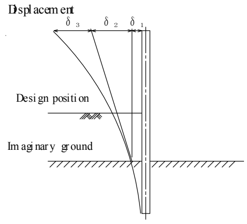
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	1.86 1.69	0.450 0.410	0.086 0.073	0.00 0.21	0.000 0.016
						ΣQ_{dw} = 0.016

Therefore, modulus of deformation Q is calculated as below
Q = 12.227 + 0.016 = 12.242

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4990\times2.25)\times114.28}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4990^3} = 0.01222\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4990\times2.25)\times114.28}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4990^2}\times(2.60+1.52) = 0.03844\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.24\times(2.60+1.52)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.01075\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00274 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.12 m
Horizontal load: P = 8.60
Moment: M = 2.06

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01222 + 0.03844 + 0.01349
= 0.06416 m
= 64.16 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 56700 \times 10^{-8}$		=	1.134×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1c} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 20042\ kN/m^3$
Calculated value $\beta = 0.45848\ m^{-1}$

Penetration length of SSP $D = 1.16 + \frac{3}{0.458} = 7.70\ m$
Whole length of SSP $L = 2.60 - 0.40 + 7.70 = 9.90\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 19801\ kN/m^3$
Calculated value $\beta = 0.45709\ m^{-1}$

Penetration length of SSP $D = 1.52 + \frac{3}{0.457} = 8.09\ m$
Whole length of SSP $L = 2.60 - 0.40 + 8.09 = 10.29\ m$

Therefore, whole length of SSP is set as 10.50 m in consideration of round unit of SSP length.

8 Calculation Result

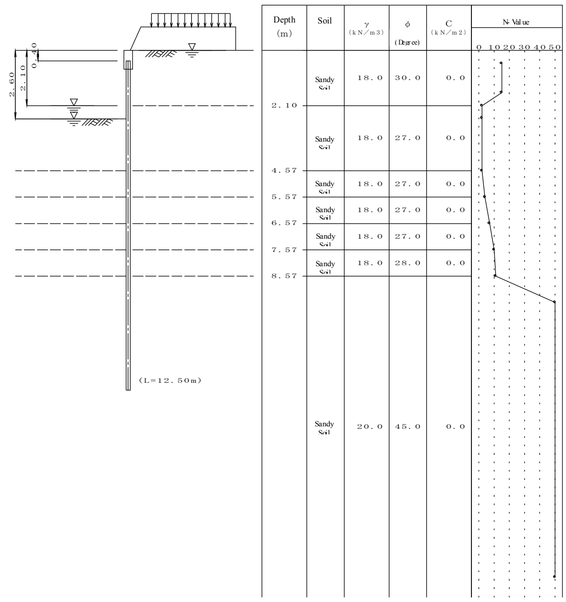
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		192.40	288.18
Stress intensity	σ (N/mm^2)		81 (180)	121 (270)
Lateral displacement	δ (mm)		39.29 (50.0)	64.16 (75.0)
Penetration depth	D (m)		7.70	8.09
Whole length of SSP	L (m)	10.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 18_STA 9+430 - 550

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity $k = 0.200$

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.4 kNm (Normal Condition)
		P_t'	=	8.7 kNm (Seismic Condition)
	Depth of acting point	H_t	=	-0.42 m (Normal Condition)
		H_t'	=	-0.25 m (Seismic Condition)
	Moment	M_m	=	0.0 kN-m/m (Normal Condition)
		M_m'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m (Seismic Condition)
		H_m	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression $K_e = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	2
4	2.57	2
5	4.57	2
6	5.57	4
7	6.57	7
8	7.57	10
9	8.57	11
10	9.57	50

No	Depth (m)	N-Value
11	20.00	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

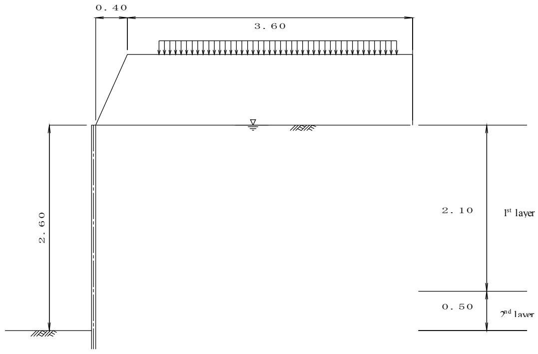
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	ϕ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic		
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	4.57	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	5.57	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	6.57	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	7.57	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	8.57	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
7	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kNm³)	ϕ (degree)	C (kNm²)	Normal	Seismic
1	Sandy soil	0.00	0.40	4.00	4.00	0.89	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.80	3.80	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 86000 cm^4
Sectional factor Z_0 = 3820 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.92
Corrosion rate (to Z_0) η = 0.92
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 180 Nmm^2 (Normal)
σ_a' = 270 Nmm^2 (Seismic)

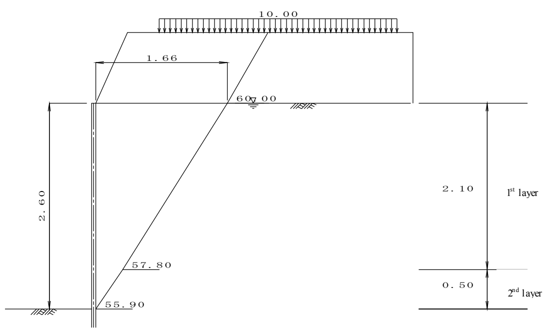
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kNm²)	Σγh (kNm²)	Q (kNm²)	γwhw (kNm²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	24.85	25.48	55.90
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	24.85	20.58	57.80
3		Embankment	30.0	——	0.0	16.02	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where
- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C : cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	0.89	1.66	2.60	2.17	3.49

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	18.0	1.53	27.52
Σ			27.52

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kNm²)	l (m)	Q X l (kNm)
1	10.0	1.37	13.75
Σ			13.75

Q surcharge load
l : width of surcharge load set by line of active rupture

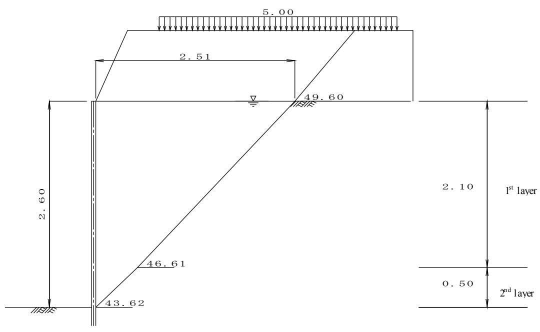
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{27.52 + 13.75 + 0.00}{1.66}$$

$= 24.85$ kN/m²

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kNm²)	Σγh (kNm²)	Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	22.08	25.48	0.200	11.31	43.62
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	22.08	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	16.02	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C} \cdot \tan\theta}$$

Where.
- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C : cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	0.89	2.51	2.60	3.27	3.49

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	18.0	2.39	43.07
Σ			43.07

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kNm²)	l (m)	Q X l (kNm)
1	5.0	2.47	12.34
Σ			12.34

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

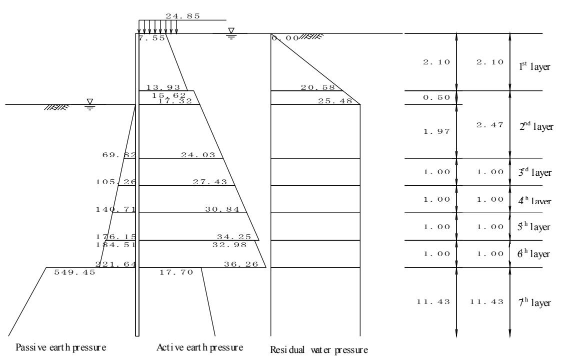
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{43.07 + 12.34 + 0.00}{2.51}$$

$= 22.08$ kN/m²

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	24.846 45.846	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	45.846 50.846	0.34585 0.34585	0.34060 0.34060
3	2.60~ 4.57	Sandy soil	10.0	27.0	—— ——	50.846 70.546	0.34585 0.34585	0.34060 0.34060
4	4.57~ 5.57	Sandy soil	10.0	27.0	—— ——	70.546 80.546	0.34585 0.34585	0.34060 0.34060
5	5.57~ 6.57	Sandy soil	10.0	27.0	—— ——	80.546 90.546	0.34585 0.34585	0.34060 0.34060
6	6.57~ 7.57	Sandy soil	10.0	27.0	—— ——	90.546 100.546	0.34585 0.34585	0.34060 0.34060
7	7.57~ 8.57	Sandy soil	10.0	28.0	—— ——	100.546 110.546	0.33303 0.33303	0.32798 0.32798
8	8.57~ 20.00	Sandy soil	10.0	45.0	—— ——	110.546 224.846	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 4.57	Sandy soil	10.0	27.0	—— ——	0.000 19.700	3.59892 3.59892	3.54425 3.54425
4	4.57~ 5.57	Sandy soil	10.0	27.0	—— ——	19.700 29.700	3.59892 3.59892	3.54425 3.54425
5	5.57~ 6.57	Sandy soil	10.0	27.0	—— ——	29.700 39.700	3.59892 3.59892	3.54425 3.54425
6	6.57~ 7.57	Sandy soil	10.0	27.0	—— ——	39.700 49.700	3.59892 3.59892	3.54425 3.54425
7	7.57~ 8.57	Sandy soil	10.0	28.0	—— ——	49.700 59.700	3.76978 3.76978	3.71251 3.71251
8	8.57~ 20.00	Sandy soil	10.0	45.0	—— ——	59.700 174.000	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.55 13.93	—— ——	7.55 13.93	0.00 20.58	—— ——
2	2.10~ 2.60	15.62 17.32	—— ——	15.62 17.32	20.58 25.48	—— ——
3	2.60~ 4.57	17.32 24.03	—— ——	17.32 24.03	25.48 25.48	0.00 69.82
4	4.57~ 5.57	24.03 27.43	—— ——	24.03 27.43	25.48 25.48	69.82 105.26
5	5.57~ 6.57	27.43 30.84	—— ——	27.43 30.84	25.48 25.48	105.26 140.71
6	6.57~ 7.57	30.84 34.25	—— ——	30.84 34.25	25.48 25.48	140.71 176.15
7	7.57~ 8.57	32.98 36.26	—— ——	32.98 36.26	25.48 25.48	184.51 221.64
8	8.57~ 20.00	17.70 36.01	—— ——	17.70 36.01	25.48 25.48	549.45 1601.41

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

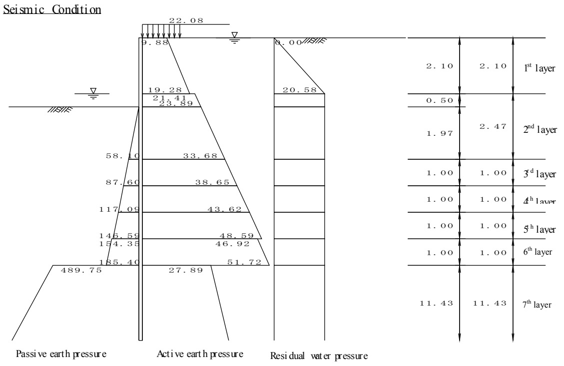
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	22.08 43.08	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	27.0	—— ——	43.08 48.08	20.58 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.60~ 4.57	Sandy Soil	10.0	27.0	—— ——	48.08 67.78	25.48 44.79	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	4.57~ 5.57	Sandy Soil	10.0	27.0	—— ——	67.78 77.78	44.79 54.59	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	5.57~ 6.57	Sandy Soil	10.0	27.0	—— ——	77.78 87.78	54.59 64.39	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	6.57~ 7.57	Sandy Soil	10.0	27.0	—— ——	87.78 97.78	64.39 74.19	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	7.57~ 8.57	Sandy Soil	10.0	28.0	—— ——	97.78 107.78	74.19 83.99	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
8	8.57~ 20.00	Sandy Soil	10.0	45.0	—— ——	107.78 222.08	83.99 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\dfrac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 4.57	Sandy soil	10.00	27.0	—— ——	0.000 19.700	0.00 19.31	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
4	4.57~ 5.57	Sandy soil	10.00	27.0	—— ——	19.700 29.700	19.31 29.11	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	5.57~ 6.57	Sandy soil	10.00	27.0	—— ——	29.700 39.700	29.11 38.91	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	6.57~ 7.57	Sandy soil	10.00	27.0	—— ——	39.700 49.700	38.91 48.71	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	7.57~ 8.57	Sandy soil	10.00	28.0	—— ——	49.700 59.700	48.71 58.51	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
8	8.57~ 20.00	Sandy soil	10.00	45.0	—— ——	59.700 174.000	58.51 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\dfrac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	9.88 19.28	—— ——	9.88 19.28	0.00 20.58	—— ——
2	2.10~ 2.60	21.41 23.89	—— ——	21.41 23.89	20.58 20.58	—— ——
3	2.60~ 4.57	23.89 33.68	—— ——	23.89 33.68	20.58 20.58	0.00 58.10
4	4.57~ 5.57	33.68 38.65	—— ——	33.68 38.65	20.58 20.58	58.10 87.60
5	5.57~ 6.57	38.65 43.62	—— ——	38.65 43.62	20.58 20.58	87.60 117.09
6	6.57~ 7.57	43.62 48.59	—— ——	43.62 48.59	20.58 20.58	117.09 146.59
7	7.57~ 8.57	46.92 51.72	—— ——	46.92 51.72	20.58 20.58	154.35 185.40
8	8.57~ 20.00	27.89 57.46	—— ——	27.89 57.46	20.58 20.58	489.75 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

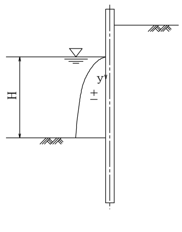
Mixed soil $P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

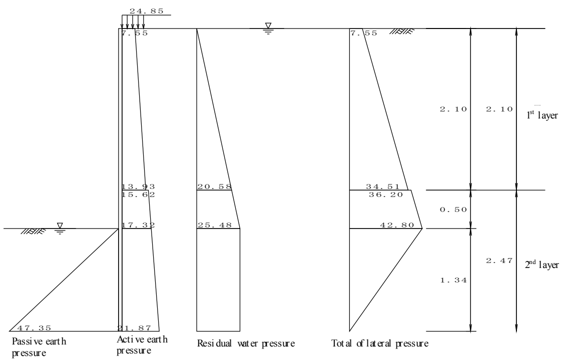
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

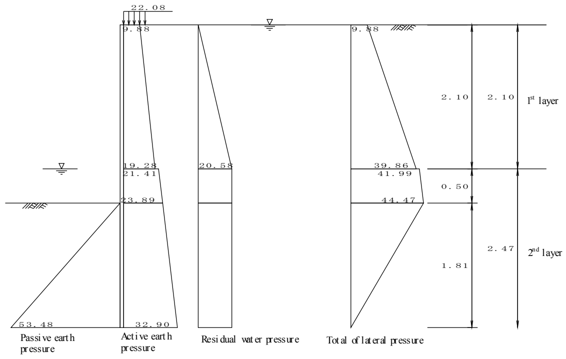


	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	7.55 13.93	0.00 20.58	—— ——	7.55 34.51
2	2.10~ 2.60	15.62 17.32	20.58 25.48	—— ——	36.20 42.80
3	2.60~ 3.94	17.32 21.87	25.48 25.48	0.00 47.35	42.80 0.00
4	3.94~ 4.57	21.87 24.03	25.48 25.48	47.35 69.82	0.00 -20.31

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.34 m (GL -3.94 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	9.88 19.28	0.00 20.58	—— ——	9.88 39.86
2	2.10~ 2.60	21.41 23.89	20.58 20.58	—— ——	41.99 44.47
3	2.60~ 4.41	23.89 32.90	20.58 20.58	0.00 53.48	44.47 0.00
4	4.41~ 4.57	32.90 33.68	20.58 20.58	53.48 58.10	0.00 -3.84

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.81 m (GL -4.41 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m		
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 =	1.00 mm (passive side)
Corrosion rate	η	=	0.92		
Section efficiency	μ	=	0.80		
Young's modulus	E	=	200000 N/mm^2		
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)		
	I	=	63296 cm^4 (after reduction by corrosion and joint)		
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$		

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	2.57	2
5	4.57	2
6	5.57	4
7	6.57	7
8	7.57	10
9	8.57	11
10	9.57	50
11	20.00	50

5-2 Normal Condition

K_h = 11656 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.390 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.57 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.94 m) to 2.57 m depth (GL -6.50 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.94	0.63	2.0	2.0	1.27
2	4.57	1.00	2.0	4.0	3.00
3	5.57	0.93	4.0	6.8	5.04
L = Σh = 2.57					ΣA = 9.31

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{9.31}{2.57} = 3.63$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 3.63^{0.406} = 11656 \text{ kN/m}^3$$

Kh (normal condition) = 11656 kN/m^3

5-3 Seismic Condition

K_h = 12803 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.399 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.51 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.41 m) to 2.51 m depth (GL -6.92 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.41	0.16	2.0	2.0	0.31
2	4.57	1.00	2.0	4.0	3.00
3	5.57	1.00	4.0	7.0	5.50
4	6.57	0.35	7.0	8.1	2.64
L = Σh = 2.51					ΣA = 11.46

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{11.46}{2.51} = 4.57$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 4.57^{0.406} = 12803 \text{ kN/m}^3$$

Kh (seismic condition) = 12803 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.55 34.51	7.93 36.23	3.24 2.54	25.65 91.88
2	2.10~ 2.60	0.50	36.20 42.80	9.05 10.70	1.67 1.50	15.10 16.08
3	2.60~ 3.94	1.34	42.80 0.00	28.59 0.00	0.89 0.45	25.46 0.00
				ΣP = 92.49		ΣM = 174.17

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.4 kN/m
depth to acting position	H_t	=	-0.42 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.34 m

Moment M_t by arbitrary load is as below
$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.45 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{184.62}{94.89} = 1.95 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.88 39.86	10.37 41.85	3.71 3.01	38.52 126.10
2	2.10~ 2.60	0.50	41.99 44.47	10.50 11.12	2.15 1.98	22.53 22.01
3	2.60~ 4.41	1.81	44.47 0.00	40.32 0.00	1.21 0.60	48.74 0.00
				ΣP = 114.16		ΣM = 257.91

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.7 kN/m
depth to acting position	H_t	=	-0.25 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.81 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 40.57 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.15 1.98	0.00 0.42
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.42

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{298.90}{123.07} = 2.43 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and joint)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	11656 kN/m^3
calculated value	β	=	0.38951 m^{-1}
resultant earth force (lateral)	P_0	=	94.89 kN/m
height of acting position of load	h_0	=	1.95 m
moment	M_0	=	184.62 kN·m/m

in consideration of ψ_m = 1.223,

maximum moment	M_{max}	=	225.88 kN·m/m
depth of generated position of M_{max}	l_m	=	0.971 m
depth of 1st fixed point	l_i	=	2.988 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	12803 kN/m^3
calculated value	β	=	0.39876 m^{-1}
resultant earth force (lateral)	P_0	=	123.07 kN/m
height of acting position of load	h_0	=	2.43 m
moment	M_0	=	298.90 kN·m/m

in consideration of ψ_m = 1.154,

maximum moment	M_{max}	=	344.83 kN·m/m
depth of generated position of M_{max}	l_m	=	0.823 m
depth of 1st fixed point	l_i	=	2.793 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{225.88\times10^6}{3514\times10^3} = 64 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{344.83\times10^6}{3514\times10^3} = 98 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.24 2.54	0.822 0.644	0.245 0.163	7.93 36.23	1.944 5.905
2	2.10~ 2.60	1.67 1.50	0.424 0.382	0.077 0.064	9.05 10.70	0.699 0.680
3	2.60~ 3.94	0.89 0.45	0.226 0.113	0.024 0.006	28.59 0.00	0.677 0.000
						ΣQ = 9.906

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

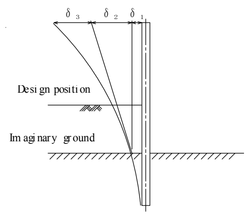
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3895\times1.95)\times94.89}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3895^3} = 0.01115 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.3895\times1.95)\times94.89}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3895^2} \times (2.60+1.34) = 0.02446 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.91\times(2.60+1.34)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00477 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00045 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 3.94 m

Horizontal load: P = 2.40

Moment: M = 1.01

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01115 + 0.02446 + 0.00522

= 0.04083 m

= 40.83 ≦ δa = 50.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.71 3.01	0.841 0.683	0.255 0.180	10.37 41.85	2.642 7.535
2	2.10~ 2.60	2.15 1.98	0.486 0.449	0.099 0.086	10.50 11.12	1.040 0.952
3	2.60~ 4.41	1.21 0.60	0.274 0.137	0.034 0.009	40.32 0.00	1.374 0.000
						ΣQ = 13.543

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

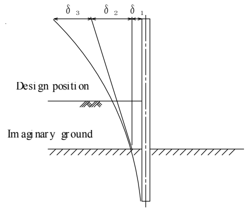
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.15 1.98	0.486 0.449	0.099 0.086	0.00 0.21	0.000 0.018
						ΣQ_{dw} = 0.018

Therefore, modulus of deformation Q is calculated as below.

Q = 13.543 + 0.018 = 13.561

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3988\times 2.43)\times 123.07}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3988^3} = 0.01509\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3988\times 2.43)\times 123.07}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.3988^2}\times(2.60+1.81) = 0.03962\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.56\times(2.60+1.81)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00921\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00214 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.41 m
Horizontal load: P = 8.70
Moment: M = 2.18

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01509 + 0.03962 + 0.01134
= 0.06606 m
= 66.06 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 11656 kN/m^3
Calculated value β = 0.36078 m^{-1}

Penetration length of SSP $D = 1.34 + \dfrac{3}{0.361} = 9.65$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.65 = 11.85$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 12803 kN/m^3
Calculated value β = 0.36935 m^{-1}

Penetration length of SSP $D = 1.81 + \dfrac{3}{0.369} = 9.94$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.94 = 12.14$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

8 Calculation Result

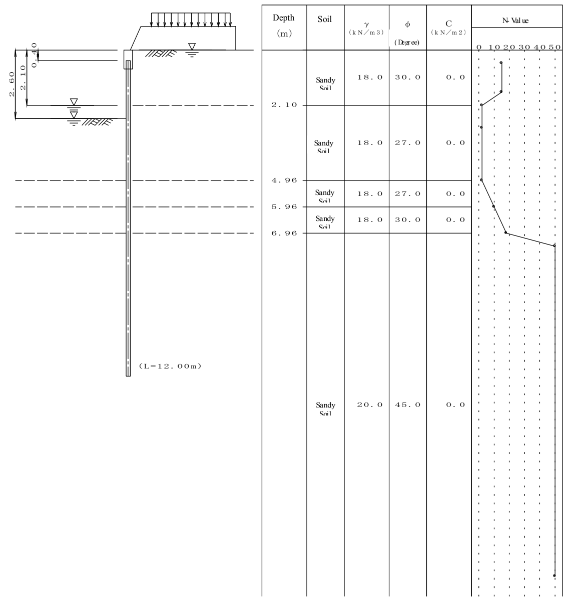
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		225.88	344.83
Stress intensity	σ (Nmm^2)		64 (180)	98 (270)
Lateral displacement	δ (mm)		40.83 (50.0)	66.06 (75.0)
Penetration depth	D (m)		9.65	9.94
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 19_STA 9+550 - 9+650

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed   calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress   Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure   trapezoidal water pressure

Lateral pressure   calculated in consideration of site conditions

Study case   - Normal Condition
- Seismic Condition

Design earthquake intensity   k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.4 kNm (Normal Condition)
		Pt'	=	8.7 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.43 m (Normal Condition)
		Ht'	=	-0.25 m (Seismic Condition)
	Moment	Mm	=	0.0 kNm/m (Normal Condition)
		Mm'	=	0.0 kNm/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load   not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope   not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_s = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value   calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	2			
4	2.96	2			
5	4.96	2			
6	5.96	10			
7	6.96	18			
8	7.46	50			
9	20.00	50			

2.142

1-6 Vertical Load

Vertical load on landside   calculated in consideration of embankment shape on landside

Vertical load on riverside   not considered

1-7 Soil Modulus

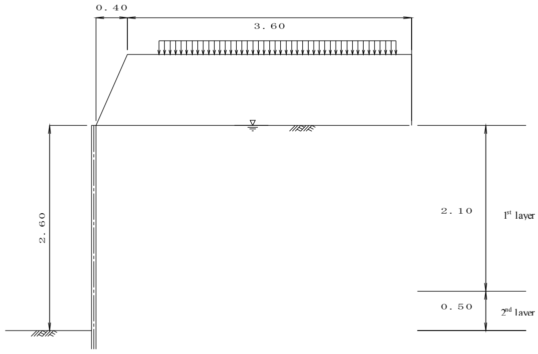
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic		
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	———	———
2	4.96	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
3	5.96	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
4	6.96	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	———	———
5	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	———	———

Note)
depth : from top of coping to bottom of the layer
soil : sandy (S), clayey (C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kNm³)	ϕ (degree)	C (kNm²)	Normal	Seismic
1	Sandy soil	0.00	0.40	4.00	4.00	0.90	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.80	3.80	10.0	5.0

Angle of rapture in embankment   calculated in consideration of embankment conditions

Case: Right Bank No. 19_STA 9+550 – 9+650

1-9 Steel Sheet Pile (SSP)

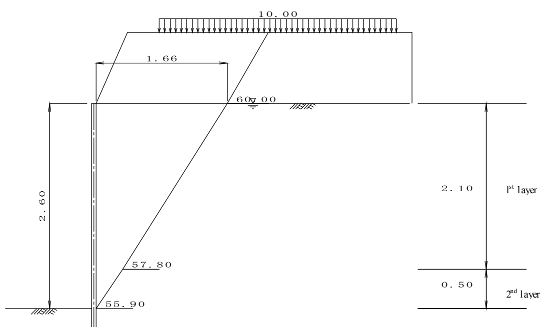
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4
Sectional factor	Z_0	=	3820 cm^3
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 Nmm^2(Normal)
	σ_a'	=	270 Nmm^2(Seismic)
Allowable displacement	δ_a	=	50.0 mm(Normal)
	δ_a'	=	75.0 mm(Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction Not reduced: I_0 applied to calculation of penetration depth Reduced: I_0 applied to calculation of section forces and displacement Reduced: Z_0 applied to calculation of stresses

Case: Right Bank No. 19_STA 9+550 – 9+650

2 Calculation of Acting Load

2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kNm²)	Σγh (kNm²)	Q (kNm²)	γwhw (kNm²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	25.10	25.48	55.90
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.10	20.58	57.80
3		Embankment	30.0	——	0.0	16.20	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta=0°$

Where

ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
   $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

Case: Right Bank No. 19_STA 9+550 – 9+650

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	0.90	1.66	2.60	2.18	3.50

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	18.0	1.55	27.88
Σ			27.88

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kNm²)	l (m)	Q X l (kNm)
1	10.0	1.38	13.81
Σ			13.81

Q surcharge load
l : width of surcharge load set by line of active rupture

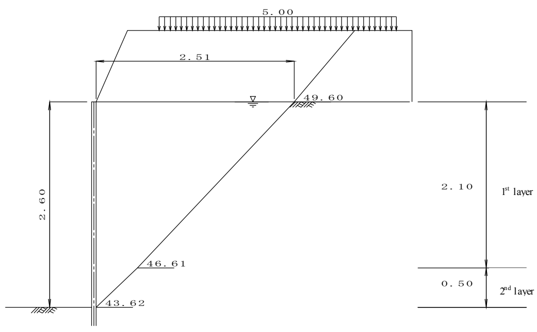
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{27.88 + 13.81 + 0.00}{1.66}$$

$$= 25.10 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kNm²)	Σγh (kNm²)	Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	22.31	25.48	0.200	11.31	43.62
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	22.31	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	16.20	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.

ζ : angle of active rupture (degree, $\zeta \geq 10.00^0$)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	0.90	2.51	2.60	3.28	3.50

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kNm³)	A (m²)	γ X A (kNm)
1	18.0	2.42	43.63
Σ			43.63

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kNm²)	l (m)	Q X l (kNm)
1	5.0	2.48	12.38
Σ			12.38

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

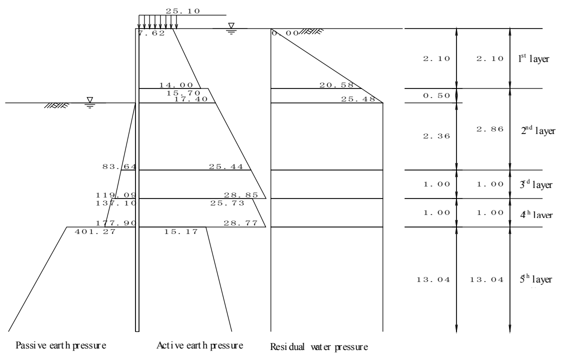
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{43.63 + 12.38 + 0.00}{2.51}$$

$$= 22.31 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka × cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	25.095 46.095	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	46.095 51.095	0.34585 0.34585	0.34060 0.34060
3	2.60~ 4.96	Sandy soil	10.0	27.0	—— ——	51.095 74.695	0.34585 0.34585	0.34060 0.34060
4	4.96~ 5.96	Sandy soil	10.0	27.0	—— ——	74.695 84.695	0.34585 0.34585	0.34060 0.34060
5	5.96~ 6.96	Sandy soil	10.0	30.0	—— ——	84.695 94.695	0.30847 0.30847	0.30378 0.30378
6	6.96~ 20.00	Sandy soil	10.0	45.0	—— ——	94.695 225.095	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 4.96	Sandy soil	10.0	27.0	—— ——	0.000 23.600	3.59892 3.59892	3.54425 3.54425
4	4.96~ 5.96	Sandy soil	10.0	27.0	—— ——	23.600 33.600	3.59892 3.59892	3.54425 3.54425

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
5	5.96~ 6.96	Sandy soil	10.0	30.0	—— ——	33.600 43.600	4.14330 4.14330	4.08035 4.08035
6	6.96~ 20.00	Sandy soil	10.0	45.0	—— ——	43.600 174.000	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.62 14.00	—— ——	7.62 14.00	0.00 20.58	—— ——
2	2.10~ 2.60	15.70 17.40	—— ——	15.70 17.40	20.58 25.48	—— ——
3	2.60~ 4.96	17.40 25.44	—— ——	17.40 25.44	25.48 25.48	0.00 83.64
4	4.96~ 5.96	25.44 28.85	—— ——	25.44 28.85	25.48 25.48	83.64 119.09
5	5.96~ 6.96	25.73 28.77	—— ——	25.73 28.77	25.48 25.48	137.10 177.90
6	6.96~ 20.00	15.17 36.05	—— ——	15.17 36.05	25.48 25.48	401.27 1601.41

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a\cdot\left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c\cdot(\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}]\cdot\cos\delta$

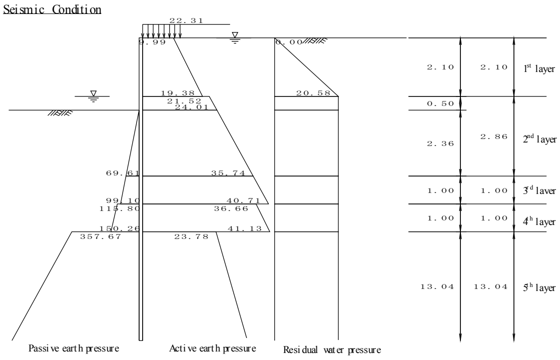
- Formula for passive earth pressure

Sandy soil $P_p = K_p\cdot\left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	22.31 43.31	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	27.0	—— ——	43.31 48.31	20.58 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.60~ 4.96	Sandy Soil	10.0	27.0	—— ——	48.31 71.91	25.48 48.61	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	4.96~ 5.96	Sandy Soil	10.0	27.0	—— ——	71.91 81.91	48.61 58.41	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	5.96~ 6.96	Sandy Soil	10.0	30.0	—— ——	81.91 91.91	58.41 68.21	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
6	6.96~ 20.00	Sandy Soil	10.0	45.0	—— ——	91.91 222.31	68.21 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 4.96	Sandy soil	10.00	27.0	—— ——	0.000 23.600	0.00 23.13	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
4	4.96~ 5.96	Sandy soil	10.00	27.0	—— ——	23.600 33.600	23.13 32.93	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	5.96~ 6.96	Sandy soil	10.00	30.0	—— ——	33.600 43.600	32.93 42.73	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
6	6.96~ 20.00	Sandy soil	10.00	45.0	—— ——	43.600 174.000	42.73 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	9.99 19.38	—— ——	9.99 19.38	0.00 20.58	—— ——
2	2.10~ 2.60	21.52 24.01	—— ——	21.52 24.01	20.58 20.58	—— ——
3	2.60~ 4.96	24.01 35.74	—— ——	24.01 35.74	20.58 20.58	0.00 69.61
4	4.96~ 5.96	35.74 40.71	—— ——	35.74 40.71	20.58 20.58	69.61 99.10
5	5.96~ 6.96	36.66 41.13	—— ——	36.66 41.13	20.58 20.58	115.80 150.26
6	6.96~ 20.00	23.78 57.52	—— ——	23.78 57.52	20.58 20.58	357.67 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

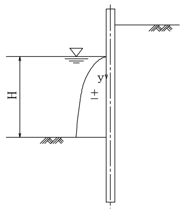
Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm\frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

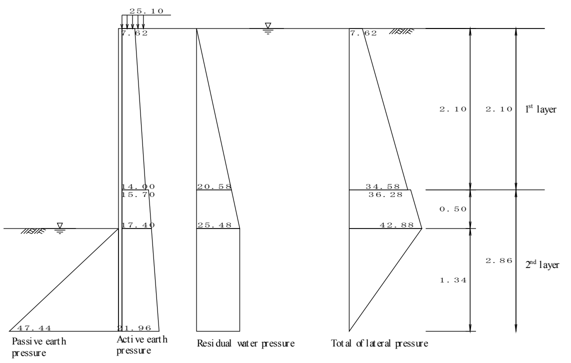
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level l_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

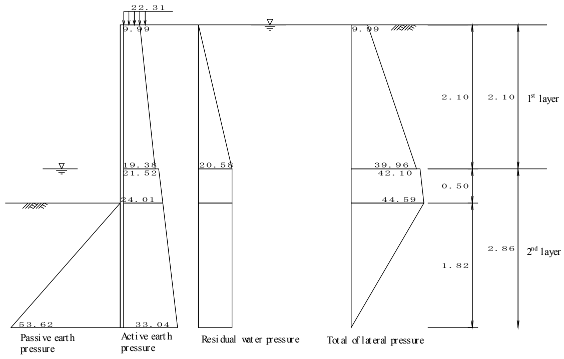


	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	7.62 14.00	0.00 20.58	—— ——	7.62 34.58
2	2.10~ 2.60	15.70 17.40	20.58 25.48	—— ——	36.28 42.88
3	2.60~ 3.94	17.40 21.96	25.48 25.48	0.00 47.44	42.88 0.00
4	3.94~ 4.96	21.96 25.44	25.48 25.48	47.44 83.64	0.00 -32.72

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.34 m (GL -3.94 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	9.99 19.38	0.00 20.58	―― ――	9.99 39.96
2	2.10~ 2.60	21.52 24.01	20.58 20.58	―― ――	42.10 44.59
3	2.60~ 4.42	24.01 33.04	20.58 20.58	0.00 53.62	44.59 0.00
4	4.42~ 4.96	33.04 35.74	20.58 20.58	53.62 69.61	0.00 -13.29

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.82 m (GL -4.42 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	2.96	2
5	4.96	2
6	5.96	10
7	6.96	18
8	7.46	50
9	20.00	50

5-2 Normal Condition

K_h = 13688 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.405 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.47 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.94 m) to 2.47 m depth (GL -6.40 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.94	1.02	2.0	2.0	2.04
2	4.96	1.00	2.0	10.0	6.00
3	5.96	0.44	10.0	13.6	5.24
	L = Σh = 2.47				ΣA = 13.28

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{13.28}{2.47} = 5.39$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 5.39^{0.406} = 13688 \text{ kN/m}^3$$

Kh (normal condition) = 13688 kNm^3

5-3 Seismic Condition

K_h = 15806 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.420 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.38 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.42 m) to 2.38 m depth (GL -6.80 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.42	0.54	2.0	2.0	1.08
2	4.96	1.00	2.0	10.0	6.00
3	5.96	0.84	10.0	16.7	11.18
	L = Σh = 2.38				ΣA = 18.26

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{18.26}{2.38} = 7.67$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 7.67^{0.406} = 15806 \text{ kN/m}^3$$

Kh (seismic condition) = 15806 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.62 34.58	8.00 36.31	3.24 2.54	25.92 92.18
2	2.10~ 2.60	0.50	36.28 42.88	9.07 10.72	1.67 1.51	15.16 16.14
3	2.60~ 3.94	1.34	42.88 0.00	28.70 0.00	0.89 0.45	25.61 0.00
				ΣP = 92.81		ΣM = 175.02

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.4 kNm
depth to acting position	H_t	=	-0.43 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.34 m

Moment M_t by arbitrary load is as below
$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.48 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{185.50}{95.21} = 1.95 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.99 39.96	10.48 41.96	3.72 3.02	38.98 126.64
2	2.10~ 2.60	0.50	42.10 44.59	10.53 11.15	2.15 1.98	22.65 22.12
3	2.60~ 4.42	1.82	44.59 0.00	40.53 0.00	1.21 0.61	49.13 0.00
				ΣP = 114.65		ΣM = 259.52

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
$K_h = 6910 \times N'^{0.406} = 6910 \times 7.67^{0.406} = 15806 \text{ kN/m}^3$
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.7 kN/m
depth to acting position	H_t	=	-0.25 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.82 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 40.61 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.15 1.98	0.00 0.43
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.43

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{300.56}{123.57} = 2.43 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	n	=	0.92
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 63296 x 10⁻⁸		=	1.266×10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\ (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	13688 kN/m³
calculated value	β	=	0.40548 m⁻¹
resultant earth force (lateral)	P_0	=	95.21 kN/m
height of acting position of load	h_0	=	1.95 m
moment	M_0	=	185.50 kN·m/m
in consideration of ψ_m = 1.210,			
maximum moment	M_{max}	=	224.44 kN·m/m
depth of generated position of M_{max}	l_m	=	0.912 m
depth of 1st fixed point	l_i	=	2.849 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	15806 kN/m³
calculated value	β	=	0.42033 m⁻¹
resultant earth force (lateral)	P_0	=	123.57 kN/m
height of acting position of load	h_0	=	2.43 m
moment	M_0	=	300.56 kN·m/m
in consideration of ψ_m = 1.141,			
maximum moment	M_{max}	=	342.98 kN·m/m
depth of generated position of M_{max}	l_m	=	0.755 m
depth of 1st fixed point	l_i	=	2.624 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	n	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm³ (original condition)
	Z	=	3514 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{224.44\times10^6}{3514\times10^3} = 64 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{342.98\times10^6}{3514\times10^3} = 98 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.24 2.54	0.822 0.645	0.245 0.163	8.00 36.31	1.964 5.922
2	2.10~ 2.60	1.67 1.51	0.424 0.382	0.077 0.064	9.07 10.72	0.702 0.683
3	2.60~ 3.94	0.89 0.45	0.227 0.113	0.024 0.006	28.70 0.00	0.681 0.000
						ΣQ = 9.952

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

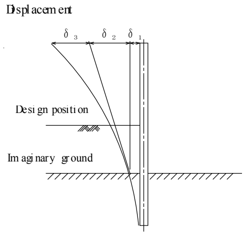
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4055\times1.95)\times95.21}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4055^3} = 0.01010 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4055\times1.95)\times95.21}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4055^2}\times(2.60+1.34) = 0.02324 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.95\times(2.60+1.34)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00480 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00045 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.94m
Horizontal load: P = 2.40
Moment: M = 1.03

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01010 + 0.02324 + 0.00525
= 0.03859 m
= 38.59 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

2.147

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.72 3.02	0.842 0.683	0.255 0.180	10.48 41.96	2.671 7.561
2	2.10~ 2.60	2.15 1.98	0.487 0.449	0.099 0.086	10.53 11.15	1.045 0.956
3	2.60~ 4.42	1.21 0.61	0.274 0.137	0.034 0.009	40.53 0.00	1.386 0.000
						ΣQ = 13.620

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

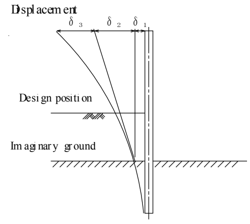
H : Depth to design position

L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.15 1.98	0.487 0.449	0.099 0.086	0.00 0.21	0.000 0.018
						ΣQ_{dw} = 0.018

Therefore, modulus of deformation Q is calculated as below.
Q = 13.620 + 0.018 = 13.638



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4203\times 2.43)\times 123.57}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4203^3} = 0.01329\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4203\times 2.43)\times 123.57}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4203^2}\times(2.60+1.82) = 0.03716\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.64\times(2.60+1.82)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00929\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00214 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.42 m
Horizontal load: P = 8.70
Moment: M = 2.18

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01329 + 0.03716 + 0.01143
= 0.06189 m
= 61.89 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below.

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x86000x 10^{-8}		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 13688 kN/m^3
Calculated value β = 0.37557 m^{-1}

Penetration length of SSP $D = 1.34 + \dfrac{3}{0.376} = 9.33$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.33 = 11.53$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 15806 kN/m^3
Calculated value β = 0.38932 m^{-1}

Penetration length of SSP $D = 1.82 + \dfrac{3}{0.389} = 9.52$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.52 = 11.72$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

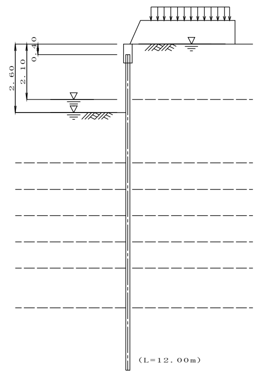
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		224.44	342.98
Stress intensity	σ (N/mm^2)		64 (180)	98 (270)
Lateral displacement	δ (mm)		38.59 (50.0)	61.89 (75.0)
Penetration depth	D (m)		9.33	9.52
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

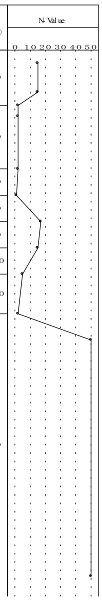
Right Bank No. 20_STA 9+650 - 9+723

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
4.52	Sandy Soil	18.0	27.0	0.0
5.52	Sandy Soil	18.0	27.0	0.0
6.52	Sandy Soil	18.0	31.0	0.0
7.52	Sandy Soil	18.0	30.0	0.0
8.52	Clayey Soil	16.0	0.0	25.0
10.02	Clayey Soil	16.0	0.0	12.0
	Sandy Soil	20.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed H = 2.60 m
Depth from coping top to rear side ground H_h = 0.00 m
Depth from coping top to SSP top H_t = 0.40 m
Riverside WL L_{wa} = 0.00 m (Normal Condition)
L_{wa}' = 0.00 m (Seismic Condition)
Landside WL L_{wp} = 2.60 m (Normal Condition)
L_{wp}' = 2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake
considered as distributed load

Arbitrary load
Horizontal load Pt = 2.5 kNm (Normal Condition)
Pt' = 8.8 kNm (Seismic Condition)
Depth of acting point Ht = -0.43 m (Normal Condition)
Ht' = -0.26 m (Seismic Condition)
Moment Mm = 0.0 kN-m/m (Normal Condition)
Mm' = 0.0 kN-m/m (Seismic Condition)
Depth of acting point Hm' = 0.00 m (Seismic Condition)
Hm = 0.00 m (Normal Condition)
('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	2
4	2.52	2
5	4.52	2
6	5.52	1
7	6.52	17
8	7.52	15
9	8.52	5
10	10.02	2

No	Depth (m)	N-Value
11	11.02	50
12	20.00	50

2.149

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on front side not considered

1-7 Soil Modulus

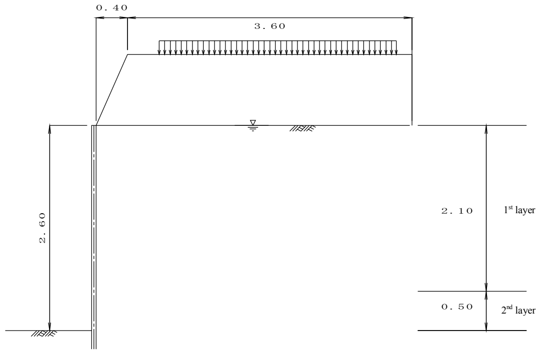
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic		
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	―――	―――
2	4.52	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
3	5.52	S	1.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
4	6.52	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	―――	―――
5	7.52	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	―――	―――
6	8.52	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	―――	―――
7	10.02	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	―――	―――
8	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	―――	―――

Note)
depth : from top of coping to bottom of the layer
soil : sandy (S), clayey (C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.40	4.00	4.00	0.90	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.80	3.80	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

Case: Right Bank No. 20_STA 9+650 – 9+723

1-9 Steel Sheet Pile (SSP)

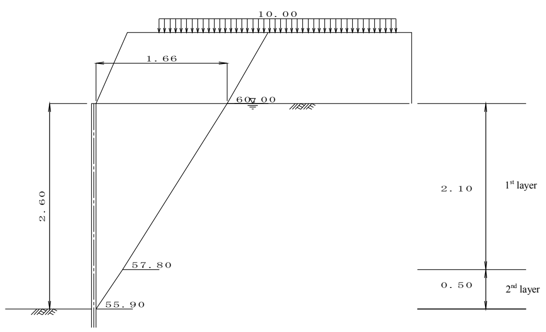
Young's modulus	E	=	200000 Nmm²			
Inertia sectional moment	I_0	=	86000 cm⁴			
Sectional factor	Z_0	=	3820 cm³			
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2	=	1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92			
Corrosion rate (to Z_0)	η	=	0.92			
Section efficiency (to I_0)	μ	=	0.80			
Section efficiency (to Z_0)	μ	=	1.00			
Round unit of SSP length			0.50 m			
Allowable stress	σ_a	=	180 Nmm² (Normal)			
	σ_a'	=	270 Nmm² (Seismic)			
Allowable displacement	δ_a	=	50.0 mm (Normal)			
	δ_a'	=	75.0 mm (Seismic)			
Bending of cantilever beam			calculated as distributed load of each layer			
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction			
			Not reduced: I_0 applied to calculation of penetration depth			
			Reduced: I_0 applied to calculation of section forces and displacement			
			Reduced: Z_0 applied to calculation of stresses			

Case: Right Bank No. 20_STA 9+650 – 9+723

2 Calculation of Acting Load

2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	25.10	25.48	55.90
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.10	20.58	57.80
3		Embankment	30.0	——	0.0	16.20	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

Case: Right Bank No. 20_STA 9+650 – 9+723

2-1-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	0.90	1.66	2.60	2.18	3.50

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.55	27.88
Σ			27.88

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.38	13.81
Σ			13.81

Q surcharge load

l : width of surcharge load set by line of active rupture

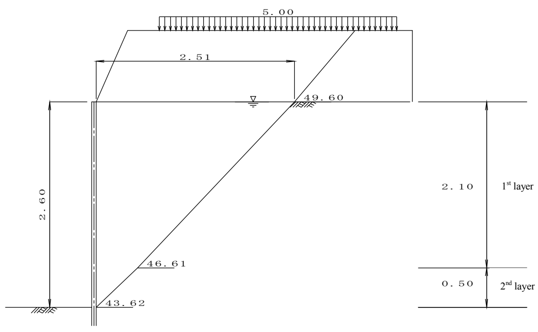
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{27.88 + 13.81 + 0.00}{1.66}$$

$$= 25.10 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	22.31	25.48	0.200	11.31	43.62
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	22.31	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	16.20	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  θ=tan⁻¹k or θ=tan⁻¹k'
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	0.90	2.51	2.60	3.28	3.50

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.42	43.63
Σ			43.63

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.48	12.38
Σ			12.38

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

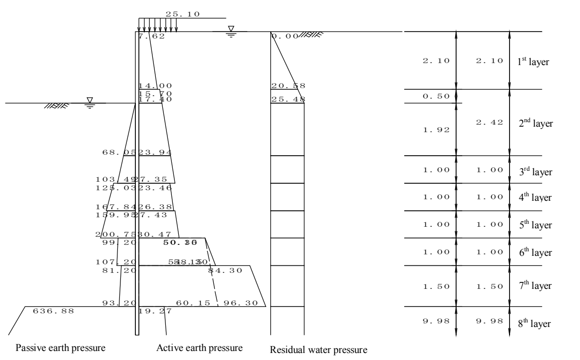
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{43.63 + 12.38 + 0.00}{2.51}$$

$$= 22.31 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	25.095 46.095	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	46.095 51.095	0.34585 0.34585	0.34060 0.34060
3	2.60~ 4.52	Sandy soil	10.0	27.0	—— ——	51.095 70.295	0.34585 0.34585	0.34060 0.34060
4	4.52~ 5.52	Sandy soil	10.0	27.0	—— ——	70.295 80.295	0.34585 0.34585	0.34060 0.34060
5	5.52~ 6.52	Sandy soil	10.0	31.0	—— ——	80.295 90.295	0.29669 0.29669	0.29219 0.29219
6	6.52~ 7.52	Sandy soil	10.0	30.0	—— ——	90.295 100.295	0.30847 0.30847	0.30378 0.30378
7	7.52~ 8.52	Clayey soil	8.0	—	25.0 25.0	100.295 108.295	—— ——	—— ——
8	8.52~ 10.02	Clayey soil	8.0	—	12.0 12.0	108.295 120.295	—— ——	—— ——
9	10.02~ 20.00	Sandy soil	10.0	45.0	—— ——	120.295 220.095	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 4.52	Sandy soil	10.0	27.0	—— ——	0.000 19.200	3.59892 3.59892	3.54425 3.54425
4	4.52~ 5.52	Sandy soil	10.0	27.0	—— ——	19.200 29.200	3.59892 3.59892	3.54425 3.54425
5	5.52~ 6.52	Sandy soil	10.0	31.0	—— ——	29.200 39.200	4.34774 4.34774	4.28169 4.28169
6	6.52~ 7.52	Sandy soil	10.0	30.0	—— ——	39.200 49.200	4.14330 4.14330	4.08035 4.08035
7	7.52~ 8.52	Clayey soil	8.0	0.0	25.0 25.0	49.200 57.200	—— ——	—— ——
8	8.52~ 10.02	Clayey soil	8.0	0.0	12.0 12.0	57.200 69.200	—— ——	—— ——
9	10.02~ 20.00	Sandy soil	10.0	45.0	—— ——	69.200 169.000	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side Pa1 (kNm²)	Active side Pa2 (kNm²)	Active side Pa (kNm²)	Residual water pressure Pw (kNm²)	Passive side Pp (kNm²)
1	0.00~ 2.10	7.62 14.00	—— ——	7.62 14.00	0.00 20.58	—— ——
2	2.10~ 2.60	15.70 17.40	—— ——	15.70 17.40	20.58 25.48	—— ——
3	2.60~ 4.52	17.40 23.94	—— ——	17.40 23.94	25.48 25.48	0.00 68.05
4	4.52~ 5.52	23.94 27.35	—— ——	23.94 27.35	25.48 25.48	68.05 103.49
5	5.52~ 6.52	23.46 26.38	—— ——	23.46 26.38	25.48 25.48	125.03 167.84
6	6.52~ 7.52	27.43 30.47	—— ——	27.43 30.47	25.48 25.48	159.95 200.75
7	7.52~ 8.52	50.30 58.30	50.15 54.15	50.30 58.30	25.48 25.48	99.20 107.20
8	8.52~ 10.02	84.30 96.30	54.15 60.15	84.30 96.30	25.48 25.48	81.20 93.20
9	10.02~ 20.00	19.27 35.25	—— ——	19.27 35.25	25.48 25.48	636.88 1555.39

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a\cdot\left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c\cdot(\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [\,K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}\,]\cdot\cos\delta$

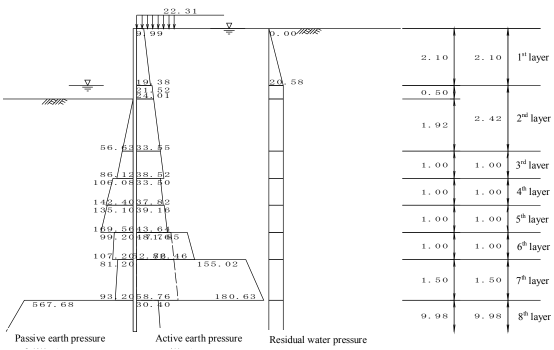
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	22.31 43.31	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	27.0	—— ——	43.31 48.31	20.58 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.60~ 4.52	Sandy Soil	10.0	27.0	—— ——	48.31 67.51	25.48 44.30	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	4.52~ 5.52	Sandy Soil	10.0	27.0	—— ——	67.51 77.51	44.30 54.10	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	5.52~ 6.52	Sandy Soil	10.0	31.0	—— ——	77.51 87.51	54.10 63.90	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
6	6.52~ 7.52	Sandy Soil	10.0	30.0	—— ——	87.51 97.51	63.90 73.70	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
7	7.52~ 8.52	Clayey Soil	8.0	—	25.0 25.0	97.51 105.51	73.70 83.50	0.200 0.200	11.31 11.31	—— ——	—— ——	35.81 34.96
8	8.52~ 10.02	Clayey Soil	8.0	—	12.0 12.0	105.51 117.51	83.50 98.20	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
9	10.02~ 20.00	Sandy Soil	10.0	45.0	—— ——	117.51 217.31	98.20 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 4.52	Sandy soil	10.00	27.0	—— ——	0.000 19.200	0.00 18.82	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
4	4.52~ 5.52	Sandy soil	10.00	27.0	—— ——	19.200 29.200	18.82 28.62	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	5.52~ 6.52	Sandy soil	10.00	31.0	—— ——	29.200 39.200	28.62 38.42	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
6	6.52~ 7.52	Sandy soil	10.00	30.0	—— ——	39.200 49.200	38.42 48.22	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
7	7.52~ 8.52	Clayey Soil	8.00	0.0	25.0 25.0	49.200 57.200	48.22 58.02	0.200 0.200	11.31 11.31	—— ——	—— ——
8	8.52~ 10.02	Clayey Soil	8.00	0.0	12.0 12.0	57.200 69.200	58.02 72.72	0.200 0.200	11.31 11.31	—— ——	—— ——
9	10.02~ 20.00	Sandy Soil	10.00	45.0	—— ——	69.200 169.000	72.72 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	9.99 19.38	—— ——	9.99 19.38	0.00 20.58	—— ——
2	2.10~ 2.60	21.52 24.01	—— ——	21.52 24.01	20.58 20.58	—— ——
3	2.60~ 4.52	24.01 33.55	—— ——	24.01 33.55	20.58 20.58	0.00 56.63
4	4.52~ 5.52	33.55 38.52	—— ——	33.55 38.52	20.58 20.58	56.63 86.12
5	5.52~ 6.52	33.50 37.82	—— ——	33.50 37.82	20.58 20.58	106.08 142.40
6	6.52~ 7.52	39.16 43.64	—— ——	39.16 43.64	20.58 20.58	135.10 169.56
7	7.52~ 8.52	71.85 82.46	48.76 52.76	71.85 82.46	20.58 20.58	99.20 107.20
8	8.52~ 10.02	155.02 180.63	52.76 58.76	155.02 180.63	20.58 20.58	81.20 93.20
9	10.02~ 20.00	30.40 56.23	—— ——	30.40 56.23	20.58 20.58	567.68 1386.38

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

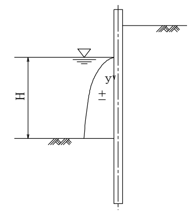
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

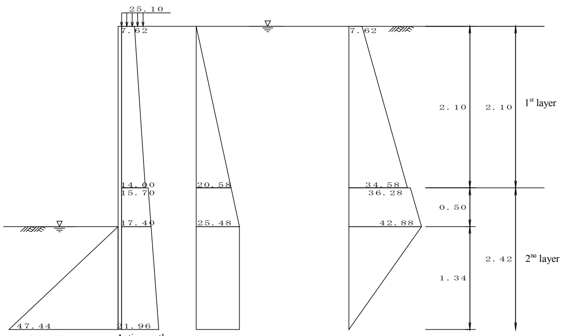
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level I_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

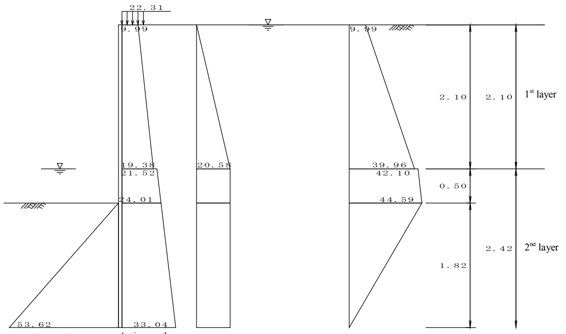


	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	7.62 14.00	0.00 20.58	—— ——	7.62 34.58
2	2.10~ 2.60	15.70 17.40	20.58 25.48	—— ——	36.28 42.88
3	2.60~ 3.94	17.40 21.96	25.48 25.48	0.00 47.44	42.88 0.00
4	3.94~ 4.52	21.96 23.94	25.48 25.48	47.44 68.05	0.00 -18.63

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.34 m (GL -3.94 m)

4-2 Seismic Condition



	Depth (m)	Pa (kN/m^2)	Pw (kN/m^2)	Pp (kN/m^2)	Ps (kN/m^2)
1	0.00~ 2.10	9.99 19.38	0.00 20.58	—— ——	9.99 39.96
2	2.10~ 2.60	21.52 24.01	20.58 20.58	—— ——	42.10 44.59
3	2.60~ 4.42	24.01 33.04	20.58 20.58	0.00 53.62	44.59 0.00
4	4.42~ 4.52	33.04 33.55	20.58 20.58	53.62 56.63	0.00 -2.50

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.82 m (GL -4.42 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} = 1.266×10^5

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	11.02	50
2	1.60	15	12	20.00	50
3	2.10	2			
4	2.52	2			
5	4.52	2			
6	5.52	1			
7	6.52	17			
8	7.52	15			
9	8.52	5			
10	10.02	2			

5-2 Normal Condition

K_h = 12438 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.396 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.53 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.94 m) to 2.53 m depth (GL -6.46 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.94	0.58	2.0	2.0	1.16
2	4.52	1.00	2.0	1.0	1.50
3	5.52	0.94	1.0	16.1	8.08
L = Σh = 2.53			ΣA =		10.74

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{10.74}{2.53} = 4.25$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 4.25^{0.406} = 12438 \text{ kN/m}^3$$

Kh (normal condition) = 12438 kN/m^3

5-3 Seismic Condition

K_h = 14866 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.414 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.42 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.42 m) to 2.42 m depth (GL -6.83 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.42	0.10	2.0	2.0	0.20
2	4.52	1.00	2.0	1.0	1.50
3	5.52	1.00	1.0	17.0	9.00
4	6.52	0.31	17.0	16.4	5.24
L = Σh = 2.42				ΣA = 15.94	

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{15.94}{2.42} = 6.60$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 6.60^{0.406} = 14866 \text{ kN/m}^3$$

Kh (seismic condition) = 14866 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.62 34.58	8.00 36.31	3.24 2.54	25.92 92.18
2	2.10~ 2.60	0.50	36.28 42.88	9.07 10.72	1.67 1.51	15.16 16.14
3	2.60~ 3.94	1.34	42.88 0.00	28.70 0.00	0.89 0.45	25.61 0.00
				ΣP = 92.81		ΣM = 175.02

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.5 kN/m
depth to acting position	H_t	=	-0.43 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.34 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.92 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{185.94}{95.31} = 1.95 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.99 39.96	10.48 41.96	3.72 3.02	38.98 126.64
2	2.10~ 2.60	0.50	42.10 44.59	10.53 11.15	2.15 1.98	22.65 22.12
3	2.60~ 4.42	1.82	44.59 0.00	40.53 0.00	1.21 0.61	49.13 0.00
				ΣP = 114.65		ΣM = 259.52

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.8 kN/m
depth to acting position	H_t	=	-0.26 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.82 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 41.17 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.15 1.98	0.00 0.43
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.43

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{301.12}{123.67} = 2.43 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	12438 kN/m^3
calculated value	β	=	0.39589 m^{-1}
resultant earth force (lateral)	P_0	=	95.31 kN/m
height of acting position of load	h_0	=	1.95 m
moment	M_0	=	185.94 kN·m/m

in consideration of ψ_m = 1.217,

maximum moment	M_{max}	=	226.32 kN·m/m
depth of generated position of M_{max}	l_m	=	0.946 m
depth of 1st fixed point	l_i	=	2.930 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	14866 kN/m^3
calculated value	β	=	0.41393 m^{-1}
resultant earth force (lateral)	P_0	=	123.67 kN/m
height of acting position of load	h_0	=	2.43 m
moment	M_0	=	301.12 kN·m/m

in consideration of ψ_m = 1.144,

maximum moment	M_{max}	=	344.58 kN·m/m
depth of generated position of M_{max}	l_m	=	0.774 m
depth of 1st fixed point	l_i	=	2.671 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{226.32 \times 10^6}{3514 \times 10^3} = 64 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{344.58 \times 10^6}{3514 \times 10^3} = 98 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.24 2.54	0.822 0.645	0.245 0.163	8.00 36.31	1.964 5.922
2	2.10~ 2.60	1.67 1.51	0.424 0.382	0.077 0.064	9.07 10.72	0.702 0.683
3	2.60~ 3.94	0.89 0.45	0.227 0.113	0.024 0.006	28.70 0.00	0.681 0.000
						ΣQ = 9.952

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

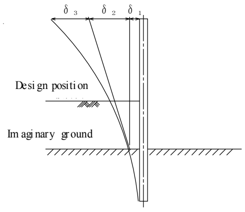
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3959\times1.95)\times95.31}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3959^3} = 0.01075\ \mathrm{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3959\times1.95)\times95.31}{2\times2.00\times10^8\times63296\times10^{-8}\times0.3959^2}\times(2.60+1.34) = 0.02407\ \mathrm{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.95\times(2.60+1.34)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00480\ \mathrm{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00047 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.94m
Horizontal load: P = 2.50
Moment: M = 1.08

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01075 + 0.02407 + 0.00527
= 0.04010 m
= 40.10 ≦ δ_a = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.72 3.02	0.842 0.683	0.255 0.180	10.48 41.96	2.671 7.561
2	2.10~ 2.60	2.15 1.98	0.487 0.449	0.099 0.086	10.53 11.15	1.045 0.956
3	2.60~ 4.42	1.21 0.61	0.274 0.137	0.034 0.009	40.53 0.00	1.386 0.000
						ΣQ = 13.620

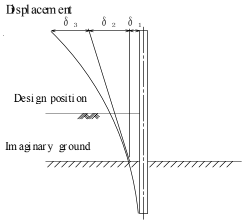
Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.15 1.98	0.487 0.449	0.099 0.086	0.00 0.21	0.000 0.018
						ΣQ_{dw} = 0.018

Therefore, modulus of deformation Q is calculated as below.
Q = 13.620 + 0.018 = 13.638

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4139\times2.43)\times123.67}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4139^3} = 0.01383\ \mathrm{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4139\times2.43)\times123.67}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4139^2}\times(2.60+1.82) = 0.03798\ \mathrm{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.64\times(2.60+1.82)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00929\ \mathrm{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00217 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.42 m
Horizontal load: P = 8.80
Moment: M = 2.29

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01383 + 0.03798 + 0.01147
= 0.06328 m
= 63.28 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

2.155

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction: K_h = 12438 kN/m^3
Calculated value: β = 0.36668 m^{-1}

Penetration length of SSP: $D = 1.34 + \dfrac{3}{0.367} = 9.52$ m
Whole length of SSP: $L = 2.60 - 0.40 + 9.52 = 11.72$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction: K_h = 14866 kN/m^3
Calculated value: β = 0.38340 m^{-1}

Penetration length of SSP: $D = 1.82 + \dfrac{3}{0.383} = 9.64$ m
Whole length of SSP: $L = 2.60 - 0.40 + 9.64 = 11.84$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

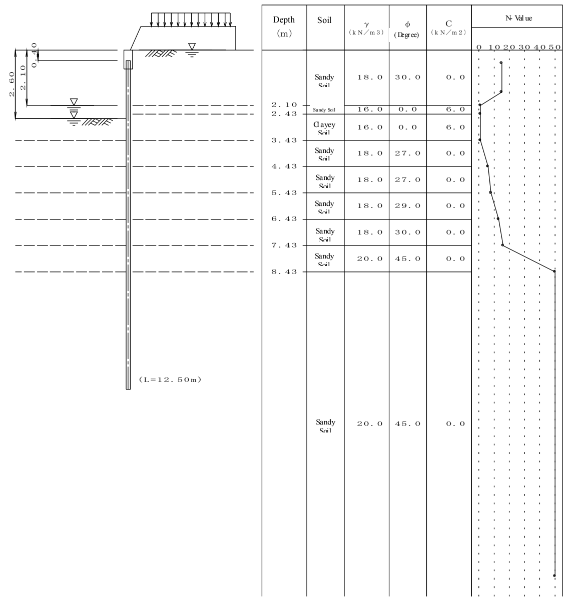
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		226.32	344.58
Stress intensity	σ (N/mm^2)		64 (180)	98 (270)
Lateral displacement	δ (mm)		40.10 (50.0)	63.28 (75.0)
Penetration depth	D (m)		9.52	9.64
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 21_STA_9+723 - 9+750

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_b	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wn}	=	0.00 m (Normal Condition)
	L_{wn}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.60 m (Normal Condition)
	L_{wn}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.5 kN/m	(Normal Condition)
		P_t'	=	8.8 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.43 m	(Normal Condition)
		H_t'	=	-0.26 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \dfrac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	20.00	50
2	1.60	15			
3	2.10	1			
4	2.43	1			
5	3.43	1			
6	4.43	6			
7	5.43	8			
8	6.43	13			
9	7.43	16			
10	8.43	50			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

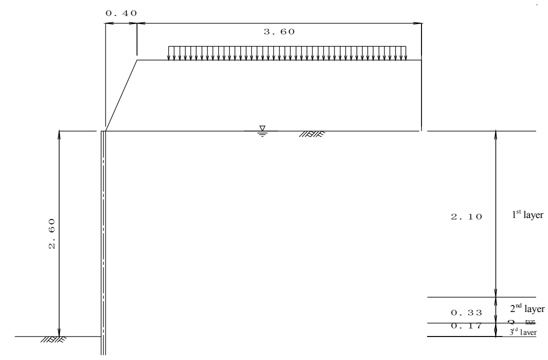
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh (kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	――	――
2	2.43	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	――	――
3	3.43	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	――	――
4	4.43	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
5	5.43	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	――	――
6	6.43	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	――	――
7	7.43	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	――	――
8	8.43	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	――	――
9	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	――	――

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_0 : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.40	4.00	4.00	0.90	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.80	3.80	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

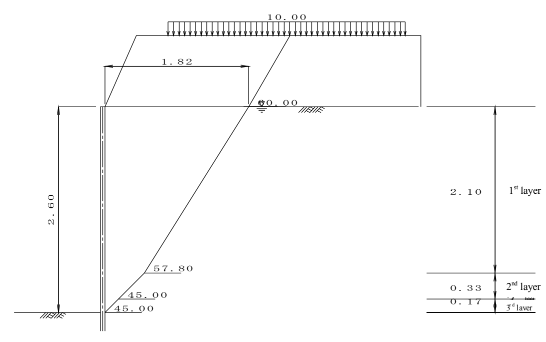
1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm^2		
Inertia sectional moment	I_0	=	114000 cm^4		
Sectional factor	Z_0	=	3250 cm^3		
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2 =	1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.84		
Corrosion rate (to Z_0)	η	=	0.87		
Section efficiency (to I_0)	μ	=	1.00		
Section efficiency (to Z_0)	μ	=	1.00		
Round unit of SSP length			0.50 m		
Allowable stress	σ_a	=	185 Nmm (Normal)		
	σ_a'	=	278 Nmm (Seismic)		
Allowable displacement	δ_a	=	50.0 mm (Normal)		
	δ_a'	=	75.0 mm (Seismic)		

Bending of cantilever beam: calculated as distributed load of each layer

Reduction of material modulus:
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.43	Clayey Soil	0.0	10.0	6.0	25.00	25.19	25.48	45.00
2	2.43～ 2.10	Clayey Soil	0.0	10.0	6.0	23.64	25.19	23.81	45.00
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.19	20.58	57.80
4		Embankment	30.0	——	0.0	16.20	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.17	0.00	0.00	0.17	0.17
2	45.00	0.33	0.17	0.17	0.50	0.50
3	57.80	2.10	0.50	0.50	1.82	2.60
4	60.00	0.90	1.82	2.60	2.34	3.50

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.69	30.49
Σ			30.49

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.54	15.42
Σ			15.42

Q surcharge load
l : width of surcharge load set by line of active rupture

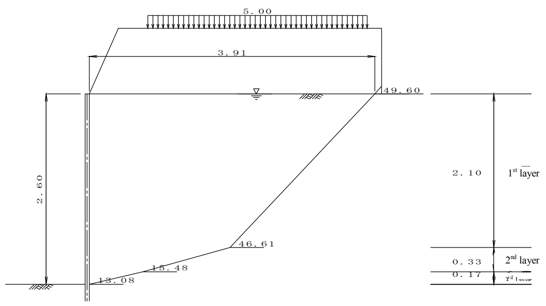
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{30.49 + 15.42 + 0.00}{1.82}$$

$$= 25.19 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.43	Clayey Soil	0.0	10.0	6.0	25.00	19.56	25.48	0.200	11.31	13.08
2	2.43~ 2.10	Clayey Soil	0.0	10.0	6.0	23.64	19.56	23.81	0.200	11.31	15.48
3	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	19.56	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	16.20	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where.

ζ : angle of active rupture (degree, $\zeta \geq 10.00^{0}$)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

Case: Right Bank No. 21_STA_9+723 - 9+750

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	13.08	0.17	0.00	0.00	0.73	0.17
2	15.48	0.33	0.73	0.17	1.92	0.50
3	46.61	2.10	1.92	0.50	3.91	2.60
4	49.60	0.11	3.91	2.60	4.00	2.71

Therefore, width of acting load shall be set as 3.91 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.42	61.47
Σ			61.47

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

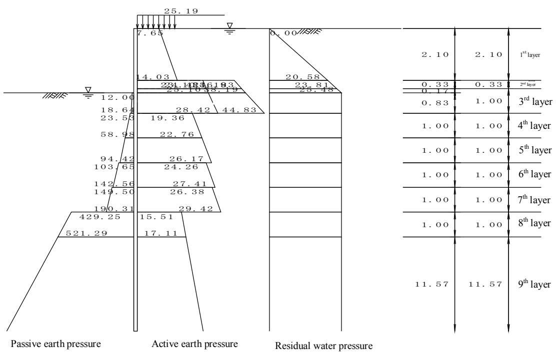
$$= \frac{61.47 + 15.00 + 0.00}{3.91}$$

$$= 19.56 \text{ kN/m}^2$$

Case: Right Bank No. 21_STA_9+723 - 9+750

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	25.193 46.193	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.43	Clayey soil	8.0	—	6.0 6.0	46.193 48.833	—— ——	—— ——
3	2.43~ 2.60	Clayey soil	8.0	—	6.0 6.0	48.833 50.193	—— ——	—— ——
4	2.60~ 3.43	Clayey soil	8.0	—	6.0 6.0	50.193 56.833	—— ——	—— ——
5	3.43~ 4.43	Sandy soil	10.0	27.0	—— ——	56.833 66.833	0.34585 0.34585	0.34060 0.34060
6	4.43~ 5.43	Sandy soil	10.0	27.0	—— ——	66.833 76.833	0.34585 0.34585	0.34060 0.34060
7	5.43~ 6.43	Sandy soil	10.0	29.0	—— ——	76.833 86.833	0.32058 0.32058	0.31571 0.31571
8	6.43~ 7.43	Sandy soil	10.0	30.0	—— ——	86.833 96.833	0.30847 0.30847	0.30378 0.30378
9	7.43~ 8.43	Sandy soil	10.0	45.0	—— ——	96.833 106.833	0.16262 0.16262	0.16015 0.16015
10	8.43~ 20.00	Sandy soil	10.0	45.0	—— ——	106.833 222.533	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Case: Right Bank No. 21_STA_9+723 - 9+750

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60~ 3.43	Clayey soil	8.0	0.0	6.0 6.0	0.000 6.640	—— ——	—— ——
5	3.43~ 4.43	Sandy soil	10.0	27.0	—— ——	6.640 16.640	3.59892 3.59892	3.54425 3.54425
6	4.43~ 5.43	Sandy soil	10.0	27.0	—— ——	16.640 26.640	3.59892 3.59892	3.54425 3.54425
7	5.43~ 6.43	Sandy soil	10.0	29.0	—— ——	26.640 36.640	3.95096 3.95096	3.89093 3.89093
8	6.43~ 7.43	Sandy soil	10.0	30.0	—— ——	36.640 46.640	4.14330 4.14330	4.08035 4.08035
9	7.43~ 8.43	Sandy soil	10.0	45.0	—— ——	46.640 56.640	9.34548 9.34548	9.20351 9.20351
10	8.43~ 20.00	Sandy soil	10.0	45.0	—— ——	56.640 172.340	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	7.65 14.03	—— ——	7.65 14.03	0.00 20.58	—— ——
2	2.10~ 2.43	34.19 36.83	23.10 24.42	34.19 36.83	20.58 23.81	—— ——
3	2.43~ 2.60	36.83 38.19	24.42 25.10	36.83 38.19	23.81 25.48	—— ——
4	2.60~ 3.43	38.19 44.83	25.10 28.42	38.19 44.83	25.48 25.48	12.00 18.64
5	3.43~ 4.43	19.36 22.76	—— ——	19.36 22.76	25.48 25.48	23.53 58.98
6	4.43~ 5.43	22.76 26.17	—— ——	22.76 26.17	25.48 25.48	58.98 94.42
7	5.43~ 6.43	24.26 27.41	—— ——	24.26 27.41	25.48 25.48	103.65 142.56
8	6.43~ 7.43	26.38 29.42	—— ——	26.38 29.42	25.48 25.48	149.50 190.31
9	7.43~ 8.43	15.51 17.11	—— ——	15.51 17.11	25.48 25.48	429.25 521.29
10	8.43~ 20.00	17.11 35.64	—— ——	17.11 35.64	25.48 25.48	521.29 1586.13

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

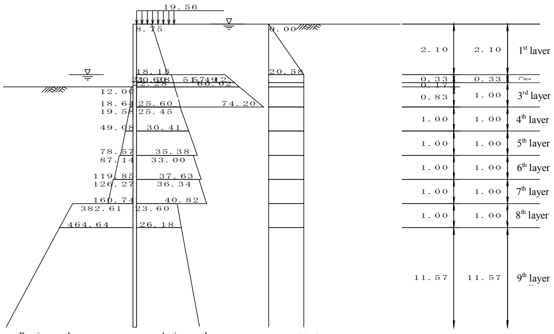
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



Passive earth pressure Active earth pressure Residual water pressure

3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	19.56 40.56	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.43	Clayey Soil	8.0	—	6.0 6.0	40.56 43.20	20.58 23.81	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
3	2.43~ 2.60	Clayey Soil	8.0	—	6.0 6.0	43.20 44.56	23.81 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
4	2.60~ 3.43	Clayey Soil	8.0	—	6.0 6.0	44.56 51.20	25.48 33.61	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
5	3.43~ 4.43	Sandy Soil	10.0	27.0	—— ——	51.20 61.20	33.61 43.41	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	4.43~ 5.43	Sandy Soil	10.0	27.0	—— ——	61.20 71.20	43.41 53.21	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——

Passive earth pressure Active earth pressure Residual water pressure

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	5.43~ 6.43	Sandy Soil	10.0	29.0	—— ——	71.20 81.20	53.21 63.01	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
8	6.43~ 7.43	Sandy Soil	10.0	30.0	—— ——	81.20 91.20	63.01 72.81	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
9	7.43~ 8.43	Sandy Soil	10.0	45.0	—— ——	91.20 101.20	72.81 82.61	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
10	8.43~ 20.00	Sandy Soil	10.0	45.0	—— ——	101.20 216.90	82.61 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.

δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 3.43	Clayey soil	8.00	0.0	6.0 6.0	0.000 6.640	0.00 8.13	0.200 0.200	11.31 11.31	—— ——	—— ——
5	3.43~ 4.43	Sandy soil	10.00	27.0	—— ——	6.640 16.640	8.13 17.93	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	4.43~ 5.43	Sandy soil	10.00	27.0	—— ——	16.640 26.640	17.93 27.73	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	5.43~ 6.43	Sandy soil	10.00	29.0	—— ——	26.640 36.640	27.73 37.53	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
8	6.43~ 7.43	Sandy soil	10.00	30.0	—— ——	36.640 46.640	37.53 47.33	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
9	7.43~ 8.43	Sandy soil	10.00	45.0	—— ——	46.640 56.640	47.33 57.13	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
10	8.43~ 20.00	Sandy soil	10.00	45.0	—— ——	56.640 172.340	57.13 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.

δ = -10.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	8.75 18.15	—— ——	8.75 18.15	0.00 20.58	—— ——
2	2.10~ 2.43	51.49 57.12	20.28 21.60	51.49 57.12	20.58 20.58	—— ——
3	2.43~ 2.60	57.12 60.02	21.60 22.28	57.12 60.02	20.58 20.58	—— ——
4	2.60~ 3.43	60.02 74.20	22.28 25.60	60.02 74.20	20.58 20.58	12.00 18.64
5	3.43~ 4.43	25.45 30.41	—— ——	25.45 30.41	20.58 20.58	19.58 49.08
6	4.43~ 5.43	30.41 35.38	—— ——	30.41 35.38	20.58 20.58	49.08 78.57
7	5.43~ 6.43	33.00 37.63	—— ——	33.00 37.63	20.58 20.58	87.14 119.85
8	6.43~ 7.43	36.34 40.82	—— ——	36.34 40.82	20.58 20.58	126.27 160.74
9	7.43~ 8.43	23.60 26.18	—— ——	23.60 26.18	20.58 20.58	382.61 464.64
10	8.43~ 20.00	26.18 56.12	—— ——	26.18 56.12	20.58 20.58	464.64 1413.78

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

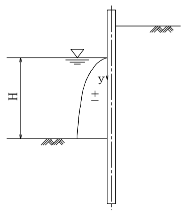
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

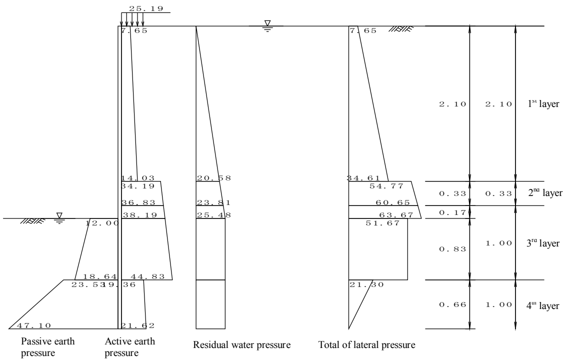
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

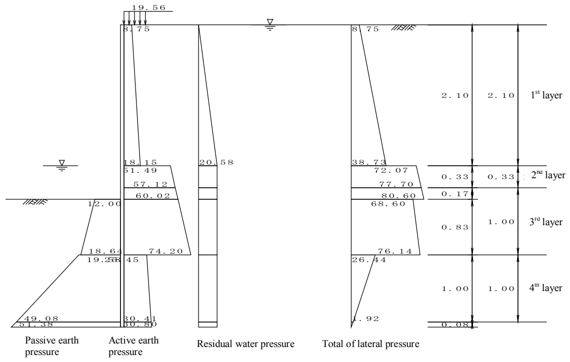


	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.10	7.65 14.03	0.00 20.58	—— ——	7.65 34.61
2	2.10～ 2.43	34.19 36.83	20.58 23.81	—— ——	54.77 60.65
3	2.43～ 2.60	36.83 38.19	23.81 25.48	—— ——	60.65 63.67
4	2.60～ 3.43	38.19 44.83	25.48 25.48	12.00 18.64	51.67 51.67
5	3.43～ 4.10	19.36 21.62	25.48 25.48	23.53 47.10	21.30 0.00
6	4.10～ 4.43	21.62 22.76	25.48 25.48	47.10 58.98	0.00 -10.73

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.50 m (GL -4.10 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.10	8.75 18.15	0.00 20.58	—— ——	8.75 38.73
2	2.10～ 2.43	51.49 57.12	20.58 20.58	—— ——	72.07 77.70
3	2.43～ 2.60	57.12 60.02	20.58 20.58	—— ——	77.70 80.60
4	2.60～ 3.43	60.02 74.20	20.58 20.58	12.00 18.64	68.60 76.14
5	3.43～ 4.43	25.45 30.41	20.58 20.58	19.58 49.08	26.44 1.92
6	4.43～ 4.51	30.41 30.80	20.58 20.58	49.08 51.38	1.92 0.00
7	4.51～ 5.43	30.80 35.38	20.58 20.58	51.38 78.57	0.00 -22.61

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.91 m (GL -4.51 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below.

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	114000 cm^4(original condition)
	I	=	95760 cm^4(after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 × 10^3 × 95760 × 10^{-8} = 1.915 × 10^5

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	1
4	2.43	1
5	3.43	1
6	4.43	6
7	5.43	8
8	6.43	13
9	7.43	16
10	8.43	50

	Depth (m)	N-value
11	20.00	50

5-2 Normal Condition

K_h = 16683 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.384 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.60 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.09 m) to 2.60 m depth (GL -6.70 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.09	0.34	4.3	6.0	1.73
2	4.43	1.00	6.0	8.0	7.00
3	5.43	1.00	8.0	13.0	10.50
4	6.43	0.27	13.0	13.8	3.59
L = Σh = 2.60				ΣA = 22.82	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{22.82}{2.60}$$

$$= 8.77$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following.

$K_h = 6910 \times N'^{0.406} = 6910 \times 8.77^{0.406} = 16683$ kN/m^3

Kh (normal condition) = 16683 kNm^3

5-3 Seismic Condition

K_h = 17697 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.390 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.57 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.51 m) and 2.57 m depth (GL -7.07 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.51	0.92	6.2	8.0	6.53
2	5.43	1.00	8.0	13.0	10.50
3	6.43	0.64	13.0	14.9	8.98
L = Σh = 2.57				ΣA = 26.01	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{26.01}{2.57}$$

$$= 10.14$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following.

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.14^{0.406} = 17697$ kN/m^3

Kh (seismic condition) = 17697 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.65 34.61	8.04 36.34	3.39 2.69	27.28 97.94
2	2.10~ 2.43	0.33	54.77 60.65	9.04 10.01	1.88 1.77	17.04 17.76
3	2.43~ 2.60	0.17	60.65 63.67	5.16 5.41	1.61 1.55	8.29 8.40
4	2.60~ 3.43	0.83	51.67 51.67	21.44 21.44	1.22 0.94	26.13 20.19
5	3.43~ 4.09	0.66	21.30 0.00	7.08 0.00	0.44 0.22	3.14 0.00
				ΣP = 123.96		ΣM = 226.17

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.5 kNm
depth to acting position	H	=	-0.43 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.49 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 11.31$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{237.48}{126.46} = 1.88 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.75 38.73	9.19 40.67	3.81 3.11	35.01 126.40
2	2.10~ 2.43	0.33	72.07 77.70	11.89 12.82	2.30 2.19	27.33 28.05
3	2.43~ 2.60	0.17	77.70 80.60	6.60 6.85	2.02 1.96	13.35 13.46
4	2.60~ 3.43	0.83	68.60 76.14	28.47 31.60	1.63 1.35	46.45 42.81
5	3.43~ 4.43	1.00	26.44 1.92	13.22 0.96	0.74 0.41	9.85 0.39
6	4.43~ 4.51	0.08	1.92 0.00	0.07 0.00	0.05 0.03	0.00 0.00
				ΣP = 162.35		ΣM = 343.10

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.8 kNm
depth to acting position	H	=	-0.26 m
moment	M_m	=	1.1 kN·m/m
depth to acting position	H_t	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.91 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 41.96$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.24 2.07	0.00 0.44
				ΣPdw = 0.21		ΣM dw = 0.44

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{385.51}{171.36} = 2.25 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 95760 × 10⁻⁸		=	1.915 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1}\frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	16683 kNm³
calculated value	β	=	0.38415 m⁻¹
resultant earth force (lateral)	P_0	=	126.46 kNm
height of acting position of load	h_0	=	1.88 m
moment	M_0	=	237.48 kN·m/m

in consideration of ψ_m = 1.240,

maximum moment	M_{max}	=	294.59 kN·m/m
depth of generated position of M_{max}	l_m	=	1.011 m
depth of 1st fixed point	l_i	=	3.056 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	17697 kNm³
calculated value	β	=	0.38986 m⁻¹
resultant earth force (lateral)	P_0	=	171.36 kNm
height of acting position of load	h_0	=	2.25 m
moment	M_0	=	385.51 kN·m/m

in consideration of ψ_m = 1.179,

maximum moment	M_{max}	=	454.56 kN·m/m
depth of generated position of M_{max}	l_m	=	0.893 m
depth of 1st fixed point	l_i	=	2.908 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm³ (original condition)
	Z	=	2828 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{294.59\times10^6}{2828\times10^3} = 104 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{454.56\times10^6}{2828\times10^3} = 161 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

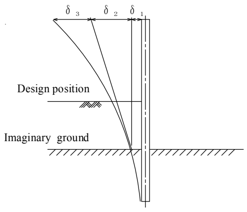
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.39 2.69	0.829 0.658	0.249 0.169	8.04 36.34	1.998 6.144
2	2.10~ 2.43	1.88 1.77	0.460 0.433	0.090 0.080	9.04 10.01	0.811 0.804
3	2.43~ 2.60	1.61 1.55	0.393 0.379	0.067 0.063	5.16 5.41	0.346 0.339
4	2.60~ 3.43	1.22 0.94	0.298 0.230	0.040 0.024	21.44 21.44	0.855 0.524
5	3.43~ 4.09	0.44 0.22	0.108 0.054	0.006 0.001	7.08 0.00	0.040 0.000
						ΣQ = 11.861

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3842\times1.88)\times126.46}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3842^3} = 0.01003 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3842\times1.88)\times126.46}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3842^2}\times(2.60+1.49) = 0.02238 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.86\times(2.60+1.49)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00425 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00035 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.09 m
Horizontal load: P = 2.50
Moment: M = 1.08

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01003 + 0.02238 + 0.00460
= 0.03700 m
= 37.00 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.81 3.11	0.845 0.689	0.256 0.183	9.19 40.67	2.356 7.445
2	2.10～ 2.43	2.30 2.19	0.510 0.485	0.108 0.099	11.89 12.82	1.283 1.266
3	2.43～ 2.60	2.02 1.96	0.448 0.436	0.086 0.081	6.60 6.85	0.565 0.556
4	2.60～ 3.43	1.63 1.35	0.362 0.301	0.058 0.041	28.47 31.60	1.639 1.284
5	3.43～ 4.43	0.74 0.41	0.165 0.091	0.013 0.004	13.22 0.96	0.170 0.004
6	4.43～ 4.51	0.05 0.03	0.012 0.006	0.000 0.000	0.07 0.00	0.000 0.000
						ΣQ = 16.568

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

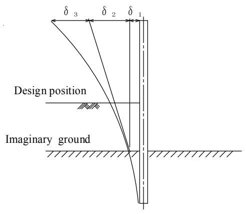
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10～ 2.60	2.24 2.07	0.497 0.460	0.103 0.090	0.00 0.21	0.000 0.019
						ΣQ_{dw} = 0.019

Therefore, modulus of deformation Q is calculated as below
Q = 16.568 + 0.019 = 16.587

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3899\times2.25)\times171.36}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3899^3} = 0.01417 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3899\times2.25)\times171.36}{2\times2.00\times10^8\times95760\times10^{-8}\times0.3899^2}\times(2.60+1.91) = 0.03655 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{16.59\times(2.60+1.91)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00793 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00152 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.51 m
Horizontal load: P = 8.80
Moment: M = 2.29

Displacement δ_m of cantilever beam by moment M_m is additionally considered

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01417 + 0.03655 + 0.00946
= 0.06018 m
= 60.18 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)
	I	=	114000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 114000 × 10^{-8}		=	2.280 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 16683 kN/m^3
Calculated value β = 0.36777 m^{-1}

Penetration length of SSP $D = 1.49 + \frac{3}{0.368} = 9.65$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.65 = 11.85$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 17697 kN/m^3
Calculated value β = 0.37323 m^{-1}

Penetration length of SSP $D = 1.91 + \frac{3}{0.373} = 9.95$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.95 = 12.15$ m

Therefore, whole length of SSP is set as 12.50 m in consideration of round unit of SSP length.

