

**REPUBLIC OF THE PHILIPPINES
DEPARTMENT OF
PUBLIC WORKS AND HIGHWAYS**

**THE DETAILED DESIGN STUDY
FOR
THE PASIG-MARIKINA RIVER
CHANNEL
IMPROVEMENT PROJECT
(PHASE IV)**

FINAL REPORT

**VOLUME-4C
STRUCTURAL CALCULATION FOR
CONTRACT PACKAGE-3 (1/2)**

AUGUST 2020

JAPAN INTERNATIONAL COOPERATION AGENCY

**CTI ENGINEERING INTERNATIONAL CO., LTD.
JAPAN WATER AGENCY
NIPPON KOEI CO., LTD.
CTI ENGINEERING CO., LTD.**

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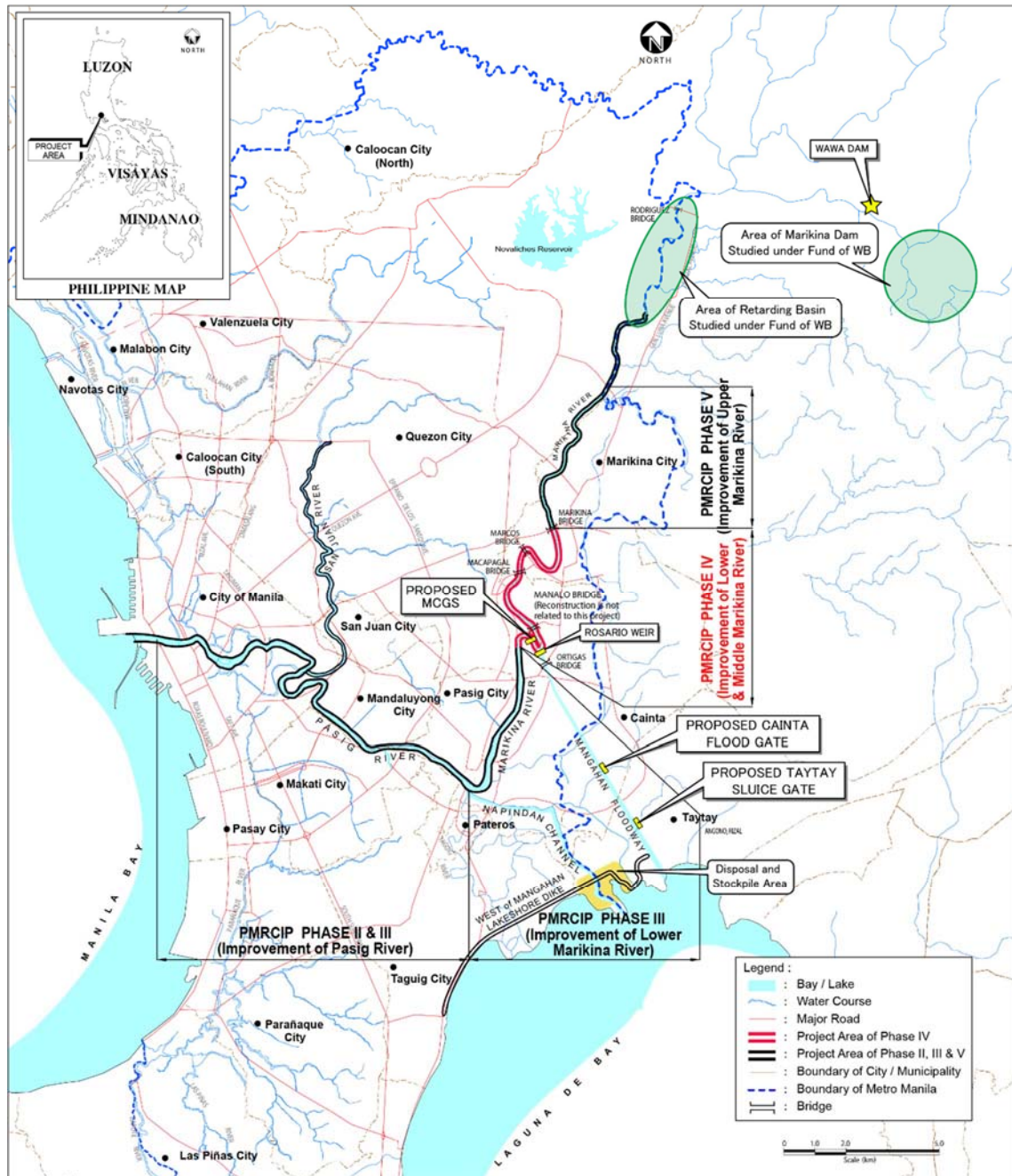
**CTI ENGINEERING INTERNATIONAL CO., LTD.
JAPAN WATER AGENCY
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COMPOSITION OF FINAL REPORT

VOLUME-1A	:	MAIN REPORT (CHAPTER 1 to 6)
VOLUME-1B	:	MAIN REPORT (CHAPTER 7 / 7.1 to 7.3)
VOLUME-1C	:	MAIN REPORT (CHAPTER 7 / 7.4 to 7.6)
VOLUME-1D	:	MAIN REPORT (CHAPTER 8 to 14)
VOLUME-2	:	APPENDIX
VOLUME-3	:	APPENDIX FOR GEOTECHNICAL INVESTIGATION
VOLUME-4A	:	STRUCTURAL CALCULATION FOR CONTRACT PACKAGE-1
VOLUME-4B	:	STRUCTURAL CALCULATION FOR CONTRACT PACKAGE-2
VOLUME-4C	:	STRUCTURAL CALCULATION FOR CONTRACT PACKAGE-3
VOLUME-5A	:	QUANTITY CALCULATION FOR CONTRACT PACKAGE-1
VOLUME-5B	:	QUANTITY CALCULATION FOR CONTRACT PACKAGE-2
VOLUME-5C	:	QUANTITY CALCULATION FOR CONTRACT PACKAGE-3
VOLUME-6	:	COST ESTIMATE

EXCHANGE RATES USED IN THE REPORT:

PHP 1.0 = JPY 2.15
US \$1.0 = JPY 108.9 = PHP 50.7
(November 2019)



PROJECT LOCATION MAP

**THE DETAILED DESIGN STUDY
FOR
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**FINAL REPORT
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STRUCTURAL CALCULATION
FOR CONTRACT PACKAGE-3
(1/2)**

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CHAPTER 1 RIVER STRUCTURE

1.1 Low Water Channel Revetment

1.1.1 Liquefaction Analysis

The calculation sheets are shown in the following pages.

1.1 LOW WATER CHANNEL REVETMENT

1.1.1 LIQUEFACTION ANALYSIS

1.1.1.1 Left Bank

PL Value

1.488

Unit volume weight of water

10.0 (kN/m³)

Load

0.0 (kN/m²)

Groundwater level

3.18 (m)

Design horizontal seismic coefficient

0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Reduction coefficient of soil constant		D _E		1		1		1		2/3		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1			

PL Value

5.398

Unit volume weight of water
Load
Groundwater level

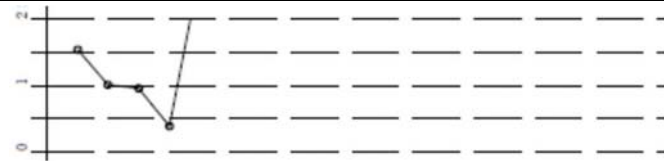
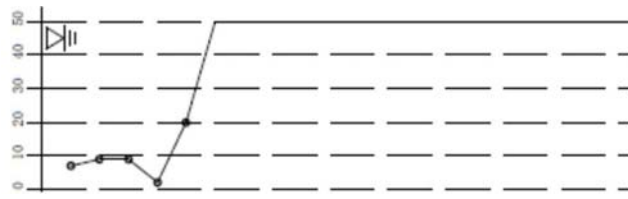
10.0 (kN/m³)0.0 (kN/m²)

0.77 (m)

Design horizontal seismic coefficient 0.20

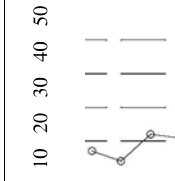
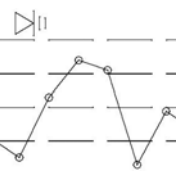
Note: .** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property								Determination of the liquid state				Reduction coefficient of soil constant				
	Layer Thickness(m)	Wet weight (kn/m ³)	Saturated weight (kn/m ³)	Judgement depth(m)	Soil category	Soil type	Observed N value	Effective Loading Pressure(kn/m ²)	Effective load at standard penetration test (kn/m ²)	F C	D ₃₀	Earthquake Dynamic coefficient		Repeated triaxial strength ratio	Dynamic shear strength ratio	Seismic response ratio	Liquefaction resistance
1.00	1.00	17.5	18.5	1.0	alluvial	sandy	7.00	15.4	15.4	36.00	0.000	1.00	0.348	0.348	0.227	1.535	D _E
2.00	1.00	17.5	18.5	2.0	alluvial	sandy	9.00	23.9	23.9	17.00	0.400	1.00	0.297	0.297	0.294	1.010	1
3.00	1.00	17.5	18.5	3.0	alluvial	sandy	9.00	32.4	32.4	24.00	0.250	1.00	0.306	0.306	0.322	0.950	1
4.00	1.00	17.5	18.5	4.0	alluvial	sandy	2.00	40.9	40.9	14.00	0.400	1.00	0.127	0.127	0.336	0.378	1/3
5.00	1.00	17.5	18.5	5.0	alluvial	sandy	20.00	49.4	49.4	14.00	0.500	1.00	0.923	0.923	0.343	2.688	1
6.00	1.00	17.5	18.5	6.0	alluvial	sandy	50.00	57.9	57.9	18.00	0.450	1.00	208.239	208.239	0.346	601.205	1
7.00	1.00	17.0	18.0	7.0	diluvial	cohesiv	50.00	65.9	65.9	0.00	0.000					**1	1
8.00	1.00	17.0	18.0	8.0	diluvial	cohesiv	50.00	73.9	73.9	0.00	0.000					**1	1
9.00	1.00	17.0	18.0	9.0	diluvial	cohesiv	50.00	81.9	81.9	0.00	0.000					**1	1
10.00	1.00	17.0	18.0	10.0	diluvial	cohesiv	50.00	89.9	89.9	0.00	0.000					**1	1
11.00	1.00	17.0	18.0	11.0	diluvial	cohesiv	50.00	97.9	97.9	0.00	0.000					**1	1
12.00	1.00	17.0	18.0	12.0	diluvial	cohesiv	50.00	105.9	105.9	0.00	0.000					**1	1
13.00	1.00	17.0	18.0	13.0	diluvial	cohesiv	50.00	113.9	113.9	0.00	0.000					**1	1
14.00	1.00	17.0	18.0	14.0	diluvial	cohesiv	50.00	121.9	121.9	0.00	0.000					**1	1
15.00	1.00	17.0	18.0	15.0	diluvial	cohesiv	50.00	129.9	129.9	0.00	0.000					**1	1
16.00	1.00	17.0	18.0	16.0	diluvial	cohesiv	50.00	137.9	137.9	0.00	0.000					**1	1
17.00	1.00	17.0	18.0	17.0	diluvial	cohesiv	50.00	145.9	145.9	0.00	0.000					**1	1
18.00	1.00	17.0	18.0	18.0	diluvial	cohesiv	50.00	153.9	153.9	0.00	0.000					**1	1
19.00	1.00	17.0	18.0	19.0	diluvial	cohesiv	50.00	161.9	161.9	0.00	0.000					**1	1
20.00	1.00	17.0	18.0	20.0	diluvial	cohesiv	50.00	169.9	169.9	0.00	0.000					**1	1



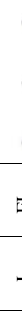
PL Value 0.000
Unit volume weight of water 10.0 (kN/m³)
Load 0.0 (kN/m²)
Groundwater level 5.49 (m)

Design horizontal seismic coefficient 0.20
Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property										Earthquake Dynamic coefficient	Repeated triaxial strength ratio	Determination of the liquid state			Reduction coefficient of soil constant				
	Layer Thickness(m)	Wet weight (kn/m ³)	Saturated weight (kn/m ³)	Judgement depth(m)	Soil categor	Soil type	Observed N value	σ _v	σ _{av}	F C			D ₅₀	C _w	R _L		R	L	FL	Liquefaction resistance
1.00	1.00	17.5	18.5	1.0	alluvial	sandy	7.00	17.5	17.5	26.00	0.000	1.00	0.296	0.296	0.197	**5			D _E	
2.00	1.00	17.5	18.5	2.0	alluvial	sandy	4.00	35.0	35.0	26.00	0.000	1.00	0.208	0.208	0.194	**5		1		
3.00	1.00	17.5	18.5	3.0	alluvial	sandy	12.00	52.5	52.5	5.00	2.000	1.00	0.276	0.276	0.191	**5		1		
4.00	1.00	17.5	18.5	4.0	alluvial	sandy	11.00	70.0	70.0	5.00	2.000	1.00	0.247	0.247	0.188	**5		1		
5.00	1.00	17.5	18.5	5.0	alluvial	sandy	5.00	87.5	87.5	29.00	1.200	1.00	0.197	0.197	0.185	**5		1		
6.00	1.00	17.5	18.5	6.0	alluvial	sandy	23.00	100.4	100.4	29.00	1.200	1.00	1.238	1.238	0.191	6.471		1		
7.00	1.00	17.5	18.5	7.0	alluvial	sandy	34.00	108.9	108.9	10.00	1.500	1.00	1.154	1.154	0.204	5.662		1		
8.00	1.00	17.5	18.5	8.0	alluvial	sandy	31.00	117.4	117.4	10.00	1.500	1.00	0.598	0.598	0.214	2.799		1		
9.00	1.00	18.0	19.0	9.0	diluvial	cohesiv	3.00	126.4	126.4	55.00	0.100					**1		1		
10.00	1.00	18.0	19.0	10.0	diluvial	cohesiv	19.00	135.4	135.4	55.00	0.100					**1		1		
11.00	1.00	18.0	19.0	11.0	diluvial	cohesiv	13.00	144.4	144.4	47.00	0.160					**1		1		
12.00	1.00	19.0	20.0	12.0	diluvial	sandy	6.00	154.4	154.4	47.00	0.160					**1		1		
13.00	1.00	19.0	20.0	13.0	diluvial	sandy	12.00	164.4	164.4	68.00	0.000					**1		1		
14.00	1.00	18.0	19.0	14.0	diluvial	cohesiv	12.00	173.4	173.4	68.00	0.000					**1		1		
15.00	1.00	18.0	19.0	15.0	diluvial	cohesiv	18.00	182.4	182.4	78.00	0.000					**1		1		
16.00	1.00	18.0	19.0	16.0	diluvial	cohesiv	19.00	191.4	191.4	78.00	0.000					**1		1		
17.00	1.00	18.0	19.0	17.0	diluvial	cohesiv	16.00	200.4	200.4	70.00	0.000					**1		1		
18.00	1.00	18.0	19.0	18.0	diluvial	cohesiv	19.00	209.4	209.4	70.00	0.000					**1		1		
19.00	1.00	18.0	19.0	19.0	diluvial	cohesiv	40.00	218.4	218.4	43.00	0.000					**1		1		
20.00	1.00	18.0	19.0	20.0	diluvial	cohesiv	50.00	227.4	227.4	43.00	0.000					**1		1		

PL Value 0.000
Unit volume weight of water 10.0 (kN/m³)
Load 0.0 (kN/m²)
Groundwater level 1.99 (m)

Design horizontal seismic coefficient 0.20
Note: : ** 1 to * * Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property										Determination of the liquid state				Reduction coefficient of soil constant		
	Layer Thickness(m)	Wet weight (kn/m ³)	Saturated weight (kn/m ³)	Judgement depth(m)	Soil category	Soil type	Observed N value	Effective Loading Pressure(kn/m ²)	Effective load at standard penetration test (kn/m ²)	Fine fraction content (%)	Particle size (mm)	Earthquake Dynamic coefficient	Repeated triaxial strength ratio	Dynamic shear strength ratio		Seismic response ratio	Liquefaction resistance
	h	γ _t	γ _{sat}	x			N	σ _{v'}	σ _{av'}	FC	D ₅₀	C _w	R _L	R	L	FL	
1.00	1.00	17.5	18.5	1.0	alluvial	sandy	9.90	17.5	17.5	97.00	0.000	0.00	0.000	0.000	0.000	**2	
2.00	1.00	17.5	18.5	2.0	alluvial	sandy	9.90	34.9	34.9	15.00	0.400	1.00	0.287	0.287	0.194	1.477	
3.00	1.00	17.5	18.5	3.0	alluvial	sandy	9.90	43.4	43.4	15.00	0.400	1.00	0.276	0.276	0.235	1.172	
4.00	1.00	17.5	18.5	4.0	alluvial	sandy	9.90	51.9	51.9	15.00	0.400	1.00	0.266	0.266	0.261	1.021	
5.89	1.89	18.0	19.0					69.0	69.0	0.00	0.000					**1	
6.89	1.00	19.0	20.0	5.9	Hongzh	cohesiv	4.00	79.0	79.0	77.00	0.000					**1	
7.89	1.00	19.0	20.0	6.9	Hongzh	sandy	3.00	89.0	89.0	77.00	0.000					**1	
8.89	1.00	19.0	20.0	7.9	Hongzh	sandy	4.00	99.0	99.0	97.00	0.000					**1	
9.89	1.00	19.0	20.0	8.9	Hongzh	sandy	5.50	108.0	108.0	97.00	0.000					**1	
10.89	1.00	18.0	19.0	9.9	Hongzh	cohesiv	7.00	117.0	117.0	87.00	0.000					**1	
11.89	1.00	18.0	19.0	10.9	Hongzh	cohesiv	7.00	126.0	126.0	87.00	0.000					**1	
12.89	1.00	18.0	19.0	11.9	Hongzh	cohesiv	13.00	135.0	135.0	94.00	0.000					**1	
13.89	1.00	18.0	19.0	12.9	Hongzh	cohesiv	12.00	144.0	144.0	94.00	0.000					**1	
14.89	1.00	18.0	19.0	13.9	Hongzh	cohesiv	10.00	153.0	153.0	88.00	0.000					**1	
15.89	1.00	18.0	19.0	14.9	Hongzh	cohesiv	9.00	162.0	162.0	88.00	0.000					**1	
16.89	1.00	18.0	19.0	15.9	Hongzh	cohesiv	12.00	171.0	171.0	88.00	0.000					**1	
17.89	1.00	18.0	19.0	16.9	Hongzh	cohesiv	12.00	180.0	180.0	88.00	0.000					**1	
18.89	1.00	18.0	19.0	17.9	Hongzh	cohesiv	11.00	189.0	189.0	31.00	0.200					**1	
19.89	1.00	18.0	19.0	18.9	Hongzh	cohesiv	13.00	198.0	198.0	31.00	0.200					**1	
20.89	1.00	18.0	19.0	19.9	Hongzh	cohesiv	17.00	207.0	207.0	29.00	0.200					**1	
21.89	1.00	18.0	19.0	20.9	Hongzh	sandy	17.00	216.0	216.0	29.00	0.200					**1	
22.89	1.00	18.0	19.0	21.9	Hongzh	cohesiv e soil	39.00	225.0	225.0	0.00	0.000					**1	
23.89	1.00	18.0	19.0	22.9	Hongzh	cohesiv	38.00	234.0	234.0	0.00	0.000					**1	
24.89	1.00	18.0	19.0	23.9	Hongzh	cohesiv	43.00	243.0	243.0	0.00	0.000					**1	
	1.00	18.0	19.0	24.9	Hongzh	cohesiv	48.00									**1	

PL Value 0.654
 Unit volume weight of water 10.0 (kN/m³)
 Load 0.0 (kN/m²)
 Groundwater level 2.55 (m)

Design horizontal seismic coefficient 0.20
 Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Reduction coefficient of soil constant		D _E																						
Determination of the liquid state		Dynamic shear strength ratio		R	Repeated triaxial strength ratio		Earthquake Dynamic coefficient		Soil Property		Observed N value		Soil type		Soil category		Judgement depth(m)		Saturated weight (kn/m3)		Wet weight (kn/m3)		Layer Thickness(m)	
		L	FL	R _L	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Liquefaction resistance																								
Seismic response ratio		L	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Dynamic shear strength ratio		R	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Repeated triaxial strength ratio		R	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Earthquake Dynamic coefficient		C _w	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Particle size (mm)		D ₅₀	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Fine fraction content (%)		FC	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Effective load at standard penetration test (kn/m2)		σ ₄₆	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Effective Loading Pressure (kn/m2)		σ _v	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Observed N value		N	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Soil type		Soil type	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Soil category		Soil category	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Judgement depth(m)		x	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Saturated weight (kn/m3)		γ _{sat}	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Wet weight (kn/m3)		γ _t	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Layer Thickness(m)		h	FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
Soil Depth (m)			FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category
			FL	R	C _w	D ₅₀	FC	σ _v	σ ₄₆	N	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category	Soil type	Soil category

PL Value 0.000
Unit volume weight of water 10.0 (kN/m³)
Load 0.0 (kN/m²)
Groundwater level 2.72 (m)

Design horizontal seismic coefficient 0.20
Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property										Earthquake Dynamic coefficient			Repeated triaxial strength ratio		Determination of the liquid state			Reduction coefficient of soil constant
	Layer Thickness(m)	Wet weight (kn/m ³)	Saturated weight (kn/m ³)	Judgement depth(m)	Soil category	Soil type	Observed N value	σ _v	σ _{vb}	F C	D ₅₀	C _w	R _L	R	L	FL			
1.00	1.00	15.5	16.5	1.0 alluvial		cohesiv		15.5	15.5	0.00	0.000	1.00	0.165	0.165	0.197	**5		D _E	
2.00	1.00	15.5	16.5	2.0 alluvial		cohesiv		31.0	31.0	82.00	0.000	1.00	0.304	0.304	0.194	**5			
3.00	1.00	15.5	16.5	3.0 alluvial		cohesiv		44.0	44.0	82.00	0.000	1.00	0.345	0.345	0.203	1.698			
4.00	1.00	15.5	16.5	4.0 alluvial		sandy		50.5	50.5	49.00	0.080	1.00	0.341	0.341	0.236	1.445			
5.00	1.00	17.5	18.5	5.0 alluvial		sandy		59.0	59.0	49.00	0.080	1.00	0.586	0.586	0.257	2.284			
6.00	1.00	15.5	16.5	6.0 alluvial		cohesiv		65.5	65.5	78.00	0.000	0.00	0.000	0.000	0.000	**2			
7.00	1.00	15.5	16.5	7.0 alluvial		cohesiv		72.0	72.0	78.00	0.000	0.00	0.000	0.000	0.000	**2			
8.00	1.00	15.5	16.5	8.0 alluvial		cohesiv		78.5	78.5	43.00	0.000	0.00	0.000	0.000	0.000	**2			
9.00	1.00	18.0	19.0	9.0 diluvial		cohesiv		87.5	87.5	43.00	0.000					**1			
10.00	1.00	18.0	19.0	10.0 diluvial		cohesiv		96.5	96.5	51.00	0.000					**1			
11.00	1.00	18.0	19.0	11.0 diluvial		cohesiv		105.5	105.5	51.00	0.000					**1			
12.00	1.00	18.0	19.0	12.0 diluvial		cohesiv		114.5	114.5	99.00	0.000					**1			
13.00	1.00	18.0	19.0	13.0 diluvial		cohesiv		123.5	123.5	99.00	0.000					**1			
14.00	1.00	18.0	19.0	14.0 diluvial		cohesiv		132.5	132.5	93.00	0.000					**1			
15.00	1.00	18.0	19.0	15.0 diluvial		cohesiv		141.5	141.5	93.00	0.000					**1			
16.00	1.00	18.0	19.0	16.0 diluvial		cohesiv		150.5	150.5	99.00	0.000					**1			
17.00	1.00	18.0	19.0	17.0 diluvial		cohesiv		159.5	159.5	99.00	0.000					**1			
18.00	1.00	18.0	19.0	18.0 diluvial		cohesiv		168.5	168.5	99.00	0.000					**1			
19.00	1.00	18.0	19.0	19.0 diluvial		cohesiv		177.5	177.5	99.00	0.000					**1			
20.00	1.00	18.0	19.0	20.0 diluvial		cohesiv		186.5	186.5	98.00	0.000					**1			

PL Value

1.321

Unit volume weight of water
Load10.0 (kN/m³)
0.0 (kN/m²)

Groundwater level

3.12 (m)

Design horizontal seismic coefficient

0.20

Note: .** 1 to * * Z Out of Scope of Liquefaction Analysis

Reduction coefficient of soil constant		D _E		1		1		1		2/3		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1		1	

PL Value 0.071
Unit volume weight of water 10.0 (kN/m³)
Load 0.0 (kN/m²)
Groundwater level 1.64 (m)