8 Calculation Result

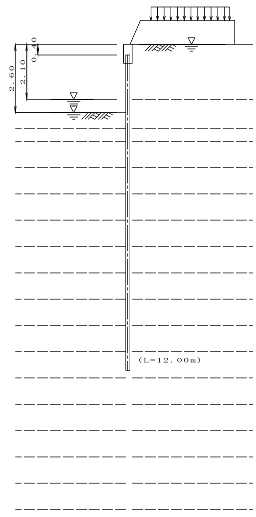
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN·m/m)		294.59	454.56
Stress intensity	σ (N/mm^2)		104 (185)	161 (278)
Lateral displacement	δ (mm)		37.00 (50.0)	60.18 (75.0)
Penetration depth	D (m)		9.65	9.95
Whole length of SSP	L (m)	12.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 22_STA 9+750 - 9+770

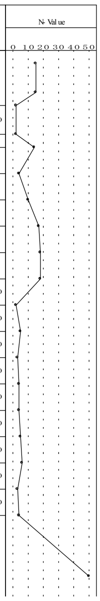
1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
	Sandy Soil	18.0	30.0	0.0
2.10	Clayey Soil	16.0	0.0	12.0
3.19	Sandy Soil	18.0	29.0	0.0
3.69	Sandy Soil	18.0	27.0	0.0
4.69	Sandy Soil	18.0	27.0	0.0
5.69	Sandy Soil	18.0	31.0	0.0
6.69	Sandy Soil	18.0	31.0	0.0
7.69	Sandy Soil	18.0	31.0	0.0
8.69	Clayey Soil	16.0	0.0	12.0
9.69	Clayey Soil	16.0	0.0	25.0
10.69	Clayey Soil	16.0	0.0	18.0
11.69	Clayey Soil	16.0	0.0	24.0
12.69	Clayey Soil	16.0	0.0	24.0
13.69	Clayey Soil	16.0	0.0	25.0
14.69	Clayey Soil	16.0	0.0	25.0
15.69	Clayey Soil	16.0	0.0	18.0
16.69	Clayey Soil	16.0	0.0	24.0
17.69	Sandy Soil	20.0	45.0	0.0

N-Value



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm³

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.5 kNm (Normal Condition)
		Pt'	=	8.8 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.43 m (Normal Condition)
		Ht'	=	-0.26 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.69	2
2	1.60	15	12	10.69	5
3	2.10	2	13	11.69	3
4	3.19	2	14	12.69	4
5	3.69	14	15	13.69	4
6	4.69	4	16	14.69	5
7	5.69	10	17	15.69	6
8	6.69	17	18	16.69	3
9	7.69	18	19	17.69	4
10	8.69	18	20	20.00	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

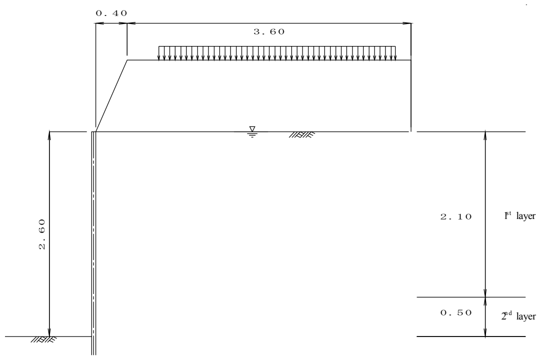
No	Depth (m)	Soil	N-value	γ (kNm³)	γ' (kNm³)	φ	C (kNm²)	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm³)	
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.19	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	3.69	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
4	4.69	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.69	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	6.69	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
7	7.69	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
8	8.69	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
9	9.69	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
10	10.69	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
11	11.69	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
12	12.69	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
13	13.69	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
14	14.69	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
15	15.69	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
16	16.69	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
17	17.69	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
18	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active / passive	10.00° / -10.00°	10.00° / -10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m²)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.40	4.00	4.00	0.91	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.80	3.80	10.0	5.0

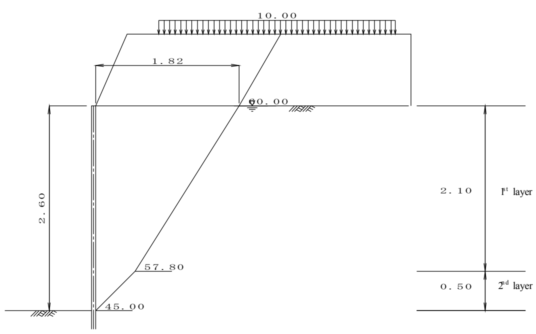
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm²	
Inertia sectional moment	I_0	=	86000 cm⁴	
Sectional factor	Z_0	=	3820 cm³	
Corrosion margin	t_1	=	1.00 mm (riverside)	t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92	
Corrosion rate (to Z_0)	η	=	0.92	
Section efficiency (to I_0)	μ	=	0.80	
Section efficiency (to Z_0)	μ	=	1.00	
Round unit of SSP length			0.50 m	
Allowable stress	σ_a	=	180 N/mm² (Normal)	
	σ_a'	=	270 N/mm² (Seismic)	
Allowable displacement	δ_a	=	50.0 mm (Normal)	
	δ_a'	=	75.0 mm (Seismic)	
Bending of cantilever beam			Calculated as distributed load of each layer	
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction	
			Not Reduced: I_0 applied to calculation of penetration depth	
			Reduced: I_0 applied to calculation of section forces and displacement	
			Reduced: Z_0 applied to calculation of stresses	

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	25.44	25.48	45.00
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.44	20.58	57.80
3		Embankment	30.0	——	0.0	16.38	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where,

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	0.91	1.82	2.60	2.35	3.51

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.72	30.88
Σ			30.88

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.55	15.48
Σ			15.48

Q surcharge load
l : width of surcharge load set by line of active rupture

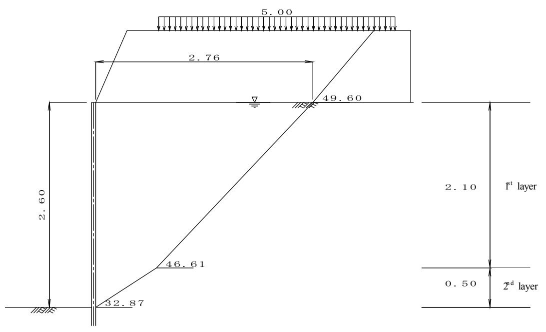
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{30.88 + 15.48 + 0.00}{1.82}$$

$$= 25.44 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	22.44	25.48	0.200	11.31	32.87
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	22.44	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	16.38	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm^3) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm^2)
- C cohesive force of soil (kNm^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	32.87	0.50	0.00	0.00	0.77	0.50
2	46.61	2.10	0.77	0.50	2.76	2.60
3	49.60	0.91	2.76	2.60	3.53	3.51

Therefore, width of acting load shall be set as 2.76 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.68	48.26
Σ			48.26

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.73	13.67
Σ			13.67

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

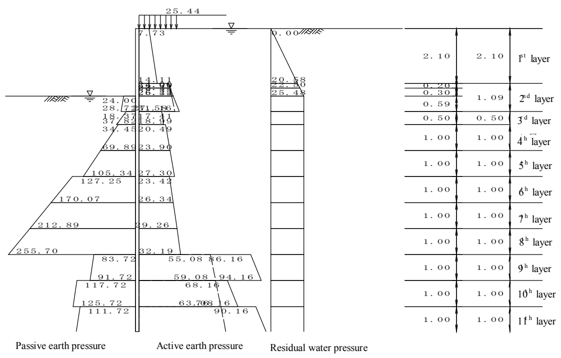
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{48.26 + 13.67 + 0.00}{2.76}$$

$$= 22.44\ kN/m^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Qa (kNm^2)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	25.437 46.437	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.30	Clayey soil	8.0	—	12.0 12.0	46.437 48.000	—— ——	—— ——
3	2.30~ 2.60	Clayey soil	8.0	—	12.0 12.0	48.000 50.437	—— ——	—— ——
4	2.60~ 3.19	Clayey soil	8.0	—	12.0 12.0	50.437 55.157	—— ——	—— ——
5	3.19~ 3.69	Sandy soil	10.0	29.0	—— ——	55.157 60.157	0.32058 0.32058	0.31571 0.31571
6	3.69~ 4.69	Sandy soil	10.0	27.0	—— ——	60.157 70.157	0.34585 0.34585	0.34060 0.34060
7	4.69~ 5.69	Sandy soil	10.0	27.0	—— ——	70.157 80.157	0.34585 0.34585	0.34060 0.34060
8	5.69~ 6.69	Sandy soil	10.0	31.0	—— ——	80.157 90.157	0.29669 0.29669	0.29219 0.29219
9	6.69~ 7.69	Sandy soil	10.0	31.0	—— ——	90.157 100.157	0.29669 0.29669	0.29219 0.29219
10	7.69~ 8.69	Sandy soil	10.0	31.0	—— ——	100.157 110.157	0.29669 0.29669	0.29219 0.29219
11	8.69~ 9.69	Clayey soil	8.0	—	12.0 12.0	110.157 118.157	—— ——	—— ——
12	9.69~ 10.69	Clayey soil	8.0	—	25.0 25.0	118.157 126.157	—— ——	—— ——
13	10.69~ 11.69	Clayey soil	8.0	—	18.0 18.0	126.157 134.157	—— ——	—— ——

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Qa (kNm^2)	Ka	Ka ×cosδ
14	11.69~ 12.69	Clayey soil	8.0	—	24.0 24.0	134.157 142.157	—— ——	—— ——
15	12.69~ 13.69	Clayey soil	8.0	—	24.0 24.0	142.157 150.157	—— ——	—— ——
16	13.69~ 14.69	Clayey soil	8.0	—	25.0 25.0	150.157 158.157	—— ——	—— ——
17	14.69~ 15.69	Clayey soil	8.0	—	25.0 25.0	158.157 166.157	—— ——	—— ——
18	15.69~ 16.69	Clayey soil	8.0	—	18.0 18.0	166.157 174.157	—— ——	—— ——
19	16.69~ 17.69	Clayey soil	8.0	—	24.0 24.0	174.157 182.157	—— ——	—— ——
20	17.69~ 20.00	Clayey soil	10.0	45.0	—— ——	182.157 205.257	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	φ (degree)	C (kNm^2)	Σγh+Qp (kNm^2)	Kp	Kp ×cosδ
4	2.60~ 3.19	Sandy soil	8.0	0.0	12.0 12.0	0.000 4.720	—— ——	—— ——
5	3.19~ 3.69	Sandy soil	10.0	29.0	—— ——	4.720 9.720	3.95096 3.95096	3.89093 3.89093
6	3.69~ 4.69	Sandy soil	10.0	27.0	—— ——	9.720 19.720	3.59892 3.59892	3.54425 3.54425
7	4.69~ 5.69	Clayey soil	10.0	27.0	—— ——	19.720 29.720	3.59892 3.59892	3.54425 3.54425
8	5.69~ 6.69	Clayey soil	10.0	31.0	—— ——	29.720 39.720	4.34774 4.34774	4.28169 4.28169
9	6.69~ 7.69	Sandy soil	10.0	31.0	—— ——	39.720 49.720	4.34774 4.34774	4.28169 4.28169
10	7.69~ 8.69	Sandy soil	10.0	31.0	—— ——	49.720 59.720	4.34774 4.34774	4.28169 4.28169
11	8.69~ 9.69	Clayey soil	8.0	0.0	12.0 12.0	59.720 67.720	—— ——	—— ——
12	9.69~ 10.69	Clayey soil	8.0	0.0	25.0 25.0	67.720 75.720	—— ——	—— ——
13	10.69~ 11.69	Clayey soil	8.0	0.0	18.0 18.0	75.720 83.720	—— ——	—— ——
14	11.69~ 12.69	Clayey soil	8.0	0.0	24.0 24.0	83.720 91.720	—— ——	—— ——
15	12.69~ 13.69	Clayey soil	8.0	0.0	24.0 24.0	91.720 99.720	—— ——	—— ——
16	13.69~ 14.69	Clayey soil	8.0	0.0	25.0 25.0	99.720 107.720	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
17	14.69~ 15.69	Clayey soil	8.0	0.0	25.0 25.0	107.720 115.720	—— ——	—— ——
18	15.69~ 16.69	Clayey soil	8.0	0.0	18.0 18.0	115.720 123.720	—— ——	—— ——
19	16.69~ 17.69	Clayey soil	8.0	0.0	24.0 24.0	123.720 131.720	—— ——	—— ——
20	17.69~ 20.00	Sandy soil	10.0	45.0	—— ——	131.720 154.820	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	7.73 14.11	—— ——	7.73 14.11	0.00 20.58	—— ——
2	2.10~ 2.30	22.44 24.00	23.22 24.00	23.22 24.00	20.58 22.50	—— ——
3	2.30~ 2.60	24.00 26.44	24.00 25.22	24.00 26.44	22.50 25.48	—— ——
4	2.60~ 3.19	26.44 31.16	25.22 27.58	26.44 31.16	25.48 25.48	24.00 28.72
5	3.19~ 3.69	17.41 18.99	—— ——	17.41 18.99	25.48 25.48	18.37 37.82
6	3.69~ 4.69	20.49 23.90	—— ——	20.49 23.90	25.48 25.48	34.45 69.89
7	4.69~ 5.69	23.90 27.30	—— ——	23.90 27.30	25.48 25.48	69.89 105.34
8	5.69~ 6.69	23.42 26.34	—— ——	23.42 26.34	25.48 25.48	127.25 170.07
9	6.69~ 7.69	26.34 29.26	—— ——	26.34 29.26	25.48 25.48	170.07 212.89
10	7.69~ 8.69	29.26 32.19	—— ——	29.26 32.19	25.48 25.48	212.89 255.70
11	8.69~ 9.69	86.16 94.16	55.08 59.08	86.16 94.16	25.48 25.48	83.72 91.72
12	9.69~ 10.69	68.16 76.16	59.08 63.08	68.16 76.16	25.48 25.48	117.72 125.72
13	10.69~ 11.69	90.16 98.16	63.08 67.08	90.16 98.16	25.48 25.48	111.72 119.72
14	11.69~ 12.69	86.16 94.16	67.08 71.08	86.16 94.16	25.48 25.48	131.72 139.72
15	12.69~ 13.69	94.16 102.16	71.08 75.08	94.16 102.16	25.48 25.48	139.72 147.72
16	13.69~ 14.69	100.16 108.16	75.08 79.08	100.16 108.16	25.48 25.48	149.72 157.72
17	14.69~ 15.69	108.16 116.16	79.08 83.08	108.16 116.16	25.48 25.48	157.72 165.72
18	15.69~ 16.69	130.16 138.16	83.08 87.08	130.16 138.16	25.48 25.48	151.72 159.72

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
19	16.69~ 17.69	126.16 134.16	87.08 91.08	126.16 134.16	25.48 25.48	171.72 179.72
20	17.69~ 20.00	29.17 32.87	——	29.17 32.87	25.48 25.48	1212.29 1424.89

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

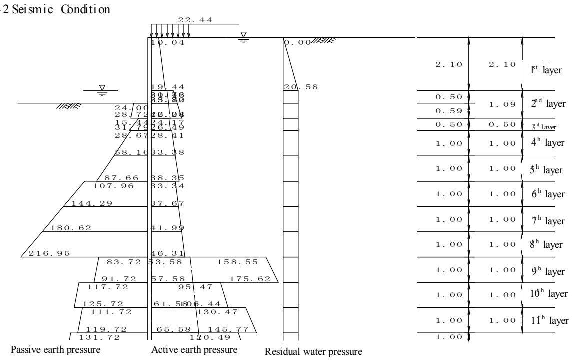
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	22.45 43.45	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Clayey Soil	8.0	—	12.0 12.0	43.45 47.45	20.58 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	33.88 32.87
3	2.60~ 3.19	Clayey Soil	8.0	—	12.0 12.0	47.45 52.17	25.48 31.26	0.200 0.200	11.31 11.31	—— ——	—— ——	32.87 31.59
4	3.19~ 3.69	Sandy Soil	10.0	29.0	—— ——	52.17 57.17	31.26 36.16	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
5	3.69~ 4.69	Sandy Soil	10.0	27.0	—— ——	57.17 67.17	36.16 45.96	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	4.69~ 5.69	Sandy Soil	10.0	27.0	—— ——	67.17 77.17	45.96 55.76	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	5.69~ 6.69	Sandy Soil	10.0	31.0	—— ——	77.17 87.17	55.76 65.56	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
8	6.69~ 7.69	Sandy Soil	10.0	31.0	—— ——	87.17 97.17	65.56 75.36	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
9	7.69~ 8.69	Sandy Soil	10.0	31.0	—— ——	97.17 107.17	75.36 85.16	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
10	8.69~ 9.69	Clayey Soil	8.0	—	12.0 12.0	107.17 115.17	85.16 94.96	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
11	9.69~ 10.69	Clayey Soil	8.0	—	25.0 25.0	115.17 123.17	94.96 104.76	0.200 0.200	11.31 11.31	—— ——	—— ——	33.84 32.87
12	10.69~ 11.69	Clayey Soil	8.0	—	18.0 18.0	123.17 131.17	104.76 114.56	0.200 0.200	11.31 11.31	—— ——	—— ——	23.61 20.95
13	11.69~ 12.69	Clayey Soil	8.0	—	24.0 24.0	131.17 139.17	114.56 124.36	0.200 0.200	11.31 11.31	—— ——	—— ——	30.96 29.75
14	12.69~ 13.69	Clayey Soil	8.0	—	24.0 24.0	139.17 147.17	124.36 134.16	0.200 0.200	11.31 11.31	—— ——	—— ——	29.75 28.44

2.168

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	13.69~ 14.69	Clayey Soil	8.0	—	25.0 25.0	147.17 155.17	134.16 143.96	0.200 0.200	11.31 11.31	—— ——	—— ——	29.56 28.29
16	14.69~ 15.69	Clayey Soil	8.0	—	25.0 25.0	155.17 163.17	143.96 153.76	0.200 0.200	11.31 11.31	—— ——	—— ——	28.29 26.91
17	15.69~ 16.69	Clayey Soil	8.0	—	18.0 18.0	163.17 171.17	153.76 163.56	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
18	16.69~ 17.69	Clayey Soil	8.0	—	24.0 24.0	171.17 179.17	163.56 173.36	0.200 0.200	11.31 11.31	—— ——	—— ——	23.73 21.80
19	17.69~ 20.00	Sandy Soil	10.0	45.0	—— ——	179.17 202.27	173.36 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= $\tan^{-1}$k

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C (kN/m²)	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
3	2.60~ 3.19	Clayey soil	8.00	0.0	12.0 12.0	0.000 4.720	0.00 5.78	0.200 0.200	11.31 11.31	—— ——	—— ——
4	3.19~ 3.69	Sandy soil	10.00	29.0	—— ——	4.720 9.720	5.78 10.68	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
5	3.69~ 4.69	Sandy soil	10.00	27.0	—— ——	9.720 19.720	10.68 20.48	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	4.69~ 5.69	Sandy soil	10.00	27.0	—— ——	19.720 29.720	20.48 30.28	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	5.69~ 6.69	Sandy soil	10.00	31.0	—— ——	29.720 39.720	30.28 40.08	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
8	6.69~ 7.69	Sandy soil	10.00	31.0	—— ——	39.720 49.720	40.08 49.88	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
9	7.69~ 8.69	Sandy Soil	10.00	31.0	—— ——	49.720 59.720	49.88 59.68	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
10	8.69~ 9.69	Clayey soil	8.00	0.0	12.0 12.0	59.720 67.720	59.68 69.48	0.200 0.200	11.31 11.31	—— ——	—— ——
11	9.69~ 10.69	Clayey soil	8.00	0.0	25.0 25.0	67.720 75.720	69.48 79.28	0.200 0.200	11.31 11.31	—— ——	—— ——
12	10.69~ 11.69	Clayey soil	8.00	0.0	18.0 18.0	75.720 83.720	79.28 89.08	0.200 0.200	11.31 11.31	—— ——	—— ——
13	11.69~ 12.69	Clayey soil	8.00	0.0	24.0 24.0	83.720 91.720	89.08 98.88	0.200 0.200	11.31 11.31	—— ——	—— ——
14	12.69~ 13.69	Clayey soil	8.00	0.0	24.0 24.0	91.720 99.720	98.88 108.68	0.200 0.200	11.31 11.31	—— ——	—— ——
15	13.69~ 14.69	Clayey soil	8.00	0.0	25.0 25.0	99.720 107.720	108.68 118.48	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
16	14.69~ 15.69	Clayey soil	8.00	0.0	25.0 25.0	107.720 115.720	118.48 128.28	0.200 0.200	11.31 11.31	—— ——	—— ——
17	15.69~ 16.69	Clayey soil	8.00	0.0	18.0 18.0	115.720 123.720	128.28 138.08	0.200 0.200	11.31 11.31	—— ——	—— ——
18	16.69~ 17.69	Clayey soil	8.00	0.0	24.0 24.0	123.720 131.720	138.08 147.88	0.200 0.200	11.31 11.31	—— ——	—— ——
19	17.69~ 20.00	Sandy soil	10.00	45.0	—— ——	131.720 154.820	147.88 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	10.04 19.44	—— ——	10.04 19.44	0.00 20.58	—— ——
2	2.10~ 2.60	30.46 35.80	21.72 23.72	30.46 35.80	20.58 20.58	—— ——
3	2.60~ 3.19	35.80 42.24	23.72 26.08	35.80 42.24	20.58 20.58	24.00 28.72
4	3.19~ 3.69	24.17 26.49	—— ——	24.17 26.49	20.58 20.58	15.44 31.79
5	3.69~ 4.69	28.41 33.38	—— ——	28.41 33.38	20.58 20.58	28.67 58.16
6	4.69~ 5.69	33.38 38.35	—— ——	33.38 38.35	20.58 20.58	58.16 87.66
7	5.69~ 6.69	33.34 37.67	—— ——	33.34 37.67	20.58 20.58	107.96 144.29
8	6.69~ 7.69	37.67 41.99	—— ——	37.67 41.99	20.58 20.58	144.29 180.62
9	7.69~ 8.69	41.99 46.31	—— ——	41.99 46.31	20.58 20.58	180.62 216.95
10	8.69~ 9.69	158.55 175.62	53.58 57.58	158.55 175.62	20.58 20.58	83.72 91.72
11	9.69~ 10.69	95.47 106.44	57.58 61.58	95.47 106.44	20.58 20.58	117.72 125.72
12	10.69~ 11.69	130.47 145.77	61.58 65.58	130.47 145.77	20.58 20.58	111.72 119.72
13	11.69~ 12.69	120.49 132.16	65.58 69.58	120.49 132.16	20.58 20.58	131.72 139.72
14	12.69~ 13.69	132.16 144.20	69.58 73.58	132.16 144.20	20.58 20.58	139.72 147.72
15	13.69~ 14.69	140.81 152.92	73.58 77.58	140.81 152.92	20.58 20.58	149.72 157.72

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
16	14.69~ 15.69	152.92 165.52	77.58 81.58	152.92 165.52	20.58 20.58	157.72 165.72
17	15.69~ 16.69	242.98 260.05	81.58 85.58	242.98 260.05	20.58 20.58	151.72 159.72
18	16.69~ 17.69	183.89 199.15	85.58 89.58	183.89 199.15	20.58 20.58	171.72 179.72
19	17.69~ 20.00	46.36 52.33	—— ——	46.36 52.33	20.58 20.58	1080.56 1270.06

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

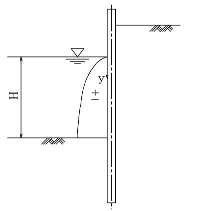
Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

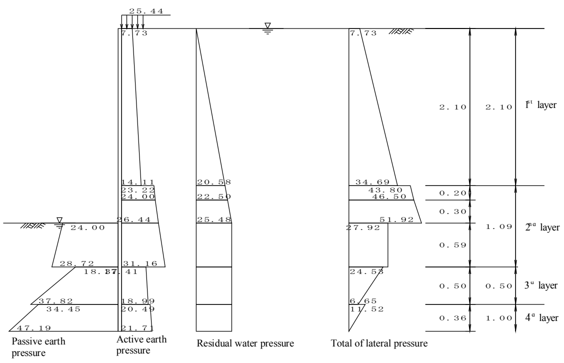
Where,
k_{hs} : design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level l_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

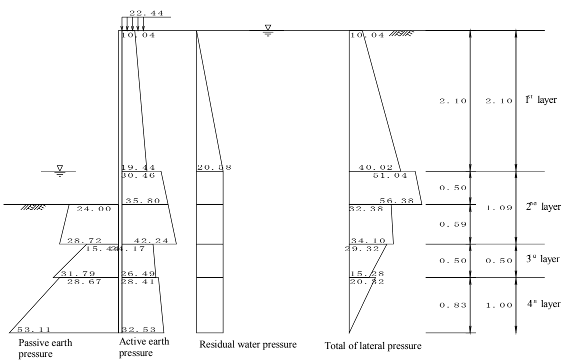


	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	7.73 14.11	0.00 20.58	—— ——	7.73 34.69
2	2.10~ 2.30	23.22 24.00	20.58 22.50	—— ——	43.80 46.50
3	2.30~ 2.60	24.00 26.44	22.50 25.48	—— ——	46.50 51.92
4	2.60~ 3.19	26.44 31.16	25.48 25.48	24.00 28.72	27.92 27.92
5	3.19~ 3.69	17.41 18.99	25.48 25.48	18.37 37.82	24.53 6.65
6	3.69~ 4.05	20.49 21.71	25.48 25.48	34.45 47.19	11.52 0.00
7	4.05~ 4.69	21.71 23.90	25.48 25.48	47.19 69.89	0.00 -20.52

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.45 m (GL -4.05 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	10.04 19.44	0.00 20.58	—— ——	10.04 40.02
2	2.10~ 2.60	30.46 35.80	20.58 20.58	—— ——	51.04 56.38
3	2.60~ 3.19	35.80 42.24	20.58 20.58	24.00 28.72	32.38 34.10
4	3.19~ 3.69	24.17 26.49	20.58 20.58	15.44 31.79	29.32 15.28
5	3.69~ 4.52	28.41 32.53	20.58 20.58	28.67 53.11	20.32 0.00
6	4.52~ 4.69	32.53 33.38	20.58 20.58	53.11 58.16	0.00 -4.21

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.92 m (GL -4.52 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 x 10^3 x 63296 x 10^{-8} = 1.266×10^5

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	9.69	2
2	1.60	15	12	10.69	5
3	2.10	2	13	11.69	3
4	3.19	2	14	12.69	4
5	3.69	14	15	13.69	4
6	4.69	4	16	14.69	5
7	5.69	10	17	15.69	6
8	6.69	17	18	16.69	3
9	7.69	18	19	17.69	4
10	8.69	18	20	20.00	50

5-2 Normal Condition

K_h = 16637 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.426 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.35 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.05 m) to 2.35 m depth (GL -6.40 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.05	0.64	10.4	4.0	4.61
2	4.69	1.00	4.0	10.0	7.00
3	5.69	0.71	10.0	15.0	8.84
L = Σh = 2.35					ΣA = 20.45

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{20.45}{2.35} = 8.71$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 8.71^{0.406} = 16637 \text{ kN/m}^3$$

Kh (normal condition) = 16637 kNm^3

5-3 Seismic Condition

K_h = 17782 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.433 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.31 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.52 m) to 2.31 m depth (GL -6.83 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.52	0.17	5.7	4.0	0.83
2	4.69	1.00	4.0	10.0	7.00
3	5.69	1.00	10.0	17.0	13.50
4	6.69	0.14	17.0	17.1	2.36
L = Σh = 2.31					ΣA = 23.70

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{23.70}{2.31} = 10.26$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 10.26^{0.406} = 17782 \text{ kN/m}^3$$

Kh (seismic condition) = 17782 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.73 34.69	8.11 36.42	3.35 2.65	27.18 96.50
2	2.10~ 2.30	0.20	43.80 46.50	4.28 4.54	1.88 1.82	8.06 8.27
3	2.30~ 2.60	0.30	46.50 51.92	7.08 7.91	1.65 1.55	11.70 12.26
4	2.60~ 3.19	0.59	27.92 27.92	8.24 8.24	1.25 1.06	10.32 8.70
5	3.19~ 3.69	0.50	24.53 6.65	6.13 1.66	0.69 0.53	4.25 0.88
6	3.69~ 4.05	0.36	11.52 0.00	2.07 0.00	0.24 0.12	0.50 0.00
				ΣP = 94.68		ΣM = 188.61

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.5 kNm
depth to acting position	H_t	=	-0.43 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.45 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 11.20 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{199.81}{97.18} = 2.06 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.04 40.02	10.55 42.02	3.82 3.12	40.27 131.05
2	2.10~ 2.60	0.50	51.04 56.38	12.76 14.10	2.25 2.09	28.73 29.39
3	2.60~ 3.19	0.59	32.38 34.10	9.55 10.06	1.72 1.53	16.45 15.34
4	3.19~ 3.69	0.50	29.32 15.28	7.33 3.82	1.16 1.00	8.51 3.80

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
5	3.69~ 4.52	0.83	20.32 0.00	8.42 0.00	0.55 0.28	4.65 0.00
				ΣP = 118.60		ΣM = 278.20

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.8 kNm
depth to acting position	H_t	=	-0.26 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.92 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 42.05 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.25 2.09	0.00 0.45
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.45

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{320.70}{127.62} = 2.51 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 63296 x 10^{-8}		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	16637 kN/m^3
calculated value	β	=	0.42575 m^{-1}
resultant earth force (lateral)	P_0	=	97.18 kN/m
height of acting position of load	h_0	=	2.06 m
moment	M_0	=	199.81 kN·m/m

in consideration of ψ_m = 1.180,

maximum moment	M_{max}	=	235.70 kN·m/m
depth of generated position of M_{max}	l_m	=	0.819 m
depth of 1st fixed point	l_i	=	2.664 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	17782 kN/m^3
calculated value	β	=	0.43289 m^{-1}
resultant earth force (lateral)	P_0	=	127.62 kN/m
height of acting position of load	h_0	=	2.51 m
moment	M_0	=	320.70 kN·m/m

in consideration of ψ_m = 1.128,

maximum moment	M_{max}	=	361.73 kN·m/m
depth of generated position of M_{max}	l_m	=	0.705 m
depth of 1st fixed point	l_i	=	2.519 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{235.70\times10^6}{3514\times10^3} = 67\ \text{N/mm}^2 \leqq \sigma_a = 180\ \text{N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{361.73\times10^6}{3514\times10^3} = 103\ \text{N/mm}^2 \leqq \sigma_a = 270\ \text{N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.35 2.65	0.827 0.654	0.248 0.167	8.11 36.42	2.010 6.095
2	2.10~ 2.30	1.88 1.82	0.465 0.449	0.091 0.086	4.28 4.54	0.391 0.390
3	2.30~ 2.60	1.65 1.55	0.408 0.383	0.072 0.064	7.08 7.91	0.509 0.506
4	2.60~ 3.19	1.25 1.06	0.309 0.261	0.043 0.031	8.24 8.24	0.354 0.256
5	3.19~ 3.69	0.69 0.53	0.171 0.130	0.014 0.008	6.13 1.66	0.085 0.013
6	3.69~ 4.05	0.24 0.12	0.059 0.030	0.002 0.000	2.07 0.00	0.004 0.000
						ΣQ = 10.613

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

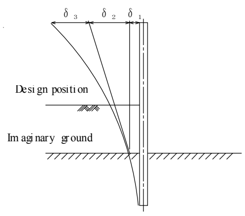
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4258\times2.06)\times97.18}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4258^3} = 0.00933\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.4258\times2.06)\times97.18}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4258^2} \times (2.60+1.45) = 0.02359\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.61\times(2.60+1.45)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00557\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00051 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.05 m

Horizontal load: P = 2.50

Moment: M = 1.08

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.00933 + 0.02359 + 0.00607

= 0.03899 m

= 38.99 ≦ δa = 50.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.82 3.12	0.845 0.690	0.256 0.183	10.55 42.02	2.705 7.706
2	2.10~ 2.60	2.25 2.09	0.498 0.461	0.104 0.090	12.76 14.10	1.321 1.270
3	2.60~ 3.19	1.72 1.53	0.381 0.338	0.063 0.051	9.55 10.06	0.606 0.509
4	3.19~ 3.69	1.16 1.00	0.257 0.220	0.030 0.022	7.33 3.82	0.222 0.086
5	3.69~ 4.52	0.55 0.28	0.122 0.061	0.007 0.002	8.42 0.00	0.060 0.000
						ΣQ = 14.484

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

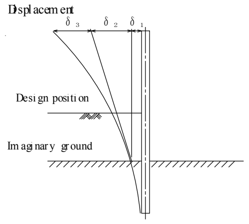
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.25 2.09	0.498 0.461	0.104 0.090	0.00 0.21	0.000 0.019
						ΣQ_{dw} = 0.019

Therefore, modulus of deformation Q is calculated as below.

Q = 14.484 + 0.019 = 14.503



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4329\times 2.51)\times 127.62}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4329^3} = 0.01297 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4329\times 2.51)\times 127.62}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4329^2}\times(2.60+1.92) = 0.03860 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{14.50\times(2.60+1.92)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.01057 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00232 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.52 m
Horizontal load: P = 8.80
Moment: M = 2.29

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01297 + 0.03860 + 0.01289$
$= 0.06446$ m
$= 64.46 \leqq \delta_a = 75.00$ mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 86000 x 10^{-8}		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 16637$ kN/m^3
Calculated value $\beta = 0.39434$ m^{-1}

Penetration length of SSP $D = 1.45 + \frac{3}{0.394} = 9.06$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.06 = 11.26$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 17782$ kN/m^3
Calculated value $\beta = 0.40096$ m^{-1}

Penetration length of SSP $D = 1.92 + \frac{3}{0.401} = 9.40$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.40 = 11.60$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

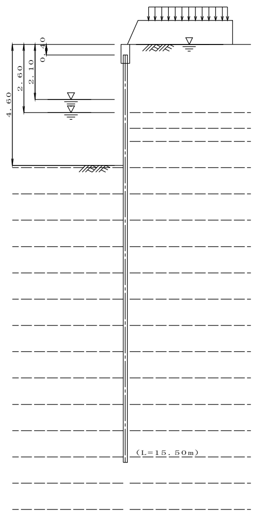
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		235.70	361.73
Stress intensity	σ (Nmm^2)		67 (180)	103 (270)
Lateral displacement	δ (mm)		38.99 (50.0)	64.46 (75.0)
Penetration depth	D (m)		9.06	9.40
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 23_STA 9+770 - 9+830

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)	N-Value
0 – 2.60	Sandy Soil	18.0	30.0	0.0	
2.60 – 3.19	Clayey Soil	16.0	0.0	12.0	
3.19 – 3.69	Sandy Soil	18.0	29.0	0.0	
3.69 – 4.69	Sandy Soil	18.0	27.0	0.0	
4.69 – 5.69	Sandy Soil	18.0	27.0	0.0	
5.69 – 6.69	Sandy Soil	18.0	31.0	0.0	
6.69 – 7.69	Sandy Soil	18.0	31.0	0.0	
7.69 – 8.69	Sandy Soil	18.0	31.0	0.0	
8.69 – 9.69	Clayey Soil	16.0	0.0	12.0	
9.69 – 10.69	Clayey Soil	16.0	0.0	25.0	
10.69 – 11.69	Clayey Soil	16.0	0.0	18.0	
11.69 – 12.69	Clayey Soil	16.0	0.0	24.0	
12.69 – 13.69	Clayey Soil	16.0	0.0	24.0	
13.69 – 14.69	Clayey Soil	16.0	0.0	25.0	
14.69 – 15.69	Clayey Soil	16.0	0.0	25.0	
15.69 – 16.69	Clayey Soil	16.0	0.0	18.0	
16.69 – 17.69	Clayey Soil	16.0	0.0	24.0	
17.69 –	Sandy Soil	20.0	45.0	0.0	

N-Value axis: 0 10 20 30 40 50

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	4.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8$ kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.5 kNm (Normal Condition)
		Pt'	=	8.8 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.43 m (Normal Condition)
		Ht'	=	-0.26 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression $K_e = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.69	2	21	20.00	50
2	1.60	15	12	10.69	5			
3	2.10	2	13	11.69	3			
4	3.19	2	14	12.69	4			
5	3.69	14	15	13.69	4			
6	4.69	4	16	14.69	5			
7	5.69	10	17	15.69	6			
8	6.69	17	18	16.69	3			
9	7.69	18	19	17.69	4			
10	8.69	18	20	18.00	50			

2.173

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

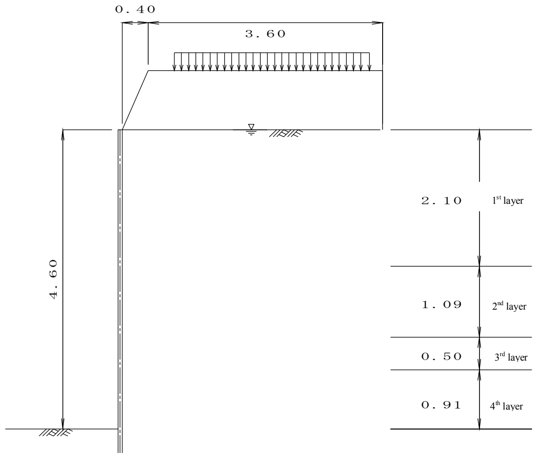
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	φ	C (kNm^2)	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3)	
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.19	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	3.69	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
4	4.69	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.69	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	6.69	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
7	7.69	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
8	8.69	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
9	9.69	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
10	10.69	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
11	11.69	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
12	12.69	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
13	13.69	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
14	14.69	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
15	15.69	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
16	16.69	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
17	17.69	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	——	——
18	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.40	4.00	4.00	0.91	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.80	3.80	10.0	5.0

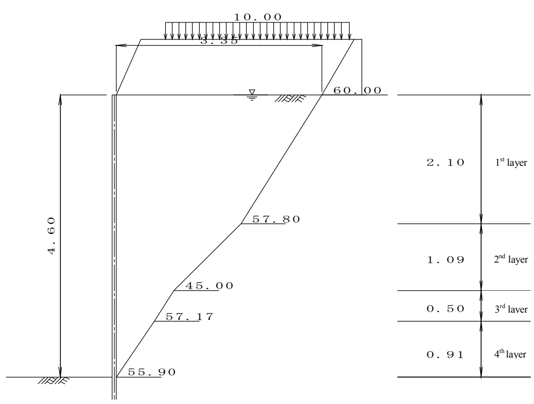
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	295000 cm^4
Sectional factor	Z_0	=	6640 cm^3
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.87
Corrosion rate (to Z_0)	η	=	0.89
Section efficiency (to I_0)	μ	=	1.00
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	185 Nmm^2 (Normal)
	σ_a'	=	278 Nmm^2 (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	4.60~ 3.69	Sandy Soil	27.0	10.0	0.0	43.82	25.64	45.08	55.90
2	3.69~ 3.19	Sandy Soil	29.0	10.0	0.0	34.72	25.64	36.16	57.17
3	3.19~ 2.10	Clayey Soil	0.0	10.0	12.0	29.72	25.64	31.26	45.00
4	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.64	20.58	57.80
5		Embankment	30.0	——	0.0	16.38	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where.

ζ : angle of active rupture (degree, ζ ≥ 10.00°)

ϕ : internal friction angle (degree)

δ : wall friction angle (degree)

θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$

γ : unit weight of soil (kNm^3) (ascending force considered under WL)

h : thickness of layer (m)

Q : surcharge load (kNm^2)

C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.91	0.00	0.00	0.62	0.91
2	57.17	0.50	0.62	0.91	0.94	1.41
3	45.00	0.59	0.94	1.41	1.53	2.00
4	57.80	2.60	1.53	2.00	3.17	4.60
5	60.00	0.91	3.17	4.60	3.69	5.51

Therefore, width of acting load shall be set as 3.17 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.94	52.89
Σ			52.89

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

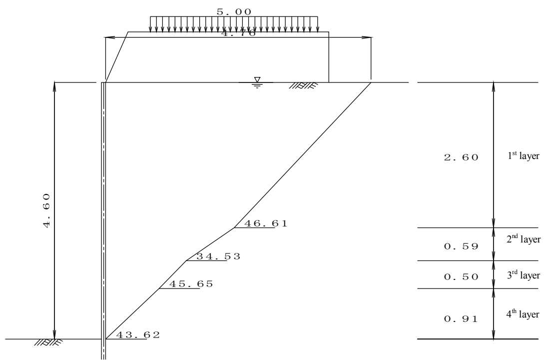
No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	2.89	28.91
Σ			28.91

Q surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L} = \frac{52.89 + 28.91 + 0.00}{3.17} = 25.84 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	4.60~ 3.69	Sandy Soil	27.0	10.0	0.0	43.82	15.51	45.08	0.200	11.31	43.62
2	3.69~ 3.19	Sandy Soil	29.0	10.0	0.0	34.72	15.51	36.16	0.200	11.31	45.65
3	3.19~ 2.10	Clayey Soil	0.0	10.0	12.0	29.72	15.51	31.26	0.200	11.31	35.10
4	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	15.51	20.58	0.200	11.31	46.61

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.62	0.91	0.00	0.00	0.95	0.91
2	45.65	0.50	0.95	0.91	1.44	1.41
3	35.10	1.09	1.44	1.41	2.99	2.50
4	46.61	2.10	2.99	2.50	4.98	4.60

Therefore, width of acting load shall be set as 4.76 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.46	62.24
Σ			62.24

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.00	15.00
Σ			15.00

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

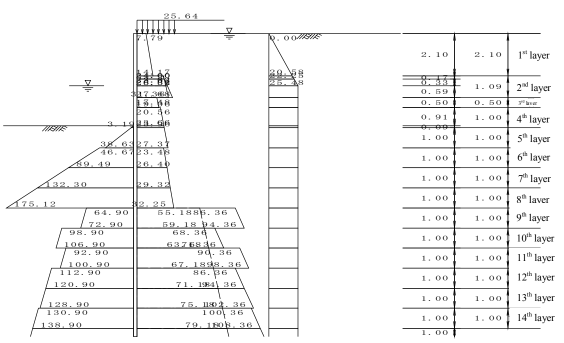
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{62.24 + 15.00 + 0.00}{4.76}$$

$$= 16.23\ \text{kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



Passive earth pressure Active earth pressure Residual water pressure

3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	25.639 46.639	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.27	Clayey soil	8.0	—	12.0 12.0	46.639 48.000	—— ——	—— ——
3	2.27~ 2.60	Clayey soil	8.0	—	12.0 12.0	48.000 50.639	—— ——	—— ——
4	2.60~ 3.19	Clayey soil	8.0	—	12.0 12.0	50.639 55.359	—— ——	—— ——
5	3.19~ 3.69	Sandy soil	10.0	29.0	—— ——	55.359 60.359	0.32058 0.32058	0.31571 0.31571
6	3.69~ 4.60	Sandy soil	10.0	27.0	—— ——	60.359 69.459	0.34585 0.34585	0.34060 0.34060
7	4.60~ 4.69	Sandy soil	10.0	27.0	—— ——	69.459 70.359	0.34585 0.34585	0.34060 0.34060
8	4.69~ 5.69	Sandy soil	10.0	27.0	—— ——	70.359 80.359	0.34585 0.34585	0.34060 0.34060
9	5.69~ 6.69	Sandy soil	10.0	31.0	—— ——	80.359 90.359	0.29669 0.29669	0.29219 0.29219
10	6.69~ 7.69	Sandy soil	10.0	31.0	—— ——	90.359 100.359	0.29669 0.29669	0.29219 0.29219
11	7.69~ 8.69	Sandy soil	10.0	31.0	—— ——	100.359 110.359	0.29669 0.29669	0.29219 0.29219
12	8.69~ 9.69	Clayey soil	8.0	—	12.0 12.0	110.359 118.359	—— ——	—— ——
13	9.69~ 10.69	Clayey soil	8.0	—	25.0 25.0	118.359 126.359	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	10.69~ 11.69	Clayey soil	8.0	—	18.0 18.0	126.359 134.359	—— ——	—— ——
15	11.69~ 12.69	Clayey soil	8.0	—	24.0 24.0	134.359 142.359	—— ——	—— ——
16	12.69~ 13.69	Clayey soil	8.0	—	24.0 24.0	142.359 150.359	—— ——	—— ——
17	13.69~ 14.69	Clayey soil	8.0	—	25.0 25.0	150.359 158.359	—— ——	—— ——
18	14.69~ 15.69	Clayey soil	8.0	—	25.0 25.0	158.359 166.359	—— ——	—— ——
19	15.69~ 16.69	Clayey soil	8.0	—	18.0 18.0	166.359 174.359	—— ——	—— ——
20	16.69~ 17.69	Clayey soil	8.0	—	24.0 24.0	174.359 182.359	—— ——	—— ——
21	17.69~ 20.00	Sandy soil	10.0	45.0	—— ——	182.359 205.459	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
7	4.60~ 4.69	Sandy soil	10.0	27.0	—— ——	0.000 0.900	3.59892 3.59892	3.54425 3.54425
8	4.69~ 5.69	Sandy soil	10.0	27.0	—— ——	0.900 10.900	3.59892 3.59892	3.54425 3.54425
9	5.69~ 6.69	Sandy soil	10.0	31.0	—— ——	10.900 20.900	4.34774 4.34774	4.28169 4.28169
10	6.69~ 7.69	Sandy soil	10.0	31.0	—— ——	20.900 30.900	4.34774 4.34774	4.28169 4.28169
11	7.69~ 8.69	Sandy soil	10.0	31.0	—— ——	30.900 40.900	4.34774 4.34774	4.28169 4.28169
12	8.69~ 9.69	Clayey soil	8.0	0.0	12.0 12.0	40.900 48.900	—— ——	—— ——
13	9.69~ 10.69	Clayey soil	8.0	0.0	25.0 25.0	48.900 56.900	—— ——	—— ——
14	10.69~ 11.69	Clayey soil	8.0	0.0	18.0 18.0	56.900 64.900	—— ——	—— ——
15	11.69~ 12.69	Clayey soil	8.0	0.0	24.0 24.0	64.900 72.900	—— ——	—— ——
16	12.69~ 13.69	Clayey soil	8.0	0.0	24.0 24.0	72.900 80.900	—— ——	—— ——
17	13.69~ 14.69	Clayey soil	8.0	0.0	25.0 25.0	80.900 88.900	—— ——	—— ——
18	14.69~ 15.69	Clayey soil	8.0	0.0	25.0 25.0	88.900 96.900	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
19	15.69~ 16.69	Clayey soil	8.0	0.0	18.0 18.0	96.900 104.900	—— ——	—— ——
20	16.69~ 17.69	Clayey soil	8.0	0.0	24.0 24.0	104.900 112.900	—— ——	—— ——
21	17.69~ 20.00	Sandy soil	10.0	45.0	—— ——	112.900 136.000	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.79 14.17	—— ——	7.79 14.17	0.00 20.58	—— ——
2	2.10~ 2.27	22.64 24.00	23.32 24.00	23.32 24.00	20.58 22.25	—— ——
3	2.27~ 2.60	24.00 26.64	24.00 25.32	24.00 26.64	22.25 25.48	—— ——
4	2.60~ 3.19	26.64 31.36	25.32 27.68	26.64 31.36	25.48 25.48	—— ——
5	3.19~ 3.69	17.48 19.06	—— ——	17.48 19.06	25.48 25.48	—— ——
6	3.69~ 4.60	20.56 23.66	—— ——	20.56 23.66	25.48 25.48	—— ——
7	4.60~ 4.69	23.66 23.96	—— ——	23.66 23.96	25.48 25.48	0.00 3.19
8	4.69~ 5.69	23.96 27.37	—— ——	23.96 27.37	25.48 25.48	3.19 38.63
9	5.69~ 6.69	23.48 26.40	—— ——	23.48 26.40	25.48 25.48	46.67 89.49
10	6.69~ 7.69	26.40 29.32	—— ——	26.40 29.32	25.48 25.48	89.49 132.30
11	7.69~ 8.69	29.32 32.25	—— ——	29.32 32.25	25.48 25.48	132.30 175.12
12	8.69~ 9.69	86.36 94.36	55.18 59.18	86.36 94.36	25.48 25.48	64.90 72.90
13	9.69~ 10.69	68.36 76.36	59.18 63.18	68.36 76.36	25.48 25.48	98.90 106.90
14	10.69~ 11.69	90.36 98.36	63.18 67.18	90.36 98.36	25.48 25.48	92.90 100.90
15	11.69~ 12.69	86.36 94.36	67.18 71.18	86.36 94.36	25.48 25.48	112.90 120.90
16	12.69~ 13.69	94.36 102.36	71.18 75.18	94.36 102.36	25.48 25.48	120.90 128.90
17	13.69~ 14.69	100.36 108.36	75.18 79.18	100.36 108.36	25.48 25.48	130.90 138.90

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
18	14.69~ 15.69	108.36 116.36	79.18 83.18	108.36 116.36	25.48 25.48	138.90 146.90
19	15.69~ 16.69	130.36 138.36	83.18 87.18	130.36 138.36	25.48 25.48	132.90 140.90
20	16.69~ 17.69	126.36 134.36	87.18 91.18	126.36 134.36	25.48 25.48	152.90 160.90
21	17.69~ 20.00	29.21 32.90	—— ——	29.21 32.90	25.48 25.48	1039.08 1251.68

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$
$P_{a2}=K_c \cdot (\Sigma\gamma h+Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

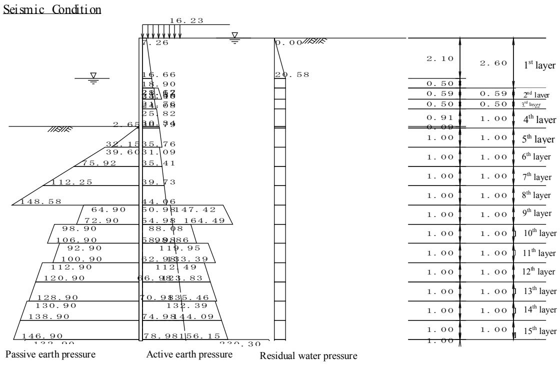
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	16.23 37.23	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Sandy Soil	10.0	30.0	—— ——	37.23 42.23	20.58 25.48	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
3	2.60~ 3.19	Clayey Soil	8.0	—	12.0 12.0	42.23 46.95	25.48 31.26	0.200 0.200	11.31 11.31	—— ——	—— ——	35.61 34.53
4	3.19~ 3.69	Sandy Soil	10.0	29.0	—— ——	46.95 51.95	31.26 36.16	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
5	3.69~ 4.60	Sandy Soil	10.0	27.0	—— ——	51.95 61.05	36.16 45.08	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	4.60~ 4.69	Sandy Soil	10.0	27.0	—— ——	61.05 61.95	45.08 45.96	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	4.69~ 5.69	Sandy Soil	10.0	27.0	—— ——	61.95 71.95	45.96 55.76	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
8	5.69~ 6.69	Sandy Soil	10.0	31.0	—— ——	71.95 81.95	55.76 65.56	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
9	6.69~ 7.69	Sandy Soil	10.0	31.0	—— ——	81.95 91.95	65.56 75.36	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
10	7.69~ 8.69	Sandy Soil	10.0	31.0	—— ——	91.95 101.95	75.36 85.16	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
11	8.69~ 9.69	Clayey Soil	8.0	—	12.0 12.0	101.95 109.95	85.16 94.96	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
12	9.69~ 10.69	Clayey Soil	8.0	—	25.0 25.0	109.95 117.95	94.96 104.76	0.200 0.200	11.31 11.31	—— ——	—— ——	35.14 34.24

2.176

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
13	10.69~ 11.69	Clayey Soil	8.0	—	18.0 18.0	117.95 125.95	104.76 114.56	0.200 0.200	11.31 11.31	—— ——	—— ——	26.77 24.63
14	11.69~ 12.69	Clayey Soil	8.0	—	24.0 24.0	125.95 133.95	114.56 124.36	0.200 0.200	11.31 11.31	—— ——	—— ——	32.55 31.46
15	12.69~ 13.69	Clayey Soil	8.0	—	24.0 24.0	133.95 141.95	124.36 134.16	0.200 0.200	11.31 11.31	—— ——	—— ——	31.46 30.28
16	13.69~ 14.69	Clayey Soil	8.0	—	25.0 25.0	141.95 149.95	134.16 143.96	0.200 0.200	11.31 11.31	—— ——	—— ——	31.22 30.07
17	14.69~ 15.69	Clayey Soil	8.0	—	25.0 25.0	149.95 157.95	143.96 153.76	0.200 0.200	11.31 11.31	—— ——	—— ——	30.07 28.84
18	15.69~ 16.69	Clayey Soil	8.0	—	18.0 18.0	157.95 165.95	153.76 163.56	0.200 0.200	11.31 11.31	—— ——	—— ——	10.19 10.00
19	16.69~ 17.69	Sandy Soil	8.0	—	24.0 24.0	165.95 173.95	163.56 173.36	0.200 0.200	11.31 11.31	—— ——	—— ——	26.14 24.49
20	17.69~ 20.00	Sandy Soil	10.0	45.0	—— ——	173.95 197.05	173.36 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
6	4.60~ 4.69	砂質土	10.00	27.0	—— ——	0.000 0.900	0.00 0.88	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	4.69~ 5.69	砂質土	10.00	27.0	—— ——	0.900 10.900	0.88 10.68	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
8	5.69~ 6.69	砂質土	10.00	31.0	—— ——	10.900 20.900	10.68 20.48	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
9	6.69~ 7.69	砂質土	10.00	31.0	—— ——	20.900 30.900	20.48 30.28	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
10	7.69~ 8.69	砂質土	10.00	31.0	—— ——	30.900 40.900	30.28 40.08	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
11	8.69~ 9.69	粘性土	8.00	0.0	12.0 12.0	40.900 48.900	40.08 49.88	0.200 0.200	11.31 11.31	—— ——	—— ——
12	9.69~ 10.69	粘性土	8.00	0.0	25.0 25.0	48.900 56.900	49.88 59.68	0.200 0.200	11.31 11.31	—— ——	—— ——
13	10.69~ 11.69	粘性土	8.00	0.0	18.0 18.0	56.900 64.900	59.68 69.48	0.200 0.200	11.31 11.31	—— ——	—— ——

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
14	11.69~ 12.69	粘性土	8.00	0.0	24.0 24.0	64.900 72.900	69.48 79.28	0.200 0.200	11.31 11.31	—— ——	—— ——
15	12.69~ 13.69	粘性土	8.00	0.0	24.0 24.0	72.900 80.900	79.28 89.08	0.200 0.200	11.31 11.31	—— ——	—— ——
16	13.69~ 14.69	粘性土	8.00	0.0	25.0 25.0	80.900 88.900	89.08 98.88	0.200 0.200	11.31 11.31	—— ——	—— ——
17	14.69~ 15.69	粘性土	8.00	0.0	25.0 25.0	88.900 96.900	98.88 108.68	0.200 0.200	11.31 11.31	—— ——	—— ——
18	15.69~ 16.69	粘性土	8.00	0.0	18.0 18.0	96.900 104.900	108.68 118.48	0.200 0.200	11.31 11.31	—— ——	—— ——
19	16.69~ 17.69	粘性土	8.00	0.0	24.0 24.0	104.900 112.900	118.48 128.28	0.200 0.200	11.31 11.31	—— ——	—— ——
20	17.69~ 20.00	砂質土	10.00	45.0	—— ——	112.900 136.000	128.28 150.92	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.
$\delta = -10.00$, $\beta = 0.00$, $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kN/m²)	Pa2 (kN/m²)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)
1	0.00~ 2.10	7.26 16.66	—— ——	7.26 16.66	0.00 20.58	—— ——
2	2.10~ 2.60	16.66 18.90	—— ——	16.66 18.90	20.58 20.58	—— ——
3	2.60~ 3.19	28.67 34.90	21.12 23.48	28.67 34.90	20.58 20.58	—— ——
4	3.19~ 3.69	21.76 24.08	—— ——	21.76 24.08	20.58 20.58	—— ——
5	3.69~ 4.60	25.82 30.34	—— ——	25.82 30.34	20.58 20.58	—— ——
6	4.60~ 4.69	30.34 30.79	—— ——	30.34 30.79	20.58 20.58	0.00 2.65
7	4.69~ 5.69	30.79 35.76	—— ——	30.79 35.76	20.58 20.58	2.65 32.15
8	5.69~ 6.69	31.09 35.41	—— ——	31.09 35.41	20.58 20.58	39.60 75.92
9	6.69~ 7.69	35.41 39.73	—— ——	35.41 39.73	20.58 20.58	75.92 112.25
10	7.69~ 8.69	39.73 44.06	—— ——	39.73 44.06	20.58 20.58	112.25 148.58

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
11	8.69~ 9.69	147.42 164.49	50.98 54.98	147.42 164.49	20.58 20.58	64.90 72.90
12	9.69~ 10.69	88.08 98.86	54.98 58.98	88.08 98.86	20.58 20.58	98.90 106.90
13	10.69~ 11.69	119.95 133.39	58.98 62.98	119.95 133.39	20.58 20.58	92.90 100.90
14	11.69~ 12.69	112.49 123.83	62.98 66.98	112.49 123.83	20.58 20.58	112.90 120.90
15	12.69~ 13.69	123.83 135.46	66.98 70.98	123.83 135.46	20.58 20.58	120.90 128.90
16	13.69~ 14.69	132.39 144.09	70.98 74.98	132.39 144.09	20.58 20.58	130.90 138.90
17	14.69~ 15.69	144.09 156.15	74.98 78.98	144.09 156.15	20.58 20.58	138.90 146.90
18	15.69~ 16.69	230.30 248.92	78.98 82.98	230.30 248.92	20.58 20.58	132.90 140.90
19	16.69~ 17.69	172.89 186.70	82.98 86.98	172.89 186.70	20.58 20.58	152.90 160.90
20	17.69~ 20.00	45.01 50.98	—— ——	45.01 50.98	20.58 20.58	926.17 1115.67

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

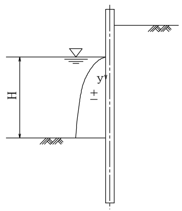
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.10	0.00	0.00
2	3.10	1.00	2.71
3	4.10	2.00	3.83
4	4.60	2.50	4.29

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

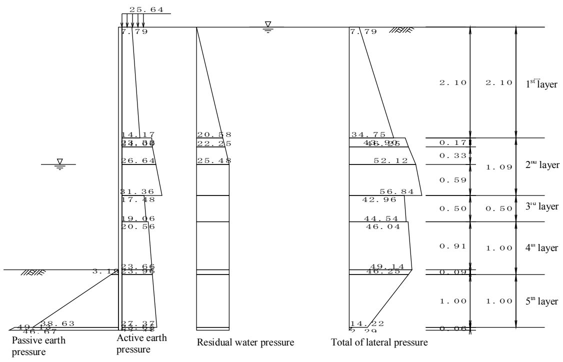
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

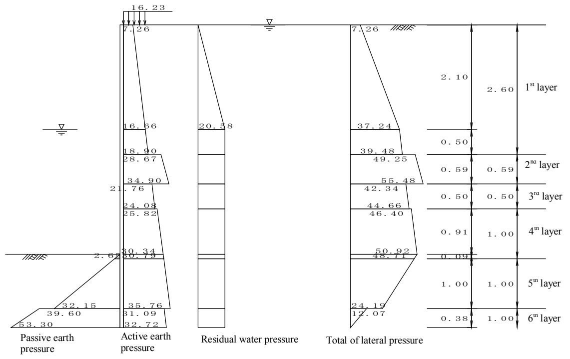


	Depth (m)	Pa (kN/m²)	Pw (kN/m²)	Pp (kN/m²)	Ps (kN/m²)
1	0.00~ 2.60	7.85 15.75	0.00 25.48	—— ——	7.85 41.23
2	2.60~ 3.19	27.84 32.56	25.48 25.48	—— ——	53.32 58.04
3	3.19~ 3.69	17.86 19.43	25.48 25.48	—— ——	43.34 44.91
4	3.69~ 4.60	20.97 24.07	25.48 25.48	—— ——	46.45 49.55
5	4.60~ 4.69	24.07 24.37	25.48 25.48	0.00 3.19	49.55 46.66
6	4.69~ 5.69	24.37 27.78	25.48 25.48	3.19 38.63	46.66 14.63
7	5.69~ 5.76	23.83 24.02	25.48 25.48	46.67 49.50	2.64 0.00
8	5.76~ 6.69	24.02 26.75	25.48 25.48	49.50 89.49	0.00 -37.26

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.16 m (GL -5.76 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)	Ps (kNm²)
1	0.00~ 2.10	7.26 16.66	0.00 20.58	—— ——	7.26 37.24
2	2.10~ 2.60	16.66 18.90	20.58 20.58	—— ——	37.24 39.48
3	2.60~ 3.19	28.67 34.90	20.58 20.58	—— ——	49.25 55.48
4	3.19~ 3.69	21.76 24.08	20.58 20.58	—— ——	42.34 44.66
5	3.69~ 4.60	25.82 30.34	20.58 20.58	—— ——	46.40 50.92
6	4.60~ 4.69	30.34 30.79	20.58 20.58	0.00 2.65	50.92 48.71
7	4.69~ 5.69	30.79 35.76	20.58 20.58	2.65 32.15	48.71 24.19
8	5.69~ 6.07	31.09 32.72	20.58 20.58	39.60 53.30	12.07 0.00
9	6.07~ 6.69	32.72 35.41	20.58 20.58	53.30 75.92	0.00 -19.93

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.47 m (GL -6.07 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m	
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87	
Section efficiency	μ	=	1.00	
Young's modulus	E	=	200000 Nmm²	
Inertia sectional moment	I_0	=	295000 cm⁴ (original condition)	
	I	=	256650 cm⁴ (after reduction by corrosion and joint)	
Inertia sectional moment	EI	=	200000 x 10³ x 256650 x 10⁻⁸ = 5.133×10⁵	

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	3.19	2
5	3.69	14
6	4.69	4
7	5.69	10
8	6.69	17
9	7.69	18
10	8.69	18

	Depth (m)	N-value
11	9.69	2
12	10.69	5
13	11.69	3
14	12.69	4
15	13.69	4
16	14.69	5
17	15.69	6
18	16.69	3
19	17.69	4
20	18.00	50

	Depth (m)	N-value
21	20.00	50

5-2 Normal Condition

K_h = 21551 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.320 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.12 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.76 m) to 3.12 m depth (GL -8.88 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	5.76	0.93	10.5	17.0	12.82
2	6.69	1.00	17.0	18.0	17.50
3	7.69	1.00	18.0	18.0	18.00
4	8.69	0.19	18.0	15.0	3.14
L = Σh = 3.12					ΣA = 51.46

A (upper N-value + lower N-value) × h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L}$$

$$= \frac{51.46}{3.12}$$

$$= 16.47$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following.

$$K_h = 6910 \times N'^{0.406} = 6910 \times 16.47^{0.406} = 21551 \text{ kN/m}^3$$

Kh (normal condition) = 21551 kNm³

5-3 Seismic Condition

K_h = 21601 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.320 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.12 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.07 m) to 3.12 m depth (GL -9.19 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	6.07	0.62	12.6	17.0	9.23
2	6.69	1.00	17.0	18.0	17.50
3	7.69	1.00	18.0	18.0	18.00
4	8.69	0.50	18.0	10.0	7.00
L = Σh = 3.12					ΣA = 51.73

A (upper N-value + lower N-value) × h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L}$$

$$= \frac{51.73}{3.12}$$

$$= 16.57$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following.

$$K_h = 6910 \times N'^{0.406} = 6910 \times 16.57^{0.406} = 21601 \text{ kN/m}^3$$

Kh (seismic condition) = 21601 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.60	2.60	7.85 41.23	10.20 53.60	4.89 4.02	49.89 215.60
2	2.60~ 3.19	0.59	53.32 58.04	15.73 17.12	2.96 2.76	46.55 47.30
3	3.19~ 3.69	0.50	43.34 44.91	10.83 11.23	2.40 2.23	26.00 25.07
4	3.69~ 4.60	0.91	46.45 49.55	21.13 22.54	1.76 1.46	37.25 32.90
5	4.60~ 4.69	0.09	49.55 46.66	2.23 2.10	1.13 1.10	2.51 2.30
6	4.69~ 5.69	1.00	46.66 14.63	23.33 7.31	0.73 0.40	17.10 2.92
7	5.69~ 5.76	0.07	2.64 0.00	0.09 0.00	0.04 0.02	0.00 0.00
				ΣP = 197.45		ΣM = 505.40

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.5 kNm
depth to acting position	H	=	-0.43 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_s	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.16 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 15.47 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{520.87}{199.95} = 2.61 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.26 37.24	7.63 39.10	5.37 4.67	40.93 182.51
2	2.10~ 2.60	0.50	37.24 39.48	9.31 9.87	3.80 3.63	35.38 35.87
3	2.60~ 3.19	0.59	49.25 55.48	14.53 16.37	3.27 3.07	47.52 50.31
4	3.19~ 3.69	0.50	42.34 44.66	10.58 11.16	2.71 2.54	28.69 28.40
5	3.69~ 4.60	0.91	46.40 50.92	21.11 23.17	2.07 1.77	43.78 41.02
6	4.60~ 4.69	0.09	50.92 48.71	2.29 2.19	1.44 1.41	3.29 3.08
7	4.69~ 5.69	1.00	48.71 24.19	24.36 12.09	1.04 0.71	25.43 8.59
8	5.69~ 6.07	0.38	12.07 0.00	2.28 0.00	0.25 0.13	0.57 0.00
				ΣP = 206.04		ΣM = 575.39

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.8 kN/m
depth to acting position	H_t	=	-0.26 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.47 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 55.68 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 3.10	1.00	0.0 2.7	0.00 1.36	3.63 3.30	0.00 4.48
2	3.10~ 4.10	1.00	2.7 3.8	1.36 1.92	2.63 2.30	3.57 4.41
3	4.10~ 4.60	0.50	3.8 4.3	0.96 1.07	1.80 1.63	1.73 1.75
				ΣP_{dw} = 6.66		ΣM_{dw} = 15.94

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{647.00}{221.50} = 2.92 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	295000 cm^4 (original condition)
	I	=	256650 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 256650 x 10^{-8}		=	5.133×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	21551 kN/m^3
calculated value	β	=	0.32008 m^{-1}
resultant earth force (lateral)	P_0	=	199.95 kN/m
height of acting position of load	h_0	=	2.61 m
moment	M_0	=	520.87 kN·m/m

in consideration of ψ_m = 1.193,

maximum moment	M_{max}	=	621.65 kN·m/m
depth of generated position of M_{max}	l_m	=	1.121 m
depth of 1st fixed point	l_i	=	3.574 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	21601 kN/m^3
calculated value	β	=	0.32027 m^{-1}
resultant earth force (lateral)	P_0	=	221.50 kN/m
height of acting position of load	h_0	=	2.92 m
moment	M_0	=	647.00 kN·m/m

in consideration of ψ_m = 1.162,

maximum moment	M_{max}	=	751.91 kN·m/m
depth of generated position of M_{max}	l_m	=	1.047 m
depth of 1st fixed point	l_i	=	3.499 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	6640 cm^3 (original condition)
	Z	=	5910 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{621.65\times10^6}{5910\times10^3} = 105 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{751.91\times10^6}{5910\times10^3} = 127 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.60	4.89 4.02	0.849 0.699	0.259 0.187	10.20 53.60	2.639 10.039
2	2.60~ 3.19	2.96 2.76	0.514 0.480	0.110 0.097	15.73 17.12	1.723 1.657
3	3.19~ 3.69	2.40 2.23	0.417 0.388	0.075 0.066	10.83 11.23	0.811 0.736
4	3.69~ 4.60	1.76 1.46	0.306 0.254	0.042 0.029	21.13 22.54	0.890 0.663
5	4.60~ 4.69	1.13 1.10	0.196 0.190	0.018 0.017	2.23 2.10	0.040 0.036
6	4.69~ 5.69	0.73 0.40	0.127 0.069	0.008 0.002	23.33 7.31	0.181 0.017
7	5.69~ 5.76	0.04 0.02	0.008 0.004	0.000 0.000	0.09 0.00	0.000 0.000
						ΣQ = 19.431

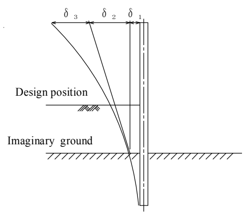
Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3} = \frac{(1+0.3201\times2.61)\times199.95}{2\times2.00\times10^8\times256650\times10^{-8}\times0.3201^3} = 0.01089 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k) = \frac{(1+2\times0.3201\times2.61)\times199.95}{2\times2.00\times10^8\times256650\times10^{-8}\times0.3201^2}\times(4.60+1.16) = 0.02919 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI} = \frac{19.43\times(4.60+1.16)^3}{2.00\times10^8\times256650\times10^{-8}} = 0.00722 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00034 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.76 m
Horizontal load: P = 2.50
Moment: M = 1.08

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01089 + 0.02919 + 0.00756
= 0.04765 m
= 47.65 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	5.37 4.67	0.885 0.769	0.276 0.220	7.63 39.10	2.104 8.603
2	2.10~ 2.60	3.80 3.63	0.626 0.599	0.155 0.144	9.31 9.87	1.445 1.417
3	2.60~ 3.19	3.27 3.07	0.539 0.507	0.119 0.107	14.53 16.37	1.732 1.746
4	3.19~ 3.69	2.71 2.54	0.447 0.419	0.085 0.076	10.58 11.16	0.899 0.844
5	3.69~ 4.60	2.07 1.77	0.342 0.292	0.052 0.038	21.11 23.17	1.093 0.891
6	4.60~ 4.69	1.44 1.41	0.237 0.232	0.026 0.025	2.29 2.19	0.059 0.054
7	4.69~ 5.69	1.04 0.71	0.172 0.117	0.014 0.007	24.36 12.09	0.340 0.080
8	5.69~ 6.07	0.25 0.13	0.041 0.021	0.001 0.000	2.28 0.00	0.002 0.000
						ΣQ = 21.308

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

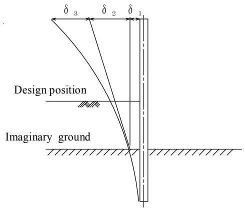
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 3.10	3.63 3.30	0.599 0.544	0.144 0.121	0.00 1.36	0.000 0.164
2	3.10~ 4.10	2.63 2.30	0.434 0.379	0.081 0.063	1.36 1.92	0.109 0.120
3	4.10~ 4.60	1.80 1.63	0.297 0.269	0.040 0.033	0.96 1.07	0.038 0.035
						ΣQ_{dw} = 0.467

Therefore, modulus of deformation Q is calculated as below

Q = 21.308 + 0.467 = 21.776

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3203\times 2.92)\times 221.50}{2\times 2.00\times 10^8\times 256650\times 10^{-8}\times 0.3203^3} = 0.01271 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times (H+L_k)$$

$$= \frac{(1+2\times 0.3203\times 2.92)\times 221.50}{2\times 2.00\times 10^8\times 256650\times 10^{-8}\times 0.3203^2}\times(4.60+1.47) = 0.03664 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{21.78\times(4.60+1.47)^3}{2.00\times 10^8\times 256650\times 10^{-8}} = 0.00948 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00136 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 6.07 m

Horizontal load: P = 8.80

Moment: M = 2.29

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01271 + 0.03664 + 0.01083

= 0.06019 m

= 60.19 ≦ δ_a = 75.00 mm

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	295000 cm^4 (original condition)
	I	=	295000 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 295000x 10^{-8}		=	5.900×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	K_h = 21551 kN/m^3
Calculated value	β = 0.30913 m^{-1}
Penetration length of SSP	$D = 1.16 + \frac{3}{0.309} = 10.86$ m
Whole length of SSP	$L = 4.60 - 0.40 + 10.86 = 15.06$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	K_h = 21601 kN/m^3
Calculated value	β = 0.30931 m^{-1}
Penetration length of SSP	$D = 1.47 + \frac{3}{0.309} = 11.17$ m
Whole length of SSP	$L = 4.60 - 0.40 + 11.17 = 15.37$ m

Therefore, whole length of SSP is set as 15.50 m in consideration of round unit of SSP length

8 Calculation Result

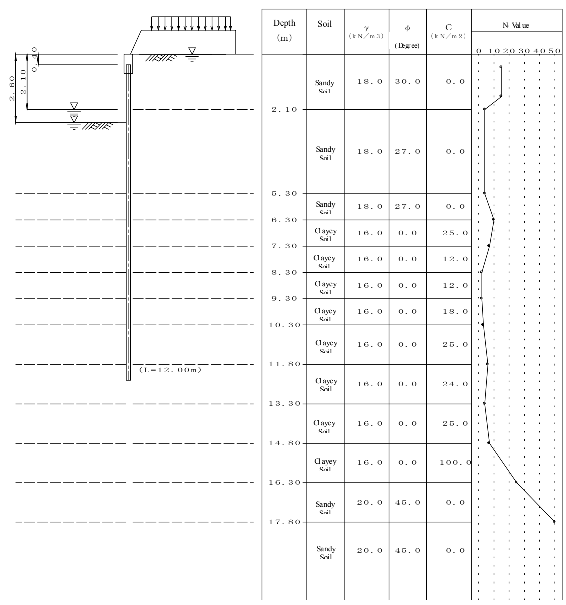
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	295000		
Section modulus	Z (cm^3)	6640		
Maximum bending moment	M_{max} (kN·m/m)		621.65	751.91
Stress intensity	σ (N/mm^2)		105 (185)	127 (278)
Lateral displacement	δ (mm)		47.65 (50.0)	60.19 (75.0)
Penetration depth	D (m)		10.86	11.17
Whole length of SSP	L (m)	15.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 24_STA 9+830 - 9+947

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Riverside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Landside WL	L_{wp}	=	2.60 m (Normal Condition)
	L_{wp}'	=	2.10 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　Chang's formula

Penetration depths　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　γ_w = 9.8 kNm^3

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.5 kNm (Normal Condition)
		Pt'	=	8.8 kNm (Seismic Condition)
	Depth of acting point	Ht	=	-0.43 m (Normal Condition)
		Ht'	=	-0.26 m (Seismic Condition)
	Moment	Mm	=	0.0 kN-m/m (Normal Condition)
		Mm'	=	0.0 kN-m/m (Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m (Seismic Condition)
		Hm	=	0.00 m (Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　ζ_0 = 10 degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N'^{0.406}$

Average N-value　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	4
4	5.30	4
5	6.30	10
6	7.30	7
7	8.30	2
8	9.30	2
9	10.30	3
10	11.80	6

No	Depth (m)	N-Value
11	13.30	4
12	14.80	7
13	16.30	25
14	17.80	50
15	20.00	50

2.181

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

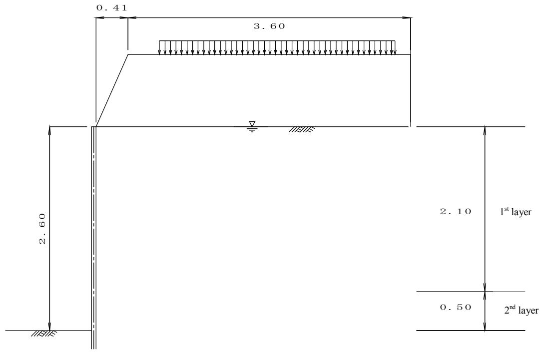
No	Depth (m)	Soil	N-value	γ (kNm^3)	γ' (kNm^3)	ϕ	C (kNm^2)	a	k'	ζ (degree)		kh(kNm^3)	
										normal	seismic		
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	———	———
2	5.30	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
3	6.30	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	———	———
4	7.30	C	7.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	———	———
5	8.30	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	———	———
6	9.30	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	———	———
7	10.30	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	———	———
8	11.80	C	6.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	———	———
9	13.30	C	4.0	16.00	8.00	0.0	24.0	0.0	0.200	auto	auto	———	———
10	14.80	C	7.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	———	———
11	16.30	C	25.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	———	———
12	17.80	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	———	———
13	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	———	———

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy (S), clayey (C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.41	4.01	4.01	0.92	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.81	3.81	10.0	5.0

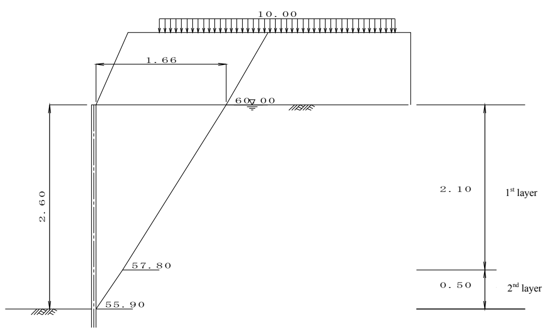
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	86000 cm⁴
Sectional factor	Z_0	=	3820 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 Nmm² (Normal)
	σ_a'	=	270 Nmm² (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition

2-1-1 Angle of Active Rupture



No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	25.49	25.48	55.90
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.49	20.58	57.80
3		Embankment	30.0	——	0.0	16.56	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ=0°

Where

- ζ : angle of active rupture (degree, ζ ≥ 10.00°)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	0.92	1.66	2.60	2.19	3.52

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.58	28.51
Σ			28.51

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.38	13.82
Σ			13.82

Q surcharge load
l : width of surcharge load set by line of active rupture

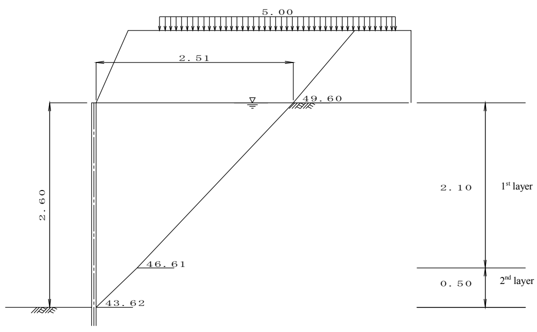
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{28.51 + 13.82 + 0.00}{1.66}$$

$$= 25.49\ \text{kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60~ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	22.74	25.48	0.200	11.31	43.62
2	2.10~ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	22.74	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	16.56	5.00	0.00	0.200	11.31	49.60

· Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

· Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Where.

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{0}$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta=\tan^{-1}k$ or $\theta=\tan^{-1}k'$
- γ : unit weight of soil (kNm³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kNm²)
- C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	0.92	2.51	2.60	3.29	3.52

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.48	44.65
Σ			44.65

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.48	12.41
Σ			12.41

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

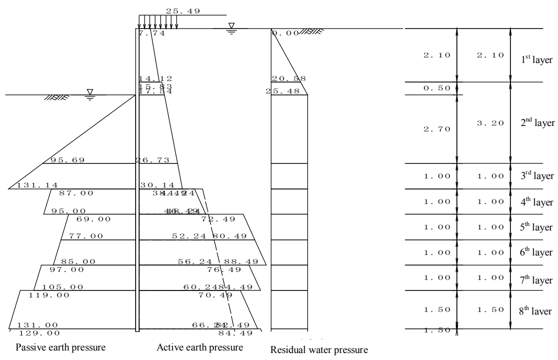
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{44.65 + 12.41 + 0.00}{2.51}$$

$$= 22.74 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	25.485 46.485	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	46.485 51.485	0.34585 0.34585	0.34060 0.34060
3	2.60~ 5.30	Sandy soil	10.0	27.0	—— ——	51.485 78.485	0.34585 0.34585	0.34060 0.34060
4	5.30~ 6.30	Sandy soil	10.0	27.0	—— ——	78.485 88.485	0.34585 0.34585	0.34060 0.34060
5	6.30~ 7.30	Clayey soil	8.0	—	25.0 25.0	88.485 96.485	—— ——	—— ——
6	7.30~ 8.30	Clayey soil	8.0	—	12.0 12.0	96.485 104.485	—— ——	—— ——
7	8.30~ 9.30	Clayey soil	8.0	—	12.0 12.0	104.485 112.485	—— ——	—— ——
8	9.30~ 10.30	Clayey soil	8.0	—	18.0 18.0	112.485 120.485	—— ——	—— ——
9	10.30~ 11.80	Clayey soil	8.0	—	25.0 25.0	120.485 132.485	—— ——	—— ——
10	11.80~ 13.30	Clayey soil	8.0	—	24.0 24.0	132.485 144.485	—— ——	—— ——
11	13.30~ 14.80	Clayey soil	8.0	—	25.0 25.0	144.485 156.485	—— ——	—— ——
12	14.80~ 16.30	Clayey soil	8.0	—	100.0 100.0	156.485 168.485	—— ——	—— ——
13	16.30~ 17.80	Sandy soil	10.0	45.0	—— ——	168.485 183.485	0.16262 0.16262	0.16015 0.16015

2.183

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	17.80~ 20.00	Sandy soil	10.0	45.0	—— ——	183.485 205.485	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C (kNm²)	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 5.30	Sandy soil	10.0	27.0	—— ——	0.000 27.000	3.59892 3.59892	3.54425 3.54425
4	5.30~ 6.30	Sandy soil	10.0	27.0	—— ——	27.000 37.000	3.59892 3.59892	3.54425 3.54425
5	6.30~ 7.30	Clayey soil	8.0	0.0	25.0 25.0	37.000 45.000	—— ——	—— ——
6	7.30~ 8.30	Clayey soil	8.0	0.0	12.0 12.0	45.000 53.000	—— ——	—— ——
7	8.30~ 9.30	Clayey soil	8.0	0.0	12.0 12.0	53.000 61.000	—— ——	—— ——
8	9.30~ 10.30	Clayey soil	8.0	0.0	18.0 18.0	61.000 69.000	—— ——	—— ——
9	10.30~ 11.80	Clayey soil	8.0	0.0	25.0 25.0	69.000 81.000	—— ——	—— ——
10	11.80~ 13.30	Clayey soil	8.0	0.0	24.0 24.0	81.000 93.000	—— ——	—— ——
11	13.30~ 14.80	Clayey soil	8.0	0.0	25.0 25.0	93.000 105.000	—— ——	—— ——
12	14.80~ 16.30	Clayey soil	8.0	0.0	100.0 100.0	105.000 117.000	—— ——	—— ——
13	16.30~ 17.80	Sandy soil	10.0	45.0	—— ——	117.000 132.000	9.34548 9.34548	9.20351 9.20351
14	17.80~ 20.00	Sandy soil	10.0	45.0	—— ——	132.000 154.000	9.34548 9.34548	9.20351 9.20351

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	7.74 14.12	—— ——	7.74 14.12	0.00 20.58	—— ——
2	2.10~ 2.60	15.83 17.54	—— ——	15.83 17.54	20.58 25.48	—— ——
3	2.60~ 5.30	17.54 26.73	—— ——	17.54 26.73	25.48 25.48	0.00 95.69
4	5.30~ 6.30	26.73 30.14	—— ——	26.73 30.14	25.48 25.48	95.69 131.14
5	6.30~ 7.30	38.49 46.49	44.24 48.24	44.24 48.24	25.48 25.48	87.00 95.00
6	7.30~ 8.30	72.49 80.49	48.24 52.24	72.49 80.49	25.48 25.48	69.00 77.00
7	8.30~ 9.30	80.49 88.49	52.24 56.24	80.49 88.49	25.48 25.48	77.00 85.00
8	9.30~ 10.30	76.49 84.49	56.24 60.24	76.49 84.49	25.48 25.48	97.00 105.00
9	10.30~ 11.80	70.49 82.49	60.24 66.24	70.49 82.49	25.48 25.48	119.00 131.00
10	11.80~ 13.30	84.49 96.49	66.24 72.24	84.49 96.49	25.48 25.48	129.00 141.00
11	13.30~ 14.80	94.49 106.49	72.24 78.24	94.49 106.49	25.48 25.48	143.00 155.00
12	14.80~ 16.30	-43.51 -31.51	78.24 84.24	78.24 84.24	25.48 25.48	305.00 317.00
13	16.30~ 17.80	26.98 29.39	—— ——	26.98 29.39	25.48 25.48	1076.81 1214.86
14	17.80~ 20.00	29.39 32.91	—— ——	29.39 32.91	25.48 25.48	1214.86 1417.34

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

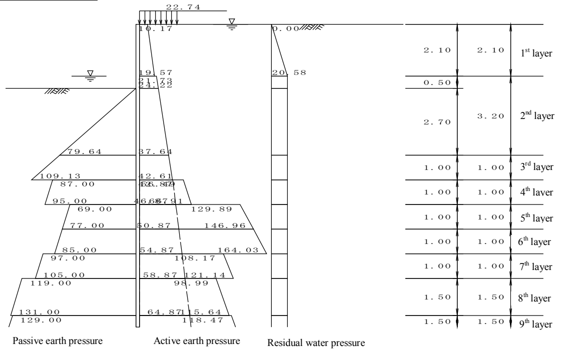
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	22.74 43.74	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.60	Clayey Soil	10.0	27.0	—— ——	43.74 48.74	20.58 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.60~ 5.30	Sandy Soil	10.0	27.0	—— ——	48.74 75.74	25.48 51.94	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	5.30~ 6.30	Sandy Soil	10.0	27.0	—— ——	75.74 85.74	51.94 61.74	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	6.30~ 7.30	Sandy Soil	8.0	—	25.0 25.0	85.74 93.74	61.74 71.54	0.200 0.200	11.31 11.31	—— ——	—— ——	36.96 36.16
6	7.30~ 8.30	Clayey Soil	8.0	—	12.0 12.0	93.74 101.74	71.54 81.34	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
7	8.30~ 9.30	Clayey Soil	8.0	—	12.0 12.0	101.74 109.74	81.34 91.14	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
8	9.30~ 10.30	Clayey Soil	8.0	—	18.0 18.0	109.74 117.74	91.14 100.94	0.200 0.200	11.31 11.31	—— ——	—— ——	27.20 25.11
9	10.30~ 11.80	Clayey Soil	8.0	—	25.0 25.0	117.74 129.74	100.94 115.64	0.200 0.200	11.31 11.31	—— ——	—— ——	33.50 31.99
10	11.80~ 13.30	Clayey Soil	8.0	—	24.0 24.0	129.74 141.74	115.64 130.34	0.200 0.200	11.31 11.31	—— ——	—— ——	31.13 29.29
11	13.30~ 14.80	Clayey Soil	8.0	—	25.0 25.0	141.74 153.74	130.34 145.04	0.200 0.200	11.31 11.31	—— ——	—— ——	30.32 28.47
12	14.80~ 16.15	Clayey Soil	8.0	—	100.0 100.0	153.74 164.57	145.04 ——	0.200 ——	11.31 ——	—— ——	—— ——	42.22 ——

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
13	16.15~ 16.30	Clayey Soil	8.0	—	100.0 100.0	164.57 165.74	—— 159.74	—— 0.200	—— 11.31	—— ——	—— ——	—— 42.01
14	16.30~ 17.80	Sandy Soil	10.0	45.0	—— ——	165.74 180.74	159.74 174.44	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
15	17.80~ 20.00	Sandy Soil	10.0	45.0	—— ——	180.74 202.74	174.44 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
δ= 10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below,

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C (kNm²)	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp × cosδ
3	2.60~ 5.30	Sandy soil	10.00	27.0	—— ——	0.000 27.000	0.00 26.46	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
4	5.30~ 6.30	Sandy soil	10.00	27.0	—— ——	27.000 37.000	26.46 36.26	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	6.30~ 7.30	Clayey soil	8.00	0.0	25.0 25.0	37.000 45.000	36.26 46.06	0.200 0.200	11.31 11.31	—— ——	—— ——
6	7.30~ 8.30	Clayey soil	8.00	0.0	12.0 12.0	45.000 53.000	46.06 55.86	0.200 0.200	11.31 11.31	—— ——	—— ——
7	8.30~ 9.30	Clayey soil	8.00	0.0	12.0 12.0	53.000 61.000	55.86 65.66	0.200 0.200	11.31 11.31	—— ——	—— ——
8	9.30~ 10.30	Clayey soil	8.00	0.0	18.0 18.0	61.000 69.000	65.66 75.46	0.200 0.200	11.31 11.31	—— ——	—— ——
9	10.30~ 11.80	Clayey soil	8.00	0.0	25.0 25.0	69.000 81.000	75.46 90.16	0.200 0.200	11.31 11.31	—— ——	—— ——
10	11.80~ 13.30	Clayey soil	8.00	0.0	24.0 24.0	81.000 93.000	90.16 104.86	0.200 0.200	11.31 11.31	—— ——	—— ——
11	13.30~ 14.80	Clayey soil	8.00	0.0	25.0 25.0	93.000 105.000	104.86 119.56	0.200 0.200	11.31 11.31	—— ——	—— ——
12	14.80~ 16.15	Clayey soil	8.00	0.0	100.0 100.0	105.000 115.830	119.56 ——	0.200 ——	11.31 ——	—— ——	—— ——
13	16.15~ 16.30	Clayey soil	8.00	0.0	100.0 100.0	115.830 117.000	—— 134.26	—— 0.200	—— 11.31	—— ——	—— ——
14	16.30~ 17.80	Sandy soil	10.00	45.0	—— ——	117.000 132.000	134.26 148.96	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
15	17.80~ 20.00	Sandy soil	10.00	45.0	—— ——	132.000 154.000	148.96 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below,
δ= -10.00, β= 0.00, θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 (kNm²)	Pa2 (kNm²)	Pa (kNm²)	Pw (kNm²)	Pp (kNm²)
1	0.00~ 2.10	10.17 19.57	—— ——	10.17 19.57	0.00 20.58	—— ——
2	2.10~ 2.60	21.73 24.22	—— ——	21.73 24.22	20.58 20.58	—— ——
3	2.60~ 5.30	24.22 37.64	—— ——	24.22 37.64	20.58 20.58	0.00 79.64
4	5.30~ 6.30	37.64 42.61	—— ——	37.64 42.61	20.58 20.58	79.64 109.13
5	6.30~ 7.30	56.49 66.91	42.87 46.87	56.49 66.91	20.58 20.58	87.00 95.00
6	7.30~ 8.30	129.89 146.96	46.87 50.87	129.89 146.96	20.58 20.58	69.00 77.00
7	8.30~ 9.30	146.96 164.03	50.87 54.87	146.96 164.03	20.58 20.58	77.00 85.00
8	9.30~ 10.30	108.17 121.14	54.87 58.87	108.17 121.14	20.58 20.58	97.00 105.00
9	10.30~ 11.80	98.99 115.64	58.87 64.87	98.99 115.64	20.58 20.58	119.00 131.00
10	11.80~ 13.30	118.47 136.02	64.87 70.87	118.47 136.02	20.58 20.58	129.00 141.00
11	13.30~ 14.80	132.84 150.78	70.87 76.87	132.84 150.78	20.58 20.58	143.00 155.00
12	14.80~ 16.15	-13.33 0.00	76.87 82.28	76.87 82.28	20.58 20.58	305.00 315.83
13	16.15~ 16.30	0.00 1.44	82.28 82.87	82.28 82.87	20.58 20.58	315.83 317.00
14	16.30~ 17.80	42.88 46.76	—— ——	42.88 46.76	20.58 20.58	959.80 1082.86
15	17.80~ 20.00	46.76 52.46	—— ——	46.76 52.46	20.58 20.58	1082.86 1263.33

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^{2})
1	2.10	0.00	0.00
2	2.60	0.50	0.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

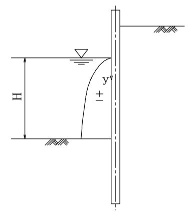
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

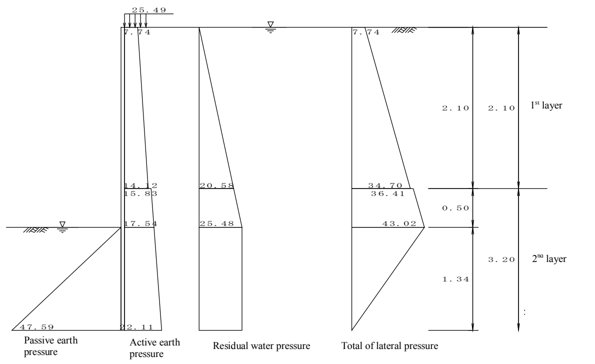
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	7.74 14.12	0.00 20.58	—— ——	7.74 34.70
2	2.10~ 2.60	15.83 17.54	20.58 25.48	—— ——	36.41 43.02
3	2.60~ 3.94	17.54 22.11	25.48 25.48	0.00 47.59	43.02 0.00
4	3.94~ 5.30	22.11 26.73	25.48 25.48	47.59 95.69	0.00 -43.48

P_a : Active earth pressure

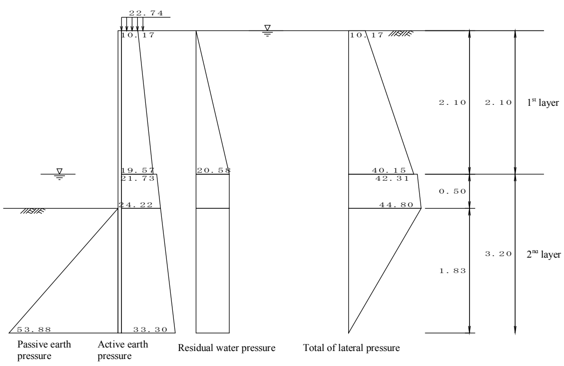
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.34 m (GL -3.94 m)

4-2 Seismic Condition



	Depth (m)	Pa (kNm^2)	Pw (kNm^2)	Pp (kNm^2)	Ps (kNm^2)
1	0.00~ 2.10	10.17 19.57	0.00 20.58	—— ——	10.17 40.15
2	2.10~ 2.60	21.73 24.22	20.58 20.58	—— ——	42.31 44.80
3	2.60~ 4.43	24.22 33.30	20.58 20.58	0.00 53.88	44.80 0.00
4	4.43~ 5.30	33.30 37.64	20.58 20.58	53.88 79.64	0.00 -21.42

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Tentative imaginary riverbed L_k: 1.83 m (GL -4.43 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m			
Corrosion margin	t_1	=	1.00 mm (active side)	t_2	=	1.00 mm (passive side)
Corrosion rate	η	=	0.92			
Section efficiency	μ	=	0.80			
Young's modulus	E	=	200000 Nmm^2			
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)			
	I	=	63296 cm^4 (after reduction by corrosion and joint)			
Inertia sectional moment	EI	=	200000 x 10^{3}x63296 x 10^{-8} =1.266×10^5			

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	4
4	5.30	4
5	6.30	10
6	7.30	7
7	8.30	2
8	9.30	2
9	10.30	3
10	11.80	6

	Depth (m)	N-value
11	13.30	4
12	14.80	7
13	16.30	25
14	17.80	50
15	20.00	50

5-2 Normal Condition

K_h = 13773 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.406 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.46 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.94 m) to 2.46 m depth (GL -6.41 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.94	1.36	4.0	4.0	5.43
2	5.30	1.00	4.0	10.0	7.00
3	6.30	0.11	10.0	9.7	1.03
	L = Σh = 2.46				ΣA = 13.46

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{13.46}{2.46}$$

$$= 5.47$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 5.47^{0.406} = 13773 \text{ kN/m}^3$$

Kh (normal condition) = 13773 kN/m³

5-3 Seismic Condition

K_h = 14694 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.413 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.42 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.43 m) to 2.42 m depth (GL -6.85 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.43	0.87	4.0	4.0	3.49
2	5.30	1.00	4.0	10.0	7.00
3	6.30	0.55	10.0	8.4	5.04
	L = Σh = 2.42				ΣA = 15.54

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{15.54}{2.42}$$

$$= 6.41$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (seismic condition) is set definitely as following:

$$K_h = 6910 \times N'^{0.406} = 6910 \times 6.41^{0.406} = 14694 \text{ kN/m}^3$$

Kh (seismic condition) = 14694 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.74 34.70	8.13 36.44	3.24 2.54	26.36 92.65
2	2.10~ 2.60	0.50	36.41 43.02	9.10 10.75	1.68 1.51	15.26 16.23
3	2.60~ 3.94	1.34	43.02 0.00	28.88 0.00	0.90 0.45	25.85 0.00
				ΣP = 93.30		ΣM = 176.35

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.5 kN/m
depth to acting position	H_t	=	-0.43 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.34 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.93 \text{ kN·m}$$

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{187.28}{95.80} = 1.95 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.17 40.15	10.68 42.16	3.73 3.03	39.81 127.60
2	2.10~ 2.60	0.50	42.31 44.80	10.58 11.20	2.16 1.99	22.85 22.32
3	2.60~ 4.43	1.83	44.80 0.00	40.92 0.00	1.22 0.61	49.83 0.00
				ΣP = 115.54		ΣM = 262.42

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.8 kN/m
depth to acting position	H_t	=	-0.26 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.83 m

Moment M_t by arbitrary load is as below
$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 41.24 \text{ kN·m}$$

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.10~ 2.60	0.50	0.0 0.9	0.00 0.21	2.16 1.99	0.00 0.43
				ΣP_{dw} = 0.21		ΣM_{dw} = 0.43

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{304.09}{124.55} = 2.44 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 63296 x 10⁻⁸		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	13773 kN/m³
calculated value	β	=	0.40610 m^{-1}
resultant earth force (lateral)	P_0	=	95.80 kN/m
height of acting position of load	h_0	=	1.95 m
moment	M_0	=	187.28 kN·m/m

in consideration of ψ_m = 1.208,

maximum moment	M_{max}	=	226.31 kN·m/m
depth of generated position of M_{max}	l_m	=	0.908 m
depth of 1st fixed point	l_i	=	2.842 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	14694 kN/m³
calculated value	β	=	0.41273 m^{-1}
resultant earth force (lateral)	P_0	=	124.55 kN/m
height of acting position of load	h_0	=	2.44 m
moment	M_0	=	304.09 kN·m/m

in consideration of ψ_m = 1.144,

maximum moment	M_{max}	=	348.00 kN·m/m
depth of generated position of M_{max}	l_m	=	0.776 m
depth of 1st fixed point	l_i	=	2.679 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm³ (original condition)
	Z	=	3514 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{226.31 \times 10^6}{3514 \times 10^3} = 64 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{348.00 \times 10^6}{3514 \times 10^3} = 99 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.24 2.54	0.822 0.645	0.245 0.163	8.13 36.44	1.996 5.948
2	2.10~ 2.60	1.68 1.51	0.425 0.383	0.078 0.064	9.10 10.75	0.706 0.687

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
3	2.60~ 3.94	0.90 0.45	0.227 0.114	0.024 0.006	28.88 0.00	0.688 0.000
						ΣQ = 10.025

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

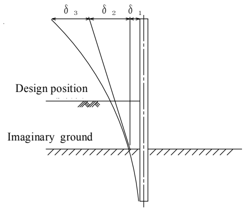
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4061\times1.95)\times95.80}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4061^3} = 0.01013 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4061\times1.95)\times95.80}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4061^2}\times(2.60+1.34) = 0.02341 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.03\times(2.60+1.34)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00485 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00047 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.94 m
Horizontal load: P = 2.50
Moment: M = 1.08

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01013 + 0.02341 + 0.00532
= 0.03887 m
= 38.87 ≦ δa = 50.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.73 3.03	0.842 0.684	0.255 0.180	10.68 42.16	2.723 7.609
2	2.10~ 2.60	2.16 1.99	0.488 0.450	0.100 0.086	10.58 11.20	1.055 0.965
3	2.60~ 4.43	1.22 0.61	0.275 0.138	0.034 0.009	40.92 0.00	1.406 0.000
						ΣQ = 13.758

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

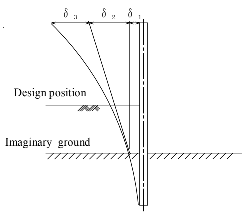
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.10~ 2.60	2.16 1.99	0.488 0.450	0.100 0.086	0.00 0.21	0.000 0.018
						ΣQ_{dw} = 0.018

Therefore, modulus of deformation Q is calculated as below.
Q = 13.758 + 0.018 = 13.777

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4127\times2.44)\times124.55}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4127^3} = 0.01405 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4127\times2.44)\times124.55}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4127^2}\times(2.60+1.83) = 0.03855 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.78\times(2.60+1.83)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00944 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00219 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.43 m
Horizontal load: P = 8.80
Moment: M = 2.29

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01405 + 0.03855 + 0.01163
= 0.06422 m
= 64.22 ≦ δ_a = 75.00 mm

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 86000 \times 10^{-8}$		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 13773\ kN/m^3$

Calculated value $\beta = 0.37615\ m^{-1}$

Penetration length of SSP $D = 1.34 + \frac{3}{0.376} = 9.32\ m$

Whole length of SSP $L = 2.60 - 0.40 + 9.32 = 11.52\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 14694\ kN/m^3$

Calculated value $\beta = 0.38228\ m^{-1}$

Penetration length of SSP $D = 1.83 + \frac{3}{0.382} = 9.67\ m$

Whole length of SSP $L = 2.60 - 0.40 + 9.67 = 11.87\ m$

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

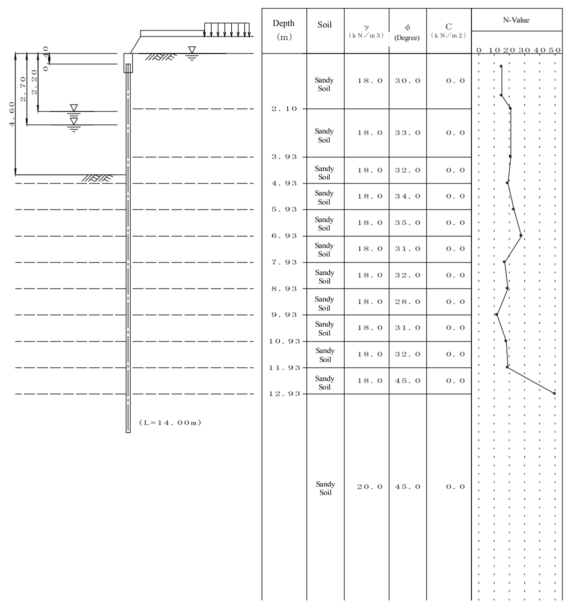
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		226.31	348.00
Stress intensity	σ (N/mm^2)		64 (180)	99 (270)
Lateral displacement	δ (mm)		38.87 (50.0)	64.22 (75.0)
Penetration depth	D (m)		9.32	9.67
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile　Design Calculation－

Right Bank No. 25_STA 10+956 - 11+050

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	4.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　Chang's formula

Penetration depths　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　γ_w = 9.8 kN/m^3

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case　- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.4 kN/m	(Normal Condition)
		Pt'	=	7.4 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.42 m	(Normal Condition)
		Ht'	=	-0.12 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN･m/m	(Normal Condition)
		Mm'	=	2.0 kN･m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　ζ_0 = 10 degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N'^{0.406}$

Average N-value　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	21
4	3.93	21
5	4.93	19
6	5.93	23
7	6.93	28
8	7.93	17
9	8.93	19
10	9.93	12

No	Depth (m)	N-Value
11	10.93	18
12	11.93	19
13	12.93	50
14	20.00	50

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

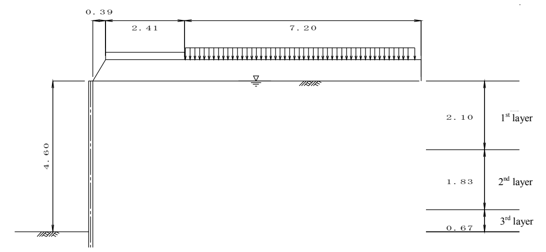
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	――	――
2	3.93	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	――	――
3	4.93	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	――	――
4	5.93	S	23.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	――	――
5	6.93	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	――	――
6	7.93	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	――	――
7	8.93	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	――	――
8	9.93	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	――	――
9	10.93	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	――	――
10	11.93	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	――	――
11	12.93	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	――	――
12	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	――	――

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	0.39	10.00	10.00	0.65	18.0	30.0	0.0	auto	auto
2	Sandy soil	0.39	0.39	2.80	2.80	0.23	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	2.82	9.80	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 180000 cm^4
Sectional factor Z_0 = 4480 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.86
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

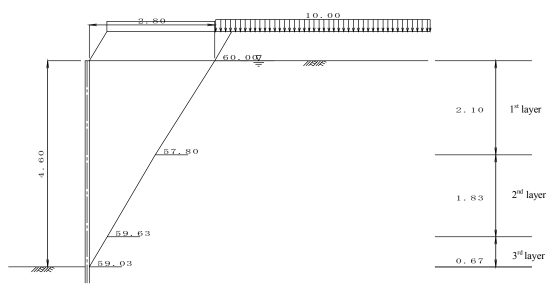
Allowable stress σ_a = 185 N/mm (Normal)
σ_a' = 278 N/mm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	Angle of rupture Z (degree)
1	4.60～ 3.93	Sandy Soil	32.0	10.0	0.0	46.00	16.50	45.08	59.03
2	3.93～ 2.10	Sandy Soil	33.0	10.0	0.0	39.30	16.50	38.51	59.63
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	16.50	20.58	57.80
4		Embankment	30.0	——	0.0	15.84	0.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	59.03	0.67	0.00	0.00	0.40	0.67
2	59.63	1.83	0.40	0.67	1.47	2.50
3	57.80	2.10	1.47	2.50	2.80	4.60
4	60.00	0.65	2.80	4.60	3.17	5.25

Therefore, width of acting load shall be set as 2.80 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	1.81	32.64
2	18.0	0.55	9.98
Σ			42.61

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	10.0	0.35	3.52
Σ			3.52

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

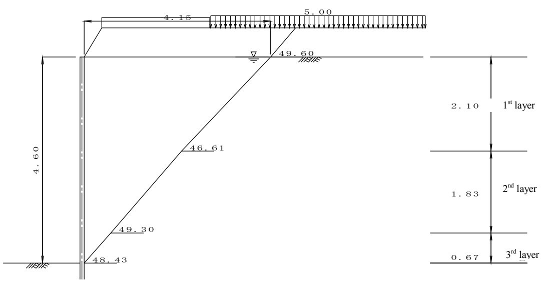
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{42.61 + 3.52 + 0.00}{2.80}$$

$$= 16.50 \ kN/m^2$$

2.190

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	4.60～ 3.93	Sandy Soil	32.0	10.0	0.0	46.00	16.60	45.08	0.200	11.31	48.43
2	3.93～ 2.10	Sandy Soil	33.0	10.0	0.0	39.30	16.60	38.51	0.200	11.31	49.30
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	16.60	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	15.84	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,

ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	48.43	0.67	0.00	0.00	0.59	0.67
2	49.30	1.83	0.59	0.67	2.17	2.50
3	46.61	2.10	2.17	2.50	4.15	4.60
4	49.60	0.65	4.15	4.60	4.71	5.25

Therefore, width of acting load shall be set as 4.15 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.75	49.56
2	18.0	0.55	9.98
Σ			59.53

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	1.89	9.44
Σ			9.44

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

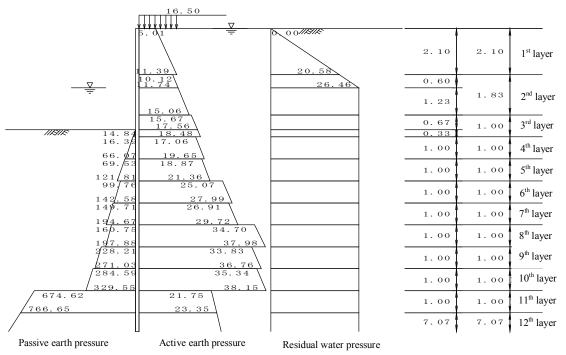
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{59.53 + 9.44 + 0.00}{4.15}$$

$= 16.60\ kN/m^2$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	16.495 37.495	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.70	Sandy soil	10.0	33.0	—— ——	37.495 43.495	0.27412 0.27412	0.26996 0.26996
3	2.70～ 3.93	Sandy soil	10.0	33.0	—— ——	43.495 55.795	0.27412 0.27412	0.26996 0.26996
4	3.93～ 4.60	Sandy soil	10.0	32.0	—— ——	55.795 62.495	0.28525 0.28525	0.28092 0.28092
5	4.60～ 4.93	Sandy soil	10.0	32.0	—— ——	62.495 65.795	0.28525 0.28525	0.28092 0.28092
6	4.93～ 5.93	Sandy soil	10.0	34.0	—— ——	65.795 75.795	0.26331 0.26331	0.25931 0.25931
7	5.93～ 6.93	Sandy soil	10.0	35.0	—— ——	75.795 85.795	0.25279 0.25279	0.24895 0.24895
8	6.93～ 7.93	Sandy soil	10.0	31.0	—— ——	85.795 95.795	0.29669 0.29669	0.29219 0.29219
9	7.93～ 8.93	Sandy soil	10.0	32.0	—— ——	95.795 105.795	0.28525 0.28525	0.28092 0.28092
10	8.93～ 9.93	Sandy soil	10.0	28.0	—— ——	105.795 115.795	0.33303 0.33303	0.32798 0.32798
11	9.93～ 10.93	Sandy soil	10.0	31.0	—— ——	115.795 125.795	0.29669 0.29669	0.29219 0.29219
12	10.93～ 11.93		10.0	32.0	—— ——	125.795 135.795	0.28525 0.28525	0.28092 0.28092
13	11.93～ 12.93		10.0	45.0	—— ——	135.795 145.795	0.16262 0.16262	0.16015 0.16015

2.191

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	12.93～ 20.00		10.0	45.0	——	145.795 216.495	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β＝ 0.00、θ＝ 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
5	4.60～ 4.93	Sandy soil	10.0	32.0	—— ——	0.000 3.300	4.56530 4.56530	4.49594 4.49594
6	4.93～ 5.93	Sandy soil	10.0	34.0	—— ——	3.300 13.300	5.04448 5.04448	4.96784 4.96784
7	5.93～ 6.93	Sandy soil	10.0	35.0	—— ——	13.300 23.300	5.30876 5.30876	5.22810 5.22810
8	6.93～ 7.93	Sandy soil	10.0	31.0	—— ——	23.300 33.300	4.34774 4.34774	4.28169 4.28169
9	7.93～ 8.93	Sandy soil	10.0	32.0	—— ——	33.300 43.300	4.56530 4.56530	4.49594 4.49594
10	8.93～ 9.93	Sandy soil	10.0	28.0	—— ——	43.300 53.300	3.76978 3.76978	3.71251 3.71251
11	9.93～ 10.93	Sandy soil	10.0	31.0	—— ——	53.300 63.300	4.34774 4.34774	4.28169 4.28169
12	10.93～ 11.93	Sandy soil	10.0	32.0	—— ——	63.300 73.300	4.56530 4.56530	4.49594 4.49594
13	11.93～ 12.93	Sandy soil	10.0	45.0	—— ——	73.300 83.300	9.34548 9.34548	9.20351 9.20351
14	12.93～ 20.00	Sandy soil	10.0	45.0	—— ——	83.300 154.000	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -10.00、β＝ 0.00、θ＝ 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	5.01 11.39	—— ——	5.01 11.39	0.00 20.58	—— ——
2	2.10～ 2.70	10.12 11.74	—— ——	10.12 11.74	20.58 26.46	—— ——
3	2.70～ 3.93	11.74 15.06	—— ——	11.74 15.06	26.46 26.46	—— ——
4	3.93～ 4.60	15.67 17.56	—— ——	15.67 17.56	26.46 26.46	—— ——

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
5	4.60~ 4.93	17.56 18.48	—— ——	17.56 18.48	26.46 26.46	0.00 14.84
6	4.93~ 5.93	17.06 19.65	—— ——	17.06 19.65	26.46 26.46	16.39 66.07
7	5.93~ 6.93	18.87 21.36	—— ——	18.87 21.36	26.46 26.46	69.53 121.81
8	6.93~ 7.93	25.07 27.99	—— ——	25.07 27.99	26.46 26.46	99.76 142.58
9	7.93~ 8.93	26.91 29.72	—— ——	26.91 29.72	26.46 26.46	149.71 194.67
10	8.93~ 9.93	34.70 37.98	—— ——	34.70 37.98	26.46 26.46	160.75 197.88
11	9.93~ 10.93	33.83 36.76	—— ——	33.83 36.76	26.46 26.46	228.21 271.03
12	10.93~ 11.93	35.34 38.15	—— ——	35.34 38.15	26.46 26.46	284.59 329.55
13	11.93~ 12.93	21.75 23.35	—— ——	21.75 23.35	26.46 26.46	674.62 766.65
14	12.93~ 20.00	23.35 34.67	—— ——	23.35 34.67	26.46 26.46	766.65 1417.34

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

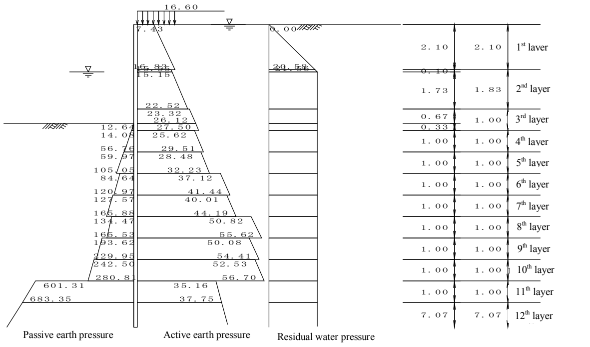
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	16.60 37.60	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	33.0	—— ——	37.60 38.60	20.58 21.56	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
3	2.20~ 3.93	Sandy Soil	10.0	33.0	—— ——	38.60 55.90	21.56 38.51	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
4	3.93~ 4.60	Sandy Soil	10.0	32.0	—— ——	55.90 62.60	38.51 45.08	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
5	4.60~ 4.93	Sandy Soil	10.0	32.0	—— ——	62.60 65.90	45.08 48.31	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
6	4.93~ 5.93	Sandy Soil	10.0	34.0	—— ——	65.90 75.90	48.31 58.11	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
7	5.93~ 6.93	Sandy Soil	10.0	35.0	—— ——	75.90 85.90	58.11 67.91	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
8	6.93~ 7.93	Sandy Soil	10.0	31.0	—— ——	85.90 95.90	67.91 77.71	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
9	7.93~ 8.93	Sandy Soil	10.0	32.0	—— ——	95.90 105.90	77.71 87.51	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
10	8.93~ 9.93	Sandy Soil	10.0	28.0	—— ——	105.90 115.90	87.51 97.31	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
11	9.93~ 10.93	Sandy Soil	10.0	31.0	—— ——	115.90 125.90	97.31 107.11	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
12	10.93~ 11.93	Sandy Soil	10.0	32.0	—— ——	125.90 135.90	107.11 116.91	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
13	11.93~ 12.93	Sandy Soil	10.0	45.0	—— ——	135.90 145.90	116.91 126.71	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	12.93~ 20.00	Sandy Soil	10.0	45.0	—— ——	145.90 216.60	126.71 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	4.60~ 4.93	Sandy soil	10.00	32.0	—— ——	0.000 3.300	0.00 3.23	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
6	4.93~ 5.93	Sandy soil	10.00	34.0	—— ——	3.300 13.300	3.23 13.03	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
7	5.93~ 6.93	Sandy soil	10.00	35.0	—— ——	13.300 23.300	13.03 22.83	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
8	6.93~ 7.93	Sandy soil	10.00	31.0	—— ——	23.300 33.300	22.83 32.63	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
9	7.93~ 8.93	Sandy soil	10.00	32.0	—— ——	33.300 43.300	32.63 42.43	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
10	8.93~ 9.93	Sandy soil	10.00	28.0	—— ——	43.300 53.300	42.43 52.23	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
11	9.93~ 10.93	Sandy soil	10.00	31.0	—— ——	53.300 63.300	52.23 62.03	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
12	10.93~ 11.93	Sandy soil	10.00	32.0	—— ——	63.300 73.300	62.03 71.83	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
13	11.93~ 12.93	Sandy soil	10.00	45.0	—— ——	73.300 83.300	71.83 81.63	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
14	12.93~ 20.00	Sandy soil	10.00	45.0	—— ——	83.300 154.000	81.63 150.92	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

δ= -10.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~ 2.10	7.43 16.83	—— ——	7.43 16.83	0.00 20.58	—— ——
2	2.10~ 2.20	15.15 15.55	—— ——	15.15 15.55	20.58 21.56	—— ——
3	2.20~ 3.93	15.55 22.52	—— ——	15.55 22.52	21.56 21.56	—— ——
4	3.93~ 4.60	23.32 26.12	—— ——	23.32 26.12	21.56 21.56	—— ——
5	4.60~ 4.93	26.12 27.50	—— ——	26.12 27.50	21.56 21.56	0.00 12.64
6	4.93~ 5.93	25.62 29.51	—— ——	25.62 29.51	21.56 21.56	14.08 56.76
7	5.93~ 6.93	28.48 32.23	—— ——	28.48 32.23	21.56 21.56	59.97 105.05
8	6.93~ 7.93	37.12 41.44	—— ——	37.12 41.44	21.56 21.56	84.64 120.97
9	7.93~ 8.93	40.01 44.19	—— ——	40.01 44.19	21.56 21.56	127.57 165.88
10	8.93~ 9.93	50.82 55.62	—— ——	50.82 55.62	21.56 21.56	134.47 165.53
11	9.93~ 10.93	50.08 54.41	—— ——	50.08 54.41	21.56 21.56	193.62 229.95
12	10.93~ 11.93	52.53 56.70	—— ——	52.53 56.70	21.56 21.56	242.50 280.81
13	11.93~ 12.93	35.16 37.75	—— ——	35.16 37.75	21.56 21.56	601.31 683.35
14	12.93~ 20.00	37.75 56.04	—— ——	37.75 56.04	21.56 21.56	683.35 1263.33

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

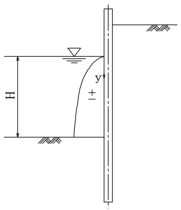
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m^2)
1	2.20	0.00	0.00
2	3.20	1.00	2.66
3	4.20	2.00	3.76
4	4.60	2.40	4.12

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

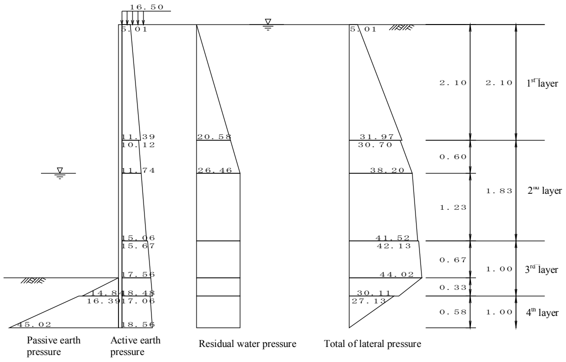
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

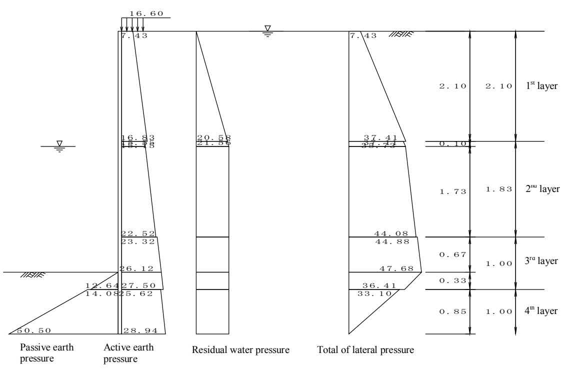


	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	5.01 11.39	0.00 20.58	—— ——	5.01 31.97
2	2.10～ 2.70	10.12 11.74	20.58 26.46	—— ——	30.70 38.20
3	2.70～ 3.93	11.74 15.06	26.46 26.46	—— ——	38.20 41.52
4	3.93～ 4.60	15.67 17.56	26.46 26.46	—— ——	42.13 44.02
5	4.60～ 4.93	17.56 18.48	26.46 26.46	0.00 14.84	44.02 30.11
6	4.93～ 5.51	17.06 18.56	26.46 26.46	16.39 45.02	27.13 0.00
7	5.51～ 5.93	18.56 19.65	26.46 26.46	45.02 66.07	0.00 -19.96

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.91 m (GL -5.51 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	7.43 16.83	0.00 20.58	—— ——	7.43 37.41
2	2.10～ 2.20	15.15 15.55	20.58 21.56	—— ——	35.73 37.11
3	2.20～ 3.93	15.55 22.52	21.56 21.56	—— ——	37.11 44.08
4	3.93～ 4.60	23.32 26.12	21.56 21.56	—— ——	44.88 47.68
5	4.60～ 4.93	26.12 27.50	21.56 21.56	0.00 12.64	47.68 36.41
6	4.93～ 5.78	25.62 28.94	21.56 21.56	14.08 50.50	33.10 0.00
7	5.78～ 5.93	28.94 29.51	21.56 21.56	50.50 56.76	0.00 -5.69

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.18 m (GL -5.78 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m	
Corrosion margin	t_1	=	1.00 mm (active side)	t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86	
Section efficiency	μ	=	1.00	
Young's modulus	E	=	200000 N/mm^2	
Inertia sectional moment	I_0	=	180000 cm^4(original condition)	
	I	=	154800 cm^4(after reduction by corrosion and section)	
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 154800 \times 10^{-8} = 3.096 \times 10^5$	

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	21
4	3.93	21
5	4.93	19
6	5.93	23
7	6.93	28
8	7.93	17
9	8.93	19
10	9.93	12

	Depth (m)	N-value
11	10.93	18
12	11.93	19
13	12.93	50
14	20.00	50

5-2 Normal Condition

K_h = 24725 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.376 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.66 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.51 m) to 2.66 m depth (GL -8.17 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	5.51	0.42	21.3	23.0	9.39
2	5.93	1.00	23.0	28.0	25.50
3	6.93	1.00	28.0	17.0	22.50
4	7.93	0.24	17.0	17.5	4.08
	L =Σh = 2.66			ΣA = 61.46	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$$= \frac{61.46}{2.66}$$

$$= 23.10$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 23.10^{0.406} = 24725$ kN/m³

Kh (normal condition) = 24725 kN/m³

5-3 Seismic Condition

K_h = 24534 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.375 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.67 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.78 m) and 2.67 m depth (GL -8.45 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	5.78	0.15	22.4	23.0	3.33
2	5.93	1.00	23.0	28.0	25.50
3	6.93	1.00	28.0	17.0	22.50
4	7.93	0.52	17.0	18.0	9.09
	L =Σh = 2.67				ΣA = 60.42

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \dfrac{\Sigma A}{L}$

$$= \frac{60.42}{2.67}$$

$$= 22.67$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 22.67^{0.406} = 24534$ kN/m³

Kh (seismic condition) = 24534 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN･m)
1	0.00～ 2.10	2.10	5.01 31.97	5.26 33.57	4.81 4.11	25.29 137.84
2	2.10～ 2.70	0.60	30.70 38.20	9.21 11.46	3.21 3.01	29.53 34.45
3	2.70～ 3.93	1.23	38.20 41.52	23.49 25.54	2.40 1.99	56.30 50.72
4	3.93～ 4.60	0.67	42.13 44.02	14.11 14.75	1.35 1.13	19.09 16.65
5	4.60～ 4.93	0.33	44.02 30.11	7.26 4.97	0.80 0.69	5.78 3.41
6	4.93～ 5.51	0.58	27.13 0.00	7.81 0.00	0.38 0.19	3.00 0.00
				ΣP = 157.44		ΣM = 382.06

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.4 kN/m
depth to acting position	H_t	=	-0.42 m
moment	M_m	=	0.0 kN･m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	0.91 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 14.22 kN･m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{396.29}{159.84} = 2.48 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN･m)
1	0.00～ 2.10	2.10	7.43 37.41	7.80 39.28	5.08 4.38	39.66 172.17
2	2.10～ 2.20	0.10	35.73 37.11	1.79 1.86	3.65 3.62	6.52 6.71
3	2.20～ 3.93	1.73	37.11 44.08	32.10 38.13	3.01 2.43	96.51 92.64
4	3.93～ 4.60	0.67	44.88 47.68	15.04 15.97	1.63 1.41	24.51 22.47
5	4.60～ 4.93	0.33	47.68 36.41	7.87 6.01	1.07 0.96	8.44 5.79
6	4.93～ 5.78	0.85	33.10 0.00	14.12 0.00	0.57 0.28	8.03 0.00
				ΣP = 179.95		ΣM = 483.45

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	7.4 kN/m
depth to acting position	H_t	=	-0.12 m
moment	M_m	=	2.0 kN･m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.18 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 45.68 kN･m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN･m)
1	2.20～ 3.20	1.00	0.0 2.7	0.00 1.33	3.25 2.92	0.00 3.87
2	3.20～ 4.20	1.00	2.7 3.8	1.33 1.88	2.25 1.92	2.99 3.60
3	4.20～ 4.60	0.40	3.8 4.1	0.75 0.82	1.45 1.32	1.09 1.08
				ΣPdw = 6.11		ΣMdw = 12.64

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{541.77}{193.46} = 2.80 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	180000 cm⁴ (original condition)
	I	=	154800 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 154800 × 10⁻⁸		=	3.096 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	24725 kN/m³
calculated value	β	=	0.37590 m⁻¹
resultant earth force (lateral)	P_0	=	159.84 kN/m
height of acting position of load	h_0	=	2.48 m
moment	M_0	=	396.29 kN･m/m

in consideration of ψ_m = 1.163,

maximum moment	M_{max}	=	460.92 kN･m/m
depth of generated position of M_{max}	l_m	=	0.894 m
depth of 1st fixed point	l_i	=	2.983 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	24534 kN/m³
calculated value	β	=	0.37517 m⁻¹
resultant earth force (lateral)	P_0	=	193.46 kN/m
height of acting position of load	h_0	=	2.80 m
moment	M_0	=	541.77 kN･m/m

in consideration of ψ_m = 1.135,

maximum moment	M_{max}	=	615.01 kN･m/m
depth of generated position of M_{max}	l_m	=	0.831 m
depth of 1st fixed point	l_i	=	2.925 m

6-3 <u>Stress Intensity</u>

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	4480 cm^3 (original condition)
	Z	=	3942 cm^3 (after reduction by corrosion and section)

6-3-1 <u>Normal Condition</u>

7

$$\sigma = \frac{M_{max}}{Z} = \frac{460.92\times10^6}{3942\times10^3} = 117\ N/mm^2 \leqq \sigma_a = 185\ N/mm^2 \quad \text{(ok)}$$

7-1-1 <u>Seismic condition</u>

$$\sigma = \frac{M_{max}}{Z} = \frac{615.01\times10^6}{3942\times10^3} = 156\ N/mm^2 \leqq \sigma_a = 278\ N/mm^2 \quad \text{(ok)}$$

7-2 <u>Displacement</u>

7-2-1 <u>Normal Condition</u>

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	4.81 4.11	0.873 0.746	0.270 0.209	5.26 33.57	1.421 7.014
2	2.10～ 2.70	3.21 3.01	0.582 0.546	0.137 0.122	9.21 11.46	1.258 1.397
3	2.70～ 3.93	2.40 1.99	0.435 0.361	0.081 0.057	23.49 25.54	1.902 1.462
4	3.93～ 4.60	1.35 1.13	0.246 0.205	0.028 0.020	14.11 14.75	0.391 0.289
5	4.60～ 4.93	0.80 0.69	0.145 0.125	0.010 0.007	7.26 4.97	0.072 0.037
6	4.93～ 5.51	0.38 0.19	0.070 0.035	0.002 0.001	7.81 0.00	0.019 0.000
						ΣQ = 15.262

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

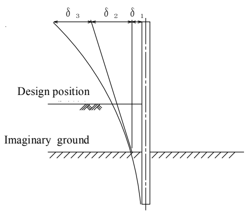
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3759\times2.48)\times159.84}{2\times2.00\times10^8\times154800\times10^{-8}\times0.3759^3} = 0.00939\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3759\times2.48)\times159.84}{2\times2.00\times10^8\times154800\times10^{-8}\times0.3759^2}\times(4.60+0.91) = 0.02881\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.26\times(4.60+0.91)^3}{2.00\times10^8\times154800\times10^{-8}} = 0.00823\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00048 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.51 m
Horizontal load: P = 2.40
Moment: M = 1.01

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00939＋0.02881＋0.00871
= 0.04691 m
= 46.91 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

7-2-2 <u>Seismic Condition</u>

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	5.08 4.38	0.879 0.758	0.273 0.215	7.80 39.28	2.131 8.431
2	2.10～ 2.20	3.65 3.62	0.631 0.625	0.157 0.155	1.79 1.86	0.281 0.287
3	2.20～ 3.93	3.01 2.43	0.520 0.420	0.112 0.076	32.10 38.13	3.586 2.894
4	3.93～ 4.60	1.63 1.41	0.282 0.243	0.036 0.027	15.04 15.97	0.541 0.434
5	4.60～ 4.93	1.07 0.96	0.186 0.167	0.016 0.013	7.87 6.01	0.127 0.079
6	4.93～ 5.78	0.57 0.28	0.098 0.049	0.005 0.001	14.12 0.00	0.066 0.000
						ΣQ = 18.857

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

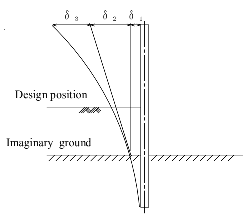
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 3.20	3.25 2.92	0.562 0.504	0.128 0.106	0.00 1.33	0.000 0.141
2	3.20～ 4.20	2.25 1.92	0.389 0.331	0.066 0.049	1.33 1.88	0.087 0.092
3	4.20～ 4.60	1.45 1.32	0.251 0.228	0.029 0.024	0.75 0.82	0.022 0.020
						ΣQ_{dw} = 0.361

Therefore, modulus of deformation Q is calculated as below:
Q = 18.857＋0.361 = 19.219

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3752\times2.80)\times193.46}{2\times2.00\times10^8\times154800\times10^{-8}\times0.3752^3} = 0.01213\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3752\times2.80)\times193.46}{2\times2.00\times10^8\times154800\times10^{-8}\times0.3752^2}\times(4.60+1.18) = 0.03981\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{19.22\times(4.60+1.18)^3}{2.00\times10^8\times154800\times10^{-8}} = 0.01201\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00159 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 5.78 m
Horizontal load: P = 7.40
Moment: M = 0.89

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=5.78\ m、h=L-H_m、H_m=0.80\ m、ただ\ \ )$$

$$= \frac{2.00\times4.98}{2\times2.00\times10^8\times154800\times10^{-8}}\times(2\times5.78-4.98) = 0.00011\ m$$

2.195

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01213 + 0.03981 + 0.01370$
$= 0.06565$ m
$= 65.65 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

Case: Right Bank No. 25_STA 10+956 - 11+050

8 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	180000 cm^4 (original condition)
	I	=	180000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 180000 \times 10^{-8}$		=	3.600×10^5

8-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

8-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 24725$ kN/m^3
Calculated value $\beta = 0.36199$ m^{-1}

Penetration length of SSP $D = 0.91 + \frac{3}{0.362} = 9.19$ m
Whole length of SSP $L = 4.60 - 0.40 + 9.19 = 13.39$ m

8-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 24534$ kN/m^3
Calculated value $\beta = 0.36129$ m^{-1}

Penetration length of SSP $D = 1.18 + \frac{3}{0.361} = 9.49$ m
Whole length of SSP $L = 4.60 - 0.40 + 9.49 = 13.69$ m

Therefore, whole length of SSP is set as 14.00 m in consideration of round unit of SSP length.

Case: Right Bank No. 25_STA 10+956 - 11+050

9 Calculation Result

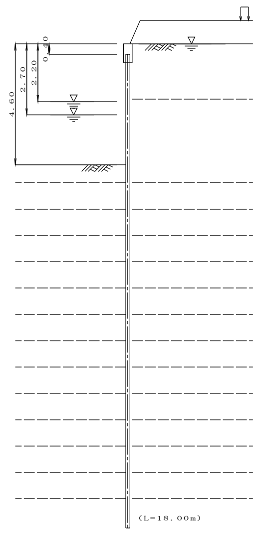
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	180000		
Section modulus	Z (cm^3)	4480		
Maximum bending moment	M_{max} (kN·m/m)		460.92	615.01
Stress intensity	σ (N/mm^2)		117 (185)	156 (278)
Lateral displacement	δ (mm)		46.91 (50.0)	65.65 (75.0)
Penetration depth	D (m)		9.19	9.49
Whole length of SSP	L (m)	14.00		

－Steel Sheet Pile Design Calculation－

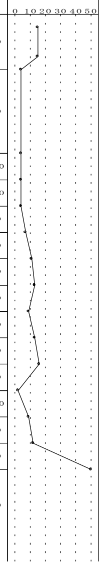
Right Bank No. 26_STA 11+050 - 11+150

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
5.28	Sandy Soil	18.0	27.0	0.0
6.28	Clayey Soil	16.0	0.0	25.0
7.28	Clayey Soil	16.0	0.0	25.0
8.28	Sandy Soil	18.0	27.0	0.0
9.28	Sandy Soil	18.0	28.0	0.0
10.28	Sandy Soil	18.0	29.0	0.0
11.28	Sandy Soil	18.0	27.0	0.0
12.28	Sandy Soil	18.0	29.0	0.0
13.28	Sandy Soil	18.0	30.0	0.0
14.28	Sandy Soil	18.0	27.0	0.0
15.28	Clayey Soil	16.0	0.0	50.0
16.28	Clayey Soil	16.0	0.0	0.0
17.28	Sandy Soil	18.0	45.0	0.0
	Sandy Soil	20.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	4.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.4 kN/m	(Normal Condition)
		Pt'	=	7.5 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.42 m	(Normal Condition)
		Ht'	=	-0.13 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN･m/m	(Normal Condition)
		Mm'	=	2.1 kN･m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	4
4	5.28	4
5	6.28	4
6	7.28	4
7	8.28	7
8	9.28	11
9	10.28	13
10	11.28	9

No	Depth (m)	N-Value
11	12.28	13
12	13.28	16
13	14.28	2
14	15.28	9
15	16.28	12
16	17.28	50
17	20.00	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

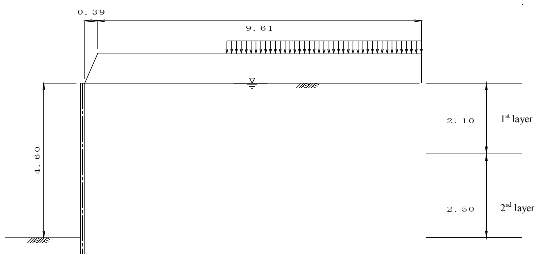
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	5.28	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	6.28	C	4.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
4	7.28	C	4.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
5	8.28	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	9.28	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
7	10.28	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
8	11.28	S	9.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
9	12.28	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
10	13.28	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
11	14.28	S	2.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
12	15.28	C	9.0	16.00	8.00	0.0	50.0	0.0	0.200	auto	auto	——	——
13	16.28	C	12.0	16.00	8.00	0.0	0.0	0.0	0.200	auto	auto	——	——
14	17.28	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
15	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.39	10.00	10.00	0.89	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	4.22	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 429000 cm⁴
Sectional factor Z_0 = 7900 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.86
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 N/mm (Normal)
σ_a' = 278 N/mm (Seismic)

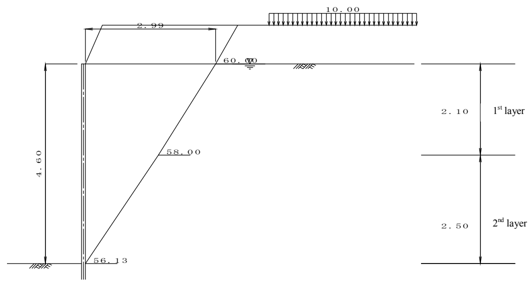
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	4.60～ 2.10	Sandy Soil	27.0	9.0	0.0	46.00	16.35	45.08	56.13
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	16.35	20.58	58.00
3		Embankment	30.0	——	0.0	16.02	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h + 2Q}{2C}}\cdot\tan\theta$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	56.13	2.50	0.00	0.00	1.68	2.50
2	58.00	2.10	1.68	2.50	2.99	4.60
3	60.00	0.89	2.99	4.60	3.50	5.49

Therefore, width of acting load shall be set as 2.99 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.72	48.90
Σ			48.90

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

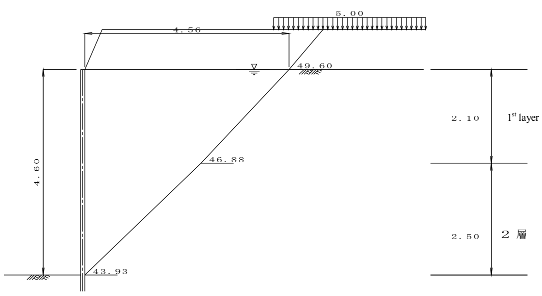
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{48.90 + 0.00 + 0.00}{2.99}$$

$$= 16.35 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	4.60～ 2.10	Sandy Soil	27.0	9.0	0.0	46.00	17.87	45.08	0.200	11.31	43.93
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	17.87	20.58	0.200	11.31	46.88

3		Embankment	30.0	——	0.0	16.02	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.93	2.50	0.00	0.00	2.60	2.50
2	46.88	2.10	2.60	2.50	4.56	4.60
3	49.60	0.89	4.56	4.60	5.32	5.49

Therefore, width of acting load shall be set as 4.56 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.22	76.03
Σ			76.03

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	1.10	5.50
Σ			5.50

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

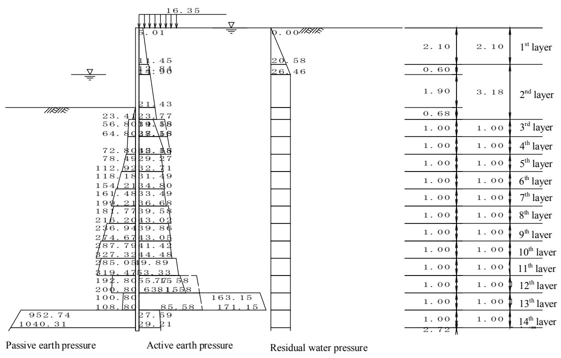
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{76.03 + 5.50 + 0.00}{4.56}$$

$$= 17.87 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	―― ――	16.352 37.352	0.31026 0.31026	0.30644 0.30644
2	2.10～ 2.70	Sandy soil	10.0	27.0	―― ――	37.352 43.352	0.34800 0.34800	0.34371 0.34371
3	2.70～ 4.60	Sandy soil	10.0	27.0	―― ――	43.352 62.352	0.34800 0.34800	0.34371 0.34371
4	4.60～ 5.28	Sandy soil	10.0	27.0	―― ――	62.352 69.152	0.34800 0.34800	0.34371 0.34371
5	5.28～ 6.28	Clayey soil	8.0	―	25.0 25.0	69.152 77.152	―― ――	―― ――
6	6.28～ 7.28	Clayey soil	8.0	―	25.0 25.0	77.152 85.152	―― ――	―― ――
7	7.28～ 8.28	Sandy soil	10.0	27.0	―― ――	85.152 95.152	0.34800 0.34800	0.34371 0.34371
8	8.28～ 9.28	Sandy soil	10.0	28.0	―― ――	95.152 105.152	0.33506 0.33506	0.33093 0.33093
9	9.28～ 10.28	Sandy soil	10.0	29.0	―― ――	105.152 115.152	0.32248 0.32248	0.31851 0.31851
10	10.28～ 11.28	Sandy soil	10.0	27.0	―― ――	115.152 125.152	0.34800 0.34800	0.34371 0.34371
11	11.28～ 12.28	Sandy soil	10.0	29.0	―― ――	125.152 135.152	0.32248 0.32248	0.31851 0.31851
12	12.28～ 13.28	Sandy soil	10.0	30.0	―― ――	135.152 145.152	0.31026 0.31026	0.30644 0.30644
13	13.28～ 14.28	Sandy soil	10.0	27.0	―― ――	145.152 155.152	0.34800 0.34800	0.34371 0.34371

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	14.28～ 15.28	Clayey soil	8.0	―	50.0 50.0	155.152 163.152	―― ――	―― ――
15	15.28～ 16.28	Clayey soil	8.0	―	0.0 0.0	163.152 171.152	―― ――	―― ――
16	16.28～ 17.28	Sandy soil	10.0	45.0	―― ――	171.152 181.152	0.16323 0.16323	0.16122 0.16122
17	17.28～ 20.00	Sandy soil	10.0	45.0	―― ――	181.152 208.352	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	4.60～ 5.28	Sandy soil	10.0	27.0	―― ――	0.000 6.800	3.48553 3.48553	3.44261 3.44261
5	5.28～ 6.28	Clayey soil	8.0	0.0	25.0 25.0	6.800 14.800	―― ――	―― ――
6	6.28～ 7.28	Clayey soil	8.0	0.0	25.0 25.0	14.800 22.800	―― ――	―― ――
7	7.28～ 8.28	Sandy soil	10.0	27.0	―― ――	22.800 32.800	3.48553 3.48553	3.44261 3.44261
8	8.28～ 9.28	Sandy soil	10.0	28.0	―― ――	32.800 42.800	3.64796 3.64796	3.60305 3.60305
9	9.28～ 10.28	Sandy soil	10.0	29.0	―― ――	42.800 52.800	3.82002 3.82002	3.77299 3.77299
10	10.28～ 11.28	Sandy soil	10.0	27.0	―― ――	52.800 62.800	3.48553 3.48553	3.44261 3.44261
11	11.28～ 12.28	Sandy soil	10.0	29.0	―― ――	62.800 72.800	3.82002 3.82002	3.77299 3.77299
12	12.28～ 13.28	Sandy soil	10.0	30.0	―― ――	72.800 82.800	4.00247 4.00247	3.95319 3.95319
13	13.28～ 14.28	Sandy soil	10.0	27.0	―― ――	82.800 92.800	3.48553 3.48553	3.44261 3.44261
14	14.28～ 15.28	Clayey soil	8.0	0.0	50.0 50.0	92.800 100.800	―― ――	―― ――
15	15.28～ 16.28	Clayey soil	8.0	0.0	0.0 0.0	100.800 108.800	―― ――	―― ――
16	16.28～ 17.28	Sandy soil	10.0	45.0	―― ――	108.800 118.800	8.86593 8.86593	8.75678 8.75678
17	17.28～ 20.00	Sandy soil	10.0	45.0	―― ――	118.800 146.000	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	5.01 11.45	―― ――	5.01 11.45	0.00 20.58	―― ――
2	2.10～ 2.70	12.84 14.90	―― ――	12.84 14.90	20.58 26.46	―― ――
3	2.70～ 4.60	14.90 21.43	―― ――	14.90 21.43	26.46 26.46	―― ――
4	4.60～ 5.28	21.43 23.77	―― ――	21.43 23.77	26.46 26.46	0.00 23.41
5	5.28～ 6.28	19.15 27.15	34.58 38.58	34.58 38.58	26.46 26.46	56.80 64.80
6	6.28～ 7.28	27.15 35.15	38.58 42.58	38.58 42.58	26.46 26.46	64.80 72.80
7	7.28～ 8.28	29.27 32.71	―― ――	29.27 32.71	26.46 26.46	78.49 112.92
8	8.28～ 9.28	31.49 34.80	―― ――	31.49 34.80	26.46 26.46	118.18 154.21
9	9.28～ 10.28	33.49 36.68	―― ――	33.49 36.68	26.46 26.46	161.48 199.21
10	10.28～ 11.28	39.58 43.02	―― ――	39.58 43.02	26.46 26.46	181.77 216.20
11	11.28～ 12.28	39.86 43.05	―― ――	39.86 43.05	26.46 26.46	236.94 274.67
12	12.28～ 13.28	41.42 44.48	―― ――	41.42 44.48	26.46 26.46	287.79 327.32
13	13.28～ 14.28	49.89 53.33	―― ――	49.89 53.33	26.46 26.46	285.05 319.47
14	14.28～ 15.28	55.15 63.15	77.58 81.58	77.58 81.58	26.46 26.46	192.80 200.80
15	15.28～ 16.28	163.15 171.15	81.58 85.58	163.15 171.15	26.46 26.46	100.80 108.80
16	16.28～ 17.28	27.59 29.21	―― ――	27.59 29.21	26.46 26.46	952.74 1040.31
17	17.28～ 20.00	29.21 33.59	―― ――	29.21 33.59	26.46 26.46	1040.31 1278.49

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

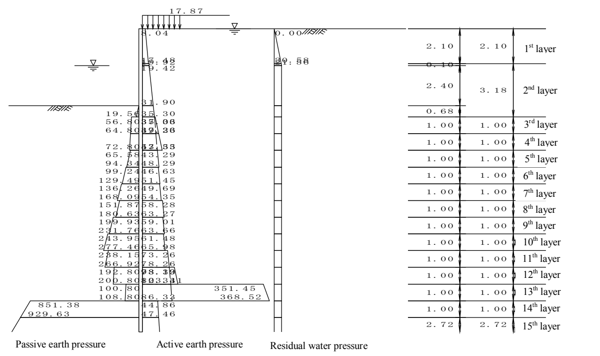
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	―― ――	17.87 38.87	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	―― ――
2	2.10～ 2.20	Sandy Soil	10.0	27.0	―― ――	38.87 39.87	20.58 21.56	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
3	2.20～ 4.60	Sandy Soil	10.0	27.0	―― ――	39.87 63.87	21.56 45.08	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
4	4.60～ 5.28	Sandy Soil	10.0	27.0	―― ――	63.87 70.67	45.08 51.74	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
5	5.28～ 6.28	Clayey Soil	8.0	―	25.0 25.0	70.67 78.67	51.74 61.54	0.200 0.200	11.31 11.31	―― ――	―― ――	38.79 38.08
6	6.28～ 7.28	Clayey Soil	8.0	―	25.0 25.0	78.67 86.67	61.54 71.34	0.200 0.200	11.31 11.31	―― ――	―― ――	38.08 37.34
7	7.28～ 8.28	Sandy Soil	10.0	27.0	―― ――	86.67 96.67	71.34 81.14	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
8	8.28～ 9.28	Sandy Soil	10.0	28.0	―― ――	96.67 106.67	81.14 90.94	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	―― ――
9	9.28～ 10.28	Sandy Soil	10.0	29.0	―― ――	106.67 116.67	90.94 100.74	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	―― ――
10	10.28～ 11.28	Sandy Soil	10.0	27.0	―― ――	116.67 126.67	100.74 110.54	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――
11	11.28～ 12.28	Sandy Soil	10.0	29.0	―― ――	126.67 136.67	110.54 120.34	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	―― ――
12	12.28～ 13.28	Sandy Soil	10.0	30.0	―― ――	136.67 146.67	120.34 130.14	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	―― ――
13	13.28～ 14.28	Sandy Soil	10.0	27.0	―― ――	146.67 156.67	130.14 139.94	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	―― ――

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	14.28～ 15.28	Clayey Soil	8.0	—	50.0 50.0	156.67 164.67	139.94 149.74	0.200 0.200	11.31 11.31	—— ——	—— ——	38.90 38.55
15	15.28～ 16.28	Clayey Soil	8.0	—	0.0 0.0	164.67 172.67	149.74 159.54	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
16	16.28～ 17.28	Sandy Soil	10.0	45.0	—— ——	172.67 182.67	159.54 169.34	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——
17	17.28～ 20.00	Sandy Soil	10.0	45.0	—— ——	182.67 209.87	169.34 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	4.60～ 5.28	Sandy soil	10.00	27.0	—— ——	0.000 6.800	0.00 6.66	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	5.28～ 6.28	Clayey soil	8.00	0.0	25.0 25.0	6.800 14.800	6.66 16.46	0.200 0.200	11.31 11.31	—— ——	—— ——
6	6.28～ 7.28	Clayey soil	8.00	0.0	25.0 25.0	14.800 22.800	16.46 26.26	0.200 0.200	11.31 11.31	—— ——	—— ——
7	7.28～ 8.28	Sandy soil	10.00	27.0	—— ——	22.800 32.800	26.26 36.06	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	8.28～ 9.28	Sandy soil	10.00	28.0	—— ——	32.800 42.800	36.06 45.86	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
9	9.28～ 10.28	Sandy soil	10.00	29.0	—— ——	42.800 52.800	45.86 55.66	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
10	10.28～ 11.28	Sandy soil	10.00	27.0	—— ——	52.800 62.800	55.66 65.46	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
11	11.28～ 12.28	Sandy soil	10.00	29.0	—— ——	62.800 72.800	65.46 75.26	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
12	12.28～ 13.28	Sandy soil	10.00	30.0	—— ——	72.800 82.800	75.26 85.06	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
13	13.28～ 14.28	Sandy soil	10.00	27.0	—— ——	82.800 92.800	85.06 94.86	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
14	14.28～ 15.28	Clayey soil	8.00	0.0	50.0 50.0	92.800 100.800	94.86 104.66	0.200 0.200	11.31 11.31	—— ——	—— ——
15	15.28～ 16.28	Clayey soil	8.00	0.0	0.0 0.0	100.800 108.800	104.66 114.46	0.200 0.200	11.31 11.31	—— ——	—— ——
16	16.28～ 17.28	Sandy soil	10.00	45.0	—— ——	108.800 118.800	114.46 124.26	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515
17	17.28～ 20.00	Sandy soil	10.00	45.0	—— ——	118.800 146.000	124.26 150.92	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	8.04 17.48	—— ——	8.04 17.48	0.00 20.58	—— ——
2	2.10～ 2.20	19.42 19.92	—— ——	19.42 19.92	20.58 21.56	—— ——
3	2.20～ 4.60	19.92 31.90	—— ——	19.92 31.90	21.56 21.56	—— ——
4	4.60～ 5.28	31.90 35.30	—— ——	31.90 35.30	21.56 21.56	0.00 19.56
5	5.28～ 6.28	37.06 47.26	35.33 39.33	37.06 47.26	21.56 21.56	56.80 64.80
6	6.28～ 7.28	47.26 57.55	39.33 43.33	47.26 57.55	21.56 21.56	64.80 72.80
7	7.28～ 8.28	43.29 48.29	—— ——	43.29 48.29	21.56 21.56	65.58 94.34
8	8.28～ 9.28	46.63 51.45	—— ——	46.63 51.45	21.56 21.56	99.24 129.49
9	9.28～ 10.28	49.69 54.35	—— ——	49.69 54.35	21.56 21.56	136.26 168.09
10	10.28～ 11.28	58.28 63.27	—— ——	58.28 63.27	21.56 21.56	151.87 180.63
11	11.28～ 12.28	59.01 63.66	—— ——	59.01 63.66	21.56 21.56	199.93 231.76
12	12.28～ 13.28	61.48 65.98	—— ——	61.48 65.98	21.56 21.56	243.95 277.46
13	13.28～ 14.28	73.26 78.26	—— ——	73.26 78.26	21.56 21.56	238.15 266.92
14	14.28～ 15.28	93.19 103.41	78.33 82.33	93.19 103.41	21.56 21.56	192.80 200.80
15	15.28～ 16.28	351.45 368.52	82.33 86.33	351.45 368.52	21.56 21.56	100.80 108.80
16	16.28～ 17.28	44.86 47.46	—— ——	44.86 47.46	21.56 21.56	851.38 929.63
17	17.28～ 20.00	47.46 54.52	—— ——	47.46 54.52	21.56 21.56	929.63 1142.47

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = \left[K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}\right] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = \left[K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}\right] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	3.20	1.00	2.66
3	4.20	2.00	3.76
4	4.60	2.40	4.12

$$p_{dw} = \pm\frac{7}{8}\, k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

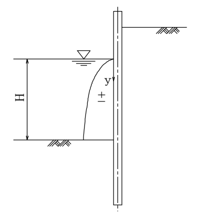
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

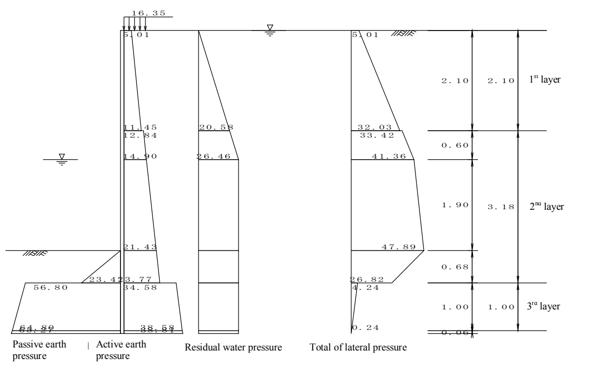
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	5.01 11.45	0.00 20.58	—— ——	5.01 32.03
2	2.10～ 2.70	12.84 14.90	20.58 26.46	—— ——	33.42 41.36
3	2.70～ 4.60	14.90 21.43	26.46 26.46	—— ——	41.36 47.89
4	4.60～ 5.28	21.43 23.77	26.46 26.46	0.00 23.41	47.89 26.82
5	5.28～ 6.28	34.58 38.58	26.46 26.46	56.80 64.80	4.24 0.24
6	6.28～ 6.34	38.58 38.81	26.46 26.46	64.80 65.27	0.24 0.00
7	6.34～ 7.28	38.81 42.58	26.46 26.46	65.27 72.80	0.00 -3.76

P_a : Active earth pressure

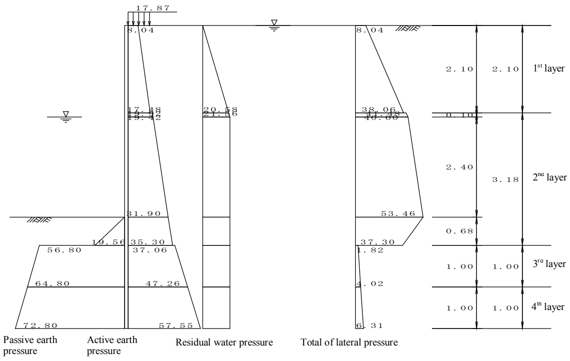
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.74 m (GL -6.34 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	8.04 17.48	0.00 20.58	—— ——	8.04 38.06
2	2.10～ 2.20	19.42 19.92	20.58 21.56	—— ——	40.00 41.48
3	2.20～ 4.60	19.92 31.90	21.56 21.56	—— ——	41.48 53.46
4	4.60～ 5.28	31.90 35.30	21.56 21.56	0.00 19.56	53.46 37.30
5	5.28～ 6.28	37.06 47.26	21.56 21.56	56.80 64.80	1.82 4.02
6	6.28～ 7.28	47.26 57.55	21.56 21.56	64.80 72.80	4.02 6.31
7	7.28～ 8.28	43.29 48.29	21.56 21.56	65.58 94.34	-0.73 -24.49

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.68 m (GL -7.28 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$K_h = 6910 \times N'^{0.406}$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	429000 cm⁴(original condition)
	I	=	368940 cm⁴(after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 368940 \times 10^{-8} = 7.379 \times 10^5$

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	12.28	13
2	1.60	15	12	13.28	16
3	2.10	4	13	14.28	2
4	5.28	4	14	15.28	9
5	6.28	4	15	16.28	12
6	7.28	4	16	17.28	50
7	8.28	7	17	20.00	50
8	9.28	11			
9	10.28	13			
10	11.28	9			

5-2 Normal Condition

K_h = 15544 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.269 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.71 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.34 m) to 3.71 m depth (GL -10.05 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	6.34	0.94	4.0	4.0	3.76
2	7.28	1.00	4.0	7.0	5.50
3	8.28	1.00	7.0	11.0	9.00
4	9.28	0.77	11.0	12.5	9.08
	L =Σh = 3.71			ΣA = 27.34	

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{27.34}{3.71} = 7.36$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 7.36^{0.406} = 15544$ kN/m³
Kh (normal condition) = 15544 kN/m³

5-3 Seismic Condition

K_h = 17114 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.276 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 3.62 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -7.28 m) and 3.62 m depth (GL -10.90 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	7.28	1.00	4.0	7.0	5.50
2	8.28	1.00	7.0	11.0	9.00
3	9.28	1.00	11.0	13.0	12.00
4	10.28	0.62	13.0	10.5	7.33
	L =Σh = 3.62			ΣA = 33.83	

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{33.83}{3.62} = 9.34$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 9.34^{0.406} = 17114$ kN/m³
Kh (seismic condition) = 17114 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	5.01 32.03	5.26 33.63	5.64 4.94	29.67 166.08
2	2.10～ 2.70	0.60	33.42 41.36	10.03 12.41	4.04 3.84	40.49 47.63
3	2.70～ 4.60	1.90	41.36 47.89	39.29 45.50	3.01 2.37	118.10 107.93
4	4.60～ 5.28	0.68	47.89 26.82	16.28 9.12	1.51 1.29	24.62 11.72
5	5.28～ 6.28	1.00	4.24 0.24	2.12 0.12	0.73 0.39	1.54 0.05
6	6.28～ 6.34	0.06	0.24 0.00	0.01 0.00	0.04 0.02	0.00 0.00
				ΣP = 173.76		ΣM = 547.84

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.4 kN/m
depth to acting position	H_t	=	-0.42 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.74 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 16.22$ kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{564.06}{176.16} = 3.20 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	8.04 38.06	8.44 39.97	6.58 5.88	55.54 235.01
2	2.10～ 2.20	0.10	40.00 41.48	2.00 2.07	5.15 5.11	10.29 10.60
3	2.20～ 4.60	2.40	41.48 53.46	49.77 64.16	4.28 3.48	213.02 223.27
4	4.60～ 5.28	0.68	53.46 37.30	18.18 12.68	2.45 2.23	44.60 28.24
5	5.28～ 6.28	1.00	1.82 4.02	0.91 2.01	1.67 1.33	1.51 2.68
6	6.28～ 7.28	1.00	4.02 6.31	2.01 3.16	0.67 0.33	1.34 1.05
				ΣP = 205.35		ΣM = 827.15

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 7.5 kN/m
depth to acting position H_t = -0.13 m
moment M_m = 2.1 kN·m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 4.60 m
Depth of Imaginary riverbed from riverbed L_k = 2.68 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 57.67 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 3.20	1.00	0.0 2.7	0.00 1.33	4.75 4.41	0.00 5.86
2	3.20～ 4.20	1.00	2.7 3.8	1.33 1.88	3.75 3.41	4.98 6.41
3	4.20～ 4.60	0.40	3.8 4.1	0.75 0.82	2.95 2.81	2.21 2.32
				ΣPdw = 6.11		ΣMdw = 21.78

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{906.60}{218.96} = 4.14 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 1.00
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 429000 cm⁴ (original condition)
I = 429000 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 429000 \times 10^{-8}$ = 8.580×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 15544 kN/m³
calculated value β = 0.25942 m⁻¹
resultant earth force (lateral) P_0 = 176.16 kN/m
height of acting position of load h_0 = 3.20 m
moment M_0 = 564.06 kN·m/m

in consideration of ψ_m = 1.195,
maximum moment M_{max} = 673.83 kN·m/m
depth of generated position of M_{max} l_m = 1.386 m
depth of 1st fixed point l_i = 4.413 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 17114 kN/m³
calculated value β = 0.26574 m⁻¹
resultant earth force (lateral) P_0 = 218.96 kN/m
height of acting position of load h_0 = 4.14 m
moment M_0 = 906.60 kN·m/m

in consideration of ψ_m = 1.126,
maximum moment M_{max} = 1020.51 kN·m/m
depth of generated position of M_{max} l_m = 1.140 m
depth of 1st fixed point l_i = 4.095 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 1.00
Module of section Z_0 = 7900 cm³ (original condition)
Z = 6952 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{673.83 \times 10^6}{6952 \times 10^3} = 97 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{1020.51 \times 10^6}{6952 \times 10^3} = 147 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

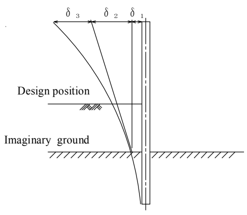
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	5.64 4.94	0.890 0.779	0.278 0.225	5.26 33.63	1.464 7.556
2	2.10～ 2.70	4.04 3.84	0.637 0.606	0.160 0.146	10.03 12.41	1.603 1.816
3	2.70～ 4.60	3.01 2.37	0.474 0.374	0.095 0.061	39.29 45.50	3.719 2.789
4	4.60～ 5.28	1.51 1.29	0.239 0.203	0.026 0.019	16.28 9.12	0.427 0.175
5	5.28～ 6.28	0.73 0.39	0.114 0.062	0.006 0.002	2.12 0.12	0.013 0.000
6	6.28～ 6.34	0.04 0.02	0.006 0.003	0.000 0.000	0.01 0.00	0.000 0.000
						ΣQ = 19.562

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.2594\times3.20)\times176.16}{2\times2.00\times10^8\times429000\times10^{-8}\times0.2594^3} = 0.01076 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.2594\times3.20)\times176.16}{2\times2.00\times10^8\times429000\times10^{-8}\times0.2594^2} \times (4.60+1.74) = 0.02573 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{19.56\times(4.60+1.74)^3}{2.00\times10^8\times429000\times10^{-8}} = 0.00581 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00026 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 6.34 m
Horizontal load: P = 2.40
Moment: M = 1.01

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01076＋0.02573＋0.00607
= 0.04257 m
= 42.57 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	6.58 5.88	0.904 0.808	0.285 0.238	8.44 39.97	2.409 9.527
2	2.10～ 2.20	5.15 5.11	0.707 0.702	0.191 0.189	2.00 2.07	0.382 0.392
3	2.20～ 4.60	4.28 3.48	0.588 0.478	0.139 0.096	49.77 64.16	6.916 6.162
4	4.60～ 5.28	2.45 2.23	0.337 0.306	0.050 0.042	18.18 12.68	0.916 0.533
5	5.28～ 6.28	1.67 1.33	0.229 0.183	0.024 0.016	0.91 2.01	0.022 0.032
6	6.28～ 7.28	0.67 0.33	0.092 0.046	0.004 0.001	2.01 3.16	0.008 0.003
						ΣQ = 27.301

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

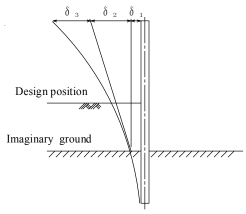
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 3.20	4.75 4.41	0.652 0.606	0.166 0.147	0.00 1.33	0.000 0.195
2	3.20～ 4.20	3.75 3.41	0.515 0.469	0.110 0.093	1.33 1.88	0.146 0.174
3	4.20～ 4.60	2.95 2.81	0.405 0.386	0.071 0.065	0.75 0.82	0.053 0.054
						ΣQ_{dw} = 0.622

Therefore, modulus of deformation Q is calculated as below:

Q = 27.301＋0.622 ＝ 27.923

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.2657\times4.14)\times218.96}{2\times2.00\times10^8\times429000\times10^{-8}\times0.2657^3} = 0.01428\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.2657\times4.14)\times218.96}{2\times2.00\times10^8\times429000\times10^{-8}\times0.2657^2}\times(4.60+2.68) = 0.04210\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{27.92\times(4.60+2.68)^3}{2.00\times10^8\times429000\times10^{-8}} = 0.01256\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00115 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 7.28 m
Horizontal load: P = 7.50
Moment: M = 0.98

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h)$$ （L＝7.28 m、h＝L－H_m、H_m＝0.80 m、ただ ）

$$= \frac{2.10\times6.48}{2\times2.00\times10^8\times429000\times10^{-8}}\times(2\times7.28-6.48) = 0.00006\ \text{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01428 + 0.04210 + 0.01377$
$= 0.07016$ m
$= 70.16 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	429000 cm^4 (original condition)
	I	=	368940 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 368940 × 10^{-8}		=	7.379 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 15544 kN/m^3
Calculated value β = 0.26939 m^{-1}

Penetration length of SSP $D = 1.74 + \dfrac{3}{0.269} = 12.88$ m
Whole length of SSP $L = 4.60 - 0.40 + 12.88 = 17.08$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 17114 kN/m^3
Calculated value β = 0.27595 m^{-1}

Penetration length of SSP $D = 2.68 + \dfrac{3}{0.276} = 13.55$ m
Whole length of SSP $L = 4.60 - 0.40 + 13.55 = 17.75$ m

Therefore, whole length of SSP is set as 18.00 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	429000		
Section modulus	Z (cm^3)	7900		
Maximum bending moment	M_{max} (kN·m/m)		673.83	1020.51
Stress intensity	σ (N/mm^2)		97 (185)	147 (278)
Lateral displacement	δ (mm)		42.57 (50.0)	70.16 (75.0)
Penetration depth	D (m)		12.88	13.55
Whole length of SSP	L (m)	18.00		

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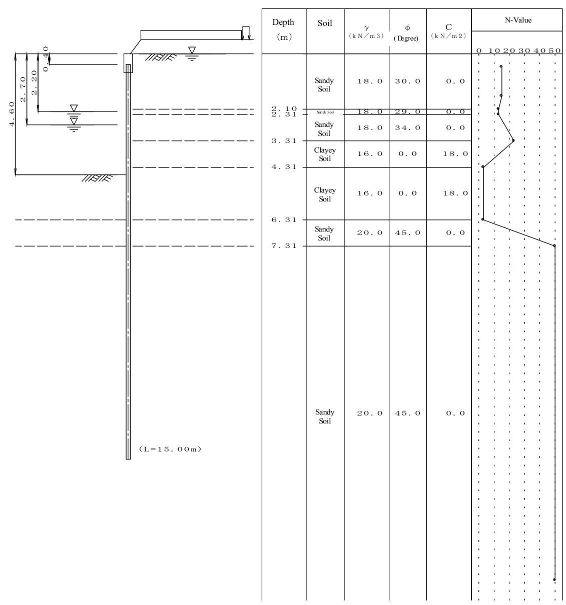
－Steel Sheet Pile　Design Calculation－

Right Bank No. 27_STA 11+150 - 11+263

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	4.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　γ_w = 9.8 kNm^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	2.4 kNm	(Normal Condition)
		Pt'	=	7.5 kNm	(Seismic Condition)
	Depth of acting point	H	=	-0.42 m	(Normal Condition)
		H'	=	-0.13 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	2.1 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　ζ_0 = 10 degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N'^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	13			
4	2.31	13			
5	3.31	23			
6	4.31	3			
7	6.31	3			
8	7.31	50			
9	20.00	50			

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

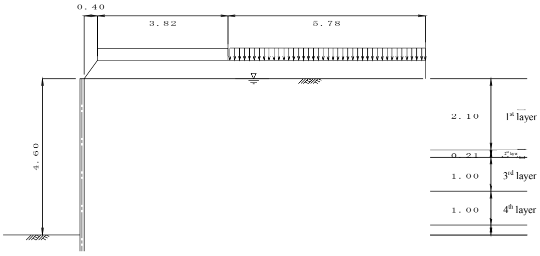
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ(degree) normal	ζ(degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.31	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
3	3.31	S	23.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
4	4.31	C	3.0	16.00	10.00	0.0	18.0	0.0	0.200	auto	auto	——	——
5	6.31	C	3.0	16.00	10.00	0.0	18.0	0.0	0.200	auto	auto	——	——
6	7.31	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
7	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.40	10.00	10.00	0.54	18.0	30.0	0.0	auto	auto
2	Sandy soil	0.40	0.40	4.22	4.22	0.35	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	4.27	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 305000 cm^4
Sectional factor Z_0 = 6220 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.86
Corrosion rate (to Z_0) η = 0.89
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

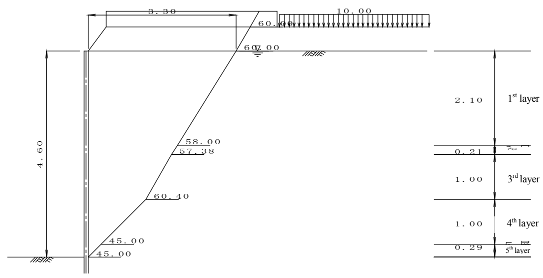
Allowable stress σ_a = 185 Nmm (Normal)
σ_a' = 278 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	4.60～ 4.31	Clayey Soil	0.0	9.0	18.0	46.00	15.91	45.08	45.00
2	4.31～ 3.31	Clayey Soil	0.0	9.0	18.0	43.10	15.91	42.24	45.00
3	3.31～ 2.31	Sandy Soil	34.0	9.0	0.0	33.10	15.91	32.44	60.40
4	2.31～ 2.10	Sandy Soil	29.0	9.0	0.0	23.10	15.91	22.64	57.38
5	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	15.91	20.58	58.00
6		Embankment	30.0	——	0.0	16.02	0.00	0.00	60.00
7		Embankment	30.0	——	0.0	6.30	0.00	0.00	60.00

• Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

• Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where.
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.29	0.00	0.00	0.29	0.29
2	45.00	1.00	0.29	0.29	1.29	1.29
3	60.40	1.00	1.29	1.29	1.86	2.29
4	57.38	0.21	1.86	2.29	1.99	2.50
5	58.00	2.10	1.99	2.50	3.30	4.60
6	60.00	0.54	3.30	4.60	3.62	5.14
7	60.00	0.35	3.62	5.14	3.82	5.49

Therefore, width of acting load shall be set as 3.30 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.76	31.69
2	18.0	1.16	20.90
Σ			52.60

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

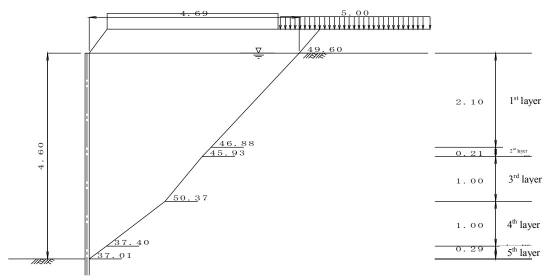
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{52.60 + 0.00 + 0.00}{3.30}$$

$$= 15.91 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	4.60～ 4.31	Clayey Soil	0.0	9.0	18.0	46.00	15.85	45.08	0.200	11.31	37.01
2	4.31～ 3.31	Clayey Soil	0.0	9.0	18.0	43.10	15.85	42.24	0.200	11.31	37.40
3	3.31～ 2.31	Sandy Soil	34.0	9.0	0.0	33.10	15.85	32.44	0.200	11.31	50.37
4	2.31～ 2.10	Sandy Soil	29.0	9.0	0.0	23.10	15.85	22.64	0.200	11.31	45.93
5	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	15.85	20.58	0.200	11.31	46.88
6		Embankment	30.0	——	0.0	16.02	0.00	0.00	0.200	11.31	49.60

• Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where.
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	37.01	0.29	0.00	0.00	0.38	0.29
2	37.40	1.00	0.38	0.29	1.69	1.29
3	50.37	1.00	1.69	1.29	2.52	2.29
4	45.93	0.21	2.52	2.29	2.72	2.50
5	46.88	2.10	2.72	2.50	4.69	4.60
6	49.60	0.54	4.69	4.60	5.15	5.14

Therefore, width of acting load shall be set as 4.69 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.55	45.88
2	18.0	1.34	24.07
Σ			69.95

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	0.88	4.40
Σ			4.40

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

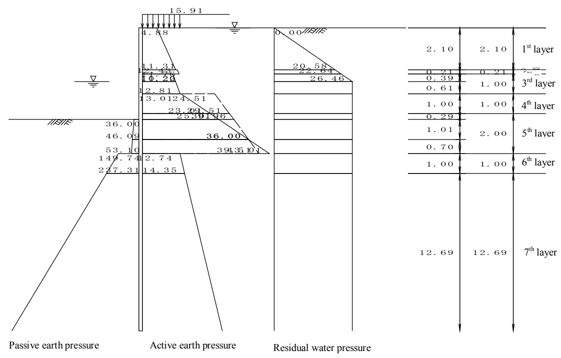
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{69.95 + 4.40 + 0.00}{4.69}$$

$$= 15.85 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m³)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	— —	15.915 36.915	0.31026 0.31026	0.30644 0.30644
2	2.10～ 2.31	Sandy soil	10.0	29.0	— —	36.915 39.015	0.32248 0.32248	0.31851 0.31851
3	2.31～ 2.70	Sandy soil	10.0	34.0	— —	39.015 42.915	0.26470 0.26470	0.26144 0.26144
4	2.70～ 3.31	Sandy soil	10.0	34.0	— —	42.915 49.015	0.26470 0.26470	0.26144 0.26144
5	3.31～ 4.31	Clayey soil	10.0	—	18.0 18.0	49.015 59.015	— —	— —
6	4.31～ 4.60	Clayey soil	10.0	—	18.0 18.0	59.015 61.915	— —	— —
7	4.60～ 5.61	Clayey soil	10.0	—	18.0 18.0	61.915 72.000	— —	— —
8	5.61～ 6.31	Clayey soil	10.0	—	18.0 18.0	72.000 79.015	— —	— —
9	6.31～ 7.31	Sandy soil	10.0	45.0	— —	79.015 89.015	0.16323 0.16323	0.16122 0.16122
10	7.31～ 20.00	Sandy soil	10.0	45.0	— —	89.015 215.915	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m³)	Kp	Kp ×cosδ
7	4.60～ 5.61	Clayey soil	10.0	0.0	18.0 18.0	0.000 10.085	— —	— —
8	5.61～ 6.31	Clayey soil	10.0	0.0	18.0 18.0	10.085 17.100	— —	— —
9	6.31～ 7.31	Sandy soil	10.0	45.0	— —	17.100 27.100	8.86593 8.86593	8.75678 8.75678
10	7.31～ 20.00	Sandy soil	10.0	45.0	— —	27.100 154.000	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below,
$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	4.88 11.31	— —	4.88 11.31	0.00 20.58	— —
2	2.10～ 2.31	11.76 12.43	— —	11.76 12.43	20.58 22.64	— —
3	2.31～ 2.70	10.20 11.22	— —	10.20 11.22	22.64 26.46	— —
4	2.70～ 3.31	11.22 12.81	— —	11.22 12.81	26.46 26.46	— —
5	3.31～ 4.31	13.01 23.01	24.51 29.51	24.51 29.51	26.46 26.46	— —
6	4.31～ 4.60	23.01 25.91	29.51 30.96	29.51 30.96	26.46 26.46	— —
7	4.60～ 5.61	25.91 36.00	30.96 36.00	30.96 36.00	26.46 26.46	36.00 46.09
8	5.61～ 6.31	36.00 43.01	36.00 39.51	36.00 43.01	26.46 26.46	46.09 53.10
9	6.31～ 7.31	12.74 14.35	— —	12.74 14.35	26.46 26.46	149.74 237.31
10	7.31～ 20.00	14.35 34.81	— —	14.35 34.81	26.46 26.46	237.31 1348.54

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

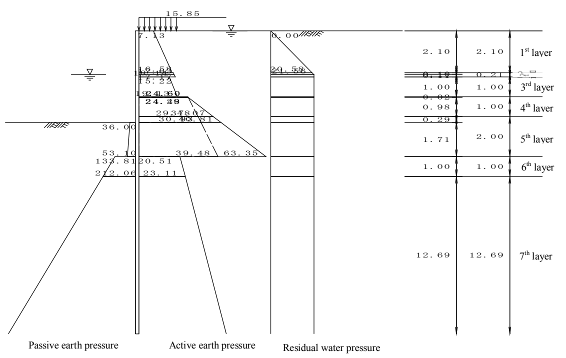
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m³)	γwhw (kN/m³)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	— —	15.85 36.85	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	— —
2	2.10～ 2.20	Sandy Soil	10.0	29.0	— —	36.85 37.85	20.58 21.56	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	— —
3	2.20～ 2.31	Sandy Soil	10.0	29.0	— —	37.85 38.95	21.56 22.64	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	— —
4	2.31～ 3.31	Sandy Soil	10.0	34.0	— —	38.95 48.95	22.64 32.44	0.200 0.200	11.31 11.31	0.39559 0.39559	0.39072 0.39072	— —
5	3.31～ 3.33	Clayey Soil	10.0	—	18.0 18.0	48.95 49.19	32.44 —	0.200 —	11.31 —	— —	— —	38.66 —
6	3.33～ 4.31	Clayey Soil	10.0	—	18.0 18.0	49.19 58.95	— 42.24	— 0.200	— 11.31	— —	— —	— 37.40

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm³)	γwhw (kNm³)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	4.31〜 4.60	Clayey Soil	10.0	—	18.0 18.0	58.95 61.85	42.24 45.08	0.200 0.200	11.31 11.31	—— ——	—— ——	37.40 37.01
8	4.60〜 6.31	Clayey Soil	10.0	—	18.0 18.0	61.85 78.95	45.08 61.84	0.200 0.200	11.31 11.31	—— ——	—— ——	37.01 34.53
9	6.31〜 7.31	Sandy Soil	10.0	45.0	—— ——	78.95 88.95	61.84 71.64	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——
10	7.31〜 20.00	Sandy Soil	10.0	45.0	—— ——	88.95 215.85	71.64 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ= 9.00、β= 0.00、θ= 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm³)	γwhw (kNm³)	k (k')	θ (degree)	Kp	Kp ×cosδ
8	4.60〜 6.31	Clayey soil	10.00	0.0	18.0 18.0	0.000 17.100	0.00 16.76	0.200 0.200	11.31 11.31	—— ——	—— ——
9	6.31〜 7.31	Sandy soil	10.00	45.0	—— ——	17.100 27.100	16.76 26.56	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515
10	7.31〜 20.00	Sandy soil	10.00	45.0	—— ——	27.100 154.000	26.56 150.92	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.
δ= -9.00、β= 0.00、θ= $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00〜 2.10	7.13 16.58	—— ——	7.13 16.58	0.00 20.58	—— ——
2	2.10〜 2.20	17.17 17.63	—— ——	17.17 17.63	20.58 21.56	—— ——
3	2.20〜 2.31	17.63 18.14	—— ——	17.63 18.14	21.56 21.56	—— ——
4	2.31〜 3.31	15.22 19.13	—— ——	15.22 19.13	21.56 21.56	—— ——
5	3.31〜 3.33	24.29 24.60	24.48 24.60	24.48 24.60	21.56 21.56	—— ——

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
6	3.33〜 4.31	24.60 37.07	24.60 29.48	24.60 37.07	21.56 21.56	—— ——
7	4.31〜 4.60	37.07 40.81	29.48 30.93	37.07 40.81	21.56 21.56	—— ——
8	4.60〜 6.31	40.81 63.35	30.93 39.48	40.81 63.35	21.56 21.56	36.00 53.10
9	6.31〜 7.31	20.51 23.11	—— ——	20.51 23.11	21.56 21.56	133.81 212.06
10	7.31〜 20.00	23.11 56.08	—— ——	23.11 56.08	21.56 21.56	212.06 1205.07

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$
$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

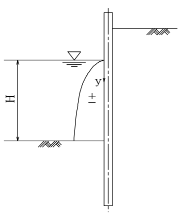
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.20	0.00	0.00
2	3.20	1.00	2.66
3	4.20	2.00	3.76
4	4.60	2.40	4.12

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where,

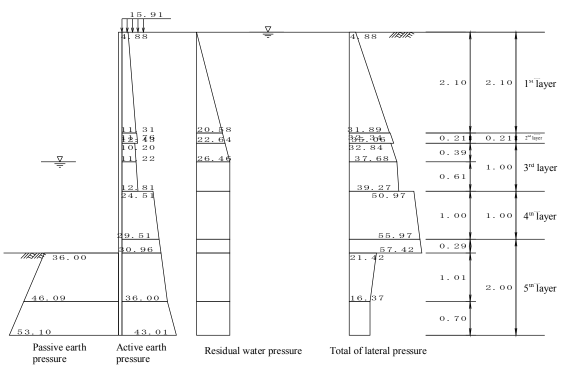
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

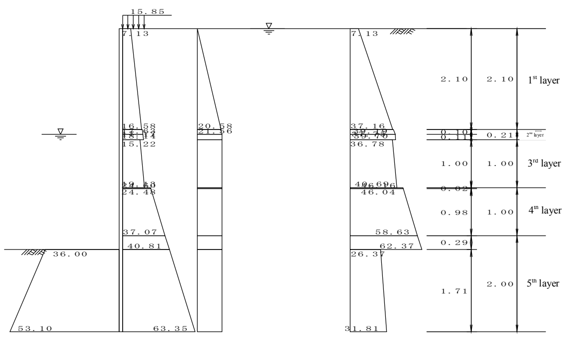


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00〜 2.10	4.88 11.31	0.00 20.58	—— ——	4.88 31.89
2	2.10〜 2.31	11.76 12.43	20.58 22.64	—— ——	32.34 35.06
3	2.31〜 2.70	10.20 11.22	22.64 26.46	—— ——	32.84 37.68
4	2.70〜 3.31	11.22 12.81	26.46 26.46	—— ——	37.68 39.27
5	3.31〜 4.31	24.51 29.51	26.46 26.46	—— ——	50.97 55.97
6	4.31〜 4.60	29.51 30.96	26.46 26.46	—— ——	55.97 57.42
7	4.60〜 5.61	30.96 36.00	26.46 26.46	36.00 46.09	21.42 16.37
8	5.61〜 6.31	36.00 43.01	26.46 26.46	46.09 53.10	16.37 16.37
9	6.31〜 7.31	12.74 14.35	26.46 26.46	149.74 237.31	-110.54 -196.50

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.71 m (GL -6.31 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00～ 2.10	7.13 16.58	0.00 20.58	—— ——	7.13 37.16
2	2.10～ 2.20	17.17 17.63	20.58 21.56	—— ——	37.75 39.19
3	2.20～ 2.31	17.63 18.14	21.56 21.56	—— ——	39.19 39.70
4	2.31～ 3.31	15.22 19.13	21.56 21.56	—— ——	36.78 40.69
5	3.31～ 3.33	24.48 24.60	21.56 21.56	—— ——	46.04 46.16
6	3.33～ 4.31	24.60 37.07	21.56 21.56	—— ——	46.16 58.63
7	4.31～ 4.60	37.07 40.81	21.56 21.56	—— ——	58.63 62.37
8	4.60～ 6.31	40.81 63.35	21.56 21.56	36.00 53.10	26.37 31.81
9	6.31～ 7.31	20.51 23.11	21.56 21.56	133.81 212.06	-91.74 -167.39

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.71 m (GL -6.31 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	305000 cm^4 (original condition)
	I	=	262300 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 262300 \times 10^{-8} = 5.246 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	13
4	2.31	13
5	3.31	23
6	4.31	3
7	6.31	3
8	7.31	50
9	20.00	50

5-2 Normal Condition

K_h = 31447 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.350 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.86 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.31 m) to 2.86 m depth (GL -9.17 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^3)
1	6.31	1.00	3.0	50.0	26.50
2	7.31	1.86	50.0	50.0	92.90
	L = Σh = 2.86				ΣA = 119.40

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{119.40}{2.86}$$

$$= 41.78$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 41.78^{0.406} = 31447$ kN/m³
Kh (normal condition) = 31447 kNm^3

5-3 Seismic Condition

K_h = 31447 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.350 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.86 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.31 m) and 2.86 m depth (GL -9.17 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^3)
1	6.31	1.00	3.0	50.0	26.50
2	7.31	1.86	50.0	50.0	92.90
	L = Σh = 2.86				ΣA = 119.40

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{119.40}{2.86}$$

$$= 41.78$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;
$K_h = 6910 \times N'^{0.406} = 6910 \times 41.78^{0.406} = 31447$ kN/m³
Kh (seismic condition) = 31447 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^3)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	4.88 31.89	5.12 33.49	5.61 4.91	28.73 164.42
2	2.10～ 2.31	0.21	32.34 35.06	3.40 3.68	4.14 4.07	14.06 14.98
3	2.31～ 2.70	0.39	32.84 37.68	6.40 7.35	3.87 3.74	24.78 27.48
4	2.70～ 3.31	0.61	37.68 39.27	11.49 11.98	3.41 3.20	39.15 38.37
5	3.31～ 4.31	1.00	50.97 55.97	25.48 27.98	2.67 2.33	67.96 65.30
6	4.31～ 4.60	0.29	55.97 57.42	8.12 8.33	1.90 1.81	15.45 15.04
7	4.60～ 5.61	1.01	21.42 16.37	10.80 8.26	1.37 1.04	14.84 8.57
8	5.61～ 6.31	0.70	16.37 16.37	5.74 5.74	0.47 0.23	2.69 1.34
				ΣP = 183.36		ΣM = 543.15

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.4 kNm
depth to acting position	H_t	=	-0.42 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.71 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 16.15$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{559.30}{185.76} = 3.01 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.13 37.16	7.49 39.01	5.61 4.91	42.00 191.56
2	2.10~ 2.20	0.10	37.75 39.19	1.89 1.96	4.18 4.14	7.88 8.12
3	2.20~ 2.31	0.11	39.19 39.70	2.16 2.18	4.07 4.04	8.78 8.81
4	2.31~ 3.31	1.00	36.78 40.69	18.39 20.34	3.67 3.33	67.43 67.81
5	3.31~ 3.33	0.02	46.04 46.16	0.55 0.56	2.99 2.98	1.66 1.66
6	3.33~ 4.31	0.98	46.16 58.63	22.52 28.61	2.65 2.33	59.70 66.52
7	4.31~ 4.60	0.29	58.63 62.37	8.50 9.04	1.90 1.81	16.18 16.34
8	4.60~ 6.31	1.71	26.37 31.81	22.55 27.20	1.14 0.57	25.71 15.50
				ΣP = 212.95		ΣM = 605.66

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	7.5 kN/m
depth to acting position	H_t	=	-0.13 m
moment	M_m	=	2.1 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	4.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.71 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 50.40$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 3.20	1.00	0.0 2.7	0.00 1.33	3.78 3.44	0.00 4.57
2	3.20~ 4.20	1.00	2.7 3.8	1.33 1.88	2.78 2.44	3.69 4.59
3	4.20~ 4.60	0.40	3.8 4.1	0.75 0.82	1.98 1.84	1.49 1.52
				ΣPdw = 6.11		ΣMdw = 15.86

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{671.91}{226.56} = 2.97 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2= 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	305000 cm⁴ (original condition)
	I	=	262300 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 262300 \times 10^{-8}$		=	5.246×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	31447 kN/m³
calculated value	β	=	0.34988 m⁻¹
resultant earth force (lateral)	P_0	=	185.76 kN/m
height of acting position of load	h_0	=	3.01 m
moment	M_0	=	559.30 kN·m/m

in consideration of ψ_m = 1.135,

maximum moment	M_{max}	=	634.59 kN·m/m
depth of generated position of M_{max}	l_m	=	0.890 m
depth of 1st fixed point	l_i	=	3.135 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	31447 kN/m³
calculated value	β	=	0.34988 m⁻¹
resultant earth force (lateral)	P_0	=	226.56 kN/m
height of acting position of load	h_0	=	2.97 m
moment	M_0	=	671.91 kN·m/m

in consideration of ψ_m = 1.138,

maximum moment	M_{max}	=	764.56 kN·m/m
depth of generated position of M_{max}	l_m	=	0.899 m
depth of 1st fixed point	l_i	=	3.143 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2= 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	6220 cm³ (original condition)
	Z	=	5536 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{634.59\times10^6}{5536\times10^3} = 115 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{764.56\times10^6}{5536\times10^3} = 138 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

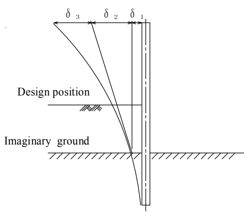
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	5.61 4.91	0.889 0.778	0.278 0.224	5.12 33.49	1.424 7.508
2	2.10~ 2.31	4.14 4.07	0.656 0.645	0.168 0.163	3.40 3.68	0.571 0.601
3	2.31~ 2.70	3.87 3.74	0.613 0.593	0.150 0.141	6.40 7.35	0.958 1.036
4	2.70~ 3.31	3.41 3.20	0.540 0.508	0.120 0.107	11.49 11.98	1.373 1.282
5	3.31~ 4.31	2.67 2.33	0.423 0.370	0.077 0.060	25.48 27.98	1.955 1.677
6	4.31~ 4.60	1.90 1.81	0.302 0.286	0.041 0.037	8.12 8.33	0.332 0.309
7	4.60~ 5.61	1.37 1.04	0.218 0.164	0.022 0.013	10.80 8.26	0.237 0.106
8	5.61~ 6.31	0.47 0.23	0.074 0.037	0.003 0.001	5.74 5.74	0.015 0.004
						ΣQ = 19.390

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3} = \frac{(1+0.3499\times3.01)\times185.76}{2\times2.00\times10^8\times262300\times10^{-8}\times0.3499^3} = 0.00849 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k) = \frac{(1+2\times0.3499\times3.01)\times185.76}{2\times2.00\times10^8\times262300\times10^{-8}\times0.3499^2}\times(4.60+1.71) = 0.02835 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI} = \frac{19.39\times(4.60+1.71)^3}{2.00\times10^8\times262300\times10^{-8}} = 0.00929 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00042 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 6.31 m
Horizontal load: P = 2.40
Moment: M = 1.01

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00849 + 0.02835 + 0.00971
= 0.04655 m
= 46.55 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	5.61 4.91	0.889 0.778	0.278 0.224	7.49 39.01	2.082 8.748
2	2.10～ 2.20	4.18 4.14	0.662 0.657	0.171 0.168	1.89 1.96	0.322 0.330
3	2.20～ 2.31	4.07 4.04	0.646 0.640	0.164 0.161	2.16 2.18	0.352 0.352
4	2.31～ 3.31	3.67 3.33	0.581 0.528	0.136 0.115	18.39 20.34	2.503 2.339
5	3.31～ 3.33	2.99 2.98	0.474 0.473	0.095 0.094	0.55 0.56	0.052 0.052
6	3.33～ 4.31	2.65 2.33	0.420 0.369	0.076 0.060	22.52 28.61	1.709 1.704
7	4.31～ 4.60	1.90 1.81	0.302 0.286	0.041 0.037	8.50 9.04	0.348 0.335
8	4.60～ 6.31	1.14 0.57	0.181 0.090	0.015 0.004	22.55 27.20	0.346 0.108
						ΣQ = 21.682

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

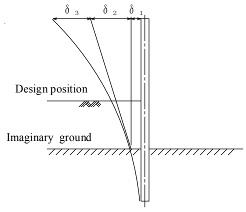
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 3.20	3.78 3.44	0.599 0.546	0.143 0.122	0.00 1.33	0.000 0.162
2	3.20～ 4.20	2.78 2.44	0.440 0.387	0.083 0.065	1.33 1.88	0.110 0.123
3	4.20～ 4.60	1.98 1.84	0.313 0.292	0.044 0.039	0.75 0.82	0.033 0.032
						ΣQ_{dw} = 0.459

Therefore, modulus of deformation Q is calculated as below

$$Q = 21.682 + 0.459 = 22.141$$

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3499\times 2.97)\times 226.56}{2\times 2.00\times 10^8\times 262300\times 10^{-8}\times 0.3499^3} = 0.01027 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3499\times 2.97)\times 226.56}{2\times 2.00\times 10^8\times 262300\times 10^{-8}\times 0.3499^2}\times(4.60+1.71) = 0.03423 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{22.14\times(4.60+1.71)^3}{2.00\times 10^8\times 262300\times 10^{-8}} = 0.01060 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00123 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 6.31 m
Horizontal load: P = 7.50
Moment: M = 0.98

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=6.31 \text{ m、} h=L-H_m\text{、}H_m=0.80 \text{ m、ただし} h\leqq L)$$

$$= \frac{2.10\times 5.51}{2\times 2.00\times 10^8\times 262300\times 10^{-8}}\times(2\times 6.31-5.51) = 0.00008 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= 0.01027 + 0.03423 + 0.01192$$
$$= 0.05642 \text{ m}$$
$$= 56.42 \leqq \delta_a = 75.00 \text{ mm (ok)}$$

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	305000 cm^4 (original condition)
	I	=	305000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 305000 × 10^{-8}		=	6.100 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 31447 kN/m^3
Calculated value β = 0.33694 m^{-1}

Penetration length of SSP $D = 1.71 + \dfrac{3}{0.337} = 10.61$ m
Whole length of SSP $L = 4.60 - 0.40 + 10.61 = 14.81$ m

7-1-2 Seismic Condi

Modules of lateral subgrade reaction K_h = 31447 kN/m^3
Calculated value β = 0.33694 m^{-1}

Penetration length of SSP $D = 1.71 + \dfrac{3}{0.337} = 10.61$ m
Whole length of SSP $L = 4.60 - 0.40 + 10.61 = 14.81$ m

Therefore, whole length of SSP is set as 15.00 m in consideration of round unit of SSP length.