Design horizontal seismic coefficient 0.20
Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property										Earthquake Dynamic coefficient		Repeated triaxial strength ratio		Determination of the liquid state			Reduction coefficient of soil constant		
	Layer Thickness(m)	Wet weight (kn/m3)	Saturated weight (kn/m3)	Judgement depth(m)	Soil category	Soil type	Observed N value	σ_v	Effective load at standard penetration test (kn/m2)	Fine fraction content (%)	Particle size (mm)	C _w	R _L	R	L	FL	Liquefaction resistance			
1.29	1.29	17.5	18.5	1.3	alluvial	sandy		22.5	22.5	55.00	0.000	1.00	0.208	0.208	0.196	**5				
2.29	1.00	15.5	16.5	2.3	alluvial	cohesive		32.2	32.2	36.00	0.000	1.00	0.230	0.230	0.232	0.992			2/3	
3.29	1.00	17.5	18.5	3.3	alluvial	sandy		40.7	40.7	83.00	0.000	0.00	0.000	0.000	0.000	0.000			**2	1
4.29	1.00	15.5	16.5	4.3	alluvial	cohesive		47.2	47.2	60.00	0.050	1.00	6.919	6.919	0.292	23.696			1	
5.29	1.00	19.0	20.0	5.3	diluvial	sandy		57.2	57.2	28.00	0.350					**1			1	
6.29	1.00	19.0	20.0	6.3	diluvial	sandy		67.2	67.2	30.00	0.250					**1			1	
7.29	1.00	19.0	20.0	7.3	diluvial	sandy		77.2	77.2	23.00	1.300					**1			1	
8.29	1.00	15.5	16.5	8.3	diluvial	cohesive		83.7	83.7	87.00	0.000					**1			1	
9.29	1.00	18.0	19.0	9.3	diluvial	cohesive		92.7	92.7	83.00	0.000					**1			1	
10.29	1.00	18.0	19.0	10.3	diluvial	cohesive		101.7	101.7	31.00	0.000					**1			1	
11.29	1.00	18.0	19.0	11.3	diluvial	cohesive		110.7	110.7	40.00	0.000					**1			1	
12.29	1.00	16.5	17.5	12.3	diluvial	cohesive		118.2	118.2	0.00	0.000					**1			1	
13.29	1.00	16.5	17.5	13.3	diluvial	cohesive		125.7	125.7	0.00	0.000					**1			1	
14.29	1.00	16.5	17.5	14.3	diluvial	cohesive		133.2	133.2	0.00	0.000					**1			1	
15.29	1.00	16.5	17.5	15.3	diluvial	cohesive		140.7	140.7	0.00	0.000					**1			1	
16.29	1.00	16.5	17.5	16.3	diluvial	cohesive		148.2	148.2	0.00	0.000					**1			1	
17.29	1.00	16.5	17.5	17.3	diluvial	cohesive		155.7	155.7	0.00	0.000					**1			1	
18.29	1.00	16.5	17.5	18.3	diluvial	cohesive		163.2	163.2	0.00	0.000					**1			1	
19.29	1.00	16.5	17.5	19.3	diluvial	cohesive		170.7	170.7	0.00	0.000					**1			1	
20.29	1.00	16.5	17.5	20.3	diluvial	cohesive		178.2	178.2	0.00	0.000					**1			1	

PL Value

0.000

Unit volume weight of water
Load

10.0 (kN/m³)0.0 (kN/m²)

Groundwater level

5.49 (m)

Design horizontal seismic coefficient 0.20

Note: .** 1 to .** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property										Repeated triaxial strength ratio		Determination of the liquid state			Reduction coefficient of soil constant					
	Layer Thickness(m)	Wet weight (kn/m3)	Saturated weight (kn/m3)	Judgement depth(m)	Soil category	Soil type	Observed N value	N	Effective Loading Pressure (kn/m2)	σ _v	σ _{1b}	F C	D ₅₀	Earthquake Dynamic coefficient			R _L	Dynamic shear strength ratio		Seismic response ratio	Liquefaction resistance
														C _w	R _L			R	L		
1.00	1.00	17.5	18.5	1.0	alluvial	sandy	7.00	17.5	17.5	17.5	26.00	0.000	1.00	0.296	0.296	0.197	**5	0.197	**5	D _E	
2.00	1.00	17.5	18.5	2.0	alluvial	sandy	4.00	35.0	35.0	35.0	26.00	0.000	1.00	0.208	0.208	0.194	**5	0.194	**5	1	
3.00	1.00	17.5	18.5	3.0	alluvial	sandy	12.00	52.5	52.5	52.5	5.00	2.000	1.00	0.276	0.276	0.191	**5	0.191	**5	1	
4.00	1.00	17.5	18.5	4.0	alluvial	sandy	11.00	70.0	70.0	70.0	5.00	2.000	1.00	0.247	0.247	0.188	**5	0.188	**5	1	
5.00	1.00	17.5	18.5	5.0	alluvial	sandy	5.00	87.5	87.5	87.5	29.00	1.200	1.00	0.197	0.197	0.185	**5	0.185	**5	1	
6.00	1.00	17.5	18.5	6.0	alluvial	sandy	23.00	100.4	100.4	100.4	29.00	1.200	1.00	1.238	1.238	0.191	6.471	0.191	6.471	1	
7.00	1.00	17.5	18.5	7.0	alluvial	sandy	34.00	108.9	108.9	108.9	10.00	1.500	1.00	1.154	1.154	0.204	5.662	0.204	5.662	1	
8.00	1.00	17.5	18.5	8.0	alluvial	sandy	31.00	117.4	117.4	117.4	10.00	1.500	1.00	0.598	0.598	0.214	2.799	0.214	2.799	1	
9.00	1.00	18.0	19.0	9.0	diluvial	cohesiv	3.00	126.4	126.4	126.4	55.00	0.100						**1	**1	1	
10.00	1.00	18.0	19.0	10.0	diluvial	cohesiv	19.00	135.4	135.4	135.4	55.00	0.100						**1	**1	1	
11.00	1.00	18.0	19.0	11.0	diluvial	cohesiv	13.00	144.4	144.4	144.4	47.00	0.160						**1	**1	1	
12.00	1.00	19.0	20.0	12.0	diluvial	sandy	6.00	154.4	154.4	154.4	47.00	0.160						**1	**1	1	
13.00	1.00	19.0	20.0	13.0	diluvial	sandy	12.00	164.4	164.4	164.4	68.00	0.000						**1	**1	1	
14.00	1.00	18.0	19.0	14.0	diluvial	cohesiv	12.00	173.4	173.4	173.4	68.00	0.000						**1	**1	1	
15.00	1.00	18.0	19.0	15.0	diluvial	cohesiv	18.00	182.4	182.4	182.4	78.00	0.000						**1	**1	1	
16.00	1.00	18.0	19.0	16.0	diluvial	cohesiv	19.00	191.4	191.4	191.4	78.00	0.000						**1	**1	1	
17.00	1.00	18.0	19.0	17.0	diluvial	cohesiv	16.00	200.4	200.4	200.4	70.00	0.000						**1	**1	1	
18.00	1.00	18.0	19.0	18.0	diluvial	cohesiv	19.00	209.4	209.4	209.4	70.00	0.000						**1	**1	1	
19.00	1.00	18.0	19.0	19.0	diluvial	cohesiv	40.00	218.4	218.4	218.4	43.00	0.000						**1	**1	1	
20.00	1.00	18.0	19.0	20.0	diluvial	cohesiv	50.00	227.4	227.4	227.4	43.00	0.000						**1	**1	1	
21.00	1.00	19.0	20.0	21.0	diluvial	sandy	21.00	237.4	237.4	237.4	74.00	0.000						**1	**1	1	
22.00	1.00	19.0	20.0	22.0	diluvial	sandy	26.00	247.4	247.4	247.4	74.00	0.000						**1	**1	1	
23.00	1.00	19.0	20.0	23.0	diluvial	sandy	30.00	257.4	257.4	257.4	57.00	0.000						**1	**1	1	
24.00	1.00	19.0	20.0	24.0	diluvial	sandy	25.00	267.4	267.4	267.4	57.00	0.000						**1	**1	1	
25.00	1.00	18.0	19.0	25.0	diluvial	cohesiv	25.00	276.4	276.4	276.4	58.00	0.000						**1	**1	1	
26.00	1.00	18.0	19.0	26.0	diluvial	cohesiv	16.00	285.4	285.4	285.4	58.00	0.000						**1	**1	1	
27.00	1.00	18.0	19.0	27.0	diluvial	cohesiv	24.00	294.4	294.4	294.4	56.00	0.000						**1	**1	1	
28.00	1.00	18.0	19.0	28.0	diluvial	cohesiv	31.00	303.4	303.4	303.4	0.00	0.000						**1	**1	1	
29.00	1.00	18.0	19.0	29.0	diluvial	cohesiv	50.00	312.4	312.4	312.4	0.00	0.000						**1	**1	1	

0.000

10.0 (kN/m³)
0.0 (kN/m²)

20

Note: ** 1 to * Z Out of Scope of Liquefaction Analysis

[illegible]

1.1.1 LIQUEFACTION ANALYSIS

1.1.1.2 Right Bank

PL Value 5.394

Unit volume weight of water 10.0 (kn/m³)Load 0.0 (kn/m²)

Groundwater level 1.82 (m)

Design horizontal seismic coefficient 0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property										Determination of the liquid state				Reduction coefficient of soil constant		
	Layer Thickness(m)	Wet weight (kn/m ³)	Saturated weight (kn/m ³)	Dynamic shear strength ratio	Soil category	Soil type	Observed N value	σ_v'	σ_{sk}	FC	D ₅₀	C _w	R _L	Dynamic shear strength ratio		Seismic response ratio	Liquefaction resistance
	h	γ_t	γ_{sat}	x		N		σ_v'	σ_{sk}	FC	D ₅₀	C _w	R _L	R	L	FL	
2.01	2.01	17.5	18.5	2.0	alluvial	Sandy	4.00	33.4	33.4	3.00	5.000	1.00	0.173	0.173	0.205	0.846	D _E
3.01	1.00	17.5	18.5	3.0	alluvial	Sandy	4.00	41.9	41.9	3.00	5.000	1.00	0.167	0.167	0.245	0.680	2/3
4.01	1.00	17.5	18.5	4.0	alluvial	Sandy	12.00	50.4	50.4	3.00	5.000	1.00	0.279	0.279	0.270	1.033	1
5.01	1.00	17.5	18.5	5.0	alluvial	Sandy	8.00	58.9	58.9	3.00	5.000	1.00	0.220	0.220	0.285	0.771	2/3
6.01	1.00	18.0	19.0	6.0	diluvial	Cohesiv	2.00	67.9	67.9	44.00	0.000					**1	1
7.01	1.00	17.5	18.5	7.0	alluvial	Sandy	3.00	76.4	76.4	44.00	0.000	0.00	0.000	0.000	0.000	**2	1
8.01	1.00	18.0	19.0	8.0	diluvial	Cohesiv	3.00	85.4	85.4	96.00	0.100					**1	1
9.01	1.00	18.0	19.0	9.0	diluvial	Cohesiv	9.00	94.4	94.4	76.00	0.000					**1	1
10.01	1.00	18.0	19.0	10.0	diluvial	Cohesiv	10.00	103.4	103.4	76.00	0.000					**1	1
11.01	1.00	18.0	19.0	11.0	diluvial	Cohesiv	13.00	112.4	112.4	83.00	0.000					**1	1
12.01	1.00	18.0	19.0	12.0	diluvial	Cohesiv	11.00	121.4	121.4	83.00	0.000					**1	1
13.01	1.00	18.0	19.0	13.0	diluvial	Cohesiv	11.00	130.4	130.4	83.00	0.000					**1	1
14.01	1.00	18.0	19.0	14.0	diluvial	Cohesiv	20.00	139.4	139.4	83.00	0.000					**1	1
15.01	1.00	18.0	19.0	15.0	diluvial	Cohesiv	50.00	148.4	148.4	74.00	0.000					**1	1
16.01	1.00	18.0	19.0	16.0	diluvial	Cohesiv	43.00	157.4	157.4	74.00	0.000					**1	1
17.01	1.00	18.0	19.0	17.0	diluvial	Cohesiv	22.00	166.4	166.4	29.00	1.200					**1	1
18.01	1.00	18.0	19.0	18.0	diluvial	Cohesiv	37.00	175.4	175.4	29.00	1.200					**1	1
19.01	1.00	18.0	19.0	19.0	diluvial	Cohesiv	36.00	184.4	184.4	34.00	0.850					**1	1
20.01	1.00	18.0	19.0	20.0	diluvial	Cohesiv	50.00	193.4	193.4	34.00	0.850					**1	1
21.01	1.00	18.0	19.0	21.0	diluvial	Cohesiv	47.00	202.4	202.4	16.00	1.200					**1	1
22.01	1.00	18.0	19.0	22.0	diluvial	Cohesiv	50.00	211.4	211.4	16.00	1.200					**1	1
23.01	1.00	18.0	19.0	23.0	diluvial	Cohesiv	50.00	220.4	220.4	23.00	0.000					**1	1
24.01	1.00	16.5	17.5	24.0	diluvial	Cohesiv	50.00	227.9	227.9	23.00	0.000					**1	1
25.01	1.00	16.5	17.5	25.0	diluvial	Cohesiv	50.00	235.4	235.4	0.00	0.000					**1	1

PL Value

0.000

Unit volume weight of water 10.0 (kn/m³)
Load 0.0 (kn/m²)

Groundwater level 3.92 (m)

Design horizontal seismic coefficient 0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property										Earthquake Dynamic coefficient	Repeated triaxial strength ratio	Determination of the liquid state			Reduction coefficient of soil constant				
	Layer Thickness(m)	Wet weight (kn/m3)	Saturated weight (kn/m3)	Dynamic shear strength ratio	Soil category	Soil type	Observed N value	σ_v	σ_{vb}	FC			D ₅₀	C _w	R _L		R	L	FL	Liquefaction resistance
0.54	0.54	15.5	16.5	0.5	alluvial	Cohesive soil	3.00	8.4	8.4	0.00	0.000	1.00	0.173	0.173	0.198	**5			D _E	1
1.54	1.00	17.5	18.5	1.5	alluvial	Sandy	14.00	25.9	25.9	0.00	0.000	1.00	0.409	0.409	0.195	**5				1
2.54	1.00	17.5	18.5	2.5	alluvial	Sandy	16.00	43.4	43.4	39.00	0.000	1.00	3.853	3.853	0.192	**5				1
3.54	1.00	17.5	18.5	3.5	alluvial	Sandy	16.00	60.9	60.9	39.00	0.000	1.00	1.662	1.662	0.189	**5				1
4.54	1.00	17.5	18.5	4.5	alluvial	Sandy	20.00	72.8	72.8	9.00	0.550	1.00	0.377	0.377	0.202	1.862				1
5.54	1.00	18.0	19.0	5.5	diluvial	Cohesive	12.00	81.8	81.8	77.00	0.550					**1				1
6.54	1.00	18.0	19.0	6.5	diluvial	Cohesive	11.00	90.8	90.8	77.00	0.000					**1				1
7.54	1.00	18.0	19.0	7.5	diluvial	Cohesive	11.00	99.8	99.8	77.00	0.000					**1				1
8.54	1.00	18.0	19.0	8.5	diluvial	Cohesive	9.00	108.8	108.8	72.00	0.000					**1				1
9.54	1.00	18.0	19.0	9.5	diluvial	Cohesive	10.00	117.8	117.8	72.00	0.000					**1				1
10.54	1.00	18.0	19.0	10.5	diluvial	Cohesive	12.00	126.8	126.8	88.00	0.000					**1				1
11.54	1.00	18.0	19.0	11.5	diluvial	Cohesive	11.00	135.8	135.8	88.00	0.000					**1				1
12.54	1.00	18.0	19.0	12.5	diluvial	Cohesive	18.00	144.8	144.8	96.00	0.000					**1				1
13.54	1.00	18.0	19.0	13.5	diluvial	Cohesive	24.00	153.8	153.8	96.00	0.000					**1				1
14.54	1.00	18.0	19.0	14.5	diluvial	Cohesive	41.00	162.8	162.8	90.00	0.000					**1				1
15.54	1.00	18.0	19.0	15.5	diluvial	Cohesive	34.00	171.8	171.8	90.00	0.000					**1				1
16.54	1.00	18.0	19.0	16.5	diluvial	Cohesive	18.00	180.8	180.8	80.00	0.000					**1				1
17.54	1.00	16.5	17.5	17.5	diluvial	Cohesive	22.00	188.3	188.3	80.00	0.000					**1				1
18.54	1.00	17.0	18.0	18.5	diluvial	Cohesive	23.00	196.3	196.3	48.00	0.100					**1				1
19.54	1.00	17.0	18.0	19.5	diluvial	Cohesive	22.00	204.3	204.3	48.00	0.100					**1				1
20.54	1.00	17.0	18.0	20.5	diluvial	Cohesive	32.00	212.3	212.3	22.00	0.000					**1				1

PL Value

0.000

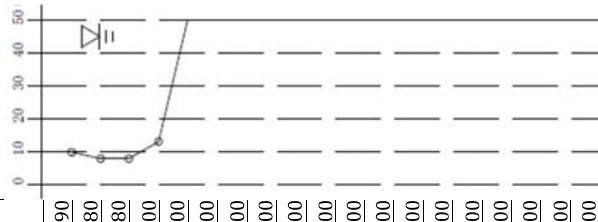
Unit volume weight of water 10.0 (kn/m³)
Load 0.0 (kn/m²)

Groundwater level 1.98 (m)

Design horizontal seismic coefficient 0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property								Earthquake Dynamic coefficient				Repeated triaxial strength ratio		Determination of the liquid state			Reduction coefficient of soil constant						
	Layer Thickness(m)	Wet weight (kN/m³)	Saturated weight (kN/m³)	Dynamic shear strength ratio	Soil category	Soil type	Observed N value	N	Effective Loading Pressure(kN/m²)	σ _w	Effective load at standard penetration test (kN/m²)	Fine fraction content (%)	Particle size (mm)	C _w	R _L	Dynamic shear strength ratio	Seismic response ratio		Liquefaction resistance	FL	L	R	D _E	
																								h
1.00	1.00	17.5	18.5	1.0	alluvial	Sandy		9.90	17.5	17.5	0.00	0.000	0.000	0.000	1.00	0.299	0.299	0.197	**5		**5	0.197	0.299	1
2.00	1.00	15.5	16.5	2.0	alluvial	Cohesiv		7.80	32.8	32.8	0.00	0.000	0.000	1.00	0.243	0.243	0.195	1.243		0.195	0.243	1		
2.95	0.95	15.5	16.5	3.0	alluvial	Cohesiv		7.80	39.0	39.0	51.00	0.080	0.000	1.00	0.395	0.395	0.239	1.653		0.239	0.395	1		
3.95	1.00	15.5	16.5	4.0	alluvial	Cohesiv		13.00	45.5	45.5	51.00	0.080	0.000	1.00	2.606	2.606	0.270	9.651		0.270	2.606	1		
4.95	1.00	15.5	16.5	5.0	alluvial	Cohesiv		50.00	52.0	52.0	51.00	0.080	0.000	1.00			0.291			0.291		1		
5.95	1.00	17.5	18.5	6.0	alluvial	Sandy		50.00	60.5	60.5	81.00	0.000	0.000	1.00			0.302			0.302		1		
6.95	1.00	17.5	18.5	7.0	alluvial	Sandy		50.00	69.0	69.0	81.00	0.000	0.000	1.00			0.308			0.308		1		
7.95	1.00	18.0	19.0	8.0	diluvial	Cohesiv		50.00	78.0	78.0	83.00	0.000	0.000					**1				1		
8.95	1.00	18.0	19.0	9.0	diluvial	Cohesiv		50.00	87.0	87.0	83.00	0.000	0.000					**1				1		
9.95	1.00	17.0	18.0	10.0	diluvial	Cohesiv		50.00	95.0	95.0	68.00	0.000	0.000					**1				1		
10.95	1.00	17.0	18.0	11.0	diluvial	Cohesiv		50.00	103.0	103.0	68.00	0.000	0.000					**1				1		
11.95	1.00	17.0	18.0	12.0	diluvial	Cohesiv		50.00	111.0	111.0	43.00	0.000	0.000					**1				1		
12.95	1.00	17.0	18.0	13.0	diluvial	Cohesiv		50.00	119.0	119.0	43.00	0.000	0.000					**1				1		
13.95	1.00	17.0	18.0	14.0	diluvial	Cohesiv		50.00	127.0	127.0	16.00	0.000	0.000					**1				1		
14.95	1.00	17.0	18.0	15.0	diluvial	Cohesiv		50.00	135.0	135.0	16.00	0.000	0.000					**1				1		
15.95	1.00	17.0	18.0	16.0	diluvial	Cohesiv		50.00	143.0	143.0	27.00	0.000	0.000					**1				1		
16.95	1.00	17.0	18.0	17.0	diluvial	Cohesiv		50.00	151.0	151.0	27.00	0.000	0.000					**1				1		
17.95	1.00	17.0	18.0	18.0	diluvial	Cohesiv		50.00	159.0	159.0	21.00	0.000	0.000					**1				1		
18.95	1.00	17.0	18.0	19.0	diluvial	Cohesiv		50.00	167.0	167.0	21.00	0.000	0.000					**1				1		



PL Value

0.000

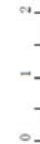
Unit volume weight of water 10.0 (kn/m³)
Load 0.0 (kn/m²)

Groundwater level

4.48 (m)

Design horizontal seismic coefficient 0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property								Determination of the liquid state				Reduction coefficient of soil constant				
	Layer Thickness(m)	Wet weight (kn/m3)	Saturated weight (kn/m3)	Dynamic shear strength ratio	Soil category	Soil type	Observed N value	Effective Loading Pressure(kN/m2)	Effective load at standard penetration test (kn/m2)	Fine fraction content (%)	Particle size (mm)	Earthquake Dynamic coefficient		Repeated triaxial strength ratio	Dynamic shear strength ratio	Seismic response ratio	Liquefaction resistance
	h	γ _t	γ _{sat}	x			N	σ _{v'}	σ _{N0'}	FC	D ₅₀	C _w	R _L	R	L	FL	
1.00	1.00	15.5	16.5	1.0	alluvial	Cohesiv	8.00	15.5	15.5	67.00	0.000	1.00	4.525	4.525	0.197	**5	
2.00	1.00	15.5	16.5	2.0	alluvial	Cohesiv	8.00	31.0	31.0	67.00	0.000	1.00	1.768	1.768	0.194	**5	
3.00	1.00	17.5	18.5	3.0	alluvial	Sandy	9.00	48.5	48.5	38.00	0.000	1.00	0.331	0.331	0.191	**5	
4.00	1.00	17.5	18.5	4.0	alluvial	Sandy	35.00	66.0	66.0	38.00	0.000	1.00	116.488	116.488	0.188	**5	
5.00	1.00	17.5	18.5	5.0	alluvial	Sandy	16.00	78.8	78.8	10.00	3.500	1.00	0.290	0.290	0.197	1.472	
6.00	1.00	17.5	18.5	6.0	alluvial	Sandy	14.00	87.3	87.3	10.00	3.500	1.00	0.263	0.263	0.214	1.231	
7.00	1.00	18.0	19.0	7.0	diluvial	Cohesiv	14.00	96.3	96.3	93.00	0.000					**1	
8.00	1.00	18.0	19.0	8.0	diluvial	Cohesiv	6.00	105.3	105.3	93.00	0.000					**1	
9.00	1.00	18.0	19.0	9.0	diluvial	Cohesiv	7.00	114.3	114.3	96.00	0.000					**1	
10.00	1.00	18.0	19.0	10.0	diluvial	Cohesiv	12.00	123.3	123.3	96.00	0.000					**1	
11.00	1.00	18.0	19.0	11.0	diluvial	Cohesiv	22.00	132.3	132.3	86.00	0.000					**1	
12.00	1.00	18.0	19.0	12.0	diluvial	Cohesiv	18.00	141.3	141.3	86.00	0.000					**1	
13.00	1.00	18.0	19.0	13.0	diluvial	Cohesiv	25.00	150.3	150.3	98.00	0.000					**1	
14.00	1.00	18.0	19.0	14.0	diluvial	Cohesiv	27.00	159.3	159.3	98.00	0.000					**1	
15.00	1.00	18.0	19.0	15.0	diluvial	Cohesiv	22.00	168.3	168.3	80.00	0.000					**1	
16.00	1.00	18.0	19.0	16.0	diluvial	Cohesiv	17.00	177.3	177.3	80.00	0.000					**1	
17.00	1.00	16.5	17.5	17.0	diluvial	Cohesiv	21.00	184.8	184.8	6.00	0.000					**1	
18.00	1.00	16.5	17.5	18.0	diluvial	Cohesiv	25.00	192.3	192.3	6.00	0.000					**1	
19.00	1.00	16.5	17.5	19.0	diluvial	Cohesiv	26.00	199.8	199.8	38.00	0.000					**1	
20.00	1.00	16.5	17.5	20.0	diluvial	Cohesiv	39.00	207.3	207.3	38.00	0.000					**1	

PL Value

1.578

Unit volume weight of water 10.0 (kn/m³)
Load 0.0 (kn/m²)
Groundwater level 4.58 (m)