8 Calculation Result

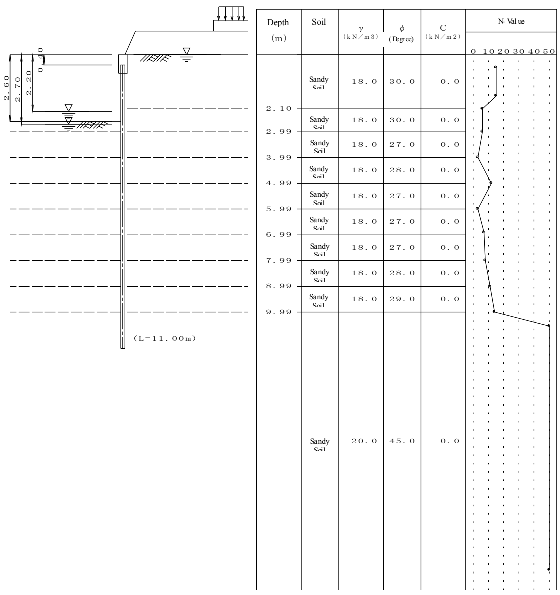
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	305000		
Section modulus	Z (cm^3)	6220		
Maximum bending moment	M_{max} (kN·m/m)		634.59	764.56
Stress intensity	σ (N/mm^2)		115 (185)	138 (278)
Lateral displacement	δ (mm)		46.55 (50.0)	56.42 (75.0)
Penetration depth	D (m)		10.61	10.61
Whole length of SSP	L (m)	15.00		

－Steel Sheet Pile　Design Calculation－

Right Bank No. 28_STA 11+610 - 11+653

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　$\gamma_w = 9.8$ kNm^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	2.5 kNm	(Normal Condition)
		P_t'	=	7.7 kNm	(Seismic Condition)
	Depth of acting point	H_t	=	-0.43 m	(Normal Condition)
		H_t'	=	-0.14 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	2.2 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　$\zeta_0 = 10$ degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression　K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N'^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	6
4	2.99	6
5	3.99	3
6	4.99	12
7	5.99	3
8	6.90	7
9	7.99	8
10	8.99	11

No	Depth (m)	N-Value
11	9.99	14
12	10.54	50
13	20.00	50

2.213

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

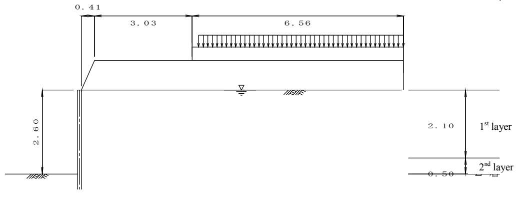
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	ϕ	C kNm^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh (kNm^3) normal	kh (kNm^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.99	S	6.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
3	3.99	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.99	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
5	5.99	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	6.99	S	7.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	7.99	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	8.99	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	——	——
9	9.99	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
10	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.41	10.00	10.00	0.92	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.44	3.44	10.00	10.00	0.42	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	3.64	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 56700 cm⁴
Sectional factor Z_0 = 2700 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

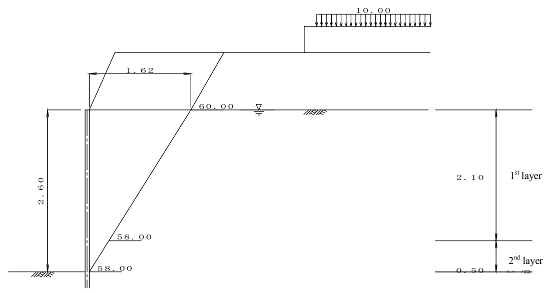
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	30.0	9.0	0.0	26.00	17.18	25.48	58.00
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	17.18	20.58	58.00
3		Embankment	30.0	——	0.0	24.12	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	58.00	0.50	0.00	0.00	0.31	0.50
2	58.00	2.10	0.31	0.50	1.62	2.60
3	60.00	0.92	1.62	2.60	2.16	3.52

Therefore, width of acting load shall be set as 1.62 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.55	27.91
Σ			27.91

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

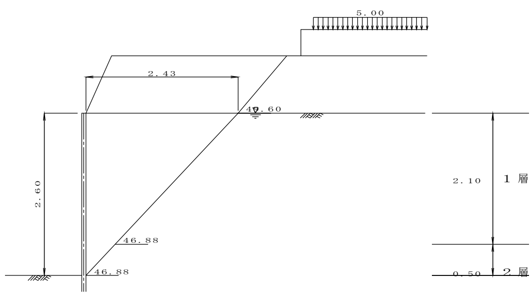
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{27.91 + 0.00 + 0.00}{1.62}$$

$$= 17.18 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	30.0	9.0	0.0	26.00	17.83	25.48	0.200	11.31	46.88
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	17.83	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	24.12	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	46.88	0.50	0.00	0.00	0.47	0.50
2	46.88	2.10	0.47	0.50	2.43	2.60
3	49.60	0.92	2.43	2.60	3.22	3.52

Therefore, width of acting load shall be set as 2.43 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.41	43.41
Σ			43.41

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Calculation of Total Acting Load

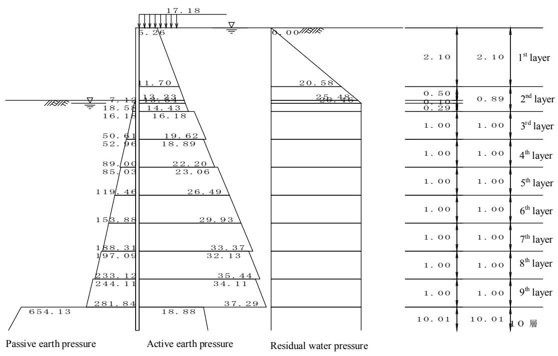
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{43.41 + 0.00 + 0.00}{2.43}$$

$$= 17.83 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	17.177 38.177	0.31026 0.31026	0.30644 0.30644
2	2.10～ 2.60	Sandy soil	10.0	30.0	—— ——	38.177 43.177	0.31026 0.31026	0.30644 0.30644
3	2.60～ 2.70	Sandy soil	10.0	30.0	—— ——	43.177 44.177	0.31026 0.31026	0.30644 0.30644
4	2.70～ 2.99	Sandy soil	10.0	30.0	—— ——	44.177 47.077	0.31026 0.31026	0.30644 0.30644
5	2.99～ 3.99	Sandy soil	10.0	27.0	—— ——	47.077 57.077	0.34800 0.34800	0.34371 0.34371
6	3.99～ 4.99	Sandy soil	10.0	28.0	—— ——	57.077 67.077	0.33506 0.33506	0.33093 0.33093
7	4.99～ 5.99	Sandy soil	10.0	27.0	—— ——	67.077 77.077	0.34800 0.34800	0.34371 0.34371
8	5.99～ 6.99	Sandy soil	10.0	27.0	—— ——	77.077 87.077	0.34800 0.34800	0.34371 0.34371
9	6.99～ 7.99	Sandy soil	10.0	27.0	—— ——	87.077 97.077	0.34800 0.34800	0.34371 0.34371
10	7.99～ 8.99	Sandy soil	10.0	28.0	—— ——	97.077 107.077	0.33506 0.33506	0.33093 0.33093
11	8.99～ 9.99	Sandy soil	10.0	29.0	—— ——	107.077 117.077	0.32248 0.32248	0.31851 0.31851
12	9.99～ 20.00	Sandy soil	10.0	45.0	—— ——	117.077 217.177	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Sandy soil	18.0	30.0	—— ——	0.000 1.800	4.00247 4.00247	3.95319 3.95319
4	2.70～ 2.99	Sandy soil	10.0	30.0	—— ——	1.800 4.700	4.00247 4.00247	3.95319 3.95319
5	2.99～ 3.99	Sandy soil	10.0	27.0	—— ——	4.700 14.700	3.48553 3.48553	3.44261 3.44261
6	3.99～ 4.99	Sandy soil	10.0	28.0	—— ——	14.700 24.700	3.64796 3.64796	3.60305 3.60305
7	4.99～ 5.99	Sandy soil	10.0	27.0	—— ——	24.700 34.700	3.48553 3.48553	3.44261 3.44261
8	5.99～ 6.99	Sandy soil	10.0	27.0	—— ——	34.700 44.700	3.48553 3.48553	3.44261 3.44261
9	6.99～ 7.99	Sandy soil	10.0	27.0	—— ——	44.700 54.700	3.48553 3.48553	3.44261 3.44261
10	7.99～ 8.99	Sandy soil	10.0	28.0	—— ——	54.700 64.700	3.64796 3.64796	3.60305 3.60305
11	8.99～ 9.99	Sandy soil	10.0	29.0	—— ——	64.700 74.700	3.82002 3.82002	3.77299 3.77299
12	9.99～ 20.00	Sandy soil	10.0	45.0	—— ——	74.700 174.800	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	5.26 11.70	—— ——	5.26 11.70	0.00 20.58	—— ——
2	2.10～ 2.60	11.70 13.23	—— ——	11.70 13.23	20.58 25.48	—— ——
3	2.60～ 2.70	13.23 13.54	—— ——	13.23 13.54	25.48 26.46	0.00 7.12
4	2.70～ 2.99	13.54 14.43	—— ——	13.54 14.43	26.46 26.46	7.12 18.58
5	2.99～ 3.99	16.18 19.62	—— ——	16.18 19.62	26.46 26.46	16.18 50.61
6	3.99～ 4.99	18.89 22.20	—— ——	18.89 22.20	26.46 26.46	52.96 89.00

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
7	4.99～ 5.99	23.06 26.49	—— ——	23.06 26.49	26.46 26.46	85.03 119.46
8	5.99～ 6.99	26.49 29.93	—— ——	26.49 29.93	26.46 26.46	119.46 153.88
9	6.99～ 7.99	29.93 33.37	—— ——	29.93 33.37	26.46 26.46	153.88 188.31
10	7.99～ 8.99	32.13 35.44	—— ——	32.13 35.44	26.46 26.46	197.09 233.12
11	8.99～ 9.99	34.11 37.29	—— ——	34.11 37.29	26.46 26.46	244.11 281.84
12	9.99～ 20.00	18.88 35.01	—— ——	18.88 35.01	26.46 26.46	654.13 1530.68

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

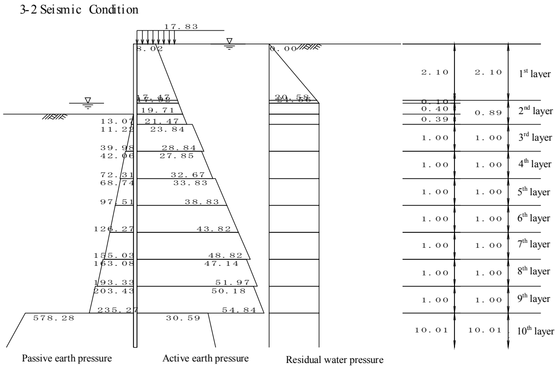
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	17.83 38.83	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10～ 2.20	Sandy Soil	10.0	30.0	—— ——	38.83 39.83	20.58 21.56	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
3	2.20～ 2.60	Sandy Soil	10.0	30.0	—— ——	39.83 43.83	21.56 25.48	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
4	2.60～ 2.99	Sandy Soil	10.0	30.0	—— ——	43.83 47.73	25.48 29.30	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
5	2.99～ 3.99	Sandy Soil	10.0	27.0	—— ——	47.73 57.73	29.30 39.10	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	3.99～ 4.99	Sandy Soil	10.0	28.0	—— ——	57.73 67.73	39.10 48.90	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——
7	4.99～ 5.99	Sandy Soil	10.0	27.0	—— ——	67.73 77.73	48.90 58.70	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
8	5.99～ 6.99	Sandy Soil	10.0	27.0	—— ——	77.73 87.73	58.70 68.50	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
9	6.99～ 7.99	Sandy Soil	10.0	27.0	—— ——	87.73 97.73	68.50 78.30	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
10	7.99～ 8.99	Sandy Soil	10.0	28.0	—— ——	97.73 107.73	78.30 88.10	0.200 0.200	11.31 11.31	0.48839 0.48839	0.48237 0.48237	—— ——
11	8.99～ 9.99	Sandy Soil	10.0	29.0	—— ——	107.73 117.73	88.10 97.90	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
12	9.99～ 20.00	Sandy Soil	10.0	45.0	—— ——	117.73 217.83	97.90 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 2.99	Sandy soil	10.00	30.0	—— ——	0.000 3.900	0.00 3.82	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
5	2.99～ 3.99	Sandy soil	10.00	27.0	—— ——	3.900 13.900	3.82 13.62	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	3.99～ 4.99	Sandy soil	10.00	28.0	—— ——	13.900 23.900	13.62 23.42	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
7	4.99～ 5.99	Sandy soil	10.00	27.0	—— ——	23.900 33.900	23.42 33.22	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
8	5.99～ 6.99	Sandy soil	10.00	27.0	—— ——	33.900 43.900	33.22 43.02	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626

	Depth (m)	Soil	γ (kN/m^3)	φ (degree)	C kN/m^2	Σγh+Qp (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
9	6.99~ 7.99	Sandy soil	10.00	27.0	—— ——	43.900 53.900	43.02 52.82	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
10	7.99~ 8.99	Sandy soil	10.00	28.0	—— ——	53.900 63.900	52.82 62.62	0.200 0.200	11.31 11.31	3.06329 3.06329	3.02557 3.02557
11	8.99~ 9.99	Sandy soil	10.00	29.0	—— ——	63.900 73.900	62.62 72.42	0.200 0.200	11.31 11.31	3.22324 3.22324	3.18356 3.18356
12	9.99~ 20.00	Sandy soil	10.00	45.0	—— ——	73.900 174.000	72.42 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ = -9.00、β = 0.00、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m^2	Pa2 kN/m^2	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2
1	0.00~ 2.10	8.02 17.47	—— ——	8.02 17.47	0.00 20.58	—— ——
2	2.10~ 2.20	17.47 17.92	—— ——	17.47 17.92	20.58 21.56	—— ——
3	2.20~ 2.60	17.92 19.71	—— ——	17.92 19.71	21.56 21.56	—— ——
4	2.60~ 2.99	19.71 21.47	—— ——	19.71 21.47	21.56 21.56	0.00 13.07
5	2.99~ 3.99	23.84 28.84	—— ——	23.84 28.84	21.56 21.56	11.22 39.98
6	3.99~ 4.99	27.85 32.67	—— ——	27.85 32.67	21.56 21.56	42.06 72.31
7	4.99~ 5.99	33.83 38.83	—— ——	33.83 38.83	21.56 21.56	68.74 97.51
8	5.99~ 6.99	38.83 43.82	—— ——	38.83 43.82	21.56 21.56	97.51 126.27
9	6.99~ 7.99	43.82 48.82	—— ——	43.82 48.82	21.56 21.56	126.27 155.03
10	7.99~ 8.99	47.14 51.97	—— ——	47.14 51.97	21.56 21.56	163.08 193.33
11	8.99~ 9.99	50.18 54.84	—— ——	50.18 54.84	21.56 21.56	203.43 235.27
12	9.99~ 20.00	30.59 56.59	—— ——	30.59 56.59	21.56 21.56	578.28 1361.58

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

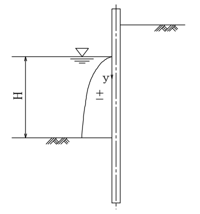
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m^2)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

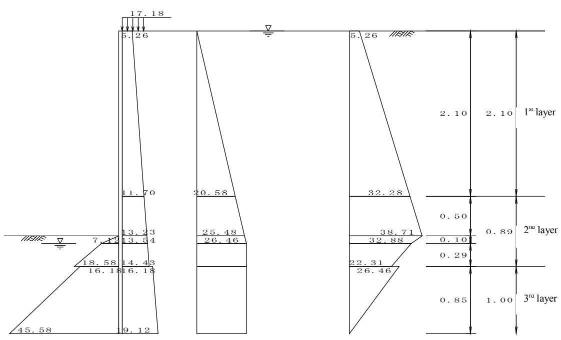
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



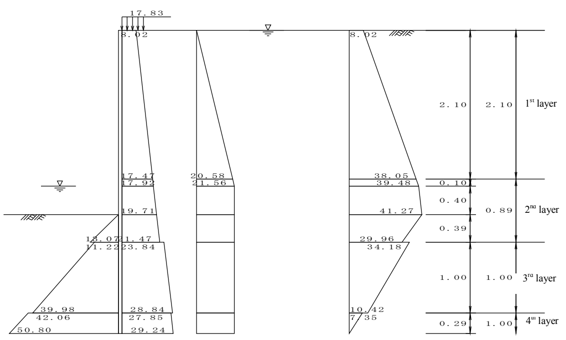
Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00~ 2.10	5.26 11.70	0.00 20.58	—— ——	5.26 32.28
2	2.10~ 2.60	11.70 13.23	20.58 25.48	—— ——	32.28 38.71
3	2.60~ 2.70	13.23 13.54	25.48 26.46	0.00 7.12	38.71 32.88
4	2.70~ 2.99	13.54 14.43	26.46 26.46	7.12 18.58	32.88 22.31
5	2.99~ 3.84	16.18 19.12	26.46 26.46	16.18 45.58	26.46 0.00
6	3.84~ 3.99	19.12 19.62	26.46 26.46	45.58 50.61	0.00 -4.53

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.24 m (GL -3.84 m)

4-2 Seismic Condition



Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00~ 2.10	8.02 17.47	0.00 20.58	—— ——	8.02 38.05
2	2.10~ 2.20	17.47 17.92	20.58 21.56	—— ——	38.05 39.48
3	2.20~ 2.60	17.92 19.71	21.56 21.56	—— ——	39.48 41.27
4	2.60~ 2.99	19.71 21.47	21.56 21.56	0.00 13.07	41.27 29.96
5	2.99~ 3.99	23.84 28.84	21.56 21.56	11.22 39.98	34.18 10.42
6	3.99~ 4.28	27.85 29.24	21.56 21.56	42.06 50.80	7.35 0.00
7	4.28~ 4.99	29.24 32.67	21.56 21.56	50.80 72.31	0.00 -18.08

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.68 m (GL -4.28 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	6
4	2.99	6
5	3.99	3
6	4.99	12
7	5.99	3
8	6.90	7
9	7.99	8
10	8.99	11

	Depth (m)	N-value
11	9.99	14
12	10.54	50
13	20.00	50

5-2 Normal Condition

K_h = 15431 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.469 \quad m^{-1}$

$$L = \frac{1}{\beta} = 2.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.84 m) to 2.13 m depth (GL -5.98 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.84	0.15	3.4	3.0	0.47
2	3.99	1.00	3.0	12.0	7.50
3	4.99	0.99	12.0	3.1	7.46
	L = Σh = 2.13				ΣA = 15.43

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{15.43}{2.13} = 7.23$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.23^{0.406} = 15431$ kN/m^3

Kh (normal condition) = 15431 kN/m^3

5-3 Seismic Condition

K_h = 15424 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.469 \quad m^{-1}$

$$L = \frac{1}{\beta} = 2.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.28 m) and 2.13 m depth (GL -6.41 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.28	0.71	5.6	12.0	6.26
2	4.99	1.00	12.0	3.0	7.50
3	5.99	0.42	3.0	4.9	1.66
	L = Σh = 2.13				ΣA = 15.42

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{15.42}{2.13} = 7.23$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 7.23^{0.406} = 15424$ kN/m^3

Kh (seismic condition) = 15424 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	5.26 32.28	5.53 33.89	3.14 2.44	17.38 82.83
2	2.10~ 2.60	0.50	32.28 38.71	8.07 9.68	1.58 1.41	12.73 13.65
3	2.60~ 2.70	0.10	38.71 32.88	1.94 1.64	1.21 1.18	2.34 1.94
4	2.70~ 2.99	0.29	32.88 22.31	4.77 3.23	1.05 0.95	4.99 3.07
5	2.99~ 3.84	0.85	26.46 0.00	11.30 0.00	0.57 0.28	6.43 0.00
				ΣP = 80.05		ΣM = 145.36

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.5 kN/m
depth to acting position	H_t	=	-0.43 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.24 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 10.68$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{156.05}{82.55} = 1.89 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.02 38.05	8.42 39.95	3.58 2.88	30.14 115.01
2	2.10~ 2.20	0.10	38.05 39.48	1.90 1.97	2.15 2.11	4.08 4.17
3	2.20~ 2.60	0.40	39.48 41.27	7.90 8.25	1.95 1.81	15.36 14.96
4	2.60~ 2.99	0.39	41.27 29.96	8.05 5.84	1.55 1.42	12.47 8.29

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
5	2.99~ 3.99	1.00	34.18 10.42	17.09 5.21	0.96 0.62	16.33 3.24
6	3.99~ 4.28	0.29	7.35 0.00	1.06 0.00	0.19 0.10	0.20 0.00
				ΣP = 105.65		ΣM = 224.26

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	7.7 kN/m
depth to acting position	H_t	=	-0.14 m
moment	M_m	=	2.2 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.68 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 36.23$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.95 1.81	0.00 0.25
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.25

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{260.74}{113.48} = 2.30 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{8}$		=	7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	15431	kN/m^3
calculated value	β	=	0.46885	m^{-1}
resultant earth force (lateral)	P_0	=	82.55	kN/m
height of acting position of load	h_0	=	1.89	m
moment	M_0	=	156.05	kN·m/m

in consideration of ψ_m = 1.76,

maximum moment	M_{max}	=	183.55	kN·m/m
depth of generated position of M_{max}	l_m	=	0.738	m
depth of 1st fixed point	l_i	=	2.413	m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	15424	kN/m^3
calculated value	β	=	0.46880	m^{-1}
resultant earth force (lateral)	P_0	=	113.48	kN/m
height of acting position of load	h_0	=	2.30	m
moment	M_0	=	260.74	kN·m/m

in consideration of ψ_m = 1.130,

maximum moment	M_{max}	=	294.62	kN·m/m
depth of generated position of M_{max}	l_m	=	0.655	m
depth of 1st fixed point	l_i	=	2.330	m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm^3 (original condition)
	Z	=	2376 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{183.55\times10^6}{2376\times10^3} = 77\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{294.62\times10^6}{2376\times10^3} = 124\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.14 2.44	0.818 0.636	0.243 0.159	5.53 33.89	1.345 5.398
2	2.10～ 2.60	1.58 1.41	0.410 0.367	0.073 0.059	8.07 9.68	0.586 0.572
3	2.60～ 2.70	1.21 1.18	0.315 0.306	0.044 0.042	1.94 1.64	0.086 0.069
4	2.70～ 2.99	1.05 0.95	0.272 0.247	0.034 0.028	4.77 3.23	0.161 0.091
5	2.99～ 3.84	0.57 0.28	0.148 0.074	0.010 0.003	11.30 0.00	0.118 0.000
						ΣQ = 8.426

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

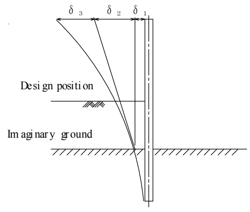
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4689\times1.89)\times82.55}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4689^3} = 0.00946\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4689\times1.89)\times82.55}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4689^2}\times(2.60+1.24) = 0.02507\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{8.43\times(2.60+1.24)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00599\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00069 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.84 m
Horizontal load: P = 2.50
Moment: M = 1.08

δ = δ_1 + δ_2 + δ_3
= 0.00946 + 0.02507 + 0.00669
= 0.04121 m
= 41.21 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.58 2.88	0.836 0.673	0.252 0.176	8.42 39.95	2.124 7.014
2	2.10～ 2.20	2.15 2.11	0.501 0.494	0.105 0.102	1.90 1.97	0.199 0.201
3	2.20～ 2.60	1.95 1.81	0.455 0.424	0.088 0.077	7.90 8.25	0.692 0.636
4	2.60～ 2.99	1.55 1.42	0.362 0.332	0.058 0.049	8.05 5.84	0.464 0.286
5	2.99～ 3.99	0.96 0.62	0.223 0.145	0.023 0.010	17.09 5.21	0.395 0.052
6	3.99～ 4.28	0.19 0.10	0.045 0.023	0.001 0.000	1.06 0.00	0.001 0.000
						ΣQ = 12.064

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

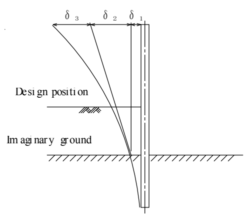
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.95 1.81	0.455 0.424	0.088 0.077	0.00 0.14	0.000 0.011
						ΣQ_{dw} = 0.011

Therefore, modulus of deformation Q is calculated as below.
Q = 12.064 + 0.011 = 12.075

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4688\times 2.30)\times 113.48}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.4688^3} = 0.01433 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times (H+L_k)$$

$$= \frac{(1+2\times 0.4688\times 2.30)\times 113.48}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.4688^2}\times(2.60+1.68) = 0.04365 \text{ m}$$

$$\delta_3 = \frac{Q\times (H+L_k)^3}{EI}$$

$$= \frac{12.07\times(2.60+1.68)^3}{2.00\times 10^8\times 39917\times 10^{-8}} = 0.01185 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00264 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.28 m
Horizontal load: P = 7.70
Moment: M = 1.08

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m \cdot h}{2EI}\times(2L-h) \qquad (L=4.28 \text{ m、} h=L-H_m\text{、} H_m=0.80 \text{ m、ただし} h\geqq L)$$

$$= \frac{2.20\times 3.48}{2\times 2.00\times 10^8\times 39917\times 10^{-8}}\times(2\times 4.28-3.48) = 0.00024 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01433 + 0.04365 + 0.01474$
$= 0.07272$ m
$= 72.72 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 15431$ kN/m^3
Calculated value $\beta = 0.42947$ m^{-1}

Penetration length of SSP $D = 1.24 + \frac{3}{0.429} = 8.23$ m
Whole length of SSP $L = 2.60 - 0.40 + 8.23 = 10.43$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 15424$ kN/m^3
Calculated value $\beta = 0.42942$ m^{-1}

Penetration length of SSP $D = 1.68 + \frac{3}{0.429} = 8.67$ m
Whole length of SSP $L = 2.60 - 0.40 + 8.67 = 10.87$ m

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

8 Calculation Result

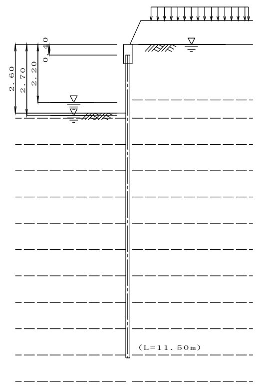
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		183.55	294.62
Stress intensity	σ (Nmm^2)		77 (180)	124 (270)
Lateral displacement	δ (mm)		41.21 (50.0)	72.72 (75.0)
Penetration depth	D (m)		8.23	8.67
Whole length of SSP	L (m)	11.00		

－Steel Sheet Pile Design Calculation－

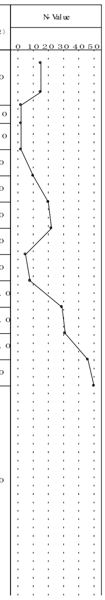
Right Bank No. 29_STA 11+788 - 11+803

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
2.79	Clayey Soil	16.0	0.0	12.0
3.79	Clayey Soil	16.0	0.0	12.0
4.79	Sandy Soil	18.0	27.0	0.0
5.79	Sandy Soil	18.0	32.0	0.0
6.79	Sandy Soil	18.0	33.0	0.0
7.79	Sandy Soil	18.0	27.0	0.0
8.79	Sandy Soil	18.0	27.0	0.0
9.79	Clayey Soil	16.0	0.0	100.0
10.79	Clayey Soil	16.0	0.0	200.0
11.79	Clayey Soil	16.0	0.0	200.0
12.79	Sandy Soil	18.0	45.0	0.0
	Sandy Soil	18.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_t	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load					
Horizontal load	Pt	=	2.5 kN/m	(Normal Condition)
	Pt'	=	7.8 kN/m	(Seismic Condition)
Depth of acting point	Ht	=	-0.44 m	(Normal Condition)
	Ht'	=	-0.15 m	(Seismic Condition)
Moment	Mm	=	0.0 kN·m/m	(Normal Condition)
	Mm'	=	2.3 kN·m/m	(Seismic Condition)
Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
	Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.79	29
2	1.60	15	12	10.79	31
3	2.10	2	13	11.79	46
4	2.79	2	14	12.79	50
5	3.79	2	15	20.00	50
6	4.79	10			
7	5.79	20			
8	6.79	22			
9	7.79	5			
10	8.79	8			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

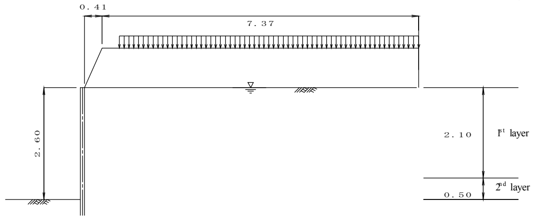
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.79	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	3.79	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
4	4.79	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.79	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
6	6.79	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
7	7.79	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
8	8.79	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
9	9.79	C	29.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	——	——
10	10.79	C	31.0	16.00	8.00	0.0	200.0	0.0	0.200	auto	auto	——	——
11	11.79	C	46.0	16.00	8.00	0.0	200.0	0.0	0.200	auto	auto	——	——
12	12.79	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
13	20.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.41	7.78	7.78	0.92	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	0.81	7.78	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 86000 cm^4
Sectional factor Z_0 = 3820 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.92
Corrosion rate (to Z_0) η = 0.92
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

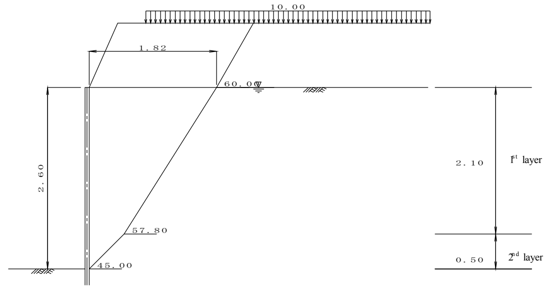
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	25.58	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	25.58	20.58	57.80
3		Embankment	30.0	——	0.0	16.56	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	0.92	1.82	2.60	2.35	3.52

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.73	31.18
Σ			31.18

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.54	15.44
Σ			15.44

Q surcharge load
l : width of surcharge load set by line of active rupture

2-1-5 Calculation of Total Acting Load

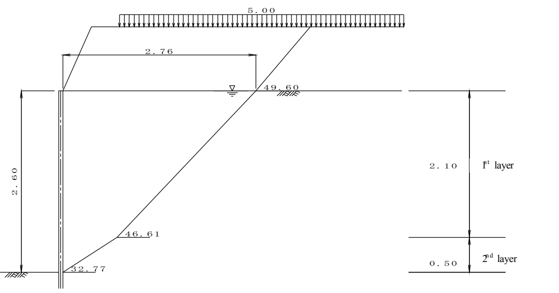
$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{31.18 + 15.44 + 0.00}{1.82}$$

$= 25.58\ kN/m^2$

2.221

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	12.0	25.00	22.63	25.48	0.200	11.31	32.77
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	22.63	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	16.56	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm^2)
C cohesive force of soil (kNm^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	32.77	0.50	0.00	0.00	0.78	0.50
2	46.61	2.10	0.78	0.50	2.76	2.60
3	49.60	0.92	2.76	2.60	3.54	3.52

Therefore, width of acting load shall be set as 2.76 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.71	48.83
Σ			48.83

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.73	13.67
Σ			13.67

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

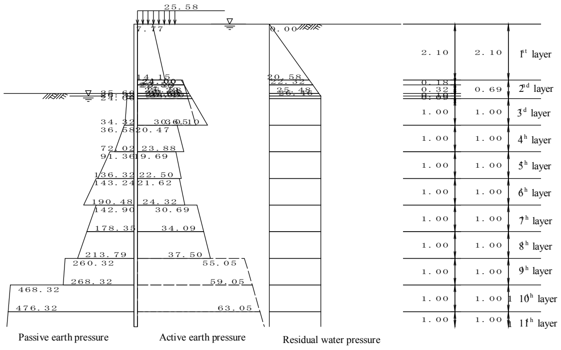
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{48.83 + 13.67 + 0.00}{2.76}$$

$$= 22.63\ \text{kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	25.580 46.580	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.28	Clayey soil	8.0	—	12.0 12.0	46.580 48.000	—— ——	—— ——
3	2.28～ 2.60	Clayey soil	8.0	—	12.0 12.0	48.000 50.580	—— ——	—— ——
4	2.60～ 2.70	Clayey soil	8.0	—	12.0 12.0	50.580 51.380	—— ——	—— ——
5	2.70～ 2.79	Clayey soil	8.0	—	12.0 12.0	51.380 52.100	—— ——	—— ——
6	2.79～ 3.79	Clayey soil	8.0	—	12.0 12.0	52.100 60.100	—— ——	—— ——
7	3.79～ 4.79	Sandy soil	10.0	27.0	—— ——	60.100 70.100	0.34585 0.34585	0.34060 0.34060
8	4.79～ 5.79	Sandy soil	10.0	32.0	—— ——	70.100 80.100	0.28525 0.28525	0.28092 0.28092
9	5.79～ 6.79	Sandy soil	10.0	33.0	—— ——	80.100 90.100	0.27412 0.27412	0.26996 0.26996
10	6.79～ 7.79	Sandy soil	10.0	27.0	—— ——	90.100 100.100	0.34585 0.34585	0.34060 0.34060
11	7.79～ 8.79	Sandy soil	10.0	27.0	—— ——	100.100 110.100	0.34585 0.34585	0.34060 0.34060
12	8.79～ 9.79	Clayey soil	8.0	—	100.0 100.0	110.100 118.100	—— ——	—— ——
13	9.79～ 10.79	Clayey soil	8.0	—	200.0 200.0	118.100 126.100	—— ——	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	10.79～ 11.79	Clayey soil	8.0	—	200.0 200.0	126.100 134.100	—— ——	—— ——
15	11.79～ 12.79	Sandy soil	10.0	45.0	—— ——	134.100 144.100	0.16262 0.16262	0.16015 0.16015
16	12.79～ 20.00	Sandy soil	10.0	45.0	—— ——	144.100 216.200	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60～ 2.70	Clayey soil	16.0	0.0	12.0 12.0	0.000 1.600	—— ——	—— ——
5	2.70～ 2.79	Clayey soil	8.0	0.0	12.0 12.0	1.600 2.320	—— ——	—— ——
6	2.79～ 3.79	Clayey soil	8.0	0.0	12.0 12.0	2.320 10.320	—— ——	—— ——
7	3.79～ 4.79	Sandy soil	10.0	27.0	—— ——	10.320 20.320	3.59892 3.59892	3.54425 3.54425
8	4.79～ 5.79	Sandy soil	10.0	32.0	—— ——	20.320 30.320	4.56530 4.56530	4.49594 4.49594
9	5.79～ 6.79	Sandy soil	10.0	33.0	—— ——	30.320 40.320	4.79713 4.79713	4.72425 4.72425
10	6.79～ 7.79	Sandy soil	10.0	27.0	—— ——	40.320 50.320	3.59892 3.59892	3.54425 3.54425
11	7.79～ 8.79	Sandy soil	10.0	27.0	—— ——	50.320 60.320	3.59892 3.59892	3.54425 3.54425
12	8.79～ 9.79	Clayey soil	8.0	0.0	100.0 100.0	60.320 68.320	—— ——	—— ——
13	9.79～ 10.79	Clayey soil	8.0	0.0	200.0 200.0	68.320 76.320	—— ——	—— ——
14	10.79～ 11.79	Clayey soil	8.0	0.0	200.0 200.0	76.320 84.320	—— ——	—— ——
15	11.79～ 12.79	Sandy soil	10.0	45.0	—— ——	84.320 94.320	9.34548 9.34548	9.20351 9.20351
16	12.79～ 20.00	Sandy soil	10.0	45.0	—— ——	94.320 166.420	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	7.77 14.15	—— ——	7.77 14.15	0.00 20.58	—— ——
2	2.10～ 2.28	22.58 24.00	23.29 24.00	23.29 24.00	20.58 22.32	—— ——
3	2.28～ 2.60	24.00 26.58	24.00 25.29	24.00 26.58	22.32 25.48	—— ——
4	2.60～ 2.70	26.58 27.38	25.29 25.69	26.58 27.38	25.48 26.46	24.00 25.60
5	2.70～ 2.79	27.38 28.10	25.69 26.05	27.38 28.10	26.46 26.46	25.60 26.32
6	2.79～ 3.79	28.10 36.10	26.05 30.05	28.10 36.10	26.46 26.46	26.32 34.32
7	3.79～ 4.79	20.47 23.88	—— ——	20.47 23.88	26.46 26.46	36.58 72.02
8	4.79～ 5.79	19.69 22.50	—— ——	19.69 22.50	26.46 26.46	91.36 136.32
9	5.79～ 6.79	21.62 24.32	—— ——	21.62 24.32	26.46 26.46	143.24 190.48
10	6.79～ 7.79	30.69 34.09	—— ——	30.69 34.09	26.46 26.46	142.90 178.35
11	7.79～ 8.79	34.09 37.50	—— ——	34.09 37.50	26.46 26.46	178.35 213.79
12	8.79～ 9.79	-89.90 -81.90	55.05 59.05	55.05 59.05	26.46 26.46	260.32 268.32
13	9.79～ 10.79	-281.90 -273.90	59.05 63.05	59.05 63.05	26.46 26.46	468.32 476.32
14	10.79～ 11.79	-273.90 -265.90	63.05 67.05	63.05 67.05	26.46 26.46	476.32 484.32
15	11.79～ 12.79	21.48 23.08	—— ——	21.48 23.08	26.46 26.46	776.04 868.07
16	12.79～ 20.00	23.08 34.63	—— ——	23.08 34.63	26.46 26.46	868.07 1531.65

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

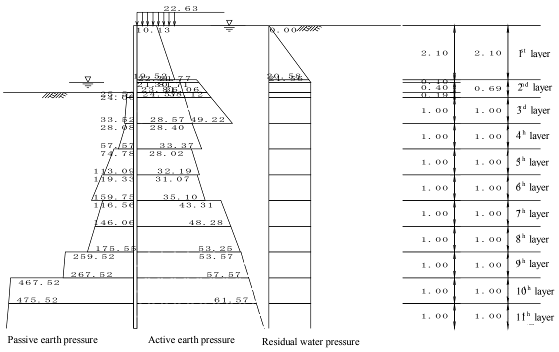
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	22.63 43.63	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Clayey soil	8.0	—	12.0 12.0	43.63 44.43	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	33.79 33.59
3	2.20~ 2.60	Clayey soil	8.0	—	12.0 12.0	44.43 47.63	21.56 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	33.59 32.77
4	2.60~ 2.79	Clayey soil	8.0	—	12.0 12.0	47.63 49.15	25.48 27.34	0.200 0.200	11.31 11.31	—— ——	—— ——	32.77 32.37
5	2.79~ 3.79	Clayey soil	8.0	—	12.0 12.0	49.15 57.15	27.34 37.14	0.200 0.200	11.31 11.31	—— ——	—— ——	32.37 30.07
6	3.79~ 4.79	Sandy Soil	10.0	27.0	—— ——	57.15 67.15	37.14 46.94	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	4.79~ 5.79	Sandy Soil	10.0	32.0	—— ——	67.15 77.15	46.94 56.74	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
8	5.79~ 6.79	Sandy Soil	10.0	33.0	—— ——	77.15 87.15	56.74 66.54	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
9	6.79~ 7.79	Sandy Soil	10.0	27.0	—— ——	87.15 97.15	66.54 76.34	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
10	7.79~ 8.79	Sandy Soil	10.0	27.0	—— ——	97.15 107.15	76.34 86.14	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
11	8.79~ 9.79	Clayey soil	8.0	—	100.0 100.0	107.15 115.15	86.14 95.94	0.200 0.200	11.31 11.31	—— ——	—— ——	43.01 42.88
12	9.79~ 10.79	Clayey soil	8.0	—	200.0 200.0	115.15 123.15	95.94 105.74	0.200 0.200	11.31 11.31	—— ——	—— ——	43.98 43.92
13	10.79~ 11.79	Clayey soil	8.0	—	200.0 200.0	123.15 131.15	105.74 115.54	0.200 0.200	11.31 11.31	—— ——	—— ——	43.92 43.85
14	11.79~ 12.79	Sandy Soil	10.0	45.0	—— ——	131.15 141.15	115.54 125.34	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	12.79~ 20.00	Sandy Soil	10.0	45.0	—— ——	141.15 213.25	125.34 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 2.79	Clayey soil	8.00	0.0	12.0 12.0	0.000 1.520	0.00 1.86	0.200 0.200	11.31 11.31	—— ——	—— ——
5	2.79~ 3.79	Clayey soil	8.00	0.0	12.0 12.0	1.520 9.520	1.86 11.66	0.200 0.200	11.31 11.31	—— ——	—— ——
6	3.79~ 4.79	Sandy soil	10.00	27.0	—— ——	9.520 19.520	11.66 21.46	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	4.79~ 5.79	Sandy soil	10.00	32.0	—— ——	19.520 29.520	21.46 31.26	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
8	5.79~ 6.79	Sandy soil	10.00	33.0	—— ——	29.520 39.520	31.26 41.06	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
9	6.79~ 7.79	Sandy soil	10.00	27.0	—— ——	39.520 49.520	41.06 50.86	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
10	7.79~ 8.79	Sandy soil	10.00	27.0	—— ——	49.520 59.520	50.86 60.66	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
11	8.79~ 9.79	Clayey soil	8.00	0.0	100.0 100.0	59.520 67.520	60.66 70.46	0.200 0.200	11.31 11.31	—— ——	—— ——
12	9.79~ 10.79	Clayey soil	8.00	0.0	200.0 200.0	67.520 75.520	70.46 80.26	0.200 0.200	11.31 11.31	—— ——	—— ——
13	10.79~ 11.79	Clayey soil	8.00	0.0	200.0 200.0	75.520 83.520	80.26 90.06	0.200 0.200	11.31 11.31	—— ——	—— ——
14	11.79~ 12.79	Sandy soil	10.00	45.0	—— ——	83.520 93.520	90.06 99.86	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
15	12.79~ 20.00	Sandy soil	10.00	45.0	—— ——	93.520 165.620	99.86 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.
δ = -10.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	10.13 19.52	—— ——	10.13 19.52	0.00 20.58	—— ——
2	2.10~ 2.20	30.71 31.77	21.81 22.21	30.71 31.77	20.58 21.56	—— ——
3	2.20~ 2.60	31.77 36.06	22.21 23.81	31.77 36.06	21.56 21.56	—— ——
4	2.60~ 2.79	36.06 38.12	23.81 24.57	36.06 38.12	21.56 21.56	24.00 25.52
5	2.79~ 3.79	38.12 49.22	24.57 28.57	38.12 49.22	21.56 21.56	25.52 33.52
6	3.79~ 4.79	28.40 33.37	—— ——	28.40 33.37	21.56 21.56	28.08 57.57
7	4.79~ 5.79	28.02 32.19	—— ——	28.02 32.19	21.56 21.56	74.78 113.09
8	5.79~ 6.79	31.07 35.10	—— ——	31.07 35.10	21.56 21.56	119.33 159.75
9	6.79~ 7.79	43.31 48.28	—— ——	43.31 48.28	21.56 21.56	116.56 146.06
10	7.79~ 8.79	48.28 53.25	—— ——	48.28 53.25	21.56 21.56	146.06 175.55
11	8.79~ 9.79	-70.36 -60.60	53.57 57.57	53.57 57.57	21.56 21.56	259.52 267.52
12	9.79~ 10.79	-261.24 -251.56	57.57 61.57	57.57 61.57	21.56 21.56	467.52 475.52
13	10.79~ 11.79	-251.56 -241.87	61.57 65.57	61.57 65.57	21.56 21.56	475.52 483.52
14	11.79~ 12.79	33.93 36.52	—— ——	33.93 36.52	21.56 21.56	685.15 767.19
15	12.79~ 20.00	36.52 55.18	—— ——	36.52 55.18	21.56 21.56	767.19 1358.66

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = \left[K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}\right] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = \left[K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}\right] \cdot \cos\delta$

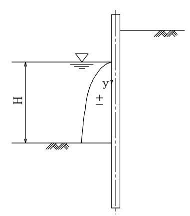
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

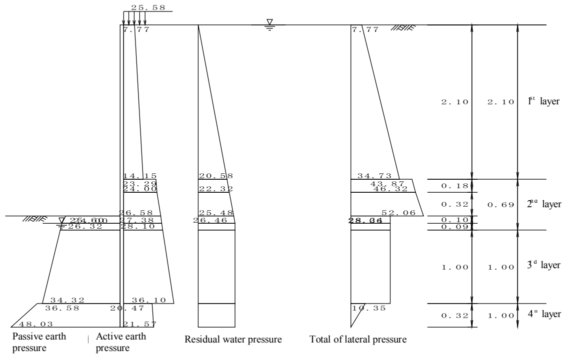
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

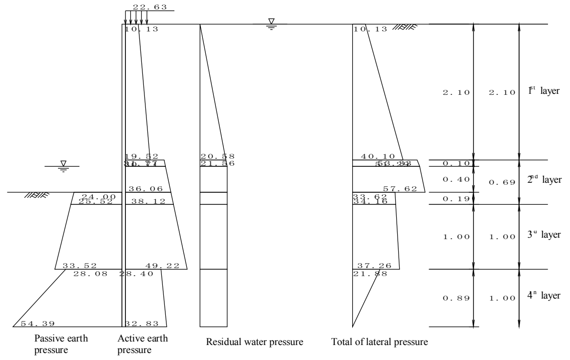


	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	7.77 14.15	0.00 20.58	―― ――	7.77 34.73
2	2.10～ 2.28	23.29 24.00	20.58 22.32	―― ――	43.87 46.32
3	2.28～ 2.60	24.00 26.58	22.32 25.48	―― ――	46.32 52.06
4	2.60～ 2.70	26.58 27.38	25.48 26.46	24.00 25.60	28.06 28.24
5	2.70～ 2.79	27.38 28.10	26.46 26.46	25.60 26.32	28.24 28.24
6	2.79～ 3.79	28.10 36.10	26.46 26.46	26.32 34.32	28.24 28.24
7	3.79～ 4.11	20.47 21.57	26.46 26.46	36.58 48.03	10.35 0.00
8	4.11～ 4.79	21.57 23.88	26.46 26.46	48.03 72.02	0.00 -21.68

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.51 m (GL -4.11 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	10.13 19.52	0.00 20.58	―― ――	10.13 40.10
2	2.10～ 2.20	30.71 31.77	20.58 21.56	―― ――	51.29 53.33
3	2.20～ 2.60	31.77 36.06	21.56 21.56	―― ――	53.33 57.62
4	2.60～ 2.79	36.06 38.12	21.56 21.56	24.00 25.52	33.62 34.16
5	2.79～ 3.79	38.12 49.22	21.56 21.56	25.52 33.52	34.16 37.26
6	3.79～ 4.68	28.40 32.83	21.56 21.56	28.08 54.39	21.88 0.00
7	4.68～ 4.79	32.83 33.37	21.56 21.56	54.39 57.57	0.00 -2.64

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.08 m (GL -4.68 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to $1/\beta$ depth. The modules are calculated by the formula below.

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	2
4	2.79	2
5	3.79	2
6	4.79	10
7	5.79	20
8	6.79	22
9	7.79	5
10	8.79	8

	Depth (m)	N-value
11	9.79	29
12	10.79	31
13	11.79	46
14	12.79	50
15	20.00	50

5-2 Normal Condition

K_h = 20210 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.447 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.24 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.11 m) to 2.24 m depth (GL -6.35 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.11	0.68	4.6	10.0	4.94
2	4.79	1.00	10.0	20.0	15.00
3	5.79	0.56	20.0	21.1	11.52
	L = Σh = 2.24			ΣA = 31.46	

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{31.46}{2.24} = 14.06$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following.

$$K_h = 6910 \times N'^{0.406} = 6910 \times 14.06^{0.406} = 20210 \text{ kN/m}^3$$

Kh (normal condition) = 20210 kN/m^3

5-3 Seismic Condition

K_h = 22191 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.458 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.19 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.68 m) and 2.19 m depth (GL -6.87 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.68	0.11	9.1	10.0	1.03
2	4.79	1.00	10.0	20.0	15.00
3	5.79	1.00	20.0	22.0	21.00
4	6.79	0.08	22.0	20.7	1.66
	L = Σh = 2.19			ΣA = 38.69	

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{38.69}{2.19} = 17.70$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following.

$$K_h = 6910 \times N'^{0.406} = 6910 \times 17.70^{0.406} = 22191 \text{ kN/m}^3$$

Kh (seismic condition) = 22191 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	7.77 34.73	8.16 36.47	3.41 2.71	27.85 98.94
2	2.10~ 2.28	0.18	43.87 46.32	3.89 4.11	1.95 1.89	7.61 7.79
3	2.28~ 2.60	0.32	46.32 52.06	7.47 8.40	1.73 1.62	12.91 13.61
4	2.60~ 2.70	0.10	28.06 28.24	1.40 1.41	1.48 1.45	2.08 2.04
5	2.70~ 2.79	0.09	28.24 28.24	1.27 1.27	1.38 1.35	1.76 1.72
6	2.79~ 3.79	1.00	28.24 28.24	14.12 14.12	0.99 0.66	13.98 9.27
7	3.79~ 4.11	0.32	10.35 0.00	1.67 0.00	0.22 0.11	0.36 0.00
				ΣP = 103.76		ΣM = 199.90

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	2.5 kN/m
depth to acting position	H_t	=	-0.44 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.51 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 11.38$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{211.29}{106.26} = 1.99 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.13 40.10	10.63 42.11	3.98 3.28	42.34 138.21
2	2.10~ 2.20	0.10	51.29 53.33	2.56 2.67	2.55 2.52	6.54 6.71
3	2.20~ 2.60	0.40	53.33 57.62	10.67 11.52	2.35 2.22	25.05 25.53
4	2.60~ 2.79	0.19	33.62 34.16	3.19 3.25	2.02 1.96	6.45 6.35
5	2.79~ 3.79	1.00	34.16 37.26	17.08 18.63	1.56 1.23	26.62 22.83
6	3.79~ 4.68	0.89	21.88 0.00	9.76 0.00	0.59 0.30	5.81 0.00
				ΣP = 132.07		ΣM = 312.43

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	7.8 kN/m
depth to acting position	H	=	-0.15 m
moment	M_m	=	2.3 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.08 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 39.99$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.35 2.22	0.00 0.30
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.30

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{352.73}{140.01} = 2.52 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63296 \times 10^{-8}$		=	1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	20210	kN/m^3
calculated value	β	=	0.44697	m^{-1}
resultant earth force (lateral)	P_0	=	106.26	kN/m
height of acting position of load	h_0	=	1.99	m
moment	M_0	=	211.29	kN·m/m

in consideration of ψ_h = 1.176,

maximum moment	M_{max}	=	248.37	kN·m/m
depth of generated position of M_{max}	l_m	=	0.773	m
depth of 1st fixed point	l_i	=	2.530	m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	22191	kN/m^3
calculated value	β	=	0.45754	m^{-1}
resultant earth force (lateral)	P_0	=	140.01	kN/m
height of acting position of load	h_0	=	2.52	m
moment	M_0	=	352.73	kN·m/m

in consideration of ψ_h = 1.117,

maximum moment	M_{max}	=	393.87	kN·m/m
depth of generated position of M_{max}	l_m	=	0.642	m
depth of 1st fixed point	l_i	=	2.359	m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{248.37 \times 10^6}{3514 \times 10^3} = 71 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{393.87 \times 10^6}{3514 \times 10^3} = 112 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

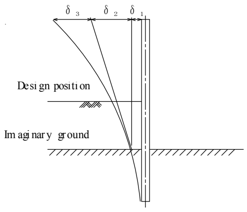
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.41 2.71	0.830 0.660	0.249 0.170	8.16 36.47	2.032 6.189
2	2.10~ 2.28	1.95 1.89	0.475 0.461	0.095 0.090	3.89 4.11	0.370 0.369
3	2.28~ 2.60	1.73 1.62	0.420 0.394	0.076 0.067	7.47 8.40	0.567 0.566
4	2.60~ 2.70	1.48 1.45	0.360 0.352	0.057 0.055	1.40 1.41	0.080 0.077
5	2.70~ 2.79	1.38 1.35	0.336 0.329	0.050 0.048	1.27 1.27	0.064 0.061
6	2.79~ 3.79	0.99 0.66	0.241 0.160	0.027 0.012	14.12 14.12	0.376 0.170
7	3.79~ 4.11	0.22 0.11	0.052 0.026	0.001 0.000	1.67 0.00	0.002 0.000
						ΣQ = 10.924

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4470\times 1.99)\times 106.26}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4470^3} = 0.00888 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4470\times 1.99)\times 106.26}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4470^2}\times(2.60+1.51) = 0.02400 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.92\times(2.60+1.51)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00600 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00053 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.11 m
Horizontal load: P = 2.50
Moment: M = 1.10

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00888 + 0.02400 + 0.00654
= 0.03941 m
= 39.41 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.98 3.28	0.851 0.701	0.259 0.188	10.63 42.11	2.755 7.929
2	2.10~ 2.20	2.55 2.52	0.544 0.537	0.121 0.118	2.56 2.67	0.311 0.316
3	2.20~ 2.60	2.35 2.22	0.502 0.473	0.105 0.094	10.67 11.52	1.118 1.087
4	2.60~ 2.79	2.02 1.96	0.431 0.418	0.080 0.075	3.19 3.25	0.254 0.244
5	2.79~ 3.79	1.56 1.23	0.333 0.262	0.049 0.031	17.08 18.63	0.842 0.582
6	3.79~ 4.68	0.59 0.30	0.127 0.064	0.008 0.002	9.76 0.00	0.075 0.000
						ΣQ = 15.512

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

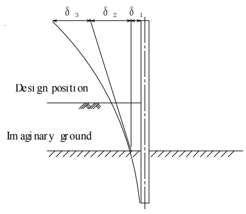
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	P_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	2.35 2.22	0.502 0.473	0.105 0.094	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below
Q = 15.512 + 0.013 = 15.525

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4575\times 2.52)\times 140.01}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4575^3} = 0.01243 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4575\times 2.52)\times 140.01}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4575^2}\times(2.60+2.08) = 0.04088 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.53\times(2.60+2.08)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.01259 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00221 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.68 m
Horizontal load: P = 7.80
Moment: M = 1.17

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.68 \text{ m、} h=L-H_m\text{、} H_m=0.80 \text{ m、ただし} H=L)$$

$$= \frac{2.30\times 3.88}{2\times 2.00\times 10^8\times 63296\times 10^{-8}}\times(2\times 4.68-3.88) = 0.00019 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01243 + 0.04088 + 0.01499
= 0.06830 m
= 68.30 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

2.226

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 86000 × 10^{-8}		=	1.720 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 20210 kN/m^3
Calculated value β = 0.41400 m^{-1}

Penetration length of SSP $D = 1.51 + \frac{3}{0.414} = 8.76$ m
Whole length of SSP $L = 2.60 - 0.40 + 8.76 = 10.96$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 22191 kN/m^3
Calculated value β = 0.42379 m^{-1}

Penetration length of SSP $D = 2.08 + \frac{3}{0.424} = 9.16$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.16 = 11.36$ m

Therefore, whole length of SSP is set as 11.50 m in consideration of round unit of SSP length.

8 Calculation Result

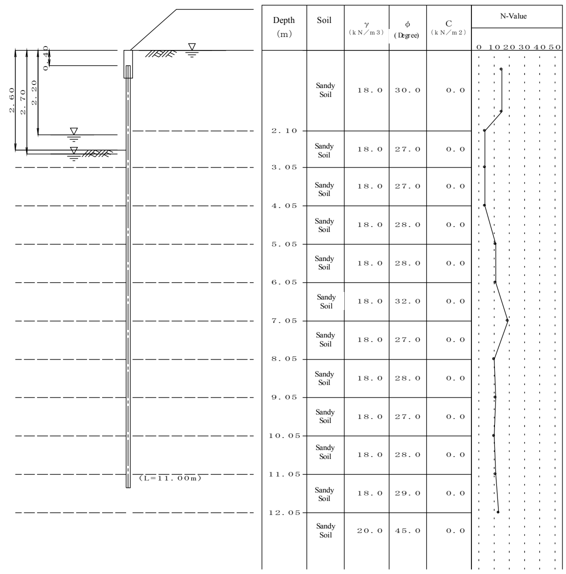
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		248.37	393.87
Stress intensity	σ (N/mm^2)		71 (180)	112 (270)
Lateral displacement	δ (mm)		39.41 (50.0)	68.30 (75.0)
Penetration depth	D (m)		8.76	9.16
Whole length of SSP	L (m)	11.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 30_STA 13+578 - 13+700

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8\ kN/m^3$

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity $k = 0.200$

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	0.4 kN/m	(Normal Condition)
		Pt'	=	6.8 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.74 m	(Normal Condition)
		Ht'	=	-0.32 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN･m/m	(Normal Condition)
		M_m'	=	0.0 kN･m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\dfrac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	10.05	10
2	1.60	15	12	11.05	11
3	2.10	4	13	12.05	13
4	3.05	4	14	13.00	50
5	4.05	4			
6	5.05	11			
7	6.05	11			
8	7.05	19			
9	8.05	10			
10	9.05	11			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

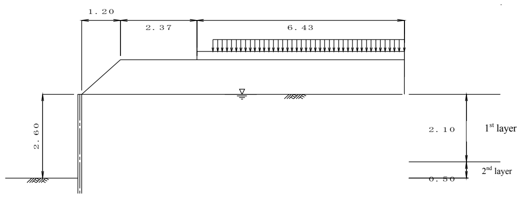
No	Depth (m)	Soil	N-value	γ kNm³	γ' kNm³	φ	C kNm²	a	k'	ζ (degree)		kh(kNm³)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	―――	―――
2	3.05	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
3	4.05	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
4	5.05	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	―――	―――
5	6.05	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	―――	―――
6	7.05	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	―――	―――
7	8.05	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
8	9.05	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	―――	―――
9	10.05	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	―――	―――
10	11.05	S	11.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	―――	―――
11	12.05	S	13.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	―――	―――
12	13.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	―――	―――

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	1.20	10.00	10.00	1.07	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.57	3.57	10.00	10.00	0.26	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm^2)	Seismic (kNm^2)
1	4.07	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 56700 cm^4
Sectional factor Z_0 = 2700 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 180 N/mm (Normal)
σ_a' = 270 N/mm (Seismic)

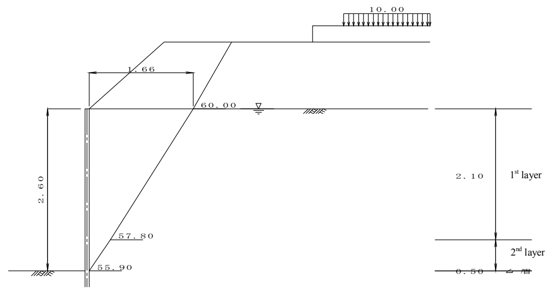
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	$\gamma w h w$ (kN/m^2)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	15.88	25.48	55.90
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	15.88	20.58	57.80
3		Embankment	30.0	——	0.0	23.94	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45^o since θ = 0^o

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^o$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	1.07	1.66	2.60	2.28	3.67

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	1.47	26.38
Σ			26.38

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

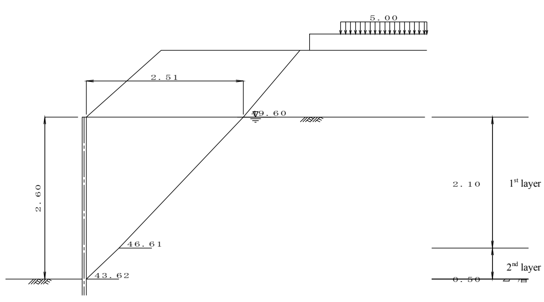
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{26.38 + 0.00 + 0.00}{1.66}$$

$$= 15.88 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	$\Sigma\gamma h$ (kN/m^2)	Q (kN/m^2)	$\gamma w h w$ (kN/m^2)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	18.15	25.48	0.200	11.31	43.62
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	18.15	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	23.94	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00^o$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	1.07	2.51	2.60	3.42	3.67

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	2.53	45.56
Σ			45.56

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Calculation of Total Acting Load

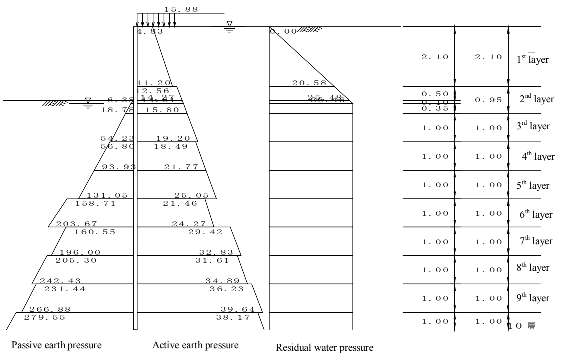
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{45.56 + 0.00 + 0.00}{2.51}$$

$$= 18.15 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	15.884 36.884	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	27.0	—— ——	36.884 41.884	0.34585 0.34585	0.34060 0.34060
3	2.60~ 2.70	Sandy soil	10.0	27.0	—— ——	41.884 42.884	0.34585 0.34585	0.34060 0.34060
4	2.70~ 3.05	Sandy soil	10.0	27.0	—— ——	42.884 46.384	0.34585 0.34585	0.34060 0.34060
5	3.05~ 4.05	Sandy soil	10.0	27.0	—— ——	46.384 56.384	0.34585 0.34585	0.34060 0.34060
6	4.05~ 5.05	Sandy soil	10.0	28.0	—— ——	56.384 66.384	0.33303 0.33303	0.32798 0.32798
7	5.05~ 6.05	Sandy soil	10.0	28.0	—— ——	66.384 76.384	0.33303 0.33303	0.32798 0.32798
8	6.05~ 7.05	Sandy soil	10.0	32.0	—— ——	76.384 86.384	0.28525 0.28525	0.28092 0.28092
9	7.05~ 8.05	Sandy soil	10.0	27.0	—— ——	86.384 96.384	0.34585 0.34585	0.34060 0.34060
10	8.05~ 9.05	Sandy soil	10.0	28.0	—— ——	96.384 106.384	0.33303 0.33303	0.32798 0.32798
11	9.05~ 10.05	Sandy soil	10.0	27.0	—— ——	106.384 116.384	0.34585 0.34585	0.34060 0.34060
12	10.05~ 11.05	Sandy soil	10.0	28.0	—— ——	116.384 126.384	0.33303 0.33303	0.32798 0.32798
13	11.05~ 12.05	Sandy soil	10.0	29.0	—— ——	126.384 136.384	0.32058 0.32058	0.31571 0.31571

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
14	12.05~ 13.00	Sandy soil	10.0	45.0	—— ——	136.384 145.884	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.59892 3.59892	3.54425 3.54425
4	2.70~ 3.05	Sandy soil	10.0	27.0	—— ——	1.800 5.300	3.59892 3.59892	3.54425 3.54425
5	3.05~ 4.05	Sandy soil	10.0	27.0	—— ——	5.300 15.300	3.59892 3.59892	3.54425 3.54425
6	4.05~ 5.05	Sandy soil	10.0	28.0	—— ——	15.300 25.300	3.76978 3.76978	3.71251 3.71251
7	5.05~ 6.05	Sandy soil	10.0	28.0	—— ——	25.300 35.300	3.76978 3.76978	3.71251 3.71251
8	6.05~ 7.05	Sandy soil	10.0	32.0	—— ——	35.300 45.300	4.56530 4.56530	4.49594 4.49594
9	7.05~ 8.05	Sandy soil	10.0	27.0	—— ——	45.300 55.300	3.59892 3.59892	3.54425 3.54425
10	8.05~ 9.05	Sandy soil	10.0	28.0	—— ——	55.300 65.300	3.76978 3.76978	3.71251 3.71251
11	9.05~ 10.05	Sandy soil	10.0	27.0	—— ——	65.300 75.300	3.59892 3.59892	3.54425 3.54425
12	10.05~ 11.05	Sandy soil	10.0	28.0	—— ——	75.300 85.300	3.76978 3.76978	3.71251 3.71251
13	11.05~ 12.05	Sandy soil	10.0	29.0	—— ——	85.300 95.300	3.95096 3.95096	3.89093 3.89093
14	12.05~ 13.00	Sandy soil	10.0	45.0	—— ——	95.300 104.800	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	4.83 11.20	—— ——	4.83 11.20	0.00 20.58	—— ——
2	2.10~ 2.60	12.56 14.27	—— ——	12.56 14.27	20.58 25.48	—— ——
3	2.60~ 2.70	14.27 14.61	—— ——	14.27 14.61	25.48 26.46	0.00 6.38
4	2.70~ 3.05	14.61 15.80	—— ——	14.61 15.80	26.46 26.46	6.38 18.78
5	3.05~ 4.05	15.80 19.20	—— ——	15.80 19.20	26.46 26.46	18.78 54.23
6	4.05~ 5.05	18.49 21.77	—— ——	18.49 21.77	26.46 26.46	56.80 93.93
7	5.05~ 6.05	21.77 25.05	—— ——	21.77 25.05	26.46 26.46	93.93 131.05
8	6.05~ 7.05	21.46 24.27	—— ——	21.46 24.27	26.46 26.46	158.71 203.67
9	7.05~ 8.05	29.42 32.83	—— ——	29.42 32.83	26.46 26.46	160.55 196.00
10	8.05~ 9.05	31.61 34.89	—— ——	31.61 34.89	26.46 26.46	205.30 242.43
11	9.05~ 10.05	36.23 39.64	—— ——	36.23 39.64	26.46 26.46	231.44 266.88
12	10.05~ 11.05	38.17 41.45	—— ——	38.17 41.45	26.46 26.46	279.55 316.68
13	11.05~ 12.05	39.90 43.06	—— ——	39.90 43.06	26.46 26.46	331.90 370.81
14	12.05~ 13.00	21.84 23.36	—— ——	21.84 23.36	26.46 26.46	877.09 964.53

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

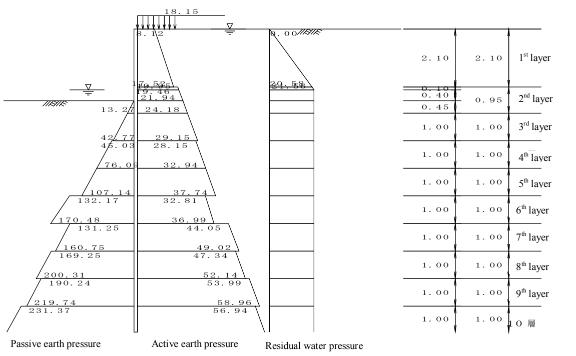
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	18.15 39.15	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	27.0	—— ——	39.15 40.15	20.58 21.56	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
3	2.20~ 2.60	Sandy Soil	10.0	27.0	—— ——	40.15 44.15	21.56 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
4	2.60~ 3.05	Sandy Soil	10.0	27.0	—— ——	44.15 48.65	25.48 29.89	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
5	3.05~ 4.05	Sandy Soil	10.0	27.0	—— ——	48.65 58.65	29.89 39.69	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
6	4.05~ 5.05	Sandy Soil	10.0	28.0	—— ——	58.65 68.65	39.69 49.49	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
7	5.05~ 6.05	Sandy Soil	10.0	28.0	—— ——	68.65 78.65	49.49 59.29	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
8	6.05~ 7.05	Sandy Soil	10.0	32.0	—— ——	78.65 88.65	59.29 69.09	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
9	7.05~ 8.05	Sandy Soil	10.0	27.0	—— ——	88.65 98.65	69.09 78.89	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
10	8.05~ 9.05	Sandy Soil	10.0	28.0	—— ——	98.65 108.65	78.89 88.69	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
11	9.05~ 10.05	Sandy Soil	10.0	27.0	—— ——	108.65 118.65	88.69 98.49	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
12	10.05~ 11.05	Sandy Soil	10.0	28.0	—— ——	118.65 128.65	98.49 108.29	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—— ——
13	11.05~ 12.05	Sandy Soil	10.0	29.0	—— ——	128.65 138.65	108.29 118.09	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——

2.230

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C kNm^2	Σγh+Q (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	12.05~ 13.00	Sandy Soil	10.0	45.0	—— ——	138.65 148.15	118.09 127.40	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm^3)	ϕ (degree)	C kNm^2	Σγh+Qp (kNm^2)	γwhw (kNm^2)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 3.05	Sandy soil	10.00	27.0	—— ——	0.000 4.500	0.00 4.41	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	3.05~ 4.05	Sandy soil	10.00	27.0	—— ——	4.500 14.500	4.41 14.21	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	4.05~ 5.05	Sandy soil	10.00	28.0	—— ——	14.500 24.500	14.21 24.01	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
7	5.05~ 6.05	Sandy soil	10.00	28.0	—— ——	24.500 34.500	24.01 33.81	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
8	6.05~ 7.05	Sandy soil	10.00	32.0	—— ——	34.500 44.500	33.81 43.61	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
9	7.05~ 8.05	Sandy soil	10.00	27.0	—— ——	44.500 54.500	43.61 53.41	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
10	8.05~ 9.05	Sandy soil	10.00	28.0	—— ——	54.500 64.500	53.41 63.21	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
11	9.05~ 10.05	Sandy soil	10.00	27.0	—— ——	64.500 74.500	63.21 73.01	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
12	10.05~ 11.05	Sandy soil	10.00	28.0	—— ——	74.500 84.500	73.01 82.81	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559
13	11.05~ 12.05	Sandy soil	10.00	29.0	—— ——	84.500 94.500	82.81 92.61	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
14	12.05~ 13.00	Sandy soil	10.00	45.0	—— ——	94.500 104.000	92.61 101.92	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm^2	Pa2 kNm^2	Pa kNm^2	Pw kNm^2	Pp kNm^2
1	0.00~ 2.10	8.12 17.52	—— ——	8.12 17.52	0.00 20.58	—— ——
2	2.10~ 2.20	19.46 19.95	—— ——	19.46 19.95	20.58 21.56	—— ——
3	2.20~ 2.60	19.95 21.94	—— ——	19.95 21.94	21.56 21.56	—— ——
4	2.60~ 3.05	21.94 24.18	—— ——	21.94 24.18	21.56 21.56	0.00 13.27
5	3.05~ 4.05	24.18 29.15	—— ——	24.18 29.15	21.56 21.56	13.27 42.77
6	4.05~ 5.05	28.15 32.94	—— ——	28.15 32.94	21.56 21.56	45.03 76.09
7	5.05~ 6.05	32.94 37.74	—— ——	32.94 37.74	21.56 21.56	76.09 107.14
8	6.05~ 7.05	32.81 36.99	—— ——	32.81 36.99	21.56 21.56	132.17 170.48
9	7.05~ 8.05	44.05 49.02	—— ——	44.05 49.02	21.56 21.56	131.25 160.75
10	8.05~ 9.05	47.34 52.14	—— ——	47.34 52.14	21.56 21.56	169.25 200.31
11	9.05~ 10.05	53.99 58.96	—— ——	53.99 58.96	21.56 21.56	190.24 219.74
12	10.05~ 11.05	56.94 61.74	—— ——	56.94 61.74	21.56 21.56	231.37 262.42
13	11.05~ 12.05	59.62 64.25	—— ——	59.62 64.25	21.56 21.56	276.40 309.10
14	12.05~ 13.00	35.87 38.33	—— ——	35.87 38.33	21.56 21.56	775.23 853.16

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

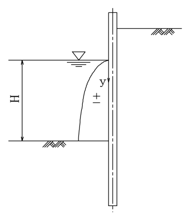
Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}]\cdot\cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm^2)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

Where,

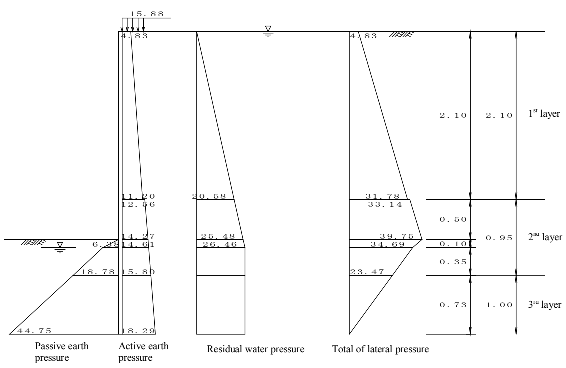
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

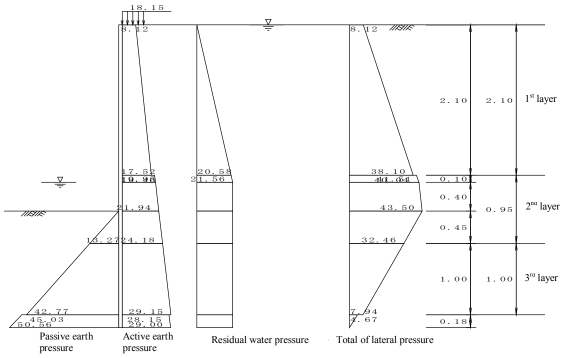


	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00~ 2.10	4.83 11.20	0.00 20.58	—— ——	4.83 31.78
2	2.10~ 2.60	12.56 14.27	20.58 25.48	—— ——	33.14 39.75
3	2.60~ 2.70	14.27 14.61	25.48 26.46	0.00 6.38	39.75 34.69
4	2.70~ 3.05	14.61 15.80	26.46 26.46	6.38 18.78	34.69 23.47
5	3.05~ 3.78	15.80 18.29	26.46 26.46	18.78 44.75	23.47 0.00
6	3.78~ 4.05	18.29 19.20	26.46 26.46	44.75 54.23	0.00 -8.56

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.18 m (GL -3.78 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00~ 2.10	8.12 17.52	0.00 20.58	—— ——	8.12 38.10
2	2.10~ 2.20	19.46 19.95	20.58 21.56	—— ——	40.04 41.51
3	2.20~ 2.60	19.95 21.94	21.56 21.56	—— ——	41.51 43.50
4	2.60~ 3.05	21.94 24.18	21.56 21.56	0.00 13.27	43.50 32.46
5	3.05~ 4.05	24.18 29.15	21.56 21.56	13.27 42.77	32.46 7.94
6	4.05~ 4.23	28.15 29.00	21.56 21.56	45.03 50.56	4.67 0.00
7	4.23~ 5.05	29.00 32.94	21.56 21.56	50.56 76.09	0.00 -21.58

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.63 m (GL -4.23 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴(original condition)
	I	=	39917 cm⁴(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	10.05	10
2	1.60	15	12	11.05	11
3	2.10	4	13	12.05	13
4	3.05	4	14	13.00	50
5	4.05	4			
6	5.05	11			
7	6.05	11			
8	7.05	19			
9	8.05	10			
10	9.05	11			

5-2 Normal Condition

K_h = 16429 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.476 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.10 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.78 m) to 2.10 m depth (GL -5.88 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.78	0.27	4.0	4.0	1.07
2	4.05	1.00	4.0	11.0	7.50
3	5.05	0.83	11.0	11.0	9.16
	L = Σh = 2.10				ΣA = 17.73

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{17.73}{2.10} = 8.44$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 8.44^{0.406} = 16429$ kN/m³

Kh (normal condition) = 16429 kN/m³

5-3 Seismic Condition

K_h = 17576 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.484 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.06 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.23 m) and 2.06 m depth (GL -6.29 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.23	0.82	5.2	11.0	6.68
2	5.05	1.00	11.0	11.0	11.00
3	6.05	0.24	11.0	12.9	2.90
	L = Σh = 2.06				ΣA = 20.58

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{20.58}{2.06} = 9.97$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 9.97^{0.406} = 17576$ kN/m³

Kh (seismic condition) = 17576 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	4.83 31.78	5.07 33.37	3.08 2.38	15.62 79.52
2	2.10~ 2.60	0.50	33.14 39.75	8.29 9.94	1.52 1.35	12.56 13.41
3	2.60~ 2.70	0.10	39.75 34.69	1.99 1.73	1.15 1.12	2.28 1.94
4	2.70~ 3.05	0.35	34.69 23.47	6.07 4.11	0.97 0.85	5.86 3.49
5	3.05~ 3.78	0.73	23.47 0.00	8.60 0.00	0.49 0.24	4.20 0.00
				ΣP = 79.16		ΣM = 138.88

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	0.4 kN/m
depth to acting position	H_t	=	-0.74 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.18 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 1.81$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{140.69}{79.56} = 1.77 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.12 38.10	8.53 40.01	3.53 2.83	30.09 113.14
2	2.10~ 2.20	0.10	40.04 41.51	2.00 2.08	2.09 2.06	4.19 4.28
3	2.20~ 2.60	0.40	41.51 43.50	8.30 8.70	1.89 1.76	15.73 15.32
4	2.60~ 3.05	0.45	43.50 32.46	9.79 7.30	1.48 1.33	14.47 9.70
5	3.05~ 4.05	1.00	32.46 7.94	16.23 3.97	0.84 0.51	13.71 2.03
6	4.05~ 4.23	0.18	4.67 0.00	0.42 0.00	0.12 0.06	0.05 0.00
				ΣP = 107.32		ΣM = 222.71

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	6.8 kN/m
depth to acting position	H_t	=	-0.32 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.63 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 30.93$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.89 1.76	0.00 0.24
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.24

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{253.87}{114.26} = 2.22 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 39917 × 10^{-8}		=	7.983 × 10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	16429 kN/m^3
calculated value	β	=	0.47626 m^{-1}
resultant earth force (lateral)	P_0	=	79.56 kN/m
height of acting position of load	h_0	=	1.77 m
moment	M_0	=	140.69 kN·m/m

in consideration of ψ_m = 1.191, maximum moment	M_{max}	=	167.50 kN·m/m
depth of generated position of M_{max}	l_m	=	0.749 m
depth of 1st fixed point	l_i	=	2.398 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	17576 kN/m^3
calculated value	β	=	0.48436 m^{-1}
resultant earth force (lateral)	P_0	=	114.26 kN/m
height of acting position of load	h_0	=	2.22 m
moment	M_0	=	253.87 kN·m/m

in consideration of ψ_m = 1.130, maximum moment	M_{max}	=	286.91 kN·m/m
depth of generated position of M_{max}	l_m	=	0.634 m
depth of 1st fixed point	l_i	=	2.256 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm^3 (original condition)
	Z	=	2376 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{167.50\times10^6}{2376\times10^3} = 70 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{286.91\times10^6}{2376\times10^3} = 121 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

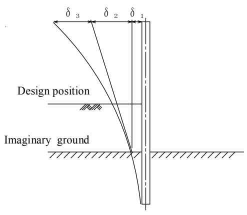
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.08 2.38	0.815 0.630	0.242 0.157	5.07 33.37	1.225 5.231
2	2.10~ 2.60	1.52 1.35	0.401 0.357	0.070 0.056	8.29 9.94	0.577 0.557
3	2.60~ 2.70	1.15 1.12	0.304 0.295	0.041 0.039	1.99 1.73	0.082 0.068
4	2.70~ 3.05	0.97 0.85	0.255 0.225	0.030 0.023	6.07 4.11	0.181 0.096
5	3.05~ 3.78	0.49 0.24	0.129 0.065	0.008 0.002	8.60 0.00	0.069 0.000
						ΣQ = 8.086

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.4763\times1.77)\times79.56}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4763^3} = 0.00850 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$
$$= \frac{(1+2\times0.4763\times1.77)\times79.56}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4763^2}\times(2.60+1.18) = 0.02231 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{8.09\times(2.60+1.18)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00548 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00012 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.78 m
Horizontal load: P = 0.40
Moment: M = 0.30

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00850 + 0.02231 + 0.00560
= 0.03640 m
= 36.40 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

2.233

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.53 2.83	0.834 0.669	0.251 0.174	8.53 40.01	2.143 6.954
2	2.10~ 2.20	2.09 2.06	0.495 0.488	0.102 0.100	2.00 2.08	0.205 0.207
3	2.20~ 2.60	1.89 1.76	0.448 0.417	0.085 0.075	8.30 8.70	0.709 0.650
4	2.60~ 3.05	1.48 1.33	0.350 0.314	0.054 0.044	9.79 7.30	0.528 0.323
5	3.05~ 4.05	0.84 0.51	0.200 0.121	0.019 0.007	16.23 3.97	0.302 0.028
6	4.05~ 4.23	0.12 0.06	0.028 0.014	0.000 0.000	0.42 0.00	0.000 0.000
						ΣQ = 12.049

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

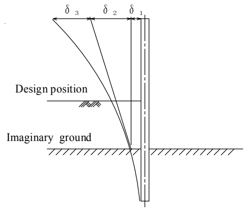
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20~ 2.60	1.89 1.76	0.448 0.417	0.085 0.075	0.00 0.14	0.000 0.010
						ΣQ_{dw} = 0.010

Therefore, modulus of deformation Q is calculated as below:

Q = 12.049＋0.010 ＝ 12.059

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4844\times2.22)\times114.26}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4844^3} = 0.01307 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4844\times2.22)\times114.26}{2\times2.00\times10^8\times39917\times10^{-8}\times0.4844^2}\times(2.60+1.63) = 0.04066 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.06\times(2.60+1.63)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.01142 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00239 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.23 m

Horizontal load: P = 6.80

Moment: M = 2.18

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01307＋0.04066＋0.01381

= 0.06754 m

= 67.54 ≦ δ_a = 75.00 mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10^{-8}		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction: K_h = 16429 kN/m^3

Calculated value: β = 0.43625 m^{-1}

Penetration length of SSP: $D = 1.18 + \dfrac{3}{0.436} = 8.06$ m

Whole length of SSP: L = 2.60－0.40＋8.06 ＝ 10.26 m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction: K_h = 17576 kN/m^3

Calculated value: β = 0.44367 m^{-1}

Penetration length of SSP: $D = 1.63 + \dfrac{3}{0.444} = 8.39$ m

Whole length of SSP: L = 2.60－0.40＋8.39 ＝ 10.59 m

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		167.50	286.91
Stress intensity	σ (N/mm^2)		70 (180)	121 (270)
Lateral displacement	δ (mm)		36.40 (50.0)	67.54 (75.0)
Penetration depth	D (m)		8.06	8.39
Whole length of SSP	L (m)	11.00		

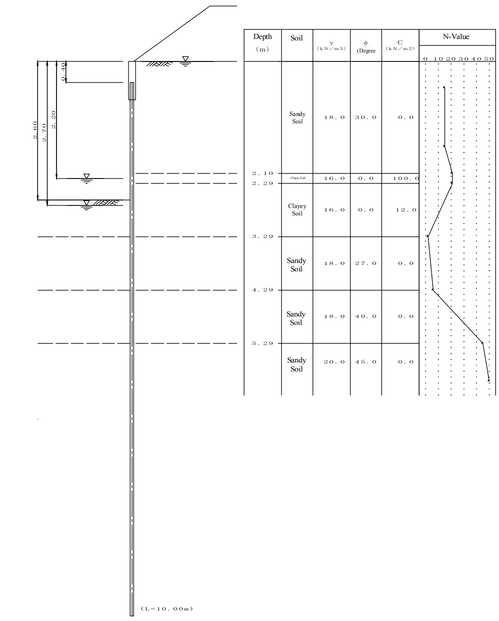
2.234

－Steel Sheet Pile Design Calculation－

Right Bank No. 31_STA_13+700 - 13+802

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress: Chang's formula

Penetration depths: $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water: γ_w = 9.8 kNm^3

Type of water pressure: trapezoidal water pressure

Lateral pressure: calculated in consideration of site conditions

Study case:
- Normal Condition
- Seismic Condition

Design earthquake intensity: k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	0.4 kNm	(Normal Condition)
		P_t'	=	6.8 kNm	(Seismic Condition)
	Depth of acting point	H_t	=	-0.73 m	(Normal Condition)
		H_t'	=	-0.32 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	0.0 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load: not considered

Minimum angle of rupture: ζ_0 = 10 degrees

Rear side angle of slope: not considered

Angle of rupture (clayey soil): $\zeta = \tan^{-1}\sqrt{1-\dfrac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression: K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula: K_h = 6910×N'$^{0.406}$

Average N-value: calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	21			
4	2.29	21			
5	3.29	2			
6	4.29	6			
7	5.29	45			
8	6.00	50			
9	20.00	50			

2.235

1-6 Vertical Load

Vertical load on landside: calculated in consideration of embankment shape on landside

Vertical load on riverside: not considered

1-7 Soil Modulus

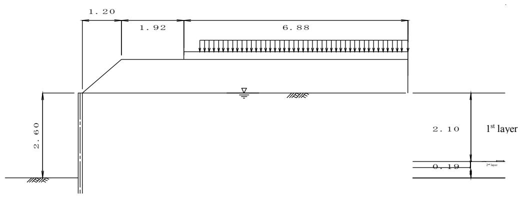
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.29	C	21.0	16.00	8.00	0.0	100.0	0.0	0.200	auto	auto	——	——
3	3.29	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
4	4.29	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.29	S	45.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
6	6.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	1.20	10.00	10.00	1.04	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.12	3.12	10.00	10.00	0.23	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	3.61	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 56700 cm⁴
Sectional factor Z_0 = 2700 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

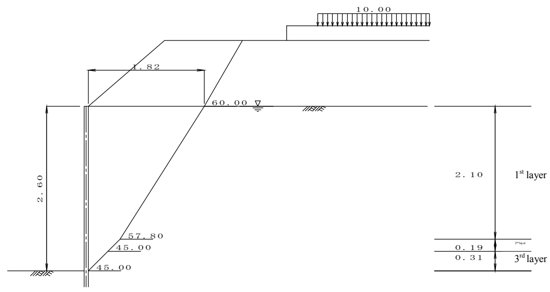
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.29	Clayey Soil	0.0	10.0	12.0	25.00	15.64	25.48	45.00
2	2.29～ 2.10	Clayey Soil	0.0	10.0	100.0	22.52	15.64	22.44	45.00
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	15.64	20.58	57.80
4		Embankment	30.0	——	0.0	22.86	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.31	0.00	0.00	0.31	0.31
2	45.00	0.19	0.31	0.31	0.50	0.50
3	57.80	2.10	0.50	0.50	1.82	2.60
4	60.00	1.04	1.82	2.60	2.42	3.64

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.58	28.50
Σ			28.50

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

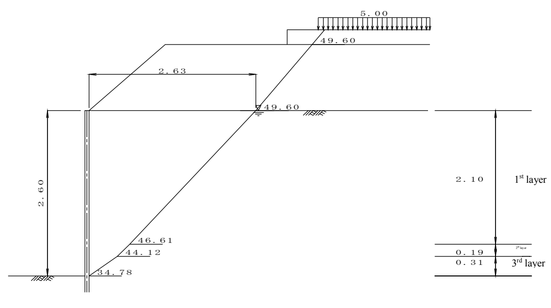
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times 1)+\Sigma P}{L}$$

$$= \frac{28.50 + 0.00 + 0.00}{1.82}$$

$$= 15.64 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.29	Clayey Soil	0.0	10.0	12.0	25.00	18.56	25.48	0.200	11.31	34.78
2	2.29～ 2.10	Clayey Soil	0.0	10.0	100.0	22.52	18.56	22.44	0.200	11.31	44.12
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	18.56	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	22.86	5.00	0.00	0.200	11.31	49.60
5		Embankment	30.0	——	0.0	4.14	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	34.78	0.31	0.00	0.00	0.45	0.31
2	44.12	0.19	0.45	0.31	0.64	0.50
3	46.61	2.10	0.64	0.50	2.63	2.60
4	49.60	1.04	2.63	2.60	3.51	3.64
5	49.60	0.23	3.51	3.64	3.71	3.87

Therefore, width of acting load shall be set as 2.63 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.57	46.24
2	18.0	0.11	2.03
Σ			48.27

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X 1 (kN/m)
1	5.0	0.10	0.49
Σ			0.49

Q surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

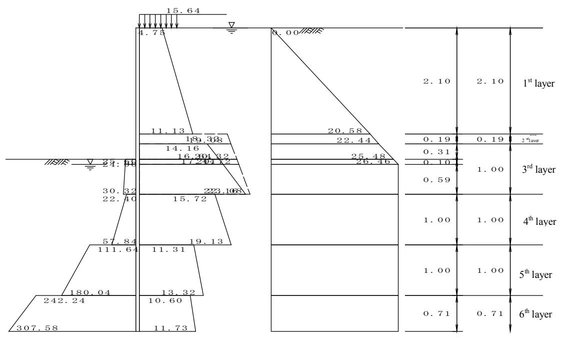
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{48.27 + 0.49 + 0.00}{2.63}$$

$= 18.56$ kN/m²

3 Lateral Pressure

3-1 Normal Condition



Passive earth pressure　Active earth pressure　Residual water pressure

3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	15.641 36.641	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.29	Clayey soil	8.0	—	100.0 100.0	36.641 38.161	—— ——	—— ——
3	2.29~ 2.60	Clayey soil	8.0	—	12.0 12.0	38.161 40.641	—— ——	—— ——
4	2.60~ 2.70	Clayey soil	8.0	—	12.0 12.0	40.641 41.441	—— ——	—— ——
5	2.70~ 3.29	Clayey soil	8.0	—	12.0 12.0	41.441 46.161	—— ——	—— ——
6	3.29~ 4.29	Sandy soil	10.0	27.0	—— ——	46.161 56.161	0.34585 0.34585	0.34060 0.34060
7	4.29~ 5.29	Sandy soil	10.0	40.0	—— ——	56.161 66.161	0.20447 0.20447	0.20137 0.20137
8	5.29~ 6.00	Sandy soil	10.0	45.0	—— ——	66.161 73.261	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60~ 2.70	Clayey soil	16.0	0.0	12.0 12.0	0.000 1.600	—— ——	—— ——
5	2.70~ 3.29	Clayey soil	8.0	0.0	12.0 12.0	1.600 6.320	—— ——	—— ——
6	3.29~ 4.29	Sandy soil	10.0	27.0	—— ——	6.320 16.320	3.59892 3.59892	3.54425 3.54425
7	4.29~ 5.29	Sandy soil	10.0	40.0	—— ——	16.320 26.320	6.94605 6.94605	6.84053 6.84053
8	5.29~ 6.00	Sandy soil	10.0	45.0	—— ——	26.320 33.420	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	4.75 11.13	—— ——	4.75 11.13	0.00 20.58	—— ——
2	2.10~ 2.29	-163.36 -161.84	18.32 19.08	18.32 19.08	20.58 22.44	—— ——
3	2.29~ 2.60	14.16 16.64	19.08 20.32	19.08 20.32	22.44 25.48	—— ——
4	2.60~ 2.70	16.64 17.44	20.32 20.72	20.32 20.72	25.48 26.46	24.00 25.60
5	2.70~ 3.29	17.44 22.16	20.72 23.08	20.72 23.08	26.46 26.46	25.60 30.32
6	3.29~ 4.29	15.72 19.13	—— ——	15.72 19.13	26.46 26.46	22.40 57.84
7	4.29~ 5.29	11.31 13.32	—— ——	11.31 13.32	26.46 26.46	111.64 180.04
8	5.29~ 6.00	10.60 11.73	—— ——	10.60 11.73	26.46 26.46	242.24 307.58

- Formula for active earth pressure

Sandy soil　$P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil　$P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil　$P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

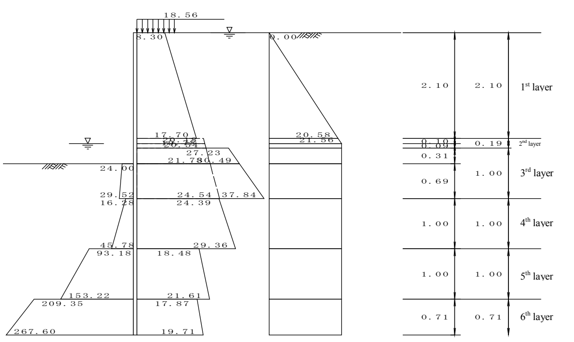
- Formula for passive earth pressure

Sandy soil　$P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil　$P_p = \Sigma\gamma h + Q + 2C$

Mixed soil　$P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



Passive earth pressure　Active earth pressure　Residual water pressure

3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	18.56 39.56	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Clayey Soil	8.0	—	100.0 100.0	39.56 40.36	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	44.14 44.13
3	2.20~ 2.29	Clayey Soil	8.0	—	100.0 100.0	40.36 41.08	21.56 22.44	0.200 0.200	11.31 11.31	—— ——	—— ——	44.13 44.12
4	2.29~ 2.60	Clayey Soil	8.0	—	12.0 12.0	41.08 43.56	22.44 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	35.35 34.78
5	2.60~ 3.29	Clayey Soil	8.0	—	12.0 12.0	43.56 49.08	25.48 32.24	0.200 0.200	11.31 11.31	—— ——	—— ——	34.78 33.45

2.237

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	3.29～ 4.29	Sandy Soil	10.0	27.0	—— ——	49.08 59.08	32.24 42.04	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
7	4.29～ 5.29	Sandy Soil	10.0	40.0	—— ——	59.08 69.08	42.04 51.84	0.200 0.200	11.31 11.31	0.31772 0.31772	0.31289 0.31289	—— ——
8	5.29～ 6.00	Sandy Soil	10.0	45.0	—— ——	69.08 76.18	51.84 58.80	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60～ 3.29	Clayey soil	8.00	0.0	12.0 12.0	0.000 5.520	0.00 6.76	0.200 0.200	11.31 11.31	—— ——	—— ——
6	3.29～ 4.29	Sandy soil	10.00	27.0	—— ——	5.520 15.520	6.76 16.56	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
7	4.29～ 5.29	Sandy soil	10.00	40.0	—— ——	15.520 25.520	16.56 26.36	0.200 0.200	11.31 11.31	6.09659 6.09659	6.00397 6.00397
8	5.29～ 6.00	Sandy soil	10.00	45.0	—— ——	25.520 32.620	26.36 33.32	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	8.30 17.70	—— ——	8.30 17.70	0.00 20.58	—— ——
2	2.10～ 2.20	-152.38 -151.41	19.78 20.18	19.78 20.18	20.58 21.56	—— ——
3	2.20～ 2.29	-151.41 -150.54	20.18 20.54	20.18 20.54	21.56 21.56	—— ——
4	2.29～ 2.60	27.23 30.49	20.54 21.78	27.23 30.49	21.56 21.56	—— ——
5	2.60～ 3.29	30.49 37.84	21.78 24.54	30.49 37.84	21.56 21.56	24.00 29.52

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
6	3.29～ 4.29	24.39 29.36	—— ——	24.39 29.36	21.56 21.56	16.28 45.78
7	4.29～ 5.29	18.48 21.61	—— ——	18.48 21.61	21.56 21.56	93.18 153.22
8	5.29～ 6.00	17.87 19.71	—— ——	17.87 19.71	21.56 21.56	209.35 267.60

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

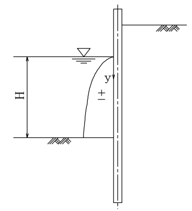
Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated

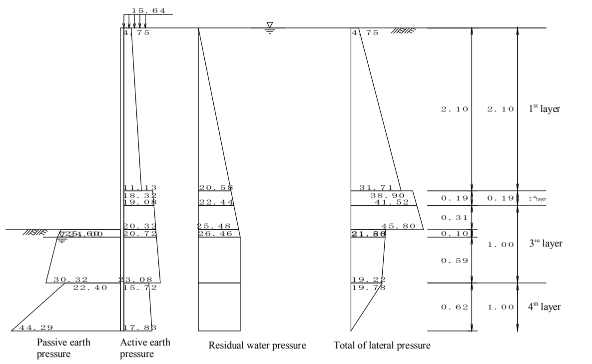


Passive earth pressure   Active earth pressure   Residual water pressure   Total of lateral pressure

4 Imaginary Riverbed

Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

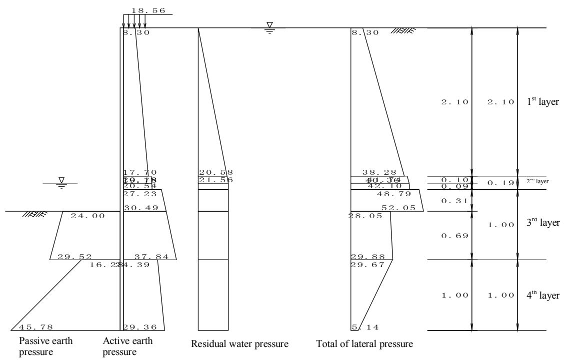


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	4.75 11.13	0.00 20.58	—— ——	4.75 31.71
2	2.10～ 2.29	18.32 19.08	20.58 22.44	—— ——	38.90 41.52
3	2.29～ 2.60	19.08 20.32	22.44 25.48	—— ——	41.52 45.80
4	2.60～ 2.70	20.32 20.72	25.48 26.46	24.00 25.60	21.80 21.58
5	2.70～ 3.29	20.72 23.08	26.46 26.46	25.60 30.32	21.58 19.22
6	3.29～ 3.91	15.72 17.83	26.46 26.46	22.40 44.29	19.78 0.00
7	3.91～ 4.29	17.83 19.13	26.46 26.46	44.29 57.84	0.00 -12.25

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.31 m (GL -3.91 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm^2	Pw kNm^2	Pp kNm^2	Ps kNm^2
1	0.00~ 2.10	8.30 17.70	0.00 20.58	—— ——	8.30 38.28
2	2.10~ 2.20	19.78 20.18	20.58 21.56	—— ——	40.36 41.74
3	2.20~ 2.29	20.18 20.54	21.56 21.56	—— ——	41.74 42.10
4	2.29~ 2.60	27.23 30.49	21.56 21.56	—— ——	48.79 52.05
5	2.60~ 3.29	30.49 37.84	21.56 21.56	24.00 29.52	28.05 29.88
6	3.29~ 4.29	24.39 29.36	21.56 21.56	16.28 45.78	29.67 5.14
7	4.29~ 5.29	18.48 21.61	21.56 21.56	93.18 153.22	-53.14 -110.05

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.69 m (GL -4.29 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	56700 cm^4(original condition)
	I	=	39917 cm^4(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	21
4	2.29	21
5	3.29	2
6	4.29	6
7	5.29	45
8	6.00	50
9	20.00	50

5-2 Normal Condition

K_h = 26281 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.536 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.87 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.91 m) to 1.87 m depth (GL -5.77 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.9	0.38	4.5	6.0	2.00
2	4.29	1.00	6.0	45.0	25.50
3	5.29	0.48	45.0	48.4	22.63
	L = Σh = 1.87				ΣA = 50.13

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L}$$
$$= \frac{50.13}{1.87}$$
$$= 26.85$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 26.85^{0.406} = 26281$ kN/m^3

Kh (normal condition) = 26281 kNm^3

5-3 Seismic Condition

K_h = 29443 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.551 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.81 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.29 m) and 1.81 m depth (GL -6.10 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.29	1.00	6.0	45.0	25.50
2	5.29	0.71	45.0	50.0	33.73
3	6.00	0.10	50.0	50.0	5.24
	L = Σh = 1.81				ΣA = 64.46

A (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L}$$
$$= \frac{64.46}{1.81}$$
$$= 35.52$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 35.52^{0.406} = 29443$ kN/m^3

Kh (seismic condition) = 29443 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	4.75 31.71	4.99 33.30	3.21 2.51	16.00 83.49
2	2.10~ 2.29	0.19	38.90 41.52	3.70 3.94	1.74 1.68	6.45 6.63
3	2.29~ 2.60	0.31	41.52 45.80	6.44 7.10	1.51 1.41	9.75 10.02
4	2.60~ 2.70	0.10	21.80 21.58	1.09 1.08	1.27 1.24	1.39 1.34
5	2.70~ 3.29	0.59	21.58 19.22	6.37 5.67	1.01 0.81	6.44 4.62
6	3.29~ 3.91	0.62	19.78 0.00	6.11 0.00	0.41 0.21	2.51 0.00
				ΣP = 79.77		ΣM = 148.62

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	0.4 kNm
depth to acting position	H_t	=	-0.73 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.31 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 1.86$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$
$$= \frac{150.48}{80.17} = 1.88 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	8.30 38.28	8.72 40.20	3.59 2.89	31.31 116.17
2	2.10~ 2.20	0.10	40.36 41.74	2.02 2.09	2.16 2.12	4.35 4.43
3	2.20~ 2.29	0.09	41.74 42.10	1.88 1.89	2.06 2.03	3.87 3.85
4	2.29~ 2.60	0.31	48.79 52.05	7.56 8.07	1.90 1.79	14.34 14.47
5	2.60~ 3.29	0.69	28.05 29.88	9.68 10.31	1.46 1.23	14.13 12.68
6	3.29~ 4.29	1.00	29.67 5.14	14.83 2.57	0.67 0.33	9.89 0.86
				ΣP = 109.82		ΣM = 230.34

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 6.8 kNm
depth to acting position H = -0.32 m
moment M_m = 0.0 kN·m/m
depth to acting position H_t = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.69 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 31.35 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.96 1.82	0.00 0.25
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.25

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{261.94}{116.75} = 2.24 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 0.80
Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 56700 cm^4 (original condition)
I = 39917 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{-8}$ = 7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1}\frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 26281 kNm^3
calculated value β = 0.53561 m^{-1}
resultant earth force (lateral) P_0 = 80.17 kNm
height of acting position of load h_0 = 1.88 m
moment M_0 = 150.48 kN·m/m

in consideration of ψ_m = 1.145,
maximum moment M_{max} = 172.29 kN·m/m
depth of generated position of M_{max} l_m = 0.599 m
depth of 1st fixed point l_i = 2.065 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 29443 kNm^3
calculated value β = 0.55104 m^{-1}
resultant earth force (lateral) P_0 = 116.75 kNm
height of acting position of load h_0 = 2.24 m
moment M_0 = 261.94 kN·m/m

in consideration of ψ_m = 1.104,
maximum moment M_{max} = 289.22 kN·m/m
depth of generated position of M_{max} l_m = 0.509 m
depth of 1st fixed point l_i = 1.934 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 1.00
Module of section Z_0 = 2700 cm^3 (original condition)
Z = 2376 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{172.29\times10^6}{2376\times10^3} = 73 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{289.22\times10^6}{2376\times10^3} = 122 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

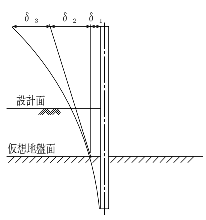
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.21 2.51	0.821 0.642	0.245 0.162	4.99 33.30	1.221 5.389
2	2.10~ 2.29	1.74 1.68	0.446 0.430	0.085 0.079	3.70 3.94	0.313 0.313
3	2.29~ 2.60	1.51 1.41	0.388 0.361	0.065 0.057	6.44 7.10	0.421 0.407
4	2.60~ 2.70	1.27 1.24	0.326 0.318	0.047 0.045	1.09 1.08	0.052 0.049
5	2.70~ 3.29	1.01 0.81	0.259 0.208	0.031 0.020	6.37 5.67	0.195 0.115
6	3.29~ 3.91	0.41 0.21	0.105 0.053	0.005 0.001	6.11 0.00	0.033 0.000
						ΣQ = 8.506

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3} = \frac{(1+0.5356\times1.88)\times80.17}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5356^3} = 0.00655 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k) = \frac{(1+2\times0.5356\times1.88)\times80.17}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5356^2}\times(2.60+1.31) = 0.02059 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI} = \frac{8.51\times(2.60+1.31)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00636 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00013 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.91 m
Horizontal load: P = 0.40
Moment: M = 0.29

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00655 + 0.02059 + 0.00648
= 0.03363 m
= 33.63 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.59 2.89	0.837 0.674	0.252 0.176	8.72 40.20	2.202 7.073
2	2.10～ 2.20	2.16 2.12	0.503 0.495	0.105 0.102	2.02 2.09	0.212 0.213
3	2.20～ 2.29	2.06 2.03	0.480 0.473	0.097 0.094	1.88 1.89	0.182 0.179
4	2.29～ 2.60	1.90 1.79	0.442 0.418	0.083 0.075	7.56 8.07	0.630 0.607
5	2.60～ 3.29	1.46 1.23	0.340 0.287	0.051 0.037	9.68 10.31	0.497 0.383
6	3.29～ 4.29	0.67 0.33	0.155 0.078	0.011 0.003	14.83 2.57	0.170 0.008
						ΣQ = 12.355

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

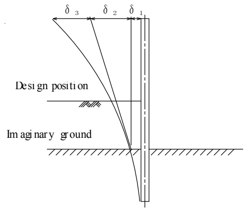
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.96 1.82	0.456 0.425	0.088 0.078	0.00 0.14	0.000 0.011
						ΣQ_{dw} = 0.011

Therefore, modulus of deformation Q is calculated as below
Q = 12.355 + 0.011 = 12.366

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5510\times 2.24)\times 116.75}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5510^3} = 0.00977\ \mathrm{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.5510\times 2.24)\times 116.75}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5510^2}\times(2.60+1.69) = 0.03588\ \mathrm{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.37\times(2.60+1.69)^3}{2.00\times 10^8\times 39917\times 10^{-8}} = 0.01223\ \mathrm{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00249 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.29 m
Horizontal load: P = 6.80
Moment: M = 2.18

δ = $\delta_1 + \delta_2 + \delta_3$
= 0.00977 + 0.03588 + 0.01472
= 0.06037 m
= 60.37 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm ^{2}
Inertia sectional moment	I_0	=	56700 cm ^{4} (original condition)
	I	=	56700 cm ^{4} (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10^{-8}		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 26281 kN/m³
Calculated value β = 0.49062 m⁻¹

Penetration length of SSP $D = 1.31 + \dfrac{3}{0.491} = 7.42$ m
Whole length of SSP $L = 2.60 - 0.40 + 7.42 = 9.62$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 29443 kN/m³
Calculated value β = 0.50475 m⁻¹

Penetration length of SSP $D = 1.69 + \dfrac{3}{0.505} = 7.63$ m
Whole length of SSP $L = 2.60 - 0.40 + 7.63 = 9.83$ m

Therefore, whole length of SSP is set as 10.00 m in consideration of round unit of SSP length.

8 Calculation Result

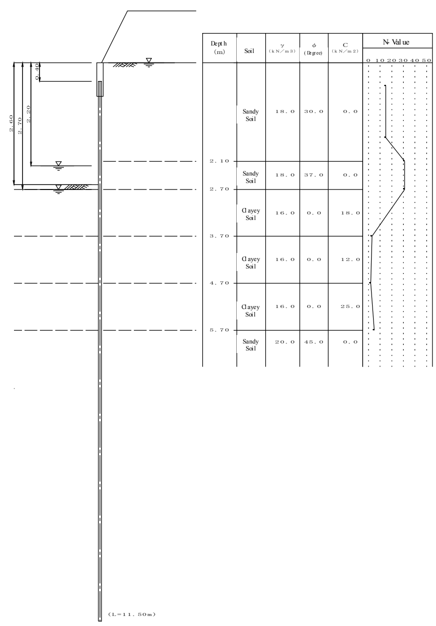
			Normal condition	Seismic condition
Inertia sectional moment	I (cm⁴)	56700		
Section modulus	Z (cm³)	2700		
Maximum bending moment	M_{max} (kN·m/m)		172.29	289.22
Stress intensity	σ (Nmm²)		73 (180)	122 (270)
Lateral displacement	δ (mm)		33.63 (50.0)	60.37 (75.0)
Penetration depth	D (m)		7.42	7.63
Whole length of SSP	L (m)	10.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 32_STA 13+802 - 13+900

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case - Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	3.3 kN/m	(Normal Condition)
		P_t'	=	9.0 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.51 m	(Normal Condition)
		H_t'	=	-0.24 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	3.6 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\dfrac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_e = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{\,0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	31			
4	2.70	31			
5	3.70	3			
6	4.70	2			
7	5.70	5			
8	6.20	50			
9	20.00	50			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

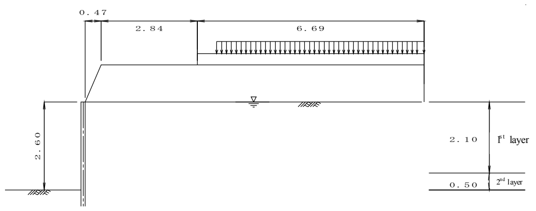
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	ϕ	C kNm^2	a	k'	ζ (degree)		kh (kNm^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.70	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
3	3.70	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	——	——
4	4.70	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
5	5.70	C	5.0	16.00	8.00	0.0	25.0	0.0	0.200	auto	auto	——	——
6	6.20	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note) depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
ϕ : internal friction angle of soil
C_0 : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (under water)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.47	10.00	10.00	1.10	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.31	3.31	10.00	10.00	0.33	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	3.88	10.00	10.0	5.0

Angle of rapture in embankment   calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus   E = 200000 Nmm²
Inertia sectional moment I_0 = 86000 cm⁴
Sectional factor Z_0 = 3820 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0)   η = 0.92
Corrosion rate (to Z_0)   η = 0.92
Section efficiency (to I_0)   μ = 0.80
Section efficiency (to Z_0)   μ = 1.00

Round unit of SSP length   0.50 m

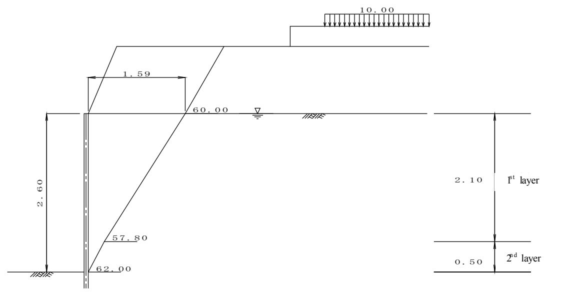
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam   calculated as distributed load of each layer

Reduction of material modulus   Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	37.0	10.0	0.0	26.00	20.83	25.48	62.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	20.83	20.58	57.80
3		Embankment	30.0	——	0.0	25.74	10.00	0.00	60.00

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

- Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	62.00	0.50	0.00	0.00	0.27	0.50
2	57.80	2.10	0.27	0.50	1.59	2.60
3	60.00	1.10	1.59	2.60	2.22	3.70

Therefore, width of acting load shall be set as 1.59 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.84	33.08
Σ			33.08

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

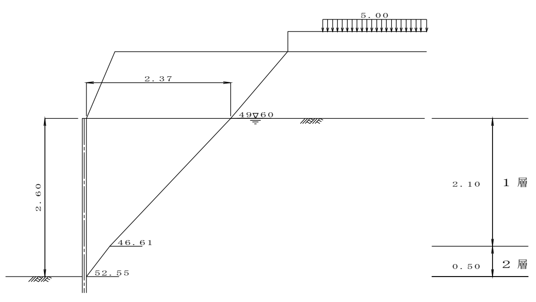
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{33.08 + 0.00 + 0.00}{1.59}$$

$= 20.83$ kN/m²

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	37.0	10.0	0.0	26.00	21.75	25.48	0.200	11.31	52.55
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	21.75	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	25.74	5.00	0.00	0.200	11.31	49.60

- Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	52.55	0.50	0.00	0.00	0.38	0.50
2	46.61	2.10	0.38	0.50	2.37	2.60
3	49.60	1.10	2.37	2.60	3.30	3.70

Therefore, width of acting load shall be set as 2.37 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.86	51.51
Σ			51.51

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Calculation of Total Acting Load

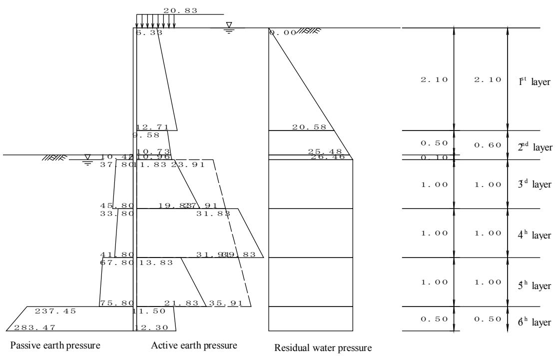
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{51.51 + 0.00 + 0.00}{2.37}$$

$= 21.75$ kN/m²

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	20.829 41.829	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.60	Sandy soil	10.0	37.0	—— ——	41.829 46.829	0.23264 0.23264	0.22910 0.22910
3	2.60~ 2.70	Sandy soil	10.0	37.0	—— ——	46.829 47.829	0.23264 0.23264	0.22910 0.22910
4	2.70~ 3.70	Clayey soil	8.0	—	18.0 18.0	47.829 55.829	—— ——	—— ——
5	3.70~ 4.70	Clayey soil	8.0	—	12.0 12.0	55.829 63.829	—— ——	—— ——
6	4.70~ 5.70	Clayey soil	8.0	—	25.0 25.0	63.829 71.829	—— ——	—— ——
7	5.70~ 6.20	Sandy soil	10.0	45.0	—— ——	71.829 76.829	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60~ 2.70	Sandy soil	18.0	37.0	—— ——	0.000 1.800	5.89457 5.89457	5.80501 5.80501
4	2.70~ 3.70	Clayey soil	8.0	0.0	18.0 18.0	1.800 9.800	—— ——	—— ——
5	3.70~ 4.70	Clayey soil	8.0	0.0	12.0 12.0	9.800 17.800	—— ——	—— ——
6	4.70~ 5.70	Clayey soil	8.0	0.0	25.0 25.0	17.800 25.800	—— ——	—— ——
7	5.70~ 6.20	Sandy soil	10.0	45.0	—— ——	25.800 30.800	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	6.33 12.71	—— ——	6.33 12.71	0.00 20.58	—— ——
2	2.10~ 2.60	9.58 10.73	—— ——	9.58 10.73	20.58 25.48	—— ——
3	2.60~ 2.70	10.73 10.96	—— ——	10.73 10.96	25.48 26.46	0.00 10.45
4	2.70~ 3.70	11.83 19.83	23.91 27.91	23.91 27.91	26.46 26.46	37.80 45.80
5	3.70~ 4.70	31.83 39.83	27.91 31.91	31.83 39.83	26.46 26.46	33.80 41.80
6	4.70~ 5.70	13.83 21.83	31.91 35.91	31.91 35.91	26.46 26.46	67.80 75.80
7	5.70~ 6.20	11.50 12.30	—— ——	11.50 12.30	26.46 26.46	237.45 283.47

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

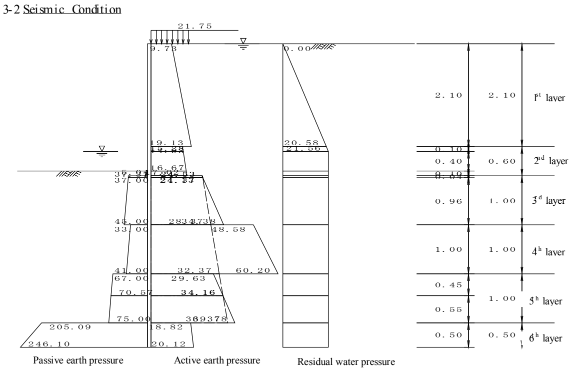
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	21.75 42.75	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	37.0	—— ——	42.75 43.75	20.58 21.56	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
3	2.20~ 2.60	Sandy Soil	10.0	37.0	—— ——	43.75 47.75	21.56 25.48	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
4	2.60~ 2.70	Sandy Soil	10.0	37.0	—— ——	47.75 48.75	25.48 26.46	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
5	2.70~ 2.74	Clayey Soil	8.0	—	18.0 18.0	48.75 49.06	26.46 ——	0.200 ——	11.31 ——	—— ——	—— ——	37.95 ——
6	2.74~ 3.70	Clayey Soil	8.0	—	18.0 18.0	49.06 56.75	—— 36.26	—— 0.200	—— 11.31	—— ——	—— ——	—— 36.90
7	3.70~ 4.70	Clayey Soil	8.0	—	12.0 12.0	56.75 64.75	36.26 46.06	0.200 0.200	11.31 11.31	—— ——	—— ——	30.46 27.85
8	4.70~ 5.15	Clayey Soil	8.0	—	25.0 25.0	64.75 68.32	46.06 ——	0.200 ——	11.31 ——	—— ——	—— ——	38.96 ——
9	5.15~ 5.70	Clayey Soil	8.0	—	25.0 25.0	68.32 72.75	—— 55.86	—— 0.200	—— 11.31	—— ——	—— ——	—— 38.26
10	5.70~ 6.20	Sandy Soil	10.0	45.0	—— ——	72.75 77.75	55.86 60.76	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below.

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C} \cdot \tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~ 2.70	Sandy soil	10.00	37.0	—— ——	0.000 1.000	0.00 0.98	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
5	2.70~ 2.74	Clayey soil	8.00	0.0	18.0 18.0	1.000 1.312	0.98 ——	0.200 ——	11.31 ——	—— ——	—— ——
6	2.74~ 3.70	Clayey soil	8.00	0.0	18.0 18.0	1.312 9.000	—— 10.78	—— 0.200	—— 11.31	—— ——	—— ——
7	3.70~ 4.70	Clayey soil	8.00	0.0	12.0 12.0	9.000 17.000	10.78 20.58	0.200 0.200	11.31 11.31	—— ——	—— ——
8	4.70~ 5.15	Clayey soil	8.00	0.0	25.0 25.0	17.000 20.569	20.58 ——	0.200 ——	11.31 ——	—— ——	—— ——
9	5.15~ 5.70	Clayey soil	8.00	0.0	25.0 25.0	20.569 25.000	—— 30.38	—— 0.200	—— 11.31	—— ——	—— ——
10	5.70~ 6.20	Sandy soil	10.00	45.0	—— ——	25.000 30.000	30.38 35.28	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below.
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	9.73 19.13	—— ——	9.73 19.13	0.00 20.58	—— ——
2	2.10~ 2.20	14.93 15.28	—— ——	14.93 15.28	20.58 21.56	—— ——
3	2.20~ 2.60	15.28 16.67	—— ——	15.28 16.67	21.56 21.56	—— ——
4	2.60~ 2.70	16.67 17.02	—— ——	16.67 17.02	21.56 21.56	0.00 5.04
5	2.70~ 2.74	24.13 24.53	24.37 24.53	24.37 24.53	21.56 21.56	37.00 37.31
6	2.74~ 3.70	24.53 34.38	24.53 28.37	24.53 34.38	21.56 21.56	37.31 45.00
7	3.70~ 4.70	48.58 60.20	28.37 32.37	48.58 60.20	21.56 21.56	33.00 41.00
8	4.70~ 5.15	29.63 34.16	32.37 34.16	32.37 34.16	21.56 21.56	67.00 70.57
9	5.15~ 5.70	34.16 39.78	34.16 36.37	34.16 39.78	21.56 21.56	70.57 75.00

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
10	5.70~ 6.20	18.82 20.12	—— ——	18.82 20.12	21.56 21.56	205.09 246.10

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

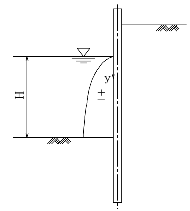
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

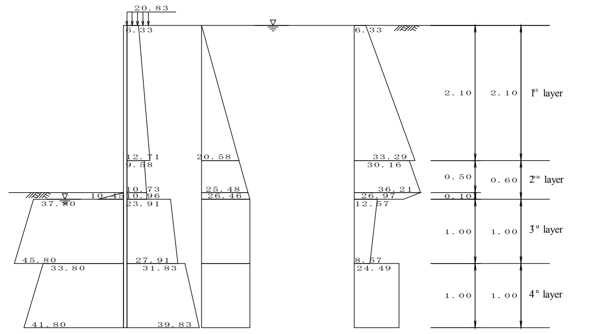
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00~ 2.10	6.33 12.71	0.00 20.58	—— ——	6.33 33.29
2	2.10~ 2.60	9.58 10.73	20.58 25.48	—— ——	30.16 36.21
3	2.60~ 2.70	10.73 10.96	25.48 26.46	0.00 10.45	36.21 26.97
4	2.70~ 3.70	23.91 27.91	26.46 26.46	37.80 45.80	12.57 8.57
5	3.70~ 4.70	31.83 39.83	26.46 26.46	33.80 41.80	24.49 24.49
6	4.70~ 5.70	31.91 35.91	26.46 26.46	67.80 75.80	-9.43 -13.43

P_a : Active earth pressure

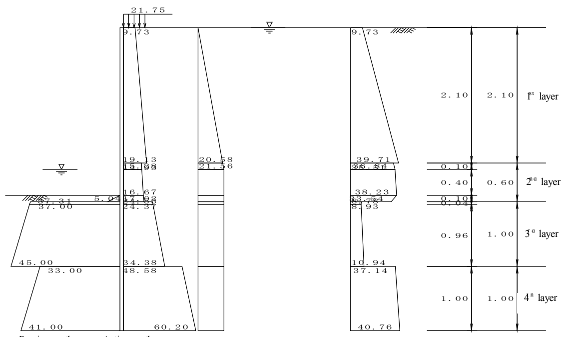
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.10 m (GL -4.70 m)

4-2 Seismic Condition



Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00~ 2.10	9.73 19.13	0.00 20.58	—— ——	9.73 39.71
2	2.10~ 2.20	14.93 15.28	20.58 21.56	—— ——	35.51 36.84
3	2.20~ 2.60	15.28 16.67	21.56 21.56	—— ——	36.84 38.23
4	2.60~ 2.70	16.67 17.02	21.56 21.56	0.00 5.04	38.23 33.54
5	2.70~ 2.74	24.37 24.53	21.56 21.56	37.00 37.31	8.93 8.78
6	2.74~ 3.70	24.53 34.38	21.56 21.56	37.31 45.00	8.78 10.94
7	3.70~ 4.70	48.58 60.20	21.56 21.56	33.00 41.00	37.14 40.76
8	4.70~ 5.15	32.37 34.16	21.56 21.56	67.00 70.57	-13.07 -14.85

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.10 m (GL -4.70 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	31
4	2.70	31
5	3.70	3
6	4.70	2
7	5.70	5
8	6.20	50
9	20.00	50

5-2 Normal Condition

K_h = 24627 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.470 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.70 m) to 2.13 m depth (GL -6.83 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	4.70	1.00	2.0	5.0	3.50
2	5.70	0.50	5.0	50.0	13.75
3	6.20	0.63	50.0	50.0	31.47
L = Σh = 2.13			ΣA = 48.72		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{48.72}{2.13}$

$= 22.88$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 22.88^{0.406} = 24627$ kN/m³

Kh (normal condition) = 24627 kNm³

5-3 Seismic Condition

K_h = 24627 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.470 \quad m^{-1}$

$$L = \frac{1}{\beta} = 2.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.70 m) and 2.13 m depth (GL -6.83 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	4.70	1.00	2.0	5.0	3.50
2	5.70	0.50	5.0	50.0	13.75
3	6.20	0.63	50.0	50.0	31.47
	L = Σh = 2.13			ΣA = 48.72	

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{48.72}{2.13}$

$= 22.88$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 22.88^{0.406} = 24627$ kN/m³

Kh (seismic condition) = 24627 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	6.33 33.29	6.64 34.95	4.00 3.30	26.58 115.34
2	2.10~ 2.60	0.50	30.16 36.21	7.54 9.05	2.43 2.27	18.35 20.52
3	2.60~ 2.70	0.10	36.21 26.97	1.81 1.35	2.07 2.03	3.74 2.74
4	2.70~ 3.70	1.00	12.57 8.57	6.29 4.29	1.67 1.33	10.48 5.72
5	3.70~ 4.70	1.00	24.49 24.49	12.24 12.24	0.67 0.33	8.16 4.08
				ΣP = 96.41		ΣM = 215.70

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.3 kNm
depth to acting position	H_t	=	-0.51 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.10 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 17.19$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{232.90}{99.71} = 2.34 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kNm²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	9.73 39.71	10.22 41.70	4.00 3.30	40.88 137.60
2	2.10~ 2.20	0.10	35.51 36.84	1.78 1.84	2.57 2.53	4.56 4.67
3	2.20~ 2.60	0.40	36.84 38.23	7.37 7.65	2.37 2.23	17.44 17.08
4	2.60~ 2.70	0.10	38.23 33.54	1.91 1.68	2.07 2.03	3.95 3.41
5	2.70~ 2.74	0.04	8.93 8.78	0.17 0.17	1.99 1.97	0.35 0.34
6	2.74~ 3.70	0.96	8.78 10.94	4.22 5.25	1.64 1.32	6.92 6.94
7	3.70~ 4.70	1.00	37.14 40.76	18.57 20.38	0.67 0.33	12.38 6.79
				ΣP = 122.91		ΣM = 263.29

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.0 kNm
depth to acting position	H_t	=	-0.24 m
moment	M_m	=	3.6 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.10 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 48.06$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kNm²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.37 2.23	0.00 0.31
				ΣPdw = 0.14		ΣMdw = 0.31

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{311.65}{132.04} = 2.36 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	86000 cm⁴ (original condition)
	I	=	63296 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 63296 × 10⁻⁸		=	1.266 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	24627 kNm³
calculated value	β	=	0.46961 m⁻¹
resultant earth force (lateral)	P_0	=	99.71 kNm
height of acting position of load	h_0	=	2.34 m
moment	M_0	=	232.90 kN·m/m

in consideration of ψ_m = 1.126,

maximum moment	M_{max}	=	262.30 kN·m/m
depth of generated position of M_{max}	l_m	=	0.646 m
depth of 1st fixed point	l_i	=	2.319 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	24627 kNm³
calculated value	β	=	0.46961 m⁻¹
resultant earth force (lateral)	P_0	=	132.04 kNm
height of acting position of load	h_0	=	2.36 m
moment	M_0	=	311.65 kN·m/m

in consideration of ψ_m = 1.124,

maximum moment	M_{max}	=	350.36 kN·m/m
depth of generated position of M_{max}	l_m	=	0.642 m
depth of 1st fixed point	l_i	=	2.314 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	n	=	0.92
Section efficiency	u	=	1.00
Module of section	Z_0	=	3820 cm^3 (original condition)
	Z	=	3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{262.30\times10^6}{3514\times10^3} = 75\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{350.36\times10^6}{3514\times10^3} = 100\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	4.00 3.30	0.851 0.702	0.259 0.189	6.64 34.95	1.724 6.599
2	2.10～ 2.60	2.43 2.27	0.518 0.482	0.111 0.098	7.54 9.05	0.836 0.883
3	2.60～ 2.70	2.07 2.03	0.440 0.433	0.083 0.080	1.81 1.35	0.149 0.108
4	2.70～ 3.70	1.67 1.33	0.355 0.284	0.055 0.036	6.29 4.29	0.349 0.156
5	3.70～ 4.70	0.67 0.33	0.142 0.071	0.010 0.002	12.24 12.24	0.117 0.030
						ΣQ = 10.952

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

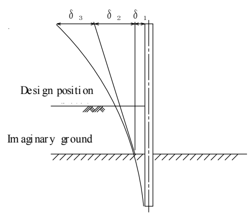
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4696\times2.34)\times99.71}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4696^3} = 0.00797\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4696\times2.34)\times99.71}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4696^2}\times(2.60+2.10) = 0.02681\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.95\times(2.60+2.10)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00898\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00105 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.70 m
Horizontal load: P = 3.30
Moment: M = 1.68

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00797 + 0.02681 + 0.01003
= 0.04481 m
= 44.81 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	4.00 3.30	0.851 0.702	0.259 0.189	10.22 41.70	2.651 7.872
2	2.10～ 2.20	2.57 2.53	0.546 0.539	0.122 0.119	1.78 1.84	0.217 0.219
3	2.20～ 2.60	2.37 2.23	0.504 0.475	0.106 0.095	7.37 7.65	0.777 0.727
4	2.60～ 2.70	2.07 2.03	0.440 0.433	0.083 0.080	1.91 1.68	0.158 0.134
5	2.70～ 2.74	1.99 1.97	0.423 0.420	0.077 0.076	0.17 0.17	0.013 0.013
6	2.74～ 3.70	1.64 1.32	0.349 0.281	0.054 0.036	4.22 5.25	0.227 0.188
7	3.70～ 4.70	0.67 0.33	0.142 0.071	0.010 0.002	18.57 20.38	0.178 0.050
						ΣQ = 13.425

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

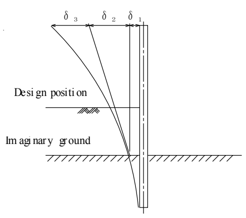
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.37 2.23	0.504 0.475	0.106 0.095	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below
Q = 13.425 + 0.013 = 13.438

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4696\times2.36)\times132.04}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4696^3} = 0.01062\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4696\times2.36)\times132.04}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4696^2}\times(2.60+2.10) = 0.03575\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{13.44\times(2.60+2.10)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.01102\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00265 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.70 m
Horizontal load: P = 9.00
Moment: M = 2.16

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.70\ m、h=L-H_m、H_m=0.80\ m、\text{ただし})$$

$$= \frac{3.60\times3.90}{2\times2.00\times10^8\times63296\times10^{-8}}\times(2\times4.70-3.90) = 0.00030\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01062 + 0.03575 + 0.01397
= 0.06035 m
= 60.35 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 86000 \times 10^{-8}$		=	1.720×10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 24627$ kN/m³

Calculated value $\beta = 0.43497$ m⁻¹

Penetration length of SSP $D = 2.10 + \frac{3}{0.435} = 9.00$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.00 = 11.20$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 24627$ kN/m³

Calculated value $\beta = 0.43497$ m⁻¹

Penetration length of SSP $D = 2.10 + \frac{3}{0.435} = 9.00$ m

Whole length of SSP $L = 2.60 - 0.40 + 9.00 = 11.20$ m

Therefore, whole length of SSP is set as 11.50 m in consideration of round unit of SSP length.

8 Calculation Result

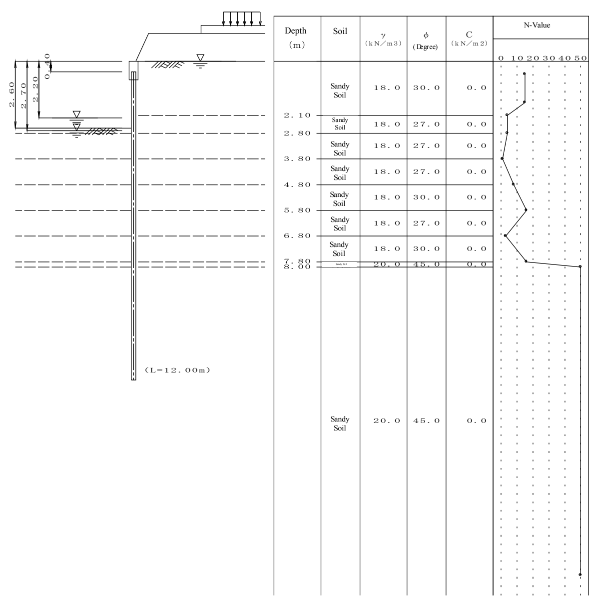
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		262.30	350.36
Stress intensity	σ (Nmm^2)		75 (180)	100 (270)
Lateral displacement	δ (mm)		44.81 (50.0)	60.35 (75.0)
Penetration depth	D (m)		9.00	9.00
Whole length of SSP	L (m)	11.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 33_STA 13+900 - 14+000

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_h	=	0.00 m
Depth from coping top to SSP top	H_r	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water $\gamma_w = 9.8\ kNm^3$

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	3.2 kNm	(Normal Condition)
		Pt'	=	9.0 kNm	(Seismic Condition)
	Depth of acting point	Ht	=	-0.51 m	(Normal Condition)
		Ht'	=	-0.24 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	3.5 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\dfrac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression $K_e = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	20.00	50
2	1.60	15			
3	2.10	4			
4	2.80	4			
5	3.80	1			
6	4.80	8			
7	5.80	16			
8	6.80	3			
9	7.80	16			
10	8.00	50			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ kNm³	γ' kNm³	φ	C kNm²	a	k'	ζ(degree)		kh(kNm³)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.80	S	4.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	3.80	S	1.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.80	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
5	5.80	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
6	6.80	S	3.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
7	7.80	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
8	8.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
9	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

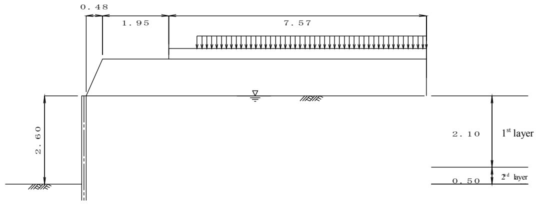
Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

2.249

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.48	10.00	10.00	1.09	18.0	30.0	0.0	auto	auto
2	Sandy soil	2.43	2.43	10.00	10.00	0.31	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	3.26	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm²
Inertia sectional moment I_0 = 86000 cm⁴
Sectional factor Z_0 = 3820 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.92
Corrosion rate (to Z_0) η = 0.92
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

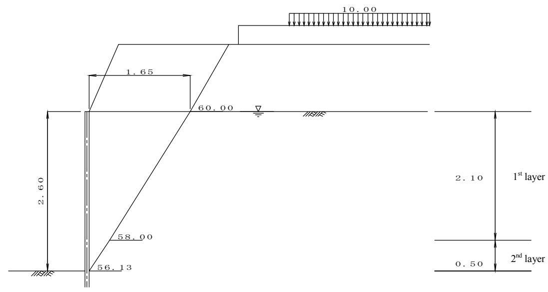
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	20.51	25.48	56.13
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	20.51	20.58	58.00
3		Embankment	30.0	——	0.0	25.20	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.50	0.00	0.00	0.34	0.50
2	58.00	2.10	0.34	0.50	1.65	2.60
3	60.00	1.09	1.65	2.60	2.28	3.69

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.88	33.80
Σ			33.80

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

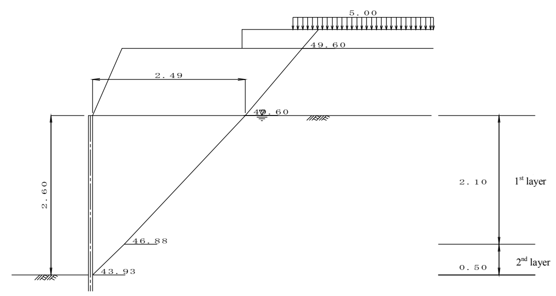
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P \quad P}{L}$$

$$= \frac{33.80 + 0.00 + 0.00}{1.65}$$

$$= 20.51 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	9.0	0.0	26.00	24.73	25.48	0.200	11.31	43.93
2	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	24.73	20.58	0.200	11.31	46.88
3		Embankment	30.0	——	0.0	25.20	5.00	0.00	0.200	11.31	49.60
4		Embankment	30.0	——	0.0	5.58	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	0.50	0.00	0.00	0.52	0.50
2	46.88	2.10	0.52	0.50	2.49	2.60
3	49.60	1.09	2.49	2.60	3.41	3.69
4	49.60	0.31	3.41	3.69	3.68	4.00

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.95	53.16
2	18.0	0.35	6.22
Σ			59.38

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	0.42	2.09
Σ			2.09

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

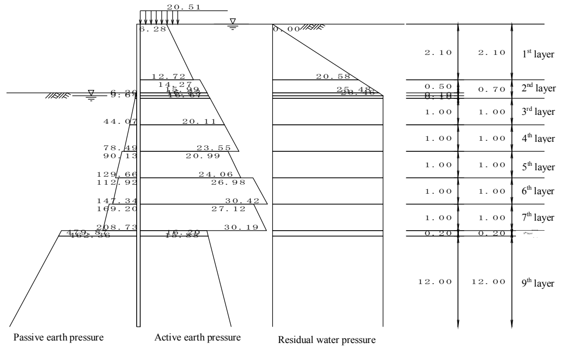
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{59.38 + 2.09 + 0.00}{2.49}$$

$$= 24.73 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	20.509 41.509	0.31026 0.31026	0.30644 0.30644
2	2.10～ 2.60	Sandy soil	10.0	27.0	—— ——	41.509 46.509	0.34800 0.34800	0.34371 0.34371
3	2.60～ 2.70	Sandy soil	10.0	27.0	—— ——	46.509 47.509	0.34800 0.34800	0.34371 0.34371
4	2.70～ 2.80	Sandy soil	10.0	27.0	—— ——	47.509 48.509	0.34800 0.34800	0.34371 0.34371
5	2.80～ 3.80	Sandy soil	10.0	27.0	—— ——	48.509 58.509	0.34800 0.34800	0.34371 0.34371
6	3.80～ 4.80	Sandy soil	10.0	27.0	—— ——	58.509 68.509	0.34800 0.34800	0.34371 0.34371
7	4.80～ 5.80	Sandy soil	10.0	30.0	—— ——	68.509 78.509	0.31026 0.31026	0.30644 0.30644
8	5.80～ 6.80	Sandy soil	10.0	27.0	—— ——	78.509 88.509	0.34800 0.34800	0.34371 0.34371
9	6.80～ 7.80	Sandy soil	10.0	30.0	—— ——	88.509 98.509	0.31026 0.31026	0.30644 0.30644
10	7.80～ 8.00	Sandy soil	10.0	45.0	—— ——	98.509 100.509	0.16323 0.16323	0.16122 0.16122
11	8.00～ 20.00	Sandy soil	10.0	45.0	—— ——	100.509 220.509	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ= 9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	ϕ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.48553 3.48553	3.44261 3.44261
4	2.70～ 2.80	Sandy soil	10.0	27.0	—— ——	1.800 2.800	3.48553 3.48553	3.44261 3.44261
5	2.80～ 3.80	Sandy soil	10.0	27.0	—— ——	2.800 12.800	3.48553 3.48553	3.44261 3.44261
6	3.80～ 4.80	Sandy soil	10.0	27.0	—— ——	12.800 22.800	3.48553 3.48553	3.44261 3.44261
7	4.80～ 5.80	Sandy soil	10.0	30.0	—— ——	22.800 32.800	4.00247 4.00247	3.95319 3.95319
8	5.80～ 6.80	Sandy soil	10.0	27.0	—— ——	32.800 42.800	3.48553 3.48553	3.44261 3.44261
9	6.80～ 7.80	Sandy soil	10.0	30.0	—— ——	42.800 52.800	4.00247 4.00247	3.95319 3.95319
10	7.80～ 8.00	Sandy soil	10.0	45.0	—— ——	52.800 54.800	8.86593 8.86593	8.75678 8.75678
11	8.00～ 20.00	Sandy soil	10.0	45.0	—— ——	54.800 174.800	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
δ= -9.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	6.28 12.72	—— ——	6.28 12.72	0.00 20.58	—— ——
2	2.10～ 2.60	14.27 15.99	—— ——	14.27 15.99	20.58 25.48	—— ——
3	2.60～ 2.70	15.99 16.33	—— ——	15.99 16.33	25.48 26.46	0.00 6.20
4	2.70～ 2.80	16.33 16.67	—— ——	16.33 16.67	26.46 26.46	6.20 9.64
5	2.80～ 3.80	16.67 20.11	—— ——	16.67 20.11	26.46 26.46	9.64 44.07
6	3.80～ 4.80	20.11 23.55	—— ——	20.11 23.55	26.46 26.46	44.07 78.49
7	4.80～ 5.80	20.99 24.06	—— ——	20.99 24.06	26.46 26.46	90.13 129.66
8	5.80～ 6.80	26.98 30.42	—— ——	26.98 30.42	26.46 26.46	112.92 147.34

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
9	6.80～ 7.80	27.12 30.19	—— ——	27.12 30.19	26.46 26.46	169.20 208.73
10	7.80～ 8.00	15.88 16.20	—— ——	15.88 16.20	26.46 26.46	462.36 479.87
11	8.00～ 20.00	16.20 35.55	—— ——	16.20 35.55	26.46 26.46	479.87 1530.68

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

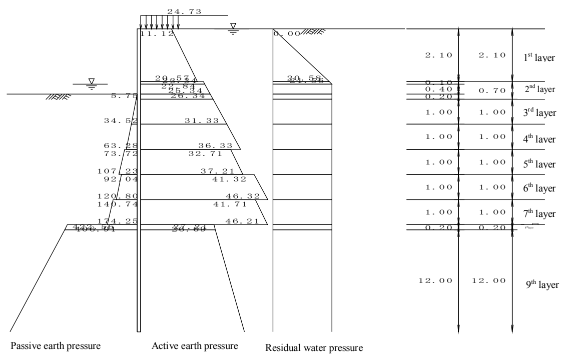
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	24.73 45.73	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10～ 2.20	Sandy Soil	10.0	27.0	—— ——	45.73 46.73	20.58 21.56	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.20～ 2.60	Sandy Soil	10.0	27.0	—— ——	46.73 50.73	21.56 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	2.60～ 2.80	Sandy Soil	10.0	27.0	—— ——	50.73 52.73	25.48 27.44	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	2.80～ 3.80	Sandy Soil	10.0	27.0	—— ——	52.73 62.73	27.44 37.24	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	3.80～ 4.80	Sandy Soil	10.0	27.0	—— ——	62.73 72.73	37.24 47.04	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
7	4.80～ 5.80	Sandy Soil	10.0	30.0	—— ——	72.73 82.73	47.04 56.84	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
8	5.80～ 6.80	Sandy Soil	10.0	27.0	—— ——	82.73 92.73	56.84 66.64	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
9	6.80～ 7.80	Sandy Soil	10.0	30.0	—— ——	92.73 102.73	66.64 76.44	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
10	7.80～ 8.00	Sandy Soil	10.0	45.0	—— ——	102.73 104.73	76.44 78.40	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——
11	8.00～ 20.00	Sandy Soil	10.0	45.0	—— ——	104.73 224.73	78.40 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 2.80	Sandy soil	10.00	27.0	—— ——	0.000 2.000	0.00 1.96	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
5	2.80～ 3.80	Sandy soil	10.00	27.0	—— ——	2.000 12.000	1.96 11.76	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	3.80～ 4.80	Sandy soil	10.00	27.0	—— ——	12.000 22.000	11.76 21.56	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
7	4.80～ 5.80	Sandy soil	10.00	30.0	—— ——	22.000 32.000	21.56 31.36	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
8	5.80～ 6.80	Sandy soil	10.00	27.0	—— ——	32.000 42.000	31.36 41.16	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
9	6.80～ 7.80	Sandy soil	10.00	30.0	—— ——	42.000 52.000	41.16 50.96	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
10	7.80～ 8.00	Sandy soil	10.00	45.0	—— ——	52.000 54.000	50.96 52.92	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515
11	8.00～ 20.00	Sandy soil	10.00	45.0	—— ——	54.000 174.000	52.92 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below
$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	11.12 20.57	—— ——	11.12 20.57	0.00 20.58	—— ——
2	2.10～ 2.20	22.84 23.34	—— ——	22.84 23.34	20.58 21.56	—— ——
3	2.20～ 2.60	23.34 25.34	—— ——	23.34 25.34	21.56 21.56	—— ——
4	2.60～ 2.80	25.34 26.34	—— ——	25.34 26.34	21.56 21.56	0.00 5.75
5	2.80～ 3.80	26.34 31.33	—— ——	26.34 31.33	21.56 21.56	5.75 34.52
6	3.80～ 4.80	31.33 36.33	—— ——	31.33 36.33	21.56 21.56	34.52 63.28
7	4.80～ 5.80	32.71 37.21	—— ——	32.71 37.21	21.56 21.56	73.72 107.23
8	5.80～ 6.80	41.32 46.32	—— ——	41.32 46.32	21.56 21.56	92.04 120.80
9	6.80～ 7.80	41.71 46.21	—— ——	41.71 46.21	21.56 21.56	140.74 174.25
10	7.80～ 8.00	26.69 27.21	—— ——	26.69 27.21	21.56 21.56	406.91 422.56
11	8.00～ 20.00	27.21 58.38	—— ——	27.21 58.38	21.56 21.56	422.56 1361.58

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

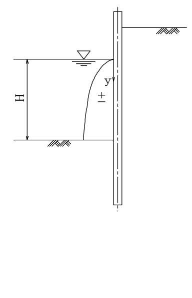
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm\frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

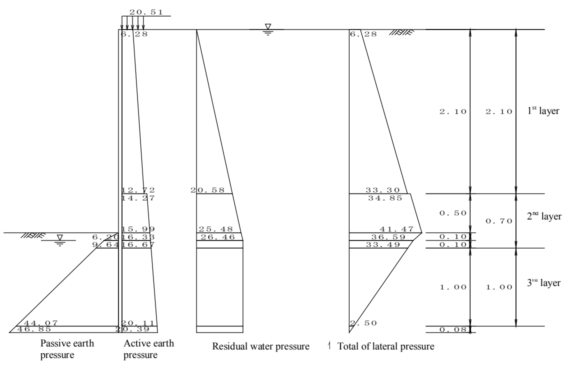
k_{hs}: design seismic coefficient
γ_w : unit weight of Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

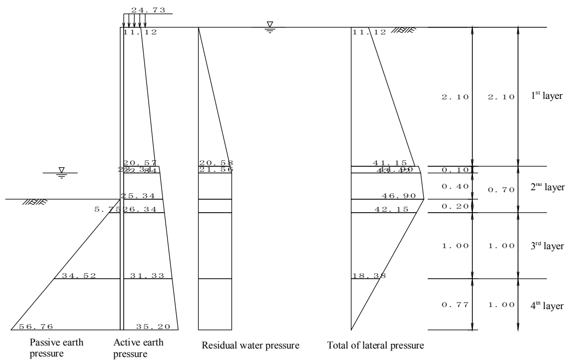


	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	6.28 12.72	0.00 20.58	—— ——	6.28 33.30
2	2.10～ 2.60	14.27 15.99	20.58 25.48	—— ——	34.85 41.47
3	2.60～ 2.70	15.99 16.33	25.48 26.46	0.00 6.20	41.47 36.59
4	2.70～ 2.80	16.33 16.67	26.46 26.46	6.20 9.64	36.59 33.49
5	2.80～ 3.80	16.67 20.11	26.46 26.46	9.64 44.07	33.49 2.50
6	3.80～ 3.88	20.11 20.39	26.46 26.46	44.07 46.85	2.50 0.00
7	3.88～ 4.80	20.39 23.55	26.46 26.46	46.85 78.49	0.00 -28.48

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.28 m (GL -3.88 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm2	Pw kNm2	Pp kNm2	Ps kNm2
1	0.00～ 2.10	11.12 20.57	0.00 20.58	—— ——	11.12 41.15
2	2.10～ 2.20	22.84 23.34	20.58 21.56	—— ——	43.42 44.90
3	2.20～ 2.60	23.34 25.34	21.56 21.56	—— ——	44.90 46.90
4	2.60～ 2.80	25.34 26.34	21.56 21.56	0.00 5.75	46.90 42.15
5	2.80～ 3.80	26.34 31.33	21.56 21.56	5.75 34.52	42.15 18.38
6	3.80～ 4.57	31.33 35.20	21.56 21.56	34.52 56.76	18.38 0.00
7	4.57～ 4.80	35.20 36.33	21.56 21.56	56.76 63.28	0.00 -5.39

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.97 m (GL -4.57 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	63296 cm^4 (after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8}$ = 1.266×10^5

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	20.00	50
2	1.60	15			
3	2.10	4			
4	2.80	4			
5	3.80	1			
6	4.80	8			
7	5.80	16			
8	6.80	3			
9	7.80	16			
10	8.00	50			

5-2 Normal Condition

K_h = 17153 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$L = \frac{1}{\beta} = 2.33 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.88 m) to 2.33 m depth (GL -6.21 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.88	0.92	1.6	8.0	4.40
2	4.80	1.00	8.0	16.0	12.00
3	5.80	0.41	16.0	10.6	5.49
	L = Σh = 2.33				ΣA = 21.88

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{21.88}{2.33}$

$= 9.39$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$K_h = 6910 \times N'^{0.406} = 6910 \times 9.39^{0.406} = 17153$ kN/m^3

Kh (normal condition) = 17153 kNm^3

5-3 Seismic Condition

K_h = 17694 kNm^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$= 0.432$ m^{-1}

$$L = \frac{1}{\beta} = 2.31 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.57 m) and 2.31 m depth (GL -6.89 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.57	0.23	6.4	8.0	1.63
2	4.80	1.00	8.0	16.0	12.00
3	5.80	1.00	16.0	3.0	9.50
4	6.80	0.09	3.0	4.1	0.31
	L = Σh = 2.31				ΣA = 23.44

A (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$= \frac{23.44}{2.31}$

$= 10.13$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following;

$K_h = 6910 \times N'^{0.406} = 6910 \times 10.13^{0.406} = 17694$ kN/m^3

Kh (seismic condition) = 17694 kNm^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	6.28 33.30	6.60 34.97	3.18 2.48	20.99 86.74
2	2.10～ 2.60	0.50	34.85 41.47	8.71 10.37	1.61 1.45	14.06 15.01
3	2.60～ 2.70	0.10	41.47 36.59	2.07 1.83	1.25 1.21	2.59 2.22
4	2.70～ 2.80	0.10	36.59 33.49	1.83 1.67	1.15 1.11	2.10 1.87
5	2.80～ 3.80	1.00	33.49 2.50	16.75 1.25	0.75 0.41	12.52 0.52
6	3.80～ 3.88	0.08	2.50 0.00	0.10 0.00	0.05 0.03	0.01 0.00
				ΣP = 86.15		ΣM = 158.62

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.2 kNm
depth to acting position	H_t	=	-0.51 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.28 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 14.05$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{172.67}{89.35} = 1.93 \text{ m}$$

2.253

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	11.12 41.15	11.68 43.21	3.87 3.17	45.24 137.11
2	2.10~ 2.20	0.10	43.42 44.90	2.17 2.25	2.44 2.41	5.30 5.40
3	2.20~ 2.60	0.40	44.90 46.90	8.98 9.38	2.24 2.11	20.12 19.76
4	2.60~ 2.80	0.20	46.90 42.15	4.69 4.21	1.91 1.84	8.94 7.75
5	2.80~ 3.80	1.00	42.15 18.38	21.07 9.19	1.44 1.11	30.34 10.17
6	3.80~ 4.57	0.77	18.38 0.00	7.11 0.00	0.52 0.26	3.66 0.00
				ΣP = 123.94		ΣM = 293.79

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 9.0 kN/m
depth to acting position H_t = -0.24 m
moment M_m = 3.5 kN·m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.97 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 46.82$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	2.24 2.11	0.00 0.29
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.29

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{340.90}{133.07} = 2.56 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.92
Section efficiency μ = 0.80
Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 86000 cm^4 (original condition)
I = 63296 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63296 \times 10^{-8}$ = 1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 17153 kN/m^3
calculated value β = 0.42901 m^{-1}
resultant earth force (lateral) P_0 = 89.35 kN/m
height of acting position of load h_0 = 1.93 m
moment M_0 = 172.67 kN·m/m

in consideration of ψ_m = 1.195,
maximum moment M_{max} = 206.37 kN·m/m
depth of generated position of M_{max} l_m = 0.839 m
depth of 1st fixed point l_i = 2.669 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 17694 kN/m^3
calculated value β = 0.43236 m^{-1}
resultant earth force (lateral) P_0 = 133.07 kN/m
height of acting position of load h_0 = 2.56 m
moment M_0 = 340.90 kN·m/m

in consideration of ψ_m = 1.124,
maximum moment M_{max} = 383.28 kN·m/m
depth of generated position of M_{max} l_m = 0.697 m
depth of 1st fixed point l_i = 2.514 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.92
Section efficiency μ = 1.00
Module of section Z_0 = 3820 cm^3 (original condition)
Z = 3514 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{206.37\times10^6}{3514\times10^3} = 59 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{383.28\times10^6}{3514\times10^3} = 109 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

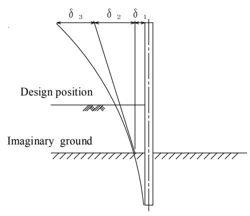
Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	3.18 2.48	0.820 0.639	0.244 0.161	6.60 34.97	1.611 5.622
2	2.10~ 2.60	1.61 1.45	0.416 0.373	0.075 0.061	8.71 10.37	0.649 0.631
3	2.60~ 2.70	1.25 1.21	0.321 0.313	0.046 0.044	2.07 1.83	0.096 0.080
4	2.70~ 2.80	1.15 1.11	0.296 0.287	0.039 0.037	1.83 1.67	0.072 0.062
5	2.80~ 3.80	0.75 0.41	0.193 0.107	0.017 0.005	16.75 1.25	0.291 0.007
6	3.80~ 3.88	0.05 0.03	0.014 0.007	0.000 0.000	0.10 0.00	0.000 0.000
						ΣQ = 9.121

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

2.254

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.4290\times1.93)\times89.35}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4290^3} = 0.00817 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$
$$= \frac{(1+2\times0.4290\times1.93)\times89.35}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4290^2} \times (2.60+1.28) = 0.01978 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{9.12\times(2.60+1.28)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.00421 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00059 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.88 m
Horizontal load: P = 3.20
Moment: M = 1.63

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00817 + 0.01978 + 0.00480
= 0.03276 m
= 32.76 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.87 3.17	0.847 0.694	0.257 0.185	11.68 43.21	3.006 7.996
2	2.10～ 2.20	2.44 2.41	0.534 0.526	0.117 0.114	2.17 2.25	0.254 0.256
3	2.20～ 2.60	2.24 2.11	0.490 0.461	0.100 0.090	8.98 9.38	0.901 0.842
4	2.60～ 2.80	1.91 1.84	0.417 0.402	0.075 0.070	4.69 4.21	0.351 0.295
5	2.80～ 3.80	1.44 1.11	0.315 0.242	0.044 0.027	21.07 9.19	0.935 0.247
6	3.80～ 4.57	0.52 0.26	0.113 0.056	0.006 0.002	7.11 0.00	0.043 0.000
						ΣQ = 15.128

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

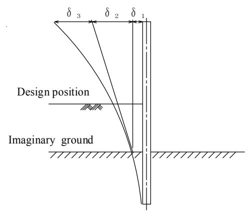
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.24 2.11	0.490 0.461	0.100 0.090	0.00 0.14	0.000 0.012
						ΣQ_{dw} = 0.012

Therefore, modulus of deformation Q is calculated as below

Q = 15.128 + 0.012 = 15.140

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4324\times2.56)\times133.07}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4324^3} = 0.01371\ \mathrm{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.4324\times2.56)\times133.07}{2\times2.00\times10^8\times63296\times10^{-8}\times0.4324^2}\times(2.60+1.97) = 0.04134\ \mathrm{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.14\times(2.60+1.97)^3}{2.00\times10^8\times63296\times10^{-8}} = 0.01144\ \mathrm{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00245 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.57 m

Horizontal load: P = 9.00

Moment: M = 2.16

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.57\ \mathrm{m}、h=L-H_m、H_m=0.80\ \mathrm{m}、ただしh\leqq L)$$

$$= \frac{3.50\times3.77}{2\times2.00\times10^8\times63296\times10^{-8}}\times(2\times4.57-3.77) = 0.00028\ \mathrm{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01371 + 0.04134 + 0.01416

= 0.06921 m

= 69.21 ≦ δ_a = 75.00 mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 86000 × 10^{-8}		=	1.720 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction — K_h = 17153 kN/m^3

Calculated value — β = 0.39736 m^{-1}

Penetration length of SSP — $D = 1.28 + \dfrac{3}{0.397} = 8.83$ m

Whole length of SSP — L = 2.60 − 0.40 + 8.83 = 11.03 m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction — K_h = 17694 kN/m^3

Calculated value — β = 0.40046 m^{-1}

Penetration length of SSP — $D = 1.97 + \dfrac{3}{0.400} = 9.46$ m

Whole length of SSP — L = 2.60 − 0.40 + 9.46 = 11.66 m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

2.255

8 Calculation Result

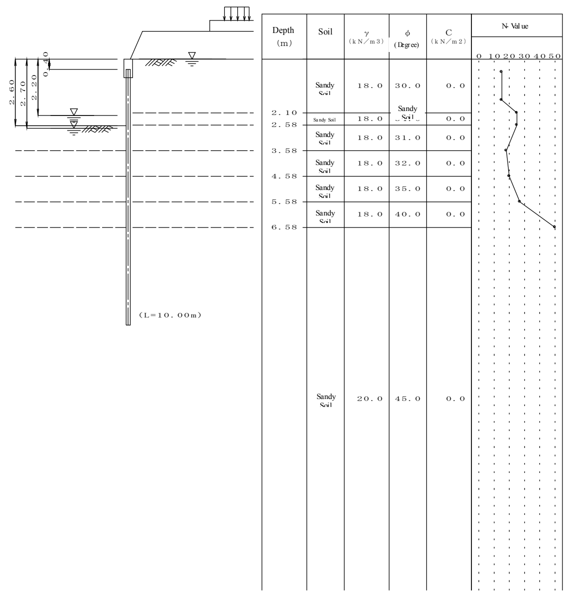
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		206.37	383.28
Stress intensity	σ (N/mm^2)		59 (180)	109 (270)
Lateral displacement	δ (mm)		32.76 (50.0)	69.21 (75.0)
Penetration depth	D (m)		8.83	9.46
Whole length of SSP	L (m)	12.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 34_STA 14+000 - 14+100

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_r	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wr}	=	0.00 m (Normal Condition)
	L_{wr}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wn}	=	2.70 m (Normal Condition)
	L_{wn}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kNm^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	3.3 kNm	(Normal Condition)
		Pt'	=	9.1 kNm	(Seismic Condition)
	Depth of acting point	H	=	-0.51 m	(Normal Condition)
		H'	=	-0.25 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN·m/m	(Normal Condition)
		M_m'	=	3.6 kN·m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	25			
4	2.58	25			
5	3.58	18			
6	4.58	20			
7	5.58	27			
8	6.58	50			
9	20.00	50			

2.256

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

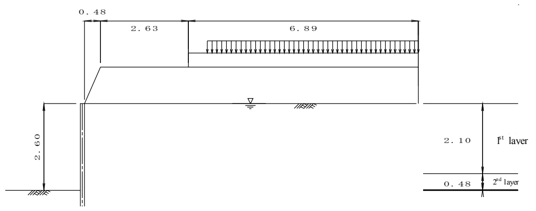
No	Depth (m)	Soil	N-value	γ kNm^3	γ' kNm^3	φ	C kNm^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kNm^3) normal	kh(kNm^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.58	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
3	3.58	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
4	4.58	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
5	5.58	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
6	6.58	S	46.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
7	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (under water)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.48	10.00	10.00	1.10	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.11	3.11	10.00	10.00	0.42	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kNm²)	Seismic (kNm²)
1	3.68	10.00	10.0	5.0

Angle of rapture in embankment   calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 Nmm^2
Inertia sectional moment I_0 = 56700 cm^4
Sectional factor Z_0 = 2700 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

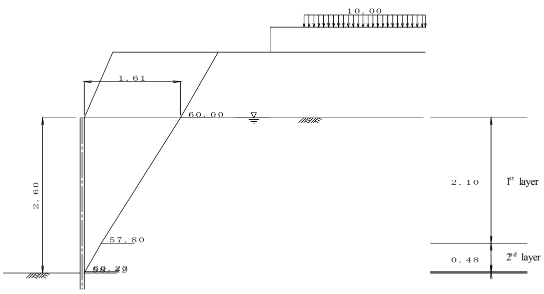
Allowable stress σ_a = 180 Nmm (Normal)
σ_a' = 270 Nmm (Seismic)

Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.58	Sandy Soil	31.0	10.0	0.0	26.00	20.75	25.48	58.42
2	2.58～ 2.10	Sandy Soil	34.0	10.0	0.0	25.80	20.75	25.28	60.23
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	20.75	20.58	57.80
4		Embankment	30.0	——	0.0	27.36	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C : cohesive force of soil (kNm²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	58.42	0.02	0.00	0.00	0.01	0.02
2	60.23	0.48	0.01	0.02	0.29	0.50
3	57.80	2.10	0.29	0.50	1.61	2.60
4	60.00	1.10	1.61	2.60	2.24	3.70

Therefore, width of acting load shall be set as 1.61 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.86	33.40
Σ			33.40

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

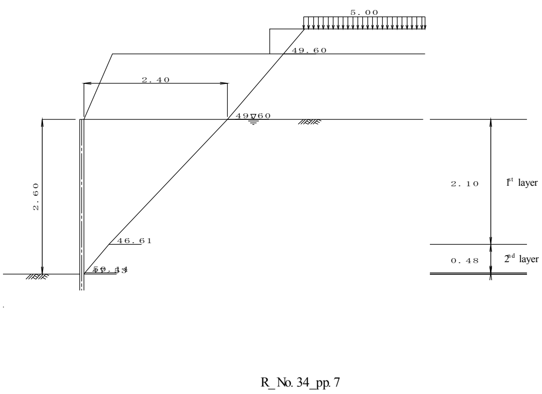
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{33.40 + 0.00 + 0.00}{1.61}$$

$$= 20.75 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.58	Sandy Soil	31.0	10.0	0.0	26.00	23.00	25.48	0.200	11.31	47.53
2	2.58～ 2.10	Sandy Soil	34.0	10.0	0.0	25.80	23.00	25.28	0.200	11.31	50.14
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	23.00	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	27.36	5.00	0.00	0.200	11.31	49.60
5		Embankment	30.0	——	0.0	7.56	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kNm³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kNm²)
C : cohesive force of soil (kNm²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	47.53	0.02	0.00	0.00	0.02	0.02
2	50.14	0.48	0.02	0.02	0.42	0.50
3	46.61	2.10	0.42	0.50	2.40	2.60
4	49.60	1.10	2.40	2.60	3.34	3.70
5	49.60	0.42	3.34	3.70	3.70	4.12

Therefore, width of acting load shall be set as 2.40 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.90	52.12
2	18.0	0.17	3.09
Σ			55.22

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	0.02	0.09
Σ			0.09

Q : surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

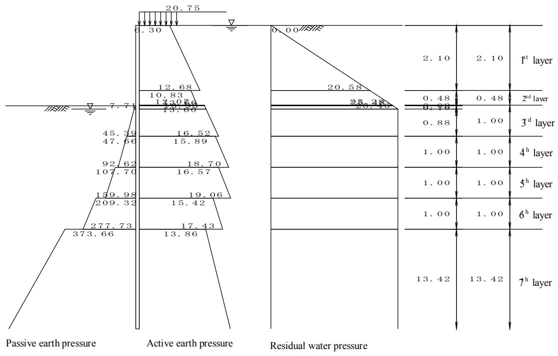
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{55.22 + 0.09 + 0.00}{2.40}$$

$$= 23.00 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qa (kNm²)	Ka	Ka ×cosδ
1	0.00~ 2.10	Sandy soil	10.0	30.0	—— ——	20.754 41.754	0.30847 0.30847	0.30378 0.30378
2	2.10~ 2.58	Sandy soil	10.0	34.0	—— ——	41.754 46.554	0.26331 0.26331	0.25931 0.25931
3	2.58~ 2.60	Sandy soil	10.0	31.0	—— ——	46.554 46.754	0.29669 0.29669	0.29219 0.29219
4	2.60~ 2.70	Sandy soil	10.0	31.0	—— ——	46.754 47.754	0.29669 0.29669	0.29219 0.29219
5	2.70~ 3.58	Sandy soil	10.0	31.0	—— ——	47.754 56.554	0.29669 0.29669	0.29219 0.29219
6	3.58~ 4.58	Sandy soil	10.0	32.0	—— ——	56.554 66.554	0.28525 0.28525	0.28092 0.28092
7	4.58~ 5.58	Sandy soil	10.0	35.0	—— ——	66.554 76.554	0.25279 0.25279	0.24895 0.24895
8	5.58~ 6.58	Sandy soil	10.0	40.0	—— ——	76.554 86.554	0.20447 0.20447	0.20137 0.20137
9	6.58~ 20.00	Sandy soil	10.0	45.0	—— ——	86.554 220.754	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	Kp	Kp ×cosδ
4	2.60~ 2.70	Sandy soil	18.0	31.0	—— ——	0.000 1.800	4.34774 4.34774	4.28169 4.28169
5	2.70~ 3.58	Sandy soil	10.0	31.0	—— ——	1.800 10.600	4.34774 4.34774	4.28169 4.28169
6	3.58~ 4.58	Sandy soil	10.0	32.0	—— ——	10.600 20.600	4.56530 4.56530	4.49594 4.49594
7	4.58~ 5.58	Sandy soil	10.0	35.0	—— ——	20.600 30.600	5.30876 5.30876	5.22810 5.22810
8	5.58~ 6.58	Sandy soil	10.0	40.0	—— ——	30.600 40.600	6.94605 6.94605	6.84053 6.84053
9	6.58~ 20.00	Sandy soil	10.0	45.0	—— ——	40.600 174.800	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below.
$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00~ 2.10	6.30 12.68	—— ——	6.30 12.68	0.00 20.58	—— ——
2	2.10~ 2.58	10.83 12.07	—— ——	10.83 12.07	20.58 25.28	—— ——
3	2.58~ 2.60	13.60 13.66	—— ——	13.60 13.66	25.28 25.48	—— ——
4	2.60~ 2.70	13.66 13.95	—— ——	13.66 13.95	25.48 26.46	0.00 7.71
5	2.70~ 3.58	13.95 16.52	—— ——	13.95 16.52	26.46 26.46	7.71 45.39
6	3.58~ 4.58	15.89 18.70	—— ——	15.89 18.70	26.46 26.46	47.66 92.62
7	4.58~ 5.58	16.57 19.06	—— ——	16.57 19.06	26.46 26.46	107.70 159.98
8	5.58~ 6.58	15.42 17.43	—— ——	15.42 17.43	26.46 26.46	209.32 277.73
9	6.58~ 20.00	13.86 35.35	—— ——	13.86 35.35	26.46 26.46	373.66 1608.77

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

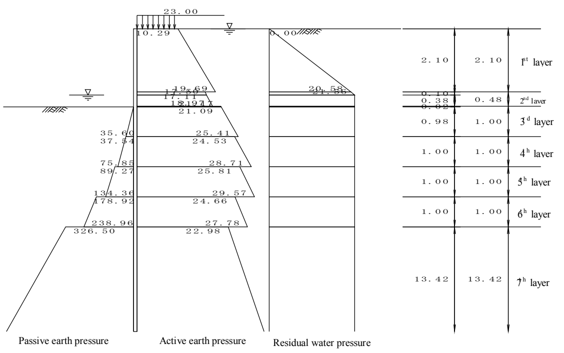
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~ 2.10	Sandy Soil	10.0	30.0	—— ——	23.00 44.00	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10~ 2.20	Sandy Soil	10.0	34.0	—— ——	44.00 45.00	20.58 21.56	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
3	2.20~ 2.58	Sandy Soil	10.0	34.0	—— ——	45.00 48.80	21.56 25.28	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
4	2.58~ 2.60	Sandy Soil	10.0	31.0	—— ——	48.80 49.00	25.28 25.48	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
5	2.60~ 3.58	Sandy Soil	10.0	31.0	—— ——	49.00 58.80	25.48 35.08	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Q (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	3.58～ 4.58	Sandy Soil	10.0	32.0	—— ——	58.80 68.80	35.08 44.88	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
7	4.58～ 5.58	Sandy Soil	10.0	35.0	—— ——	68.80 78.80	44.88 54.68	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
8	5.58～ 6.58	Sandy Soil	10.0	40.0	—— ——	78.80 88.80	54.68 64.48	0.200 0.200	11.31 11.31	0.31772 0.31772	0.31289 0.31289	—— ——
9	6.58～ 20.00	Sandy Soil	10.0	45.0	—— ——	88.80 223.00	64.48 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kNm³)	φ (degree)	C kNm²	Σγh+Qp (kNm²)	γwhw (kNm²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60～ 3.58	Sandy soil	10.00	31.0	—— ——	0.000 9.800	0.00 9.60	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
6	3.58～ 4.58	Sandy soil	10.00	32.0	—— ——	9.800 19.800	9.60 19.40	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
7	4.58～ 5.58	Sandy soil	10.00	35.0	—— ——	19.800 29.800	19.40 29.20	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
8	5.58～ 6.58	Sandy soil	10.00	40.0	—— ——	29.800 39.800	29.20 39.00	0.200 0.200	11.31 11.31	6.09659 6.09659	6.00397 6.00397
9	6.58～ 20.00	Sandy soil	10.00	45.0	—— ——	39.800 174.000	39.00 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kNm²	Pa2 kNm²	Pa kNm²	Pw kNm²	Pp kNm²
1	0.00～ 2.10	10.29 19.69	—— ——	10.29 19.69	0.00 20.58	—— ——
2	2.10～ 2.20	17.11 17.50	—— ——	17.11 17.50	20.58 21.56	—— ——
3	2.20～ 2.58	17.50 18.97	—— ——	17.50 18.97	21.56 21.56	—— ——
4	2.58～ 2.60	21.09 21.17	—— ——	21.09 21.17	21.56 21.56	—— ——
5	2.60～ 3.58	21.17 25.41	—— ——	21.17 25.41	21.56 21.56	0.00 35.60
6	3.58～ 4.58	24.53 28.71	—— ——	24.53 28.71	21.56 21.56	37.54 75.85
7	4.58～ 5.58	25.81 29.57	—— ——	25.81 29.57	21.56 21.56	89.27 134.36
8	5.58～ 6.58	24.66 27.78	—— ——	24.66 27.78	21.56 21.56	178.92 238.96
9	6.58～ 20.00	22.98 57.70	—— ——	22.98 57.70	21.56 21.56	326.50 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kNm²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

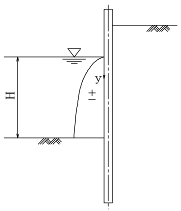
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

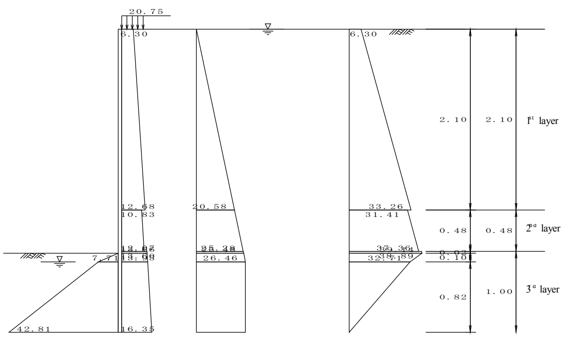
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



Passive earth pressure　Active earth pressure　Residual water pressure　Total of lateral pressure

	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	6.30 12.68	0.00 20.58	—— ——	6.30 33.26
2	2.10～ 2.58	10.83 12.07	20.58 25.28	—— ——	31.41 37.36
3	2.58～ 2.60	13.60 13.66	25.28 25.48	—— ——	38.89 39.14
4	2.60～ 2.70	13.66 13.95	25.48 26.46	0.00 7.71	39.14 32.71
5	2.70～ 3.52	13.95 16.35	26.46 26.46	7.71 42.81	32.71 0.00
6	3.52～ 3.58	16.35 16.52	26.46 26.46	42.81 45.39	0.00 -2.40

P_a : Active earth pressure

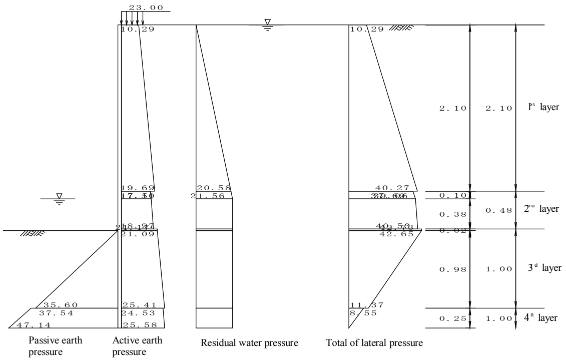
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.92 m (GL -3.52 m)

4-2 Seismic Condition



	Depth (m)	Pa kNm²	Pw kNm²	Pp kNm²	Ps kNm²
1	0.00～ 2.10	10.29 19.69	0.00 20.58	—— ——	10.29 40.27
2	2.10～ 2.20	17.11 17.50	20.58 21.56	—— ——	37.69 39.06
3	2.20～ 2.58	17.50 18.97	21.56 21.56	—— ——	39.06 40.53
4	2.58～ 2.60	21.09 21.17	21.56 21.56	—— ——	42.65 42.73
5	2.60～ 3.58	21.17 25.41	21.56 21.56	0.00 35.60	42.73 11.37
6	3.58～ 3.83	24.53 25.58	21.56 21.56	37.54 47.14	8.55 0.00
7	3.83～ 4.58	25.58 28.71	21.56 21.56	47.14 75.85	0.00 -25.59

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.23 m (GL -3.83 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below,

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 Nmm²
Inertia sectional moment	I_0	=	56700 cm⁴(original condition)
	I	=	39917 cm⁴(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	25
4	2.58	25
5	3.58	18
6	4.58	20
7	5.58	27
8	6.58	50
9	20.00	50

5-2 Normal Condition

K_h = 23674 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.522 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.92 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.52 m) to 1.92 m depth (GL -5.44 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.52	0.06	18.4	18.0	1.10
2	3.58	1.00	18.0	20.0	19.00
3	4.58	0.86	20.0	26.0	19.69
	L = Σh = 1.92			ΣA = 39.79	

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{39.79}{1.92} = 20.76$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 20.76^{0.406} = 23674$ kN/m³

Kh (normal condition) = 23674 kNm³

5-3 Seismic Condition

K_h = 24350 kNm³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.525 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.90 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.83 m) and 1.90 m depth (GL -5.73 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.83	0.75	18.5	20.0	14.43
2	4.58	1.00	20.0	27.0	23.50
3	5.58	0.15	27.0	30.5	4.41
	L = Σh = 1.90			ΣA = 42.34	

A (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{42.34}{1.90} = 22.25$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 22.25^{0.406} = 24350$ kN/m³
Kh (seismic condition) = 24350 kNm³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kNm²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	6.30 33.26	6.62 34.93	2.82 2.12	18.67 74.04
2	2.10～ 2.58	0.48	31.41 37.36	7.54 8.97	1.26 1.10	9.50 9.86
3	2.58～ 2.60	0.02	38.89 39.14	0.39 0.39	0.93 0.93	0.36 0.36
4	2.60～ 2.70	0.10	39.14 32.71	1.96 1.64	0.89 0.85	1.73 1.40
5	2.70～ 3.52	0.82	32.71 0.00	13.41 0.00	0.55 0.27	7.33 0.00
				ΣP = 75.83		ΣM = 123.24

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.3 kNm
depth to acting position	H_t	=	-0.51 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	0.92 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 13.30$ kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{136.54}{79.13} = 1.73 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00~ 2.10	2.10	10.29 40.27	10.81 42.29	3.13 2.43	33.83 102.77
2	2.10~ 2.20	0.10	37.69 39.06	1.88 1.95	1.70 1.66	3.20 3.25
3	2.20~ 2.58	0.38	39.06 40.53	7.42 7.70	1.50 1.38	11.16 10.61
4	2.58~ 2.60	0.02	42.65 42.73	0.43 0.43	1.24 1.24	0.53 0.53
5	2.60~ 3.58	0.98	42.73 11.37	20.94 5.57	0.90 0.58	18.92 3.21
6	3.58~ 3.83	0.25	8.55 0.00	1.07 0.00	0.17 0.08	0.18 0.00
				ΣP = 100.49		ΣM = 188.19

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.1 kN/m
depth to acting position	H	=	-0.25 m
moment	M_m	=	3.6 kN·m/m
depth to acting position	H_t	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.23 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 40.73$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20~ 2.60	0.40	0.0 0.7	0.00 0.14	1.50 1.36	0.00 0.19
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.19

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{229.11}{109.72} = 2.09 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{-8}$		=	7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	23674 kN/m^3
calculated value	β	=	0.52181 m^{-1}
resultant earth force (lateral)	P_0	=	79.13 kN/m
height of acting position of load	h_0	=	1.73 m
moment	M_0	=	136.54 kN·m/m

in consideration of ψ_m = 1.172,

maximum moment	M_{max}	=	160.03 kN·m/m
depth of generated position of M_{max}	l_m	=	0.657 m
depth of 1^{st} fixed point	l_i	=	2.162 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	24350 kN/m^3
calculated value	β	=	0.52549 m^{-1}
resultant earth force (lateral)	P_0	=	109.72 kN/m
height of acting position of load	h_0	=	2.09 m
moment	M_0	=	229.11 kN·m/m

in consideration of ψ_m = 1.126,

maximum moment	M_{max}	=	258.03 kN·m/m
depth of generated position of M_{max}	l_m	=	0.577 m
depth of 1^{st} fixed point	l_i	=	2.072 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm^3 (original condition)
	Z	=	2376 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{160.03 \times 10^6}{2376 \times 10^3} = 67 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{258.03 \times 10^6}{2376 \times 10^3} = 109 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

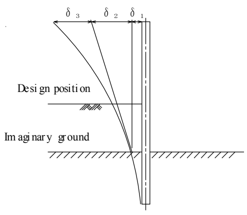
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00~ 2.10	2.82 2.12	0.801 0.602	0.235 0.145	6.62 34.93	1.557 5.063
2	2.10~ 2.58	1.26 1.10	0.358 0.312	0.056 0.044	7.54 8.97	0.425 0.392
3	2.58~ 2.60	0.93 0.93	0.265 0.263	0.032 0.032	0.39 0.39	0.012 0.012
4	2.60~ 2.70	0.89 0.85	0.252 0.242	0.029 0.027	1.96 1.64	0.057 0.044
5	2.70~ 3.52	0.55 0.27	0.155 0.078	0.011 0.003	13.41 0.00	0.153 0.000
						ΣQ = 7.716

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$
$$= \frac{(1+0.5218\times1.73)\times79.13}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5218^3} = 0.00663 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$
$$= \frac{(1+2\times0.5218\times1.73)\times79.13}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5218^2} \times (2.60+0.92) = 0.01794 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$
$$= \frac{7.72\times(2.60+0.92)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00421 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00073 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.52 m
Horizontal load: P = 3.30
Moment: M = 1.68

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00663 + 0.01794 + 0.00495
= 0.02952 m
= 29.52 ≦ δa = 50.00 mm (ok)

Where
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

2.261

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.13 2.43	0.817 0.635	0.243 0.159	10.81 42.29	2.626 6.712
2	2.10～ 2.20	1.70 1.66	0.443 0.434	0.084 0.081	1.88 1.95	0.158 0.158
3	2.20～ 2.58	1.50 1.38	0.393 0.360	0.067 0.057	7.42 7.70	0.497 0.438
4	2.58～ 2.60	1.24 1.24	0.325 0.323	0.047 0.047	0.43 0.43	0.020 0.020
5	2.60～ 3.58	0.90 0.58	0.236 0.151	0.026 0.011	20.94 5.57	0.537 0.060
6	3.58～ 3.83	0.17 0.08	0.044 0.022	0.001 0.000	1.07 0.00	0.001 0.000
						ΣQ = 11.226

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

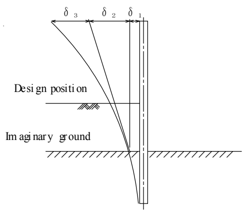
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.50 1.36	0.391 0.356	0.066 0.056	0.00 0.14	0.000 0.008
						ΣQ_{dw} = 0.008

Therefore, modulus of deformation Q is calculated as below

Q = 11.226＋0.008 ＝ 11.234

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5255\times2.09)\times109.72}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5255^3} = 0.00993\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5255\times2.09)\times109.72}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5255^2}\times(2.60+1.23) = 0.03045\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.23\times(2.60+1.23)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00791\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00234 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.83 m
Horizontal load: P = 9.10
Moment: M = 2.28

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h)$$ （L＝3.83 m、h＝L－H_m、H_m＝0.80 m、ただし ）

$$= \frac{3.60\times3.03}{2\times2.00\times10^8\times39917\times10^{-8}}\times(2\times3.83-3.03) = 0.00032\ \text{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00993＋0.03045＋0.01057
= 0.05095 m
= 50.95 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 Nmm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10^8		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction — K_h = 23674 kN/m³
Calculated value — β = 0.47797 m^{-1}

Penetration length of SSP — $D = 0.92 + \dfrac{3}{0.478} = 7.20$ m
Whole length of SSP — L = 2.60－0.40＋7.20 = 9.40 m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction — K_h = 24350 kN/m³
Calculated value — β = 0.48134 m^{-1}

Penetration length of SSP — $D = 1.23 + \dfrac{3}{0.481} = 7.46$ m
Whole length of SSP — L = 2.60－0.40＋7.46 = 9.66 m

Therefore, whole length of SSP is set as 10.00 m in consideration of round unit of SSP length.

8 Calculation Result

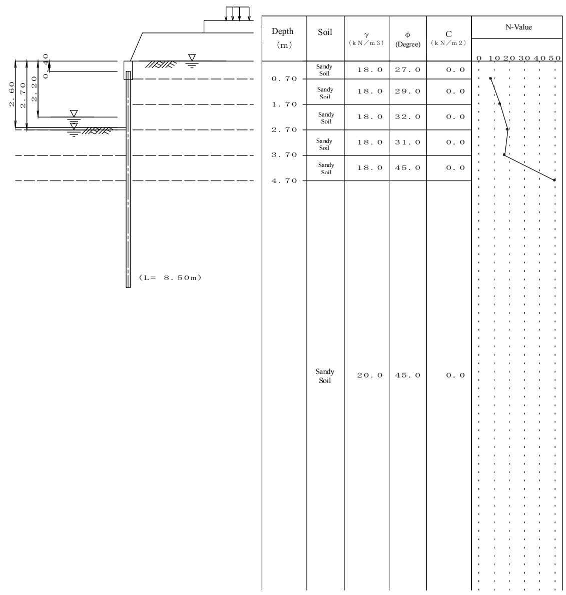
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		160.03	258.03
Stress intensity	σ (Nmm^2)		67 (180)	109 (270)
Lateral displacement	δ (mm)		29.52 (50.0)	50.95 (75.0)
Penetration depth	D (m)		7.20	7.46
Whole length of SSP	L (m)	10.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 35_STA 14+100 - 14+200

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　γ_w = 9.8 kN/m^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	3.3 kN/m	(Normal Condition)
		Pt'	=	9.1 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.52 m	(Normal Condition)
		Ht'	=	-0.25 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN·m/m	(Normal Condition)
		Mm'	=	3.6 kN·m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　ζ_0 = 10 degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$

Equilibrium factor of compression　　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N'^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.70	8
2	1.70	14
3	2.70	19
4	3.70	17
5	4.70	50
6	20.00	50

No	Depth (m)	N-Value

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

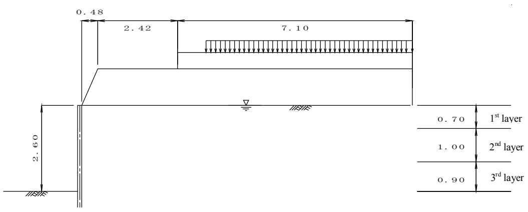
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	0.70	S	8.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
2	1.70	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
3	2.70	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
4	3.70	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
5	4.70	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
6	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.48	10.00	10.00	1.11	18.0	30.0	0.0	auto	auto
2	Sandy soil	2.90	2.90	10.00	10.00	0.49	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	3.76	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus $E = 200000$ N/mm²
Inertia sectional moment $I_0 = 32400$ cm⁴
Sectional factor $Z_0 = 1800$ cm³

Corrosion margin $t_1 = 1.00$ mm (riverside) $t_2 = 1.00$ mm (landside)

Corrosion rate (to I_0) $\eta = 0.85$
Corrosion rate (to Z_0) $\eta = 0.85$
Section efficiency (to I_0) $\mu = 0.80$
Section efficiency (to Z_0) $\mu = 1.00$

Round unit of SSP length 0.50 m

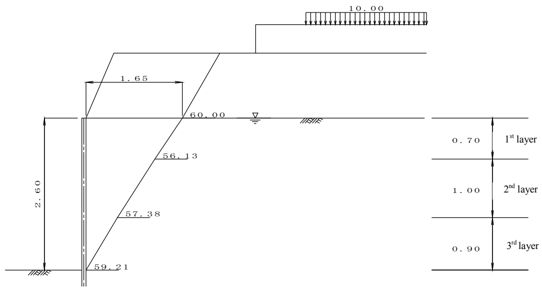
Allowable stress $\sigma_a = 180$ N/mm (Normal)
$\sigma_a' = 270$ N/mm (Seismic)

Allowable displacement $\delta_a = 50.0$ mm (Normal)
$\delta_a' = 75.0$ mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60〜 1.70	Sandy Soil	32.0	9.0	0.0	26.00	20.96	25.48	59.21
2	1.70〜 0.70	Sandy Soil	29.0	9.0	0.0	17.00	20.96	16.66	57.38
3	0.70〜 0.00	Sandy Soil	27.0	9.0	0.0	7.00	20.96	6.86	56.13
4		Embankment	30.0	——	0.0	28.80	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	59.21	0.90	0.00	0.00	0.54	0.90
2	57.38	1.00	0.54	0.90	1.18	1.90
3	56.13	0.70	1.18	1.90	1.65	2.60
4	60.00	1.11	1.65	2.60	2.29	3.71

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.92	34.50
Σ			34.50

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

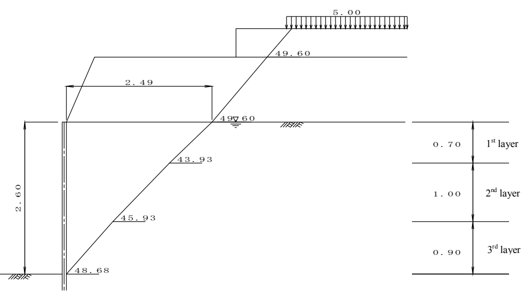
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{34.50 + 0.00 + 0.00}{1.65}$$

$$= 20.96 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60〜 1.70	Sandy Soil	32.0	9.0	0.0	26.00	24.64	25.48	0.200	11.31	48.68
2	1.70〜 0.70	Sandy Soil	29.0	9.0	0.0	17.00	24.64	16.66	0.200	11.31	45.93
3	0.70〜 0.00	Sandy Soil	27.0	9.0	0.0	7.00	24.64	6.86	0.200	11.31	43.93
4		Embankment	30.0	——	0.0	28.80	5.00	0.00	0.200	11.31	49.60
5		Embankment	30.0	——	0.0	8.82	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	48.68	0.90	0.00	0.00	0.79	0.90
2	45.93	1.00	0.79	0.90	1.76	1.90
3	43.93	0.70	1.76	1.90	2.49	2.60
4	49.60	1.11	2.49	2.60	3.43	3.71
5	49.60	0.49	3.43	3.71	3.85	4.20

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.02	54.31
2	18.0	0.36	6.52
Σ			60.83

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	0.09	0.44
Σ			0.44

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

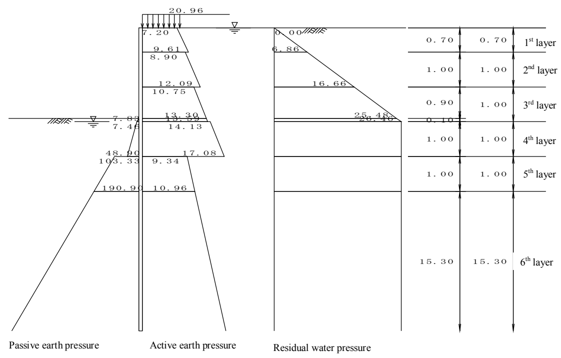
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{60.83 + 0.44 + 0.00}{2.49}$$

$$= 24.64 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 0.70	Sandy soil	10.0	27.0	—— ——	20.956 27.956	0.34800 0.34800	0.34371 0.34371
2	0.70～ 1.70	Sandy soil	10.0	29.0	—— ——	27.956 37.956	0.32248 0.32248	0.31851 0.31851
3	1.70～ 2.60	Sandy soil	10.0	32.0	—— ——	37.956 46.956	0.28683 0.28683	0.28330 0.28330
4	2.60～ 2.70	Sandy soil	10.0	32.0	—— ——	46.956 47.956	0.28683 0.28683	0.28330 0.28330
5	2.70～ 3.70	Sandy soil	10.0	31.0	—— ——	47.956 57.956	0.29838 0.29838	0.29471 0.29471
6	3.70～ 4.70	Sandy soil	10.0	45.0	—— ——	57.956 67.956	0.16323 0.16323	0.16122 0.16122
7	4.70～ 20.00	Sandy soil	10.0	45.0	—— ——	67.956 220.956	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60～ 2.70	Sandy soil	18.0	32.0	—— ——	0.000 1.800	4.40199 4.40199	4.34780 4.34780
5	2.70～ 3.70	Sandy soil	10.0	31.0	—— ——	1.800 11.800	4.19615 4.19615	4.14448 4.14448
6	3.70～ 4.70	Sandy soil	10.0	45.0	—— ——	11.800 21.800	8.86593 8.86593	8.75678 8.75678
7	4.70～ 20.00	Sandy soil	10.0	45.0	—— ——	21.800 174.800	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = -9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 0.70	7.20 9.61	—— ——	7.20 9.61	0.00 6.86	—— ——
2	0.70～ 1.70	8.90 12.09	—— ——	8.90 12.09	6.86 16.66	—— ——
3	1.70～ 2.60	10.75 13.30	—— ——	10.75 13.30	16.66 25.48	—— ——
4	2.60～ 2.70	13.30 13.59	—— ——	13.30 13.59	25.48 26.46	0.00 7.83
5	2.70～ 3.70	14.13 17.08	—— ——	14.13 17.08	26.46 26.46	7.46 48.90
6	3.70～ 4.70	9.34 10.96	—— ——	9.34 10.96	26.46 26.46	103.33 190.90
7	4.70～ 20.00	10.96 35.62	—— ——	10.96 35.62	26.46 26.46	190.90 1530.68

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

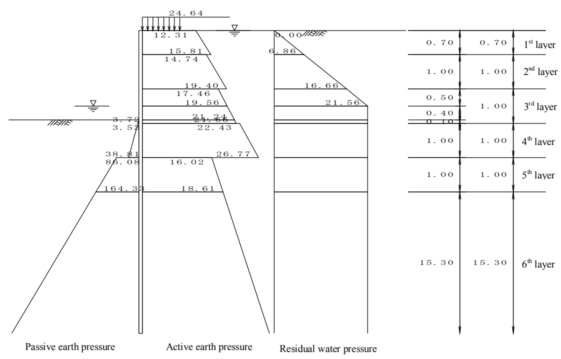
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 0.70	Sandy Soil	10.0	27.0	—— ——	24.65 31.65	0.00 6.86	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
2	0.70～ 1.70	Sandy Soil	10.0	29.0	—— ——	31.65 41.65	6.86 16.66	0.200 0.200	11.31 11.31	0.47163 0.47163	0.46582 0.46582	—— ——
3	1.70～ 2.20	Sandy Soil	10.0	32.0	—— ——	41.65 46.65	16.66 21.56	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
4	2.20～ 2.60	Sandy Soil	10.0	32.0	—— ——	46.65 50.65	21.56 25.48	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
5	2.60～ 2.70	Sandy Soil	10.0	32.0	—— ——	50.65 51.65	25.48 26.46	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
6	2.70～ 3.70	Sandy Soil	10.0	31.0	—— ——	51.65 61.65	26.46 36.26	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	—— ——
7	3.70～ 4.70	Sandy Soil	10.0	45.0	—— ——	61.65 71.65	36.26 46.06	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——
8	4.70～ 20.00	Sandy Soil	10.0	45.0	—— ——	71.65 224.65	46.06 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60～ 2.70	Sandy soil	10.00	32.0	―― ――	0.000 1.000	0.00 0.98	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
6	2.70～ 3.70	Sandy soil	10.00	31.0	―― ――	1.000 11.000	0.98 10.78	0.200 0.200	11.31 11.31	3.57258 3.57258	3.52859 3.52859
7	3.70～ 4.70	Sandy soil	10.00	45.0	―― ――	11.000 21.000	10.78 20.58	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515
8	4.70～ 20.00	Sandy soil	10.00	45.0	―― ――	21.000 174.000	20.58 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta =$ -9.00、$\beta =$ 0.00、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 0.70	12.31 15.81	―― ――	12.31 15.81	0.00 6.86	―― ――
2	0.70～ 1.70	14.74 19.40	―― ――	14.74 19.40	6.86 16.66	―― ――
3	1.70～ 2.20	17.46 19.56	―― ――	17.46 19.56	16.66 21.56	―― ――
4	2.20～ 2.60	19.56 21.24	―― ――	19.56 21.24	21.56 21.56	―― ――
5	2.60～ 2.70	21.24 21.66	―― ――	21.24 21.66	21.56 21.56	0.00 3.72
6	2.70～ 3.70	22.43 26.77	―― ――	22.43 26.77	21.56 21.56	3.53 38.81
7	3.70～ 4.70	16.02 18.61	―― ――	16.02 18.61	21.56 21.56	86.08 164.33
8	4.70～ 20.00	18.61 58.36	―― ――	18.61 58.36	21.56 21.56	164.33 1361.58

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

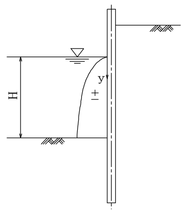
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

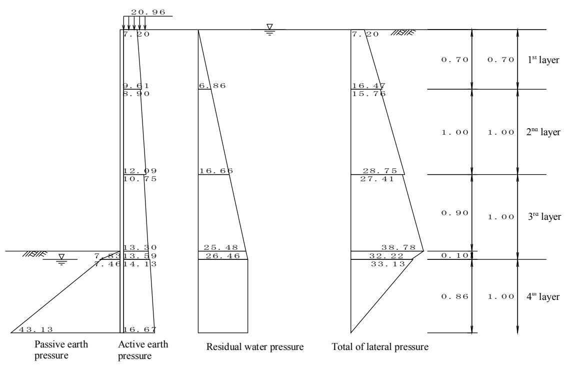
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

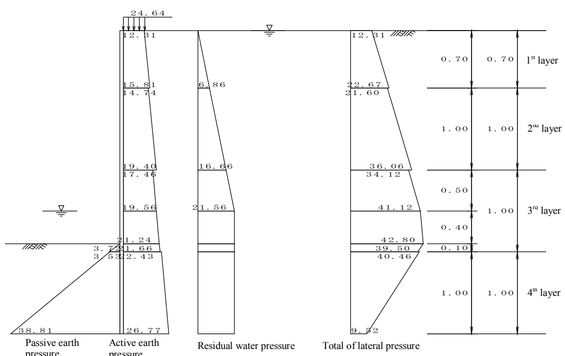


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 0.70	7.20 9.61	0.00 6.86	――	7.20 16.47
2	0.70～ 1.70	8.90 12.09	6.86 16.66	――	15.76 28.75
3	1.70～ 2.60	10.75 13.30	16.66 25.48	――	27.41 38.78
4	2.60～ 2.70	13.30 13.59	25.48 26.46	0.00 7.83	38.78 32.22
5	2.70～ 3.56	14.13 16.67	26.46 26.46	7.46 43.13	33.13 0.00
6	3.56～ 3.70	16.67 17.08	26.46 26.46	43.13 48.90	0.00 -5.36

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.96 m (GL -3.56 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 0.70	12.31 15.81	0.00 6.86	―― ――	12.31 22.67
2	0.70～ 1.70	14.74 19.40	6.86 16.66	―― ――	21.60 36.06
3	1.70～ 2.20	17.46 19.56	16.66 21.56	―― ――	34.12 41.12
4	2.20～ 2.60	19.56 21.24	21.56 21.56	―― ――	41.12 42.80
5	2.60～ 2.70	21.24 21.66	21.56 21.56	0.00 3.72	42.80 39.50
6	2.70～ 3.70	22.43 26.77	21.56 21.56	3.53 38.81	40.46 9.52
7	3.70～ 4.70	16.02 18.61	21.56 21.56	86.08 164.33	-48.50 -124.15

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.10 m (GL -3.70 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	32400 cm^4(original condition)
	I	=	22032 cm^4(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	200000 x 10^3 x 22032 x 10^{-8} = 4.406 × 10^4

	Depth (m)	N-value
1	0.70	8
2	1.70	14
3	2.70	19
4	3.70	17
5	4.70	50
6	20.00	50

5-2 Normal Condition

K_h = 29765 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.641 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.56 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.56 m) to 1.56 m depth (GL -5.12 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.56	0.14	17.3	17.0	2.39
2	3.70	1.00	17.0	50.0	33.50
3	4.70	0.42	50.0	50.0	21.03
	L =Σh = 1.56				ΣA = 56.92

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{56.92}{1.56}$$

$$= 36.49$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 36.49^{0.406} = 29765$ kN/m^3

Kh (normal condition) = 29765 kN/m^3

5-3 Seismic Condition

K_h = 30689 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.646 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.55 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.70 m) and 1.55 m depth (GL -5.25 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.70	1.00	17.0	50.0	33.50
2	4.70	0.55	50.0	50.0	27.40
	L =Σh = 1.55				ΣA = 60.90

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{60.90}{1.55}$$

$$= 39.34$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 39.34^{0.406} = 30689$ kN/m^3

Kh (seismic condition) = 30689 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 0.70	0.70	7.20 16.47	2.52 5.76	3.33 3.09	8.39 17.83
2	0.70～ 1.70	1.00	15.76 28.75	7.88 14.37	2.53 2.19	19.92 31.54
3	1.70～ 2.60	0.90	27.41 38.78	12.34 17.45	1.56 1.26	19.25 22.00
4	2.60～ 2.70	0.10	38.78 32.22	1.94 1.61	0.93 0.89	1.80 1.44
5	2.70～ 3.56	0.86	33.13 0.00	14.26 0.00	0.57 0.29	8.18 0.00
				ΣP = 78.14		ΣM = 130.35

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.3 kN/m
depth to acting position	H_t	=	-0.52 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	0.96 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 13.47 kN·m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{143.82}{81.44} = 1.77 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 0.70	0.70	12.31 22.67	4.31 7.93	3.47 3.23	14.94 25.65
2	0.70～ 1.70	1.00	21.60 36.06	10.80 18.03	2.67 2.33	28.80 42.07
3	1.70～ 2.20	0.50	34.12 41.12	8.53 10.28	1.83 1.67	15.64 17.13
4	2.20～ 2.60	0.40	41.12 42.80	8.22 8.56	1.37 1.23	11.24 10.56
5	2.60～ 2.70	0.10	42.80 39.50	2.14 1.97	1.07 1.03	2.28 2.04
6	2.70～ 3.70	1.00	40.46 9.52	20.23 4.76	0.67 0.33	13.49 1.59
				ΣP = 105.77		ΣM = 185.43

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.1 kN/m
depth to acting position	H_t	=	-0.25 m
moment	M_m	=	3.6 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.10 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 39.55 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	1.37 1.23	0.00 0.17
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.17

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{225.14}{115.01} = 1.96 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	32400 cm^4 (original condition)
	I	=	22032 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 22032 \times 10^{-8}$		=	4.406×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x}\ (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	29765 kN/m^3
calculated value	β	=	0.64105 m^{-1}
resultant earth force (lateral)	P_0	=	81.44 kN/m
height of acting position of load	h_0	=	1.77 m
moment	M_0	=	143.82 kN・m/m

in consideration of ψ_m = 1.120,

maximum moment	M_{max}	=	161.09 kN・m/m
depth of generated position of M_{max}	l_m	=	0.464 m
depth of 1st fixed point	l_i	=	1.689 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	30689 kN/m^3
calculated value	β	=	0.64597 m^{-1}
resultant earth force (lateral)	P_0	=	115.01 kN/m
height of acting position of load	h_0	=	1.96 m
moment	M_0	=	225.14 kN・m/m

in consideration of ψ_m = 1.100,

maximum moment	M_{max}	=	247.75 kN・m/m
depth of generated position of M_{max}	l_m	=	0.427 m
depth of 1st fixed point	l_i	=	1.643 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	1.00
Module of section	Z_0	=	1800 cm^3 (original condition)
	Z	=	1530 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{161.09\times10^6}{1530\times10^3} = 105\ \text{N/mm}^2 \leqq \sigma_a = 180\ \text{N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{247.75\times10^6}{1530\times10^3} = 162\ \text{N/mm}^2 \leqq \sigma_a = 270\ \text{N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.70	3.33 3.09	0.934 0.869	0.301 0.268	2.52 5.76	0.758 1.546
2	0.70～ 1.70	2.53 2.19	0.710 0.616	0.192 0.151	7.88 14.37	1.516 2.168
3	1.70～ 2.60	1.56 1.26	0.438 0.354	0.082 0.055	12.34 17.45	1.012 0.965
4	2.60～ 2.70	0.93 0.89	0.260 0.251	0.031 0.029	1.94 1.61	0.060 0.047
5	2.70～ 3.56	0.57 0.29	0.161 0.081	0.012 0.003	14.26 0.00	0.175 0.000
						ΣQ = 8.246

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

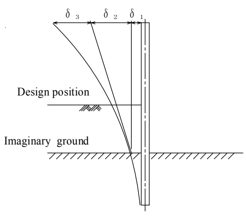
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.6411\times1.77)\times81.44}{2\times2.00\times10^8\times22032\times10^{-8}\times0.6411^3} = 0.00748\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.6411\times1.77)\times81.44}{2\times2.00\times10^8\times22032\times10^{-8}\times0.6411^2}\times(2.60+0.96) = 0.02614\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{8.25\times(2.60+0.96)^3}{2.00\times10^8\times22032\times10^{-8}} = 0.00845\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00137 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.56 m
Horizontal load: P = 3.30
Moment: M = 1.72

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.00748 + 0.02614 + 0.00982$
$= 0.04344$ m
$= 43.44 \leqq \delta a = 50.00$ mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.70	3.47 3.23	0.937 0.874	0.302 0.271	4.31 7.93	1.301 2.147
2	0.70～ 1.70	2.67 2.33	0.721 0.631	0.197 0.157	10.80 18.03	2.131 2.832
3	1.70～ 2.20	1.83 1.67	0.496 0.450	0.102 0.086	8.53 10.28	0.874 0.886
4	2.20～ 2.60	1.37 1.23	0.369 0.333	0.060 0.049	8.22 8.56	0.492 0.423
5	2.60～ 2.70	1.07 1.03	0.288 0.279	0.038 0.035	2.14 1.97	0.080 0.070
6	2.70～ 3.70	0.67 0.33	0.180 0.090	0.015 0.004	20.23 4.76	0.309 0.019
						ΣQ = 11.563

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

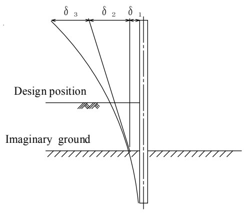
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.37 1.23	0.369 0.333	0.060 0.049	0.00 0.14	0.000 0.007
						ΣQ_{dw} = 0.007

Therefore, modulus of deformation Q is calculated as below:
Q = 11.563 + 0.007 = 11.570

2.268

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.6460\times 1.96)\times 115.01}{2\times 2.00\times 10^8\times 22032\times 10^{-8}\times 0.6460^3} = 0.01096\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.6460\times 1.96)\times 115.01}{2\times 2.00\times 10^8\times 22032\times 10^{-8}\times 0.6460^2}\times(2.60+1.10) = 0.04084\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.57\times(2.60+1.10)^3}{2.00\times 10^8\times 22032\times 10^{-8}} = 0.01330\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00384 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.70 m
Horizontal load: P = 9.10
Moment: M = 2.28

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=3.70\ \text{m、}h=L-H_m\text{、}H_m=0.80\ \text{m、ただし}$$

$$= \frac{3.60\times 2.90}{2\times 2.00\times 10^8\times 22032\times 10^{-8}}\times(2\times 3.70-2.90) = 0.00053\ \text{m}$$

$$\delta = \delta_1+\delta_2+\delta_3$$
$$= 0.01096+0.04084+0.01767$$
$$= 0.06947\ \text{m}$$
$$= 69.47 \leqq \delta_a = 75.00\ \text{mm (ok)}$$

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	32400 cm^4 (original condition)
	I	=	32400 cm^4 (after reduction by corrosion and section)
EI = 200000 x 10^3 x 32400 x 10^{-8}		=	6.480 × 10^4

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 29765 kN/m^3
Calculated value β = 0.58213 m^{-1}

Penetration length of SSP $D = 0.96 + \frac{3}{0.582} = 6.11$ m
Whole length of SSP $L = 2.60 - 0.40 + 6.11 = 8.31$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 30689 kN/m^3
Calculated value β = 0.58659 m^{-1}

Penetration length of SSP $D = 1.10 + \frac{3}{0.587} = 6.21$ m
Whole length of SSP $L = 2.60 - 0.40 + 6.21 = 8.41$ m

Therefore, whole length of SSP is set as 8.50 m in consideration of round unit of SSP length.