Design horizontal seismic coefficient 0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property								Determination of the liquid state				Reduction coefficient of soil constant				
	Layer Thickness(m)	Wet weight (kn/m³)	Saturated weight (kn/m³)	Dynamic shear strength ratio	Soil category	Soil type	Observed N value	σ_v	Effective load at standard penetration test (kn/m²)	Fine fraction content (%)	Particle size (mm)	Earthquake Dynamic coefficient		Repeated triaxial strength ratio	Dynamic shear strength ratio	Seismic response ratio	Liquefaction resistance
	h	γ_t	γ_{sat}	x			N	σ_v	σ_{nb}	FC	D ₅₀	C _w	R _L	R	L	FL	
0.67	0.67	17.5	18.5	0.7	alluvial	Sandy soil	9.00	11.8	11.8	0.00	0.000	1.00	0.294	0.294	0.198	**5	
1.67	1.00	17.5	18.5	1.7	alluvial	Sandy	4.00	29.3	29.3	0.00	0.000	1.00	0.177	0.177	0.195	**5	
2.67	1.00	17.5	18.5	2.7	alluvial	Sandy	2.00	46.8	46.8	36.00	0.000	1.00	0.164	0.164	0.192	**5	
3.67	1.00	17.5	18.5	3.7	alluvial	Sandy	15.00	64.3	64.3	36.00	0.000	1.00	0.829	0.829	0.189	**5	
4.67	1.00	17.5	18.5	4.7	alluvial	Sandy	10.00	81.0	81.0	13.00	1.500	1.00	0.235	0.235	0.188	1.251	
5.67	1.00	17.5	18.5	5.7	alluvial	Sandy	14.00	89.5	89.5	13.00	1.500	1.00	0.271	0.271	0.205	1.317	
6.67	1.00	17.5	18.5	6.7	alluvial	Sandy	6.00	98.0	98.0	6.00	3.000	1.00	0.167	0.167	0.218	0.763	
7.67	1.00	18.0	19.0	7.7	diluvial	Cohesiv	12.00	107.0	107.0	91.00	0.000					**1	
8.67	1.00	18.0	19.0	8.7	diluvial	Cohesiv	18.00	116.0	116.0	91.00	0.000					**1	
9.67	1.00	18.0	19.0	9.7	diluvial	Cohesiv	11.00	125.0	125.0	91.00	0.000					**1	
10.67	1.00	18.0	19.0	10.7	diluvial	Cohesiv	21.00	134.0	134.0	92.00	0.000					**1	
11.67	1.00	18.0	19.0	11.7	diluvial	Cohesiv	21.00	143.0	143.0	92.00	0.000					**1	
12.67	1.00	18.0	19.0	12.7	diluvial	Cohesiv	18.00	152.0	152.0	76.00	0.000					**1	
13.67	1.00	18.0	19.0	13.7	diluvial	Cohesiv	20.00	161.0	161.0	76.00	0.000					**1	
14.67	1.00	18.0	19.0	14.7	diluvial	Cohesiv	13.00	170.0	170.0	99.00	0.000					**1	
15.67	1.00	18.0	19.0	15.7	diluvial	Cohesiv	13.00	179.0	179.0	99.00	0.000					**1	
16.67	1.00	18.0	19.0	16.7	diluvial	Cohesiv	12.00	188.0	188.0	96.00	0.000					**1	
17.67	1.00	18.0	19.0	17.7	diluvial	Cohesiv	23.00	197.0	197.0	96.00	0.000					**1	
18.67	1.00	16.5	17.5	18.7	diluvial	Cohesiv	37.00	204.5	204.5	16.00	0.000					**1	
19.67	1.00	16.5	17.5	19.7	diluvial	Cohesiv	39.00	212.0	212.0	16.00	0.000					**1	

PL Value

0.687

Unit volume weight of water 10.0 (kn/m³)
Load 0.0 (kn/m²)

Groundwater level

4.30 (m)

Design horizontal seismic coefficient 0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Reduction coefficient of soil constant		Determination of the liquid state				Soil Property																
		Dynamic shear strength ratio		Seismic response ratio		Liquefaction resistance		Observed N value														
D _E		R	L	FL	C _w	R _L	σ _v	σ _{av}	F _C	D ₅₀	γ _t	γ _{sat}	x	Soil category	Soil type	N	0	10	20	30	40	50
1	1	0.941	0.197	**5	1.00	0.941	17.5	17.5	8.00	1.500	1.00	18.5	1.0	alluvial	Sandy	16.00						
1	1	1.168	0.194	**5	1.00	1.168	35.0	35.0	8.00	1.500	20.00	18.5	2.0	alluvial	Sandy	20.00						
1	1	0.318	0.191	**5	1.00	0.318	52.5	52.5	8.00	2.000	15.00	18.5	3.0	alluvial	Sandy	15.00						
1	1	0.269	0.188	**5	1.00	0.269	70.0	70.0	8.00	2.000	13.00	18.5	4.0	alluvial	Sandy	13.00						
1	1	0.000	0.000	**4	0.00	0.000	81.2	81.2	4.00	3.400	19.00	18.5	5.0	alluvial	Sandy	19.00						
1	1	0.000	0.000	**4	0.00	0.000	89.7	89.7	4.00	3.400	11.00	18.5	6.0	alluvial	Sandy	11.00						
1	1	0.254	0.228	1.115	1.00	0.254	98.2	98.2	0.00	1.200	14.00	18.5	7.0	alluvial	Sandy	14.00						
2/3	1	0.210	0.237	0.885	1.00	0.210	106.7	106.7	0.00	1.200	10.00	18.5	8.0	alluvial	Sandy	10.00						
1	1			**1			115.2	115.2	83.00	0.000	23.00	18.5	9.0	diluvial	Cohesiv	23.00						
1	1			**1			124.2	124.2	83.00	0.000	26.00	18.0	10.0	diluvial	Cohesiv	26.00						
1	1			**1			133.2	133.2	97.00	0.000	26.00	18.0	11.0	diluvial	Cohesiv	26.00						
1	1			**1			142.2	142.2	97.00	0.000	24.00	18.0	12.0	diluvial	Cohesiv	24.00						
1	1			**1			151.2	151.2	90.00	0.100	17.00	18.0	13.0	diluvial	Cohesiv	17.00						
1	1			**1			160.2	160.2	90.00	0.100	21.00	18.0	14.0	diluvial	Cohesiv	21.00						
1	1			**1			169.2	169.2	78.00	0.000	37.00	18.0	15.0	diluvial	Cohesiv	37.00						
1	1			**1			178.2	178.2	78.00	0.000	30.00	18.0	16.0	diluvial	Cohesiv	30.00						
1	1			**1			187.2	187.2	93.00	0.000	37.00	18.0	17.0	diluvial	Cohesiv	37.00						
1	1			**1			196.2	196.2	93.00	0.000	34.00	18.0	18.0	diluvial	Cohesiv	34.00						
1	1			**1			205.2	205.2	91.00	0.000	27.00	18.0	19.0	diluvial	Cohesiv	27.00						
1	1			**1			214.2	214.2	91.00	0.000	15.00	18.0	20.0	diluvial	Sandy	15.00						

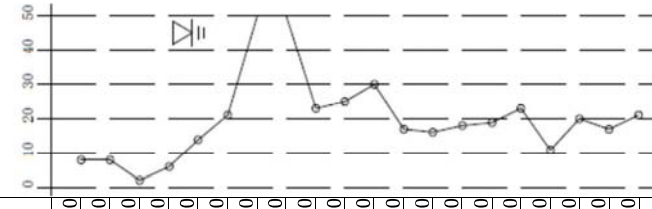
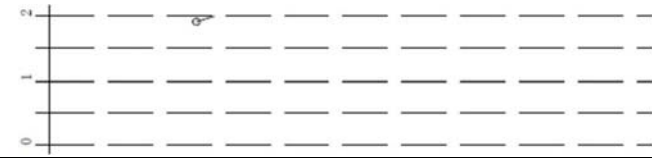
PL Value 0.000

Unit volume weight of water 10.0 (kn/m³)
Load 0.0 (kn/m²)

Groundwater level 4.79 (m)

Design horizontal seismic coefficient 0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)		Soil Property										Determination of the liquid state				Reduction coefficient of soil constant		
		Layer Thickness(m)	Wet weight (kn/m ³)	Saturated weight (kn/m ³)	Dynamic shear strength ratio	Soil category	Soil type	Observed N value	σ _v	σ _N	F C	D ₅₀	Earthquake Dynamic coefficient	Repeated triaxial strength ratio	Dynamic shear strength ratio	Seismic response ratio	Liquefaction resistance	D _E
1.00	1.00	17.5	18.5	1.0	alluvial	Sandy		17.5	17.5	0.00	0.000	1.00	0.267	0.267	0.197	**5		1
2.00	1.00	17.5	18.5	2.0	alluvial	Sandy		35.0	35.0	97.00	0.000	1.00	28.509	28.509	0.194	**5		
3.00	1.00	17.5	18.5	3.0	alluvial	Sandy		52.5	52.5	97.00	0.100	1.00	0.266	0.266	0.191	**5		
4.00	1.00	17.5	18.5	4.0	alluvial	Sandy		70.0	70.0	32.00	0.200	1.00	0.232	0.232	0.188	**5		
5.00	1.00	17.5	18.5	5.0	alluvial	Sandy		85.6	85.6	32.00	0.200	1.00	0.362	0.362	0.189	1.909		
6.00	1.00	17.5	18.5	6.0	alluvial	Sandy		94.1	94.1	17.00	0.700	1.00	0.423	0.423	0.205	2.061		
7.00	1.00	17.5	18.5	7.0	alluvial	Sandy		102.6	102.6	17.00	0.700	1.00	34.594	34.594	0.217	159.07		
8.00	1.00	17.5	18.5	8.0	alluvial	Sandy		111.1	111.1	0.00	2.500	0.00	0.000	0.000	0.000	**4		
9.00	1.00	17.5	18.5	9.0	alluvial	Sandy		119.6	119.6	0.00	2.500	0.00	0.000	0.000	0.000	**4		
10.00	1.00	18.0	19.0	10.0	diluvial	Cohesiv		128.6	128.6	99.00	0.000					**1		
11.00	1.00	18.0	19.0	11.0	diluvial	Cohesiv		137.6	137.6	99.00	0.000					**1		
12.00	1.00	18.0	19.0	12.0	diluvial	Cohesiv		146.6	146.6	94.00	0.000					**1		
13.00	1.00	18.0	19.0	13.0	diluvial	Cohesiv		155.6	155.6	94.00	0.000					**1		
14.00	1.00	18.0	19.0	14.0	diluvial	Cohesiv		164.6	164.6	84.00	0.000					**1		
15.00	1.00	18.0	19.0	15.0	diluvial	Cohesiv		173.6	173.6	84.00	0.000					**1		
16.00	1.00	18.0	19.0	16.0	diluvial	Cohesiv		182.6	182.6	100.00	0.000					**1		
17.00	1.00	18.0	19.0	17.0	diluvial	Cohesiv		191.6	191.6	100.00	0.000					**1		
18.00	1.00	18.0	19.0	18.0	diluvial	Cohesiv		200.6	200.6	93.00	0.000					**1		
19.00	1.00	18.0	19.0	19.0	diluvial	Cohesiv		209.6	209.6	93.00	0.000					**1		
20.00	1.00	18.0	19.0	20.0	diluvial	Cohesiv		218.6	218.6	96.00	0.000					**1		

PL Value

2,984

Unit volume weight of water
Load10.0 (kn/m³)0.0 (kn/m²)

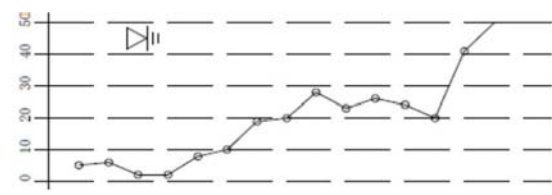
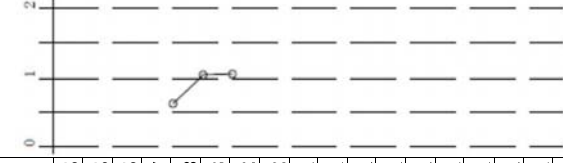
Groundwater level

3.29 (m)

Design horizontal seismic coefficient

0.20

Note: ** 1 to ** Z Out of Scope of Liquefaction Analysis

Soil Depth (m)	Soil Property								Determination of the liquid state				Reduction coefficient of soil constant						
	Layer Thickness(m)	Wet weight (kn/m ³)	Saturated weight (kn/m ³)	Dynamic shear strength ratio	Soil category	Soil type	N	Observed N value	σ_v	σ_{vh}	FC	D ₅₀		C _w	R _L	R	L	FL	Liquefaction resistance
1.01	1.01	17.5	18.5	1.0	alluvial	Sandy	5.00		17.7	17.7	16.00	0.000	1.00	0.226	0.226	0.197	**5		1
2.01	1.00	17.5	18.5	2.0	alluvial	Sandy	6.00		35.2	35.2	16.00	0.000	1.00	0.226	0.226	0.194	**5	1	
3.01	1.00	15.5	16.5	3.0	alluvial	Cohesiv	2.00		50.7	50.7	0.00	0.000	1.00	0.114	0.114	0.191	**5	1	
4.01	1.00	15.5	16.5	4.0	alluvial	Cohesiv	2.00		59.7	59.7	21.00	0.700	1.00	0.132	0.132	0.211	0.627	1/3	
5.01	1.00	15.5	16.5	5.0	alluvial	Cohesiv	8.00		66.2	66.2	21.00	0.700	1.00	0.242	0.242	0.233	1.038	1	
6.01	1.00	17.5	18.5	6.0	alluvial	Sandy	10.00		74.7	74.7	21.00	0.700	1.00	0.262	0.262	0.248	1.053	1	
7.01	1.00	17.5	18.5	7.0	alluvial	Sandy	19.00		83.2	83.2	97.00	0.000	0.00	0.000	0.000	0.000	**2	1	
8.01	1.00	17.5	18.5	8.0	alluvial	Sandy	20.00		91.7	91.7	97.00	0.000	0.00	0.000	0.000	0.000	**2	1	
9.01	1.00	18.0	19.0	9.0	diluvial	Cohesiv	28.00		100.7	100.7	97.00	0.000					**1	1	
10.01	1.00	18.0	19.0	10.0	diluvial	Cohesiv	23.00		109.7	109.7	97.00	0.000					**1	1	
11.01	1.00	18.0	19.0	11.0	diluvial	Cohesiv	26.00		118.7	118.7	94.00	0.000					**1	1	
12.01	1.00	18.0	19.0	12.0	diluvial	Cohesiv	24.00		127.7	127.7	94.00	0.000					**1	1	
13.01	1.00	18.0	19.0	13.0	diluvial	Cohesiv	20.00		136.7	136.7	28.00	0.000					**1	1	
14.01	1.00	18.0	19.0	14.0	diluvial	Cohesiv	41.00		145.7	145.7	28.00	0.000					**1	1	
15.01	1.00	18.0	19.0	15.0	diluvial	Cohesiv	50.00		154.7	154.7	9.00	0.000					**1	1	
16.01	1.00	18.0	19.0	16.0	diluvial	Cohesiv	50.00		163.7	163.7	9.00	0.000					**1	1	
17.01	1.00	16.5	17.5	17.0	diluvial	Cohesiv	50.00		171.2	171.2	13.00	0.000					**1	1	

1.1.2 Steel Sheet Pile

The summary of the structure calculation of the steel sheet pile for low water revetment is shown in the following table.

Table Summary of Steel Sheet Pile Calculation

Bank	Block No.	Sta.			Length in Longitudinal direction	Specification					Length			RIPRAP (SIDE SLOPE: 1.5 :1)				
		From	-	To		Combined				Total	SSP	H-beam	FINISHED HEIGHT FROM DRB	FINIS D TOP WIDTH	CLASS			
						No.	Name	Unit Mass (kg/m2)	Section Modulus (cm3/m)							Moment of Inertia (cm4/m)		
					(m)				(kg/m2)	(cm3/m)	(cm4/m)	(m)	(m)	(m)	(m)			
Left Bank	L-12	9+205	-	9+320	107.58	11	10H-700x200x12x19	234	5,540	299,700	15.0	13.0	14.5	2.5	2.5	C		
	L-13	9+320	-	9+560	230.49	51	50H-1000x300x19x40	550	21,110	1,543,500	23.0	21.0	22.5	3.5	3.5	C		
	L-14	9+560	-	9+800	267.21	25	10H-950x250x16x22	321	10,570	688,700	18.0	16.0	17.5	1.5	3.5	C		
	L-15	9+800	-	9+900	100.98	31	25H-1000x250x16x25	370	12,980	935,900	21.0	19.0	20.5	2.5	5.0	B		
	L-16	9+900	-	10+020	120.99	19	10H-750x250x14x22	280	7,640	414,700	16.0	14.0	15.5	1.5	3.5	B		
	L-17	10+020	-	10+360	332.08	22	10H-850x250x14x22	293	8,840	532,300	19.5	17.5	19.0	1.5	3.5	B		
	L-18	10+360	-	10+520	160.22	23	10H-900x250x14x22	299	9,470	597,600	18.0	16.0	17.5	1.5	3.5	B		
	L-19	10+520	-	10+580	60.10	19	10H-750x250x14x22	280	7,640	414,700	15.0	13.0	14.5	1.5	3.5	B		
	L-20	10+580	-	10+640	60.00	14	10H-700x250x12x19	250	6,270	331,300	13.5	11.5	13.0	1.5	3.5	B		
	L-21	10+640	-	10+760	86.91	23	10H-900x250x14x22	299	9,470	597,600	17.5	15.5	17.0	1.5	3.5	B		
	L-22	10+760	-	11+040	230.40	22	10H-850x250x14x22	293	8,840	532,300	17.5	15.5	17.0	1.5	3.5	UP TO 11+000 : B, FROM 11+000: A		
	L-23	11+040	-	11+180	140.19	1	10H-400x200x9x12	169	2,320	87,800	12.0	10.0	11.5	1.5	3.5	A		
	L-24	11+180	-	11+460	282.50	23	10H-900x250x14x22	299	9,470	597,600	20.5	18.5	20.0	1.5	3.5	A		
	L-25	11+460	-	11+640	182.49	21	10H-800x250x14x22	287	8,240	471,700	20.5	18.5	20.0	1.5	3.5	A		
	L-26	11+640	-	11+800	164.63	8	10H-600x200x12x16	212	4,270	208,200	15.5	13.5	15.0	1.5	3.5	A		
	L-27	11+800	-	12+040	266.26	19	10H-750x250x14x22	280	7,640	414,700	17.5	15.5	17.0	1.5	3.5	C		
	L-28	12+040	-	12+280	260.87	8	10H-600x200x12x16	212	4,270	208,200	15.0	13.0	14.5	1.5	3.5	UP TO 12+200 : C, FROM 12+200: A		
	L-29	12+280	-	12+520	249.09	2	10H-400x200x9x16	182	2,700	98,700	13.0	11.0	12.5	1.5	3.5	A		
	L-30	12+520	-	12+820	304.65	1	10H-400x200x9x12	169	2,320	87,800	12.0	10.0	11.5	1.5	3.5	A		
	L-31	12+820	-	13+000	179.78	6	10H-500x200x12x16	202	3,540	149,900	14.0	12.0	13.5	1.5	3.5	A		
	L-32	13+000	-	13+320	322.81		SP-50H	186	2,760	51,100	12.5	12.5	0.0	1.5	3.5	A		
	L-33	13+320	-	13+360	31.22	4	10H-450x200x9x19	196	3,280	128,300	15.0	13.0	14.5	1.5	3.5	A		
	Right Bank	R-18	9+200	-	9+380	196.62	38	25H-1000x300x16x32	426	16,330	1,129,800	21.5	19.5	21	3.5	5	B	
		R-19	9+380	-	9+700	300.75	32	25H-1000x300x16x22	377	13,420	962,300	22.0	20	21.5	1.5	3.5	B	
		R-20	9+700	-	9+900	182.87	11	10H-700x200x12x19	234	5,540	299,700	16.5	14.5	16	1.5	3.5	B	
		R-21	9+900	-	10+380	493.71	24	10H-900x250x14x25	311	10,120	631,400	21.5	19.5	21	1.5	3.5	B	
		R-22	10+380	-	10+520	140.72	25	10H-950x250x16x22	321	10,570	688,700	19.5	17.5	19	1.5	3.5	B	
		R-23	10+520	-	10+540	20.67	8	10H-600x200x12x16	212	4,270	208,200	13.5	11.5	13	1.5	3.5	B	
		R-24	10+540	-	10+660	122.88	7	10H-550x200x12x16	207	3,900	177,600	11.5	9.5	11	1.5	3.5	B	
		R-25	10+660	-	10+760	125.77	7	10H-550x200x12x16	207	3,900	177,600	11.5	9.5	11	1.5	5.5	B	
		R-26	10+760	-	10+820	79.86	1	10H-400x200x9x12	169	2,320	87,800	13.0	11	12.5	1.5	5.5	B	
		R-27	10+820	-	10+980	205.01	29	25H-1000x250x16x22	358	12,240	892,400	19.5	17.5	19	1.5	5.5	B	
		R-28	10+980	-	11+200	220.61	23	10H-900x250x14x22	299	9,470	597,600	19.0	17	18.5	1.5	3.5	UP TO 11+000 : B FROM 11+000: A	
R-29		11+200	-	11+360	160.68	1	10H-400x200x9x12	169	2,320	87,800	12.5	10.5	12	1.5	3.5	A		
R-30		11+360	-	11+700	328.31	1	10H-400x200x9x12	169	2,320	87,800	14.0	12	13.5	1.5	3.5	A		
R-31		11+700	-	11+980	214.88	27	10H-1000x250x16x25	340	11,980	806,700	21.5	19.5	21	1.5	3.5	A		
R-32		11+980	-	12+000	16.30		SP-50H	186	2,760	51,100	11.0	11	0	1.5	3.5	A		
R-33		12+000	-	12+240	198.95	1	10H-400x200x9x12	169	2,320	87,800	13.0	11	12.5	1.5	3.5	A		
R-34		12+240	-	12+520	265.59	1	10H-400x200x9x12	169	2,320	87,800	12.5	10.5	12	1.5	3.5	A		
R-35		12+520	-	12+540	18.97		SP-25H	126	1,610	24,400	9.0	9	0	1.5	3.5	A		
R-36		12+540	-	12+660	116.78	21	10H-800x250x14x22	287	8,240	471,700	18.5	16.5	18	1.5	3.5	A		
R-37		12+660	-	12+740	80.13	12	10H-700x250x12x16	238	5,740	308,300	16.0	14	15.5	1.5	3.5	A		
R-38		12+740	-	12+980	240.44	15	10H-700x200x12x25	254	6,370	334,800	17.0	15	16.5	1.5	3.5	A		
R-39		12+980	-	13+100	120.17	22	10H-850x250x14x22	293	8,840	532,300	21.5	19.5	21	1.5	3.5	A		
R-40		13+100	-	13+220	118.37	10	10H-700x200x12x16	224	5,130	281,600	18.0	16	17.5	1.5	3.5	A		
R-41		13+220	-	13+375	146.11	24	10H-900x250x14x25	311	10,120	631,400	23.0	21	22.5	2.5	5	A		

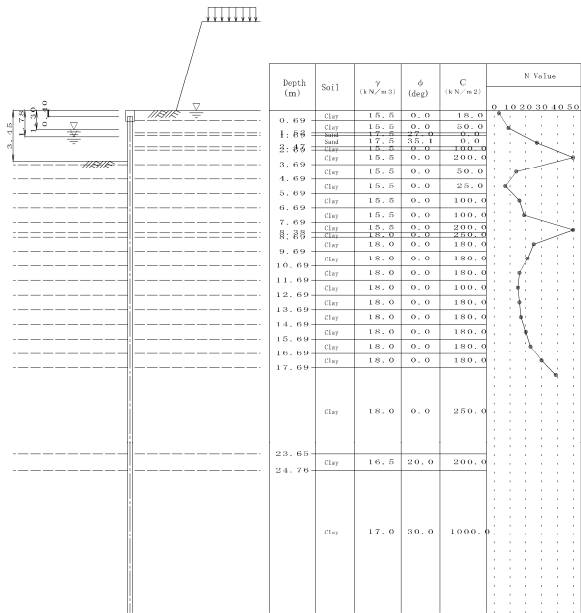
Table Design Cross-section and Calculation Result