8 Calculation Result

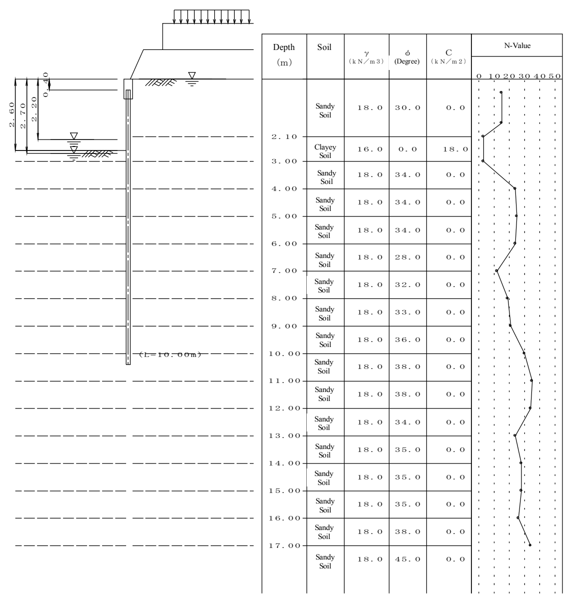
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	32400		
Section modulus	Z (cm^3)	1800		
Maximum bending moment	M_{max} (kN·m/m)		161.09	247.75
Stress intensity	σ (N/mm^2)		105 (180)	162 (270)
Lateral displacement	δ (mm)		43.44 (50.0)	69.47 (75.0)
Penetration depth	D (m)		6.11	6.21
Whole length of SSP	L (m)	8.50		

－Steel Sheet Pile　Design Calculation－

Right Bank No. 36_STA 14+200 - 14+300

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　Chang's formula

Penetration depths　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　γ_w = 9.8 kN/m^3

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	P_t	=	3.2 kN/m	(Normal Condition)
		P_t'	=	8.9 kN/m	(Seismic Condition)
	Depth of acting point	H_t	=	-0.50 m	(Normal Condition)
		H_t'	=	-0.23 m	(Seismic Condition)
	Moment	M_m	=	0.0 kN･m/m	(Normal Condition)
		M_m'	=	3.2 kN･m/m	(Seismic Condition)
	Depth of acting point	H_m'	=	0.00 m	(Seismic Condition)
		H_m	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　ζ_0 = 10 degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N'^{0.406}$

Average N-value　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	3
4	3.00	3
5	4.00	24
6	5.00	25
7	6.00	24
8	7.00	12
9	8.00	19
10	9.00	21

No	Depth (m)	N-Value
11	10.00	30
12	11.00	35
13	12.00	34
14	13.00	24
15	14.00	28
16	15.00	28
17	16.00	26
18	17.00	34
19	18.00	50

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

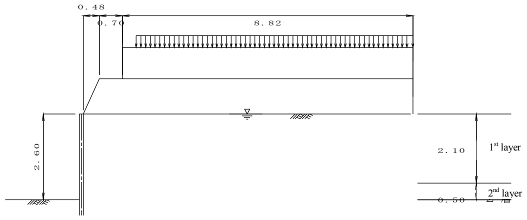
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	――	――
2	3.00	C	3.0	16.00	8.00	0.0	18.0	0.0	0.200	auto	auto	――	――
3	4.00	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	――	――
4	5.00	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	――	――
5	6.00	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	――	――
6	7.00	S	12.0	18.00	10.00	28.0	0.0	0.0	0.200	auto	auto	――	――
7	8.00	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	――	――
8	9.00	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	――	――
9	10.00	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	――	――
10	11.00	S	35.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	――	――
11	12.00	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	――	――
12	13.00	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	――	――
13	14.00	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	――	――
14	15.00	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	――	――
15	16.00	S	26.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	――	――
16	17.00	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	――	――
17	18.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	――	――

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.48	10.00	10.00	1.07	18.0	30.0	0.0	auto	auto
2	Sandy soil	1.18	1.18	10.00	10.00	0.96	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.60	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 63000 cm⁴
Sectional factor Z_0 = 3150 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.91
Corrosion rate (to Z_0) η = 0.91
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 180 N/mm (Normal)
σ_a' = 270 N/mm (Seismic)

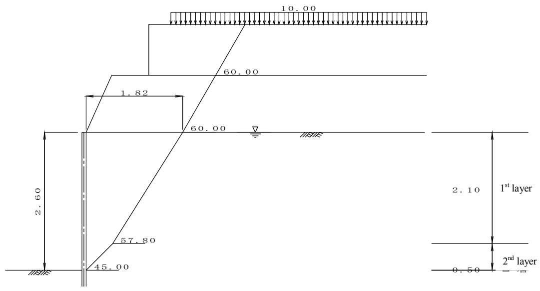
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	18.0	25.00	42.22	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	42.22	20.58	57.80
3		Embankment	30.0	—	0.0	36.54	10.00	0.00	60.00
4		Embankment	30.0	—	0.0	17.28	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	1.07	1.82	2.60	2.44	3.67
4	60.00	0.96	2.44	3.67	2.99	4.63

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.02	36.43
2	18.0	1.48	26.56
Σ			62.99

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.39	13.94
Σ			13.94

Q: surcharge load
l : width of surcharge load set by line of active rupture

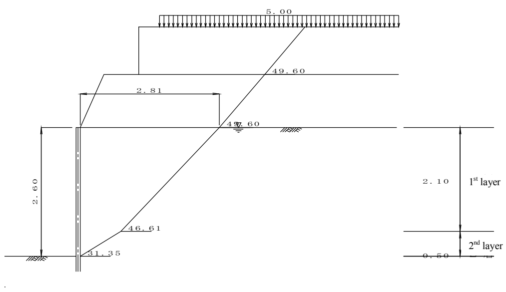
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{62.99 + 13.94 + 0.00}{1.82}$$

$$= 42.22 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	$\Sigma\gamma h$ (kN/m²)	Q (kN/m²)	$\gamma_w h_w$ (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	18.0	25.00	44.10	25.48	0.200	11.31	31.35
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	44.10	20.58	0.200	11.31	46.61
3		Embankment	30.0	—	0.0	36.54	5.00	0.00	0.200	11.31	49.60
4		Embankment	30.0	—	0.0	17.28	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	31.35	0.50	0.00	0.00	0.82	0.50
2	46.61	2.10	0.82	0.50	2.81	2.60
3	49.60	1.07	2.81	2.60	3.72	3.67
4	49.60	0.96	3.72	3.67	4.53	4.63

Therefore, width of acting load shall be set as 2.81 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.23	58.19
2	18.0	2.83	50.89
Σ			109.08

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.93	14.67
Σ			14.67

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

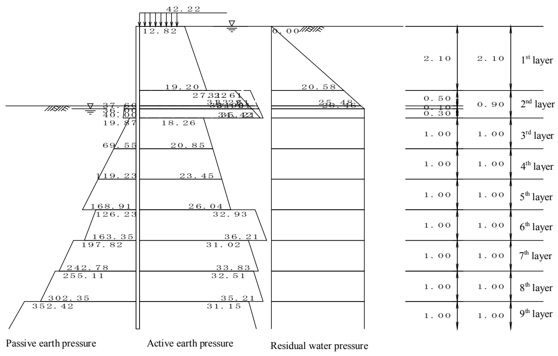
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{109.08 + 14.67 + 0.00}{2.81}$$

$$= 44.10 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	42.216 63.216	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Clayey soil	8.0	—	18.0 18.0	63.216 67.216	—— ——	—— ——
3	2.60～ 2.70	Clayey soil	8.0	—	18.0 18.0	67.216 68.016	—— ——	—— ——
4	2.70～ 3.00	Clayey soil	8.0	—	18.0 18.0	68.016 70.416	—— ——	—— ——
5	3.00～ 4.00	Sandy soil	10.0	34.0	—— ——	70.416 80.416	0.26331 0.26331	0.25931 0.25931
6	4.00～ 5.00	Sandy soil	10.0	34.0	—— ——	80.416 90.416	0.26331 0.26331	0.25931 0.25931
7	5.00～ 6.00	Sandy soil	10.0	34.0	—— ——	90.416 100.416	0.26331 0.26331	0.25931 0.25931
8	6.00～ 7.00	Sandy soil	10.0	28.0	—— ——	100.416 110.416	0.33303 0.33303	0.32798 0.32798
9	7.00～ 8.00	Sandy soil	10.0	32.0	—— ——	110.416 120.416	0.28525 0.28525	0.28092 0.28092
10	8.00～ 9.00	Sandy soil	10.0	33.0	—— ——	120.416 130.416	0.27412 0.27412	0.26996 0.26996
11	9.00～ 10.00	Sandy soil	10.0	36.0	—— ——	130.416 140.416	0.24257 0.24257	0.23889 0.23889
12	10.00～ 11.00	Sandy soil	10.0	38.0	—— ——	140.416 150.416	0.22298 0.22298	0.21959 0.21959
13	11.00～ 12.00	Sandy soil	10.0	38.0	—— ——	150.416 160.416	0.22298 0.22298	0.21959 0.21959

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	12.00～ 13.00	Sandy soil	10.0	34.0	—— ——	160.416 170.416	0.26331 0.26331	0.25931 0.25931
15	13.00～ 14.00	Sandy soil	10.0	35.0	—— ——	170.416 180.416	0.25279 0.25279	0.24895 0.24895
16	14.00～ 15.00	Sandy soil	10.0	35.0	—— ——	180.416 190.416	0.25279 0.25279	0.24895 0.24895
17	15.00～ 16.00	Sandy soil	10.0	35.0	—— ——	190.416 200.416	0.25279 0.25279	0.24895 0.24895
18	16.00～ 17.00	Sandy soil	10.0	38.0	—— ——	200.416 210.416	0.22298 0.22298	0.21959 0.21959
19	17.00～ 18.00	Sandy soil	10.0	45.0	—— ——	210.416 220.416	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Clayey soil	16.0	0.0	18.0 18.0	0.000 1.600	—— ——	—— ——
4	2.70～ 3.00	Clayey soil	8.0	0.0	18.0 18.0	1.600 4.000	—— ——	—— ——
5	3.00～ 4.00	Sandy soil	10.0	34.0	—— ——	4.000 14.000	5.04448 5.04448	4.96784 4.96784
6	4.00～ 5.00	Sandy soil	10.0	34.0	—— ——	14.000 24.000	5.04448 5.04448	4.96784 4.96784
7	5.00～ 6.00	Sandy soil	10.0	34.0	—— ——	24.000 34.000	5.04448 5.04448	4.96784 4.96784
8	6.00～ 7.00	Sandy soil	10.0	28.0	—— ——	34.000 44.000	3.76978 3.76978	3.71251 3.71251
9	7.00～ 8.00	Sandy soil	10.0	32.0	—— ——	44.000 54.000	4.56530 4.56530	4.49594 4.49594
10	8.00～ 9.00	Sandy soil	10.0	33.0	—— ——	54.000 64.000	4.79713 4.79713	4.72425 4.72425
11	9.00～ 10.00	Sandy soil	10.0	36.0	—— ——	64.000 74.000	5.59154 5.59154	5.50659 5.50659
12	10.00～ 11.00	Sandy soil	10.0	38.0	—— ——	74.000 84.000	6.21981 6.21981	6.12532 6.12532
13	11.00～ 12.00	Sandy soil	10.0	38.0	—— ——	84.000 94.000	6.21981 6.21981	6.12532 6.12532
14	12.00～ 13.00	Sandy soil	10.0	34.0	—— ——	94.000 104.000	5.04448 5.04448	4.96784 4.96784
15	13.00～ 14.00	Sandy soil	10.0	35.0	—— ——	104.000 114.000	5.30876 5.30876	5.22810 5.22810
16	14.00～ 15.00	Sandy soil	10.0	35.0	—— ——	114.000 124.000	5.30876 5.30876	5.22810 5.22810

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
17	15.00～ 16.00	Sandy soil	10.0	35.0	—— ——	124.000 134.000	5.30876 5.30876	5.22810 5.22810
18	16.00～ 17.00	Sandy soil	10.0	38.0	—— ——	134.000 144.000	6.21981 6.21981	6.12532 6.12532
19	17.00～ 18.00	Sandy soil	10.0	45.0	—— ——	144.000 154.000	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	12.82 19.20	—— ——	12.82 19.20	0.00 20.58	—— ——
2	2.10～ 2.60	27.22 31.22	31.61 33.61	31.61 33.61	20.58 25.48	—— ——
3	2.60～ 2.70	31.22 32.02	33.61 34.01	33.61 34.01	25.48 26.46	36.00 37.60
4	2.70～ 3.00	32.02 34.42	34.01 35.21	34.01 35.21	26.46 26.46	37.60 40.00
5	3.00～ 4.00	18.26 20.85	—— ——	18.26 20.85	26.46 26.46	19.87 69.55
6	4.00～ 5.00	20.85 23.45	—— ——	20.85 23.45	26.46 26.46	69.55 119.23
7	5.00～ 6.00	23.45 26.04	—— ——	23.45 26.04	26.46 26.46	119.23 168.91
8	6.00～ 7.00	32.93 36.21	—— ——	32.93 36.21	26.46 26.46	126.23 163.35
9	7.00～ 8.00	31.02 33.83	—— ——	31.02 33.83	26.46 26.46	197.82 242.78
10	8.00～ 9.00	32.51 35.21	—— ——	32.51 35.21	26.46 26.46	255.11 302.35
11	9.00～ 10.00	31.15 33.54	—— ——	31.15 33.54	26.46 26.46	352.42 407.49
12	10.00～ 11.00	30.83 33.03	—— ——	30.83 33.03	26.46 26.46	453.27 514.53
13	11.00～ 12.00	33.03 35.23	—— ——	33.03 35.23	26.46 26.46	514.53 575.78
14	12.00～ 13.00	41.60 44.19	—— ——	41.60 44.19	26.46 26.46	466.98 516.66
15	13.00～ 14.00	42.43 44.92	—— ——	42.43 44.92	26.46 26.46	543.72 596.00
16	14.00～ 15.00	44.92 47.40	—— ——	44.92 47.40	26.46 26.46	596.00 648.28
17	15.00～ 16.00	47.40 49.89	—— ——	47.40 49.89	26.46 26.46	648.28 700.57
18	16.00～ 17.00	44.01 46.21	—— ——	44.01 46.21	26.46 26.46	820.79 882.05
19	17.00～ 18.00	33.70 35.30	—— ——	33.70 35.30	26.46 26.46	1325.30 1417.34

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

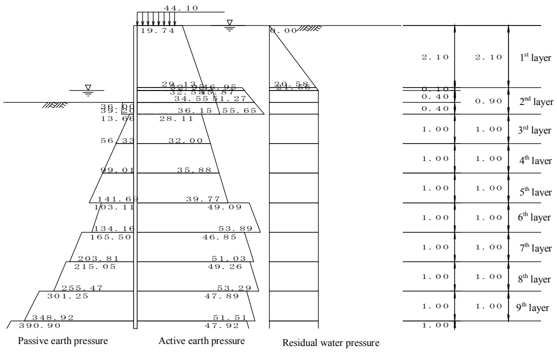
- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00~2.10	Sandy Soil	10.0	30.0	—	44.10 65.10	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—
2	2.10~2.20	Clayey Soil	8.0	—	18.0 18.0	65.10 65.90	20.58 21.56	0.200 0.200	11.31 11.31	—	—	32.09 31.95
3	2.20~2.60	Clayey Soil	8.0	—	18.0 18.0	65.90 69.10	21.56 25.48	0.200 0.200	11.31 11.31	—	—	31.95 31.35
4	2.60~3.00	Clayey Soil	8.0	—	18.0 18.0	69.10 72.30	25.48 29.40	0.200 0.200	11.31 11.31	—	—	31.35 30.73
5	3.00~4.00	Sandy Soil	10.0	34.0	—	72.30 82.30	29.40 39.20	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—
6	4.00~5.00	Sandy Soil	10.0	34.0	—	82.30 92.30	39.20 49.00	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
7	5.00~6.00	Sandy Soil	10.0	34.0	—	92.30 102.30	49.00 58.80	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—
8	6.00~7.00	Sandy Soil	10.0	28.0	—	102.30 112.30	58.80 68.60	0.200 0.200	11.31 11.31	0.48730 0.48730	0.47989 0.47989	—
9	7.00~8.00	Sandy Soil	10.0	32.0	—	112.30 122.30	68.60 78.40	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—
10	8.00~9.00	Sandy Soil	10.0	33.0	—	122.30 132.30	78.40 88.20	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—
11	9.00~10.00	Sandy Soil	10.0	36.0	—	132.30 142.30	88.20 98.00	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—
12	10.00~11.00	Sandy Soil	10.0	38.0	—	142.30 152.30	98.00 107.80	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—
13	11.00~12.00	Sandy Soil	10.0	38.0	—	152.30 162.30	107.80 117.60	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—
14	12.00~13.00	Sandy Soil	10.0	34.0	—	162.30 172.30	117.60 127.40	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—
15	13.00~14.00	Sandy Soil	10.0	35.0	—	172.30 182.30	127.40 137.20	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—
16	14.00~15.00	Sandy Soil	10.0	35.0	—	182.30 192.30	137.20 147.00	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—
17	15.00~16.00	Sandy Soil	10.0	35.0	—	192.30 202.30	147.00 156.80	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—
18	16.00~17.00	Sandy Soil	10.0	38.0	—	202.30 212.30	156.80 166.60	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—
19	17.00~18.00	Sandy Soil	10.0	45.0	—	212.30 222.30	166.60 176.40	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta=10.00$、$\beta=0.00$、$\theta=0.00$

$$K_a=\frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta=\tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60~3.00	Clayey soil	8.00	0.0	18.0 18.0	0.000 3.200	0.00 3.92	0.200 0.200	11.31 11.31	—	—
5	3.00~4.00	Sandy soil	10.00	34.0	—	3.200 13.200	3.92 13.72	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
6	4.00~5.00	Sandy soil	10.00	34.0	—	13.200 23.200	13.72 23.52	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
7	5.00~6.00	Sandy soil	10.00	34.0	—	23.200 33.200	23.52 33.32	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
8	6.00~7.00	Sandy soil	10.00	28.0	—	33.200 43.200	33.32 43.12	0.200 0.200	11.31 11.31	3.15350 3.15350	3.10559 3.10559

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
9	7.00~8.00	Sandy soil	10.00	32.0	—	43.200 53.200	43.12 52.92	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
10	8.00~9.00	Sandy soil	10.00	33.0	—	53.200 63.200	52.92 62.72	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
11	9.00~10.00	Sandy soil	10.00	36.0	—	63.200 73.200	62.72 72.52	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
12	10.00~11.00	Sandy soil	10.00	38.0	—	73.200 83.200	72.52 82.32	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
13	11.00~12.00	Sandy soil	10.00	38.0	—	83.200 93.200	82.32 92.12	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
14	12.00~13.00	Sandy soil	10.00	34.0	—	93.200 103.200	92.12 101.92	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
15	13.00~14.00	Sandy soil	10.00	35.0	—	103.200 113.200	101.92 111.72	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
16	14.00~15.00	Sandy soil	10.00	35.0	—	113.200 123.200	111.72 121.52	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
17	15.00~16.00	Sandy soil	10.00	35.0	—	123.200 133.200	121.52 131.32	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
18	16.00~17.00	Sandy soil	10.00	38.0	—	133.200 143.200	131.32 141.12	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
19	17.00~18.00	Sandy soil	10.00	45.0	—	143.200 153.200	141.12 150.92	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta=-10.00$、$\beta=0.00$、$\theta=\tan^{-1}k$

$$K_p=\frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00~2.10	19.74 29.13	—	19.74 29.13	0.00 20.58	—
2	2.10~2.20	45.87 46.95	32.55 32.95	45.87 46.95	20.58 21.56	—
3	2.20~2.60	46.95 51.27	32.95 34.55	46.95 51.27	21.56 21.56	—
4	2.60~3.00	51.27 55.65	34.55 36.15	51.27 55.65	21.56 21.56	36.00 39.20
5	3.00~4.00	28.11 32.00	—	28.11 32.00	21.56 21.56	13.66 56.33
6	4.00~5.00	32.00 35.88	—	32.00 35.88	21.56 21.56	56.33 99.01
7	5.00~6.00	35.88 39.77	—	35.88 39.77	21.56 21.56	99.01 141.69
8	6.00~7.00	49.09 53.89	—	49.09 53.89	21.56 21.56	103.11 134.16

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
9	7.00~8.00	46.85 51.03	—	46.85 51.03	21.56 21.56	165.50 203.81
10	8.00~9.00	49.26 53.29	—	49.26 53.29	21.56 21.56	215.05 255.47
11	9.00~10.00	47.89 51.51	—	47.89 51.51	21.56 21.56	301.25 348.92
12	10.00~11.00	47.92 51.29	—	47.92 51.29	21.56 21.56	390.90 444.30
13	11.00~12.00	51.29 54.65	—	51.29 54.65	21.56 21.56	444.30 497.70
14	12.00~13.00	63.10 66.99	—	63.10 66.99	21.56 21.56	397.76 440.43
15	13.00~14.00	64.65 68.40	—	64.65 68.40	21.56 21.56	465.30 510.39
16	14.00~15.00	68.40 72.15	—	68.40 72.15	21.56 21.56	510.39 555.47
17	15.00~16.00	72.15 75.90	—	72.15 75.90	21.56 21.56	555.47 600.56
18	16.00~17.00	68.12 71.49	—	68.12 71.49	21.56 21.56	711.31 764.71
19	17.00~18.00	54.93 57.52	—	54.93 57.52	21.56 21.56	1174.73 1256.77

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$

$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h+\dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

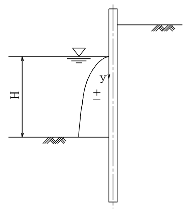
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated

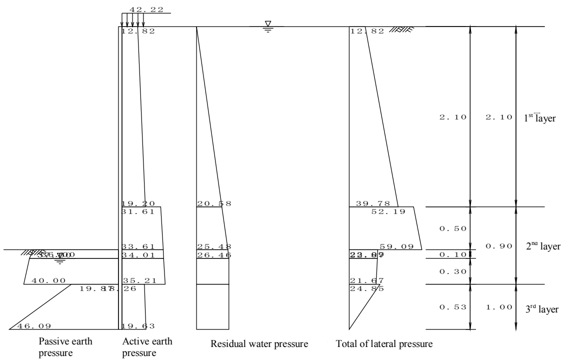


Passive earth pressure   Active earth pressure   Residual water pressure   Total of lateral pressure

4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

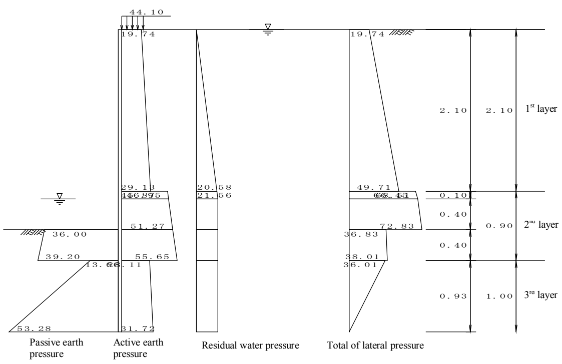


	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	12.82 19.20	0.00 20.58	—— ——	12.82 39.78
2	2.10～ 2.60	31.61 33.61	20.58 25.48	—— ——	52.19 59.09
3	2.60～ 2.70	33.61 34.01	25.48 26.46	36.00 37.60	23.09 22.87
4	2.70～ 3.00	34.01 35.21	26.46 26.46	37.60 40.00	22.87 21.67
5	3.00～ 3.53	18.26 19.63	26.46 26.46	19.87 46.09	24.85 0.00
6	3.53～ 4.00	19.63 20.85	26.46 26.46	46.09 69.55	0.00 -22.24

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.93 m (GL -3.53 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	19.74 29.13	0.00 20.58	—— ——	19.74 49.71
2	2.10～ 2.20	45.87 46.95	20.58 21.56	—— ——	66.45 68.51
3	2.20～ 2.60	46.95 51.27	21.56 21.56	—— ——	68.51 72.83
4	2.60～ 3.00	51.27 55.65	21.56 21.56	36.00 39.20	36.83 38.01
5	3.00～ 3.93	28.11 31.72	21.56 21.56	13.66 53.28	36.01 0.00
6	3.93～ 4.00	31.72 32.00	21.56 21.56	53.28 56.33	0.00 -2.78

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.33 m (GL -3.93 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B = 1.0000 m	
Corrosion margin	t_1 = 1.00 mm (active side)	t_2 = 1.00 mm (passive side)
Corrosion rate	η = 0.91	
Section efficiency	μ = 0.80	
Young's modulus	E = 200000 N/mm^2	
Inertia sectional moment	I_0 = 63000 cm^4(original condition)	
	I = 45864 cm^4(after reduction by corrosion and joint)	
Inertia sectional moment	EI = $200000 \times 10^3 \times 45864 \times 10^{-8} = 9.173 \times 10^4$	

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	10.00	30
2	1.60	15	12	11.00	35
3	2.10	3	13	12.00	34
4	3.00	3	14	13.00	24
5	4.00	24	15	14.00	28
6	5.00	25	16	15.00	28
7	6.00	24	17	16.00	26
8	7.00	12	18	17.00	34
9	8.00	19	19	18.00	50
10	9.00	21			

5-2 Normal Condition

K_h = 24788 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.510 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.96 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.53 m) to 1.96 m depth (GL -5.49 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.53	0.47	14.1	24.0	8.99
2	4.00	1.00	24.0	25.0	24.50
3	5.00	0.49	25.0	24.5	12.11
	L =Σh = 1.96				ΣA = 45.60

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{45.60}{1.96} = 23.25$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 23.25^{0.406} = 24788$ kN/m³

Kh (normal condition) = 24788 kN/m³

5-3 Seismic Condition

K_h = 25313 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}} = 0.513 \ m^{-1}$$

$$L = \frac{1}{\beta} = 1.95 \ m$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) and 1.95 m depth (GL -5.88 m).

	Depth Z (m)	Thickness h (m)	N-value		Area (m²)
			upper	lower	
1	3.93	0.07	22.5	24.0	1.66
2	4.00	1.00	24.0	25.0	24.50
3	5.00	0.88	25.0	24.1	21.60
	L =Σh = 1.95			ΣA = 47.77	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L} = \frac{47.77}{1.95} = 24.48$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 24.48^{0.406} = 25313$ kN/m³

Kh (seismic condition) = 25313 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN・m)
1	0.00～ 2.10	2.10	12.82 39.78	13.47 41.77	2.83 2.13	38.08 88.88
2	2.10～ 2.60	0.50	52.19 59.09	13.05 14.77	1.26 1.09	16.45 16.17
3	2.60～ 2.70	0.10	23.09 22.87	1.15 1.14	0.89 0.86	1.03 0.98
4	2.70～ 3.00	0.30	22.87 21.67	3.43 3.25	0.73 0.63	2.50 2.04
5	3.00～ 3.53	0.53	24.85 0.00	6.56 0.00	0.35 0.18	2.31 0.00
				ΣP = 98.59		ΣM = 168.44

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.2 kN/m
depth to acting position	H_t	=	-0.50 m
moment	M_m	=	0.0 kN・m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	0.93 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 12.89 kN・m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{181.33}{101.79} = 1.78 \ m$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN・m)
1	0.00～ 2.10	2.10	19.74 49.71	20.72 52.20	3.23 2.53	66.90 131.98
2	2.10～ 2.20	0.10	66.45 68.51	3.32 3.43	1.80 1.76	5.96 6.03
3	2.20～ 2.60	0.40	68.51 72.83	13.70 14.57	1.60 1.46	21.85 21.29
4	2.60～ 3.00	0.40	36.83 38.01	7.37 7.60	1.20 1.06	8.80 8.07
5	3.00～ 3.93	0.93	36.01 0.00	16.72 0.00	0.62 0.31	10.35 0.00
				ΣP = 139.62		ΣM = 281.24

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	8.9 kN/m
depth to acting position	H_t	=	-0.23 m
moment	M_m	=	3.2 kN・m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.33 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 40.21 kN・m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN・m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	1.60 1.46	0.00 0.20
				ΣPdw = 0.14		ΣMdw = 0.20

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{321.65}{148.66} = 2.16 \ m$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	63000 cm⁴ (original condition)
	I	=	45864 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 45864 × 10⁻⁸		=	9.173 × 10⁴

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	24788 kN/m³
calculated value	β	=	0.50982 m⁻¹
resultant earth force (lateral)	P_0	=	101.79 kN/m
height of acting position of load	h_0	=	1.78 m
moment	M_0	=	181.33 kN・m/m

in consideration of ψ_m = 1.170,

maximum moment	M_{max}	=	212.11 kN・m/m
depth of generated position of M_{max}	l_m	=	0.669 m
depth of 1st fixed point	l_i	=	2.210 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	25313 kN/m³
calculated value	β	=	0.51250 m⁻¹
resultant earth force (lateral)	P_0	=	148.66 kN/m
height of acting position of load	h_0	=	2.16 m
moment	M_0	=	321.65 kN・m/m

in consideration of ψ_m = 1.124,

maximum moment	M_{max}	=	361.57 kN・m/m
depth of generated position of M_{max}	l_m	=	0.588 m
depth of 1st fixed point	l_i	=	2.120 m

6-3 <u>Stress Intensity</u>

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.91
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3150 cm^3 (original condition)
	Z	=	2867 cm^3 (after reduction by corrosion and section)

6-3-1 <u>Normal Condition</u>

$$\sigma = \frac{M_{max}}{Z} = \frac{212.11\times10^6}{2867\times10^3} = 74\ N/mm^2 \leqq \sigma_a = 180\ N/mm^2 \quad (ok)$$

6-3-2 <u>Seismic condition</u>

$$\sigma = \frac{M_{max}}{Z} = \frac{361.57\times10^6}{2867\times10^3} = 126\ N/mm^2 \leqq \sigma_a = 270\ N/mm^2 \quad (ok)$$

6-4 <u>Displacement</u>

6-4-1 <u>Normal Condition</u>

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	2.83 2.13	0.802 0.603	0.235 0.145	13.47 41.77	3.170 6.071
2	2.10～ 2.60	1.26 1.09	0.357 0.310	0.056 0.043	13.05 14.77	0.734 0.637
3	2.60～ 2.70	0.89 0.86	0.254 0.244	0.029 0.027	1.15 1.14	0.034 0.031
4	2.70～ 3.00	0.73 0.63	0.206 0.178	0.020 0.015	3.43 3.25	0.068 0.048
5	3.00～ 3.53	0.35 0.18	0.100 0.050	0.005 0.001	6.56 0.00	0.032 0.000
						ΣQ = 10.825

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

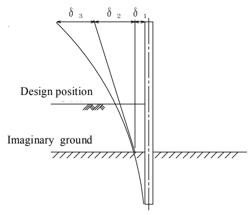
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5098\times1.78)\times101.79}{2\times2.00\times10^8\times45864\times10^{-8}\times0.5098^3} = 0.00799\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5098\times1.78)\times101.79}{2\times2.00\times10^8\times45864\times10^{-8}\times0.5098^2}\times(2.60+0.93) = 0.02121\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.83\times(2.60+0.93)^3}{2.00\times10^8\times45864\times10^{-8}} = 0.00518\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00062 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.53 m
Horizontal load: P = 3.20
Moment: M = 1.60

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00799 + 0.02121 + 0.00580
= 0.03500 m
= 35.00 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 <u>Seismic Condition</u>

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.23 2.53	0.822 0.644	0.245 0.163	20.72 52.20	5.081 8.492
2	2.10～ 2.20	1.80 1.76	0.457 0.448	0.089 0.086	3.32 3.43	0.294 0.293
3	2.20～ 2.60	1.60 1.46	0.406 0.372	0.071 0.061	13.70 14.57	0.977 0.883
4	2.60～ 3.00	1.20 1.06	0.304 0.270	0.042 0.033	7.37 7.60	0.306 0.253
5	3.00～ 3.93	0.62 0.31	0.158 0.079	0.012 0.003	16.72 0.00	0.197 0.000
						ΣQ = 16.775

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

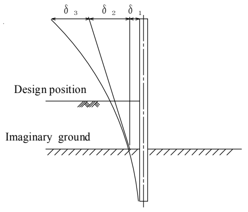
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.60 1.46	0.406 0.372	0.071 0.061	0.00 0.14	0.000 0.008
						ΣQ_{dw} = 0.008

Therefore, modulus of deformation Q is calculated as below:
Q = 16.775 + 0.008 = 16.783

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5125\times2.16)\times148.66}{2\times2.00\times10^8\times45864\times10^{-8}\times0.5125^3} = 0.01269\ m$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5125\times2.16)\times148.66}{2\times2.00\times10^8\times45864\times10^{-8}\times0.5125^2}\times(2.60+1.33) = 0.03900\ m$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{16.78\times(2.60+1.33)^3}{2.00\times10^8\times45864\times10^{-8}} = 0.01109\ m$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00213 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.93 m
Horizontal load: P = 8.90
Moment: M = 2.05

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=3.93\ m、h=L-H_m、H_m=0.80\ m、ただ\ )$$

$$= \frac{3.20\times3.13}{2\times2.00\times10^8\times45864\times10^{-8}}\times(2\times3.93-3.13) = 0.00026\ m$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01269 + 0.03900 + 0.01348
= 0.06518 m
= 65.18 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	63000 cm^4 (original condition)
	I	=	63000 cm^4 (after reduction by corrosion and section)
EI = $200000 \times 10^3 \times 63000 \times 10^{-8}$		=	1.260×10^5

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 24788$ kN/m^3

Calculated value $\beta = 0.47093$ m^{-1}

Penetration length of SSP $D = 0.93 + \frac{3}{0.471} = 7.30$ m

Whole length of SSP $L = 2.60 - 0.40 + 7.30 = 9.50$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 25313$ kN/m^3

Calculated value $\beta = 0.47340$ m^{-1}

Penetration length of SSP $D = 1.33 + \frac{3}{0.473} = 7.67$ m

Whole length of SSP $L = 2.60 - 0.40 + 7.67 = 9.87$ m

Therefore, whole length of SSP is set as 10.00 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	63000		
Section modulus	Z (cm^3)	3150		
Maximum bending moment	M_{max} (kN·m/m)		212.11	361.57
Stress intensity	σ (N/mm^2)		74 (180)	126 (270)
Lateral displacement	δ (mm)		35.00 (50.0)	65.18 (75.0)
Penetration depth	D (m)		7.30	7.67
Whole length of SSP	L (m)	10.00		

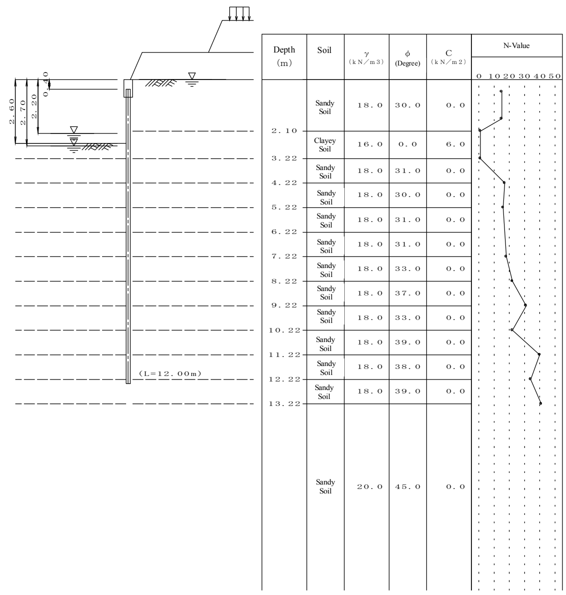
－Steel Sheet Pile　Design Calculation－

Right Bank No. 37_STA_14+300 - 14+350

Case: Right Bank No. 37_STA_14+300 - 14+350

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　　calculated in consideration of geotechnical conditions

Case: Right Bank No. 37_STA_14+300 - 14+350

1-3 Applied Formula

Formula for generated stress　　Chang's formula

Penetration depths　　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　　$\gamma_w = 9.8$ kN/m^3

Type of water pressure　　trapezoidal water pressure

Lateral pressure　　calculated in consideration of site conditions

Study case　　- Normal Condition
- Seismic Condition

Design earthquake intensity　　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	3.3 kN/m	(Normal Condition)
		Pt'	=	9.1 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.52 m	(Normal Condition)
		Ht'	=	-0.25 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN･m/m	(Normal Condition)
		Mm'	=	3.7 kN･m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　　not considered

Minimum angle of rupture　　$\zeta_0 = 10$ degrees

Rear side angle of slope　　not considered

Angle of rupture (clayey soil)　　$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression　　$K_c = 0.50$ (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　　$K_h = 6910 \times N'^{0.406}$

Average N-value　　calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	1
4	3.22	1
5	4.22	17
6	5.22	16
7	7.22	18
8	8.22	22
9	9.22	31
10	10.22	22

No	Depth (m)	N-Value
11	11.22	40
12	12.22	34
13	13.22	41
14	20.00	50

Case: Right Bank No. 37_STA_14+300 - 14+350

1-6 Vertical Load

Vertical load on landside　　calculated in consideration of embankment shape on landside

Vertical load on riverside　　not considered

1-7 Soil Modulus

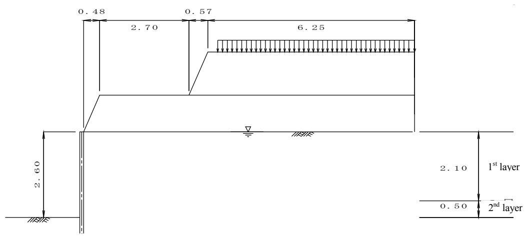
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	ϕ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.22	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	4.22	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
4	5.22	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
5	6.22	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
6	7.22	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
7	8.22	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
8	9.22	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
9	10.22	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
10	11.22	S	40.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
11	12.22	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
12	13.22	S	41.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
13	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.48	10.00	10.00	1.11	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.18	3.75	10.00	10.00	1.30	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	4.05	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 114400 cm⁴
Sectional factor Z_0 = 3250 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.84
Corrosion rate (to Z_0) η = 0.87
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 N/mm (Normal)
σ_a' = 278 N/mm (Seismic)

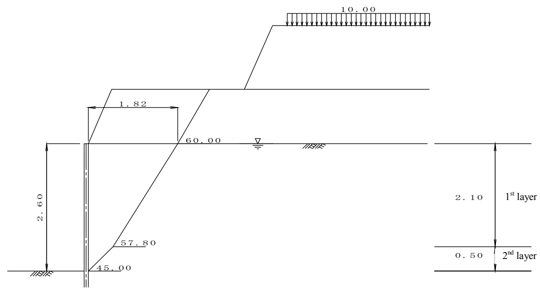
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	20.86	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	20.86	20.58	57.80
3		Embankment	30.0	——	0.0	43.38	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	1.11	1.82	2.60	2.46	3.71

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.11	38.02
Σ			38.02

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

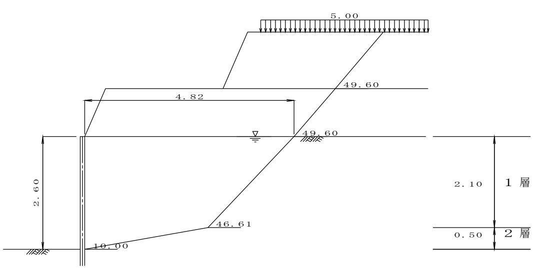
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{38.02 + 0.00 + 0.00}{1.82}$$

$$= 20.86 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	37.72	25.48	0.200	11.31	10.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	37.72	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	43.38	5.00	0.00	0.200	11.31	49.60
4		Embankment	30.0	——	0.0	23.40	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	10.00	0.50	0.00	0.00	2.84	0.50
2	46.61	2.10	2.84	0.50	4.82	2.60
3	49.60	1.11	4.82	2.60	5.77	3.71
4	49.60	1.30	5.77	3.71	6.87	5.01

Therefore, width of acting load shall be set as 4.82 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.61	100.96
2	18.0	3.71	66.78
Σ			167.74

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.82	14.11
Σ			14.11

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

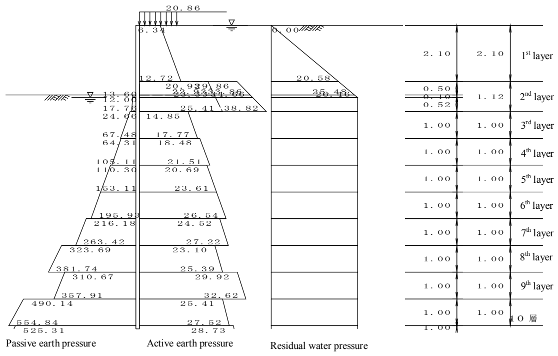
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{167.74 + 14.11 + 0.00}{4.82}$$

$$= 37.72 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	20.862 41.862	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Clayey soil	8.0	—	6.0 6.0	41.862 45.862	—— ——	—— ——
3	2.60～ 2.70	Clayey soil	8.0	—	6.0 6.0	45.862 46.662	—— ——	—— ——
4	2.70～ 3.22	Clayey soil	8.0	—	6.0 6.0	46.662 50.822	—— ——	—— ——
5	3.22～ 4.22	Sandy soil	10.0	31.0	—— ——	50.822 60.822	0.29669 0.29669	0.29219 0.29219
6	4.22～ 5.22	Sandy soil	10.0	30.0	—— ——	60.822 70.822	0.30847 0.30847	0.30378 0.30378
7	5.22～ 6.22	Sandy soil	10.0	31.0	—— ——	70.822 80.822	0.29669 0.29669	0.29219 0.29219
8	6.22～ 7.22	Sandy soil	10.0	31.0	—— ——	80.822 90.822	0.29669 0.29669	0.29219 0.29219
9	7.22～ 8.22	Sandy soil	10.0	33.0	—— ——	90.822 100.822	0.27412 0.27412	0.26996 0.26996
10	8.22～ 9.22	Sandy soil	10.0	37.0	—— ——	100.822 110.822	0.23264 0.23264	0.22910 0.22910
11	9.22～ 10.22	Sandy soil	10.0	33.0	—— ——	110.822 120.822	0.27412 0.27412	0.26996 0.26996
12	10.22～ 11.22	Sandy soil	10.0	39.0	—— ——	120.822 130.822	0.21359 0.21359	0.21035 0.21035
13	11.22～ 12.22	Sandy soil	10.0	38.0	—— ——	130.822 140.822	0.22298 0.22298	0.21959 0.21959

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	12.22～ 13.22	Sandy soil	10.0	39.0	—— ——	140.822 150.822	0.21359 0.21359	0.21035 0.21035
15	13.22～ 20.00	Sandy soil	10.0	45.0	—— ——	150.822 218.622	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Clayey soil	16.0	0.0	6.0 6.0	0.000 1.600	—— ——	—— ——
4	2.70～ 3.22	Clayey soil	8.0	0.0	6.0 6.0	1.600 5.760	—— ——	—— ——
5	3.22～ 4.22	Sandy soil	10.0	31.0	—— ——	5.760 15.760	4.34774 4.34774	4.28169 4.28169
6	4.22～ 5.22	Sandy soil	10.0	30.0	—— ——	15.760 25.760	4.14330 4.14330	4.08035 4.08035
7	5.22～ 6.22	Sandy soil	10.0	31.0	—— ——	25.760 35.760	4.34774 4.34774	4.28169 4.28169
8	6.22～ 7.22	Sandy soil	10.0	31.0	—— ——	35.760 45.760	4.34774 4.34774	4.28169 4.28169
9	7.22～ 8.22	Sandy soil	10.0	33.0	—— ——	45.760 55.760	4.79713 4.79713	4.72425 4.72425
10	8.22～ 9.22	Sandy soil	10.0	37.0	—— ——	55.760 65.760	5.89457 5.89457	5.80501 5.80501
11	9.22～ 10.22	Sandy soil	10.0	33.0	—— ——	65.760 75.760	4.79713 4.79713	4.72425 4.72425
12	10.22～ 11.22	Sandy soil	10.0	39.0	—— ——	75.760 85.760	6.56948 6.56948	6.46967 6.46967
13	11.22～ 12.22	Sandy soil	10.0	38.0	—— ——	85.760 95.760	6.21981 6.21981	6.12532 6.12532
14	12.22～ 13.22	Sandy soil	10.0	39.0	—— ——	95.760 105.760	6.56948 6.56948	6.46967 6.46967
15	13.22～ 20.00	Sandy soil	10.0	45.0	—— ——	105.760 173.560	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

2.280

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	6.34 12.72	—— ——	6.34 12.72	0.00 20.58	—— ——
2	2.10～ 2.60	29.86 33.86	20.93 22.93	29.86 33.86	20.58 25.48	—— ——
3	2.60～ 2.70	33.86 34.66	22.93 23.33	33.86 34.66	25.48 26.46	12.00 13.60
4	2.70～ 3.22	34.66 38.82	23.33 25.41	34.66 38.82	26.46 26.46	13.60 17.76
5	3.22～ 4.22	14.85 17.77	—— ——	14.85 17.77	26.46 26.46	24.66 67.48
6	4.22～ 5.22	18.48 21.51	—— ——	18.48 21.51	26.46 26.46	64.31 105.11
7	5.22～ 6.22	20.69 23.61	—— ——	20.69 23.61	26.46 26.46	110.30 153.11
8	6.22～ 7.22	23.61 26.54	—— ——	23.61 26.54	26.46 26.46	153.11 195.93
9	7.22～ 8.22	24.52 27.22	—— ——	24.52 27.22	26.46 26.46	216.18 263.42
10	8.22～ 9.22	23.10 25.39	—— ——	23.10 25.39	26.46 26.46	323.69 381.74
11	9.22～ 10.22	29.92 32.62	—— ——	29.92 32.62	26.46 26.46	310.67 357.91
12	10.22～ 11.22	25.41 27.52	—— ——	25.41 27.52	26.46 26.46	490.14 554.84
13	11.22～ 12.22	28.73 30.92	—— ——	28.73 30.92	26.46 26.46	525.31 586.56
14	12.22～ 13.22	29.62 31.73	—— ——	29.62 31.73	26.46 26.46	619.54 684.23
15	13.22～ 20.00	24.15 35.01	—— ——	24.15 35.01	26.46 26.46	973.36 1597.36

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

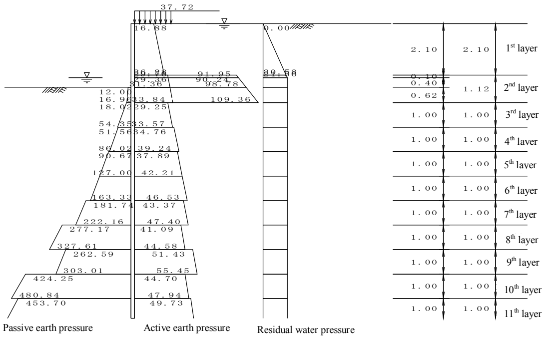
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	37.72 58.72	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10～ 2.20	Clayey Soil	8.0	—	6.0 6.0	58.72 59.52	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
3	2.20～ 2.60	Clayey Soil	8.0	—	6.0 6.0	59.52 62.72	21.56 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
4	2.60～ 3.22	Clayey Soil	8.0	—	6.0 6.0	62.72 67.68	25.48 31.56	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
5	3.22～ 4.22	Sandy Soil	10.0	31.0	—— ——	67.68 77.68	31.56 41.36	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
6	4.22～ 5.22	Sandy Soil	10.0	30.0	—— ——	77.68 87.68	41.36 51.16	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
7	5.22～ 6.22	Sandy Soil	10.0	31.0	—— ——	87.68 97.68	51.16 60.96	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
8	6.22～ 7.22	Sandy Soil	10.0	31.0	—— ——	97.68 107.68	60.96 70.76	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
9	7.22～ 8.22	Sandy Soil	10.0	33.0	—— ——	107.68 117.68	70.76 80.56	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
10	8.22～ 9.22	Sandy Soil	10.0	37.0	—— ——	117.68 127.68	80.56 90.36	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
11	9.22～ 10.22	Sandy Soil	10.0	33.0	—— ——	127.68 137.68	90.36 100.16	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
12	10.22～ 11.22	Sandy Soil	10.0	39.0	—— ——	137.68 147.68	100.16 109.96	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
13	11.22～ 12.22	Sandy Soil	10.0	38.0	—— ——	147.68 157.68	109.96 119.76	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
14	12.22～ 13.22	Sandy Soil	10.0	39.0	—— ——	157.68 167.68	119.76 129.56	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
15	13.22～ 20.00	Sandy Soil	10.0	45.0	—— ——	167.68 235.48	129.56 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 3.22	Clayey soil	8.00	0.0	6.0 6.0	0.000 4.960	0.00 6.08	0.200 0.200	11.31 11.31	—— ——	—— ——
5	3.22～ 4.22	Sandy soil	10.00	31.0	—— ——	4.960 14.960	6.08 15.88	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
6	4.22～ 5.22	Sandy soil	10.00	30.0	—— ——	14.960 24.960	15.88 25.68	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
7	5.22～ 6.22	Sandy soil	10.00	31.0	—— ——	24.960 34.960	25.68 35.48	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
8	6.22～ 7.22	Sandy soil	10.00	31.0	—— ——	34.960 44.960	35.48 45.28	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
9	7.22～ 8.22	Sandy soil	10.00	33.0	—— ——	44.960 54.960	45.28 55.08	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
10	8.22～ 9.22	Sandy soil	10.00	37.0	—— ——	54.960 64.960	55.08 64.88	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
11	9.22～ 10.22	Sandy soil	10.00	33.0	—— ——	64.960 74.960	64.88 74.68	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
12	10.22～ 11.22	Sandy soil	10.00	39.0	—— ——	74.960 84.960	74.68 84.48	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
13	11.22～ 12.22	Sandy soil	10.00	38.0	—— ——	84.960 94.960	84.48 94.28	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
14	12.22～ 13.22	Sandy soil	10.00	39.0	—— ——	94.960 104.960	94.28 104.08	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
15	13.22～ 20.00	Sandy soil	10.00	45.0	—— ——	104.960 172.760	104.08 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	16.88 26.28	—— ——	16.88 26.28	0.00 20.58	—— ——
2	2.10～ 2.20	90.24 91.95	29.36 29.76	90.24 91.95	20.58 21.56	—— ——
3	2.20～ 2.60	91.95 98.78	29.76 31.36	91.95 98.78	21.56 21.56	—— ——
4	2.60～ 3.22	98.78 109.36	31.36 33.84	98.78 109.36	21.56 21.56	12.00 16.96
5	3.22～ 4.22	29.25 33.57	—— ——	29.25 33.57	21.56 21.56	18.02 54.35
6	4.22～ 5.22	34.76 39.24	—— ——	34.76 39.24	21.56 21.56	51.56 86.02
7	5.22～ 6.22	37.89 42.21	—— ——	37.89 42.21	21.56 21.56	90.67 127.00
8	6.22～ 7.22	42.21 46.53	—— ——	42.21 46.53	21.56 21.56	127.00 163.33
9	7.22～ 8.22	43.37 47.40	—— ——	43.37 47.40	21.56 21.56	181.74 222.16
10	8.22～ 9.22	41.09 44.58	—— ——	41.09 44.58	21.56 21.56	277.17 327.61
11	9.22～ 10.22	51.43 55.45	—— ——	51.43 55.45	21.56 21.56	262.59 303.01
12	10.22～ 11.22	44.70 47.94	—— ——	44.70 47.94	21.56 21.56	424.25 480.84
13	11.22～ 12.22	49.73 53.10	—— ——	49.73 53.10	21.56 21.56	453.70 507.10
14	12.22～ 13.22	51.19 54.44	—— ——	51.19 54.44	21.56 21.56	537.44 594.04
15	13.22～ 20.00	43.38 60.93	—— ——	43.38 60.93	21.56 21.56	861.03 1417.23

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

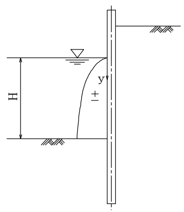
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

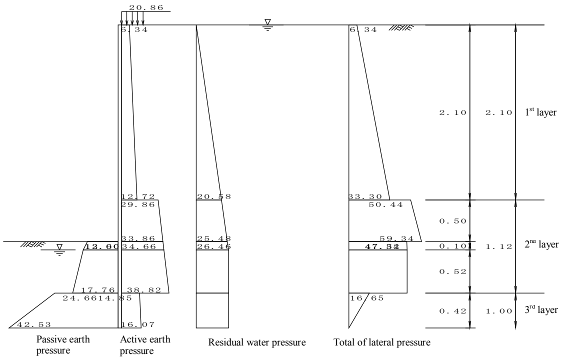
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

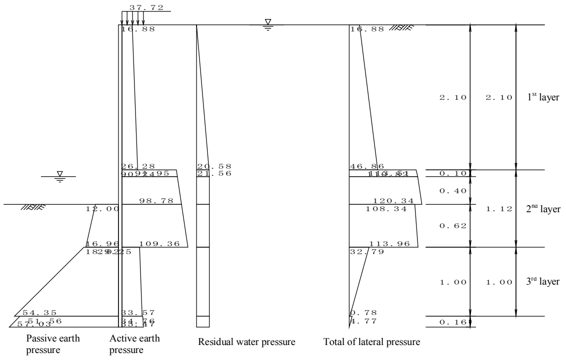


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	6.34 12.72	0.00 20.58	——	6.34 33.30
2	2.10～ 2.60	29.86 33.86	20.58 25.48	——	50.44 59.34
3	2.60～ 2.70	33.86 34.66	25.48 26.46	12.00 13.60	47.34 47.52
4	2.70～ 3.22	34.66 38.82	26.46 26.46	13.60 17.76	47.52 47.52
5	3.22～ 3.64	14.85 16.07	26.46 26.46	24.66 42.53	16.65 0.00
6	3.64～ 4.22	16.07 17.77	26.46 26.46	42.53 67.48	0.00 -23.25

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.04 m (GL -3.64 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	16.88 26.28	0.00 20.58	——	16.88 46.86
2	2.10～ 2.20	90.24 91.95	20.58 21.56	——	110.82 113.51
3	2.20～ 2.60	91.95 98.78	21.56 21.56	——	113.51 120.34
4	2.60～ 3.22	98.78 109.36	21.56 21.56	12.00 16.96	108.34 113.96
5	3.22～ 4.22	29.25 33.57	21.56 21.56	18.02 54.35	32.79 0.78
6	4.22～ 4.38	34.76 35.47	21.56 21.56	51.56 57.03	4.77 0.00
7	4.38～ 5.22	35.47 39.24	21.56 21.56	57.03 86.02	0.00 -25.22

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.78 m (GL -4.38 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴(original condition)
	I	=	95760 cm⁴(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 95760 \times 10^{-8} = 1.915 \times 10^5$

	Depth (m)	N-value		Depth (m)	N-value
1	0.50	15	11	11.22	40
2	1.60	15	12	12.22	34
3	2.10	1	13	13.22	41
4	3.22	1	14	20.00	50
5	4.22	17			
6	5.22	16			
7	7.22	18			
8	8.22	22			
9	9.22	31			
10	10.22	22			

5-2 Normal Condition

K_h = 21021 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.407 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.46 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.64 m) to 2.46 m depth (GL -6.09 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.64	0.58	7.7	17.0	7.19
2	4.22	1.00	17.0	16.0	16.50
3	5.22	0.87	16.0	16.9	14.37
	L =Σh = 2.46				ΣA = 38.06

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{38.06}{2.46}$$

$$= 15.49$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 15.49^{0.406} = 21021$ kN/m³

Kh (normal condition) = 21021 kN/m³

5-3 Seismic Condition

K_h = 21655 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.410 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.44 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.38 m) and 2.44 m depth (GL -6.82 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.38	0.84	16.8	16.0	13.81
2	5.22	1.60	16.0	17.6	26.84
	L =Σh = 2.44				ΣA = 40.65

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{40.65}{2.44}$$

$$= 16.67$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 16.67^{0.406} = 21655$ kN/m³

Kh (seismic condition) = 21655 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN･m)
1	0.00～ 2.10	2.10	6.34 33.30	6.65 34.96	2.94 2.24	19.55 78.22
2	2.10～ 2.60	0.50	50.44 59.34	12.61 14.84	1.37 1.20	17.28 17.86
3	2.60～ 2.70	0.10	47.34 47.52	2.37 2.38	1.00 0.97	2.38 2.31
4	2.70～ 3.22	0.52	47.52 47.52	12.36 12.36	0.76 0.59	9.44 7.30
5	3.22～ 3.64	0.42	16.65 0.00	3.47 0.00	0.28 0.14	0.97 0.00
				ΣP = 101.99		ΣM = 155.29

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.3 kN/m
depth to acting position	H_t	=	-0.52 m
moment	M_m	=	0.0 kN･m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.04 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 13.72$ kN･m

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{169.01}{105.29} = 1.61 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN･m)
1	0.00～ 2.10	2.10	16.88 46.86	17.72 49.20	3.68 2.98	65.21 146.57
2	2.10～ 2.20	0.10	110.82 113.51	5.54 5.68	2.25 2.21	12.44 12.56
3	2.20～ 2.60	0.40	113.51 120.34	22.70 24.07	2.05 1.91	46.44 46.02
4	2.60～ 3.22	0.62	108.34 113.96	33.58 35.33	1.57 1.37	52.80 48.24
5	3.22～ 4.22	1.00	32.79 0.78	16.39 0.39	0.83 0.49	13.53 0.19
6	4.22～ 4.38	0.16	4.77 0.00	0.38 0.00	0.11 0.05	0.04 0.00
				ΣP = 201.99		ΣM = 444.04

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	9.1 kN/m
depth to acting position	H_t	=	-0.25 m
moment	M_m	=	3.7 kN･m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.78 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 45.82$ kN･m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN･m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	2.05 1.91	0.00 0.26
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.26

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{490.13}{220.22} = 2.23 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 95760 \times 10^{-8}$		=	1.915×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	21021 kN/m³
calculated value	β	=	0.40700 m⁻¹
resultant earth force (lateral)	P_0	=	105.29 kN/m
height of acting position of load	h_0	=	1.61 m
moment	M_0	=	169.01 kN･m/m

in consideration of ψ_m = 1.278,

maximum moment	M_{max}	=	216.01 kN･m/m
depth of generated position of M_{max}	l_m	=	1.005 m
depth of 1st fixed point	l_i	=	2.935 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	21655 kN/m³
calculated value	β	=	0.41004 m⁻¹
resultant earth force (lateral)	P_0	=	220.22 kN/m
height of acting position of load	h_0	=	2.23 m
moment	M_0	=	490.13 kN･m/m

in consideration of ψ_m = 1.169,

maximum moment	M_{max}	=	572.71 kN･m/m
depth of generated position of M_{max}	l_m	=	0.830 m
depth of 1st fixed point	l_i	=	2.745 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm³ (original condition)
	Z	=	2828 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{216.01 \times 10^6}{2828 \times 10^3} = 76 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{572.71 \times 10^6}{2828 \times 10^3} = 203 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	2.94 2.24	0.808 0.615	0.238 0.150	6.65 34.96	1.586 5.258
2	2.10～ 2.60	1.37 1.20	0.377 0.331	0.062 0.049	12.61 14.84	0.783 0.723
3	2.60～ 2.70	1.00 0.97	0.276 0.267	0.035 0.032	2.37 2.38	0.082 0.077
4	2.70～ 3.22	0.76 0.59	0.210 0.162	0.021 0.012	12.36 12.36	0.253 0.154
5	3.22～ 3.64	0.28 0.14	0.076 0.038	0.003 0.001	3.47 0.00	0.010 0.000
						ΣQ = 8.926

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

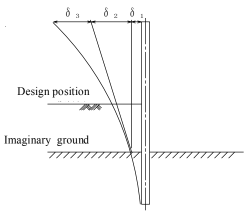
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4070 \times 1.61) \times 105.29}{2 \times 2.00 \times 10^8 \times 95760 \times 10^{-8} \times 0.4070^3} = 0.00674 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.4070 \times 1.61) \times 105.29}{2 \times 2.00 \times 10^8 \times 95760 \times 10^{-8} \times 0.4070^2} \times (2.60+1.04) = 0.01392 \text{ m}$$

$$\delta_3 = \frac{Q \times (H+L_k)^3}{EI}$$

$$= \frac{8.93 \times (2.60+1.04)^3}{2.00 \times 10^8 \times 95760 \times 10^{-8}} = 0.00224 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00034 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.64 m
Horizontal load: P = 3.30
Moment: M = 1.72

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.00674 + 0.01392 + 0.00258$
$= 0.02324$ m
$= 23.24 \leqq \delta a = 50.00$ mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.68 2.98	0.840 0.680	0.254 0.179	17.72 49.20	4.504 8.803
2	2.10～ 2.20	2.25 2.21	0.513 0.505	0.109 0.106	5.54 5.68	0.604 0.602
3	2.20～ 2.60	2.05 1.91	0.467 0.437	0.092 0.081	22.70 24.07	2.091 1.961
4	2.60～ 3.22	1.57 1.37	0.359 0.312	0.057 0.044	33.58 35.33	1.906 1.539
5	3.22～ 4.22	0.83 0.49	0.189 0.112	0.017 0.006	16.39 0.39	0.273 0.002
6	4.22～ 4.38	0.11 0.05	0.024 0.012	0.000 0.000	0.38 0.00	0.000 0.000
						ΣQ = 22.286

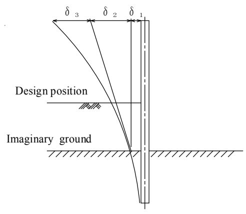
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha) \times \alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.05 1.91	0.467 0.437	0.092 0.081	0.00 0.14	0.000 0.011
						ΣQ_{dw} = 0.011

Therefore, modulus of deformation Q is calculated as below:
Q = 22.286＋0.011 = 22.297

Displacement



$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4100 \times 2.23) \times 220.22}{2 \times 2.00 \times 10^8 \times 95760 \times 10^{-8} \times 0.4100^3} = 0.01595 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.4100 \times 2.23) \times 220.22}{2 \times 2.00 \times 10^8 \times 95760 \times 10^{-8} \times 0.4100^2} \times (2.60+1.78) = 0.04230 \text{ m}$$

$$\delta_3 = \frac{Q \times (H+L_k)^3}{EI}$$

$$= \frac{22.30 \times (2.60+1.78)^3}{2.00 \times 10^8 \times 95760 \times 10^{-8}} = 0.00978 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00144 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.38 m
Horizontal load: P = 9.10
Moment: M = 2.28

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m \cdot h}{2EI} \times (2L - h) \qquad (L=4.38 \text{ m、} h=L-H_m\text{、} H_m=0.80 \text{ m、ただし} \qquad)$$

$$= \frac{3.70 \times 3.58}{2 \times 2.00 \times 10^8 \times 95760 \times 10^{-8}} \times (2 \times 4.38 - 3.58) = 0.00018 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01595 + 0.04230 + 0.01140$
$= 0.06965$ m
$= 69.65 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	114000 cm^4 (original condition)
	I	=	114000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 114000 × 10^{-8}		=	2.280 × 10^5

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 21021 kN/m^3
Calculated value β = 0.38964 m^{-1}

Penetration length of SSP $D = 1.04 + \frac{3}{0.390} = 8.74$ m
Whole length of SSP $L = 2.60 - 0.40 + 8.74 = 10.94$ m

7-1-2 Seismic Conditic

Modules of lateral subgrade reaction K_h = 21655 kN/m^3
Calculated value β = 0.39255 m^{-1}

Penetration length of SSP $D = 1.78 + \frac{3}{0.393} = 9.42$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.42 = 11.62$ m

Therefore, whole length of SSP is set as 12.00 m in consideration of round unit of SSP length.

8 Calculation Result

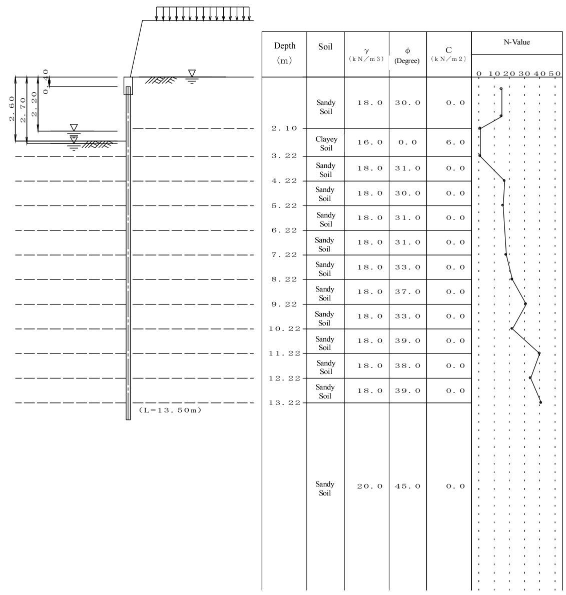
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	114000		
Section modulus	Z (cm^3)	3250		
Maximum bending moment	M_{max} (kN・m/m)		216.01	572.71
Stress intensity	σ (N/mm^2)		76 (185)	203 (278)
Lateral displacement	δ (mm)		23.24 (50.0)	69.65 (75.0)
Penetration depth	D (m)		8.74	9.42
Whole length of SSP	L (m)	12.00		

−Steel Sheet Pile Design Calculation−

Right Bank No. 38_STA 14+350 - 14+395

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	6.5 kN/m	(Normal Condition)
		Pt'	=	11.2 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.45 m	(Normal Condition)
		Ht'	=	-0.30 m	(Seismic Condition)
	Moment	Mm	=	3.0 kN·m/m	(Normal Condition)
		Mm'	=	12.3 kN·m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	11.22	40
2	1.60	15	12	12.22	34
3	2.10	1	13	13.22	41
4	3.22	1	14	20.00	50
5	4.22	17			
6	5.22	16			
7	7.22	18			
8	8.22	22			
9	9.22	31			
10	10.22	22			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

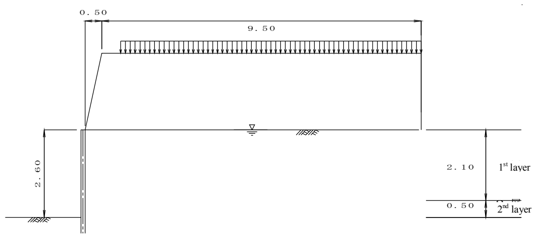
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.22	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	4.22	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
4	5.22	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
5	6.22	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
6	7.22	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
7	8.22	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
8	9.22	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
9	10.22	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
10	11.22	S	40.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
11	12.22	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
12	13.22	S	41.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
13	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.50	10.00	10.00	2.29	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.06	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus $E = 200000$ N/mm²
Inertia sectional moment $I_0 = 212000$ cm⁴
Sectional factor $Z_0 = 5560$ cm³

Corrosion margin $t_1 = 1.00$ mm (riverside) $t_2 = 1.00$ mm (landside)

Corrosion rate (to I_0) $\eta = 0.86$
Corrosion rate (to Z_0) $\eta = 0.89$
Section efficiency (to I_0) $\mu = 1.00$
Section efficiency (to Z_0) $\mu = 1.00$

Round unit of SSP length 0.50 m

Allowable stress $\sigma_a = 185$ N/mm (Normal)
$\sigma_a' = 278$ N/mm (Seismic)

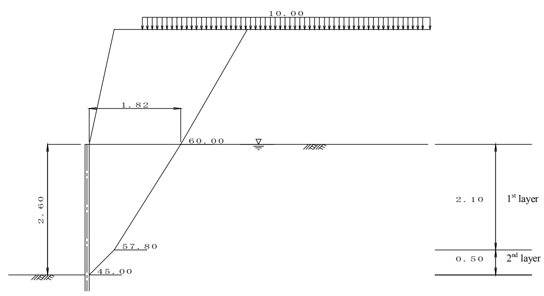
Allowable displacement $\delta_a = 50.0$ mm (Normal)
$\delta_a' = 75.0$ mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	61.96	25.48	45.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	61.96	20.58	57.80
3		Embankment	30.0	——	0.0	41.22	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.50	0.00	0.00	0.50	0.50
2	57.80	2.10	0.50	0.50	1.82	2.60
3	60.00	2.29	1.82	2.60	3.14	4.89

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.11	92.06
Σ			92.06

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	2.08	20.85
Σ			20.85

Q: surcharge load
l : width of surcharge load set by line of active rupture

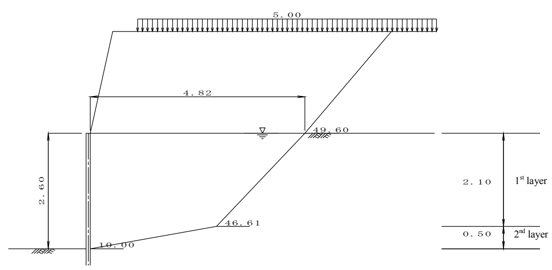
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{92.06 + 20.85 + 0.00}{1.82}$$

$$= 61.96 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Clayey Soil	0.0	10.0	6.0	25.00	53.33	25.48	0.200	11.31	10.00
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	53.33	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	41.22	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	10.00	0.50	0.00	0.00	2.84	0.50
2	46.61	2.10	2.84	0.50	4.82	2.60
3	49.60	2.29	4.82	2.60	6.77	4.89

Therefore, width of acting load shall be set as 4.82 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	12.70	228.58
Σ			228.58

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	5.71	28.55
Σ			28.55

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

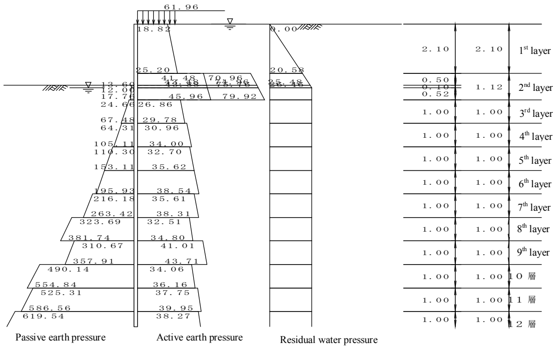
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{228.58 + 28.55 + 0.00}{4.82}$$

$$= 53.33 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	―― ――	61.956 82.956	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Clayey soil	8.0	―	6.0 6.0	82.956 86.956	―― ――	―― ――
3	2.60～ 2.70	Clayey soil	8.0	―	6.0 6.0	86.956 87.756	―― ――	―― ――
4	2.70～ 3.22	Clayey soil	8.0	―	6.0 6.0	87.756 91.916	―― ――	―― ――
5	3.22～ 4.22	Sandy soil	10.0	31.0	―― ――	91.916 101.916	0.29669 0.29669	0.29219 0.29219
6	4.22～ 5.22	Sandy soil	10.0	30.0	―― ――	101.916 111.916	0.30847 0.30847	0.30378 0.30378
7	5.22～ 6.22	Sandy soil	10.0	31.0	―― ――	111.916 121.916	0.29669 0.29669	0.29219 0.29219
8	6.22～ 7.22	Sandy soil	10.0	31.0	―― ――	121.916 131.916	0.29669 0.29669	0.29219 0.29219
9	7.22～ 8.22	Sandy soil	10.0	33.0	―― ――	131.916 141.916	0.27412 0.27412	0.26996 0.26996
10	8.22～ 9.22	Sandy soil	10.0	37.0	―― ――	141.916 151.916	0.23264 0.23264	0.22910 0.22910
11	9.22～ 10.22	Sandy soil	10.0	33.0	―― ――	151.916 161.916	0.27412 0.27412	0.26996 0.26996
12	10.22～ 11.22	Sandy soil	10.0	39.0	―― ――	161.916 171.916	0.21359 0.21359	0.21035 0.21035
13	11.22～ 12.22	Sandy soil	10.0	38.0	―― ――	171.916 181.916	0.22298 0.22298	0.21959 0.21959

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	12.22～ 13.22	Sandy soil	10.0	39.0	―― ――	181.916 191.916	0.21359 0.21359	0.21035 0.21035
15	13.22～ 20.00	Sandy soil	10.0	45.0	―― ――	191.916 259.716	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Clayey soil	16.0	0.0	6.0 6.0	0.000 1.600	―― ――	―― ――
4	2.70～ 3.22	Clayey soil	8.0	0.0	6.0 6.0	1.600 5.760	―― ――	―― ――
5	3.22～ 4.22	Sandy soil	10.0	31.0	―― ――	5.760 15.760	4.34774 4.34774	4.28169 4.28169
6	4.22～ 5.22	Sandy soil	10.0	30.0	―― ――	15.760 25.760	4.14330 4.14330	4.08035 4.08035
7	5.22～ 6.22	Sandy soil	10.0	31.0	―― ――	25.760 35.760	4.34774 4.34774	4.28169 4.28169
8	6.22～ 7.22	Sandy soil	10.0	31.0	―― ――	35.760 45.760	4.34774 4.34774	4.28169 4.28169
9	7.22～ 8.22	Sandy soil	10.0	33.0	―― ――	45.760 55.760	4.79713 4.79713	4.72425 4.72425
10	8.22～ 9.22	Sandy soil	10.0	37.0	―― ――	55.760 65.760	5.89457 5.89457	5.80501 5.80501
11	9.22～ 10.22	Sandy soil	10.0	33.0	―― ――	65.760 75.760	4.79713 4.79713	4.72425 4.72425
12	10.22～ 11.22	Sandy soil	10.0	39.0	―― ――	75.760 85.760	6.56948 6.56948	6.46967 6.46967
13	11.22～ 12.22	Sandy soil	10.0	38.0	―― ――	85.760 95.760	6.21981 6.21981	6.12532 6.12532
14	12.22～ 13.22	Sandy soil	10.0	39.0	―― ――	95.760 105.760	6.56948 6.56948	6.46967 6.46967
15	13.22～ 20.00	Sandy soil	10.0	45.0	―― ――	105.760 173.560	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = -10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos\theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}}\right]^2}$$

2.288

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	18.82 25.20	―― ――	18.82 25.20	0.00 20.58	―― ――
2	2.10～ 2.60	70.96 74.96	41.48 43.48	70.96 74.96	20.58 25.48	―― ――
3	2.60～ 2.70	74.96 75.76	43.48 43.88	74.96 75.76	25.48 26.46	12.00 13.60
4	2.70～ 3.22	75.76 79.92	43.88 45.96	75.76 79.92	26.46 26.46	13.60 17.76
5	3.22～ 4.22	26.86 29.78	―― ――	26.86 29.78	26.46 26.46	24.66 67.48
6	4.22～ 5.22	30.96 34.00	―― ――	30.96 34.00	26.46 26.46	64.31 105.11
7	5.22～ 6.22	32.70 35.62	―― ――	32.70 35.62	26.46 26.46	110.30 153.11
8	6.22～ 7.22	35.62 38.54	―― ――	35.62 38.54	26.46 26.46	153.11 195.93
9	7.22～ 8.22	35.61 38.31	―― ――	35.61 38.31	26.46 26.46	216.18 263.42
10	8.22～ 9.22	32.51 34.80	―― ――	32.51 34.80	26.46 26.46	323.69 381.74
11	9.22～ 10.22	41.01 43.71	―― ――	41.01 43.71	26.46 26.46	310.67 357.91
12	10.22～ 11.22	34.06 36.16	―― ――	34.06 36.16	26.46 26.46	490.14 554.84
13	11.22～ 12.22	37.75 39.95	―― ――	37.75 39.95	26.46 26.46	525.31 586.56
14	12.22～ 13.22	38.27 40.37	―― ――	38.27 40.37	26.46 26.46	619.54 684.23
15	13.22～ 20.00	30.74 41.59	―― ――	30.74 41.59	26.46 26.46	973.36 1597.36

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

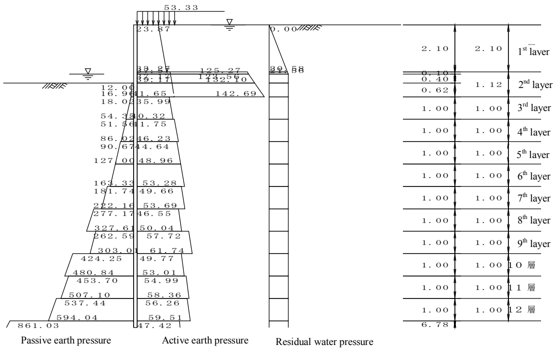
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	53.34 74.34	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10～ 2.20	Clayey Soil	8.0	—	6.0 6.0	74.34 75.14	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
3	2.20～ 2.60	Clayey Soil	8.0	—	6.0 6.0	75.14 78.34	21.56 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
4	2.60～ 3.22	Clayey Soil	8.0	—	6.0 6.0	78.34 83.30	25.48 31.56	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
5	3.22～ 4.22	Sandy Soil	10.0	31.0	—— ——	83.30 93.30	31.56 41.36	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
6	4.22～ 5.22	Sandy Soil	10.0	30.0	—— ——	93.30 103.30	41.36 51.16	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
7	5.22～ 6.22	Sandy Soil	10.0	31.0	—— ——	103.30 113.30	51.16 60.96	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
8	6.22～ 7.22	Sandy Soil	10.0	31.0	—— ——	113.30 123.30	60.96 70.76	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
9	7.22～ 8.22	Sandy Soil	10.0	33.0	—— ——	123.30 133.30	70.76 80.56	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
10	8.22～ 9.22	Sandy Soil	10.0	37.0	—— ——	133.30 143.30	80.56 90.36	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
11	9.22～ 10.22	Sandy Soil	10.0	33.0	—— ——	143.30 153.30	90.36 100.16	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
12	10.22～ 11.22	Sandy Soil	10.0	39.0	—— ——	153.30 163.30	100.16 109.96	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
13	11.22～ 12.22	Sandy Soil	10.0	38.0	—— ——	163.30 173.30	109.96 119.76	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
14	12.22～ 13.22	Sandy Soil	10.0	39.0	—— ——	173.30 183.30	119.76 129.56	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	13.22～ 20.00	Sandy Soil	10.0	45.0	—— ——	183.30 251.10	129.56 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 3.22	Clayey soil	8.00	0.0	6.0 6.0	0.000 4.960	0.00 6.08	0.200 0.200	11.31 11.31	—— ——	—— ——
5	3.22～ 4.22	Sandy soil	10.00	31.0	—— ——	4.960 14.960	6.08 15.88	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
6	4.22～ 5.22	Sandy soil	10.00	30.0	—— ——	14.960 24.960	15.88 25.68	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
7	5.22～ 6.22	Sandy soil	10.00	31.0	—— ——	24.960 34.960	25.68 35.48	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
8	6.22～ 7.22	Sandy soil	10.00	31.0	—— ——	34.960 44.960	35.48 45.28	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
9	7.22～ 8.22	Sandy soil	10.00	33.0	—— ——	44.960 54.960	45.28 55.08	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
10	8.22～ 9.22	Sandy soil	10.00	37.0	—— ——	54.960 64.960	55.08 64.88	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
11	9.22～ 10.22	Sandy soil	10.00	33.0	—— ——	64.960 74.960	64.88 74.68	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
12	10.22～ 11.22	Sandy soil	10.00	39.0	—— ——	74.960 84.960	74.68 84.48	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
13	11.22～ 12.22	Sandy soil	10.00	38.0	—— ——	84.960 94.960	84.48 94.28	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
14	12.22～ 13.22	Sandy soil	10.00	39.0	—— ——	94.960 104.960	94.28 104.08	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
15	13.22～ 20.00	Sandy soil	10.00	45.0	—— ——	104.960 172.760	104.08 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	23.87 33.27	—— ——	23.87 33.27	0.00 20.58	—— ——
2	2.10～ 2.20	123.56 125.27	37.17 37.57	123.56 125.27	20.58 21.56	—— ——
3	2.20～ 2.60	125.27 132.10	37.57 39.17	125.27 132.10	21.56 21.56	—— ——
4	2.60～ 3.22	132.10 142.69	39.17 41.65	132.10 142.69	21.56 21.56	12.00 16.96
5	3.22～ 4.22	35.99 40.32	—— ——	35.99 40.32	21.56 21.56	18.02 54.35
6	4.22～ 5.22	41.75 46.23	—— ——	41.75 46.23	21.56 21.56	51.56 86.02
7	5.22～ 6.22	44.64 48.96	—— ——	44.64 48.96	21.56 21.56	90.67 127.00
8	6.22～ 7.22	48.96 53.28	—— ——	48.96 53.28	21.56 21.56	127.00 163.33
9	7.22～ 8.22	49.66 53.69	—— ——	49.66 53.69	21.56 21.56	181.74 222.16
10	8.22～ 9.22	46.55 50.04	—— ——	46.55 50.04	21.56 21.56	277.17 327.61
11	9.22～ 10.22	57.72 61.74	—— ——	57.72 61.74	21.56 21.56	262.59 303.01
12	10.22～ 11.22	49.77 53.01	—— ——	49.77 53.01	21.56 21.56	424.25 480.84
13	11.22～ 12.22	54.99 58.36	—— ——	54.99 58.36	21.56 21.56	453.70 507.10
14	12.22～ 13.22	56.26 59.51	—— ——	56.26 59.51	21.56 21.56	537.44 594.04
15	13.22～ 20.00	47.42 64.97	—— ——	47.42 64.97	21.56 21.56	861.03 1417.23

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1}=\Sigma\gamma h+Q-2C$
$P_{a2}=K_c\cdot(\Sigma\gamma h+Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma\gamma h+Q)-2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p=\Sigma\gamma h+Q+2C$

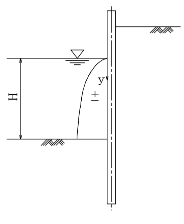
Mixed soil $P_p=[K_p(\Sigma\gamma h+Q)+2C\sqrt{K_p}]\cdot\cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

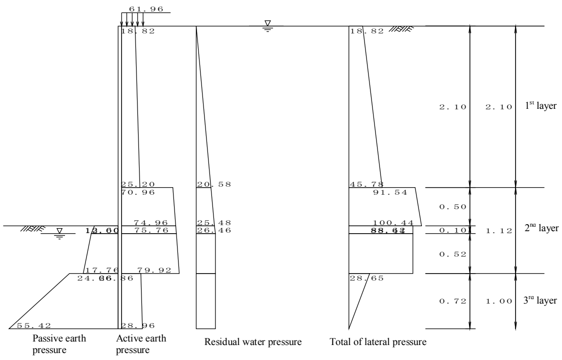
Where,
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

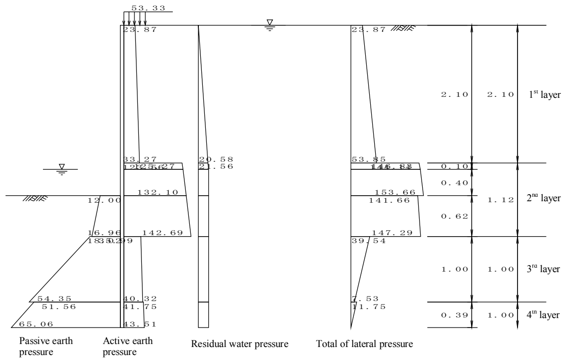


	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	18.82 25.20	0.00 20.58	—— ——	18.82 45.78
2	2.10～ 2.60	70.96 74.96	20.58 25.48	—— ——	91.54 100.44
3	2.60～ 2.70	74.96 75.76	25.48 26.46	12.00 13.60	88.44 88.62
4	2.70～ 3.22	75.76 79.92	26.46 26.46	13.60 17.76	88.62 88.62
5	3.22～ 3.94	26.86 28.96	26.46 26.46	24.66 55.42	28.65 0.00
6	3.94～ 4.22	28.96 29.78	26.46 26.46	55.42 67.48	0.00 -11.24

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.34 m (GL -3.94 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	23.87 33.27	0.00 20.58	—— ——	23.87 53.85
2	2.10～ 2.20	123.56 125.27	20.58 21.56	—— ——	144.14 146.83
3	2.20～ 2.60	125.27 132.10	21.56 21.56	—— ——	146.83 153.66
4	2.60～ 3.22	132.10 142.69	21.56 21.56	12.00 16.96	141.66 147.29
5	3.22～ 4.22	35.99 40.32	21.56 21.56	18.02 54.35	39.54 7.53
6	4.22～ 4.61	41.75 43.51	21.56 21.56	51.56 65.06	11.75 0.00
7	4.61～ 5.22	43.51 46.23	21.56 21.56	65.06 86.02	0.00 -18.24

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.01 m (GL -4.61 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	212000 cm^4(original condition)
	I	=	182320 cm^4(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 182320 \times 10^{-8} = 3.646 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	1
4	3.22	1
5	4.22	17
6	5.22	16
7	7.22	18
8	8.22	22
9	9.22	31
10	10.22	22

	Depth (m)	N-value
11	11.22	40
12	12.22	34
13	13.22	41
14	20.00	50

5-2 Normal Condition

K_h = 21561 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.349 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.87 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.94 m) to 2.87 m depth (GL -6.81 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.94	0.28	12.5	17.0	4.15
2	4.22	1.00	17.0	16.0	16.50
3	5.22	1.59	16.0	17.6	26.64
	L =Σh = 2.87				ΣA = 47.29

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{47.29}{2.87}$$

$$= 16.49$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 16.49^{0.406} = 21561$ kN/m^3

Kh (normal condition) = 21561 kN/m^3

5-3 Seismic Condition

K_h = 21821 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.350 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.86 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.61 m) and 2.86 m depth (GL -7.47 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.61	0.61	16.6	16.0	9.91
2	5.22	2.00	16.0	18.0	34.00
3	7.22	0.25	18.0	19.0	4.65
	L =Σh = 2.86				ΣA = 48.56

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{48.56}{2.86}$$

$$= 16.98$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 16.98^{0.406} = 21821$ kN/m^3

Kh (seismic condition) = 21821 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	18.82 45.78	19.76 48.07	3.24 2.54	63.99 122.01
2	2.10～ 2.60	0.50	91.54 100.44	22.88 25.11	1.67 1.50	38.25 37.79
3	2.60～ 2.70	0.10	88.44 88.62	4.42 4.43	1.30 1.27	5.77 5.63
4	2.70～ 3.22	0.52	88.62 88.62	23.04 23.04	1.06 0.89	24.54 20.54
5	3.22～ 3.94	0.72	28.65 0.00	10.29 0.00	0.48 0.24	4.93 0.00
				ΣP = 181.05		ΣM = 323.45

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	6.5 kN/m
depth to acting position	H_t	=	-0.45 m
moment	M_m	=	3.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.34 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 31.52$ kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{354.98}{187.55} = 1.89 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	23.87 53.85	25.06 56.54	3.91 3.21	98.04 181.60
2	2.10～ 2.20	0.10	144.14 146.83	7.21 7.34	2.48 2.45	17.86 17.95
3	2.20～ 2.60	0.40	146.83 153.66	29.37 30.73	2.28 2.15	66.91 65.93
4	2.60～ 3.22	0.62	141.66 147.29	43.91 45.66	1.81 1.60	79.28 72.99
5	3.22～ 4.22	1.00	39.54 7.53	19.77 3.76	1.06 0.73	20.93 2.73
6	4.22～ 4.61	0.39	11.75 0.00	2.30 0.00	0.26 0.13	0.60 0.00
				ΣP = 271.66		ΣM = 624.82

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	11.2 kN/m
depth to acting position	H_t	=	-0.30 m
moment	M_m	=	12.3 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.01 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 67.31$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	2.28 2.15	0.00 0.29
				ΣPdw = 0.14		ΣMdw = 0.29

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{692.43}{282.99} = 2.45 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.86
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	212000 cm⁴ (original condition)
	I	=	182320 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 182320 × 10⁻⁸		=	3.646 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1}\frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \; (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	21561 kN/m³
calculated value	β	=	0.34869 m⁻¹
resultant earth force (lateral)	P_0	=	187.55 kN/m
height of acting position of load	h_0	=	1.89 m
moment	M_0	=	354.98 kN·m/m

in consideration of ψ_m = 1.274,

maximum moment	M_{max}	=	452.25 kN·m/m
depth of generated position of M_{max}	l_m	=	1.167 m
depth of 1st fixed point	l_i	=	3.420 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	21821 kN/m³
calculated value	β	=	0.34973 m⁻¹
resultant earth force (lateral)	P_0	=	282.99 kN/m
height of acting position of load	h_0	=	2.45 m
moment	M_0	=	692.43 kN·m/m

in consideration of ψ_m = 1.186,

maximum moment	M_{max}	=	821.21 kN·m/m
depth of generated position of M_{max}	l_m	=	1.010 m
depth of 1st fixed point	l_i	=	3.256 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.89
Section efficiency	μ	=	1.00
Module of section	Z_0	=	5560 cm³ (original condition)
	Z	=	4948 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{452.25 \times 10^6}{4948 \times 10^3} = 91 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{821.21 \times 10^6}{4948 \times 10^3} = 166 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

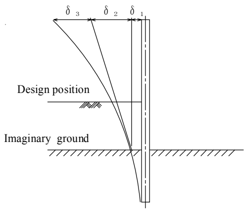
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.24 2.54	0.822 0.645	0.245 0.163	19.76 48.07	4.850 7.839
2	2.10～ 2.60	1.67 1.50	0.424 0.382	0.077 0.064	22.88 25.11	1.770 1.600
3	2.60～ 2.70	1.30 1.27	0.331 0.323	0.049 0.047	4.42 4.43	0.216 0.206
4	2.70～ 3.22	1.06 0.89	0.270 0.226	0.033 0.024	23.04 23.04	0.766 0.546
5	3.22～ 3.94	0.48 0.24	0.122 0.061	0.007 0.002	10.29 0.00	0.073 0.000
						ΣQ = 17.865

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha) \times \alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3487\times 1.89)\times 187.55}{2\times 2.00\times 10^8\times 182320\times 10^{-8}\times 0.3487^3} = 0.01007 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3487\times 1.89)\times 187.55}{2\times 2.00\times 10^8\times 182320\times 10^{-8}\times 0.3487^2}\times(2.60+1.34) = 0.01933 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{17.87\times(2.60+1.34)^3}{2.00\times 10^8\times 182320\times 10^{-8}} = 0.00299 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.61\text{ m、}h=L-H_m\text{、}H_m=0.80\text{ m、ただし}H=L)$$

$$= \frac{12.30\times 3.81}{2\times 2.00\times 10^8\times 182320\times 10^{-8}}\times(2\times 4.61-3.81) = 0.00035 \text{ m}$$

δ_3' is calculated as 0.00043 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.94 m
Horizontal load: P = 6.50
Moment: M = 2.93

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01007＋0.01933＋0.00348
= 0.03288 m
= 32.88 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.91 3.21	0.848 0.696	0.258 0.186	25.06 56.54	6.467 10.528
2	2.10～ 2.20	2.48 2.45	0.537 0.530	0.119 0.116	7.21 7.34	0.854 0.850
3	2.20～ 2.60	2.28 2.15	0.494 0.465	0.102 0.091	29.37 30.73	2.994 2.809
4	2.60～ 3.22	1.81 1.60	0.391 0.347	0.067 0.053	43.91 45.66	2.925 2.426
5	3.22～ 4.22	1.06 0.73	0.230 0.157	0.024 0.012	19.77 3.76	0.481 0.044
6	4.22～ 4.61	0.26 0.13	0.057 0.028	0.002 0.000	2.30 0.00	0.004 0.000
						ΣQ = 30.382

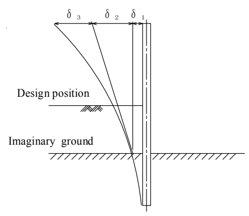
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.28 2.15	0.494 0.465	0.102 0.091	0.00 0.14	0.000 0.013
						ΣQ_{dw} = 0.013

Therefore, modulus of deformation Q is calculated as below:
Q = 30.382＋0.013 ＝ 30.394

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3497\times 2.45)\times 282.99}{2\times 2.00\times 10^8\times 182320\times 10^{-8}\times 0.3497^3} = 0.01683 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.3497\times 2.45)\times 282.99}{2\times 2.00\times 10^8\times 182320\times 10^{-8}\times 0.3497^2}\times(2.60+2.01) = 0.03967 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{30.39\times(2.60+2.01)^3}{2.00\times 10^8\times 182320\times 10^{-8}} = 0.00818 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00110 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.61 m
Horizontal load: P = 11.20
Moment: M = 3.36

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.61\text{ m、}h=L-H_m\text{、}H_m=0.80\text{ m、ただし}H=L)$$

$$= \frac{12.30\times 3.81}{2\times 2.00\times 10^8\times 182320\times 10^{-8}}\times(2\times 4.61-3.81) = 0.00035 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01683＋0.03967＋0.00963
= 0.06613 m
= 66.13 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	212000 cm^4 (original condition)
	I	=	212000 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 212000 \times 10^{-8}$		=	4.240×10^5

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 21561\ kN/m^3$
Calculated value	$\beta = 0.33578\ m^{-1}$
Penetration length of SSP	$D = 1.34 + \frac{3}{0.336} = 10.27\ m$
Whole length of SSP	$L = 2.60 - 0.40 + 10.27 = 12.47\ m$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 21821\ kN/m^3$
Calculated value	$\beta = 0.33679\ m^{-1}$
Penetration length of SSP	$D = 2.01 + \frac{3}{0.337} = 10.92\ m$
Whole length of SSP	$L = 2.60 - 0.40 + 10.92 = 13.12\ m$

Therefore, whole length of SSP is set as 13.50 m in consideration of round unit of SSP length.