Bank	Block No.	Cross Section for Calculation		Calculation Result									
		Sta	Boring Name	Stress Intensity				Lateral Displacement					
				Normal Conditon		Seismic Conditon		Normal Conditon			Seismic Conditon		
				(N/mm2)		(N/mm2)		(mm)		(mm)			
Left Bank	L-12	9+300	BMLL-26	116	< 180 OK	266	< 270 OK	35.31	< 50.00 OK	59.08	< 75.00 OK		
	L-13	9+360	DD-BH-L10	37	< 180 OK	159	< 270 OK	20.39	< 50.00 OK	74.84	< 75.00 OK		
	L-14	9+560	BMLL-27	119	< 180 OK	185	< 270 OK	48.59	< 50.00 OK	56.56	< 75.00 OK		
	L-15	9+820	BMLL-28	81	< 180 OK	166	< 270 OK	16.77	< 50.00 OK	15.21	< 75.00 OK		
	L-16	9+940	BDM-12	118	< 180 OK	116	< 270 OK	49.88	< 50.00 OK	40.92	< 75.00 OK		
	L-17	10+100	BMLL-29	89	< 180 OK	86	< 270 OK	47.94	< 50.00 OK	11.60	< 75.00 OK		
	L-18	10+420	BMLL-30	109	< 180 OK	156	< 270 OK	47.37	< 50.00 OK	57.21	< 75.00 OK		
	L-19	10+560	DD-BH-L11	104	< 180 OK	261	< 270 OK	35.87	< 50.00 OK	73.02	< 75.00 OK		
	L-20	10+640	BMLL-31	124	< 180 OK	263	< 270 OK	34.81	< 50.00 OK	60.14	< 75.00 OK		
	L-21	10+700	DD-BH-L12	109	< 180 OK	228	< 270 OK	43.08	< 50.00 OK	71.37	< 75.00 OK		
	L-22	10+800	DD-BH-L12	45	< 180 OK	186	< 270 OK	19.06	< 50.00 OK	74.75	< 75.00 OK		
	L-23	11+040	BMLL-32	129	< 180 OK	178	< 270 OK	41.87	< 50.00 OK	53.52	< 75.00 OK		
	L-24	11+340	BMLL-33	86	< 180 OK	102	< 270 OK	48.42	< 50.00 OK	45.90	< 75.00 OK		
	L-25	11+520	DD-BH-L13	80	< 180 OK	81	< 270 OK	48.82	< 50.00 OK	40.68	< 75.00 OK		
	L-26	11+640	BMLL-34	119	< 180 OK	121	< 270 OK	49.54	< 50.00 OK	41.72	< 75.00 OK		
	L-27	11+940	BMLL-35	101	< 180 OK	115	< 270 OK	48.21	< 50.00 OK	46.62	< 75.00 OK		
	L-28	12+080	BL-15	121	< 180 OK	166	< 270 OK	47.86	< 50.00 OK	59.79	< 75.00 OK		
	L-29	12+320	BMLL-36	127	< 180 OK	134	< 270 OK	49.80	< 50.00 OK	43.61	< 75.00 OK		
	L-30	12+540	BMLL-37	124	< 180 OK	124	< 270 OK	41.23	< 50.00 OK	34.09	< 75.00 OK		
	L-31	12+840	BMLL-38	121	< 180 OK	123	< 270 OK	49.21	< 50.00 OK	41.77	< 75.00 OK		
L-32	13+020	BMLL-39	69	< 180 OK	69	< 270 OK	49.24	< 50.00 OK	38.00	< 75.00 OK			
L-33	13+340	BMLL-40	100	< 180 OK	99	< 270 OK	49.23	< 50.00 OK	38.28	< 75.00 OK			
Right Bank	R-18	9+280	BR13	60	< 180 OK	165	< 270 OK	30.67	< 50.00 OK	73.80	< 0.00 OK		
	R-19	9+500	BMRL-27	88	< 180 OK	91	< 270 OK	49.42	< 50.00 OK	42.39	< 0.00 OK		
	R-20	9+840	BMRL-28	115	< 180 OK	108	< 270 OK	48.88	< 50.00 OK	37.52	< 0.00 OK		
	R-21	9+960	DD-BH-R11	81	< 180 OK	82	< 270 OK	49.16	< 50.00 OK	39.04	< 0.00 OK		
	R-22	10+440	BMRL-30	99	< 180 OK	100	< 270 OK	49.04	< 50.00 OK	40.61	< 0.00 OK		
	R-23	10+520	DD-BH-R12	142	< 180 OK	138	< 270 OK	45.88	< 50.00 OK	38.45	< 0.00 OK		
	R-24	10+640	BMRL-31	132	< 180 OK	251	< 270 OK	30.38	< 50.00 OK	42.78	< 0.00 OK		
	R-25	10+740	BDM-13	131	< 180 OK	249	< 270 OK	29.95	< 50.00 OK	42.22	< 0.00 OK		
	R-26	10+780	DD-BH-R13	112	< 180 OK	95	< 270 OK	40.40	< 50.00 OK	27.60	< 0.00 OK		
	R-27	10+900	DD-BH-R13	61	< 180 OK	155	< 270 OK	23.28	< 50.00 OK	44.17	< 0.00 OK		
	R-28	11+060	DD-BH-R13	109	< 180 OK	191	< 270 OK	47.84	< 50.00 OK	62.40	< 0.00 OK		
	R-29	11+340	BMRL-33	134	< 180 OK	155	< 270 OK	46.76	< 50.00 OK	45.79	< 0.00 OK		
	R-30	11+500	DD-BH-R14	103	< 180 OK	110	< 270 OK	42.49	< 50.00 OK	35.87	< 0.00 OK		
	R-31	11+880	DD-BH-R15	82	< 180 OK	85	< 270 OK	48.33	< 50.00 OK	41.05	< 0.00 OK		
	R-32	11+960	BMRL-35	88	< 180 OK	117	< 270 OK	47.65	< 50.00 OK	56.62	< 0.00 OK		
	R-33	12+100	DD-BH-R16	129	< 180 OK	216	< 270 OK	47.55	< 50.00 OK	74.82	< 0.00 OK		
	R-34	12+300	BMRL-36	121	< 180 OK	181	< 270 OK	40.97	< 50.00 OK	56.61	< 0.00 OK		
	R-35	12+520	DD-BH-R17	117	< 180 OK	161	< 270 OK	49.93	< 50.00 OK	65.35	< 0.00 OK		
	R-36	12+560	BMRL-37	81	< 180 OK	120	< 270 OK	47.29	< 50.00 OK	62.02	< 0.00 OK		
	R-37	12+660	BMRL-38	126	< 180 OK	197	< 270 OK	49.17	< 50.00 OK	68.00	< 0.00 OK		
R-38	12+900	DD-BH-R18	106	< 180 OK	106	< 270 OK	49.84	< 50.00 OK	40.84	< 0.00 OK			
R-39	13+000	BR-15	75	< 180 OK	75	< 270 OK	49.28	< 50.00 OK	37.99	< 0.00 OK			
R-40	13+140	BMRL-39	109	< 180 OK	109	< 270 OK	48.10	< 50.00 OK	39.62	< 0.00 OK			
R-41	13+380	BMRL-40	72	< 180 OK	94	< 270 OK	49.94	< 50.00 OK	57.42	< 0.00 OK			

The calculation sheets are shown in the following pages.

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	=	3.45 m
Depth from coping top to rear side ground	H ₀	=	0.00 m
Depth from coping top to SSP top	H _b	=	0.40 m
Landside WL	L _{wa}	=	0.00 m (Normal Condition)
	L _{wa}	=	0.00 m (Seismic Condition)
Riverside WL	L _{wp}	=	1.78 m (Normal Condition)
	L _{wp}	=	1.30 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$	
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 = 61.1 kN/m (Normal Condition) Pt' = 147.5 kN/m (Seismic Condition)
	Depth of acting point	Ht = 0.0 m (Normal Condition) Ht' = 0.0 m (Seismic Condition)
	Moment	Mm = 39.00 kN·m/m (Normal Condition) Mm' = 234.9kN·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	$\zeta_0 = 10 \text{ degrees}$	
Rear side angle of slope	not considered	
Angle of rupture (clayey soil)	$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma_h \cdot 2Q}{2C}} \cdot \tan \theta$	
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)	

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{b0} \left(\frac{B_B}{0.3} \right)^{-3/4}$
	$K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2)
	B _B = 10.00 m
	E ₀ = 2800 N
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	0.19	3	11	10.19	21
2	1.19	9	12	11.19	16
3	2.19	27	13	12.19	15
4	3.19	50	14	13.19	16
5	4.19	14	15	14.19	17
6	5.19	7	16	15.19	20
7	6.19	16	17	16.19	23
8	7.19	19	18	17.19	30
9	8.19	50	19	18.19	39
10	9.19	25			

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

Soil Modulus		
No	Depth m (include Projection Length)	Thickness m (excluding projected length)
1	0.69	0.69
2	1.52	0.83
3	1.69	0.17
4	2.47	0.78
5	2.69	0.22
6	3.69	1.00
7	4.69	1.00
8	5.69	1.00
9	6.69	1.00
10	7.69	1.00
11	8.38	0.69
12	8.69	0.31
13	9.69	1.00
14	10.69	1.00
15	11.69	1.00
16	12.69	1.00
17	13.69	1.00
18	14.69	1.00
19	15.69	1.00
20	16.69	1.00
21	17.69	1.00
22	23.65	5.96
23	24.76	1.11
24	33.10	8.34

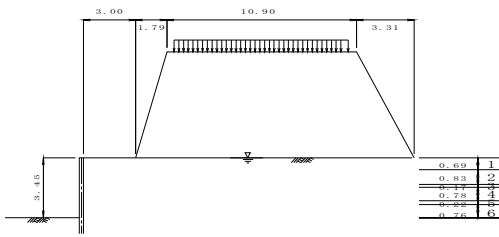
No	Depth m	earth Soil	N Value kN/m3	γ kN/m3	γ' degree	ϕ degree	C kN/m2	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.69	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200	Auto	Auto
2	1.52	C	9.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto
3	1.69	S	9.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
4	2.47	S	27.0	17.50	7.70	35.1	0.0	0.0	0.200	Auto	Auto
5	2.69	C	27.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
6	3.69	C	50.0	15.50	5.70	0.0	200.0	0.0	0.200	Auto	Auto
7	4.69	C	14.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto
8	5.69	C	7.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
9	6.69	C	16.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
10	7.69	C	19.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
11	8.38	C	50.0	15.50	5.70	0.0	200.0	0.0	0.200	Auto	Auto
12	8.69	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
13	9.69	C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	10.69	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	11.69	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	12.69	C	15.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
17	13.69	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
18	14.69	C	17.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
19	15.69	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
20	16.69	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
21	17.69	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
22	23.65	C	39.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
23	24.76	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
24	33.10	C	121.5	17.00	7.20	30.0	1000.0	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_a : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside

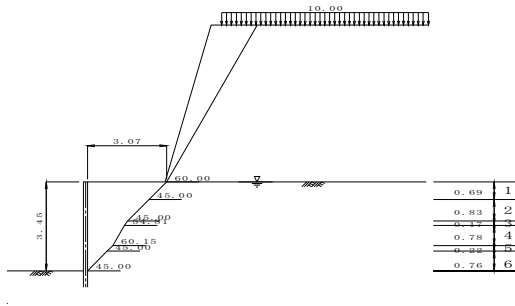


Fill shape and soil constants

No	Soil	X Coordinate	Thickness	soil single weight γ	internal friction angle	stickiness	decay angle ζ

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	$\gamma \times A$ kN/m	Angle of Rupture ζ degree
1	3.45 ~ 2.69	Clay	0.0	15.0	200.0	21.57	39.61	33.81	45.00
2	2.69 ~ 2.47	Clay	0.0	15.0	100.0	17.23	39.61	26.36	45.00
3	2.47 ~ 1.69	Sand	35.1	15.0	0.0	15.98	39.61	24.21	60.15
4	1.69 ~ 1.52	Sand	27.0	15.0	0.0	9.97	39.61	16.56	54.81
5	1.52 ~ 0.69	Clay	0.0	15.0	50.0	8.66	39.61	14.90	45.00
6	0.69 ~ 0.00	Clay	0.0	15.0	18.0	3.93	39.61	6.76	45.00
7		embankment t	30.0	—	0.0	115.71	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 $\theta = 0^\circ$

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 $\theta = \tan^{-1}k'$

		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m2	Seismic Condition kN/m2	ϕ degree	C kN/m2	Normal Condition degree	Seismic Condition degree
1	Sand	3.00	4.79	15.69	19.00	6.09	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	5.20	15.20	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 700 -200 -12-19-18
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 299700 \text{ cm}^4$
Sectional factor $Z_0 = 5540 \text{ cm}^3$

Corrosion margin $t_1 = 1.00 \text{ mm}$ (riverside) $t_2 = 1.00 \text{ mm}$ (landside)

Corrosion rate (to I_0) $\eta = 0.84$
Corrosion rate (to Z_0) $\eta = 0.86$
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 $\sigma_a = 180 \text{ N/mm}$ (Normal)
 $\sigma_a^* = 270 \text{ N/mm}$ (Seismic)

Allowable displacement $\delta_a = 50.0 \text{ mm}$ (Normal)
 $\delta_a^* = 75.0 \text{ mm}$ (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

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.76	0.00	0.00	0.76	0.76
2	45.00	0.22	0.76	0.76	0.98	0.98
3	60.15	0.78	0.98	0.98	1.43	1.76
4	54.81	0.17	1.43	1.76	1.55	1.93
5	45.00	0.83	1.55	1.93	2.38	2.76
6	45.00	0.69	2.38	2.76	3.07	3.45
7	60.00	6.09	3.07	3.45	6.58	9.54

From the above table, the loading width (L) on the ground surface is 3.07 m.

2.1.3 Acting Load by Embankment

No	γ kN/m3	A m2	$\gamma \times A$ kN/m
1	19.0	5.67	107.66
Σ			107.66

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	Qxl kN/m
1	10.0	1.38	13.83
Σ			13.83

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

l: Loading width of uniform load surrounded by main collapse line

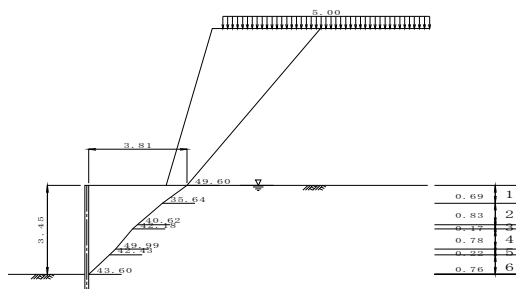
2.1.5 Calculated Load

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

$$= \frac{107.66 + 13.83 + 0.00}{3.07}$$

$$= 39.61 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No.	Depth, m	Soil	α , degree	β , degree	C, kN/m ²	γ , kN/m ³	Q, kN/m ²	γ_{sat} , kN/m ³	ϕ , (°)	θ , degree	Angle of Repose φ , degree
1	3.45–2.69	Clay	0.0	15.0	200.0	21.57	81.10	53.81	0.200	11.31	43.60
2	2.69–2.47	Clay	0.0	15.0	100.0	17.23	81.10	26.36	0.200	11.31	42.43
3	2.47–1.69	Sand	35.1	15.0	0.0	15.98	81.10	24.21	0.200	11.31	49.99
4	1.69–1.52	Sand	27.0	15.0	0.0	9.97	81.10	16.56	0.200	11.31	42.18
5	1.52–0.69	Clay	0.0	15.0	50.0	8.66	81.10	14.90	0.200	11.31	40.62
6	0.69–0.00	Clay	0.0	15.0	18.0	3.93	81.10	6.76	0.200	11.31	35.64
7	embankment	embankment	30.0	—	0.0	115.71	5.00	0.00	0.200	11.31	49.60

- Major collapse angle of Sand, intermediate soil, and split rock

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

- Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

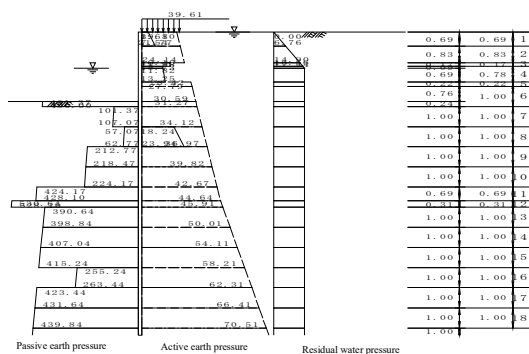
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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)

3 Lateral Forth

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	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	Ka	Ka $\times$ cm ³
1	0.00– 0.69	Clay	5.7	—	18.0 18.0	39.609 43.542	—	—
2	0.69– 1.52	Clay	5.7	—	80.0 80.0	43.542 48.273	—	—
3	1.52– 1.69	Sand	7.7	27.0	—	48.273 49.262	0.33738 0.33738	0.32589 0.32589
4	1.69– 1.78	Sand	7.7	35.1	—	49.262 50.275	0.24677 0.24677	0.23836 0.23836
5	1.78– 2.47	Sand	7.7	35.1	—	50.275 55.588	0.24677 0.24677	0.23836 0.23836
6	2.47– 2.69	Clay	5.7	—	100.0 100.0	55.588 56.842	—	—
7	2.69– 3.45	Clay	5.7	—	200.0 200.0	56.842 61.174	—	—
8	3.45– 3.69	Clay	5.7	—	200.0 200.0	61.174 62.542	—	—
9	3.69– 4.69	Clay	5.7	—	50.0 50.0	62.542 68.242	—	—
10	4.69– 5.69	Clay	5.7	—	25.0 25.0	68.242 73.942	—	—
11	5.69– 6.69	Clay	5.7	—	100.0 100.0	73.942 79.642	—	—
12	6.69– 7.69	Clay	5.7	—	100.0 100.0	79.642 85.342	—	—

$$\theta = \tan^{-1}k \text{ or } \theta = \tan^{-1}k'$$

- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.60	0.76	0.00	0.00	0.80	0.76
2	42.43	0.22	0.80	0.76	1.04	0.98
3	49.99	0.78	1.04	0.98	1.69	1.96
4	42.18	0.17	1.69	1.76	1.88	1.93
5	40.62	0.83	1.88	1.93	2.85	2.76
6	35.64	0.69	2.85	2.76	3.81	3.45
7	49.60	6.09	3.81	3.45	8.99	9.54

From the above table, the loading width (L) on the ground surface is 3.81 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	15.27	290.10
Σ			290.10

 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	Qd kN/m
1	5.0	3.79	18.97
Σ			18.97

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

1: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

$$\begin{aligned} Q &= \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L} \\ &= \frac{290.10 + 18.97 + 0.00}{3.81} \\ &= 81.10 \text{ kN/m}^2 \end{aligned}$$

13	7.69- 8.38	Clay	5.7	—	200.0 200.0	85.342 89.275	—	—
14	8.38- 8.69	Clay	8.2	—	250.0 250.0	89.275 91.817	—	—
15	8.69- 9.69	Clay	8.2	—	180.0 180.0	91.817 100.017	—	—
16	9.69- 10.69	Clay	8.2	—	180.0 180.0	100.017 108.217	—	—
17	10.69- 11.69	Clay	8.2	—	180.0 180.0	108.217 116.417	—	—
18	11.69- 12.69	Clay	8.2	—	100.0 100.0	116.417 124.617	—	—
19	12.69- 13.69	Clay	8.2	—	180.0 180.0	124.617 132.817	—	—
20	13.69- 14.69	Clay	8.2	—	180.0 180.0	132.817 141.017	—	—
21	14.69- 15.69	Clay	8.2	—	180.0 180.0	141.017 149.217	—	—
22	15.69- 16.69	Clay	8.2	—	180.0 180.0	149.217 157.417	—	—
23	16.69- 17.69	Clay	8.2	—	180.0 180.0	157.417 165.617	—	—
24	17.69- 23.65	Clay	8.2	—	250.0 250.0	165.617 214.489	—	—
25	23.65- 24.76	Clay	6.7	—	200.0 200.0	214.489 221.926	—	—
26	24.76- 33.10	Clay	7.2	—	1000.0 1000.0	221.926 281.974	—	—

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

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_p$ kN/m ²	K _p	K _p × cos ϕ
8	3.45– 3.69	Clay	5.7	0.0	200.0 200.0	0.000 1.368	_____	_____
9	3.69– 4.69	Clay	5.7	0.0	50.0 50.0	1.368 7.068	_____	_____
10	4.69– 5.69	Clay	5.7	0.0	25.0 25.0	7.068 12.768	_____	_____
11	5.69– 6.69	Clay	5.7	0.0	100.0 100.0	12.768 18.468	_____	_____
12	6.69– 7.69	Clay	5.7	0.0	100.0 100.0	18.468 24.168	_____	_____
13	7.69– 8.38	Clay	5.7	0.0	200.0 200.0	24.168 28.101	_____	_____
14	8.38– 8.69	Clay	8.2	0.0	250.0 250.0	28.101 30.651	_____	_____

15	8.69- 9.69	Clay	8.2	0.0	180.0 180.0	30.643 38.843	=====	=====
16	9.69- 10.69	Clay	8.2	0.0	180.0 180.0	38.843 47.043	=====	=====
17	10.69- 11.69	Clay	8.2	0.0	180.0 180.0	47.043 55.243	=====	=====
18	11.69- 12.69	Clay	8.2	0.0	100.0 100.0	55.243 63.443	=====	=====
19	12.69- 13.69	Clay	8.2	0.0	180.0 180.0	63.443 71.643	=====	=====
20	13.69- 14.69	Clay	8.2	0.0	180.0 180.0	71.643 79.843	=====	=====
21	14.69- 15.69	Clay	8.2	0.0	180.0 180.0	79.843 88.043	=====	=====
22	15.69- 16.69	Clay	8.2	0.0	180.0 180.0	88.043 96.243	=====	=====
23	16.69- 17.69	Clay	8.2	0.0	180.0 180.0	96.243 104.443	=====	=====
24	17.69- 23.65	Clay	8.2	0.0	230.0 230.0	104.443 153.315	=====	=====
25	23.65- 24.76	Clay	6.7	20.0	200.0 200.0	153.315 160.752	=====	=====
26	24.76- 33.10	Clay	7.2	30.0	1000.0 1000.0	160.752 220.800	=====	=====

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00- 0.69	2.61 7.54	19.80 21.77	19.80 21.77	6.00 6.76	=====
2	0.69- 1.52	-56.46 -51.73	21.77 24.14	21.77 24.14	6.76 14.90	=====
3	1.52- 1.69	=====	=====	15.73 16.16	14.90 16.56	=====
4	1.69- 1.78	=====	=====	11.82 11.98	16.56 17.44	=====
5	1.78- 2.47	11.98 13.25	=====	11.98 13.25	17.44 17.44	=====
6	2.47- 2.69	-144.41 -143.16	27.79 28.42	27.79 28.42	17.44 17.44	=====
7	2.69- 3.45	-343.16 -338.83	28.42 30.59	28.42 30.59	17.44 17.44	=====
8	3.45- 3.69	-338.83 -337.46	30.59 31.27	30.59 31.27	17.44 17.44	400.00 401.37
9	3.69- 4.69	-37.46 -31.76	31.27 34.12	31.27 34.12	17.44 17.44	101.37 107.07

10	4.69- 5.69	18.24 23.94	34.12 36.97	34.12 36.97	17.44 17.44	57.07 62.77
11	5.69- 6.69	-126.06 -120.36	36.97 39.82	36.97 39.82	17.44 17.44	212.77 218.47
12	6.69- 7.69	-120.36 -114.66	39.82 42.67	39.82 42.67	17.44 17.44	218.47 224.17
13	7.69- 8.38	-314.66 -310.72	42.67 44.64	42.67 44.64	17.44 17.44	424.17 428.10
14	8.38- 8.69	-410.72 -408.18	44.64 45.91	44.64 45.91	17.44 17.44	528.10 530.64
15	8.69- 9.69	-308.18 -299.98	45.91 50.01	45.91 50.01	17.44 17.44	390.64 398.84
16	9.69- 10.69	-299.98 -251.78	50.01 54.11	50.01 54.11	17.44 17.44	398.84 407.04
17	10.69- 11.69	-251.78 -243.58	54.11 58.21	54.11 58.21	17.44 17.44	407.04 415.24
18	11.69- 12.69	-83.58 -75.38	58.21 62.31	58.21 62.31	17.44 17.44	255.24 263.44
19	12.69- 13.69	-235.38 -227.18	62.31 66.41	62.31 66.41	17.44 17.44	423.44 431.64
20	13.69- 14.69	-227.18 -218.98	66.41 70.51	66.41 70.51	17.44 17.44	431.64 439.84
21	14.69- 15.69	-218.98 -210.78	70.51 74.61	70.51 74.61	17.44 17.44	439.84 448.04
22	15.69- 16.69	-210.78 -202.58	74.61 78.71	74.61 78.71	17.44 17.44	448.04 456.24
23	16.69- 17.69	-202.58 -194.38	78.71 82.81	78.71 82.81	17.44 17.44	456.24 464.44
24	17.69- 23.65	-334.38 -285.51	82.81 107.24	82.81 107.24	17.44 17.44	604.44 653.32
25	23.65- 24.76	-185.51 -178.07	107.24 110.96	107.24 110.96	17.44 17.44	553.32 560.75
26	24.76- 33.10	-1778.07 -1718.03	110.96 140.99	110.96 140.99	17.44 17.44	2160.75 2220.80

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5

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

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

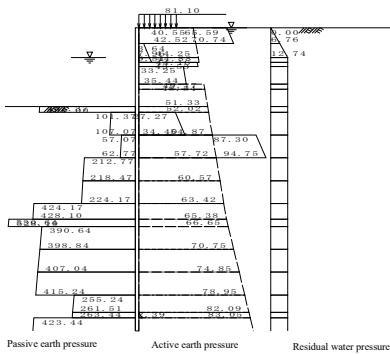
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



0.69	0.69	1
0.61	0.61	2
0.78	0.78	4
0.76	1.00	6
1.00	1.00	7
1.00	1.00	8
1.00	1.00	9
1.00	1.00	10
0.69	0.69	11
0.31	0.31	12
1.00	1.00	13
1.00	1.00	14
1.00	1.00	15
0.76	1.00	16
1.00	1.00	17

3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γ_{shw} kN/m2	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 0.69	Clay	5.7	---	18.0 18.0	81.10 85.03	0.00 6.76	0.200 0.200	11.31 11.31	-----	-----	35.95 35.64
2	0.69- 1.30	Clay	5.7	---	50.0 50.0	85.03 88.51	6.76 12.74	0.200 0.200	11.31 11.31	-----	-----	40.82 40.68
3	1.30- 1.52	Clay	5.7	---	50.0 50.0	88.51 89.76	12.74 14.90	0.200 0.200	11.31 11.31	-----	-----	40.68 40.62
4	1.52- 1.69	Sand	7.7	27.0	-----	89.76 91.07	14.90 16.56	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	-----
5	1.69- 2.47	Sand	7.7	35.1	-----	91.07 97.08	16.56 24.21	0.200 0.200	11.31 11.31	0.37794 0.37794	0.36596 0.36596	-----
6	2.47- 2.69	Clay	5.7	---	100.0 100.0	97.08 98.33	24.21 26.36	0.200 0.200	11.31 11.31	-----	-----	42.46 42.43
7	2.69- 3.45	Clay	5.7	---	200.0 200.0	98.33 102.66	26.36 33.81	0.200 0.200	11.31 11.31	-----	-----	43.66 43.60
8	3.45- 3.69	Clay	5.7	---	200.0 200.0	102.66 104.03	33.81 36.16	0.200 0.200	11.31 11.31	-----	-----	43.60 43.58
9	3.69- 4.69	Clay	5.7	---	50.0 50.0	104.03 109.73	36.16 45.96	0.200 0.200	11.31 11.31	-----	-----	40.84 39.82
10	4.69- 5.69	Clay	5.7	---	25.0 25.0	109.73 115.43	45.96 55.76	0.200 0.200	11.31 11.31	-----	-----	36.12 35.79
11	5.69- 6.69	Clay	5.7	---	100.0 100.0	115.43 121.13	55.76 65.56	0.200 0.200	11.31 11.31	-----	-----	42.03 41.90
No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γ_{shw} kN/m2	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
12	6.69- 7.69	Clay	5.7	---	100.0 100.0	121.13 126.83	65.56 75.36	0.200 0.200	11.31 11.31	-----	-----	41.90 41.77

13	7.69- 8.38	Clay	5.7	---	200.0 200.0	126.83 130.76	75.36 82.12	0.200 0.200	11.31 11.31	-----	-----	43.29 43.24
14	8.38- 8.69	Clay	8.2	---	250.0 250.0	130.76 133.31	82.12 85.16	0.200 0.200	11.31 11.31	-----	-----	43.58 43.55
15	8.69- 9.69	Clay	8.2	---	180.0 180.0	133.31 141.51	85.16 94.96	0.200 0.200	11.31 11.31	-----	-----	43.02 42.91
16	9.69- 10.69	Clay	8.2	---	180.0 180.0	141.51 149.71	94.96 104.76	0.200 0.200	11.31 11.31	-----	-----	42.91 42.80
17	10.69- 11.69	Clay	8.2	---	180.0 180.0	149.71 157.91	104.76 114.56	0.200 0.200	11.31 11.31	-----	-----	42.80 42.69
18	11.69- 12.45	Clay	8.2	---	100.0 100.0	157.91 164.17	114.56 -----	0.200 -----	11.31 -----	-----	-----	41.08 -----
19	12.45- 12.69	Clay	8.2	---	100.0 100.0	164.17 166.11	----- 124.36	----- 0.200	----- 11.31	-----	-----	40.91 -----
20	12.69- 13.69	Clay	8.2	---	180.0 180.0	166.11 174.31	124.36 134.16	0.200 0.200	11.31 11.31	-----	-----	42.58 42.47
21	13.69- 14.69	Clay	8.2	---	180.0 180.0	174.31 182.51	134.16 143.96	0.200 0.200	11.31 11.31	-----	-----	42.47 42.36
22	14.69- 15.69	Clay	8.2	---	180.0 180.0	182.51 190.71	143.96 153.76	0.200 0.200	11.31 11.31	-----	-----	42.36 42.25
23	15.69- 16.69	Clay	8.2	---	180.0 180.0	190.71 198.91	153.76 163.56	0.200 0.200	11.31 11.31	-----	-----	42.25 42.14
24	16.69- 17.69	Clay	8.2	---	180.0 180.0	198.91 207.11	163.56 173.36	0.200 0.200	11.31 11.31	-----	-----	42.14 42.04
25	17.69- 23.65	Clay	8.2	---	250.0 250.0	207.11 255.98	173.36 231.77	0.200 0.200	11.31 11.31	-----	-----	42.81 42.34
26	23.65- 24.76	Clay	6.7	---	200.0 200.0	255.98 263.42	231.77 242.65	0.200 0.200	11.31 11.31	-----	-----	41.74 41.66
27	24.76- 33.10	Clay	7.2	---	1000.0 1000.0	263.42 323.46	242.65 324.38	0.200 0.200	11.31 11.31	-----	-----	44.26 44.10

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q_p$ kN/m2	γ_{shw} kN/m2	k (k')	θ degree	K_p	$K_p \times \cos \delta$
8	3.45- 3.69	Clay	5.70	0.0	200.0 200.0	0.000 1.368	0.00 2.35	0.200 0.200	11.31 11.31	-----	-----
9	3.69- 4.69	Clay	5.70	0.0	50.0 50.0	1.368 7.068	2.35 12.15	0.200 0.200	11.31 11.31	-----	-----
10	4.69- 5.69	Clay	5.70	0.0	25.0 25.0	7.068 12.768	12.15 21.95	0.200 0.200	11.31 11.31	-----	-----
11	5.69- 6.69	Clay	5.70	0.0	100.0 100.0	12.768 18.468	21.95 31.75	0.200 0.200	11.31 11.31	-----	-----

12	6.69- 7.69	Clay	5.70	0.0	100.0 100.0	18.468 24.168	31.75 41.55	0.200 0.200	11.31 11.31	=====	=====
13	7.69- 8.38	Clay	5.70	0.0	200.0 200.0	24.168 28.101	41.55 48.31	0.200 0.200	11.31 11.31	=====	=====
14	8.38- 8.69	Clay	8.20	0.0	250.0 250.0	28.101 30.643	48.31 51.35	0.200 0.200	11.31 11.31	=====	=====
15	8.69- 9.69	Clay	8.20	0.0	180.0 180.0	30.643 38.843	51.35 61.15	0.200 0.200	11.31 11.31	=====	=====
16	9.69- 10.69	Clay	8.20	0.0	180.0 180.0	38.843 47.043	61.15 70.95	0.200 0.200	11.31 11.31	=====	=====
17	10.69- 11.69	Clay	8.20	0.0	180.0 180.0	47.043 55.243	70.95 80.75	0.200 0.200	11.31 11.31	=====	=====
18	11.69- 12.45	Clay	8.20	0.0	100.0 100.0	55.243 61.511	80.75 -----	0.200 -----	11.31 -----	=====	=====
19	12.45- 12.69	Clay	8.20	0.0	100.0 100.0	61.511 63.443	----- 90.55	----- 0.200	----- 11.31	=====	=====
20	12.69- 13.69	Clay	8.20	0.0	180.0 180.0	63.443 71.643	90.55 100.35	0.200 0.200	11.31 11.31	=====	=====
21	13.69- 14.69	Clay	8.20	0.0	180.0 180.0	71.643 79.843	100.35 110.15	0.200 0.200	11.31 11.31	=====	=====
22	14.69- 15.69	Clay	8.20	0.0	180.0 180.0	79.843 88.043	110.15 119.95	0.200 0.200	11.31 11.31	=====	=====
23	15.69- 16.69	Clay	8.20	0.0	180.0 180.0	88.043 96.243	119.95 129.75	0.200 0.200	11.31 11.31	=====	=====
24	16.69- 17.69	Clay	8.20	0.0	180.0 180.0	96.243 104.443	129.75 139.55	0.200 0.200	11.31 11.31	=====	=====
25	17.69- 23.65	Clay	8.20	0.0	250.0 250.0	104.443 153.315	139.55 197.96	0.200 0.200	11.31 11.31	=====	=====
26	23.65- 24.76	Clay	6.70	20.0	200.0 200.0	153.315 160.752	197.96 208.84	0.200 0.200	11.31 11.31	=====	=====
27	24.76- 33.10	Clay	7.20	30.0	1000.0 1000.0	160.752 220.800	208.84 290.57	0.200 0.200	11.31 11.31	=====	=====

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00- 0.69	65.59 70.74	40.55 42.52	65.59 70.74	0.00 6.76	-----
2	0.69- 1.30	3.64 7.96	42.52 44.25	42.52 44.25	6.76 12.74	-----
3	1.30- 1.52	7.96 9.51	44.25 44.88	44.25 44.88	12.74 12.74	-----

Sand $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
 Clay $P_{a1} = \Sigma \gamma h + Q - 2 C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
 Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m2
1	1.30	0.00	0.00
2	2.30	1.00	2.51
3	3.30	2.00	3.58
4	3.45	2.15	3.69

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

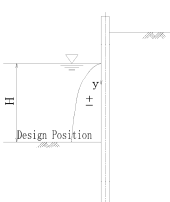
Where,

k_{dw} : 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



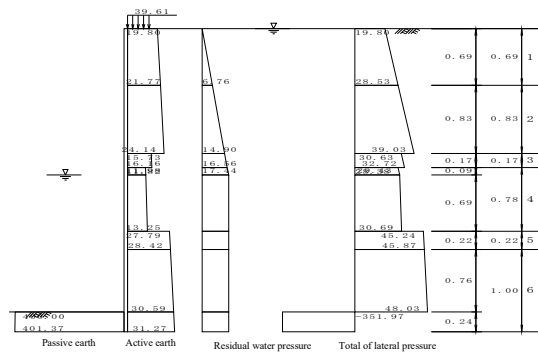
4 Imaginary Riverbed

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	1.52- 1.69	43.53 44.16	-----	43.53 44.16	12.74 12.74	-----
5	1.69- 2.47	33.25 35.44	-----	33.25 35.44	12.74 12.74	-----
6	2.47- 2.69	-82.49 -80.96	48.54 49.17	48.54 49.17	12.74 12.74	-----
7	2.69- 3.45	-281.50 -276.25	49.17 51.33	49.17 51.33	12.74 12.74	-----
8	3.45- 3.69	-276.25 -274.60	51.33 52.02	51.33 52.02	12.74 12.74	400.00 401.37
9	3.69- 4.69	27.27 34.40	52.02 54.87	52.02 54.87	12.74 12.74	101.37 107.07
10	4.69- 5.69	87.30 94.75	54.87 57.72	87.30 94.75	12.74 12.74	57.07 62.77
11	5.69- 6.69	-60.04 -53.04	57.72 60.57	57.72 60.57	12.74 12.74	212.77 218.47
12	6.69- 7.69	-53.04 -46.05	60.57 63.42	60.57 63.42	12.74 12.74	218.47 224.17
13	7.69- 8.38	-240.96 -242.18	63.42 65.38	63.42 65.38	12.74 12.74	428.17 428.10
14	8.38- 8.69	-242.18 -239.29	65.38 66.65	65.38 66.65	12.74 12.74	528.10 530.64
15	8.69- 9.69	-198.99 -189.01	66.65 70.75	66.65 70.75	12.74 12.74	390.64 398.84
16	9.69- 10.69	-189.01 -179.02	70.75 74.85	70.75 74.85	12.74 12.74	398.84 407.04
17	10.69- 11.69	-179.02 -169.03	74.85 78.95	74.85 78.95	12.74 12.74	407.04 415.24
18	11.69- 12.45	-7.75 0.00	78.95 82.09	78.95 82.09	12.74 12.74	255.24 261.51
19	12.45- 12.69	0.00 2.39	82.09 83.05	82.09 83.05	12.74 12.74	261.51 263.44
20	12.69- 13.69	-159.03 -149.02	83.05 87.15	83.05 87.15	12.74 12.74	423.44 431.64
21	13.69- 14.69	-149.02 -139.00	87.15 91.25	87.15 91.25	12.74 12.74	431.64 439.84
22	14.69- 15.69	-139.00 -128.97	91.25 95.35	91.25 95.35	12.74 12.74	439.84 448.04
23	15.69- 16.69	-128.97 -118.93	95.35 99.45	95.35 99.45	12.74 12.74	448.04 456.24
24	16.69- 17.69	-118.93 -108.89	99.45 103.55	99.45 103.55	12.74 12.74	456.24 464.44
25	17.69- 23.65	-249.64 -190.00	103.55 127.99	103.55 127.99	12.74 12.74	604.44 653.32
26	23.65- 24.76	-89.25 -80.10	127.99 131.71	127.99 131.71	12.74 12.74	553.32 560.75
27	24.76- 33.10	-1683.19 -1610.77	131.71 161.73	131.71 161.73	12.74 12.74	2160.75 2220.80

- Formula for active earth pressure

4.1 Normal Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.69	19.80 21.77	0.00 6.76	----- -----	19.80 28.53
2	0.69- 1.52	21.77 24.14	6.76 14.90	----- -----	28.53 39.03
3	1.52- 1.69	15.73 16.16	14.90 16.56	----- -----	30.63 32.72
4	1.69- 1.78	11.82 11.98	16.56 17.44	----- -----	28.38 29.43
5	1.78- 2.47	11.98 13.25	17.44 17.44	----- -----	29.43 30.69
6	2.47- 2.69	27.79 28.42	17.44 17.44	----- -----	45.24 45.87
7	2.69- 3.45	28.42 30.59	17.44 17.44	----- -----	45.87 48.03
8	3.45- 3.69	30.59 31.27	17.44 17.44	400.00 401.37	-351.97 -352.65

P_a : Active earth pressure

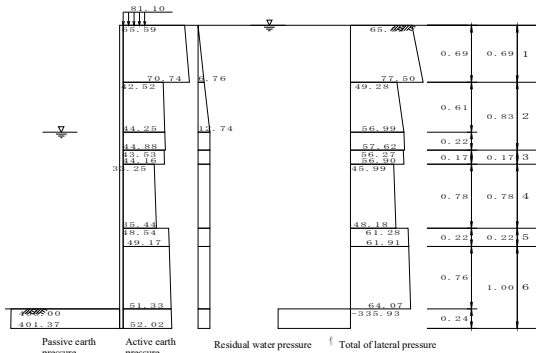
P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed L_k : 0.00 m (GL -3.45 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.69	65.99 70.74	0.00 6.76	— —	65.99 77.50
2	0.69- 1.30	42.52 44.25	6.76 12.74	— —	49.28 56.99
3	1.30- 1.52	44.25 44.88	12.74 12.74	— —	56.99 57.62
4	1.52- 1.69	43.53 44.16	12.74 12.74	— —	56.27 56.90
5	1.69- 2.47	33.25 35.44	12.74 12.74	— —	45.99 48.18
6	2.47- 2.69	48.54 49.17	12.74 12.74	— —	61.28 61.91
7	2.69- 3.45	49.17 51.33	12.74 12.74	— —	61.91 64.07
8	3.45- 3.69	51.33 52.02	12.74 12.74	400.00 401.37	-335.93 -336.61

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure Ps = Pa + Pw - Pp

Imaginary riverbed Lk: 0.00 m (GL -3.45 m)

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	3.45	0.74	40.6	14.0	20.22
2	4.19	1.00	14.0	7.0	10.50
3	5.19	1.00	7.0	16.0	11.50
4	6.19	0.96	16.0	18.9	16.78
L = Σh=3.70			ΣA=		59.00

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

Average N-value $N' = \frac{\sum A}{L}$
 $= \frac{59.00}{3.70}$
 $= 15.94$

Kh is recalculated from the calculated average N value.

$E_0 = 2800N' = 2800 \times 15.94 = 44622 \text{ kN/m}^2$
 $K_{10} = \frac{1}{0.3} \times \alpha \times 44622 = 148742 \text{ kN/m}^3$ (α:Normal Condition =1, Seismi Condition =2)
 $K_h = K_{10}(B_H/0.3)^{-3/4} = 148742(10.00/0.3)^{-3/4} = 10722 \text{ kN/m}^3$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 10722 kN/m3.

5.3 Seismic Condition

Assuming Kh = 20931 kN/m3,

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.319 \text{ m}^{-1}$

$L = \frac{1}{\beta} = 3.13 \text{ m}$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.45 m) and 3.13 m depth (GL -6.58 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	3.45	0.74	40.6	14.0	20.22
2	4.19	1.00	14.0	7.0	10.50
3	5.19	1.00	7.0	16.0	11.50
4	6.19	0.99	16.0	17.2	6.50
L = Σh=3.13			ΣA=		48.72

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

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$K_h = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4}$ (BH=10.00m)
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α :Normal Condition =1, Seismi Condition =2)
 $E_0 = 2800N'$

where:

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}}$

Material Name	10 H H 700 -200 - 12-19-18
Unit width	B = 1.0000 m
Corrosion margin	t1 = 1.00 mm (active side) t2 = 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	I0 = 299700 cm ⁴ (original condition) I = 251748 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 251748 × 10 ⁻⁸ = 5.035 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.19	3	11	10.19	21
2	1.19	9	12	11.19	16
3	2.19	27	13	12.19	15
4	3.19	50	14	13.19	16
5	4.19	14	15	14.19	17
6	5.19	7	16	15.19	20
7	6.19	16	17	16.19	23
8	7.19	19	18	17.19	30
9	8.19	50	19	18.19	39
10	9.19	25			

5.2 Normal Condition

Assuming Kh = 10722 kN/m3,

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.270 \text{ m}^{-1}$

$L = \frac{1}{\beta} = 3.70 \text{ m}$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.45 m) to 3.70 m depth (GL -7.15 m).

Average N-value $N' = \frac{\sum A}{L}$
 $= \frac{48.72}{3.13}$
 $= 15.56$

Kh is recalculated from the calculated average N value.

$E_0 = 2800N' = 2800 \times 15.56 = 43555 \text{ kN/m}^2$
 $K_{10} = \frac{1}{0.3} \times \alpha \times 43555 = 290364 \text{ kN/m}^3$ (α :Normal Condition =1, Seismi Condition =2)
 $K_h = K_{10}(B_H/0.3)^{-3/4} = 290364(10.00/0.3)^{-3/4} = 20931 \text{ kN/m}^3$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 20931 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.69	0.69	19.80 28.53	6.83 9.84	3.22 2.99	22.00 29.43
2	0.69- 1.52	0.83	28.53 39.03	11.84 16.20	2.48 2.21	29.41 35.74
3	1.52- 1.69	0.17	30.63 32.72	2.60 2.78	1.87 1.82	4.88 5.05
4	1.69- 1.78	0.09	28.38 29.43	1.28 1.32	1.75 1.70	2.21 2.25
5	1.78- 2.47	0.69	29.43 30.69	10.15 10.59	1.44 1.21	14.62 12.81
6	2.47- 2.69	0.22	45.24 45.87	4.98 5.05	0.91 0.83	4.51 4.20
7	2.69- 3.45	0.76	45.87 48.03	17.43 18.25	0.51 0.25	8.83 4.62
ΣP =			119.15	ΣM =	180.58	

Ps : active earth pressure + residual water pressure - passive earth pressure
P : load Ps 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	P1 = 61.1 kN/m
depth to acting position	H1 = 0.0 m
moment	Mm = 39.2 kN·m/m
depth to acting position	Hm = 0.00 m

Height from riverbed to top of coping $H = 3.45$ m
 Depth of Imaginary riverbed from riverbed $L_k = 0.00$ m

Moment M_i by arbitrary load is as below
 $M_i = P_i \cdot (H + L_k - H_i) + M_m = 250.00 \text{ kN}\cdot\text{m}$
 h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{430.57}{180.25} = 2.39 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 180.25}{3.45} = 104.49 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth, Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.69	0.69	65.59 77.50	22.63 26.74	3.22 2.99	72.86 79.95
2	0.69~ 1.30	0.61	49.28 56.99	15.03 17.38	2.56 2.35	38.43 40.91
3	1.30~ 1.52	0.22	56.99 57.62	6.27 6.34	2.08 2.00	13.02 12.70
4	1.52~ 1.69	0.17	56.27 56.90	4.78 4.84	1.87 1.82	8.96 8.79
5	1.69~ 2.47	0.78	45.99 48.18	17.93 18.79	1.50 1.24	26.90 23.30
6	2.47~ 2.69	0.22	61.28 61.91	6.74 6.81	0.91 0.83	6.11 5.67
7	2.69~ 3.45	0.76	61.91 64.07	23.52 24.35	0.51 0.25	11.92 6.17
			$\Sigma P =$	202.15	$\Sigma M =$	355.68

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

Arbitrary load lateral load $P_i = 147.5 \text{ kN/m}$
 depth to acting position $H_i = 0.00 \text{ m}$
 moment $M_m = 234.9 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_m = 0.00 \text{ m}$
 Height from riverbed to top of coping $H = 3.45 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_i \cdot (H + L_k - H_i) + M_m = 743.77 \text{ kN}\cdot\text{m}$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_a = 10722 \text{ kN/m}^3$
 calculated value $\beta = 0.27012 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 180.25 \text{ kN/m}$
 height of acting position of load $h_0 = 2.39 \text{ m}$
 moment $M_0 = 430.57 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_m = 1.283$,
 maximum moment $M_{\max} = 552.49 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 1.524 \text{ m}$
 depth of 1st fixed point $l_i = 4.432 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_a = 20931 \text{ kN/m}^3$
 calculated value $\beta = 0.31929 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 354.49 \text{ kN/m}$
 height of acting position of load $h_0 = 3.11 \text{ m}$
 moment $M_0 = 1103.25 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_m = 1.148$,
 maximum moment $M_{\max} = 1266.07 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 1.012 \text{ m}$
 depth of 1st fixed point $l_i = 3.472 \text{ m}$

6.3 Stress Intensity

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

Material Name 10 H₂ H 700-200-12-19-18
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.86$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 5540 \text{ cm}^3$ (original condition)
 $Z = 4764 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{552.49 \times 10^6}{4764 \times 10^3} = 116 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{1266.07 \times 10^6}{4764 \times 10^3} = 266 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

Hydrodynamic Pressure

No	Depth, Z m	Thickness h m	Hydrodynamic Pressure p_{dw} kN/m ²	Loads P_{dw} kN	Arm length Y m	Moment M_{dw} kN · m
1	1.30~ 2.30	1.00	0.0 2.5	0.00 1.26	1.82 1.48	0.00 1.87
2	2.30~ 3.30	1.00	2.5 3.6	1.26 1.78	0.82 0.48	1.03 0.86
3	3.30~ 3.45	0.15	3.6 3.7	0.27 0.28	0.10 0.05	0.03 0.01
			$\Sigma P_{dw} =$	4.84	$\Sigma M_{dw} =$	3.79

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{dw}}{\Sigma P + P_i + \Sigma P_{dw}} = \frac{1103.25}{354.49} = 3.11 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 354.49}{3.45} = 205.50 \text{ kN/m}$$

6.2 Sectional Force

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

Material name 10 H₂ H 700-200-12-19-18
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.84$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 299700 \text{ cm}^4$ (original condition)
 $I = 251748 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 251748 \times 10^{-8} = 5.035 \times 10^8$

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

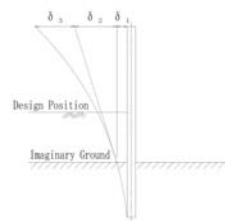
$$\phi_a = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

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

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

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

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

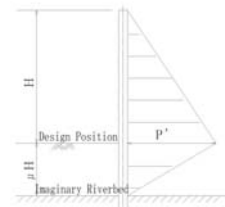


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^2}$$

$$= \frac{(1 + 0.2701 \times 2.39) \times 180.25}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.2701^2} = 0.01494 \text{ m}$$

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

$$= \frac{(1 + 2 \times 0.2701 \times 2.39) \times 180.25}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.2701^2} \times (3.45 + 0.00) = 0.01939 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.00}{3.45} = 0.000$$

$$\delta_3 = \frac{P' \cdot H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4)$$

$$= \frac{104.49 \times 3.45^4}{120 \times 2.00 \times 10^8 \times 251748 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4)$$

$$= 0.00098 \text{ m}$$

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

$$= 0.01494 + 0.01939 + 0.00098$$

$$= 0.03531 \text{ m}$$

$$\text{Size} = 35.31 \text{ mm} \leq \delta a = 50.00 \text{ mm}$$

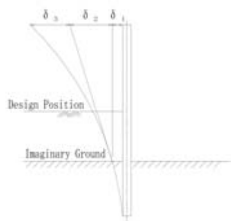
where:
 δ 1: amount of displacement at the virtual ground surface

Where,

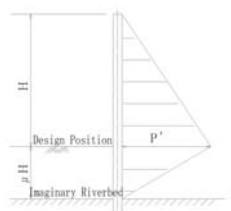
- δ_1 : Displacement at imaginary ground
- δ_2 : Displacement by angle of inclination slope at imaginary ground
- δ_3 : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

6.4.2 Seismic Condition

Displacement Calculation



$$\begin{aligned}\delta_1 &= \frac{(1 + \beta h_a) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3193 \times 3.11) \times 354.49}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.3193^3} = 0.02156 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_a) \times P_0}{2 E I \beta^2} \times (H + L_a) \\ &= \frac{(1 + 2 \times 0.3193 \times 3.11) \times 354.49}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.3193^2} \times (3.45 + 0.00) = 0.03559 \text{ m}\end{aligned}$$



$$\begin{aligned}\mu &= \frac{L_k}{H} = \frac{0.00}{3.45} = 0.000 \\ \delta_3 &= \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{205.50 \times 3.45^4}{120 \times 2.00 \times 10^8 \times 251748 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4) \\ &= 0.00193 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.02156 + 0.03559 + 0.00193 \\ &= 0.05908 \text{ m} \\ \text{Size} &= 59.08 \leq \delta_a = 75.00 \text{ mm}\end{aligned}$$

- 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:

Material Name	10 H _ H 700 -200 - 12-19-18
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 = 299700 cm ⁴ (original condition)
	I = 299700 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 299700 × 10 ⁻⁸	= 5.994 × 10 ⁵

7.1 Penetration Depth and Whole Length of SSP (Chang)

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

$$\begin{aligned}D &= L_k + \frac{3}{\beta} \\ L &= H - H_{ik} + D \\ \beta &= 4 \sqrt{\frac{K_b \times B}{4 E I}}\end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 10722 kN/m ³
Calculated value	β = 0.25860 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.259}$ = 11.60 m
Whole length of SSP	L = 3.45 - 0.40 + 11.60 = 14.65 m

7.1.1 Seismic Condition

Modules of lateral subgrade reaction	K_b = 20931 kN/m ³
Calculated value	β = 0.30567 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.306}$ = 9.81 m
Whole length of SSP	L = 3.45 - 0.40 + 9.81 = 12.86 m

Therefore, the total length of the sheet pile is 15.00 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile 10 H _ H 700 -200 - 12-19-18

			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	299700		
Sectional Modulus	Z (cm ³)	5540		
Maximum bending moment	Mmax (kN · m · m)		552.49	1266.07
Stress intensity	σ (N/mm ²)		116 (180)	266 (270)
Lateral displacement	δ (mm)		35.31 (50.0)	59.08 (75.0)
Penetration depths	D (m)		11.60	9.81
Whole length of SSP	L (m)	15.00		