Case: Right Bank No. 38_STA 14+350 - 14+395

8 Calculation Result

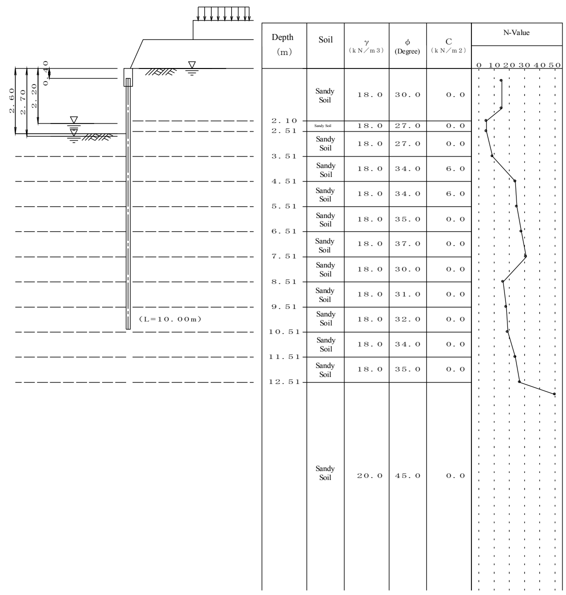
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	212000		
Section modulus	Z (cm^3)	5560		
Maximum bending moment	M_{max} (kN·m/m)		452.25	821.21
Stress intensity	σ (N/mm^2)		91 (185)	166 (278)
Lateral displacement	δ (mm)		32.88 (50.0)	66.13 (75.0)
Penetration depth	D (m)		10.27	10.92
Whole length of SSP	L (m)	13.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 39_STA 14+835 - 14+943

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	φ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
2.51	Sandy Soil	18.0	27.0	0.0
3.51	Sandy Soil	18.0	27.0	0.0
4.51	Sandy Soil	18.0	34.0	6.0
5.51	Sandy Soil	18.0	34.0	6.0
6.51	Sandy Soil	18.0	35.0	0.0
7.51	Sandy Soil	18.0	37.0	0.0
8.51	Sandy Soil	18.0	30.0	0.0
9.51	Sandy Soil	18.0	31.0	0.0
10.51	Sandy Soil	18.0	32.0	0.0
11.51	Sandy Soil	18.0	34.0	0.0
12.51	Sandy Soil	18.0	35.0	0.0
	Sandy Soil	20.0	45.0	0.0

1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load					
Horizontal load	Pt	=	3.5 kN/m	(Normal Condition)
	Pt'	=	9.4 kN/m	(Seismic Condition)
Depth of acting point	Ht	=	-0.53 m	(Normal Condition)
	Ht'	=	-0.27 m	(Seismic Condition)
Moment	Mm	=	0.0 kN・m/m	(Normal Condition)
	Mm'	=	3.8 kN・m/m	(Seismic Condition)
Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
	Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \dfrac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	5
4	2.51	5
5	3.51	9
6	4.51	24
7	5.51	25
8	6.51	28
9	7.51	31
10	8.51	16

No	Depth (m)	N-Value
11	9.51	18
12	10.51	19
13	11.51	24
14	12.51	27
15	13.00	50
16	20.00	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

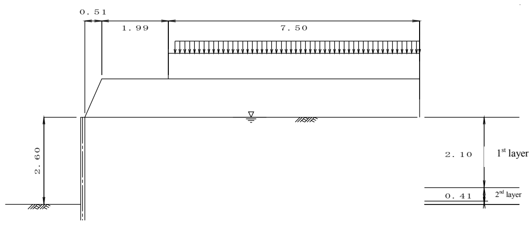
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.51	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	3.51	S	9.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	4.51	S	24.0	18.00	10.00	34.0	6.0	0.0	0.200	auto	auto	——	——
5	5.51	S	25.0	18.00	10.00	34.0	6.0	0.0	0.200	auto	auto	——	——
6	6.51	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
7	7.51	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
8	8.51	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
9	9.51	S	18.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
10	10.51	S	19.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
11	11.51	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
12	12.51	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
13	20.00	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	9.00°	9.00°
passive	-9.00°	-9.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	φ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.51	10.00	10.00	1.14	18.0	30.0	0.0	auto	auto
2	Sandy soil	2.50	2.50	10.00	10.00	0.77	2.7	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	2.70	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 56700 cm⁴
Sectional factor Z_0 = 2700 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 180 N/mm (Normal)
σ_a' = 270 N/mm (Seismic)

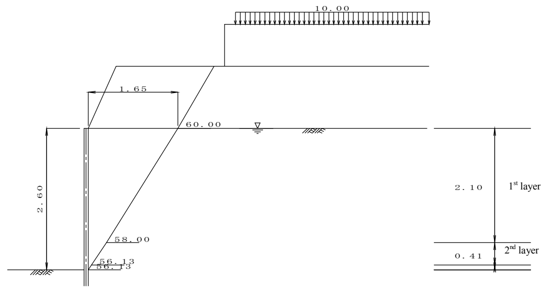
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.51	Sandy Soil	27.0	9.0	0.0	26.00	21.44	25.48	56.13
2	2.51～ 2.10	Sandy Soil	27.0	9.0	0.0	25.10	21.44	24.60	56.13
3	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	21.44	20.58	58.00
4		Embankment	30.0	——	0.0	22.60	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	56.13	0.09	0.00	0.00	0.06	0.09
2	56.13	0.41	0.06	0.09	0.34	0.50
3	58.00	2.10	0.34	0.50	1.65	2.60
4	60.00	1.14	1.65	2.60	2.31	3.74

Therefore, width of acting load shall be set as 1.65 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	1.96	35.34
Σ			35.34

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

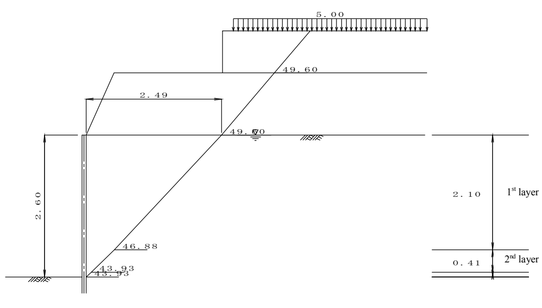
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{35.34 + 0.00 + 0.00}{1.65}$$

$$= 21.44 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.51	Sandy Soil	27.0	9.0	0.0	26.00	26.33	25.48	0.200	11.31	43.93
2	2.51～ 2.10	Sandy Soil	27.0	9.0	0.0	25.10	26.33	24.60	0.200	11.31	43.93
3	2.10～ 0.00	Sandy Soil	30.0	9.0	0.0	21.00	26.33	20.58	0.200	11.31	46.88
4		Embankment	30.0	——	0.0	22.60	5.00	0.00	0.200	11.31	49.60
5		Embankment	30.0	——	0.0	2.08	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	43.93	0.09	0.00	0.00	0.09	0.09
2	43.93	0.41	0.09	0.09	0.52	0.50
3	46.88	2.10	0.52	0.50	2.49	2.60
4	49.60	1.14	2.49	2.60	3.46	3.74
5	49.60	0.77	3.46	3.74	4.11	4.51

Therefore, width of acting load shall be set as 2.49 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.10	55.73
2	2.7	0.99	2.67
Σ			58.40

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X 1 (kN/m)
1	5.0	1.41	7.06
Σ			7.06

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

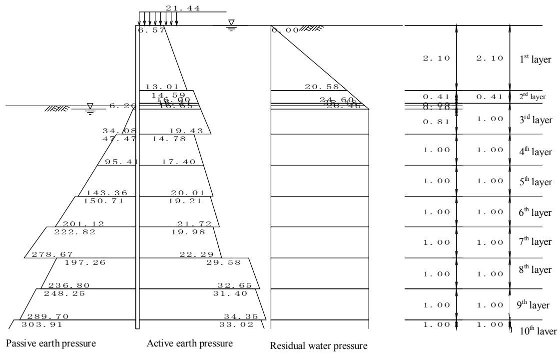
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{58.40 + 7.06 + 0.00}{2.49}$$

$$= 26.33 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	21.443 42.443	0.31026 0.31026	0.30644 0.30644
2	2.10～ 2.51	Sandy soil	10.0	27.0	—— ——	42.443 46.543	0.34800 0.34800	0.34371 0.34371
3	2.51～ 2.60	Sandy soil	10.0	27.0	—— ——	46.543 47.443	0.34800 0.34800	0.34371 0.34371
4	2.60～ 2.70	Sandy soil	10.0	27.0	—— ——	47.443 48.443	0.34800 0.34800	0.34371 0.34371
5	2.70～ 3.51	Sandy soil	10.0	27.0	—— ——	48.443 56.543	0.34800 0.34800	0.34371 0.34371
6	3.51～ 4.51	Sandy soil	10.0	34.0	—— ——	56.543 66.543	0.26470 0.26470	0.26144 0.26144
7	4.51～ 5.51	Sandy soil	10.0	34.0	—— ——	66.543 76.543	0.26470 0.26470	0.26144 0.26144
8	5.51～ 6.51	Sandy soil	10.0	35.0	—— ——	76.543 86.543	0.25410 0.25410	0.25097 0.25097
9	6.51～ 7.51	Sandy soil	10.0	37.0	—— ——	86.543 96.543	0.23377 0.23377	0.23089 0.23089
10	7.51～ 8.51	Sandy soil	10.0	30.0	—— ——	96.543 106.543	0.31026 0.31026	0.30644 0.30644
11	8.51～ 9.51	Sandy soil	10.0	31.0	—— ——	106.543 116.543	0.29838 0.29838	0.29471 0.29471
12	9.51～ 10.51	Sandy soil	10.0	32.0	—— ——	116.543 126.543	0.28683 0.28683	0.28330 0.28330
13	10.51～ 11.51	Sandy soil	10.0	34.0	—— ——	126.543 136.543	0.26470 0.26470	0.26144 0.26144

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	11.51～ 12.51	Sandy soil	10.0	35.0	—— ——	136.543 146.543	0.25410 0.25410	0.25097 0.25097
15	12.51～ 20.00	Sandy soil	10.0	45.0	—— ——	146.543 221.443	0.16323 0.16323	0.16122 0.16122

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 9.00、β ＝ 0.00、θ ＝ 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60～ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.48553 3.48553	3.44261 3.44261
5	2.70～ 3.51	Sandy soil	10.0	27.0	—— ——	1.800 9.900	3.48553 3.48553	3.44261 3.44261
6	3.51～ 4.51	Sandy soil	10.0	34.0	—— ——	9.900 19.900	4.85443 4.85443	4.79467 4.79467
7	4.51～ 5.51	Sandy soil	10.0	34.0	—— ——	19.900 29.900	4.85443 4.85443	4.79467 4.79467
8	5.51～ 6.51	Sandy soil	10.0	35.0	—— ——	29.900 39.900	5.10344 5.10344	5.04061 5.04061
9	6.51～ 7.51	Sandy soil	10.0	37.0	—— ——	39.900 49.900	5.65410 5.65410	5.58449 5.58449
10	7.51～ 8.51	Sandy soil	10.0	30.0	—— ——	49.900 59.900	4.00247 4.00247	3.95319 3.95319
11	8.51～ 9.51	Sandy soil	10.0	31.0	—— ——	59.900 69.900	4.19615 4.19615	4.14448 4.14448
12	9.51～ 10.51	Sandy soil	10.0	32.0	—— ——	69.900 79.900	4.40199 4.40199	4.34780 4.34780
13	10.51～ 11.51	Sandy soil	10.0	34.0	—— ——	79.900 89.900	4.85443 4.85443	4.79467 4.79467
14	11.51～ 12.51	Sandy soil	10.0	35.0	—— ——	89.900 99.900	5.10344 5.10344	5.04061 5.04061
15	12.51～ 20.00	Sandy soil	10.0	45.0	—— ——	99.900 174.800	8.86593 8.86593	8.75678 8.75678

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -9.00、β ＝ 0.00、θ ＝ 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	6.57 13.01	—— ——	6.57 13.01	0.00 20.58	—— ——
2	2.10～ 2.51	14.59 16.00	—— ——	14.59 16.00	20.58 24.60	—— ——
3	2.51～ 2.60	16.00 16.31	—— ——	16.00 16.31	24.60 25.48	—— ——
4	2.60～ 2.70	16.31 16.65	—— ——	16.31 16.65	25.48 26.46	0.00 6.20
5	2.70～ 3.51	16.65 19.43	—— ——	16.65 19.43	26.46 26.46	6.20 34.08
6	3.51～ 4.51	14.78 17.40	—— ——	14.78 17.40	26.46 26.46	47.47 95.41
7	4.51～ 5.51	17.40 20.01	—— ——	17.40 20.01	26.46 26.46	95.41 143.36
8	5.51～ 6.51	19.21 21.72	—— ——	19.21 21.72	26.46 26.46	150.71 201.12
9	6.51～ 7.51	19.98 22.29	—— ——	19.98 22.29	26.46 26.46	222.82 278.67
10	7.51～ 8.51	29.58 32.65	—— ——	29.58 32.65	26.46 26.46	197.26 236.80
11	8.51～ 9.51	31.40 34.35	—— ——	31.40 34.35	26.46 26.46	248.25 289.70
12	9.51～ 10.51	33.02 35.85	—— ——	33.02 35.85	26.46 26.46	303.91 347.39
13	10.51～ 11.51	33.08 35.70	—— ——	33.08 35.70	26.46 26.46	383.09 431.04
14	11.51～ 12.51	34.27 36.78	—— ——	34.27 36.78	26.46 26.46	453.15 503.56
15	12.51～ 20.00	23.63 35.70	—— ——	23.63 35.70	26.46 26.46	874.80 1530.68

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

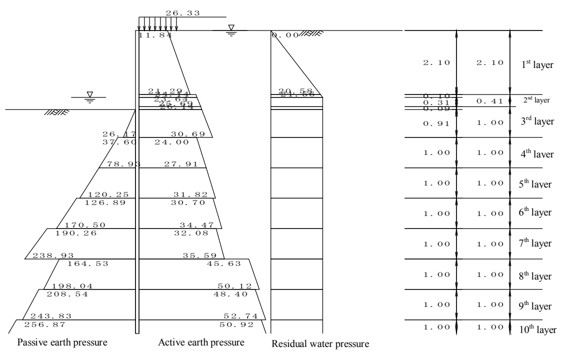
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	26.33 47.33	0.00 20.58	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
2	2.10～ 2.20	Sandy Soil	10.0	27.0	—— ——	47.33 48.33	20.58 21.56	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
3	2.20～ 2.51	Sandy Soil	10.0	27.0	—— ——	48.33 51.43	21.56 24.60	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
4	2.51～ 2.60	Sandy Soil	10.0	27.0	—— ——	51.43 52.33	24.60 25.48	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
5	2.60～ 3.51	Sandy Soil	10.0	27.0	—— ——	52.33 61.43	25.48 34.40	0.200 0.200	11.31 11.31	0.50574 0.50574	0.49951 0.49951	—— ——
6	3.51～ 4.51	Sandy Soil	10.0	34.0	—— ——	61.43 71.43	34.40 44.20	0.200 0.200	11.31 11.31	0.39559 0.39559	0.39072 0.39072	—— ——
7	4.51～ 5.51	Sandy Soil	10.0	34.0	—— ——	71.43 81.43	44.20 54.00	0.200 0.200	11.31 11.31	0.39559 0.39559	0.39072 0.39072	—— ——
8	5.51～ 6.51	Sandy Soil	10.0	35.0	—— ——	81.43 91.43	54.00 63.80	0.200 0.200	11.31 11.31	0.38174 0.38174	0.37704 0.37704	—— ——
9	6.51～ 7.51	Sandy Soil	10.0	37.0	—— ——	91.43 101.43	63.80 73.60	0.200 0.200	11.31 11.31	0.35524 0.35524	0.35087 0.35087	—— ——
10	7.51～ 8.51	Sandy Soil	10.0	30.0	—— ——	101.43 111.43	73.60 83.40	0.200 0.200	11.31 11.31	0.45543 0.45543	0.44982 0.44982	—— ——
11	8.51～ 9.51	Sandy Soil	10.0	31.0	—— ——	111.43 121.43	83.40 93.20	0.200 0.200	11.31 11.31	0.43976 0.43976	0.43434 0.43434	—— ——
12	9.51～ 10.51	Sandy Soil	10.0	32.0	—— ——	121.43 131.43	93.20 103.00	0.200 0.200	11.31 11.31	0.42457 0.42457	0.41935 0.41935	—— ——
13	10.51～ 11.51	Sandy Soil	10.0	34.0	—— ——	131.43 141.43	103.00 112.80	0.200 0.200	11.31 11.31	0.39559 0.39559	0.39072 0.39072	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
14	11.51～ 12.51	Sandy Soil	10.0	35.0	—— ——	141.43 151.43	112.80 122.60	0.200 0.200	11.31 11.31	0.38174 0.38174	0.37704 0.37704	—— ——
15	12.51～ 20.00	Sandy Soil	10.0	45.0	—— ——	151.43 226.33	122.60 196.00	0.200 0.200	11.31 11.31	0.26304 0.26304	0.25980 0.25980	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 9.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60～ 3.51	Sandy soil	10.00	27.0	—— ——	0.000 9.100	0.00 8.92	0.200 0.200	11.31 11.31	2.91211 2.91211	2.87626 2.87626
6	3.51～ 4.51	Sandy soil	10.00	34.0	—— ——	9.100 19.100	8.92 18.72	0.200 0.200	11.31 11.31	4.18373 4.18373	4.13222 4.13222
7	4.51～ 5.51	Sandy soil	10.00	34.0	—— ——	19.100 29.100	18.72 28.52	0.200 0.200	11.31 11.31	4.18373 4.18373	4.13222 4.13222
8	5.51～ 6.51	Sandy soil	10.00	35.0	—— ——	29.100 39.100	28.52 38.32	0.200 0.200	11.31 11.31	4.41499 4.41499	4.36064 4.36064
9	6.51～ 7.51	Sandy soil	10.00	37.0	—— ——	39.100 49.100	38.32 48.12	0.200 0.200	11.31 11.31	4.92675 4.92675	4.86609 4.86609
10	7.51～ 8.51	Sandy soil	10.00	30.0	—— ——	49.100 59.100	48.12 57.92	0.200 0.200	11.31 11.31	3.39273 3.39273	3.35096 3.35096
11	8.51～ 9.51	Sandy soil	10.00	31.0	—— ——	59.100 69.100	57.92 67.72	0.200 0.200	11.31 11.31	3.57258 3.57258	3.52859 3.52859
12	9.51～ 10.51	Sandy soil	10.00	32.0	—— ——	69.100 79.100	67.72 77.52	0.200 0.200	11.31 11.31	3.76368 3.76368	3.71734 3.71734
13	10.51～ 11.51	Sandy soil	10.00	34.0	—— ——	79.100 89.100	77.52 87.32	0.200 0.200	11.31 11.31	4.18373 4.18373	4.13222 4.13222
14	11.51～ 12.51	Sandy soil	10.00	35.0	—— ——	89.100 99.100	87.32 97.12	0.200 0.200	11.31 11.31	4.41499 4.41499	4.36064 4.36064
15	12.51～ 20.00	Sandy soil	10.00	45.0	—— ——	99.100 174.000	97.12 170.52	0.200 0.200	11.31 11.31	7.92269 7.92269	7.82515 7.82515

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -9.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	11.84 21.29	—— ——	11.84 21.29	0.00 20.58	—— ——
2	2.10～ 2.20	23.64 24.14	—— ——	23.64 24.14	20.58 21.56	—— ——
3	2.20～ 2.51	24.14 25.69	—— ——	24.14 25.69	21.56 21.56	—— ——
4	2.51～ 2.60	25.69 26.14	—— ——	25.69 26.14	21.56 21.56	—— ——
5	2.60～ 3.51	26.14 30.69	—— ——	26.14 30.69	21.56 21.56	0.00 26.17
6	3.51～ 4.51	24.00 27.91	—— ——	24.00 27.91	21.56 21.56	37.60 78.93
7	4.51～ 5.51	27.91 31.82	—— ——	27.91 31.82	21.56 21.56	78.93 120.25
8	5.51～ 6.51	30.70 34.47	—— ——	30.70 34.47	21.56 21.56	126.89 170.50
9	6.51～ 7.51	32.08 35.59	—— ——	32.08 35.59	21.56 21.56	190.26 238.93
10	7.51～ 8.51	45.63 50.12	—— ——	45.63 50.12	21.56 21.56	164.53 198.04
11	8.51～ 9.51	48.40 52.74	—— ——	48.40 52.74	21.56 21.56	208.54 243.83
12	9.51～ 10.51	50.92 55.12	—— ——	50.92 55.12	21.56 21.56	256.87 294.04
13	10.51～ 11.51	51.35 55.26	—— ——	51.35 55.26	21.56 21.56	326.86 368.18
14	11.51～ 12.51	53.33 57.10	—— ——	53.33 57.10	21.56 21.56	388.53 432.14
15	12.51～ 20.00	39.34 58.80	—— ——	39.34 58.80	21.56 21.56	775.47 1361.58

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot \left[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot \left[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}\right] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

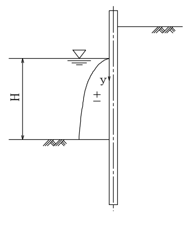
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm\frac{7}{8}\, k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

Where,

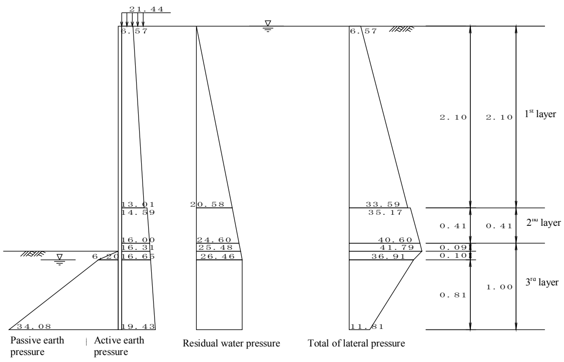
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

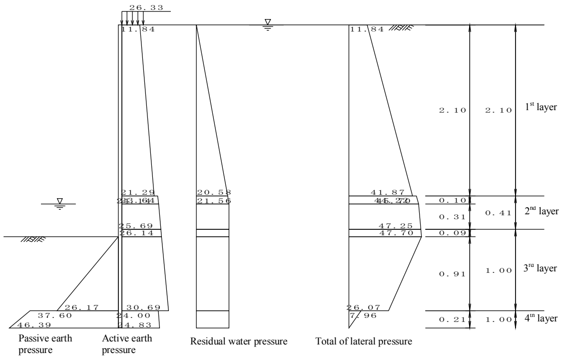


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	6.57 13.01	0.00 20.58	—— ——	6.57 33.59
2	2.10～ 2.51	14.59 16.00	20.58 24.60	—— ——	35.17 40.60
3	2.51～ 2.60	16.00 16.31	24.60 25.48	—— ——	40.60 41.79
4	2.60～ 2.70	16.31 16.65	25.48 26.46	0.00 6.20	41.79 36.91
5	2.70～ 3.51	16.65 19.43	26.46 26.46	6.20 34.08	36.91 11.81
6	3.51～ 4.51	14.78 17.40	26.46 26.46	47.47 95.41	-6.22 -51.56

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.91 m (GL -3.51 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	11.84 21.29	0.00 20.58	—— ——	11.84 41.87
2	2.10～ 2.20	23.64 24.14	20.58 21.56	—— ——	44.22 45.70
3	2.20～ 2.51	24.14 25.69	21.56 21.56	—— ——	45.70 47.25
4	2.51～ 2.60	25.69 26.14	21.56 21.56	—— ——	47.25 47.70
5	2.60～ 3.51	26.14 30.69	21.56 21.56	0.00 26.17	47.70 26.07
6	3.51～ 3.72	24.00 24.83	21.56 21.56	37.60 46.39	7.96 0.00
7	3.72～ 4.51	24.83 27.91	21.56 21.56	46.39 78.93	0.00 -29.46

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.12 m (GL -3.72 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴(original condition)
	I	=	39917 cm⁴(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	5
4	2.51	5
5	3.51	9
6	4.51	24
7	5.51	25
8	6.51	28
9	7.51	31
10	8.51	16

	Depth (m)	N-value
11	9.51	18
12	10.51	19
13	11.51	24
14	12.51	27
15	13.00	50
16	20.00	50

5-2 Normal Condition

K_h = 23467 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.521 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.92 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.51 m) to 1.92 m depth (GL -5.43 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.51	1.00	9.0	24.0	16.50
2	4.51	0.92	24.0	24.9	22.52
	L =Σh = 1.92				ΣA = 39.02

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{39.02}{1.92} = 20.32$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 20.32^{0.406} = 23467$ kN/m³
Kh (normal condition) = 23467 kN/m³

5-3 Seismic Condition

K_h = 24192 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.525 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.91 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.72 m) and 1.91 m depth (GL -5.63 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.72	0.79	12.2	24.0	14.25
2	4.51	1.00	24.0	25.0	24.50
3	5.51	0.12	25.0	25.4	2.99
	L =Σh = 1.91				ΣA = 41.74

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{41.74}{1.91} = 21.90$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 21.90^{0.406} = 24192$ kN/m³
Kh (seismic condition) = 24192 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN・m)
1	0.00～ 2.10	2.10	6.57 33.59	6.90 35.27	2.81 2.11	19.39 74.41
2	2.10～ 2.51	0.41	35.17 40.60	7.21 8.32	1.27 1.14	9.18 9.46
3	2.51～ 2.60	0.09	40.60 41.79	1.83 1.88	0.97 0.94	1.77 1.77
4	2.60～ 2.70	0.10	41.79 36.91	2.09 1.85	0.88 0.84	1.83 1.56
5	2.70～ 3.51	0.81	36.91 11.81	14.95 4.78	0.54 0.27	8.07 1.29
				ΣP = 85.07		ΣM = 128.73

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 3.5 kN/m
depth to acting position H_t = -0.53 m
moment M_m = 0.0 kN・m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 0.91 m

Moment M_t by arbitrary load is as below
$M_t = P_t\cdot(H + L_k - H_t) + M_m = 14.14$ kN・m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{142.87}{88.57} = 1.61 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN・m)
1	0.00～ 2.10	2.10	11.84 41.87	12.44 43.96	3.02 2.32	37.59 102.12
2	2.10～ 2.20	0.10	44.22 45.70	2.21 2.29	1.59 1.56	3.51 3.56
3	2.20～ 2.51	0.31	45.70 47.25	7.08 7.32	1.42 1.32	10.05 9.64
4	2.51～ 2.60	0.09	47.25 47.70	2.13 2.15	1.18 1.15	2.51 2.47
5	2.60～ 3.51	0.91	47.70 26.07	21.70 11.86	0.82 0.52	17.78 6.12
6	3.51～ 3.72	0.21	7.96 0.00	0.85 0.00	0.14 0.07	0.12 0.00
				ΣP = 113.99		ΣM = 195.49

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 9.4 kN/m
depth to acting position H_t = -0.27 m
moment M_m = 3.8 kN・m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.12 m

Moment M_t by arbitrary load is as below
$M_t = P_t\cdot(H + L_k - H_t) + M_m = 41.33$ kN・m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN・m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	1.39 1.26	0.00 0.17
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.17

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{236.99}{123.53} = 1.92 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	39917 cm^4 (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{-8}$		=	7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	23467 kN/m^3
calculated value	β	=	0.52066 m^{-1}
resultant earth force (lateral)	P_0	=	88.57 kN/m
height of acting position of load	h_0	=	1.61 m
moment	M_0	=	142.87 kN・m/m

in consideration of ψ_m = 1.191,

maximum moment	M_{max}	=	170.21 kN・m/m
depth of generated position of M_{max}	l_m	=	0.686 m
depth of 1st fixed point	l_i	=	2.194 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	24192 kN/m^3
calculated value	β	=	0.52464 m^{-1}
resultant earth force (lateral)	P_0	=	123.53 kN/m
height of acting position of load	h_0	=	1.92 m
moment	M_0	=	236.99 kN・m/m

in consideration of ψ_m = 1.145,

maximum moment	M_{max}	=	271.27 kN・m/m
depth of generated position of M_{max}	l_m	=	0.611 m
depth of 1st fixed point	l_i	=	2.108 m

2.299

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	1.00
Module of section	Z_0	=	2700 cm^3 (original condition)
	Z	=	2376 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{170.21\times10^6}{2376\times10^3} = 72 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{271.27\times10^6}{2376\times10^3} = 114 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

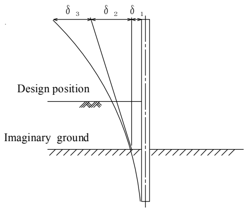
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	2.81 2.11	0.801 0.601	0.235 0.144	6.90 35.27	1.621 5.095
2	2.10～ 2.51	1.27 1.14	0.363 0.324	0.058 0.047	7.21 8.32	0.417 0.389
3	2.51～ 2.60	0.97 0.94	0.276 0.268	0.035 0.033	1.83 1.88	0.063 0.061
4	2.60～ 2.70	0.88 0.84	0.250 0.240	0.029 0.027	2.09 1.85	0.060 0.049
5	2.70～ 3.51	0.54 0.27	0.154 0.077	0.011 0.003	14.95 4.78	0.168 0.014
						ΣQ = 7.938

Y : Height from imaginary riverbed to acting position
α : $\alpha = \dfrac{Y}{H+L_k}$
ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5207\times1.61)\times 88.57}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5207^3} = 0.00723 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5207\times1.61)\times 88.57}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5207^2}\times(2.60+0.91) = 0.01925 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{7.94\times(2.60+0.91)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00430 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00078 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.51 m
Horizontal load: P = 3.50
Moment: M = 1.86

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00723＋0.01925＋0.00507
= 0.03155 m
= 31.55 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.02 2.32	0.812 0.624	0.240 0.154	12.44 43.96	2.990 6.778
2	2.10～ 2.20	1.59 1.56	0.427 0.418	0.078 0.075	2.21 2.29	0.173 0.172
3	2.20～ 2.51	1.42 1.32	0.381 0.354	0.063 0.055	7.08 7.32	0.449 0.404
4	2.51～ 2.60	1.18 1.15	0.318 0.310	0.045 0.043	2.13 2.15	0.096 0.092
5	2.60～ 3.51	0.82 0.52	0.220 0.139	0.022 0.009	21.70 11.86	0.487 0.109
6	3.51～ 3.72	0.14 0.07	0.038 0.019	0.001 0.000	0.85 0.00	0.001 0.000
						ΣQ = 11.750

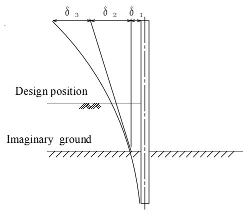
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.39 1.26	0.373 0.337	0.061 0.051	0.00 0.14	0.000 0.007
						ΣQ_{dw} = 0.007

Therefore, modulus of deformation Q is calculated as below:
Q = 11.750＋0.007 = 11.757

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5246\times1.92)\times 123.53}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5246^3} = 0.01075 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.5246\times1.92)\times 123.53}{2\times2.00\times10^8\times39917\times10^{-8}\times0.5246^2}\times(2.60+1.12) = 0.03153 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.76\times(2.60+1.12)^3}{2.00\times10^8\times39917\times10^{-8}} = 0.00760 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00225 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.72 m
Horizontal load: P = 9.40
Moment: M = 2.54

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=3.72\text{ m}、h=L-H_m、H_m=0.80\text{ m}、ただし...)$$

$$= \frac{3.80\times2.92}{2\times2.00\times10^8\times39917\times10^{-8}}\times(2\times3.72-2.92) = 0.00031 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01075＋0.03153＋0.01016
= 0.05244 m
= 52.44 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10^{-8}		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction
Calculated value

K_h = 23467 kN/m^3
β = 0.47692 m^{-1}

Penetration length of SSP
Whole length of SSP

$$D = 0.91 + \frac{3}{0.477} = 7.20 \text{ m}$$

$$L = 2.60 - 0.40 + 7.20 = 9.40 \text{ m}$$

7-1-2 Seismic Condition

Modules of lateral subgrade reaction
Calculated value

K_h = 24192 kN/m^3
β = 0.48056 m^{-1}

Penetration length of SSP
Whole length of SSP

$$D = 1.12 + \frac{3}{0.481} = 7.37 \text{ m}$$

$$L = 2.60 - 0.40 + 7.37 = 9.57 \text{ m}$$

Therefore, whole length of SSP is set as 10.00 m in consideration of round unit of SSP length.

8 Calculation Result

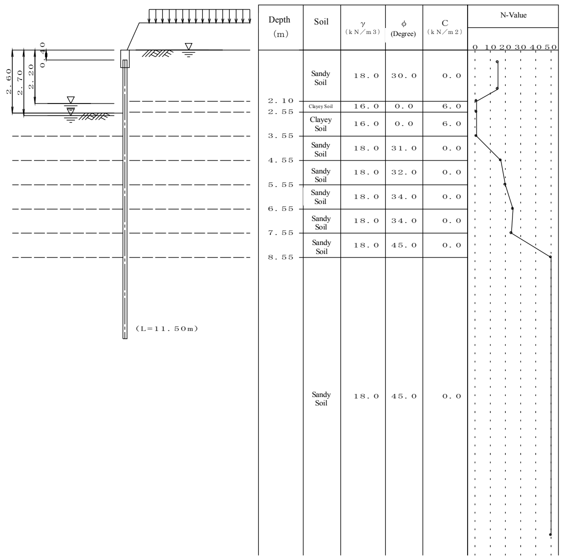
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		170.21	271.27
Stress intensity	σ (N/mm^2)		72 (180)	114 (270)
Lateral displacement	δ (mm)		31.55 (50.0)	52.44 (75.0)
Penetration depth	D (m)		7.20	7.37
Whole length of SSP	L (m)	10.00		

－Steel Sheet Pile Design Calculation－

Right Bank No. 40_STA 14+985 - 15+072

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_t	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	3.4 kN/m	(Normal Condition)
		Pt'	=	10.4 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.52 m	(Normal Condition)
		Ht'	=	-0.37 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN・m/m	(Normal Condition)
		Mm'	=	0.0 kN・m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan\theta}$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.50	15
2	1.60	15
3	2.10	1
4	2.55	1
5	3.55	1
6	4.55	17
7	5.55	20
8	6.55	25
9	7.55	24
10	8.55	50

No	Depth (m)	N-Value
11	20.00	50

2.302

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

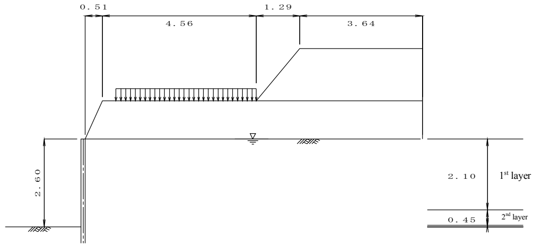
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	ϕ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.55	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
3	3.55	C	1.0	16.00	8.00	0.0	6.0	0.0	0.200	auto	auto	——	——
4	4.55	S	17.0	18.00	10.00	31.0	0.0	0.0	0.200	auto	auto	——	——
5	5.55	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
6	6.55	S	25.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
7	7.55	S	24.0	18.00	10.00	34.0	0.0	0.0	0.200	auto	auto	——	——
8	8.55	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
9	20.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- ϕ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active passive	10.00° -10.00°	10.00° -10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.51	10.00	10.00	1.12	18.0	30.0	0.0	auto	auto
2	Sandy soil	5.07	6.36	10.00	10.00	1.55	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.91	5.07	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴
Sectional factor	Z_0	=	3250 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0)	η	=	0.84
Corrosion rate (to Z_0)	η	=	0.87
Section efficiency (to I_0)	μ	=	1.00
Section efficiency (to Z_0)	μ	=	1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 N/mm (Normal)
σ_a' = 278 N/mm (Seismic)

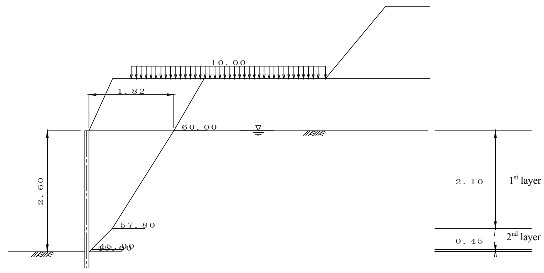
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.55	Clayey Soil	0.0	10.0	6.0	25.00	29.47	25.48	45.00
2	2.55～ 2.10	Clayey Soil	0.0	10.0	6.0	24.60	29.47	24.99	45.00
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	29.47	20.58	57.80
4		Embankment	30.0	——	0.0	48.06	0.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.05	0.00	0.00	0.05	0.05
2	45.00	0.45	0.05	0.05	0.50	0.50
3	57.80	2.10	0.50	0.50	1.82	2.60
4	60.00	1.12	1.82	2.60	2.47	3.72

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.12	38.12
Σ			38.12

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.56	15.59
Σ			15.59

Q: surcharge load
l : width of surcharge load set by line of active rupture

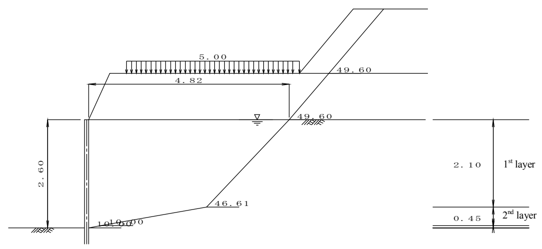
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q \times l)+\Sigma P}{L}$$

$$= \frac{38.12 + 15.59 + 0.00}{1.82}$$

$$= 29.47 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.55	Clayey Soil	0.0	10.0	6.0	25.00	29.56	25.48	0.200	11.31	10.00
2	2.55～ 2.10	Clayey Soil	0.0	10.0	6.0	24.60	29.56	24.99	0.200	11.31	10.00
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	29.56	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	48.06	0.00	0.00	0.200	11.31	49.60
5		Embankment	30.0	——	0.0	27.90	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	10.00	0.05	0.00	0.00	0.28	0.05
2	10.00	0.45	0.28	0.05	2.84	0.50
3	46.61	2.10	2.84	0.50	4.82	2.60
4	49.60	1.12	4.82	2.60	5.77	3.72
5	49.60	1.55	5.77	3.72	7.09	5.27

Therefore, width of acting load shall be set as 4.82 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.65	101.66
2	18.0	1.11	20.05
Σ			121.71

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	4.16	20.80
Σ			20.80

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

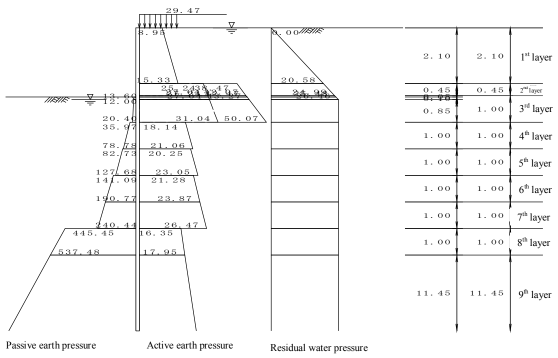
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{121.71 + 20.80 + 0.00}{4.82}$$

$$= 29.56 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	29.471 50.471	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.55	Clayey soil	8.0	—	6.0 6.0	50.471 54.071	—— ——	—— ——
3	2.55～ 2.60	Clayey soil	8.0	—	6.0 6.0	54.071 54.471	—— ——	—— ——
4	2.60～ 2.70	Clayey soil	8.0	—	6.0 6.0	54.471 55.271	—— ——	—— ——
5	2.70～ 3.55	Clayey soil	8.0	—	6.0 6.0	55.271 62.071	—— ——	—— ——
6	3.55～ 4.55	Sandy soil	10.0	31.0	—— ——	62.071 72.071	0.29669 0.29669	0.29219 0.29219
7	4.55～ 5.55	Sandy soil	10.0	32.0	—— ——	72.071 82.071	0.28525 0.28525	0.28092 0.28092
8	5.55～ 6.55	Sandy soil	10.0	34.0	—— ——	82.071 92.071	0.26331 0.26331	0.25931 0.25931
9	6.55～ 7.55	Sandy soil	10.0	34.0	—— ——	92.071 102.071	0.26331 0.26331	0.25931 0.25931
10	7.55～ 8.55	Sandy soil	10.0	45.0	—— ——	102.071 112.071	0.16262 0.16262	0.16015 0.16015
11	8.55～ 20.00	Sandy soil	10.0	45.0	—— ——	112.071 226.571	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60～ 2.70	Clayey soil	16.0	0.0	6.0 6.0	0.000 1.600	—— ——	—— ——
5	2.70～ 3.55	Clayey soil	8.0	0.0	6.0 6.0	1.600 8.400	—— ——	—— ——
6	3.55～ 4.55	Sandy soil	10.0	31.0	—— ——	8.400 18.400	4.34774 4.34774	4.28169 4.28169
7	4.55～ 5.55	Sandy soil	10.0	32.0	—— ——	18.400 28.400	4.56530 4.56530	4.49594 4.49594
8	5.55～ 6.55	Sandy soil	10.0	34.0	—— ——	28.400 38.400	5.04448 5.04448	4.96784 4.96784
9	6.55～ 7.55	Sandy soil	10.0	34.0	—— ——	38.400 48.400	5.04448 5.04448	4.96784 4.96784
10	7.55～ 8.55	Sandy soil	10.0	45.0	—— ——	48.400 58.400	9.34548 9.34548	9.20351 9.20351
11	8.55～ 20.00	Sandy soil	10.0	45.0	—— ——	58.400 172.900	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ= -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	8.95 15.33	—— ——	8.95 15.33	0.00 20.58	—— ——
2	2.10～ 2.55	38.47 42.07	25.24 27.04	38.47 42.07	20.58 24.99	—— ——
3	2.55～ 2.60	42.07 42.47	27.04 27.24	42.07 42.47	24.99 25.48	—— ——
4	2.60～ 2.70	42.47 43.27	27.24 27.64	42.47 43.27	25.48 26.46	12.00 13.60
5	2.70～ 3.55	43.27 50.07	27.64 31.04	43.27 50.07	26.46 26.46	13.60 20.40
6	3.55～ 4.55	18.14 21.06	—— ——	18.14 21.06	26.46 26.46	35.97 78.78
7	4.55～ 5.55	20.25 23.05	—— ——	20.25 23.05	26.46 26.46	82.73 127.68
8	5.55～ 6.55	21.28 23.87	—— ——	21.28 23.87	26.46 26.46	141.09 190.77
9	6.55～ 7.55	23.87 26.47	—— ——	23.87 26.47	26.46 26.46	190.77 240.44

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
10	7.55～ 8.55	16.35 17.95	—— ——	16.35 17.95	26.46 26.46	445.45 537.48
11	8.55～ 20.00	17.95 36.29	—— ——	17.95 36.29	26.46 26.46	537.48 1591.29

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma \gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

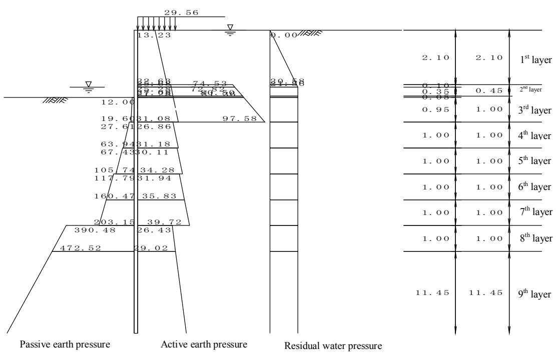
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	29.56 50.56	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10～ 2.20	Clayey Soil	8.0	——	6.0 6.0	50.56 51.36	20.58 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
3	2.20～ 2.55	Clayey Soil	8.0	——	6.0 6.0	51.36 54.16	21.56 24.99	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
4	2.55～ 2.60	Clayey Soil	8.0	——	6.0 6.0	54.16 54.56	24.99 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
5	2.60～ 3.55	Clayey Soil	8.0	——	6.0 6.0	54.56 62.16	25.48 34.79	0.200 0.200	11.31 11.31	—— ——	—— ——	10.00 10.00
6	3.55～ 4.55	Sandy Soil	10.0	31.0	—— ——	62.16 72.16	34.79 44.59	0.200 0.200	11.31 11.31	0.43879 0.43879	0.43213 0.43213	—— ——
7	4.55～ 5.55	Sandy Soil	10.0	32.0	—— ——	72.16 82.16	44.59 54.39	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
8	5.55～ 6.55	Sandy Soil	10.0	34.0	—— ——	82.16 92.16	54.39 64.19	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
9	6.55～ 7.55	Sandy Soil	10.0	34.0	—— ——	92.16 102.16	64.19 73.99	0.200 0.200	11.31 11.31	0.39477 0.39477	0.38878 0.38878	—— ——
10	7.55～ 8.55	Sandy Soil	10.0	45.0	—— ——	102.16 112.16	73.99 83.79	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
11	8.55～ 20.00	Sandy Soil	10.0	45.0	—— ——	112.16 226.66	83.79 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60～ 3.55	Clayey soil	8.00	0.0	6.0 6.0	0.000 7.600	0.00 9.31	0.200 0.200	11.31 11.31	—— ——	—— ——
6	3.55～ 4.55	Sandy soil	10.00	31.0	—— ——	7.600 17.600	9.31 19.11	0.200 0.200	11.31 11.31	3.68877 3.68877	3.63273 3.63273
7	4.55～ 5.55	Sandy soil	10.00	32.0	—— ——	17.600 27.600	19.11 28.91	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
8	5.55～ 6.55	Sandy soil	10.00	34.0	—— ——	27.600 37.600	28.91 38.71	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
9	6.55～ 7.55	Sandy soil	10.00	34.0	—— ——	37.600 47.600	38.71 48.51	0.200 0.200	11.31 11.31	4.33360 4.33360	4.26776 4.26776
10	7.55～ 8.55	Sandy soil	10.00	45.0	—— ——	47.600 57.600	48.51 58.31	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
11	8.55～ 20.00	Sandy soil	10.00	45.0	——	57.600 172.100	58.31 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

δ= -10.00、β = 0.00、θ = $\tan^{-1}$k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	13.23 22.63	—— ——	13.23 22.63	0.00 20.58	—— ——
2	2.10～ 2.20	72.82 74.53	25.28 25.68	72.82 74.53	20.58 21.56	—— ——
3	2.20～ 2.55	74.53 80.50	25.68 27.08	74.53 80.50	21.56 21.56	—— ——
4	2.55～ 2.60	80.50 81.36	27.08 27.28	80.50 81.36	21.56 21.56	—— ——
5	2.60～ 3.55	81.36 97.58	27.28 31.08	81.36 97.58	21.56 21.56	12.00 19.60
6	3.55～ 4.55	26.86 31.18	—— ——	26.86 31.18	21.56 21.56	27.61 63.94
7	4.55～ 5.55	30.11 34.28	—— ——	30.11 34.28	21.56 21.56	67.43 105.74
8	5.55～ 6.55	31.94 35.83	—— ——	31.94 35.83	21.56 21.56	117.79 160.47
9	6.55～ 7.55	35.83 39.72	—— ——	35.83 39.72	21.56 21.56	160.47 203.15
10	7.55～ 8.55	26.43 29.02	—— ——	26.43 29.02	21.56 21.56	390.48 472.52
11	8.55～ 20.00	29.02 58.64	—— ——	29.02 58.64	21.56 21.56	472.52 1411.81

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c\cdot(\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}]\cdot\cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

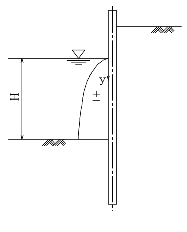
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

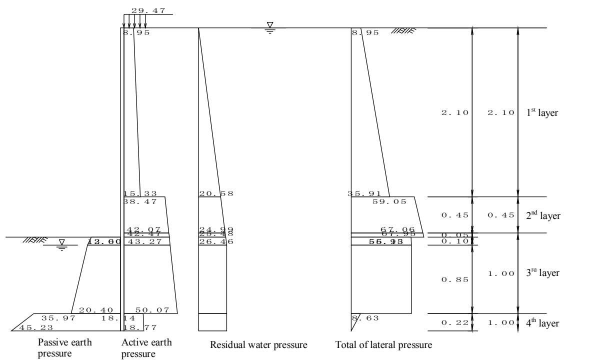
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	8.95 15.33	0.00 20.58	—— ——	8.95 35.91
2	2.10～ 2.55	38.47 42.07	20.58 24.99	—— ——	59.05 67.06
3	2.55～ 2.60	42.07 42.47	24.99 25.48	—— ——	67.06 67.95
4	2.60～ 2.70	42.47 43.27	25.48 26.46	12.00 13.60	55.95 56.13
5	2.70～ 3.55	43.27 50.07	26.46 26.46	13.60 20.40	56.13 56.13
6	3.55～ 3.77	18.14 18.77	26.46 26.46	35.97 45.23	8.63 0.00
7	3.77～ 4.55	18.77 21.06	26.46 26.46	45.23 78.78	0.00 -31.27

P_a : Active earth pressure

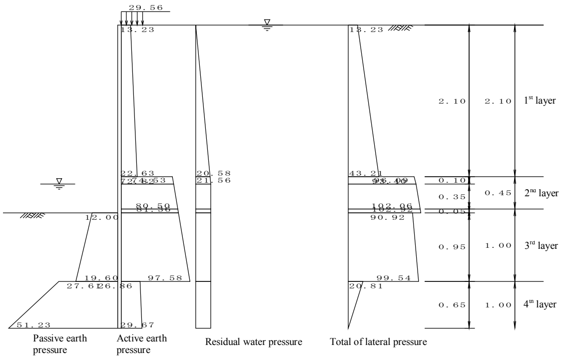
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.17 m (GL -3.77 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	13.23 22.63	0.00 20.58	—— ——	13.23 43.21
2	2.10～ 2.20	72.82 74.53	20.58 21.56	—— ——	93.40 96.09
3	2.20～ 2.55	74.53 80.50	21.56 21.56	—— ——	96.09 102.06
4	2.55～ 2.60	80.50 81.36	21.56 21.56	—— ——	102.06 102.92
5	2.60～ 3.55	81.36 97.58	21.56 21.56	12.00 19.60	90.92 99.54
6	3.55～ 4.20	26.86 29.67	21.56 21.56	27.61 51.23	20.81 0.00
7	4.20～ 4.55	29.67 31.18	21.56 21.56	51.23 63.94	0.00 -11.19

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.60 m (GL -4.20 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	114000 cm^4(original condition)
	I	=	95760 cm^4(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 95760 \times 10^{-8} = 1.915 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	1
4	2.55	1
5	3.55	1
6	4.55	17
7	5.55	20
8	6.55	25
9	7.55	24
10	8.55	50
11	20.00	50

5-2 Normal Condition

K_h = 21745 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.410 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.44 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.77 m) to 2.44 m depth (GL -6.20 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.77	0.78	4.5	17.0	8.41
2	4.55	1.00	17.0	20.0	18.50
3	5.55	0.65	20.0	23.3	14.12
	L =Σh = 2.44				ΣA = 41.03

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{41.03}{2.44}$$

$$= 16.84$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 16.84^{0.406} = 21745$ kN/m^3
Kh (normal condition) = 21745 kN/m^3

5-3 Seismic Condition

K_h = 23162 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.417 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.40 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.20 m) and 2.40 m depth (GL -6.60 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.20	0.35	11.4	17.0	4.97
2	4.55	1.00	17.0	20.0	18.50
3	5.55	1.00	20.0	25.0	22.50
4	6.55	0.05	25.0	25.0	1.21
	L =Σh = 2.40				ΣA = 47.18

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{47.18}{2.40}$$

$$= 19.67$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 19.67^{0.406} = 23162$ kN/m^3
Kh (seismic condition) = 23162 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	8.95 35.91	9.40 37.71	3.07 2.37	28.82 89.23
2	2.10～ 2.55	0.45	59.05 67.06	13.29 15.09	1.52 1.37	20.15 20.62
3	2.55～ 2.60	0.05	67.06 67.95	1.68 1.70	1.20 1.18	2.01 2.01
4	2.60～ 2.70	0.10	55.95 56.13	2.80 2.81	1.13 1.10	3.17 3.09
5	2.70～ 3.55	0.85	56.13 56.13	23.86 23.86	0.78 0.50	18.68 11.92
6	3.55～ 3.77	0.22	8.63 0.00	0.93 0.00	0.14 0.07	0.13 0.00
				ΣP = 133.11		ΣM = 199.82

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	3.4 kN/m
depth to acting position	H_t	=	-0.52 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.17 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 14.57$ kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{214.40}{136.51} = 1.57 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	13.23 43.21	13.89 45.37	3.50 2.80	48.62 127.04
2	2.10～ 2.20	0.10	93.40 96.09	4.67 4.80	2.07 2.03	9.65 9.77
3	2.20～ 2.55	0.35	96.09 102.06	16.82 17.86	1.88 1.77	31.67 31.56
4	2.55～ 2.60	0.05	102.06 102.92	2.55 2.57	1.63 1.62	4.17 4.16
5	2.60～ 3.55	0.95	90.92 99.54	43.19 47.28	1.28 0.97	55.43 45.72
6	3.55～ 4.20	0.65	20.81 0.00	6.77 0.00	0.43 0.22	2.93 0.00
				ΣP = 205.76		ΣM = 370.72

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	10.4 kN/m
depth to acting position	H_t	=	-0.37 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.60 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 47.53$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	1.87 1.73	0.00 0.24
				ΣPdw = 0.14		ΣMdw = 0.24

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{418.49}{216.30} = 1.93 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.84
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	95760 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 95760 × 10⁻⁸		=	1.915 × 10⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	21745 kN/m³
calculated value	β	=	0.41046 m⁻¹
resultant earth force (lateral)	P_0	=	136.51 kN/m
height of acting position of load	h_0	=	1.57 m
moment	M_0	=	214.40 kN·m/m

in consideration of ψ_m = 1.284,

maximum moment	M_{max}	=	275.19 kN·m/m
depth of generated position of M_{max}	l_m	=	1.003 m
depth of 1st fixed point	l_i	=	2.917 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	23162 kN/m³
calculated value	β	=	0.41699 m⁻¹
resultant earth force (lateral)	P_0	=	216.30 kN/m
height of acting position of load	h_0	=	1.93 m
moment	M_0	=	418.49 kN·m/m

in consideration of ψ_m = 1.203,

maximum moment	M_{max}	=	503.61 kN·m/m
depth of generated position of M_{max}	l_m	=	0.876 m
depth of 1st fixed point	l_i	=	2.760 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	3250 cm³ (original condition)
	Z	=	2828 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{275.19 \times 10^6}{2828 \times 10^3} = 97 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{503.61 \times 10^6}{2828 \times 10^3} = 178 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.07 2.37	0.814 0.628	0.241 0.156	9.40 37.71	2.270 5.884
2	2.10～ 2.55	1.52 1.37	0.403 0.363	0.070 0.058	13.29 15.09	0.932 0.873
3	2.55～ 2.60	1.20 1.18	0.319 0.314	0.045 0.044	1.68 1.70	0.076 0.075
4	2.60～ 2.70	1.13 1.10	0.301 0.292	0.041 0.038	2.80 2.81	0.114 0.108
5	2.70～ 3.55	0.78 0.50	0.208 0.133	0.020 0.008	23.86 23.86	0.480 0.201
6	3.55～ 3.77	0.14 0.07	0.038 0.019	0.001 0.000	0.93 0.00	0.001 0.000
						ΣQ = 11.013

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

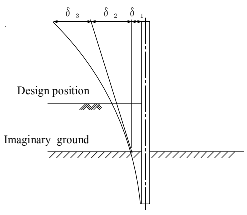
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4105\times1.57)\times136.51}{2\times2.00\times10^8\times95760\times10^{-8}\times0.4105^3} = 0.00848 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times0.4105\times1.57)\times136.51}{2\times2.00\times10^8\times95760\times10^{-8}\times0.4105^2} \times (2.60+1.17) = 0.01824 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{11.01\times(2.60+1.17)^3}{2.00\times10^8\times95760\times10^{-8}} = 0.00307 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00038 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.77 m
Horizontal load: P = 3.40
Moment: M = 1.77

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00848＋0.01824＋0.00345
= 0.03017 m
= 30.17 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.50 2.80	0.833 0.667	0.251 0.173	13.89 45.37	3.483 7.842
2	2.10～ 2.20	2.07 2.03	0.492 0.484	0.101 0.098	4.67 4.80	0.473 0.472
3	2.20～ 2.55	1.88 1.77	0.448 0.421	0.086 0.076	16.82 17.86	1.438 1.359
4	2.55～ 2.60	1.63 1.62	0.389 0.385	0.066 0.065	2.55 2.57	0.168 0.166
5	2.60～ 3.55	1.28 0.97	0.306 0.230	0.042 0.024	43.19 47.28	1.811 1.157
6	3.55～ 4.20	0.43 0.22	0.103 0.052	0.005 0.001	6.77 0.00	0.035 0.000
						ΣQ ＝ 18.403

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H + L_k}$

ζ : $\zeta = \frac{(3 - \alpha) \times \alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

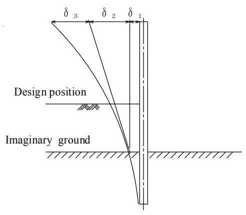
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.87 1.73	0.444 0.413	0.084 0.073	0.00 0.14	0.000 0.010
						ΣQ_{dw} ＝ 0.010

Therefore, modulus of deformation Q is calculated as below:

Q ＝ 18.403＋0.010 ＝ 18.413

Displacement



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2EI\beta^3}$$

$$= \frac{(1 + 0.4170 \times 1.93) \times 216.30}{2 \times 2.00 \times 10^8 \times 95760 \times 10^{-8} \times 0.4170^3} = 0.01407 \text{ m}$$

$$\delta_2 = \frac{(1 + 2\beta h_0) \times P_0}{2EI\beta^2} \times (H + L_k)$$

$$= \frac{(1 + 2 \times 0.4170 \times 1.93) \times 216.30}{2 \times 2.00 \times 10^8 \times 95760 \times 10^{-8} \times 0.4170^2} \times (2.60 + 1.60) = 0.03565 \text{ m}$$

$$\delta_3 = \frac{Q \times (H + L_k)^3}{EI}$$

$$= \frac{18.41 \times (2.60 + 1.60)^3}{2.00 \times 10^8 \times 95760 \times 10^{-8}} = 0.00712 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00152 m in consideration of following values:

Height from imaginary riverbed to top of SSP: L = 4.20 m

Horizontal load: P = 10.40

Moment: M = 3.85

$\delta = \delta_1 + \delta_2 + \delta_3$

= 0.01407＋0.03565＋0.00864

= 0.05836 m

= 58.36 ≦ δ_a = 75.00 mm (ok)

Where,

δ_1 : Displacement at imaginary ground

δ_2 : Displacement by angle of inclination slope at imaginary ground

δ_3 : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	114000 cm⁴ (original condition)
	I	=	114000 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 114000 × 10⁻⁸		=	2.280 × 10⁵

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 21745 kN/m³

Calculated value β = 0.39296 m⁻¹

Penetration length of SSP $D = 1.17 + \frac{3}{0.393} = 8.80$ m

Whole length of SSP L = 2.60－0.40＋8.80 = 11.00 m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 23162 kN/m³

Calculated value β = 0.39920 m⁻¹

Penetration length of SSP $D = 1.60 + \frac{3}{0.399} = 9.12$ m

Whole length of SSP L = 2.60－0.40＋9.12 = 11.32 m

Therefore, whole length of SSP is set as 11.50 m in consideration of round unit of SSP length.

8 Calculation Result

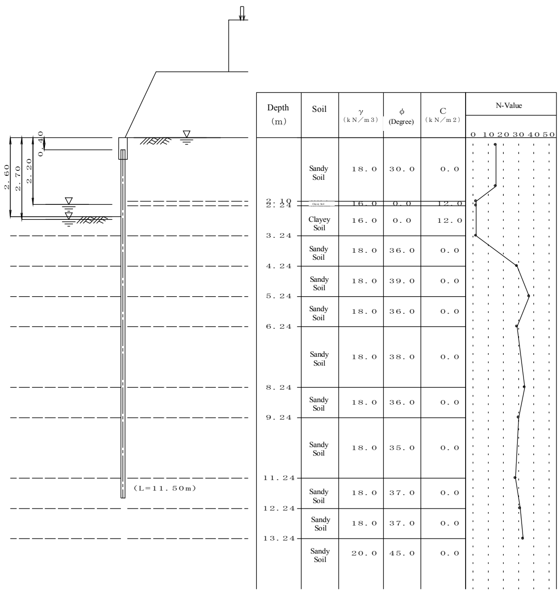
			Normal condition	Seismic condition
Inertia sectional moment	I (cm⁴)	114000		
Section modulus	Z (cm³)	3250		
Maximum bending moment	M_{max} (kN･m/m)		275.19	503.61
Stress intensity	σ (N/mm²)		97 (185)	178 (278)
Lateral displacement	δ (mm)		30.17 (50.0)	58.36 (75.0)
Penetration depth	D (m)		8.80	9.12
Whole length of SSP	L (m)	11.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 41_STA 15+409 - 15+441

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	9.7 kN/m	(Normal Condition)
		Pt'	=	19.8 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.95 m	(Normal Condition)
		Ht'	=	-0.75 m	(Seismic Condition)
	Moment	Mm	=	3.6 kN･m/m	(Normal Condition)
		Mm'	=	21.3 kN･m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.24	15
2	1.60	15
3	2.10	2
4	2.24	2
5	3.24	2
6	4.24	29
7	5.24	37
8	6.24	29
9	8.24	34
10	9.24	30

No	Depth (m)	N-Value
11	11.24	28
12	12.24	31
13	13.24	33
14	14.24	50

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.24	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
3	3.24	C	2.0	16.00	8.00	0.0	12.0	0.0	0.200	auto	auto	——	——
4	4.24	S	29.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
5	5.24	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
6	6.24	S	29.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
7	8.24	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
8	9.24	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
9	11.24	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
10	12.24	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
11	13.24	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
12	14.24	S	50.0	20.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

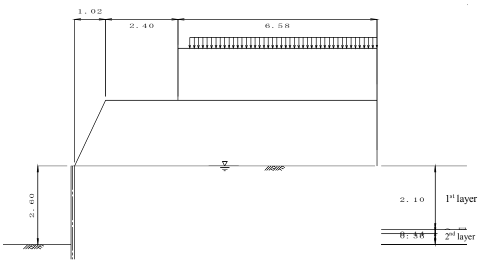
Note)
depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

2.309

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	1.02	10.00	10.00	2.18	18.0	30.0	0.0	auto	auto
2	Sandy soil	3.42	3.42	10.00	10.00	1.71	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	3.81	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus $E = 200000\ N/mm^2$
Inertia sectional moment $I_0 = 154000\ cm^4$
Sectional factor $Z_0 = 4160\ cm^3$

Corrosion margin $t_1 = 1.00$ mm (riverside) $t_2 = 1.00$ mm (landside)

Corrosion rate (to I_0) $\eta = 0.85$
Corrosion rate (to Z_0) $\eta = 0.87$
Section efficiency (to I_0) $\mu = 1.00$
Section efficiency (to Z_0) $\mu = 1.00$

Round unit of SSP length 0.50 m

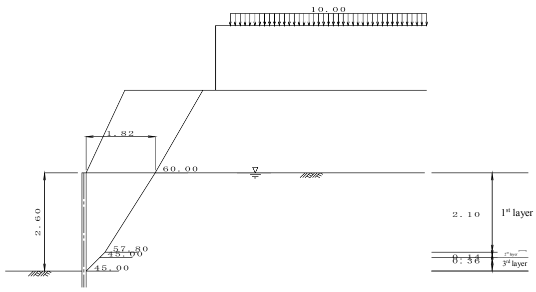
Allowable stress $\sigma_a = 185$ N/mm (Normal)
$\sigma_a' = 278$ N/mm (Seismic)

Allowable displacement $\delta_a = 50.0$ mm (Normal)
$\delta_a' = 75.0$ mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load
2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.24	Clayey Soil	0.0	10.0	12.0	25.00	41.81	25.48	45.00
2	2.24～ 2.10	Clayey Soil	0.0	10.0	12.0	22.12	41.81	21.95	45.00
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	41.81	20.58	57.80
4		Embankment	30.0	——	0.0	70.02	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.36	0.00	0.00	0.36	0.36
2	45.00	0.14	0.36	0.36	0.50	0.50
3	57.80	2.10	0.50	0.50	1.82	2.60
4	60.00	2.18	1.82	2.60	3.08	4.78

Therefore, width of acting load shall be set as 1.82 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.23	76.19
Σ			76.19

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

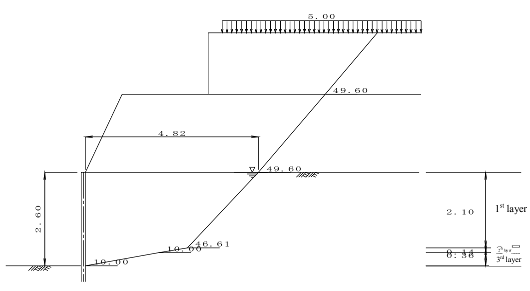
2-1-4 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times 1)+\Sigma P}{L}$$

$$= \frac{76.19 + 0.00 + 0.00}{1.82}$$

$$= 41.81\ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.24	Clayey Soil	0.0	10.0	12.0	25.00	72.55	25.48	0.200	11.31	10.00
2	2.24～ 2.10	Clayey Soil	0.0	10.0	12.0	22.12	72.55	21.95	0.200	11.31	10.00
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	72.55	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	70.02	5.00	0.00	0.200	11.31	49.60
5		Embankment	30.0	——	0.0	30.78	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
ζ : angle of active rupture (degree, ζ ≥ 10.00°)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m³) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m²)
C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	10.00	0.36	0.00	0.00	2.04	0.36
2	10.00	0.14	2.04	0.36	2.84	0.50
3	46.61	2.10	2.84	0.50	4.82	2.60
4	49.60	2.18	4.82	2.60	6.68	4.78
5	49.60	1.71	6.68	4.78	8.13	6.49

Therefore, width of acting load shall be set as 4.82 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	11.42	205.56
2	18.0	6.81	122.62
Σ			328.18

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	4.32	21.61
Σ			21.61

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

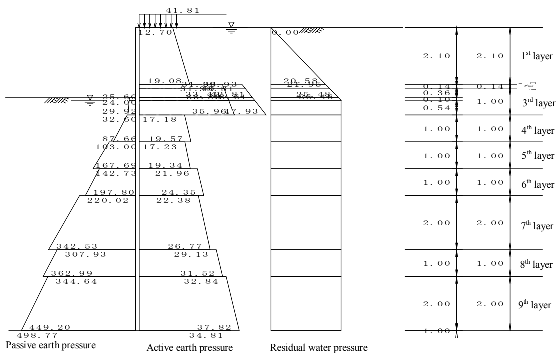
$$Q = \frac{\Sigma(\gamma \times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{328.18 + 21.61 + 0.00}{4.82}$$

$= 72.55$ kN/m²

3 Lateral Pressure

3-1 Normal Condition



Passive earth pressure   Active earth pressure   Residual water pressure

3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	41.809 62.809	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.24	Clayey soil	8.0	—	12.0 12.0	62.809 63.929	—— ——	—— ——
3	2.24～ 2.60	Clayey soil	8.0	—	12.0 12.0	63.929 66.809	—— ——	—— ——
4	2.60～ 2.70	Clayey soil	8.0	—	12.0 12.0	66.809 67.609	—— ——	—— ——
5	2.70～ 3.24	Clayey soil	8.0	—	12.0 12.0	67.609 71.929	—— ——	—— ——
6	3.24～ 4.24	Sandy soil	10.0	36.0	—— ——	71.929 81.929	0.24257 0.24257	0.23889 0.23889
7	4.24～ 5.24	Sandy soil	10.0	39.0	—— ——	81.929 91.929	0.21359 0.21359	0.21035 0.21035
8	5.24～ 6.24	Sandy soil	10.0	36.0	—— ——	91.929 101.929	0.24257 0.24257	0.23889 0.23889
9	6.24～ 8.24	Sandy soil	10.0	38.0	—— ——	101.929 121.929	0.22298 0.22298	0.21959 0.21959
10	8.24～ 9.24	Sandy soil	10.0	36.0	—— ——	121.929 131.929	0.24257 0.24257	0.23889 0.23889
11	9.24～ 11.24	Sandy soil	10.0	35.0	—— ——	131.929 151.929	0.25279 0.25279	0.24895 0.24895
12	11.24～ 12.24	Sandy soil	10.0	37.0	—— ——	151.929 161.929	0.23264 0.23264	0.22910 0.22910
13	12.24～ 13.24	Sandy soil	10.0	37.0	—— ——	161.929 171.929	0.23264 0.23264	0.22910 0.22910

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	13.24～ 14.24	Sandy soil	10.0	45.0	—— ——	171.929 181.929	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60～ 2.70	Clayey soil	16.0	0.0	12.0 12.0	0.000 1.600	—— ——	—— ——
5	2.70～ 3.24	Clayey soil	8.0	0.0	12.0 12.0	1.600 5.920	—— ——	—— ——
6	3.24～ 4.24	Sandy soil	10.0	36.0	—— ——	5.920 15.920	5.59154 5.59154	5.50659 5.50659
7	4.24～ 5.24	Sandy soil	10.0	39.0	—— ——	15.920 25.920	6.56948 6.56948	6.46967 6.46967
8	5.24～ 6.24	Sandy soil	10.0	36.0	—— ——	25.920 35.920	5.59154 5.59154	5.50659 5.50659
9	6.24～ 8.24	Sandy soil	10.0	38.0	—— ——	35.920 55.920	6.21981 6.21981	6.12532 6.12532
10	8.24～ 9.24	Sandy soil	10.0	36.0	—— ——	55.920 65.920	5.59154 5.59154	5.50659 5.50659
11	9.24～ 11.24	Sandy soil	10.0	35.0	—— ——	65.920 85.920	5.30876 5.30876	5.22810 5.22810
12	11.24～ 12.24	Sandy soil	10.0	37.0	—— ——	85.920 95.920	5.89457 5.89457	5.80501 5.80501
13	12.24～ 13.24	Sandy soil	10.0	37.0	—— ——	95.920 105.920	5.89457 5.89457	5.80501 5.80501
14	13.24～ 14.24	Sandy soil	10.0	45.0	—— ——	105.920 115.920	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

2.311

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	12.70 19.08	—— ——	12.70 19.08	0.00 20.58	—— ——
2	2.10～ 2.24	38.81 39.93	31.40 31.96	38.81 39.93	20.58 21.95	—— ——
3	2.24～ 2.60	39.93 42.81	31.96 33.40	39.93 42.81	21.95 25.48	—— ——
4	2.60～ 2.70	42.81 43.61	33.40 33.80	42.81 43.61	25.48 26.46	24.00 25.60
5	2.70～ 3.24	43.61 47.93	33.80 35.96	43.61 47.93	26.46 26.46	25.60 29.92
6	3.24～ 4.24	17.18 19.57	—— ——	17.18 19.57	26.46 26.46	32.60 87.66
7	4.24～ 5.24	17.23 19.34	—— ——	17.23 19.34	26.46 26.46	103.00 167.69
8	5.24～ 6.24	21.96 24.35	—— ——	21.96 24.35	26.46 26.46	142.73 197.80
9	6.24～ 8.24	22.38 26.77	—— ——	22.38 26.77	26.46 26.46	220.02 342.53
10	8.24～ 9.24	29.13 31.52	—— ——	29.13 31.52	26.46 26.46	307.93 362.99
11	9.24～ 11.24	32.84 37.82	—— ——	32.84 37.82	26.46 26.46	344.64 449.20
12	11.24～ 12.24	34.81 37.10	—— ——	34.81 37.10	26.46 26.46	498.77 556.82
13	12.24～ 13.24	37.10 39.39	—— ——	37.10 39.39	26.46 26.46	556.82 614.87
14	13.24～ 14.24	27.54 29.14	—— ——	27.54 29.14	26.46 26.46	974.84 1066.87

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

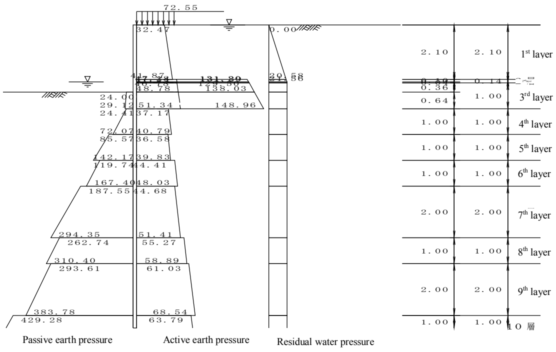
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	— —	72.55 93.55	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	— —
2	2.10～ 2.20	Clayey Soil	8.0	—	12.0 12.0	93.55 94.35	20.58 21.56	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
3	2.20～ 2.24	Clayey Soil	8.0	—	12.0 12.0	94.35 94.67	21.56 21.95	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
4	2.24～ 2.60	Clayey Soil	8.0	—	12.0 12.0	94.67 97.55	21.95 25.48	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
5	2.60～ 3.24	Clayey Soil	8.0	—	12.0 12.0	97.55 102.67	25.48 31.75	0.200 0.200	11.31 11.31	— —	— —	10.00 10.00
6	3.24～ 4.24	Sandy Soil	10.0	36.0	— —	102.67 112.67	31.75 41.55	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	— —
7	4.24～ 5.24	Sandy Soil	10.0	39.0	— —	112.67 122.67	41.55 51.35	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	— —
8	5.24～ 6.24	Sandy Soil	10.0	36.0	— —	122.67 132.67	51.35 61.15	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	— —
9	6.24～ 8.24	Sandy Soil	10.0	38.0	— —	132.67 152.67	61.15 80.75	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	— —
10	8.24～ 9.24	Sandy Soil	10.0	36.0	— —	152.67 162.67	80.75 90.55	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	— —
11	9.24～ 11.24	Sandy Soil	10.0	35.0	— —	162.67 182.67	90.55 110.15	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	— —
12	11.24～ 12.24	Sandy Soil	10.0	37.0	— —	182.67 192.67	110.15 119.95	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	— —
13	12.24～ 13.24	Sandy Soil	10.0	37.0	— —	192.67 202.67	119.95 129.75	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	— —
14	13.24～ 14.24	Sandy Soil	10.0	45.0	— —	202.67 212.67	129.75 139.55	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60～ 3.24	Clayey soil	8.00	0.0	12.0 12.0	0.000 5.120	0.00 6.27	0.200 0.200	11.31 11.31	— —	— —
6	3.24～ 4.24	Sandy soil	10.00	36.0	— —	5.120 15.120	6.27 16.07	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
7	4.24～ 5.24	Sandy soil	10.00	39.0	— —	15.120 25.120	16.07 25.87	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
8	5.24～ 6.24	Sandy soil	10.00	36.0	— —	25.120 35.120	25.87 35.67	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
9	6.24～ 8.24	Sandy soil	10.00	38.0	— —	35.120 55.120	35.67 55.27	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
10	8.24～ 9.24	Sandy soil	10.00	36.0	— —	55.120 65.120	55.27 65.07	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
11	9.24～ 11.24	Sandy soil	10.00	35.0	— —	65.120 85.120	65.07 84.67	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
12	11.24～ 12.24	Sandy soil	10.00	37.0	— —	85.120 95.120	84.67 94.47	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
13	12.24～ 13.24	Sandy soil	10.00	37.0	— —	95.120 105.120	94.47 104.27	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
14	13.24～ 14.24	Sandy soil	10.00	45.0	— —	105.120 115.120	104.27 114.07	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ = -10.00、β = 0.00、θ = $\tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	32.47 41.87	— —	32.47 41.87	0.00 20.58	— —
2	2.10～ 2.20	129.50 131.20	46.78 47.18	129.50 131.20	20.58 21.56	— —
3	2.20～ 2.24	131.20 131.89	47.18 47.34	131.20 131.89	21.56 21.56	— —
4	2.24～ 2.60	131.89 138.03	47.34 48.78	131.89 138.03	21.56 21.56	— —
5	2.60～ 3.24	138.03 148.96	48.78 51.34	138.03 148.96	21.56 21.56	24.00 29.12
6	3.24～ 4.24	37.17 40.79	— —	37.17 40.79	21.56 21.56	24.41 72.07
7	4.24～ 5.24	36.58 39.83	— —	36.58 39.83	21.56 21.56	85.57 142.17
8	5.24～ 6.24	44.41 48.03	— —	44.41 48.03	21.56 21.56	119.74 167.40
9	6.24～ 8.24	44.68 51.41	— —	44.68 51.41	21.56 21.56	187.55 294.35
10	8.24～ 9.24	55.27 58.89	— —	55.27 58.89	21.56 21.56	262.74 310.40
11	9.24～ 11.24	61.03 68.54	— —	61.03 68.54	21.56 21.56	293.61 383.78
12	11.24～ 12.24	63.79 67.28	— —	63.79 67.28	21.56 21.56	429.28 479.71
13	12.24～ 13.24	67.28 70.77	— —	67.28 70.77	21.56 21.56	479.71 530.14
14	13.24～ 14.24	52.44 55.03	— —	52.44 55.03	21.56 21.56	862.35 944.38

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c\cdot(\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h+Q) - 2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p\cdot[\Sigma\gamma h + \frac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h+Q) + 2C\sqrt{K_p}]\cdot\cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\gamma_w\cdot\sqrt{H\cdot y}$$

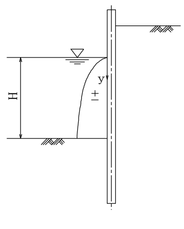
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

y : depth from water surface to the point where active water pressure is calculated



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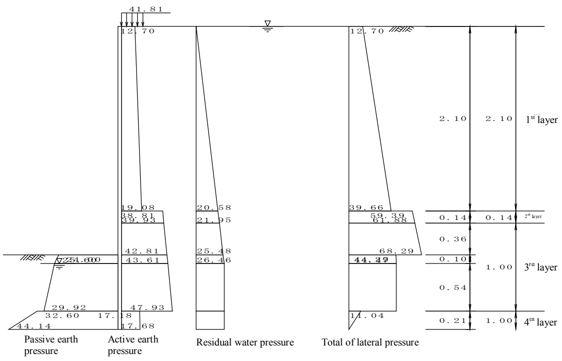
4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

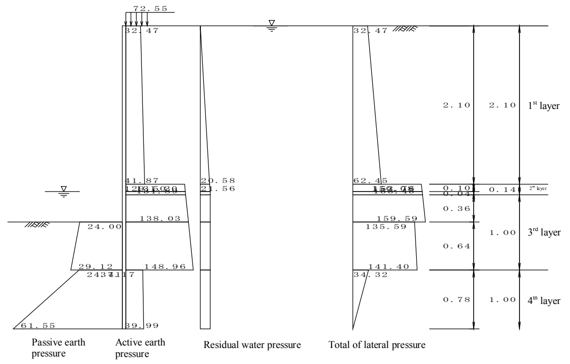


	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	12.70 19.08	0.00 20.58	—— ——	12.70 39.66
2	2.10～ 2.24	38.81 39.93	20.58 21.95	—— ——	59.39 61.88
3	2.24～ 2.60	39.93 42.81	21.95 25.48	—— ——	61.88 68.29
4	2.60～ 2.70	42.81 43.61	25.48 26.46	24.00 25.60	44.29 44.47
5	2.70～ 3.24	43.61 47.93	26.46 26.46	25.60 29.92	44.47 44.47
6	3.24～ 3.45	17.18 17.68	26.46 26.46	32.60 44.14	11.04 0.00
7	3.45～ 4.24	17.68 19.57	26.46 26.46	44.14 87.66	0.00 -41.63

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.85 m (GL -3.45 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	32.47 41.87	0.00 20.58	—— ——	32.47 62.45
2	2.10～ 2.20	129.50 131.20	20.58 21.56	—— ——	150.08 152.76
3	2.20～ 2.24	131.20 131.89	21.56 21.56	—— ——	152.76 153.45
4	2.24～ 2.60	131.89 138.03	21.56 21.56	—— ——	153.45 159.59
5	2.60～ 3.24	138.03 148.96	21.56 21.56	24.00 29.12	135.59 141.40
6	3.24～ 4.02	37.17 39.99	21.56 21.56	24.41 61.55	34.32 0.00
7	4.02～ 4.24	39.99 40.79	21.56 21.56	61.55 72.07	0.00 -9.72

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.42 m (GL -4.02 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4(original condition)
	I	=	130900 cm^4(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 130900 \times 10^{-8} = 2.618 \times 10^5$

	Depth (m)	N-value
1	0.24	15
2	1.60	15
3	2.10	2
4	2.24	2
5	3.24	2
6	4.24	29
7	5.24	37
8	6.24	29
9	8.24	34
10	9.24	30

	Depth (m)	N-value
11	11.24	28
12	12.24	31
13	13.24	33
14	14.24	50

5-2 Normal Condition

K_h = 26996 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.401 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.50 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.45 m) to 2.50 m depth (GL -5.95 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.45	0.79	7.7	29.0	14.49
2	4.24	1.00	29.0	37.0	33.00
3	5.24	0.71	37.0	31.4	24.11
L =Σh = 2.50			ΣA = 71.59		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{71.59}{2.50}$$

$$= 28.69$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 28.69^{0.406} = 26996$ kN/m^3

Kh (normal condition) = 26996 kN/m^3

5-3 Seismic Condition

K_h = 28223 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.405 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.47 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.02 m) and 2.47 m depth (GL -6.49 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.02	0.22	23.0	29.0	5.74
2	4.24	1.00	29.0	37.0	33.00
3	5.24	1.00	37.0	29.0	33.00
4	6.24	0.25	29.0	29.6	7.25
L =Σh = 2.47			ΣA = 78.99		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{78.99}{2.47}$$

$$= 32.01$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 32.01^{0.406} = 28223$ kN/m^3

Kh (seismic condition) = 28223 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	12.70 39.66	13.34 41.64	2.75 2.05	36.67 85.35
2	2.10～ 2.24	0.14	59.39 61.88	4.16 4.33	1.30 1.26	5.42 5.44
3	2.24～ 2.60	0.36	61.88 68.29	11.14 12.29	1.09 0.97	12.14 11.92
4	2.60～ 2.70	0.10	44.29 44.47	2.21 2.22	0.82 0.78	1.81 1.74
5	2.70～ 3.24	0.54	44.47 44.47	12.01 12.01	0.57 0.39	6.84 4.68
6	3.24～ 3.45	0.21	11.04 0.00	1.16 0.00	0.14 0.07	0.16 0.00
				ΣP = 116.51		ΣM = 172.17

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 9.7 kN/m
depth to acting position H_t = -0.95 m
moment M_m = 3.6 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 0.85 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 46.28$ kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$
$$= \frac{218.44}{126.21} = 1.73 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	32.47 62.45	34.09 65.57	3.32 2.62	113.16 171.74
2	2.10～ 2.20	0.10	150.08 152.76	7.50 7.64	1.89 1.85	14.15 14.15
3	2.20～ 2.24	0.04	152.76 153.45	3.06 3.07	1.81 1.79	5.52 5.50
4	2.24～ 2.60	0.36	153.45 159.59	27.62 28.73	1.66 1.54	45.83 44.22
5	2.60～ 3.24	0.64	135.59 141.40	43.39 45.25	1.21 0.99	52.32 44.91
6	3.24～ 4.02	0.78	34.32 0.00	13.37 0.00	0.52 0.26	6.95 0.00
				ΣP = 279.29		ΣM = 518.45

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 19.8 kN/m
depth to acting position H_t = -0.75 m
moment M_m = 21.3 kN·m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.42 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 115.73$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	1.69 1.55	0.00 0.21
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.21

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{634.40}{299.22} = 2.12 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.85
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 154000 cm⁴ (original condition)
I = 130900 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 130900 \times 10^{-8} = 2.618 \times 10^5$

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1}\frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 26996 kN/m³
calculated value β = 0.40070 m^{-1}
resultant earth force (lateral) P_0 = 126.21 kN/m
height of acting position of load h_0 = 1.73 m
moment M_0 = 218.44 kN·m/m

in consideration of ψ_m = 1.255,
maximum moment M_{max} = 274.11 kN·m/m
depth of generated position of M_{max} l_m = 0.990 m
depth of 1st fixed point l_i = 2.950 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 28223 kN/m³
calculated value β = 0.40518 m^{-1}
resultant earth force (lateral) P_0 = 299.22 kN/m
height of acting position of load h_0 = 2.12 m
moment M_0 = 634.40 kN·m/m

in consideration of ψ_m = 1.185,
maximum moment M_{max} = 751.69 kN·m/m
depth of generated position of M_{max} l_m = 0.870 m
depth of 1st fixed point l_i = 2.809 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.87
Section efficiency μ = 1.00
Module of section Z_0 = 4160 cm³ (original condition)
Z = 3619 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{274.11\times10^6}{3619\times10^3} = 76 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{751.69\times10^6}{3619\times10^3} = 208 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

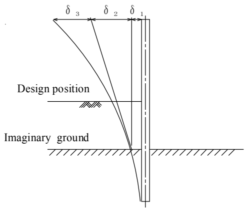
Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	2.75 2.05	0.797 0.594	0.233 0.142	13.34 41.64	3.111 5.895
2	2.10～ 2.24	1.30 1.26	0.378 0.364	0.062 0.058	4.16 4.33	0.259 0.252
3	2.24～ 2.60	1.09 0.97	0.316 0.281	0.045 0.036	11.14 12.29	0.497 0.440
4	2.60～ 2.70	0.82 0.78	0.237 0.227	0.026 0.024	2.21 2.22	0.057 0.053
5	2.70～ 3.24	0.57 0.39	0.165 0.113	0.013 0.006	12.01 12.01	0.155 0.074
6	3.24～ 3.45	0.14 0.07	0.041 0.020	0.001 0.000	1.16 0.00	0.001 0.000
						ΣQ = 10.794

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

2.314

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4007\times 1.73)\times 126.21}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.4007^3} = 0.00634 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4007\times 1.73)\times 126.21}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.4007^2}\times(2.60+0.85) = 0.01236 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.79\times(2.60+0.85)^3}{2.00\times 10^8\times 130900\times 10^{-8}} = 0.00169 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00072 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.45 m
Horizontal load: P = 9.70
Moment: M = 9.22

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.02 \text{ m、} h=L-H_m\text{、} H_m=0.80 \text{ m、ただ } .)$$

$$= \frac{21.30\times 3.22}{2\times 2.00\times 10^8\times 130900\times 10^{-8}}\times(2\times 4.02-3.22) = 0.00063 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.00634 + 0.01236 + 0.00249$
$= 0.02120$ m
$= 21.20 \leqq \delta a = 50.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.32 2.62	0.826 0.652	0.247 0.166	34.09 65.57	8.425 10.899
2	2.10～ 2.20	1.89 1.85	0.469 0.461	0.093 0.090	7.50 7.64	0.697 0.687
3	2.20～ 2.24	1.81 1.79	0.449 0.446	0.086 0.085	3.06 3.07	0.262 0.260
4	2.24～ 2.60	1.66 1.54	0.413 0.383	0.073 0.064	27.62 28.73	2.030 1.838
5	2.60～ 3.24	1.21 0.99	0.300 0.247	0.041 0.028	43.39 45.25	1.758 1.266
6	3.24～ 4.02	0.52 0.26	0.129 0.065	0.008 0.002	13.37 0.00	0.107 0.000
						ΣQ = 28.228

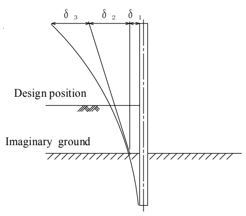
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.69 1.55	0.419 0.386	0.076 0.065	0.00 0.14	0.000 0.009
						ΣQ_{dw} = 0.009

Therefore, modulus of deformation Q is calculated as below:
Q = 28.228 + 0.009 = 28.237

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4052\times 2.12)\times 299.22}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.4052^3} = 0.01597 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4052\times 2.12)\times 299.22}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.4052^2}\times(2.60+1.42) = 0.03803 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{28.24\times(2.60+1.42)^3}{2.00\times 10^8\times 130900\times 10^{-8}} = 0.00700 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00209 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.02 m
Horizontal load: P = 19.80
Moment: M = 14.85

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.02 \text{ m、} h=L-H_m\text{、} H_m=0.80 \text{ m、ただし })$$

$$= \frac{21.30\times 3.22}{2\times 2.00\times 10^8\times 130900\times 10^{-8}}\times(2\times 4.02-3.22) = 0.00063 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01597 + 0.03803 + 0.00973$
$= 0.06373$ m
$= 63.73 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	154000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 154000 × 10^{-8}		=	3.080 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction $K_h = 26996$ kN/m^3
Calculated value $\beta = 0.38474$ m^{-1}

Penetration length of SSP $D = 0.85 + \frac{3}{0.385} = 8.65$ m
Whole length of SSP $L = 2.60 - 0.40 + 8.65 = 10.85$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 28223$ kN/m^3
Calculated value $\beta = 0.38904$ m^{-1}

Penetration length of SSP $D = 1.42 + \frac{3}{0.389} = 9.13$ m
Whole length of SSP $L = 2.60 - 0.40 + 9.13 = 11.33$ m

Therefore, whole length of SSP is set as 11.50 m in consideration of round unit of SSP length.

8 Calculation Result

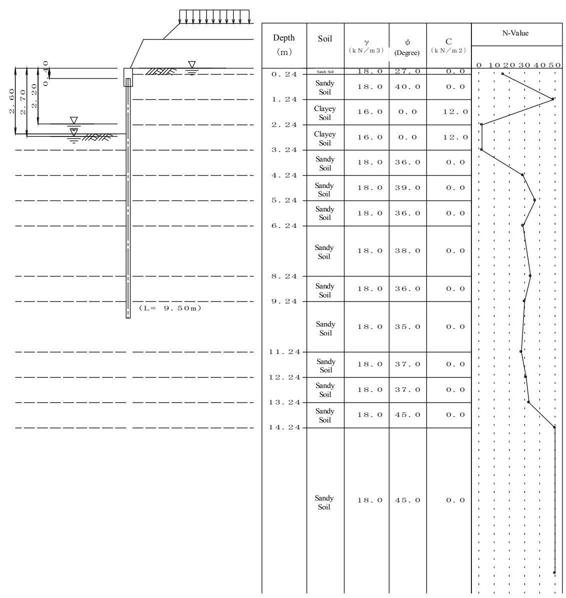
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	154000		
Section modulus	Z (cm^3)	4160		
Maximum bending moment	M_{max} (kN·m/m)		274.11	751.69
Stress intensity	σ (N/mm^2)		76 (185)	208 (278)
Lateral displacement	δ (mm)		21.20 (50.0)	63.73 (75.0)
Penetration depth	D (m)		8.65	9.13
Whole length of SSP	L (m)	11.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 42_STA 15+476 - 15+494

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \dfrac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	3.5 kN/m	(Normal Condition)
		Pt'	=	9.5 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.53 m	(Normal Condition)
		Ht'	=	-0.27 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN･m/m	(Normal Condition)
		Mm'	=	3.7 kN･m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \dfrac{\Sigma\gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value
1	0.24	16
2	1.24	49
3	2.24	2
4	3.24	2
5	4.24	29
6	5.24	37
7	6.24	29
8	8.24	34
9	9.24	30
10	11.24	28

No	Depth (m)	N-Value
11	12.24	31
12	13.24	33
13	14.24	50
14	20.00	50

2.317

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

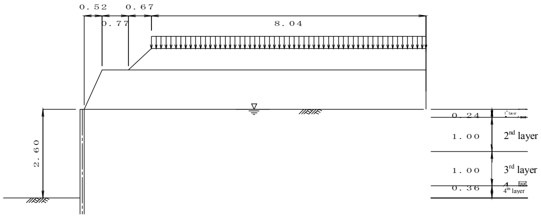
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	0.24	S	16.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
2	1.24	S	49.0	18.00	10.00	40.0	0.0	0.0	0.200	auto	auto	——	——
3	2.24	C	2.0	16.00	10.00	0.0	12.0	0.0	0.200	auto	auto	——	——
4	3.24	C	2.0	16.00	10.00	0.0	12.0	0.0	0.200	auto	auto	——	——
5	4.24	S	29.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
6	5.24	S	37.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
7	6.24	S	29.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
8	8.24	S	34.0	18.00	10.00	38.0	0.0	0.0	0.200	auto	auto	——	——
9	9.24	S	30.0	18.00	10.00	36.0	0.0	0.0	0.200	auto	auto	——	——
10	11.24	S	28.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
11	12.24	S	31.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
12	13.24	S	33.0	18.00	10.00	37.0	0.0	0.0	0.200	auto	auto	——	——
13	14.24	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
14	20.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m^3)	ϕ (degree)	C (kN/m^2)	Normal	Seismic
1	Sandy soil	0.00	0.52	10.00	10.00	1.15	18.0	30.0	0.0	auto	auto
2	Sandy soil	1.29	1.96	10.00	10.00	0.63	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m^2)	Seismic (kN/m^2)
1	1.96	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm^2
Inertia sectional moment I_0 = 56700 cm^4
Sectional factor Z_0 = 2700 cm^3

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.88
Corrosion rate (to Z_0) η = 0.88
Section efficiency (to I_0) μ = 0.80
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 180 N/mm (Normal)
σ_a' = 270 N/mm (Seismic)

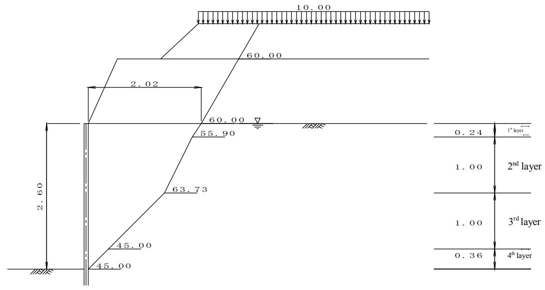
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	Σγh (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	Angle of rupture Z (degree)
1	2.60～ 2.24	Clayey Soil	0.0	10.0	12.0	26.00	33.77	25.48	45.00
2	2.24～ 1.24	Clayey Soil	0.0	10.0	12.0	22.40	33.77	21.95	45.00
3	1.24～ 0.24	Sandy Soil	40.0	10.0	0.0	12.40	33.77	12.15	63.73
4	0.24～ 0.00	Sandy Soil	27.0	10.0	0.0	2.40	33.77	2.35	55.90
5		Embankment	30.0	—	0.0	32.04	10.00	0.00	60.00
6		Embankment	30.0	—	0.0	11.34	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,

ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.36	0.00	0.00	0.36	0.36
2	45.00	1.00	0.36	0.36	1.36	1.36
3	63.73	1.00	1.36	1.36	1.85	2.36
4	55.90	0.24	1.85	2.36	2.02	2.60
5	60.00	1.15	2.02	2.60	2.68	3.75
6	60.00	0.63	2.68	3.75	3.04	4.38

Therefore, width of acting load shall be set as 2.02 m

2-1-3 Acting Load by Embankment

No	γ (kN/m^3)	A (m^2)	γ X A (kN/m)
1	18.0	2.40	43.22
2	18.0	0.78	14.03
Σ			57.25

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m^2)	l (m)	Q X l (kN/m)
1	10.0	1.08	10.84
Σ			10.84

Q: surcharge load
l : width of surcharge load set by line of active rupture

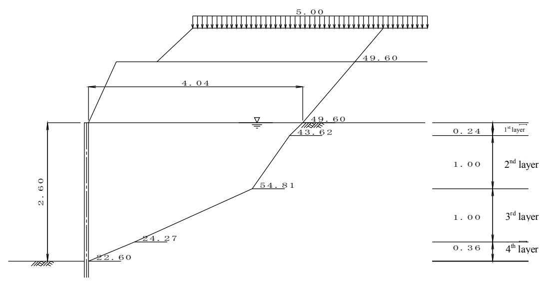
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{57.25 + 10.84 + 0.00}{2.02}$$

$$= 33.77 \ kN/m^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m^2)	Σγh (kN/m^2)	Q (kN/m^2)	γwhw (kN/m^2)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.24	Clayey Soil	0.0	10.0	12.0	26.00	36.60	25.48	0.200	11.31	22.60
2	2.24～ 1.24	Clayey Soil	0.0	10.0	12.0	22.40	36.60	21.95	0.200	11.31	24.27
3	1.24～ 0.24	Sandy Soil	40.0	10.0	0.0	12.40	36.60	12.15	0.200	11.31	54.81
4	0.24～ 0.00	Sandy Soil	27.0	10.0	0.0	2.40	36.60	2.35	0.200	11.31	43.62
5		Embankment	30.0	—	0.0	32.04	5.00	0.00	0.200	11.31	49.60
6		Embankment	30.0	—	0.0	11.34	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta)+\sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,

ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
ϕ : internal friction angle (degree)
δ : wall friction angle (degree)
θ : earthquake combination angle (degree)
$\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
γ : unit weight of soil (kN/m^3) (ascending force considered under WL)
h : thickness of layer (m)
Q : surcharge load (kN/m^2)
C cohesive force of soil (kN/m^2)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	22.60	0.36	0.00	0.00	0.86	0.36
2	24.27	1.00	0.86	0.36	3.08	1.36
3	54.81	1.00	3.08	1.36	3.79	2.36
4	43.62	0.24	3.79	2.36	4.04	2.60
5	49.60	1.15	4.04	2.60	5.02	3.75
6	49.60	0.63	5.02	3.75	5.55	4.38

Therefore, width of acting load shall be set as 4.04 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	4.91	88.36
2	18.0	2.31	41.52
Σ			129.88

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	3.59	17.97
Σ			17.97

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

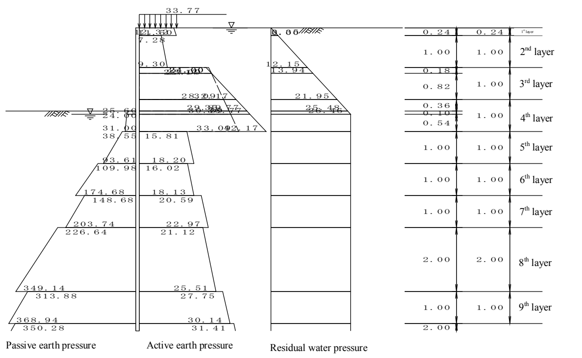
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{129.88 + 17.97 + 0.00}{4.04}$$

$$= 36.60 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 0.24	Sandy soil	10.0	27.0	——	33.772 36.172	0.34585 0.34585	0.34060 0.34060
2	0.24～ 1.24	Sandy soil	10.0	40.0	——	36.172 46.172	0.20447 0.20447	0.20137 0.20137
3	1.24～ 1.42	Clayey soil	10.0	—	12.0 12.0	46.172 48.000	——	——
4	1.42～ 2.24	Clayey soil	10.0	—	12.0 12.0	48.000 56.172	——	——
5	2.24～ 2.60	Clayey soil	10.0	—	12.0 12.0	56.172 59.772	——	——
6	2.60～ 2.70	Clayey soil	10.0	—	12.0 12.0	59.772 60.772	——	——
7	2.70～ 3.24	Clayey soil	10.0	—	12.0 12.0	60.772 66.172	——	——
8	3.24～ 4.24	Sandy soil	10.0	36.0	——	66.172 76.172	0.24257 0.24257	0.23889 0.23889
9	4.24～ 5.24	Sandy soil	10.0	39.0	——	76.172 86.172	0.21359 0.21359	0.21035 0.21035
10	5.24～ 6.24	Sandy soil	10.0	36.0	——	86.172 96.172	0.24257 0.24257	0.23889 0.23889
11	6.24～ 8.24	Sandy soil	10.0	38.0	——	96.172 116.172	0.22298 0.22298	0.21959 0.21959
12	8.24～ 9.24	Sandy soil	10.0	36.0	——	116.172 126.172	0.24257 0.24257	0.23889 0.23889
13	9.24～ 11.24	Sandy soil	10.0	35.0	——	126.172 146.172	0.25279 0.25279	0.24895 0.24895

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
14	11.24～ 12.24	Sandy soil	10.0	37.0	——	146.172 156.172	0.23264 0.23264	0.22910 0.22910
15	12.24～ 13.24	Sandy soil	10.0	37.0	——	156.172 166.172	0.23264 0.23264	0.22910 0.22910
16	13.24～ 14.24	Sandy soil	10.0	45.0	——	166.172 176.172	0.16262 0.16262	0.16015 0.16015
17	14.24～ 20.00	Sandy soil	10.0	45.0	——	176.172 233.772	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
6	2.60～ 2.70	Clayey soil	16.0	0.0	12.0 12.0	0.000 1.600	——	——
7	2.70～ 3.24	Clayey soil	10.0	0.0	12.0 12.0	1.600 7.000	——	——
8	3.24～ 4.24	Sandy soil	10.0	36.0	——	7.000 17.000	5.59154 5.59154	5.50659 5.50659
9	4.24～ 5.24	Sandy soil	10.0	39.0	——	17.000 27.000	6.56948 6.56948	6.46967 6.46967
10	5.24～ 6.24	Sandy soil	10.0	36.0	——	27.000 37.000	5.59154 5.59154	5.50659 5.50659
11	6.24～ 8.24	Sandy soil	10.0	38.0	——	37.000 57.000	6.21981 6.21981	6.12532 6.12532
12	8.24～ 9.24	Sandy soil	10.0	36.0	——	57.000 67.000	5.59154 5.59154	5.50659 5.50659
13	9.24～ 11.24	Sandy soil	10.0	35.0	——	67.000 87.000	5.30876 5.30876	5.22810 5.22810
14	11.24～ 12.24	Sandy soil	10.0	37.0	——	87.000 97.000	5.89457 5.89457	5.80501 5.80501
15	12.24～ 13.24	Sandy soil	10.0	37.0	——	97.000 107.000	5.89457 5.89457	5.80501 5.80501
16	13.24～ 14.24	Sandy soil	10.0	45.0	——	107.000 117.000	9.34548 9.34548	9.20351 9.20351
17	14.24～ 20.00	Sandy soil	10.0	45.0	——	117.000 174.600	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

2.319

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 0.24	11.50 12.32	——	11.50 12.32	0.00 2.35	——
2	0.24～ 1.24	7.28 9.30	——	7.28 9.30	2.35 12.15	——
3	1.24～ 1.42	22.17 24.00	23.09 24.00	23.09 24.00	12.15 13.94	——
4	1.42～ 2.24	24.00 32.17	24.00 28.09	24.00 32.17	13.94 21.95	——
5	2.24～ 2.60	32.17 35.77	28.09 29.89	32.17 35.77	21.95 25.48	——
6	2.60～ 2.70	35.77 36.77	29.89 30.39	35.77 36.77	25.48 26.46	24.00 25.60
7	2.70～ 3.24	36.77 42.17	30.39 33.09	36.77 42.17	26.46 26.46	25.60 31.00
8	3.24～ 4.24	15.81 18.20	——	15.81 18.20	26.46 26.46	38.55 93.61
9	4.24～ 5.24	16.02 18.13	——	16.02 18.13	26.46 26.46	109.98 174.68
10	5.24～ 6.24	20.59 22.97	——	20.59 22.97	26.46 26.46	148.68 203.74
11	6.24～ 8.24	21.12 25.51	——	21.12 25.51	26.46 26.46	226.64 349.14
12	8.24～ 9.24	27.75 30.14	——	27.75 30.14	26.46 26.46	313.88 368.94
13	9.24～ 11.24	31.41 36.39	——	31.41 36.39	26.46 26.46	350.28 454.85
14	11.24～ 12.24	33.49 35.78	——	33.49 35.78	26.46 26.46	505.04 563.09
15	12.24～ 13.24	35.78 38.07	——	35.78 38.07	26.46 26.46	563.09 621.14
16	13.24～ 14.24	26.61 28.21	——	26.61 28.21	26.46 26.46	984.78 1076.81
17	14.24～ 20.00	28.21 37.44	——	28.21 37.44	26.46 26.46	1076.81 1606.93

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

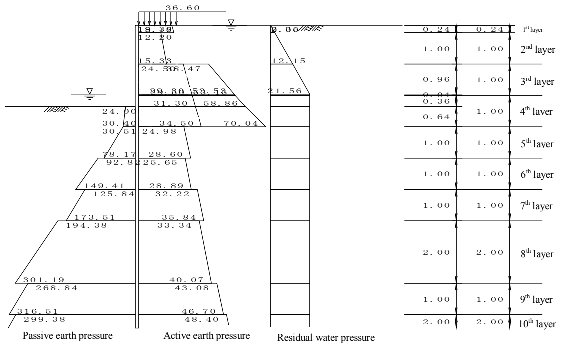
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 0.24	Sandy Soil	10.0	27.0	—— ——	36.60 39.00	0.00 2.35	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
2	0.24～ 1.24	Sandy Soil	10.0	40.0	—— ——	39.00 49.00	2.35 12.15	0.200 0.200	11.31 11.31	0.31772 0.31772	0.31289 0.31289	—— ——
3	1.24～ 2.20	Clayey Soil	10.0	—	12.0 12.0	49.00 58.60	12.15 21.56	0.200 0.200	11.31 11.31	—— ——	—— ——	28.16 24.45
4	2.20～ 2.24	Clayey Soil	10.0	—	12.0 12.0	58.60 59.00	21.56 21.95	0.200 0.200	11.31 11.31	—— ——	—— ——	24.45 24.27
5	2.24～ 2.60	Clayey Soil	10.0	—	12.0 12.0	59.00 62.60	21.95 25.48	0.200 0.200	11.31 11.31	—— ——	—— ——	24.27 22.60
6	2.60～ 3.24	Clayey Soil	10.0	—	12.0 12.0	62.60 69.00	25.48 31.75	0.200 0.200	11.31 11.31	—— ——	—— ——	22.60 19.10
7	3.24～ 4.24	Sandy Soil	10.0	36.0	—— ——	69.00 79.00	31.75 41.55	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—— ——
8	4.24～ 5.24	Sandy Soil	10.0	39.0	—— ——	79.00 89.00	41.55 51.35	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	—— ——
9	5.24～ 6.24	Sandy Soil	10.0	36.0	—— ——	89.00 99.00	51.35 61.15	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—— ——
10	6.24～ 8.24	Sandy Soil	10.0	38.0	—— ——	99.00 119.00	61.15 80.75	0.200 0.200	11.31 11.31	0.34194 0.34194	0.33674 0.33674	—— ——
11	8.24～ 9.24	Sandy Soil	10.0	36.0	—— ——	119.00 129.00	80.75 90.55	0.200 0.200	11.31 11.31	0.36758 0.36758	0.36200 0.36200	—— ——
12	9.24～ 11.24	Sandy Soil	10.0	35.0	—— ——	129.00 149.00	90.55 110.15	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	—— ——
13	11.24～ 12.24	Sandy Soil	10.0	37.0	—— ——	149.00 159.00	110.15 119.95	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——
14	12.24～ 13.24	Sandy Soil	10.0	37.0	—— ——	159.00 169.00	119.95 129.75	0.200 0.200	11.31 11.31	0.35458 0.35458	0.34919 0.34919	—— ——

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
15	13.24～ 14.24	Sandy Soil	10.0	45.0	—— ——	169.00 179.00	129.75 139.55	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
16	14.24～ 20.00	Sandy Soil	10.0	45.0	—— ——	179.00 236.60	139.55 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}}\cdot\tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
6	2.60～ 3.24	Clayey soil	10.00	0.0	12.0 12.0	0.000 6.400	0.00 6.27	0.200 0.200	11.31 11.31	—— ——	—— ——
7	3.24～ 4.24	Sandy soil	10.00	36.0	—— ——	6.400 16.400	6.27 16.07	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
8	4.24～ 5.24	Sandy soil	10.00	39.0	—— ——	16.400 26.400	16.07 25.87	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
9	5.24～ 6.24	Sandy soil	10.00	36.0	—— ——	26.400 36.400	25.87 35.67	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
10	6.24～ 8.24	Sandy soil	10.00	38.0	—— ——	36.400 56.400	35.67 55.27	0.200 0.200	11.31 11.31	5.42254 5.42254	5.34016 5.34016
11	8.24～ 9.24	Sandy soil	10.00	36.0	—— ——	56.400 66.400	55.27 65.07	0.200 0.200	11.31 11.31	4.84018 4.84018	4.76665 4.76665
12	9.24～ 11.24	Sandy soil	10.00	35.0	—— ——	66.400 86.400	65.07 84.67	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
13	11.24～ 12.24	Sandy soil	10.00	37.0	—— ——	86.400 96.400	84.67 94.47	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
14	12.24～ 13.24	Sandy soil	10.00	37.0	—— ——	96.400 106.400	94.47 104.27	0.200 0.200	11.31 11.31	5.12098 5.12098	5.04318 5.04318
15	13.24～ 14.24	Sandy soil	10.00	45.0	—— ——	106.400 116.400	104.27 114.07	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
16	14.24～ 20.00	Sandy soil	10.00	45.0	—— ——	116.400 174.000	114.07 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ= -10.00、β = 0.00、θ = $\tan^{-1}$k

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 0.24	18.19 19.38	—— ——	18.19 19.38	0.00 2.35	—— ——
2	0.24～ 1.24	12.20 15.33	—— ——	12.20 15.33	2.35 12.15	—— ——
3	1.24～ 2.20	38.47 52.53	24.50 29.30	38.47 52.53	12.15 21.56	—— ——
4	2.20～ 2.24	52.53 53.15	29.30 29.50	52.53 53.15	21.56 21.56	—— ——
5	2.24～ 2.60	53.15 58.86	29.50 31.30	53.15 58.86	21.56 21.56	—— ——
6	2.60～ 3.24	58.86 70.04	31.30 34.50	58.86 70.04	21.56 21.56	24.00 30.40
7	3.24～ 4.24	24.98 28.60	—— ——	24.98 28.60	21.56 21.56	30.51 78.17
8	4.24～ 5.24	25.65 28.89	—— ——	25.65 28.89	21.56 21.56	92.82 149.41
9	5.24～ 6.24	32.22 35.84	—— ——	32.22 35.84	21.56 21.56	125.84 173.51
10	6.24～ 8.24	33.34 40.07	—— ——	33.34 40.07	21.56 21.56	194.38 301.19
11	8.24～ 9.24	43.08 46.70	—— ——	43.08 46.70	21.56 21.56	268.84 316.51
12	9.24～ 11.24	48.40 55.90	—— ——	48.40 55.90	21.56 21.56	299.38 389.55
13	11.24～ 12.24	52.03 55.52	—— ——	52.03 55.52	21.56 21.56	435.73 486.16
14	12.24～ 13.24	55.52 59.01	—— ——	55.52 59.01	21.56 21.56	486.16 536.59
15	13.24～ 14.24	43.73 46.31	—— ——	43.73 46.31	21.56 21.56	872.85 954.88
16	14.24～ 20.00	46.31 61.22	—— ——	46.31 61.22	21.56 21.56	954.88 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$

$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

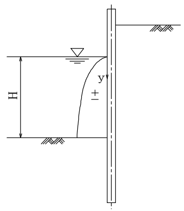
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

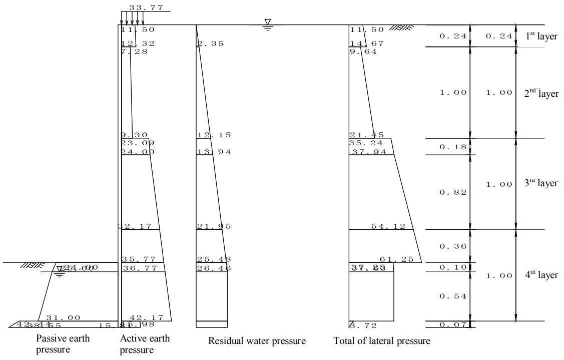
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

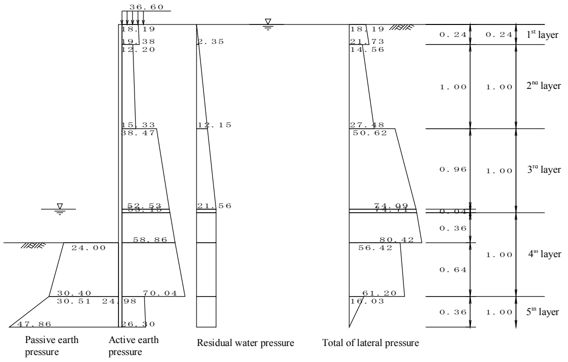


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 0.24	11.50 12.32	0.00 2.35	—— ——	11.50 14.67
2	0.24～ 1.24	7.28 9.30	2.35 12.15	—— ——	9.64 21.45
3	1.24～ 1.42	23.09 24.00	12.15 13.94	—— ——	35.24 37.94
4	1.42～ 2.24	24.00 32.17	13.94 21.95	—— ——	37.94 54.12
5	2.24～ 2.60	32.17 35.77	21.95 25.48	—— ——	54.12 61.25
6	2.60～ 2.70	35.77 36.77	25.48 26.46	24.00 25.60	37.25 37.63
7	2.70～ 3.24	36.77 42.17	26.46 26.46	25.60 31.00	37.63 37.63
8	3.24～ 3.31	15.81 15.98	26.46 26.46	38.55 42.44	3.72 0.00
9	3.31～ 4.24	15.98 18.20	26.46 26.46	42.44 93.61	0.00 -48.96

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 0.71 m (GL -3.31 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 0.24	18.19 19.38	0.00 2.35	—— ——	18.19 21.73
2	0.24～ 1.24	12.20 15.33	2.35 12.15	—— ——	14.56 27.48
3	1.24～ 2.20	38.47 52.53	12.15 21.56	—— ——	50.62 74.09
4	2.20～ 2.24	52.53 53.15	21.56 21.56	—— ——	74.09 74.71
5	2.24～ 2.60	53.15 58.86	21.56 21.56	—— ——	74.71 80.42
6	2.60～ 3.24	58.86 70.04	21.56 21.56	24.00 30.40	56.42 61.20
7	3.24～ 3.60	24.98 26.30	21.56 21.56	30.51 47.86	16.03 0.00
8	3.60～ 4.24	26.30 28.60	21.56 21.56	47.86 78.17	0.00 -28.01

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.00 m (GL -3.60 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.88
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	56700 cm⁴(original condition)
	I	=	39917 cm⁴(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 39917 \times 10^{-8} = 7.983 \times 10^4$

	Depth (m)	N-value
1	0.24	16
2	1.24	49
3	2.24	2
4	3.24	2
5	4.24	29
6	5.24	37
7	6.24	29
8	8.24	34
9	9.24	30
10	11.24	28

	Depth (m)	N-value
11	12.24	31
12	13.24	33
13	14.24	50
14	20.00	50

5-2 Normal Condition

K_h = 25420 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.531 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.88 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.31 m) to 1.88 m depth (GL -5.19 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.31	0.93	3.9	29.0	15.29
2	4.24	0.95	29.0	36.6	31.28
	L =Σh = 1.88				ΣA = 46.57

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{46.57}{1.88} = 24.74$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 24.74^{0.406} = 25420$ kN/m³
Kh (normal condition) = 25420 kN/m³

5-3 Seismic Condition

K_h = 27132 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.540 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 1.85 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.60 m) and 1.85 m depth (GL -5.46 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.60	0.64	11.8	29.0	12.98
2	4.24	1.00	29.0	37.0	33.00
3	5.24	0.22	37.0	35.3	7.81
	L =Σh = 1.85				ΣA = 53.80

A: (upper N-value + lower N-value) × h/2

Average N-value
$$N' = \frac{\Sigma A}{L} = \frac{53.80}{1.85} = 29.04$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 29.04^{0.406} = 27132$ kN/m³
Kh (seismic condition) = 27132 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN･m)
1	0.00～ 0.24	0.24	11.50 14.67	1.38 1.76	3.23 3.15	4.46 5.55
2	0.24～ 1.24	1.00	9.64 21.45	4.82 10.72	2.74 2.40	13.19 25.78
3	1.24～ 1.42	0.18	35.24 37.94	3.22 3.47	2.01 1.95	6.47 6.76
4	1.42～ 2.24	0.82	37.94 54.12	15.50 22.12	1.62 1.34	25.05 29.70
5	2.24～ 2.60	0.36	54.12 61.25	9.74 11.03	0.95 0.83	9.26 9.16
6	2.60～ 2.70	0.10	37.25 37.63	1.86 1.88	0.68 0.64	1.26 1.21
7	2.70～ 3.24	0.54	37.63 37.63	10.16 10.16	0.43 0.25	4.38 2.55
8	3.24～ 3.31	0.07	3.72 0.00	0.13 0.00	0.05 0.02	0.01 0.00
				ΣP = 107.96		ΣM = 144.78

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 3.5 kN/m
depth to acting position H_t = -0.53 m
moment M_m = 0.0 kN･m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 0.71 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 13.44$ kN･m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{158.22}{111.46} = 1.42 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN･m)
1	0.00～ 0.24	0.24	18.19 21.73	2.18 2.61	3.52 3.44	7.69 8.98
2	0.24～ 1.24	1.00	14.56 27.48	7.28 13.74	3.03 2.70	22.06 37.07
3	1.24～ 2.20	0.96	50.62 74.09	24.30 35.56	2.04 1.72	49.66 61.31
4	2.20～ 2.24	0.04	74.09 74.71	1.48 1.49	1.39 1.38	2.06 2.06
5	2.24～ 2.60	0.36	74.71 80.42	13.45 14.47	1.24 1.12	16.73 16.27
6	2.60～ 3.24	0.64	56.42 61.20	18.05 19.58	0.79 0.58	14.27 11.31
7	3.24～ 3.60	0.36	16.03 0.00	2.92 0.00	0.24 0.12	0.71 0.00
				ΣP = 157.13		ΣM = 250.18

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 9.5 kN/m
depth to acting position H_t = -0.27 m
moment M_m = 3.7 kN･m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.00 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 40.50$ kN･m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN･m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	1.27 1.14	0.00 0.16
				ΣPdw = 0.14		ΣMdw = 0.16

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{290.83}{166.76} = 1.74 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 0.80
Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 56700 cm⁴ (original condition)
I = 39917 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 39917 \times 10^{-8}$ = 7.983×10^4

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 25420 kN/m³
calculated value β = 0.53117 m⁻¹
resultant earth force (lateral) P_0 = 111.46 kN/m
height of acting position of load h_0 = 1.42 m
moment M_0 = 158.22 kN･m/m

in consideration of ψ_m = 1.225,
maximum moment M_{max} = 193.84 kN･m/m
depth of generated position of M_{max} l_m = 0.714 m
depth of 1st fixed point l_i = 2.193 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 27132 kN/m³
calculated value β = 0.53989 m⁻¹
resultant earth force (lateral) P_0 = 166.76 kN/m
height of acting position of load h_0 = 1.74 m
moment M_0 = 290.83 kN･m/m

in consideration of ψ_m = 1.161,
maximum moment M_{max} = 337.52 kN･m/m
depth of generated position of M_{max} l_m = 0.618 m
depth of 1st fixed point l_i = 2.073 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.88
Section efficiency μ = 1.00
Module of section Z_0 = 2700 cm³ (original condition)
Z = 2376 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{193.84\times10^6}{2376\times10^3} = 82 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{337.52\times10^6}{2376\times10^3} = 142 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

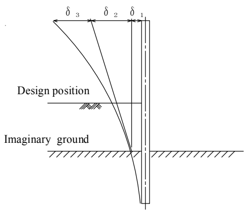
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.24	3.23 3.15	0.976 0.952	0.321 0.309	1.38 1.76	0.443 0.544
2	0.24～ 1.24	2.74 2.40	0.827 0.726	0.248 0.200	4.82 10.72	1.193 2.143
3	1.24～ 1.42	2.01 1.95	0.607 0.589	0.147 0.139	3.22 3.47	0.473 0.483
4	1.42～ 2.24	1.62 1.34	0.488 0.406	0.100 0.071	15.50 22.12	1.546 1.574
5	2.24～ 2.60	0.95 0.83	0.287 0.251	0.037 0.029	9.74 11.03	0.363 0.318
6	2.60～ 2.70	0.68 0.64	0.205 0.195	0.020 0.018	1.86 1.88	0.036 0.033
7	2.70～ 3.24	0.43 0.25	0.130 0.076	0.008 0.003	10.16 10.16	0.082 0.028
8	3.24～ 3.31	0.05 0.02	0.014 0.007	0.000 0.000	0.13 0.00	0.000 0.000
						ΣQ = 9.261

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5312\times 1.42)\times 111.46}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5312^3} = 0.00817 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.5312\times 1.42)\times 111.46}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5312^2}\times(2.60+0.71) = 0.02054 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{9.26\times(2.60+0.71)^3}{2.00\times 10^8\times 39917\times 10^{-8}} = 0.00421 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00066 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.31 m
Horizontal load: P = 3.50
Moment: M = 1.86

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.00817+0.02054+0.00487$
$= 0.03358$ m
$= 33.58 \leqq \delta a = 50.00$ mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 0.24	3.52 3.44	0.978 0.956	0.322 0.311	2.18 2.61	0.703 0.812
2	0.24～ 1.24	3.03 2.70	0.841 0.748	0.254 0.210	7.28 13.74	1.852 2.889
3	1.24～ 2.20	2.04 1.72	0.567 0.478	0.130 0.096	24.30 35.56	3.169 3.420
4	2.20～ 2.24	1.39 1.38	0.386 0.382	0.065 0.064	1.48 1.49	0.096 0.095
5	2.24～ 2.60	1.24 1.12	0.345 0.312	0.053 0.044	13.45 14.47	0.709 0.631
6	2.60～ 3.24	0.79 0.58	0.219 0.160	0.022 0.012	18.05 19.58	0.403 0.238
7	3.24～ 3.60	0.24 0.12	0.067 0.034	0.002 0.001	2.92 0.00	0.006 0.000
						ΣQ = 15.022

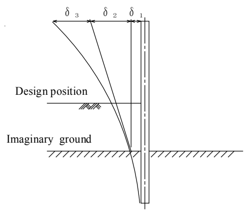
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	1.27 1.14	0.353 0.316	0.055 0.045	0.00 0.14	0.000 0.006
						ΣQ_{dw} = 0.006

Therefore, modulus of deformation Q is calculated as below:
Q = 15.022＋0.006 = 15.028

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.5399\times 1.74)\times 166.76}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5399^3} = 0.01289 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.5399\times 1.74)\times 166.76}{2\times 2.00\times 10^8\times 39917\times 10^{-8}\times 0.5399^2}\times(2.60+1.00) = 0.03723 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{15.03\times(2.60+1.00)^3}{2.00\times 10^8\times 39917\times 10^{-8}} = 0.00881 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00207 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.60 m
Horizontal load: P = 9.50
Moment: M = 2.57

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=3.60\text{ m、}h=L-H_m\text{、}H_m=0.80\text{ m、ただし }h\leqq L)$$

$$= \frac{3.70\times 2.80}{2\times 2.00\times 10^8\times 39917\times 10^{-8}}\times(2\times 3.60-2.80) = 0.00029 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
$= 0.01289+0.03723+0.01116$
$= 0.06128$ m
$= 61.28 \leqq \delta_a = 75.00$ mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	56700 cm^4 (original condition)
	I	=	56700 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 56700 × 10^{-8}		=	1.134 × 10^5

7-1 Penetration Depth and Whole Length of SSP（Chang）

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 25420 kN/m^3
Calculated value β = 0.48655 m^{-1}

Penetration length of SSP $D = 0.71 + \frac{3}{0.487} = 6.88$ m
Whole length of SSP $L = 2.60 - 0.40 + 6.88 = 9.08$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 27132 kN/m^3
Calculated value β = 0.49454 m^{-1}

Penetration length of SSP $D = 1.00 + \frac{3}{0.495} = 7.07$ m
Whole length of SSP $L = 2.60 - 0.40 + 7.07 = 9.27$ m

Therefore, whole length of SSP is set as 9.50 m in consideration of round unit of SSP length.

8 Calculation Result

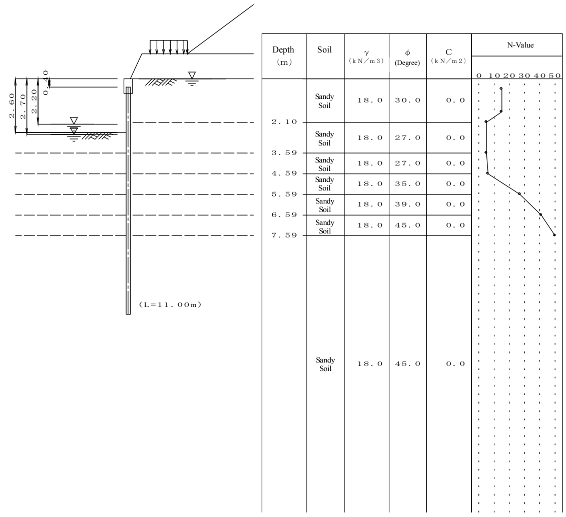
			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	56700		
Section modulus	Z (cm^3)	2700		
Maximum bending moment	M_{max} (kN·m/m)		193.84	337.52
Stress intensity	σ (N/mm^2)		82 (180)	142 (270)
Lateral displacement	δ (mm)		33.58 (50.0)	61.28 (75.0)
Penetration depth	D (m)		6.88	7.07
Whole length of SSP	L (m)	9.50		

－Steel Sheet Pile Design Calculation－

Right Bank No. 43_STA 16+667 - 16+724

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_{lt}	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress Chang's formula

Penetration depths $L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water γ_w = 9.8 kN/m^3

Type of water pressure trapezoidal water pressure

Lateral pressure calculated in consideration of site conditions

Study case
- Normal Condition
- Seismic Condition

Design earthquake intensity k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load					
	Horizontal load	Pt	=	4.0 kN/m	(Normal Condition)
		Pt'	=	10.3 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.57 m	(Normal Condition)
		Ht'	=	-0.32 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN·m/m	(Normal Condition)
		Mm'	=	4.7 kN·m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture ζ_0 = 10 degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan\theta$

Equilibrium factor of compression K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula $K_h = 6910 \times N'^{0.406}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15			
2	1.60	15			
3	2.10	5			
4	3.59	5			
5	4.59	6			
6	5.59	27			
7	6.59	41			
8	7.59	50			
9	20.00	50			

1-6 Vertical Load

Vertical load on landside calculated in consideration of embankment shape on landside

Vertical load on riverside not considered

1-7 Soil Modulus

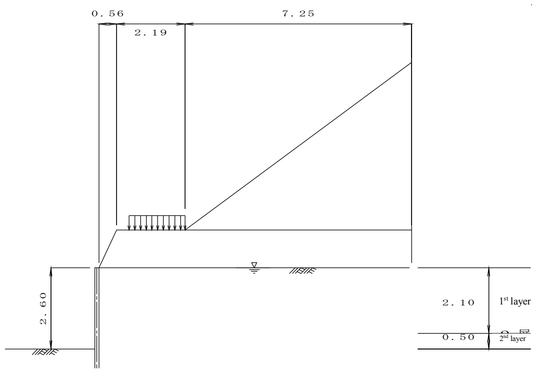
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	φ	C kN/m^2	a	k'	ζ (degree)		kh(kN/m^3)	
										normal	seismic	normal	seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	3.59	S	5.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
3	4.59	S	6.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
4	5.59	S	27.0	18.00	10.00	35.0	0.0	0.0	0.200	auto	auto	——	——
5	6.59	S	41.0	18.00	10.00	39.0	0.0	0.0	0.200	auto	auto	——	——
6	7.59	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
7	20.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
- depth : from top of coping to bottom of the layer
- soil : sandy(S), clayey(C), mixed (M)
- N-value : average N-value in the layer
- γ : wet unit weight of soil
- γ' : saturated unit weight of soil
- φ : internal friction angle of soil
- C_o : soil adhesion
- a : slope of soil adhesion
- k' : design seismic coefficient (underwater)
- ζ : angle of active rupture
- kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active passive	10.00° -10.00°	10.00° -10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.56	10.00	10.00	1.21	18.0	30.0	0.0	auto	auto
2	Sandy soil	2.75	10.00	10.00	10.00	5.37	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	0.96	2.75	10.0	5.0

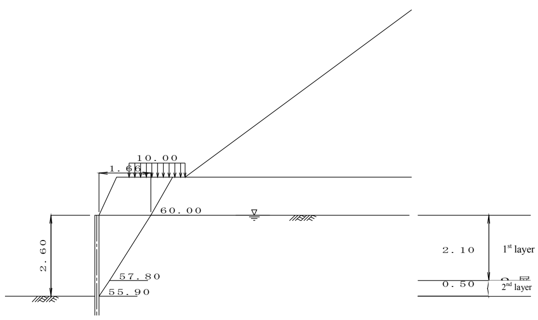
Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴
Sectional factor	Z_0	=	3820 cm³
Corrosion margin	t_1	=	1.00 mm (riverside) t_2 = 1.00 mm (landside)
Corrosion rate (to I_0)	η	=	0.92
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	0.80
Section efficiency (to Z_0)	μ	=	1.00
Round unit of SSP length			0.50 m
Allowable stress	σ_a	=	180 N/mm (Normal)
	σ_a'	=	270 N/mm (Seismic)
Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a'	=	75.0 mm (Seismic)
Bending of cantilever beam			calculated as distributed load of each layer
Reduction of material modulus			Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
			Not reduced: I_0 applied to calculation of penetration depth
			Reduced: I_0 applied to calculation of section forces and displacement
			Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	31.11	25.48	55.90
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	31.11	20.58	57.80
3		Embankment	30.0	——	0.0	118.44	0.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1 - \frac{\Sigma\gamma h + 2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
  $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	55.90	0.50	0.00	0.00	0.34	0.50
2	57.80	2.10	0.34	0.50	1.66	2.60
3	60.00	1.21	1.66	2.60	2.36	3.81

Therefore, width of acting load shall be set as 1.66 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	2.09	37.69
Σ			37.69

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.40	14.00
Σ			14.00

Q: surcharge load
l : width of surcharge load set by line of active rupture

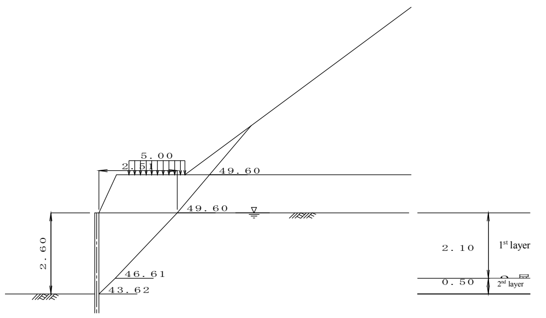
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{37.69 + 14.00 + 0.00}{1.66}$$

$$= 31.11 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	φ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.10	Sandy Soil	27.0	10.0	0.0	26.00	31.86	25.48	0.200	11.31	43.62
2	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	31.86	20.58	0.200	11.31	46.61
3		Embankment	30.0	——	0.0	118.44	0.00	0.00	0.200	11.31	49.60
4		Embankment	30.0	——	0.0	96.66	0.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi+\delta) + \sqrt{\dfrac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^{\circ}$)
- φ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	43.62	0.50	0.00	0.00	0.52	0.50
2	46.61	2.10	0.52	0.50	2.51	2.60
3	49.60	1.21	2.51	2.60	3.54	3.81
4	49.60	1.58	3.54	3.81	4.89	5.39

Therefore, width of acting load shall be set as 2.51 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.32	59.78
2	18.0	0.62	11.24
Σ			71.03

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	1.79	8.95
Σ			8.95

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

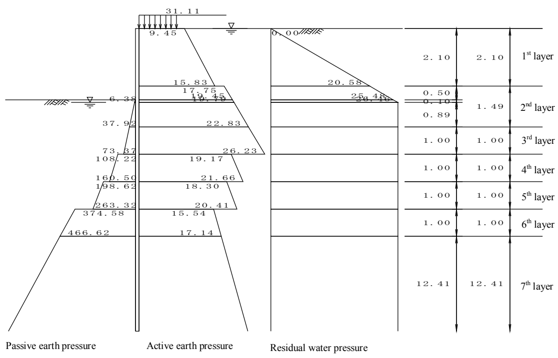
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{71.03 + 8.95 + 0.00}{2.51}$$

$$= 31.86 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	31.115 52.115	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.60	Sandy soil	10.0	27.0	—— ——	52.115 57.115	0.34585 0.34585	0.34060 0.34060
3	2.60～ 2.70	Sandy soil	10.0	27.0	—— ——	57.115 58.115	0.34585 0.34585	0.34060 0.34060
4	2.70～ 3.59	Sandy soil	10.0	27.0	—— ——	58.115 67.015	0.34585 0.34585	0.34060 0.34060
5	3.59～ 4.59	Sandy soil	10.0	27.0	—— ——	67.015 77.015	0.34585 0.34585	0.34060 0.34060
6	4.59～ 5.59	Sandy soil	10.0	35.0	—— ——	77.015 87.015	0.25279 0.25279	0.24895 0.24895
7	5.59～ 6.59	Sandy soil	10.0	39.0	—— ——	87.015 97.015	0.21359 0.21359	0.21035 0.21035
8	6.59～ 7.59	Sandy soil	10.0	45.0	—— ——	97.015 107.015	0.16262 0.16262	0.16015 0.16015
9	7.59～ 20.00	Sandy soil	10.0	45.0	—— ——	107.015 231.115	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
3	2.60～ 2.70	Sandy soil	18.0	27.0	—— ——	0.000 1.800	3.59892 3.59892	3.54425 3.54425
4	2.70～ 3.59	Sandy soil	10.0	27.0	—— ——	1.800 10.700	3.59892 3.59892	3.54425 3.54425
5	3.59～ 4.59	Sandy soil	10.0	27.0	—— ——	10.700 20.700	3.59892 3.59892	3.54425 3.54425
6	4.59～ 5.59	Sandy soil	10.0	35.0	—— ——	20.700 30.700	5.30876 5.30876	5.22810 5.22810
7	5.59～ 6.59	Sandy soil	10.0	39.0	—— ——	30.700 40.700	6.56948 6.56948	6.46967 6.46967
8	6.59～ 7.59	Sandy soil	10.0	45.0	—— ——	40.700 50.700	9.34548 9.34548	9.20351 9.20351
9	7.59～ 20.00		10.0	45.0	—— ——	50.700 174.800	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	9.45 15.83	—— ——	9.45 15.83	0.00 20.58	—— ——
2	2.10～ 2.60	17.75 19.45	—— ——	17.75 19.45	20.58 25.48	—— ——
3	2.60～ 2.70	19.45 19.79	—— ——	19.45 19.79	25.48 26.46	0.00 6.38
4	2.70～ 3.59	19.79 22.83	—— ——	19.79 22.83	26.46 26.46	6.38 37.92
5	3.59～ 4.59	22.83 26.23	—— ——	22.83 26.23	26.46 26.46	37.92 73.37
6	4.59～ 5.59	19.17 21.66	—— ——	19.17 21.66	26.46 26.46	108.22 160.50
7	5.59～ 6.59	18.30 20.41	—— ——	18.30 20.41	26.46 26.46	198.62 263.32
8	6.59～ 7.59	15.54 17.14	—— ——	15.54 17.14	26.46 26.46	374.58 466.62
9	7.59～ 20.00	17.14 37.01	—— ——	17.14 37.01	26.46 26.46	466.62 1608.77

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

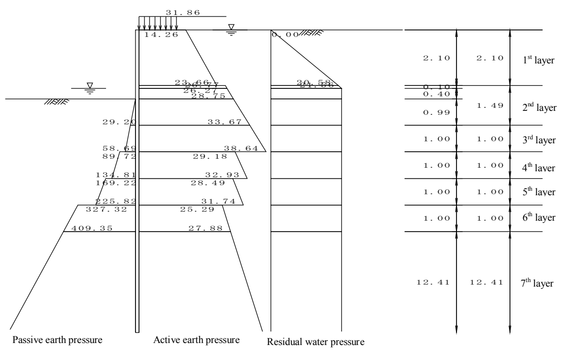
- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	―― ――	31.86 52.86	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	―― ――
2	2.10～ 2.20	Sandy Soil	10.0	27.0	―― ――	52.86 53.86	20.58 21.56	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
3	2.20～ 2.60	Sandy Soil	10.0	27.0	―― ――	53.86 57.86	21.56 25.48	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
4	2.60～ 3.59	Sandy Soil	10.0	27.0	―― ――	57.86 67.76	25.48 35.18	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――
5	3.59～ 4.59	Sandy Soil	10.0	27.0	―― ――	67.76 77.76	35.18 44.98	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	―― ――

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
6	4.59～ 5.59	Sandy Soil	10.0	35.0	―― ――	77.76 87.76	44.98 54.78	0.200 0.200	11.31 11.31	0.38098 0.38098	0.37519 0.37519	―― ――
7	5.59～ 6.59	Sandy Soil	10.0	39.0	―― ――	87.76 97.76	54.78 64.58	0.200 0.200	11.31 11.31	0.32966 0.32966	0.32465 0.32465	―― ――
8	6.59～ 7.59	Sandy Soil	10.0	45.0	―― ――	97.76 107.76	64.58 74.38	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	―― ――
9	7.59～ 20.00	Sandy Soil	10.0	45.0	―― ――	107.76 231.86	74.38 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	―― ――

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta= 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}} \cdot \tan\theta$$

3-2-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	ϕ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
4	2.60～ 3.59	Sandy soil	10.00	27.0	―― ――	0.000 9.900	0.00 9.70	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
5	3.59～ 4.59	Sandy soil	10.00	27.0	―― ――	9.900 19.900	9.70 19.50	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
6	4.59～ 5.59	Sandy soil	10.00	35.0	―― ――	19.900 29.900	19.50 29.30	0.200 0.200	11.31 11.31	4.57827 4.57827	4.50872 4.50872
7	5.59～ 6.59	Sandy soil	10.00	39.0	―― ――	29.900 39.900	29.30 39.10	0.200 0.200	11.31 11.31	5.74696 5.74696	5.65965 5.65965
8	6.59～ 7.59	Sandy soil	10.00	45.0	―― ――	39.900 49.900	39.10 48.90	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
9	7.59～ 20.00	Sandy soil	10.00	45.0	―― ――	49.900 174.000	48.90 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;

$\delta= -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta-\theta) \cdot \left[1-\sqrt{\frac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	14.26 23.66	―― ――	14.26 23.66	0.00 20.58	―― ――
2	2.10～ 2.20	26.27 26.77	―― ――	26.27 26.77	20.58 21.56	―― ――
3	2.20～ 2.60	26.77 28.75	―― ――	26.77 28.75	21.56 21.56	―― ――
4	2.60～ 3.59	28.75 33.67	―― ――	28.75 33.67	21.56 21.56	0.00 29.20
5	3.59～ 4.59	33.67 38.64	―― ――	33.67 38.64	21.56 21.56	29.20 58.69
6	4.59～ 5.59	29.18 32.93	―― ――	29.18 32.93	21.56 21.56	89.72 134.81
7	5.59～ 6.59	28.49 31.74	―― ――	28.49 31.74	21.56 21.56	169.22 225.82
8	6.59～ 7.59	25.29 27.88	―― ――	25.29 27.88	21.56 21.56	327.32 409.35
9	7.59～ 20.00	27.88 59.99	―― ――	27.88 59.99	21.56 21.56	409.35 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1}=K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1}=\Sigma \gamma h+Q-2C$

$P_{a2}=K_c \cdot (\Sigma \gamma h+Q)$

K_c : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1}=[K_a(\Sigma \gamma h+Q)-2C\sqrt{K_a}] \cdot \cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p=K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p=\Sigma \gamma h+Q+2C$

Mixed soil $P_p=[K_p(\Sigma \gamma h+Q)+2C\sqrt{K_p}] \cdot \cos\delta$

3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1	2.20	0.00	0.00
2	2.60	0.40	0.69

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

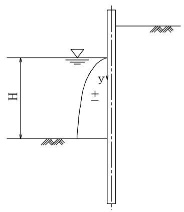
Where,

k_{hs}: design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

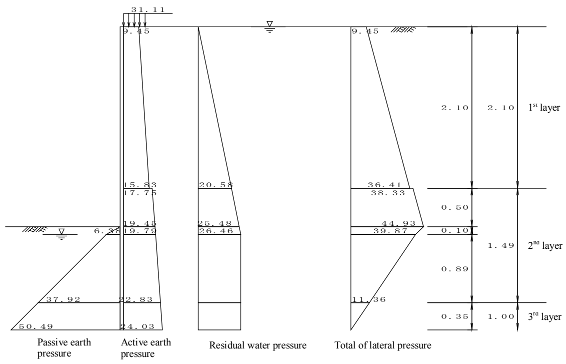
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition

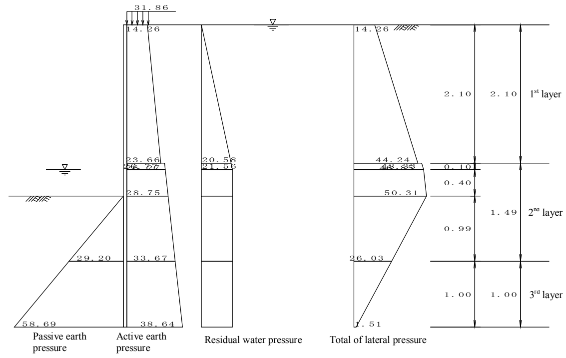


	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	9.45 15.83	0.00 20.58	―― ――	9.45 36.41
2	2.10～ 2.60	17.75 19.45	20.58 25.48	―― ――	38.33 44.93
3	2.60～ 2.70	19.45 19.79	25.48 26.46	0.00 6.38	44.93 39.87
4	2.70～ 3.59	19.79 22.83	26.46 26.46	6.38 37.92	39.87 11.36
5	3.59～ 3.95	22.83 24.03	26.46 26.46	37.92 50.49	11.36 0.00
6	3.95～ 4.59	24.03 26.23	26.46 26.46	50.49 73.37	0.00 -20.67

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.35 m (GL -3.95 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	14.26 23.66	0.00 20.58	―― ――	14.26 44.24
2	2.10～ 2.20	26.27 26.77	20.58 21.56	―― ――	46.85 48.33
3	2.20～ 2.60	26.77 28.75	21.56 21.56	―― ――	48.33 50.31
4	2.60～ 3.59	28.75 33.67	21.56 21.56	0.00 29.20	50.31 26.03
5	3.59～ 4.59	33.67 38.64	21.56 21.56	29.20 58.69	26.03 1.51
6	4.59～ 5.59	29.18 32.93	21.56 21.56	89.72 134.81	-38.99 -80.32

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.99 m (GL -4.59 m)

4th layer

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.92
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm²
Inertia sectional moment	I_0	=	86000 cm⁴(original condition)
	I	=	63296 cm⁴(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 63296 \times 10^{-8} = 1.266 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	5
4	3.59	5
5	4.59	6
6	5.59	27
7	6.59	41
8	7.59	50
9	20.00	50

5-2 Normal Condition

K_h = 21786 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.455 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.20 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.94 m) to 2.20 m depth (GL -6.14 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	3.9	0.65	5.4	6.0	3.66
2	4.59	1.00	6.0	27.0	16.50
3	5.59	0.55	27.0	34.7	16.98
	L =Σh = 2.20				ΣA = 37.14

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{37.14}{2.20}$$

$$= 16.92$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 16.92^{0.406} = 21786$ kN/m³

Kh (normal condition) = 21786 kN/m³

5-3 Seismic Condition

K_h = 25953 kN/m³ is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.476 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.10 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.59 m) and 2.10 m depth (GL -6.69 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m²)
1	4.59	1.00	6.0	27.0	16.50
2	5.59	1.00	27.0	41.0	34.00
3	6.59	0.10	41.0	41.9	4.22
	L =Σh = 2.10				ΣA = 54.72

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{54.72}{2.10}$$

$$= 26.03$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:

$K_h = 6910 \times N'^{0.406} = 6910 \times 26.03^{0.406} = 25953$ kN/m³

Kh (seismic condition) = 25953 kN/m³

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m²)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	9.45 36.41	9.92 38.23	3.24 2.54	32.20 97.29
2	2.10～ 2.60	0.50	38.33 44.93	9.58 11.23	1.68 1.51	16.08 16.98
3	2.60～ 2.70	0.10	44.93 39.87	2.25 1.99	1.31 1.28	2.95 2.55
4	2.70～ 3.59	0.89	39.87 11.36	17.74 5.06	0.95 0.65	16.82 3.29
5	3.59～ 3.94	0.35	11.36 0.00	2.01 0.00	0.24 0.12	0.48 0.00
				ΣP = 98.03		ΣM = 188.63

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 4.0 kN/m
depth to acting position H_t = -0.57 m
moment M_m = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.34 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 18.06 kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{206.69}{102.03} = 2.03 \text{ m}$$

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m²)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	14.26 44.24	14.97 46.45	3.89 3.19	58.24 148.17
2	2.10～ 2.20	0.10	46.85 48.33	2.34 2.42	2.46 2.42	5.75 5.86
3	2.20～ 2.60	0.40	48.33 50.31	9.67 10.06	2.26 2.12	21.81 21.37
4	2.60～ 3.59	0.99	50.31 26.03	24.91 12.89	1.66 1.33	41.34 17.14
5	3.59～ 4.59	1.00	26.03 1.51	13.02 0.75	0.67 0.33	8.68 0.25
				ΣP = 137.47		ΣM = 328.62

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load P_t = 10.3 kN/m
depth to acting position H_t = -0.32 m
moment M_m = 4.7 kN·m/m
depth to acting position H_m = 0.80 m
Height from riverbed to top of coping H = 2.60 m
Depth of Imaginary riverbed from riverbed L_k = 1.99 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m$ = 55.27 kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m²)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	2.26 2.12	0.00 0.29
				ΣPdw = 0.14		ΣMdw = 0.29

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{384.18}{147.91} = 2.60 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width B = 1.0000 m
Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.92
Section efficiency μ = 0.80
Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 86000 cm⁴ (original condition)
I = 63296 cm⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 63296 \times 10^{-8}$ = 1.266×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1}\frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} \left(\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x\right)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction K_h = 21786 kN/m³
calculated value β = 0.45543 m⁻¹
resultant earth force (lateral) P_0 = 102.03 kN/m
height of acting position of load h_0 = 2.03 m
moment M_0 = 206.69 kN·m/m

in consideration of ψ_m = 1.166,
maximum moment M_{max} = 240.93 kN·m/m
depth of generated position of M_{max} l_m = 0.742 m
depth of 1st fixed point l_i = 2.467 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction K_h = 25953 kN/m³
calculated value β = 0.47581 m⁻¹
resultant earth force (lateral) P_0 = 147.91 kN/m
height of acting position of load h_0 = 2.60 m
moment M_0 = 384.18 kN·m/m

in consideration of ψ_m = 1.104,
maximum moment M_{max} = 424.22 kN·m/m
depth of generated position of M_{max} l_m = 0.589 m
depth of 1st fixed point l_i = 2.240 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate η = 0.92
Section efficiency μ = 1.00
Module of section Z_0 = 3820 cm³ (original condition)
Z = 3514 cm³ (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{240.93 \times 10^6}{3514 \times 10^3} = 69 \text{ N/mm}^2 \leqq \sigma_a = 180 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{424.22 \times 10^6}{3514 \times 10^3} = 121 \text{ N/mm}^2 \leqq \sigma_a = 270 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

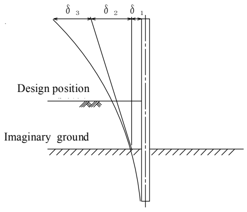
6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.24 2.54	0.823 0.645	0.246 0.163	9.92 38.23	2.437 6.244
2	2.10～ 2.60	1.68 1.51	0.425 0.383	0.078 0.064	9.58 11.23	0.744 0.719
3	2.60～ 2.70	1.31 1.28	0.332 0.324	0.049 0.047	2.25 1.99	0.110 0.093
4	2.70～ 3.59	0.95 0.65	0.240 0.165	0.027 0.013	17.74 5.06	0.471 0.065
5	3.59～ 3.94	0.24 0.12	0.060 0.030	0.002 0.000	2.01 0.00	0.004 0.000
						ΣQ = 10.888

Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha) \times \alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4554\times 2.03)\times 102.03}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4554^3} = 0.00820 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4554\times 2.03)\times 102.03}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4554^2}\times(2.60+1.34) = 0.02181 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{10.89\times(2.60+1.34)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.00528 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00079 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.94 m
Horizontal load: P = 4.00
Moment: M = 2.28

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00820＋0.02181＋0.00607
= 0.03607 m
= 36.07 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.89 3.19	0.847 0.695	0.258 0.186	14.97 46.45	3.858 8.619
2	2.10～ 2.20	2.46 2.42	0.535 0.528	0.118 0.115	2.34 2.42	0.276 0.278
3	2.20～ 2.60	2.26 2.12	0.492 0.463	0.101 0.091	9.67 10.06	0.977 0.911
4	2.60～ 3.59	1.66 1.33	0.362 0.290	0.058 0.038	24.91 12.89	1.432 0.489
5	3.59～ 4.59	0.67 0.33	0.145 0.073	0.010 0.003	13.02 0.75	0.131 0.002
						ΣQ = 16.971

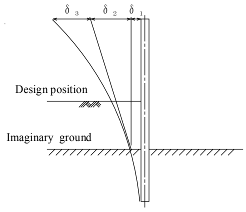
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$
Q : $\zeta\times P$
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.26 2.12	0.492 0.463	0.101 0.091	0.00 0.14	0.000 0.012
						ΣQ_{dw} = 0.012

Therefore, modulus of deformation Q is calculated as below:
Q = 16.971＋0.012 = 16.984

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.4758\times 2.60)\times 147.91}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4758^3} = 0.01213 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times 0.4758\times 2.60)\times 147.91}{2\times 2.00\times 10^8\times 63296\times 10^{-8}\times 0.4758^2}\times(2.60+1.99) = 0.04112 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{16.98\times(2.60+1.99)^3}{2.00\times 10^8\times 63296\times 10^{-8}} = 0.01297 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00290 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.59 m
Horizontal load: P = 10.30
Moment: M = 3.30

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h) \qquad (L=4.59\text{ m、}h=L-H_m\text{、}H_m=0.80\text{ m、ただし})$$

$$= \frac{4.70\times 3.79}{2\times 2.00\times 10^8\times 63296\times 10^{-8}}\times(2\times 4.59-3.79) = 0.00038 \text{ m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01213＋0.04112＋0.01625
= 0.06950 m
= 69.50 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

2.331

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	86000 cm^4 (original condition)
	I	=	86000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 86000 × 10^{-8}		=	1.720 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{1t} + D$$
$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 21786 kN/m^3
Calculated value β = 0.42184 m^{-1}

Penetration length of SSP $D = 1.34 + \frac{3}{0.422} = 8.46$ m
Whole length of SSP $L = 2.60 - 0.40 + 8.46 = 10.66$ m

7-1-2 Seismic Condition

Modules of lateral subgrade reaction K_h = 25953 kN/m^3
Calculated value β = 0.44071 m^{-1}

Penetration length of SSP $D = 1.99 + \frac{3}{0.441} = 8.80$ m
Whole length of SSP $L = 2.60 - 0.40 + 8.80 = 11.00$ m

Therefore, whole length of SSP is set as 11.00 m in consideration of round unit of SSP length.

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	86000		
Section modulus	Z (cm^3)	3820		
Maximum bending moment	M_{max} (kN·m/m)		240.93	424.22
Stress intensity	σ (N/mm^2)		69 (180)	121 (270)
Lateral displacement	δ (mm)		36.07 (50.0)	69.50 (75.0)
Penetration depth	D (m)		8.46	8.80
Whole length of SSP	L (m)	11.00		

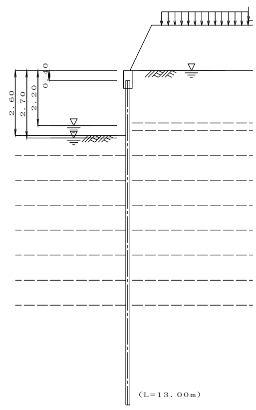
a

－Steel Sheet Pile　Design Calculation－

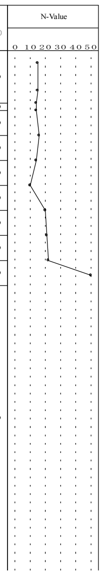
Right Bank No. 44_STA 16+760 - 16+840

1 Design Conditions

1-1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth (m)	Soil	γ (kN/m3)	ϕ (Degree)	C (kN/m2)
2.10	Sandy Soil	18.0	30.0	0.0
2.40	Sandy Soil	18.0	29.0	0.0
3.40	Sandy Soil	18.0	30.0	0.0
4.40	Sandy Soil	18.0	29.0	0.0
5.40	Sandy Soil	18.0	27.0	0.0
6.40	Sandy Soil	18.0	32.0	0.0
7.40	Sandy Soil	18.0	33.0	0.0
8.40	Sandy Soil	18.0	33.0	0.0
9.40	Sandy Soil	18.0	45.0	0.0
	Sandy Soil	18.0	45.0	0.0



1-2 Dimensions of Structure

Depth from coping top to riverbed	H	=	2.60 m
Depth from coping top to rear side ground	H_0	=	0.00 m
Depth from coping top to SSP top	H_k	=	0.40 m
Landside WL	L_{wa}	=	0.00 m (Normal Condition)
	L_{wa}'	=	0.00 m (Seismic Condition)
Riverside WL	L_{wp}	=	2.70 m (Normal Condition)
	L_{wp}'	=	2.20 m (Seismic Condition)

Imaginary riverbed　calculated in consideration of geotechnical conditions

1-3 Applied Formula

Formula for generated stress　Chang's formula

Penetration depths　$L = \frac{3}{\beta}$

1-4 Constant Numbers for Design

Unit weight of water　γ_w = 9.8 kN/m^3

Type of water pressure　trapezoidal water pressure

Lateral pressure　calculated in consideration of site conditions

Study case　- Normal Condition
- Seismic Condition

Design earthquake intensity　k = 0.200

Dynamic water pressure due to earthquake considered as distributed load

Arbitrary load	Horizontal load	Pt	=	7.2 kN/m	(Normal Condition)
		Pt'	=	16.7 kN/m	(Seismic Condition)
	Depth of acting point	Ht	=	-0.81 m	(Normal Condition)
		Ht'	=	-0.64 m	(Seismic Condition)
	Moment	Mm	=	0.0 kN･m/m	(Normal Condition)
		Mm'	=	9.6 kN･m/m	(Seismic Condition)
	Depth of acting point	Hm'	=	0.00 m	(Seismic Condition)
		Hm	=	0.80 m	(Normal Condition)

('Depth' means distance from top of coping)

Wind load, Impact load　not considered

Minimum angle of rupture　ζ_0 = 10 degrees

Rear side angle of slope　not considered

Angle of rupture (clayey soil)　$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$

Equilibrium factor of compression　K_c = 0.50 (considered in Seismic Condition)

1-5 Lateral Foundation Modulus

Applied formula　$K_h = 6910 \times N^{0.406}$

Average N-value　calculated from average N-value between imaginary riverbed and depth as 1/β

N-value distribution

No	Depth (m)	N-Value	No	Depth (m)	N-Value
1	0.50	15	11	9.00	50
2	1.60	15	12	20.00	50
3	2.10	14			
4	2.40	14			
5	3.40	16			
6	4.40	14			
7	5.40	10			
8	6.40	20			
9	7.40	21			
10	8.40	22			

1-6 Vertical Load

Vertical load on landside　calculated in consideration of embankment shape on landside

Vertical load on riverside　not considered

1-7 Soil Modulus

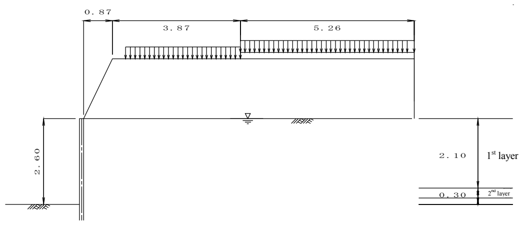
No	Depth (m)	Soil	N-value	γ kN/m^3	γ' kN/m^3	ϕ	C kN/m^2	a	k'	ζ (degree) normal	ζ (degree) seismic	kh(kN/m^3) normal	kh(kN/m^3) seismic
1	2.10	S	15.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
2	2.40	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
3	3.40	S	16.0	18.00	10.00	30.0	0.0	0.0	0.200	auto	auto	——	——
4	4.40	S	14.0	18.00	10.00	29.0	0.0	0.0	0.200	auto	auto	——	——
5	5.40	S	10.0	18.00	10.00	27.0	0.0	0.0	0.200	auto	auto	——	——
6	6.40	S	20.0	18.00	10.00	32.0	0.0	0.0	0.200	auto	auto	——	——
7	7.40	S	21.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
8	8.40	S	22.0	18.00	10.00	33.0	0.0	0.0	0.200	auto	auto	——	——
9	9.40	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——
10	20.00	S	50.0	18.00	10.00	45.0	0.0	0.0	0.200	auto	auto	——	——

Note)
depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
ϕ : internal friction angle of soil
C_o : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal	Seismic
active	10.00°	10.00°
passive	-10.00°	-10.00°

1-8 Embankment on Landside



Embankment shape and soil modulus

No	Soil	X-coordinate				Embankment height	Wet unit weight	Internal friction angle	Cohesive force	Angle of rupture	
		1 (m)	2 (m)	3 (m)	4 (m)	h (m)	γ (kN/m³)	ϕ (degree)	C (kN/m²)	Normal	Seismic
1	Sandy soil	0.00	0.87	10.00	10.00	1.82	18.0	30.0	0.0	auto	auto
2	Sandy soil	4.74	4.74	10.00	10.00	0.19	18.0	30.0	0.0	auto	auto

Surcharge load acting on embankment

No	Acting period		Load	
	from (m)	to (m)	Normal (kN/m²)	Seismic (kN/m²)
1	1.27	10.00	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1-9 Steel Sheet Pile (SSP)

Young's modulus E = 200000 N/mm²
Inertia sectional moment I_0 = 154000 cm⁴
Sectional factor Z_0 = 4160 cm³

Corrosion margin t_1 = 1.00 mm (riverside) t_2 = 1.00 mm (landside)

Corrosion rate (to I_0) η = 0.85
Corrosion rate (to Z_0) η = 0.87
Section efficiency (to I_0) μ = 1.00
Section efficiency (to Z_0) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_a = 185 N/mm (Normal)
σ_a' = 278 N/mm (Seismic)

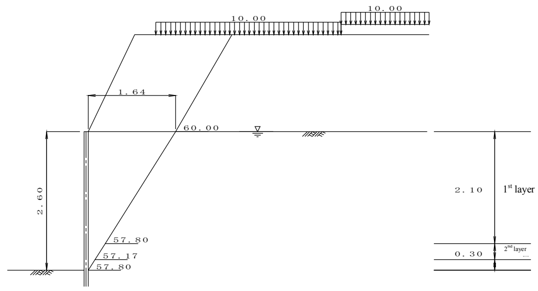
Allowable displacement δ_a = 50.0 mm (Normal)
δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I_0 applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I_0 applied to calculation of penetration depth
Reduced: I_0 applied to calculation of section forces and displacement
Reduced: Z_0 applied to calculation of stresses

2 Calculation of Acting Load

2-1 Normal Condition



2-1-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	Angle of rupture Z (degree)
1	2.60～ 2.40	Sandy Soil	30.0	10.0	0.0	26.00	43.23	25.48	57.80
2	2.40～ 2.10	Sandy Soil	29.0	10.0	0.0	24.00	43.23	23.52	57.17
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	43.23	20.58	57.80
4		Embankment	30.0	——	0.0	36.18	10.00	0.00	60.00

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\frac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

・Angle of active rupture of clayey soil

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0°$

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-1-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end		Coordinate of upper end	
			X (m)	Y (m)	X (m)	Y (m)
1	57.80	0.20	0.00	0.00	0.13	0.20
2	57.17	0.30	0.13	0.20	0.32	0.50
3	57.80	2.10	0.32	0.50	1.64	2.60
4	60.00	1.82	1.64	2.60	2.69	4.42

Therefore, width of acting load shall be set as 1.64 m

2-1-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	3.15	56.75
Σ			56.75

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-1-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	10.0	1.42	14.23
Σ			14.23

Q: surcharge load
l : width of surcharge load set by line of active rupture

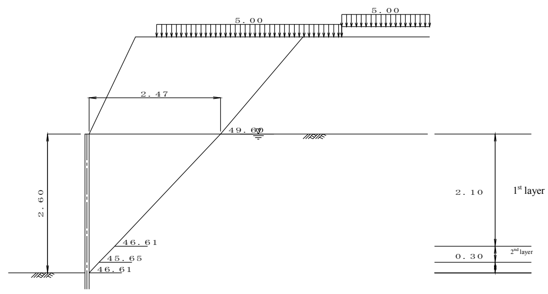
2-1-5 Calculation of Total Acting Load

$$Q = \frac{\Sigma(\gamma\times A)+\Sigma(Q\times l)+\Sigma P}{L}$$

$$= \frac{56.75 + 14.23 + 0.00}{1.64}$$

$$= 43.23 \text{ kN/m}^2$$

2-2 Earthquake Condition



2-2-1 Angle of Active Rupture

No	Depth (m)	Soil	ϕ (degree)	δ (degree)	C (kN/m²)	Σγh (kN/m²)	Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Angle of rupture Z (degree)
1	2.60～ 2.40	Sandy Soil	30.0	10.0	0.0	26.00	42.83	25.48	0.200	11.31	46.61
2	2.40～ 2.10	Sandy Soil	29.0	10.0	0.0	24.00	42.83	23.52	0.200	11.31	45.65
3	2.10～ 0.00	Sandy Soil	30.0	10.0	0.0	21.00	42.83	20.58	0.200	11.31	46.61
4		Embankment	30.0	——	0.0	36.18	5.00	0.00	0.200	11.31	49.60

・Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1}\frac{-\sin(\phi+\delta)+\sqrt{\frac{\cos(\delta+\theta)\cdot\sin(\phi+\delta)}{\sin(\phi-\theta)}}}{\cos(\phi+\delta)}$$

Where,
- ζ : angle of active rupture (degree, $\zeta \geq 10.00°$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree) $\theta = \tan^{-1}k$ or $\theta = \tan^{-1}k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under WL)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C cohesive force of soil (kN/m²)

2-2-2 Coordinates of Line of Active Rupture

No	Angle of rupture ζ (degree)	Thickness of layer Z (m)	Coordinate of lower end X (m)	Coordinate of lower end Y (m)	Coordinate of upper end X (m)	Coordinate of upper end Y (m)
1	46.61	0.20	0.00	0.00	0.19	0.20
2	45.65	0.30	0.19	0.20	0.48	0.50
3	46.61	2.10	0.48	0.50	2.47	2.60
4	49.60	1.82	2.47	2.60	4.02	4.42

Therefore, width of acting load shall be set as 2.47 m

2-2-3 Acting Load by Embankment

No	γ (kN/m³)	A (m²)	γ X A (kN/m)
1	18.0	5.11	91.96
Σ			91.96

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2-2-4 Acting Load by Surcharge Load

No	Q (kN/m²)	l (m)	Q X l (kN/m)
1	5.0	2.75	13.73
Σ			13.73

Q: surcharge load
l : width of surcharge load set by line of active rupture

2-2-5 Calculation of Total Acting Load

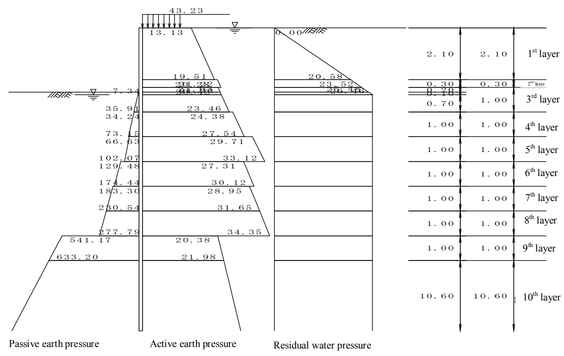
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{91.96 + 13.73 + 0.00}{2.47}$$

$$= 42.83 \text{ kN/m}^2$$

3 Lateral Pressure

3-1 Normal Condition



3-1-1 Soil Modulus of Active Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qa (kN/m²)	Ka	Ka ×cosδ
1	0.00～ 2.10	Sandy soil	10.0	30.0	—— ——	43.228 64.228	0.30847 0.30847	0.30378 0.30378
2	2.10～ 2.40	Sandy soil	10.0	29.0	—— ——	64.228 67.228	0.32058 0.32058	0.31571 0.31571
3	2.40～ 2.60	Sandy soil	10.0	30.0	—— ——	67.228 69.228	0.30847 0.30847	0.30378 0.30378
4	2.60～ 2.70	Sandy soil	10.0	30.0	—— ——	69.228 70.228	0.30847 0.30847	0.30378 0.30378
5	2.70～ 3.40	Sandy soil	10.0	30.0	—— ——	70.228 77.228	0.30847 0.30847	0.30378 0.30378
6	3.40～ 4.40	Sandy soil	10.0	29.0	—— ——	77.228 87.228	0.32058 0.32058	0.31571 0.31571
7	4.40～ 5.40	Sandy soil	10.0	27.0	—— ——	87.228 97.228	0.34585 0.34585	0.34060 0.34060
8	5.40～ 6.40	Sandy soil	10.0	32.0	—— ——	97.228 107.228	0.28525 0.28525	0.28092 0.28092
9	6.40～ 7.40	Sandy soil	10.0	33.0	—— ——	107.228 117.228	0.27412 0.27412	0.26996 0.26996
10	7.40～ 8.40	Sandy soil	10.0	33.0	—— ——	117.228 127.228	0.27412 0.27412	0.26996 0.26996
11	8.40～ 9.40	Sandy soil	10.0	45.0	—— ——	127.228 137.228	0.16262 0.16262	0.16015 0.16015
12	9.40～ 20.00	Sandy soil	10.0	45.0	—— ——	137.228 243.228	0.16262 0.16262	0.16015 0.16015

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-2 Soil Modulus of Passive Side

	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	Kp	Kp ×cosδ
4	2.60～ 2.70	Sandy soil	18.0	30.0	—— ——	0.000 1.800	4.14330 4.14330	4.08035 4.08035
5	2.70～ 3.40	Sandy soil	10.0	30.0	—— ——	1.800 8.800	4.14330 4.14330	4.08035 4.08035
6	3.40～ 4.40	Sandy soil	10.0	29.0	—— ——	8.800 18.800	3.95096 3.95096	3.89093 3.89093
7	4.40～ 5.40	Sandy soil	10.0	27.0	—— ——	18.800 28.800	3.59892 3.59892	3.54425 3.54425
8	5.40～ 6.40	Sandy soil	10.0	32.0	—— ——	28.800 38.800	4.56530 4.56530	4.49594 4.49594
9	6.40～ 7.40	Sandy soil	10.0	33.0	—— ——	38.800 48.800	4.79713 4.79713	4.72425 4.72425
10	7.40～ 8.40	Sandy soil	10.0	33.0	—— ——	48.800 58.800	4.79713 4.79713	4.72425 4.72425
11	8.40～ 9.40	Sandy soil	10.0	45.0	—— ——	58.800 68.800	9.34548 9.34548	9.20351 9.20351
12	9.40～ 20.00	Sandy soil	10.0	45.0	—— ——	68.800 174.800	9.34548 9.34548	9.20351 9.20351

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -10.00、β = 0.00、θ = 0.00

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta \cdot \cos(\delta+\theta) \cdot \left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-1-3 Lateral Pressure

	Depth (m)	Active side Pa1 kN/m²	Active side Pa2 kN/m²	Active side Pa kN/m²	Residual water pressure Pw kN/m²	Passive side Pp kN/m²
1	0.00～ 2.10	13.13 19.51	—— ——	13.13 19.51	0.00 20.58	—— ——
2	2.10～ 2.40	20.28 21.22	—— ——	20.28 21.22	20.58 23.52	—— ——
3	2.40～ 2.60	20.42 21.03	—— ——	20.42 21.03	23.52 25.48	—— ——
4	2.60～ 2.70	21.03 21.33	—— ——	21.03 21.33	25.48 26.46	0.00 7.34
5	2.70～ 3.40	21.33 23.46	—— ——	21.33 23.46	26.46 26.46	7.34 35.91
6	3.40～ 4.40	24.38 27.54	—— ——	24.38 27.54	26.46 26.46	34.24 73.15
7	4.40～ 5.40	29.71 33.12	—— ——	29.71 33.12	26.46 26.46	66.63 102.07
8	5.40～ 6.40	27.31 30.12	—— ——	27.31 30.12	26.46 26.46	129.48 174.44

	Depth (m)	Active side Pa1 kN/m²	Active side Pa2 kN/m²	Active side Pa kN/m²	Residual water pressure Pw kN/m²	Passive side Pp kN/m²
9	6.40～ 7.40	28.95 31.65	—— ——	28.95 31.65	26.46 26.46	183.30 230.54
10	7.40～ 8.40	31.65 34.35	—— ——	31.65 34.35	26.46 26.46	230.54 277.79
11	8.40～ 9.40	20.38 21.98	—— ——	20.38 21.98	26.46 26.46	541.17 633.20
12	9.40～ 20.00	21.98 38.95	—— ——	21.98 38.95	26.46 26.46	633.20 1608.77

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c \cdot (\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos\delta$

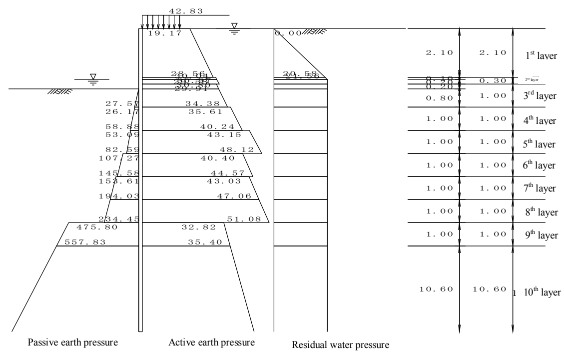
- Formula for passive earth pressure

Sandy soil $P_p = K_p \cdot [\Sigma\gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos\delta$

3-2 Seismic Condition



3-2-1 Soil Modulus of Active Side

No	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Q (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Ka	Ka ×cosδ	θ (degree)
1	0.00～ 2.10	Sandy Soil	10.0	30.0	—— ——	42.83 63.83	0.00 20.58	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
2	2.10～ 2.20	Sandy Soil	10.0	29.0	—— ——	63.83 64.83	20.58 21.56	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
3	2.20～ 2.40	Sandy Soil	10.0	29.0	—— ——	64.83 66.83	21.56 23.52	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
4	2.40～ 2.60	Sandy Soil	10.0	30.0	—— ——	66.83 68.83	23.52 25.48	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
5	2.60～ 3.40	Sandy Soil	10.0	30.0	—— ——	68.83 76.83	25.48 33.32	0.200 0.200	11.31 11.31	0.45442 0.45442	0.44752 0.44752	—— ——
6	3.40～ 4.40	Sandy Soil	10.0	29.0	—— ——	76.83 86.83	33.32 43.12	0.200 0.200	11.31 11.31	0.47058 0.47058	0.46343 0.46343	—— ——
7	4.40～ 5.40	Sandy Soil	10.0	27.0	—— ——	86.83 96.83	43.12 52.92	0.200 0.200	11.31 11.31	0.50461 0.50461	0.49695 0.49695	—— ——
8	5.40～ 6.40	Sandy Soil	10.0	32.0	—— ——	96.83 106.83	52.92 62.72	0.200 0.200	11.31 11.31	0.42366 0.42366	0.41722 0.41722	—— ——
9	6.40～ 7.40	Sandy Soil	10.0	33.0	—— ——	106.83 116.83	62.72 72.52	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
10	7.40～ 8.40	Sandy Soil	10.0	33.0	—— ——	116.83 126.83	72.52 82.32	0.200 0.200	11.31 11.31	0.40899 0.40899	0.40278 0.40278	—— ——
11	8.40～ 9.40	Sandy Soil	10.0	45.0	—— ——	126.83 136.83	82.32 92.12	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——
12	9.40～ 20.00	Sandy Soil	10.0	45.0	—— ——	136.83 242.83	92.12 196.00	0.200 0.200	11.31 11.31	0.26273 0.26273	0.25874 0.25874	—— ——

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
$\delta = 10.00$、$\beta = 0.00$、$\theta = 0.00$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta+\theta)\cdot\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\cdot\sin(\phi-\beta-\theta)}{\cos(\delta+\theta)\cdot\cos(-\beta)}}\right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1}\sqrt{1-\frac{\Sigma\gamma h+2Q}{2C}\cdot\tan\theta}$$

3-2-2 Soil Modulus of Passive Side

No	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
5	2.60～ 3.40	Sandy soil	10.00	30.0	—— ——	0.000 8.000	0.00 7.84	0.200 0.200	11.31 11.31	3.49953 3.49953	3.44637 3.44637
6	3.40～ 4.40	Sandy soil	10.00	29.0	—— ——	8.000 18.000	7.84 17.64	0.200 0.200	11.31 11.31	3.32141 3.32141	3.27095 3.27095
7	4.40～ 5.40	Sandy soil	10.00	27.0	—— ——	18.000 28.000	17.64 27.44	0.200 0.200	11.31 11.31	2.99498 2.99498	2.94948 2.94948
8	5.40～ 6.40	Sandy soil	10.00	32.0	—— ——	28.000 38.000	27.44 37.24	0.200 0.200	11.31 11.31	3.89012 3.89012	3.83102 3.83102
9	6.40～ 7.40	Sandy soil	10.00	33.0	—— ——	38.000 48.000	37.24 47.04	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230

No	Depth (m)	Soil	γ (kN/m³)	φ (degree)	C kN/m²	Σγh+Qp (kN/m²)	γwhw (kN/m²)	k (k')	θ (degree)	Kp	Kp ×cosδ
10	7.40～ 8.40	Sandy soil	10.00	33.0	—— ——	48.000 58.000	47.04 56.84	0.200 0.200	11.31 11.31	4.10466 4.10466	4.04230 4.04230
11	8.40～ 9.40	Sandy soil	10.00	45.0	—— ——	58.000 68.000	56.84 66.64	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345
12	9.40～ 20.00	Sandy soil	10.00	45.0	—— ——	68.000 174.000	66.64 170.52	0.200 0.200	11.31 11.31	8.33000 8.33000	8.20345 8.20345

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
$\delta = -10.00$、$\beta = 0.00$、$\theta = \tan^{-1}k$

$$K_p = \frac{\cos^2(\phi-\theta)}{\cos\theta\cdot\cos(\delta-\theta)\cdot\left[1-\sqrt{\dfrac{\sin(\phi-\delta)\cdot\sin(\phi+\beta-\theta)}{\cos(\delta-\theta)\cdot\cos(-\beta)}}\right]^2}$$

3-2-3 Lateral Pressure

No	Depth (m)	Active side			Residual water pressure	Passive side
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00～ 2.10	19.17 28.56	—— ——	19.17 28.56	0.00 20.58	—— ——
2	2.10～ 2.20	29.58 30.04	—— ——	29.58 30.04	20.58 21.56	—— ——
3	2.20～ 2.40	30.04 30.97	—— ——	30.04 30.97	21.56 21.56	—— ——
4	2.40～ 2.60	29.91 30.80	—— ——	29.91 30.80	21.56 21.56	—— ——
5	2.60～ 3.40	30.80 34.38	—— ——	30.80 34.38	21.56 21.56	0.00 27.57
6	3.40～ 4.40	35.61 40.24	—— ——	35.61 40.24	21.56 21.56	26.17 58.88
7	4.40～ 5.40	43.15 48.12	—— ——	43.15 48.12	21.56 21.56	53.09 82.59
8	5.40～ 6.40	40.40 44.57	—— ——	40.40 44.57	21.56 21.56	107.27 145.58
9	6.40～ 7.40	43.03 47.06	—— ——	43.03 47.06	21.56 21.56	153.61 194.03
10	7.40～ 8.40	47.06 51.08	—— ——	47.06 51.08	21.56 21.56	194.03 234.45
11	8.40～ 9.40	32.82 35.40	—— ——	32.82 35.40	21.56 21.56	475.80 557.83
12	9.40～ 20.00	35.40 62.83	—— ——	35.40 62.83	21.56 21.56	557.83 1427.40

- Formula for active earth pressure

Sandy soil $P_{a1} = K_a\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_{a1} = \Sigma\gamma h + Q - 2C$
$P_{a2} = K_c\cdot(\Sigma\gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma\gamma h + Q) - 2C\sqrt{K_a}]\cdot\cos\delta$

- Formula for passive earth pressure

Sandy soil $P_p = K_p\cdot[\Sigma\gamma h + \dfrac{Q}{\cos(-\beta)}]\cdot\cos\delta$

Clayey soil $P_p = \Sigma\gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma\gamma h + Q) + 2C\sqrt{K_p}]\cdot\cos\delta$

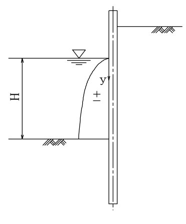
3-2-4 Dynamic Water Pressure due to Earthquake

No	Depth Z (m)	WL y (m)	p_{dw} (kN/m²)
1 2	2.20 2.60	0.00 0.40	0.00 0.69

$p_{dw} = \pm\frac{7}{8}k_{hs}\cdot\ldots\sqrt{H\cdot\ldots}$ Passive earth pressure Active earth pressure Residual water pressure Total of lateral pressure

Where,

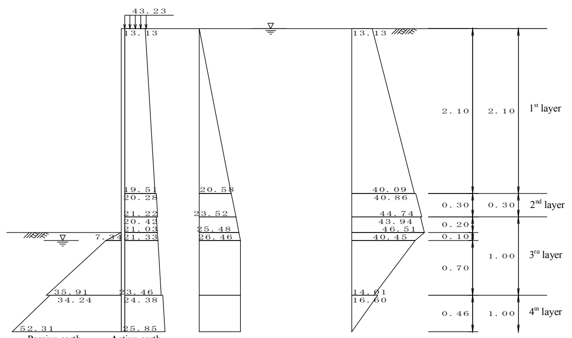
k_{hs}: design seismic coefficient
γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level L_k is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4-1 Normal Condition



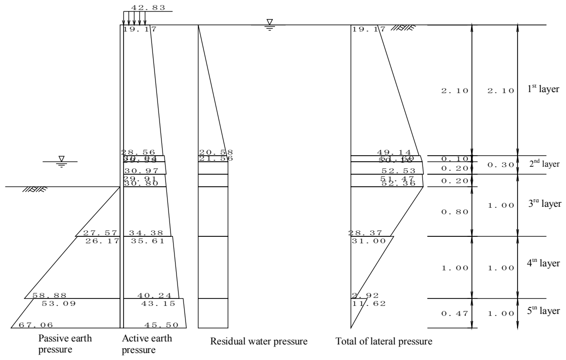
Passive earth pressure　Active earth pressure　Residual water pressure　Total of lateral pressure

No	Depth (m)	Pa kN/m²	Pw kN/m²	Pp kN/m²	Ps kN/m²
1	0.00～ 2.10	13.13 19.51	0.00 20.58	—— ——	13.13 40.09
2	2.10～ 2.40	20.28 21.22	20.58 23.52	—— ——	40.86 44.74
3	2.40～ 2.60	20.42 21.03	23.52 25.48	—— ——	43.94 46.51
4	2.60～ 2.70	21.03 21.33	25.48 26.46	0.00 7.34	46.51 40.45
5	2.70～ 3.40	21.33 23.46	26.46 26.46	7.34 35.91	40.45 14.01
6	3.40～ 3.86	24.38 25.85	26.46 26.46	34.24 52.31	16.60 0.00
7	3.86～ 4.40	25.85 27.54	26.46 26.46	52.31 73.15	0.00 -19.15

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 1.26 m (GL -3.86 m)

4-2 Seismic Condition



	Depth (m)	Pa kN/m^2	Pw kN/m^2	Pp kN/m^2	Ps kN/m^2
1	0.00～ 2.10	19.17 28.56	0.00 20.58	—— ——	19.17 49.14
2	2.10～ 2.20	29.58 30.04	20.58 21.56	—— ——	50.16 51.60
3	2.20～ 2.40	30.04 30.97	21.56 21.56	—— ——	51.60 52.53
4	2.40～ 2.60	29.91 30.80	21.56 21.56	—— ——	51.47 52.36
5	2.60～ 3.40	30.80 34.38	21.56 21.56	0.00 27.57	52.36 28.37
6	3.40～ 4.40	35.61 40.24	21.56 21.56	26.17 58.88	31.00 2.92
7	4.40～ 4.87	43.15 45.50	21.56 21.56	53.09 67.06	11.62 0.00
8	4.87～ 5.40	45.50 48.12	21.56 21.56	67.06 82.59	0.00 -12.91

P_a : Active earth pressure
P_w : Residual water pressure
P_p : Passive earth pressure
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k: 2.27 m (GL -4.87 m)

5 Modulus of Lateral Subgrade Reaction

5-1 Formula for Modulus of Lateral Subgrade Reaction

Modulus of lateral subgrade reaction is calculated on the average N-value from imaginary riverbed to 1/β depth. The modules are calculated by the formula below;

$$K_h = 6910 \times N'^{0.406}$$

where,

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	0.80
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4(original condition)
	I	=	130900 cm^4(after reduction by corrosion and joint)
Inertia sectional moment	EI	=	$200000 \times 10^3 \times 130900 \times 10^{-8} = 2.618 \times 10^5$

	Depth (m)	N-value
1	0.50	15
2	1.60	15
3	2.10	14
4	2.40	14
5	3.40	16
6	4.40	14
7	5.40	10
8	6.40	20
9	7.40	21
10	8.40	22

	Depth (m)	N-value
11	9.00	50
12	20.00	50

5-2 Normal Condition

K_h = 20214 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.373 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.68 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.86 m) to 2.68 m depth (GL -6.55 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	3.86	0.54	15.1	14.0	7.79
2	4.40	1.00	14.0	10.0	12.00
3	5.40	1.00	10.0	20.0	15.00
4	6.40	0.15	20.0	20.1	2.95
	L =Σh = 2.68			ΣA = 37.74	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{37.74}{2.68}$$

$$= 14.07$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 14.07^{0.406} = 20214$ kN/m^3
Kh (normal condition) = 20214 kN/m^3

5-3 Seismic Condition

K_h = 21596 kN/m^3 is set tentatively.

$$\beta = \sqrt[4]{\frac{Kh \cdot B}{4EI}}$$

$$= 0.379 \quad m^{-1}$$

$$L = \frac{1}{\beta} = 2.64 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.87 m) and 2.64 m depth (GL -7.51 m).

	Depth Z (m)	Thickness h (m)	N-value upper	N-value lower	Area (m^2)
1	4.87	0.53	12.1	10.0	5.82
2	5.40	1.00	10.0	20.0	15.00
3	6.40	1.00	20.0	21.0	20.50
4	7.40	0.11	21.0	21.1	2.37
	L =Σh = 2.64			ΣA = 43.69	

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$

$$= \frac{43.69}{2.64}$$

$$= 16.56$$

Calculated Kh is equal to tentative one, so modulus of lateral subgrade reaction (normal condition) is set definitely as following:
$K_h = 6910 \times N'^{0.406} = 6910 \times 16.56^{0.406} = 21596$ kN/m^3
Kh (seismic condition) = 21596 kN/m^3

6 Sectional Forces and Displacement

Chang's formula is applied to calculate stress, displacement and penetration depth of SSP.

6-1 Calculation of Resultant Lateral Force P_0 & Acting Elevation h_0

6-1-1 Normal Condition

	Depth Z (m)	Thickness h (m)	Total of lateral force Ps (kN/m^2)	Load P (kN)	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	13.13 40.09	13.79 42.10	3.16 2.46	43.63 103.74
2	2.10～ 2.40	0.30	40.86 44.74	6.13 6.71	1.66 1.56	10.20 10.50
3	2.40～ 2.60	0.20	43.94 46.51	4.39 4.65	1.40 1.33	6.14 6.19
4	2.60～ 2.70	0.10	46.51 40.45	2.33 2.02	1.23 1.20	2.86 2.42
5	2.70～ 3.40	0.70	40.45 14.01	14.16 4.90	0.93 0.70	13.18 3.42
6	3.40～ 3.86	0.46	16.60 0.00	3.85 0.00	0.31 0.15	1.19 0.00
				ΣP = 105.03		ΣM = 203.48

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	7.2 kN/m
depth to acting position	H_t	=	-0.81 m
moment	M_m	=	0.0 kN·m/m
depth to acting position	H_m	=	0.00 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	1.26 m

Moment M_t by arbitrary load is as below
$M_t = P_t \cdot (H + L_k - H_t) + M_m = 33.66$ kN·m
h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{237.14}{112.23} = 2.11 \text{ m}$$

2.337

6-1-2 Seismic Condition

	Depth Z (m)	Thickness h (m)	Lateral load Ps (kN/m^2)	Load P kN	Arm length Y (m)	Moment M (kN·m)
1	0.00～ 2.10	2.10	19.17 49.14	20.13 51.60	4.17 3.47	84.00 179.25
2	2.10～ 2.20	0.10	50.16 51.60	2.51 2.58	2.74 2.71	6.87 6.98
3	2.20～ 2.40	0.20	51.60 52.53	5.16 5.25	2.61 2.54	13.45 13.35
4	2.40～ 2.60	0.20	51.47 52.36	5.15 5.24	2.41 2.34	12.39 12.26
5	2.60～ 3.40	0.80	52.36 28.37	20.95 11.35	2.01 1.74	42.04 19.75
6	3.40～ 4.40	1.00	31.00 2.92	15.50 1.46	1.14 0.81	17.68 1.18
7	4.40～ 4.87	0.47	11.62 0.00	2.75 0.00	0.32 0.16	0.87 0.00
				ΣP = 149.62		ΣM = 410.07

P_s : active earth pressure + residual water pressure - passive earth pressure
P : load P_s x h/2 x B
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load P x Y

Arbitrary load lateral load	P_t	=	16.7 kN/m
depth to acting position	H_t	=	-0.64 m
moment	M_m	=	9.6 kN·m/m
depth to acting position	H_m	=	0.80 m
Height from riverbed to top of coping	H	=	2.60 m
Depth of Imaginary riverbed from riverbed	L_k	=	2.27 m

Moment M_t by arbitrary load is as below

$M_t = P_t \cdot (H + L_k - H_t) + M_m = 101.68$ kN·m

Dynamic water pressure

No	Depth Z (m)	Thickness h (m)	Dynamic water pressure P_{dw} (kN/m^2)	Load P_{dw} kN	Arm length Y (m)	Moment M_{dw} (kN·m)
1	2.20～ 2.60	0.40	0.0 0.7	0.00 0.14	2.54 2.41	0.00 0.33
				ΣP_{dw} = 0.14		ΣM_{dw} = 0.33

h_0, Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$

$$= \frac{512.08}{166.46} = 3.08 \text{ m}$$

6-2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Unit width	B	=	1.0000 m
Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.85
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	130900 cm^4 (after reduction by corrosion and section)
EI = $200000 \times 10^3 \times 130900 \times 10^{-8}$		=	2.618×10^5

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4EI}}$$

$$\phi_m = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp\left(-\tan^{-1}\frac{1}{1+2\beta h_0}\right)$$

$$M_{max} = M_0 \cdot \phi_m$$

$$l_m = \frac{1}{\beta} \times \tan^{-1}\frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1}\frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos\beta x + (1+\beta h_0)\sin\beta x)$$

6-2-1 Normal Condition

modulus of lateral subgrade reaction	K_h	=	20214 kN/m^3
calculated value	β	=	0.37274 m^{-1}
resultant earth force (lateral)	P_0	=	112.23 kN/m
height of acting position of load	h_0	=	2.11 m
moment	M_0	=	237.14 kN·m/m

in consideration of ψ_m = 1.211, maximum moment	M_{max}	=	287.16 kN·m/m
depth of generated position of M_{max}	l_m	=	0.994 m
depth of 1st fixed point	l_i	=	3.101 m

6-2-2 Seismic Condition

modulus of lateral subgrade reaction	K_h	=	21596 kN/m^3
calculated value	β	=	0.37895 m^{-1}
resultant earth force (lateral)	P_0	=	166.46 kN/m
height of acting position of load	h_0	=	3.08 m
moment	M_0	=	512.08 kN·m/m

in consideration of ψ_m = 1.115, maximum moment	M_{max}	=	570.73 kN·m/m
depth of generated position of M_{max}	l_m	=	0.769 m
depth of 1st fixed point	l_i	=	2.842 m

6-3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Corrosion margin	t_1	=	1.00 mm (active side) t_2 = 1.00 mm (passive side)
Corrosion rate	η	=	0.87
Section efficiency	μ	=	1.00
Module of section	Z_0	=	4160 cm^3 (original condition)
	Z	=	3619 cm^3 (after reduction by corrosion and section)

6-3-1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{287.16 \times 10^6}{3619 \times 10^3} = 79 \text{ N/mm}^2 \leqq \sigma_a = 185 \text{ N/mm}^2 \quad \text{(ok)}$$

6-3-2 Seismic condition

$$\sigma = \frac{M_{max}}{Z} = \frac{570.73 \times 10^6}{3619 \times 10^3} = 158 \text{ N/mm}^2 \leqq \sigma_a = 278 \text{ N/mm}^2 \quad \text{(ok)}$$

6-4 Displacement

6-4-1 Normal Condition

Modules of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	3.16 2.46	0.819 0.638	0.244 0.160	13.79 42.10	3.361 6.740
2	2.10～ 2.40	1.66 1.56	0.431 0.405	0.079 0.071	6.13 6.71	0.487 0.476
3	2.40～ 2.60	1.40 1.33	0.362 0.344	0.058 0.053	4.39 4.65	0.253 0.244
4	2.60～ 2.70	1.23 1.20	0.319 0.310	0.045 0.043	2.33 2.02	0.105 0.087
5	2.70～ 3.40	0.93 0.70	0.241 0.181	0.027 0.015	14.16 4.90	0.378 0.075
6	3.40～ 3.86	0.31 0.15	0.080 0.040	0.003 0.001	3.85 0.00	0.012 0.000
						ΣQ = 12.218

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

ζ : $\zeta = \frac{(3-\alpha)\times\alpha^2}{6}$

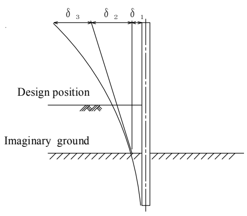
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3727\times 2.11)\times 112.23}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3727^3} = 0.00740 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2} \times (H+L_k)$$

$$= \frac{(1+2\times 0.3727\times 2.11)\times 112.23}{2\times 2.00\times 10^8\times 130900\times 10^{-8}\times 0.3727^2} \times (2.60+1.26) = 0.01535 \text{ m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{12.22\times(2.60+1.26)^3}{2.00\times 10^8\times 130900\times 10^{-8}} = 0.00269 \text{ m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00070 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 3.86 m
Horizontal load: P = 7.20
Moment: M = 5.83

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.00740 + 0.01535 + 0.00339
= 0.02614 m
= 26.14 ≦ δa = 50.00 mm (ok)

Where,
Displacement at imaginary ground
Displacement by angle of inclination slope at imaginary ground
Displacement at higher part of imaginary ground as cantilever
Displacement at top of SSP
Allowable displacement

6-4-2 Seismic Condition

Modulus of deformation

	Depth (m)	Y (m)	α	ζ	P (kN)	Q (kN)
1	0.00～ 2.10	4.17 3.47	0.856 0.713	0.262 0.194	20.13 51.60	5.273 9.993
2	2.10～ 2.20	2.74 2.71	0.562 0.555	0.128 0.126	2.51 2.58	0.322 0.324
3	2.20～ 2.40	2.61 2.54	0.535 0.521	0.118 0.112	5.16 5.25	0.607 0.590
4	2.40～ 2.60	2.41 2.34	0.494 0.480	0.102 0.097	5.15 5.24	0.524 0.507
5	2.60～ 3.40	2.01 1.74	0.412 0.357	0.073 0.056	20.95 11.35	1.532 0.637
6	3.40～ 4.40	1.14 0.81	0.234 0.166	0.025 0.013	15.50 1.46	0.391 0.019
7	4.40～ 4.87	0.32 0.16	0.065 0.032	0.002 0.001	2.75 0.00	0.006 0.000
						ΣQ = 20.726

Y : Height from imaginary riverbed to acting position

α : $\alpha = \dfrac{Y}{H+L_k}$

ζ : $\zeta = \dfrac{(3-\alpha)\times\alpha^2}{6}$

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

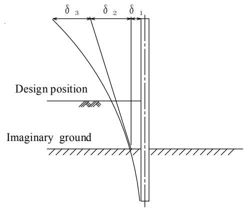
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth (m)	Y (m)	α	ζ	p_{dw} (kN)	Q_{dw} (kN)
1	2.20～ 2.60	2.54 2.41	0.521 0.494	0.112 0.102	0.00 0.14	0.000 0.014
						ΣQ_{dw} = 0.014

Therefore, modulus of deformation Q is calculated as below:

Q = 20.726＋0.014 ＝ 20.740

Displacement



$$\delta_1 = \frac{(1+\beta h_0)\times P_0}{2EI\beta^3}$$

$$= \frac{(1+0.3790\times3.08)\times166.46}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3790^3} = 0.01265\ \text{m}$$

$$\delta_2 = \frac{(1+2\beta h_0)\times P_0}{2EI\beta^2}\times(H+L_k)$$

$$= \frac{(1+2\times0.3790\times3.08)\times166.46}{2\times2.00\times10^8\times130900\times10^{-8}\times0.3790^2}\times(2.60+2.27) = 0.03595\ \text{m}$$

$$\delta_3 = \frac{Q\times(H+L_k)^3}{EI}$$

$$= \frac{20.74\times(2.60+2.27)^3}{2.00\times10^8\times130900\times10^{-8}} = 0.00917\ \text{m}$$

Additional displacement δ_3' generated by horizontal load (P) and moment (M) acting at top of SSP is considered.

$$\delta_3' = \frac{PL^3}{3EI} + \frac{ML^2}{2EI}$$

δ_3' is calculated as 0.00295 m in consideration of following values:
Height from imaginary riverbed to top of SSP: L = 4.87 m
Horizontal load: P = 16.70
Moment: M = 10.69

Displacement δ_{3m} of cantilever beam by moment M_m is additionally considered.

$$\delta_{3m} = \frac{M_m\cdot h}{2EI}\times(2L-h)$$ （L＝4.87 m、h＝L－H_m、H_m=0.80 m、ただし.. ‒ ‒,

$$= \frac{9.60\times4.07}{2\times2.00\times10^8\times130900\times10^{-8}}\times(2\times4.87-4.07) = 0.00042\ \text{m}$$

$\delta = \delta_1 + \delta_2 + \delta_3$
= 0.01265＋0.03595＋0.01254
= 0.06114 m
= 61.14 ≦ δ_a = 75.00 mm (ok)

Where,
δ_1 : Displacement at imaginary ground
δ_2 : Displacement by angle of inclination slope at imaginary ground
δ_3 : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Unit width	B	=	1.0000 m
Corrosion rate	η	=	1.00
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm^2
Inertia sectional moment	I_0	=	154000 cm^4 (original condition)
	I	=	154000 cm^4 (after reduction by corrosion and section)
EI = 200000 × 10^3 × 154000 × 10^{-8}		=	3.080 × 10^5

7-1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_k, penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{1t} + D$$

$$\beta = \sqrt[4]{\frac{K_h\cdot B}{4EI}}$$

7-1-1 Normal Condition

Modules of lateral subgrade reaction K_h = 20214 kN/m^3
Calculated value β = 0.35790 m^{-1}

Penetration length of SSP $D = 1.26 + \dfrac{3}{0.358} = 9.65$ m
Whole length of SSP L = 2.60−0.40+9.65 = 11.85 m

7-1-2 Seismic Conditio

Modules of lateral subgrade reaction K_h = 21596 kN/m^3
Calculated value β = 0.36386 m^{-1}

Penetration length of SSP $D = 2.27 + \dfrac{3}{0.364} = 10.52$ m
Whole length of SSP L = 2.60−0.40+10.52 = 12.72 m

Therefore, whole length of SSP is set as 13.00 m in consideration of round unit of SSP length.

2.339

8 Calculation Result

			Normal condition	Seismic condition
Inertia sectional moment	I (cm^4)	154000		
Section modulus	Z (cm^3)	4160		
Maximum bending moment	M_{max} (kN·m/m)		287.16	570.73
Stress intensity	σ (N/mm^2)		79 (185)	158 (278)
Lateral displacement	δ (mm)		26.14 (50.0)	61.14 (75.0)
Penetration depth	D (m)		9.65	10.52
Whole length of SSP	L (m)	13.00		