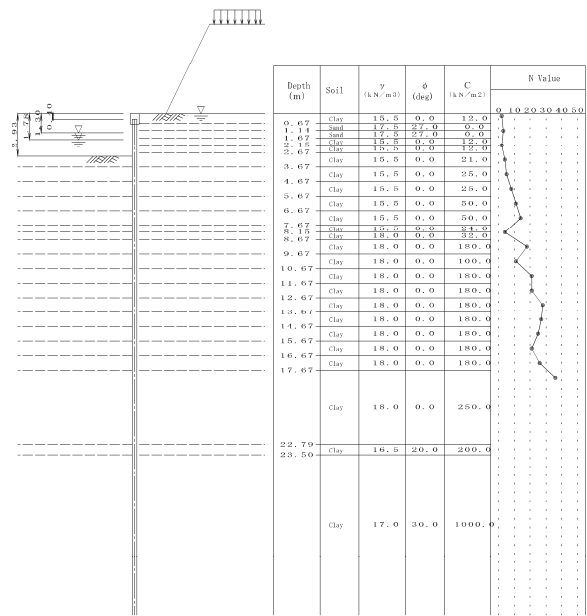
Block No. : L-13
Sta. : 9+320~9+560

Design Cross Section : Sta 9+360
Boring Name : DD-BH-L10

Specification : SSP SP-50H
(Combined) : H 1000-300-19-40-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed
Depth from coping top to rear side ground
Depth from coping top to SSP top
Landside WL
Riverside WL

H = 2.93 m
H₀ = 0.00 m
H_h = 0.40 m
L_{wa} = 0.00 m (Normal Condition)
L_{wa} = 0.00 m (Seismic Condition)
L_{wp} = 1.78 m (Normal Condition)
L_{wp} = 1.30 m (Seismic Condition)

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	0.17	2	11	10.17	11
2	1.17	3	12	11.17	21
3	2.17	2	13	12.17	21
4	3.17	4	14	13.17	28
5	4.17	5	15	14.17	27
6	5.17	8	16	15.17	25
7	6.17	11	17	16.17	21
8	7.17	14	18	17.17	26
9	8.17	4	19	18.17	36
10	9.17	18			

1.6 Vertical Load

Vertical load on landside
Vertical load on riverside

calculated in consideration of embankment shape on landside
not considered

1.7 Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	0.67	0.67
2	1.14	0.47
3	1.67	0.53
4	2.15	0.48
5	2.67	0.52
6	3.67	1.00
7	4.67	1.00
8	5.67	1.00
9	6.67	1.00
10	7.67	1.00
11	8.15	0.48
12	8.67	0.52
13	9.67	1.00
14	10.67	1.00
15	11.67	1.00
16	12.67	1.00
17	13.67	1.00
18	14.67	1.00
19	15.67	1.00
20	16.67	1.00
21	17.67	1.00
22	22.79	5.12
23	23.50	0.71
24	33.10	9.60

1.3 Applied Formula

Formula for generated stress
Penetration depths

Chang's formula
$$L = \frac{3}{\beta}$$

1.4 Design Constant

Unit weight of water
Type of water pressure
Lateral pressure
Study case
Design earthquake intensity
Dynamic water pressure due to earthquake considered as distributed load
Arbitrary load
Horizontal load
Depth of acting point
Moment
Depth of acting point
Wind load, Impact load
Minimum angle of rupture
Rear side angle of slope
Angle of rupture (clayey soil)
Equilibrium factor of compression

$\gamma_w = 9.8 \text{ kN/m}^3$
trapezoidal water pressure
calculated in consideration of site conditions
- Normal Condition
- Seismic Condition
k = 2000
Pt = 61.1 kN/m (Normal Condition)
Pt' = 147.5 kN/m (Seismic Condition)
Ht = 0.0 m (Normal Condition)
Ht' = 0.0 m (Seismic Condition)
Mm = 39.00 kN·m/m (Normal Condition)
Mm' = 234.9kN·m/m (Seismic Condition)
Hm = 0.00 m (Seismic Condition)
Hm = 0.00 m (Normal Condition)
(*Depth' means distance from top of coping)
not considered
 $\zeta_0 = 10 \text{ degrees}$
not considered
 $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h^2 2Q}{2C}} \cdot \tan \theta$
K_c = 0.50 (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula
Average N-value

$$K_{10} = K_{10} \left(\frac{B_{10}}{0.3} \right)^{-3/4}$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

B₁₀ = 10.00 m
E₀ = 2800N
calculated from average N-value between imaginary riverbed and depth as 1/β

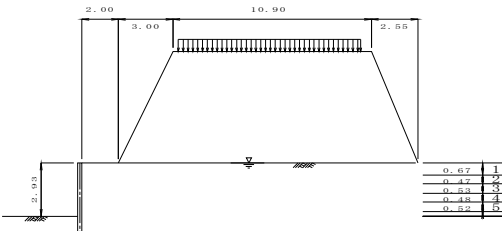
No	Depth m	earth Soil	N Value kN/m3	γ kN/m3	γ' kN/m3	ϕ degree	C kN/m2	a	k'	ζ (degree) Normal Condition	Seismic Condition	Normal Condition	Seismic Condition
1	0.67	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto	-----	-----
2	1.14	S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	-----	-----
3	1.67	S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	-----	-----
4	2.15	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto	-----	-----
5	2.67	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto	-----	-----
6	3.67	C	3.5	15.50	5.70	0.0	21.0	0.0	0.200	Auto	Auto	-----	-----
7	4.67	C	5.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto	-----	-----
8	5.67	C	8.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto	-----	-----
9	6.67	C	11.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto	-----	-----
10	7.67	C	14.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto	-----	-----
11	8.15	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto	-----	-----
12	8.67	C	4.0	18.00	8.20	0.0	32.0	0.0	0.200	Auto	Auto	-----	-----
13	9.67	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
14	10.67	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	-----	-----
15	11.67	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
16	12.67	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
17	13.67	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
18	14.67	C	27.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
19	15.67	C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
20	16.67	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
21	17.67	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	-----	-----
22	22.79	C	36.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	-----	-----
23	23.50	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto	-----	-----
24	33.10	C	121.5	17.00	7.20	30.0	1000.0	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
C₀ : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	2.00	5.00	15.90	18.45	6.12	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	5.30	15.30	10.0	5.0

Material name	50 H _ H 1000 -300 -19 -40 -18
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 1543500 cm ⁴
Sectional factor	Z ₀ = 21110 cm ³

Corrosion rate (to I_0)	η	=	0.91
Corrosion rate (to Z_0)	η	=	0.92
Section efficiency (to I_0)	μ	=	1.00
Section efficiency (to Z_0)	μ	=	1.00

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

Allowable displacement	δ_a	=	50.0
	δ_a'	=	75.0

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

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)

No	Angle of Rapine γ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.26	0.00	0.00	0.26	0.26
2	45.00	0.52	0.26	0.26	0.78	0.78
3	45.00	0.48	0.78	0.78	1.26	1.26
4	54.81	0.53	1.26	1.26	1.63	1.79
5	54.81	0.47	1.63	1.79	1.97	2.26
6	45.00	0.67	1.97	2.26	2.64	2.93
7	60.00	6.12	2.64	2.93	6.17	9.05

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	5.52	104.87
Σ			104.87

No	Q kN/m ²	l m	Qsd kN/m
1	10.0	0.87	8.69
Σ			8.69

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{104.87 + 8.69 + 0.00}{2.64}$$

$$= 43.09 \text{ kN/m}^2$$
[illegible]

No	Depth, m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ w/m ³ kN/m ³	Angle of Repose ζ degree
1	2.93 - 2.67	Clay	0.0	15.0	21.0	18.70	43.09	28.71	45.00
2	2.67 - 2.15	Clay	0.0	15.0	12.0	12.72	43.09	26.17	45.00
3	2.15 - 1.67	Clay	0.0	15.0	12.0	14.28	43.09	21.07	45.00
4	1.67 - 1.14	Sand	27.0	15.0	0.0	11.52	43.09	16.37	54.81
5	1.14 - 0.67	Sand	27.0	15.0	0.0	7.44	43.09	11.17	54.81
6	0.67 - 0.00	Clay	0.0	15.0	12.0	3.82	43.09	6.57	45.00
7		embankment L	30.0	—	0.0	116.28	10.00	0.00	60.00

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

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)

$$\theta = \tan^{-1}k \text{ or } \theta = \tan^{-1}k'$$

0.67	1
0.47	2
0.53	3
0.48	4
0.52	5

No	Depth, m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma$ h kN/m ²	Q kN/m ²	γ whs kN/m ²	k (t ²)	θ degree	Angle of Repose ζ degree
1	2.93 – 2.67	Clay	0.0	15.0	23.0	18.70	96.78	28.71	0.200	11.31	34.61
2	2.67 – 2.15	Clay	0.0	15.0	12.0	12.22	96.78	26.17	0.200	11.31	30.42
3	2.15 – 1.67	Clay	0.0	15.0	12.0	14.26	96.78	21.07	0.200	11.31	30.64
4	1.67 – 1.14	Sand	27.0	15.0	0.0	11.52	96.78	16.37	0.200	11.31	42.18
5	1.14 – 0.67	Sand	27.0	15.0	0.0	7.44	96.78	11.57	0.200	11.31	42.18
6	0.67 – 0.00	Clay	0.0	15.0	12.0	3.82	96.78	6.57	0.200	11.31	31.43
7		embankment	30.0	—	0.0	116.28	5.00	0.00	0.200	11.31	49.60

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$
$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

- 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 Collapse Line

No	Angle of Rupture : ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	34.61	0.26	0.00	0.00	0.38	0.26
2	30.42	0.52	0.38	0.26	1.26	0.78
3	30.64	0.48	1.26	0.78	2.07	1.26
4	42.18	0.53	2.07	1.26	2.66	1.79
5	42.18	0.47	2.66	1.79	3.18	2.26
6	31.43	0.67	3.18	2.26	4.27	2.93
7	49.60	6.12	4.27	2.93	9.48	9.05

From the above table, the loading width (L) on the ground surface is 4.27 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	20.66	392.61
Σ			392.61

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	Qxl kN/m
1	5.0	4.10	20.90
Σ			20.90

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

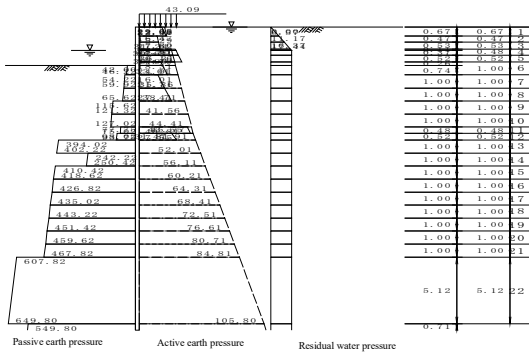
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{392.61 + 20.90 + 0.00}{4.27}$$

$$= 96.78 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Qa$ kN/m ²	Ka	$Ka \times \cos \delta$
1 0.00~0.67	Clay	5.7	—	12.0 12.0	43.092 46.911	—	—
2 0.67~1.14	Sand	7.7	27.0	—	46.911 50.530	0.33738 0.33738	0.32589 0.32589
3 1.14~1.67	Sand	7.7	27.0	—	50.530 54.611	0.33738 0.33738	0.32589 0.32589
4 1.67~1.78	Clay	5.7	—	12.0 12.0	54.611 55.238	—	—
5 1.78~2.15	Clay	5.7	—	12.0 12.0	55.238 57.347	—	—
6 2.15~2.67	Clay	5.7	—	12.0 12.0	57.347 60.311	—	—
7 2.67~2.93	Clay	5.7	—	21.0 21.0	60.311 61.793	—	—
8 2.93~3.67	Clay	5.7	—	21.0 21.0	61.793 66.011	—	—
9 3.67~4.67	Clay	5.7	—	25.0 25.0	66.011 71.711	—	—
10 4.67~5.67	Clay	5.7	—	25.0 25.0	71.711 77.411	—	—
11 5.67~6.67	Clay	5.7	—	50.0 50.0	77.411 83.111	—	—
12 6.67~7.67	Clay	5.7	—	50.0 50.0	83.111 88.811	—	—

13	7.67~8.15	Clay	5.7	—	24.0 24.0	88.811 91.547	—	—
14	8.15~8.67	Clay	8.2	—	32.0 32.0	91.547 95.811	—	—
15	8.67~9.67	Clay	8.2	—	180.0 180.0	95.811 104.011	—	—
16	9.67~10.67	Clay	8.2	—	100.0 100.0	104.011 112.211	—	—
17	10.67~11.67	Clay	8.2	—	180.0 180.0	112.211 120.411	—	—
18	11.67~12.67	Clay	8.2	—	180.0 180.0	120.411 128.611	—	—
19	12.67~13.67	Clay	8.2	—	180.0 180.0	128.611 136.811	—	—
20	13.67~14.67	Clay	8.2	—	180.0 180.0	136.811 145.011	—	—
21	14.67~15.67	Clay	8.2	—	180.0 180.0	145.011 153.211	—	—
22	15.67~16.67	Clay	8.2	—	180.0 180.0	153.211 161.411	—	—
23	16.67~17.67	Clay	8.2	—	180.0 180.0	161.411 169.611	—	—
24	17.67~22.79	Clay	8.2	—	250.0 250.0	169.611 211.395	—	—
25	22.79~23.50	Clay	6.7	—	200.0 200.0	211.395 216.352	—	—
26	23.50~33.10	Clay	7.2	—	1000.0 1000.0	216.352 285.472	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Qp$ kN/m ²	Kp	$Kp \times \cos \delta$
8	2.93~3.67	Clay	5.7	0.0	21.0 21.0	0.000 4.218	—	—
9	3.67~4.67	Clay	5.7	0.0	25.0 25.0	4.218 9.918	—	—
10	4.67~5.67	Clay	5.7	0.0	25.0 25.0	9.918 15.618	—	—
11	5.67~6.67	Clay	5.7	0.0	50.0 50.0	15.618 21.318	—	—
12	6.67~7.67	Clay	5.7	0.0	50.0 50.0	21.318 27.018	—	—
13	7.67~8.15	Clay	5.7	0.0	24.0 24.0	27.018 29.754	—	—
14	8.15~8.67	Clay	8.2	0.0	32.0 32.0	29.754 34.018	—	—

15	8.67~9.67	Clay	8.2	0.0	180.0 180.0	34.018 42.218	—	—
16	9.67~10.67	Clay	8.2	0.0	100.0 100.0	42.218 50.418	—	—
17	10.67~11.67	Clay	8.2	0.0	180.0 180.0	50.418 58.618	—	—
18	11.67~12.67	Clay	8.2	0.0	180.0 180.0	58.618 66.818	—	—
19	12.67~13.67	Clay	8.2	0.0	180.0 180.0	66.818 75.018	—	—
20	13.67~14.67	Clay	8.2	0.0	180.0 180.0	75.018 83.218	—	—
21	14.67~15.67	Clay	8.2	0.0	180.0 180.0	83.218 91.418	—	—
22	15.67~16.67	Clay	8.2	0.0	180.0 180.0	91.418 99.618	—	—
23	16.67~17.67	Clay	8.2	0.0	180.0 180.0	99.618 107.818	—	—
24	17.67~22.79	Clay	8.2	0.0	250.0 250.0	107.818 149.802	—	—
25	22.79~23.50	Clay	6.7	20.0	200.0 200.0	149.802 154.559	—	—
26	23.50~33.10	Clay	7.2	30.0	1000.0 1000.0	154.559 223.679	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00~0.67	19.09 22.91	21.55 23.46	21.55 23.46	— 6.57	—
2	0.67~1.14	—	15.29 16.47	15.29 16.47	— 11.17	—
3	1.14~1.67	—	16.47 17.80	16.47 17.80	— 16.37	—
4	1.67~1.78	30.61 31.24	27.31 27.62	30.61 31.24	16.37 17.44	—
5	1.78~2.15	31.24 33.35	27.62 28.67	31.24 33.35	17.44 17.44	—
6	2.15~2.67	33.35 36.31	28.67 30.16	33.35 36.31	17.44 17.44	—
7	2.67~2.93	18.31 19.79	30.16 30.90	30.16 30.90	17.44 17.44	—
8	2.93~3.67	19.79 24.01	30.90 33.01	30.90 33.01	17.44 17.44	42.00 46.22

9	3.67~ 4.67	16.01 21.71	33.01 35.86	33.01 35.86	17.44 17.44	54.22 59.92
10	4.67~ 5.67	21.71 27.41	35.86 38.71	35.86 38.71	17.44 17.44	59.92 65.62
11	5.67~ 6.67	22.99 16.89	38.71 41.56	38.71 41.56	17.44 17.44	115.62 121.32
12	6.67~ 7.67	16.89 11.19	41.56 44.41	41.56 44.41	17.44 17.44	121.32 127.02
13	7.67~ 8.15	40.81 43.55	44.41 45.77	44.41 45.77	17.44 17.44	75.02 77.75
14	8.15~ 8.67	27.55 31.81	45.77 47.91	45.77 47.91	17.44 17.44	93.75 98.02
15	8.67~ 9.67	264.19 255.99	47.91 52.01	47.91 52.01	17.44 17.44	394.02 402.22
16	9.67~ 10.67	95.99 87.79	52.01 56.11	52.01 56.11	17.44 17.44	242.22 250.42
17	10.67~ 11.67	247.79 239.59	56.11 60.21	56.11 60.21	17.44 17.44	410.42 418.62
18	11.67~ 12.67	239.59 231.39	60.21 64.31	60.21 64.31	17.44 17.44	418.62 426.82
19	12.67~ 13.67	231.39 223.19	64.31 68.41	64.31 68.41	17.44 17.44	426.82 435.02
20	13.67~ 14.67	223.19 214.99	68.41 72.51	68.41 72.51	17.44 17.44	435.02 443.22
21	14.67~ 15.67	214.99 206.79	72.51 76.61	72.51 76.61	17.44 17.44	443.22 451.42
22	15.67~ 16.67	206.79 198.59	76.61 80.71	76.61 80.71	17.44 17.44	451.42 459.62
23	16.67~ 17.67	198.59 190.39	80.71 84.81	80.71 84.81	17.44 17.44	459.62 467.82
24	17.67~ 22.79	330.39 288.41	84.81 105.80	84.81 105.80	17.44 17.44	607.82 649.80
25	22.79~ 23.50	188.41 183.65	105.80 108.18	105.80 108.18	17.44 17.44	549.80 554.56
26	23.50~ 33.10	1783.65 1714.53	108.18 142.74	108.18 142.74	17.44 17.44	2154.56 2223.08

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

14	7.67~ 8.15	Clay	5.7	—	24.0 24.0	142.50 145.24	75.17 79.87	0.200 0.200	11.31 11.31	— —	— —	34.06 33.93
15	8.15~ 8.67	Clay	8.2	—	32.0 32.0	145.24 149.50	79.87 84.97	0.200 0.200	11.31 11.31	— —	— —	35.90 35.72
16	8.67~ 9.67	Clay	8.2	—	180.0 180.0	149.50 157.70	84.97 94.77	0.200 0.200	11.31 11.31	— —	— —	42.80 42.69
17	9.67~ 10.46	Clay	8.2	—	100.0 100.0	157.70 164.17	94.77 —	0.200 0.200	11.31 11.31	— —	— —	41.09 —
18	10.46~ 10.67	Clay	8.2	—	100.0 100.0	164.17 165.90	— 104.57	0.200 0.200	11.31 11.31	— —	— —	— 40.91
19	10.67~ 11.67	Clay	8.2	—	180.0 180.0	165.90 174.10	104.57 114.37	0.200 0.200	11.31 11.31	— —	— —	42.58 42.47
20	11.67~ 12.67	Clay	8.2	—	180.0 180.0	174.10 182.30	114.37 124.17	0.200 0.200	11.31 11.31	— —	— —	42.47 42.36
21	12.67~ 13.67	Clay	8.2	—	180.0 180.0	182.30 190.50	124.17 133.97	0.200 0.200	11.31 11.31	— —	— —	42.36 42.25
22	13.67~ 14.67	Clay	8.2	—	180.0 180.0	190.50 198.70	133.97 143.77	0.200 0.200	11.31 11.31	— —	— —	42.25 42.15
23	14.67~ 15.67	Clay	8.2	—	180.0 180.0	198.70 206.90	143.77 153.57	0.200 0.200	11.31 11.31	— —	— —	42.15 42.04
24	15.67~ 16.67	Clay	8.2	—	180.0 180.0	206.90 215.10	153.57 163.37	0.200 0.200	11.31 11.31	— —	— —	42.04 41.94
25	16.67~ 17.67	Clay	8.2	—	180.0 180.0	215.10 223.30	163.37 173.17	0.200 0.200	11.31 11.31	— —	— —	41.94 41.83
26	17.67~ 22.79	Clay	8.2	—	250.0 250.0	223.30 265.29	173.17 223.34	0.200 0.200	11.31 11.31	— —	— —	42.65 42.25
27	22.79~ 23.50	Clay	6.7	—	200.0 200.0	265.29 270.04	223.34 230.30	0.200 0.200	11.31 11.31	— —	— —	41.64 41.58
28	23.50~ 33.10	Clay	7.2	—	1000.0 1000.0	270.04 339.16	230.30 324.38	0.200 0.200	11.31 11.31	— —	— —	44.25 44.06

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

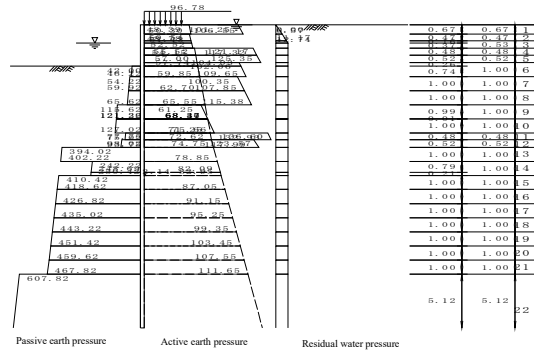
Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

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

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ ulw kN/m ²	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
8	2.93~ 3.67	Clay	5.70	0.0	21.0 21.0	0.000 4.218	0.00 7.25	0.200 0.200	11.31 11.31	— —	— —
9	3.67~ 4.67	Clay	5.70	0.0	25.0 25.0	4.218 9.918	7.25 17.05	0.200 0.200	11.31 11.31	— —	— —
10	4.67~ 5.67	Clay	5.70	0.0	25.0 25.0	9.918 15.618	17.05 26.85	0.200 0.200	11.31 11.31	— —	— —
11	5.67~ 6.66	Clay	5.70	0.0	50.0 50.0	15.618 21.261	26.85 —	0.200 —	11.31 —	— —	— —

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ ulw kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00~ 0.67	Clay	5.7	—	12.0 12.0	96.78 100.60	0.00 6.57	0.200 0.200	11.31 11.31	— —	— —	31.74 31.43
2	0.67~ 1.14	Sand	7.7	27.0	—	100.60 104.22	6.57 11.17	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— —
3	1.14~ 1.30	Sand	7.7	27.0	—	104.22 105.45	11.17 12.74	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— —
4	1.30~ 1.67	Sand	7.7	27.0	—	105.45 108.30	12.74 16.37	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— —
5	1.67~ 2.15	Clay	5.7	—	12.0 12.0	108.30 111.04	16.37 21.07	0.200 0.200	11.31 11.31	— —	— —	30.84 30.64
6	2.15~ 2.67	Clay	5.7	—	12.0 12.0	111.04 114.00	21.07 26.17	0.200 0.200	11.31 11.31	— —	— —	30.64 30.42
7	2.67~ 2.93	Clay	5.7	—	21.0 21.0	114.00 115.48	26.17 28.71	0.200 0.200	11.31 11.31	— —	— —	34.70 34.61
8	2.93~ 3.67	Clay	5.7	—	21.0 21.0	115.48 119.70	28.71 35.97	0.200 0.200	11.31 11.31	— —	— —	34.61 34.36
9	3.67~ 4.67	Clay	5.7	—	25.0 25.0	119.70 125.40	35.97 45.77	0.200 0.200	11.31 11.31	— —	— —	35.55 35.24
10	4.67~ 5.67	Clay	5.7	—	25.0 25.0	125.40 131.10	45.77 55.57	0.200 0.200	11.31 11.31	— —	— —	35.24 34.94
11	5.67~ 6.66	Clay	5.7	—	50.0 50.0	131.10 136.75	55.57 —	0.200 —	11.31 —	— —	— —	39.01 —
12	6.66~ 6.67	Clay	5.7	—	50.0 50.0	136.75 136.80	— 65.37	— 0.200	— 11.31	— —	— —	— 38.80
13	6.67~ 7.67	Clay	5.7	—	50.0 50.0	136.80 142.50	65.37 75.17	0.200 0.200	11.31 11.31	— —	— —	38.80 38.59

12	6.66~ 6.67	Clay	5.70	0.0	50.0 50.0	21.261 21.318	— 36.65	— 0.200	— 11.31	— —	— —
13	6.67~ 7.67	Clay	5.70	0.0	50.0 50.0	21.318 27.018	36.65 46.45	0.200 0.200	11.31 11.31	— —	— —
14	7.67~ 8.15	Clay	5.70	0.0	24.0 24.0	27.018 29.754	46.45 51.16	0.200 0.200	11.31 11.31	— —	— —
15	8.15~ 8.67	Clay	8.20	0.0	32.0 32.0	29.754 34.018	51.16 56.25	0.200 0.200	11.31 11.31	— —	— —
16	8.67~ 9.67	Clay	8.20	0.0	180.0 180.0	34.018 42.218	56.25 66.05	0.200 0.200	11.31 11.31	— —	— —
17	9.67~ 10.46	Clay	8.20	0.0	100.0 100.0	42.218 48.690	66.05 —	0.200 —	11.31 —	— —	— —
18	10.46~ 10.67	Clay	8.20	0.0	100.0 100.0	48.690 50.418	— 75.85	— 0.200	— 11.31	— —	— —
19	10.67~ 11.67	Clay	8.20	0.0	180.0 180.0	50.418 58.618	75.85 85.65	0.200 0.200	11.31 11.31	— —	— —
20	11.67~ 12.67	Clay	8.20	0.0	180.0 180.0	58.618 66.818	85.65 95.45	0.200 0.200	11.31 11.31	— —	— —
21	12.67~ 13.67	Clay	8.20	0.0	180.0 180.0	66.818 75.018	95.45 105.25	0.200 0.200	11.31 11.31	— —	— —
22	13.67~ 14.67	Clay	8.20	0.0	180.0 180.0	75.018 83.218	105.25 115.05	0.200 0.200	11.31 11.31	— —	— —
23	14.67~ 15.67	Clay	8.20	0.0	180.0 180.0	83.218 91.418	115.05 124.85	0.200 0.200	11.31 11.31	— —	— —
24	15.67~ 16.67	Clay	8.20	0.0	180.0 180.0	91.418 99.618	124.85 134.65	0.200 0.200	11.31 11.31	— —	— —
25	16.67~ 17.67	Clay	8.20	0.0	180.0 180.0	99.618 107.818	134.65 144.45	0.200 0.200	11.31 11.31	— —	— —
26	17.67~ 22.79	Clay	8.20	0.0	250.0 250.0	107.818 149.802	144.45 194.63	0.200 0.200	11.31 11.31	— —	— —
27	22.79~ 23.50	Clay	6.70	20.0	200.0 200.0	149.802 154.559	194.63 201.59	0.200 0.200	11.31 11.31	— —	— —
28	23.50~ 33.10	Clay	7.20	30.0	1000.0 1000.0	154.559 223.679	201.59 295.67	0.200 0.200	11.31 11.31	— —	— —

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

3	1.14- 1.30	50.54 51.13	----- -----	50.54 51.13	11.17 12.74	----- -----
4	1.30- 1.67	51.13 52.52	----- -----	51.13 52.52	12.74 12.74	----- -----
5	1.67- 2.15	117.32 121.17	54.15 55.52	117.32 121.17	12.74 12.74	----- -----
6	2.15- 2.67	121.17 125.35	55.52 57.00	121.17 125.35	12.74 12.74	----- -----
7	2.67- 2.93	102.06 104.03	57.00 57.74	102.06 104.03	12.74 12.74	----- -----
8	2.93- 3.67	104.03 109.65	57.74 59.85	104.03 109.65	12.74 12.74	42.00 46.22
9	3.67- 4.67	100.35 107.85	59.85 62.70	100.35 107.85	12.74 12.74	54.22 59.92
10	4.67- 5.67	107.85 115.38	62.70 65.55	107.85 115.38	12.74 12.74	59.92 65.62
11	5.67- 6.66	61.25 68.37	65.55 68.37	65.55 68.37	12.74 12.74	115.62 121.26
12	6.66- 6.67	68.37 68.44	68.37 68.40	68.37 68.44	12.74 12.74	121.26 121.32
13	6.67- 7.67	68.44 75.66	68.40 71.25	68.44 75.66	12.74 12.74	121.32 127.02
14	7.67- 8.15	132.93 136.60	71.25 72.62	132.93 136.60	12.74 12.74	75.02 77.75
15	8.15- 8.67	117.99 123.57	72.62 74.75	117.99 123.57	12.74 12.74	93.75 98.02
16	8.67- 9.67	179.27 169.28	74.75 78.85	74.75 78.85	12.74 12.74	394.02 402.22
17	9.67- 10.46	-8.01 0.00	78.85 82.09	78.85 82.09	12.74 12.74	242.22 248.69
18	10.46- 10.67	0.00 2.14	82.09 82.95	82.09 82.95	12.74 12.74	248.69 250.42
19	10.67- 11.67	-159.28 -149.27	82.95 87.05	82.95 87.05	12.74 12.74	410.42 418.62
20	11.67- 12.67	-149.27 -139.25	87.05 91.15	87.05 91.15	12.74 12.74	418.62 426.82
21	12.67- 13.67	-139.25 -129.22	91.15 95.25	91.15 95.25	12.74 12.74	426.82 435.02
22	13.67- 14.67	-129.22 -119.18	95.25 99.35	95.25 99.35	12.74 12.74	435.02 443.22
23	14.67- 15.67	-119.18 -109.14	99.35 103.45	99.35 103.45	12.74 12.74	443.22 451.42
24	15.67- 16.67	-109.14 -99.08	103.45 107.55	103.45 107.55	12.74 12.74	451.42 459.62
25	16.67- 17.67	-99.08 -89.02	107.55 111.65	107.55 111.65	12.74 12.74	459.62 467.82
26	17.67- 22.79	-229.90 -178.61	111.65 132.64	111.65 132.64	12.74 12.74	607.82 649.80
27	22.79- 23.50	-77.80 -71.95	132.64 135.02	132.64 135.02	12.74 12.74	540.80 554.56
28	23.50- 33.10	-1675.20 -1591.82	135.02 169.58	135.02 169.58	12.74 12.74	2154.56 2223.68

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma \cdot h + Q - 2 \cdot C$$

$$P_{a2} = K_a \cdot (\sum \gamma \cdot h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma \cdot h + Q + 2 \cdot C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	1.30	0.00	0.00
2	2.30	1.00	2.19
3	2.93	1.63	2.80

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

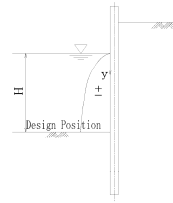
Where,

k_{dw} : 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

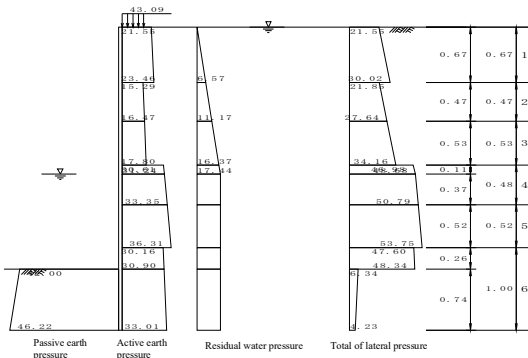


4 Imaginary Riverbed

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

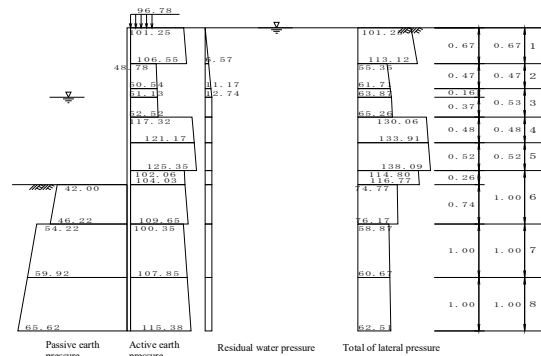


No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.67	21.55 23.46	0.00 6.57	----- -----	21.55 30.02
2	0.67- 1.14	15.29 16.47	6.57 11.17	----- -----	21.85 27.64
3	1.14- 1.67	16.47 17.80	11.17 16.37	----- -----	27.64 34.16
4	1.67- 1.78	30.61 31.24	16.37 17.44	----- -----	46.98 48.68
5	1.78- 2.15	31.24 33.35	17.44 17.44	----- -----	48.68 50.79
6	2.15- 2.67	33.35 36.31	17.44 17.44	----- -----	50.79 53.75
7	2.67- 2.93	36.31 30.90	17.44 17.44	----- -----	47.00 48.34
8	2.93- 3.67	30.90 33.01	17.44 17.44	42.00 46.22	6.34 4.23
9	3.67- 4.67	33.01 35.86	17.44 17.44	54.22 59.92	-3.77 -6.62

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure Ps = Pa + Pw - Pp

Imaginary riverbed Lk: 0.00 m (GL -3.67 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.67	101.25 106.55	0.00 6.57	----- -----	101.25 113.12
2	0.67- 1.14	48.78 50.54	6.57 11.17	----- -----	55.35 61.71
3	1.14- 1.30	50.54 51.13	11.17 12.74	----- -----	61.71 63.87
4	1.30- 1.67	51.13 52.52	12.74 12.74	----- -----	63.87 65.26
5	1.67- 2.15	117.32 121.17	12.74 12.74	----- -----	130.06 133.91
6	2.15- 2.67	121.17 125.35	12.74 12.74	----- -----	133.91 138.09
7	2.67- 2.93	102.06 104.03	12.74 12.74	----- -----	114.80 116.77
8	2.93- 3.67	104.03 109.65	12.74 12.74	42.00 46.22	74.77 76.17
9	3.67- 4.67	100.35 107.85	12.74 12.74	54.22 59.92	58.87 60.67
10	4.67- 5.67	107.85 115.38	12.74 12.74	59.92 65.62	60.67 62.51

No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
11	5.67- 6.66	65.55 68.37	12.74 12.74	115.62 121.26	-37.33 -40.15

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure

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

Imaginary riverbed L₄: 2.74 m (GL -5.67 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{40} = K_{40} \left(\frac{B_u}{0.3} \right)^{-3/4} \quad (B_u = 10.00m)$$
$$K_{40} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$
$$E_0 = 2800 N'$$

where:

$$\beta = \sqrt[4]{\frac{K_{40} \cdot B}{4 E I}}$$

Material Name	50 H	H 1000 -300 -19 -40 -18
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	= 1.00
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 1543500 cm ⁴ (original condition)
	I	= 1404585 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	= 200000 × 10 ³ × 1404585 × 10 ⁻⁸ = 2.809 × 10 ⁶

No	Depth Z m	N Value	No	Depth Z m	N Value
1	0.17	2	11	10.17	11
2	1.17	3	12	11.17	21
3	2.17	2	13	12.17	21
4	3.17	4	14	13.17	28
5	4.17	5	15	14.17	27
6	5.17	8	16	15.17	25
7	6.17	11	17	16.17	21
8	7.17	14	18	17.17	26
9	8.17	4	19	18.17	36
10	9.17	18			

5.2 Normal Condition

Assuming Kh = 6751 kN/m3,

$$\beta = \sqrt[4]{\frac{K_{40} \cdot B}{4 E I}} = 0.157 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 6.39 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.67 m) to

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.67	0.50	9.5	11.0	5.13
2	6.17	1.00	11.0	14.0	12.50
3	7.17	1.00	14.0	4.0	9.00
4	8.17	1.00	4.0	18.0	11.00
5	9.17	1.00	18.0	11.0	14.50
6	10.17	0.65	11.0	17.5	9.18
L = Σh = 5.15			ΣA =		61.31

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

Average N-value $N' = \frac{\Sigma A}{L}$
$$= \frac{61.31}{5.15}$$

$$= 11.91$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 11.91 = 33361 \text{ kN/m}^2$$
$$K_{40} = \frac{1}{0.3} \alpha \times 33361 = 222409 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$
$$K_{40} = K_{40} (B_u/0.3)^{-3/4} = 222409 (10.00/0.3)^{-3/4} = 16032 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 16032 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.67	0.67	21.55 30.02	7.22 10.06	3.45 3.22	24.88 32.42
2	0.67~ 1.14	0.47	21.85 27.64	5.14 6.50	2.84 2.69	14.60 17.45
3	1.14~ 1.67	0.53	27.64 34.16	7.32 9.05	2.35 2.18	17.24 19.71
4	1.67~ 1.78	0.11	46.98 48.68	2.58 2.08	1.96 1.93	5.07 5.16
5	1.78~ 2.15	0.37	48.68 50.79	9.01 9.40	1.77 1.64	15.91 15.44
6	2.15~ 2.67	0.52	50.79 53.75	13.21 13.98	1.35 1.17	17.78 16.40

6.39 m depth (GL -10.06 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	3.67	0.50	4.5	5.0	2.38
2	4.17	1.00	5.0	8.0	6.50
3	5.17	1.00	8.0	11.0	9.50
4	6.17	1.00	11.0	14.0	12.50
5	7.17	1.00	14.0	4.0	9.00
6	8.17	1.00	4.0	18.0	11.00
7	9.17	0.89	18.0	11.8	13.22
L = $\Sigma h = 6.39$			$\Sigma A = 64.09$		

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

Average N-value $N' = \frac{\Sigma A}{L}$
$$= \frac{64.09}{6.39}$$

$$= 10.03$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 10.03 = 28096 \text{ kN/m}^2$$
$$K_{40} = \frac{1}{0.3} \alpha \times 28096 = 93652 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$
$$K_{40} = K_{40} (B_u/0.3)^{-3/4} = 93652 (10.00/0.3)^{-3/4} = 6751 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 6751 kN/m3.

5.3 Seismic Condition

Assuming Kh = 16032 kN/m3,

$$\beta = \sqrt[4]{\frac{K_{40} \cdot B}{4 E I}} = 0.194 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 5.15 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.67 m) and 5.15 m depth (GL -10.82 m).

7	2.67~ 2.93	0.26	47.60 48.34	6.19 6.28	0.91 0.85	5.65 5.19
8	2.93~ 3.67	0.74	6.34 4.23	2.35 1.57	0.49 0.25	1.16 0.39
			ΣP =	112.51	ΣM =	214.45

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 _i	= 61.1 kN/m
depth to acting position	H _i	= 0.0 m
moment	M _{in}	= 39.2 kN·m/m
depth to acting position	H _m	= 0.00 m
Height from riverbed to top of coping	H	= 2.93 m
Depth of Imaginary riverbed from riverbed	L _k	= 0.74 m

Moment M_i by arbitrary load is as below
$$M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 263.44 \text{ kN} \cdot \text{m}$$

h₀: Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_i}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i}$$
$$= \frac{477.88}{173.61} = 2.75 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 173.61}{3.67} = 94.61 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.67	0.67	101.25 113.12	33.92 37.89	5.45 5.22	184.75 197.94
2	0.67~ 1.14	0.47	55.35 61.71	12.01 14.50	4.94 4.69	63.00 67.96
3	1.14~ 1.30	0.16	61.71 63.87	4.94 5.11	4.48 4.42	22.10 22.60
4	1.30~ 1.67	0.37	63.87 65.26	11.82 12.07	4.25 4.12	50.18 49.78
5	1.67~ 2.15	0.48	130.06 133.91	31.21 32.14	3.84 3.68	119.86 118.27
6	2.15~ 2.67	0.52	133.91 138.09	34.82 35.90	3.35 3.17	116.52 113.93
7	2.67~ 2.93	0.26	114.80 116.77	14.92 15.18	2.91 2.83	43.48 42.91
8	2.93~ 3.67	0.74	74.77 76.17	27.67 28.18	2.49 2.25	68.98 63.32
9	3.67~ 4.67	1.00	58.87 60.67	29.44 30.34	1.67 1.33	49.06 40.45

10	4.67- 5.67	1.00	60.67 62.51	30.34 31.25	0.67 0.33	20.22 10.42
$\Sigma P = 474.65$			$\Sigma M = 1463.72$			

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

Arbitrary load lateral load $P_i = 147.5 \text{ kN/m}$
 depth to acting position $H_i = 0.00 \text{ m}$
 moment $M_{i0} = 234.9 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_m = 0.00 \text{ m}$
 Height from riverbed to top of coping $H = 2.93 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 2.74 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_i \cdot (H + L_k - H_i) + M_{i0} = 1071.23 \text{ kN}\cdot\text{m}$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	1.30- 2.30	1.00	0.0 2.2	0.00 1.99	4.04 3.70	0.00 4.65
2	2.30- 2.93	0.63	2.2 2.8	0.69 0.88	3.16 2.95	2.18 2.60
$\Sigma P_{hw} = 2.67$			$\Sigma M_{hw} = 8.83$			

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_{i0}}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{hw}}{\Sigma P + P_i + \Sigma P_{hw}} = \frac{2545.78}{624.81} = 4.07 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 624.81}{5.67} = 220.39 \text{ kN/m}$$

6.2 Sectional Force

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

Material name 50 H _ H 1000 -300 -19 -40 -18
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm (active side)}$ $t_2 = 1.00 \text{ mm (passive side)}$
 Corrosion rate $\eta = 0.91$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 1543500 \text{ cm}^4$ (original condition)
 $I = 1404585 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 1404585 \times 10^{-8}$
 $= 2.809 \times 10^6$

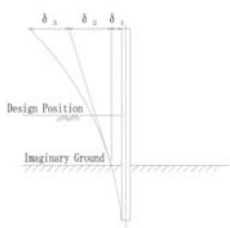
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{3078.35 \times 10^6}{19421 \times 10^3} = 159 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

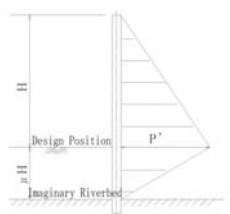
6.4.1 Normal Condition

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1 + 0.1566 \times 2.75) \times 173.61}{2 \times 2.00 \times 10^6 \times 1404585 \times 10^{-8} \times 0.1566^3} = 0.01152 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) = \frac{(1 + 2 \times 0.1566 \times 2.75) \times 173.61}{2 \times 2.00 \times 10^6 \times 1404585 \times 10^{-8} \times 0.1566^2} \times (2.93 + 0.74) = 0.00861 \text{ m}$$



$$\beta = \sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_b = 6751 \text{ kN/m}^3$
 calculated value $\beta = 0.15656 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 173.61 \text{ kN/m}$
 height of acting position of load $h_0 = 2.75 \text{ m}$
 moment $M_0 = 477.88 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{tm} = 1.498$,
 maximum moment $M_{\max} = 715.83 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 3.148 \text{ m}$
 depth of 1st fixed point $l_i = 8.165 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_b = 16032 \text{ kN/m}^3$
 calculated value $\beta = 0.19435 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 624.81 \text{ kN/m}$
 height of acting position of load $h_0 = 4.07 \text{ m}$
 moment $M_0 = 2545.78 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{tm} = 1.209$,
 maximum moment $M_{\max} = 3078.35 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 1.900 \text{ m}$
 depth of 1st fixed point $l_i = 5.941 \text{ m}$

6.3 Stress Intensity

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

Material Name 50 H _ H 1000 -300 -19 -40 -18
 Corrosion margin $t_1 = 1.00 \text{ mm (active side)}$ $t_2 = 1.00 \text{ mm (passive side)}$
 Corrosion rate $\eta = 0.92$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 21110 \text{ cm}^3$ (original condition)
 $Z = 19421 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{715.83 \times 10^6}{19421 \times 10^3} = 37 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

$$\mu = \frac{L_k}{H} = \frac{0.74}{2.93} = 0.253$$

$$\delta_3 = \frac{P' \cdot H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4)$$

$$= \frac{94.61 \times 2.93^4}{120 \times 2.00 \times 10^6 \times 1404585 \times 10^{-8}} (4 + 20 \times 0.253 + 40 \times 0.253^2 + 35 \times 0.253^3 + 11 \times 0.253^4)$$

$$= 0.00025 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01152 + 0.00861 + 0.00025 = 0.02039 \text{ m}$$

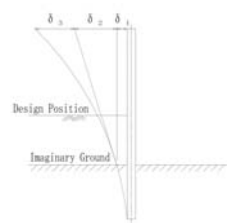
$$\text{Size} = 20.39 \leq \delta_a = 50.00 \text{ mm}$$

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

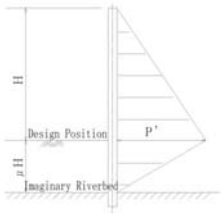
6.4.2 Seismic Condition

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1 + 0.1944 \times 4.07) \times 624.81}{2 \times 2.00 \times 10^6 \times 1404585 \times 10^{-8} \times 0.1944^3} = 0.02714 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) = \frac{(1 + 2 \times 0.1944 \times 4.07) \times 624.81}{2 \times 2.00 \times 10^6 \times 1404585 \times 10^{-8} \times 0.1944^2} \times (2.93 + 2.74) = 0.04313 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{2.74}{2.93} = 0.935$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4)$$

$$= \frac{220.39 \times 2.93^4}{120 \times 2.00 \times 10^8 \times 1404585 \times 10^{-8}} (4+20 \times 0.935+40 \times 0.935^2+35 \times 0.935^3+11 \times 0.935^4)$$

$$= 0.00456 \text{ m}$$

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

$$= 0.02714 + 0.04313 + 0.00456$$

$$= 0.07484 \text{ m}$$

$$\text{Size} = 74.84 \text{ mm} \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	50 H ₁₀₀₀₋₃₀₀₋₁₉₋₄₀₋₁₈
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 = 1543500 cm ⁴ (original condition)
	I = 1543500 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 1543500 × 10 ⁻⁸	= 3.087 × 10 ⁶

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:

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

$$L = H - H_{11} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_b = 6751 \text{ kN/m}^3$
Calculated value $\beta = 0.15291 \text{ m}^{-1}$

Penetration length of SSP $D = 0.74 + \frac{3}{0.153} = 20.36 \text{ m}$
Whole length of SSP $L = 2.93 - 0.40 + 20.36 = 22.89 \text{ m}$

7.1.1 Seismic Condition

Modules of lateral subgrade reaction $K_b = 16032 \text{ kN/m}^3$
Calculated value $\beta = 0.18982 \text{ m}^{-1}$

Penetration length of SSP $D = 2.74 + \frac{3}{0.190} = 18.54 \text{ m}$
Whole length of SSP $L = 2.93 - 0.40 + 18.54 = 21.07 \text{ m}$

Therefore, the total length of the sheet pile is 23.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 50 H ₁₀₀₀₋₃₀₀₋₁₉₋₄₀₋₁₈				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	1543500		
Sectional Modulus	Z (cm ³)	21110		
Maximum bending moment	Mmax (kN × m × m)		715.83	3078.35
Stress intensity	σ (N/mm ²)		37 (180)	159 (270)
Lateral displacement	δ (mm)		20.39 (50.0)	74.84 (75.0)
Penetration depth	D (m)		20.36	18.54
Whole length of SSP	L (m)	23.00		

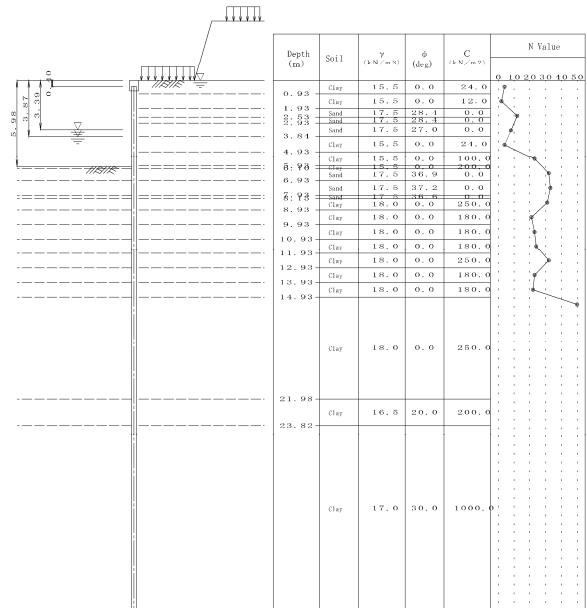
Block No. : L-14
Sta. : 9+560~9+800

Design Cross Section : Sta 9+560
Boring Name : BMLL-27

Specification : SSP SP-10H
(Combined) : H 950-250-16-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	= 5.98 m
Depth from coping top to rear side ground	H ₀	= 0.00 m
Depth from coping top to SSP top	H _a	= 0.40 m
Landside WL	L _{wa}	= 0.00 m (Normal Condition)
	L _{wa'}	= 0.00 m (Seismic Condition)
Riverside WL	L _{wp}	= 3.87 m (Normal Condition)
	L _{wp'}	= 3.39 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$	
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	$P_t = 30.0 \text{ kN/m}$ (Normal Condition)
		$P_t' = 76.3 \text{ kN/m}$ (Seismic Condition)
	Depth of acting point	$H_t = 0.0 \text{ m}$ (Normal Condition)
		$H_t' = 0.0 \text{ m}$ (Seismic Condition)
	Moment	$M_m = 0.00 \text{ kN} \cdot \text{m/m}$ (Normal Condition)
		$M_m' = 58.5 \text{ kN} \cdot \text{m/m}$ (Seismic Condition)
	Depth of acting point	$H_m = 0.00 \text{ m}$ (Seismic Condition)
		$H_m' = 0.00 \text{ m}$ (Normal Condition)
		(‘Depth’ means distance from top of coping)
Wind load, Impact load	not considered	
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$	
Rear side angle of slope	not considered	
Angle of rupture (clayey soil)	$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$	
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)	

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{b0} \left(\frac{B_B}{0.3} \right)^{-3/4}$
	$K_{b0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$
	$B_B = 10.00 \text{ m}$
	$E_0 = 2800 \text{ N}$
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	0.43	4	11	10.43	23
2	1.43	2	12	11.43	24
3	2.43	12	13	12.43	32
4	3.43	8	14	13.43	23
5	4.43	4	15	14.43	22
6	5.43	23	16	15.43	50
7	6.43	32			
8	7.43	33			
9	8.43	31			
10	9.43	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 (Include Projection Length)	Thickness m (excluding projected length)
1	0.93	0.93
2	1.93	1.00
3	2.53	0.60
4	2.93	0.40
5	3.84	0.91
6	4.93	1.09
7	5.93	1.00
8	6.10	0.17
9	6.93	0.83
10	7.93	1.00
11	8.15	0.22
12	8.93	0.78
13	9.93	1.00
14	10.93	1.00
15	11.93	1.00
16	12.93	1.00
17	13.93	1.00
18	14.93	1.00
19	21.98	7.65
20	23.82	1.84
21	35.20	11.38

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{b0} \left(\frac{B_B}{0.3} \right)^{-3/4}$
	$K_{b0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$
	$B_B = 10.00 \text{ m}$
	$E_0 = 2800 \text{ N}$
Average N-value	calculated from average N-value between imaginary riverbed and depth as 1/β

Surcharge load acting on embankment

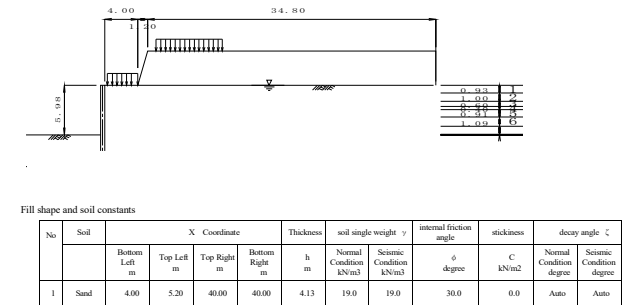
No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	6.22	14.22	10.0	5.0
2	0.35	4.00	5.0	0.0

Angle of rupture in embankment	calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

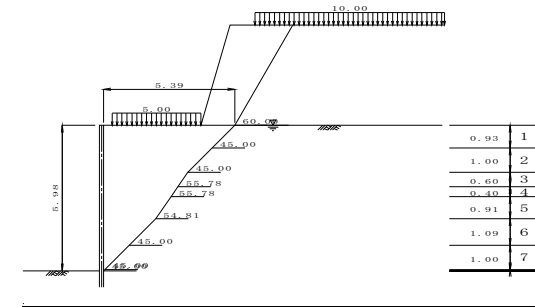
Material name	10 H H 950 -250 -16 -22 -18		
Young's modulus	$E = 200000 \text{ N/mm}^2$		
Inertia sectional moment	$I_0 = 688700 \text{ cm}^4$		
Sectional factor	$Z_0 = 10570 \text{ cm}^3$		
Corrosion margin	$t_1 = 1.00 \text{ mm}$ (riverside)	$t_2 = 1.00 \text{ mm}$ (landside)	
Corrosion rate (to I_0)	$\eta = 0.86$		
Corrosion rate (to Z_0)	$\eta = 0.88$		
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	$\sigma_a = 180 \text{ N/mm}$ (Normal)		
	$\sigma_a' = 270 \text{ N/mm}$ (Seismic)		
Allowable displacement	$\delta_a = 50.0 \text{ mm}$ (Normal)		
	$\delta_a' = 75.0 \text{ mm}$ (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		

1.8 Embankment on Landside



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	Σ γ h kN/m2	Q kN/m2	γ wto kN/m2	Angle of Rupture ζ degree
1	5.98~5.93	Clay	0.0	15.0	200.0	37.91	35.15	58.60	45.00
2	5.93~4.93	Clay	0.0	15.0	100.0	37.62	35.15	58.11	45.00
3	4.93~3.84	Clay	0.0	15.0	24.0	31.92	35.15	48.31	45.00
4	3.84~2.93	Sand	27.0	15.0	0.0	25.71	35.15	37.63	54.81
5	2.93~2.53	Sand	28.4	15.0	0.0	18.70	35.15	28.71	55.78
6	2.53~1.93	Sand	28.4	15.0	0.0	15.62	35.15	24.79	55.78
7	1.93~0.93	Clay	0.0	15.0	12.0	11.00	35.15	18.91	45.00
8	0.93~0.00	Clay	0.0	15.0	24.0	5.30	35.15	9.11	45.00
9		embankment	30.0		0.0	78.47	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

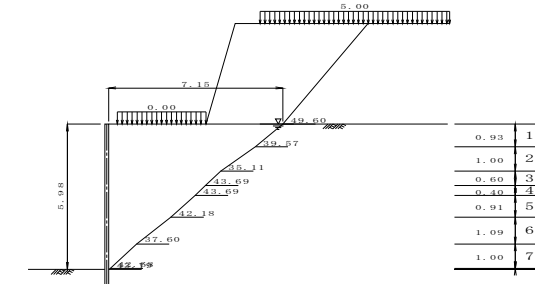
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C}} \cdot \tan \theta$$

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

Where,

ζ : angle of active rupture (degree, ζ ≥ 10.00°)
φ : internal friction angle (degree)

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ wto kN/m2	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	5.98~5.93	Clay	0.0	15.0	200.0	37.91	50.38	58.60	0.200	11.31	43.79
2	5.93~4.93	Clay	0.0	15.0	100.0	37.62	50.38	58.11	0.200	11.31	42.68
3	4.93~3.84	Clay	0.0	15.0	24.0	31.92	50.38	48.31	0.200	11.31	37.60
4	3.84~2.93	Sand	27.0	15.0	0.0	25.71	50.38	37.63	0.200	11.31	42.18
5	2.93~2.53	Sand	28.4	15.0	0.0	18.70	50.38	28.71	0.200	11.31	43.69
6	2.53~1.93	Sand	28.4	15.0	0.0	15.62	50.38	24.79	0.200	11.31	43.69
7	1.93~0.93	Clay	0.0	15.0	12.0	11.00	50.38	18.91	0.200	11.31	35.11
8	0.93~0.00	Clay	0.0	15.0	24.0	5.30	50.38	9.11	0.200	11.31	39.57
9		embankment	30.0		0.0	78.47	5.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.05	0.00	0.00	0.05	0.05
2	45.00	1.00	0.05	0.05	1.05	1.05
3	45.00	1.09	1.05	1.05	2.14	2.14
4	54.81	0.91	2.14	2.14	2.78	3.05
5	55.78	0.40	2.78	3.05	3.05	3.45
6	55.78	0.60	3.05	3.45	3.46	4.05
7	45.00	1.00	3.46	4.05	4.46	5.05
8	45.00	0.93	4.46	5.05	5.39	5.98
9	60.00	4.13	5.39	5.98	7.78	10.11

From the above table, the loading width (L) on the ground surface is 5.39 m.

2.1.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	8.19	155.69
Σ			155.69

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	Qxl kN/m
1	10.0	1.56	15.56
2	5.0	3.65	18.25
Σ			33.81

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

l: Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{155.69 + 33.81 + 0.00}{5.39}$$
$$= 35.15 \text{ kN/m}^2$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.79	0.05	0.00	0.00	0.05	0.05
2	42.68	1.00	0.05	0.05	1.14	1.05
3	37.60	1.09	1.14	1.05	2.55	2.14
4	42.18	0.91	2.55	2.14	3.56	3.05
5	43.69	0.40	3.56	3.05	3.97	3.45
6	43.69	0.60	3.97	3.45	4.60	4.05
7	35.11	1.00	4.60	4.05	6.03	5.05
8	39.57	0.93	6.03	5.05	7.15	5.98
9	49.60	4.13	7.15	5.98	10.66	10.11

From the above table, the loading width (L) on the ground surface is 7.15 m.

2.2.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	17.79	338.03
Σ			338.03

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	Qxl kN/m
1	5.0	4.44	22.22
2	0.0	3.65	0.00
Σ			22.22

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

l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

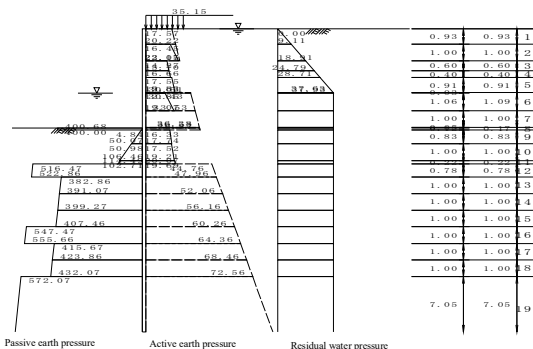
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{338.03 + 22.22 + 0.00}{7.15}$$

$$= 50.38 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00- 0.93	Clay	5.7	—	24.0 24.0	35.146 40.447	— —	— —
2	0.93- 1.93	Clay	5.7	—	12.0 12.0	40.447 46.147	— —	— —
3	1.93- 2.53	Sand	7.7	28.4	— —	46.147 50.767	0.3202 0.3202	0.30931 0.30931
4	2.53- 2.93	Sand	7.7	28.4	— —	50.767 53.847	0.3202 0.3202	0.30931 0.30931
5	2.93- 3.84	Sand	7.7	27.0	— —	53.847 60.854	0.33738 0.33738	0.32589 0.32589
6	3.84- 3.87	Clay	5.7	—	24.0 24.0	60.854 61.025	— —	— —
7	3.87- 4.93	Clay	5.7	—	24.0 24.0	61.025 67.067	— —	— —
8	4.93- 5.93	Clay	5.7	—	100.0 100.0	67.067 72.767	— —	— —
9	5.93- 5.98	Clay	5.7	—	200.0 200.0	72.767 73.052	— —	— —

17	10.93- 11.93	Clay	8.2	0.0	180.0 180.0	39.265 47.465	— —	— —
18	11.93- 12.93	Clay	8.2	0.0	250.0 250.0	47.465 55.665	— —	— —
19	12.93- 13.93	Clay	8.2	0.0	180.0 180.0	55.665 63.865	— —	— —
20	13.93- 14.93	Clay	8.2	0.0	180.0 180.0	63.865 72.065	— —	— —
21	14.93- 21.98	Clay	8.2	0.0	250.0 250.0	72.065 129.875	— —	— —
22	21.98- 23.82	Clay	6.7	20.0	200.0 200.0	129.875 142.203	— —	— —
23	23.82- 35.20	Clay	7.2	30.0	1000.0 1000.0	142.203 224.139	— —	— —

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	
1	0.00- 0.93	-12.85 -7.55	17.57 20.22	17.57 20.22	0.00 9.11	— —
2	0.93- 1.93	16.45 22.15	20.22 23.07	20.22 23.07	9.11 18.91	— —
3	1.93- 2.53	14.27 15.70	— —	14.27 15.70	18.91 24.79	— —
4	2.53- 2.93	15.70 16.66	— —	15.70 16.66	24.79 28.71	— —
5	2.93- 3.84	17.55 19.83	— —	17.55 19.83	28.71 37.63	— —
6	3.84- 3.87	12.85 13.03	30.43 30.51	30.43 30.51	37.63 37.93	— —
7	3.87- 4.93	13.03 19.07	30.51 33.53	30.51 33.53	37.93 37.93	— —
8	4.93- 5.93	-132.93 -127.23	33.53 36.38	33.53 36.38	37.93 37.93	— —
9	5.93- 5.98	-127.23 -126.95	36.38 36.53	36.38 36.53	37.93 37.93	— —
10	5.98- 6.10	-126.95 -126.26	36.53 36.87	36.53 36.87	37.93 37.93	400.00 400.68
11	6.10- 6.93	16.33 17.74	— —	16.33 17.74	37.93 37.93	4.84 50.07
12	6.93- 7.93	17.52 19.21	— —	17.52 19.21	37.93 37.93	50.98 106.46
13	7.93- 8.15	19.69 20.07	— —	19.69 20.07	37.93 37.93	102.71 114.49

10	5.98- 6.10	Clay	5.7	—	200.0 200.0	73.052 73.736	— —	— —
11	6.10- 6.93	Sand	7.7	36.9	— —	73.736 80.127	0.22925 0.22925	0.22144 0.22144
12	6.93- 7.93	Sand	7.7	37.2	— —	80.127 87.827	0.22641 0.22641	0.21870 0.21870
13	7.93- 8.15	Sand	7.7	36.6	— —	87.827 89.521	0.23211 0.23211	0.22420 0.22420
14	8.15- 8.93	Clay	8.2	—	250.0 250.0	89.521 95.917	— —	— —
15	8.93- 9.93	Clay	8.2	—	180.0 180.0	95.917 104.117	— —	— —
16	9.93- 10.93	Clay	8.2	—	180.0 180.0	104.117 112.317	— —	— —
17	10.93- 11.93	Clay	8.2	—	180.0 180.0	112.317 120.517	— —	— —
18	11.93- 12.93	Clay	8.2	—	250.0 250.0	120.517 128.717	— —	— —
19	12.93- 13.93	Clay	8.2	—	180.0 180.0	128.717 136.917	— —	— —
20	13.93- 14.93	Clay	8.2	—	180.0 180.0	136.917 145.117	— —	— —
21	14.93- 21.98	Clay	8.2	—	250.0 250.0	145.117 202.927	— —	— —
22	21.98- 23.82	Clay	6.7	—	200.0 200.0	202.927 215.255	— —	— —
23	23.82- 35.20	Clay	7.2	—	1000.0 1000.0	215.255 297.191	— —	— —

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	K_p	$K_p \times \cos \delta$
10	5.98- 6.10	Clay	5.7	0.0	200.0 200.0	0.000 0.684	— —	— —
11	6.10- 6.93	Sand	7.7	36.9	— —	0.684 7.075	7.32679 7.32679	7.07714 7.07714
12	6.93- 7.93	Sand	7.7	37.2	— —	7.075 14.775	7.45965 7.45965	7.20546 7.20546
13	7.93- 8.15	Sand	7.7	36.6	— —	14.775 16.469	7.19709 7.19709	6.95185 6.95185
14	8.15- 8.93	Clay	8.2	0.0	250.0 250.0	16.469 22.865	— —	— —
15	8.93- 9.93	Clay	8.2	0.0	180.0 180.0	22.865 31.065	— —	— —
16	9.93- 10.93	Clay	8.2	0.0	180.0 180.0	31.065 39.265	— —	— —

14	8.15- 8.93	-410.48 -404.08	44.76 47.96	44.76 47.96	37.93 37.93	516.47 522.86
15	8.93- 9.93	-264.08 -255.88	47.96 52.06	47.96 52.06	37.93 37.93	382.86 391.07
16	9.93- 10.93	-255.88 -247.68	52.06 56.16	52.06 56.16	37.93 37.93	391.07 399.27
17	10.93- 11.93	-247.68 -239.48	56.16 60.26	56.16 60.26	37.93 37.93	399.27 407.46
18	11.93- 12.93	-239.48 -231.28	60.26 64.36	60.26 64.36	37.93 37.93	407.46 415.66
19	12.93- 13.93	-231.28 -223.08	64.36 68.46	64.36 68.46	37.93 37.93	415.66 423.86
20	13.93- 14.93	-223.08 -214.88	68.46 72.56	68.46 72.56	37.93 37.93	423.86 432.07
21	14.93- 21.98	-354.88 -297.07	72.56 101.46	72.56 101.46	37.93 37.93	572.07 629.88
22	21.98- 23.82	-197.07 -184.74	101.46 107.63	101.46 107.63	37.93 37.93	629.88 642.20
23	23.82- 35.20	-1784.74 -1702.81	107.63 148.60	107.63 148.60	37.93 37.93	2142.20 2224.14

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma \cdot h + Q - 2C$$

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

K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

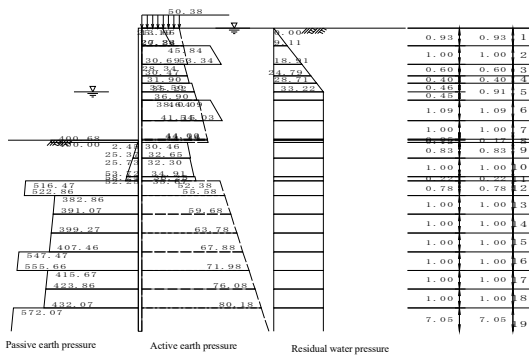
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma \cdot h + Q + 2C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{subw} kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 0.93	Clay	5.7	—	24.0 24.0	50.38 55.68	0.00 9.11	0.200 0.200	11.31 11.31	—	—	40.00 39.57
2	0.93- 1.93	Clay	5.7	—	12.0 12.0	55.68 61.38	9.11 18.91	0.200 0.200	11.31 11.31	—	—	35.76 35.11
3	1.93- 2.53	Sand	7.7	28.4	—	61.38 66.00	18.91 24.79	0.200 0.200	11.31 11.31	0.47800 0.47800	0.46172 0.46172	—
4	2.53- 2.93	Sand	7.7	28.4	—	66.00 69.08	24.79 28.71	0.200 0.200	11.31 11.31	0.47800 0.47800	0.46172 0.46172	—
5	2.93- 3.39	Sand	7.7	27.0	—	69.08 72.62	28.71 32.22	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
6	3.39- 3.84	Sand	7.7	27.0	—	72.62 76.09	32.22 37.63	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
7	3.84- 4.93	Clay	5.7	—	24.0 24.0	76.09 82.30	37.63 48.31	0.200 0.200	11.31 11.31	—	—	38.04 37.60
8	4.93- 5.93	Clay	5.7	—	100.0 100.0	82.30 88.09	48.31 58.11	0.200 0.200	11.31 11.31	—	—	42.82 42.66
9	5.93- 5.98	Clay	5.7	—	200.0 200.0	88.09 88.29	58.11 58.60	0.200 0.200	11.31 11.31	—	—	43.79 43.79
10	5.98- 6.10	Clay	5.7	—	200.0 200.0	88.29 88.97	58.60 59.78	0.200 0.200	11.31 11.31	—	—	43.79 43.78
11	6.10- 6.93	Sand	7.7	36.9	—	88.97 95.36	59.78 67.91	0.200 0.200	11.31 11.31	0.35446 0.35446	0.34239 0.34239	—
12	6.93- 7.93	Sand	7.7	37.2	—	95.36 103.06	67.91 77.71	0.200 0.200	11.31 11.31	0.35067 0.35067	0.33872 0.33872	—
13	7.93- 8.15	Sand	7.7	36.6	—	103.06 104.76	77.71 79.87	0.200 0.200	11.31 11.31	0.35829 0.35829	0.34608 0.34608	—

* The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active		Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pw kN/m ²	
1	0.00- 0.93	11.65 20.28	25.19 27.84	25.19 9.11	0.00 —
2	0.93- 1.93	45.84 53.34	27.84 30.69	45.84 53.34	9.11 —
3	1.93- 2.53	28.34 30.47	—	28.34 30.47	18.91 24.79
4	2.53- 2.93	30.47 31.90	—	30.47 31.90	24.79 28.71
5	2.93- 3.39	—	33.50 35.22	—	28.71 33.22
6	3.39- 3.84	—	35.22 36.90	—	33.22 37.63
7	3.84- 4.93	46.09 54.03	38.04 41.15	46.09 54.03	33.22 37.63
8	4.93- 5.93	-100.51 -95.27	41.15 44.00	41.15 44.00	33.22 37.63
9	5.93- 5.98	-293.99 -293.65	44.00 44.14	44.00 44.14	33.22 37.63
10	5.98- 6.10	-293.65 -292.82	44.14 44.49	44.14 44.49	400.00 400.68
11	6.10- 6.93	30.46 32.65	—	30.46 32.65	33.22 37.63
12	6.93- 7.93	32.30 34.91	—	32.30 34.91	33.22 37.63
13	7.93- 8.15	35.67 36.25	—	35.67 36.25	33.22 37.63
14	8.15- 8.93	-373.84 -366.10	52.38 55.58	52.38 55.58	33.22 37.63

14	8.15- 8.93	Clay	8.2	—	250.0 250.0	104.76 111.15	79.87 87.51	0.200 0.200	11.31 11.31	—	—	43.85 43.78
15	8.93- 9.93	Clay	8.2	—	180.0 180.0	111.15 119.35	87.51 97.31	0.200 0.200	11.31 11.31	—	—	43.31 43.22
16	9.93- 10.93	Clay	8.2	—	180.0 180.0	119.35 127.55	97.31 107.11	0.200 0.200	11.31 11.31	—	—	43.22 43.10
17	10.93- 11.93	Clay	8.2	—	180.0 180.0	127.55 135.75	107.11 116.91	0.200 0.200	11.31 11.31	—	—	43.10 42.99
18	11.93- 12.93	Clay	8.2	—	250.0 250.0	135.75 143.95	116.91 126.71	0.200 0.200	11.31 11.31	—	—	43.22 43.44
19	12.93- 13.93	Clay	8.2	—	180.0 180.0	143.95 152.15	126.71 136.51	0.200 0.200	11.31 11.31	—	—	42.88 42.76
20	13.93- 14.93	Clay	8.2	—	180.0 180.0	152.15 160.35	136.51 146.31	0.200 0.200	11.31 11.31	—	—	42.76 42.65
21	14.93- 21.98	Clay	8.2	—	250.0 250.0	160.35 218.16	146.31 215.40	0.200 0.200	11.31 11.31	—	—	43.27 42.70
22	21.98- 23.82	Clay	6.7	—	200.0 200.0	218.16 230.49	215.40 233.44	0.200 0.200	11.31 11.31	—	—	42.18 42.03
23	23.82- 35.20	Clay	7.2	—	1000.0 1000.0	230.49 312.43	233.44 344.96	0.200 0.200	11.31 11.31	—	—	48.25 48.13

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{subw} kN/m ²	k (k ²)	θ degree	K_p	$K_p \times \cos \delta$
10	5.98- 6.10	Clay	5.70	0.0	200.0 200.0	0.000 0.684	0.00 1.18	0.200 0.200	11.31 11.31	—	—
11	6.10- 6.93	Sand	7.70	36.9	—	0.684 7.075	1.18 9.31	0.200 0.200	11.31 11.31	3.58567 3.58567	3.58567 3.58567
12	6.93- 7.93	Sand	7.70	37.2	—	7.075 14.775	9.31 19.11	0.200 0.200	11.31 11.31	3.63610 3.63610	3.63610 3.63610
13	7.93- 8.15	Sand	7.70	36.6	—	14.775 16.469	19.11 21.27	0.200 0.200	11.31 11.31	3.53610 3.53610	3.53610 3.53610
14	8.15- 8.93	Clay	8.20	0.0	250.0 250.0	16.469 28.865	21.27 28.91	0.200 0.200	11.31 11.31	—	—
15	8.93- 9.93	Clay	8.20	0.0	180.0 180.0	22.865 31.065	28.91 38.71	0.200 0.200	11.31 11.31	—	—
16	9.93- 10.93	Clay	8.20	0.0	180.0 180.0	31.065 39.265	38.71 48.51	0.200 0.200	11.31 11.31	—	—
17	10.93- 11.93	Clay	8.20	0.0	180.0 180.0	39.265 47.465	48.51 58.31	0.200 0.200	11.31 11.31	—	—
18	11.93- 12.93	Clay	8.20	0.0	250.0 250.0	47.465 55.665	58.31 68.11	0.200 0.200	11.31 11.31	—	—

15	8.93- 9.93	-225.89 -215.94	55.58 59.68	55.58 59.68	33.22 33.22	382.86 391.07
16	9.93- 10.93	-215.94 -205.98	59.68 63.78	59.68 63.78	33.22 33.22	391.07 399.27
17	10.93- 11.93	-205.98 -196.01	63.78 67.88	63.78 67.88	33.22 33.22	399.27 407.46
18	11.93- 12.93	-336.33 -326.39	67.88 71.98	67.88 71.98	33.22 33.22	547.47 555.66
19	12.93- 13.93	-186.03 -176.04	71.98 76.08	71.98 76.08	33.22 33.22	415.67 423.86
20	13.93- 14.93	-176.04 -166.05	76.08 80.18	76.08 80.18	33.22 33.22	423.86 432.07
21	14.93- 21.98	-306.49 -236.17	80.18 109.08	80.18 109.08	33.22 33.22	572.07 629.88
22	21.98- 23.82	-135.63 -120.53	109.08 115.25	109.08 115.25	33.22 33.22	529.88 542.20
23	23.82- 35.20	-1722.87 -1624.08	115.25 156.21	115.25 156.21	33.22 33.22	2142.20 2224.14

- Formula for active earth pressure

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

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

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

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

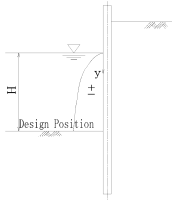
3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	3.39	0.00	0.00
2	4.39	1.00	2.76
3	5.39	2.00	3.90
4	5.98	2.59	4.44

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

Where,
 k_{hw} : design seismic coefficient
 γ_w : unit weight of water
H: water depth of river side

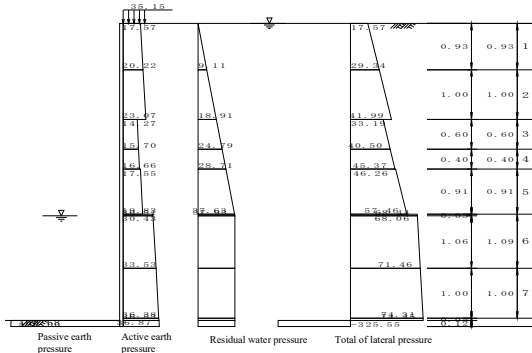
y : depth from water surface to the point where active water pressure is calculated



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



No	Depth, m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00-0.93	17.57 20.22	0.00 9.11	— —	17.57 29.34
2	0.93-1.93	20.22 23.07	9.11 18.91	— —	29.34 41.99

3	1.93-2.53	28.34 30.47	18.91 24.79	— —	47.26 55.27
4	2.53-2.93	30.47 31.90	24.79 28.71	— —	55.27 60.61
5	2.93-3.39	33.30 35.22	28.71 33.22	— —	62.23 68.44
6	3.39-3.84	35.22 36.90	33.22 33.22	— —	68.44 70.12
7	3.84-4.93	46.09 54.03	33.22 33.22	— —	79.31 87.25
8	4.93-5.93	41.15 44.00	33.22 33.22	— —	74.37 77.22
9	5.93-5.98	44.00 44.14	33.22 33.22	— —	77.22 77.37
10	5.98-6.10	44.14 44.49	33.22 33.22	400.00 400.68	-322.63 -322.98

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure Ps = Pa + Pw - Pp

Imaginary riverbed Lk: 0.00 m (GL -5.98 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{\Delta} = K_{\Delta 0} \left(\frac{B_{\Delta}}{0.3} \right)^{-1/4} \quad (B_{\Delta} = 10.00\text{m})$$

$$K_{\Delta 0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_{\Delta} = 2800\text{N}'$$

where:

$$\beta = 4\sqrt{\frac{K_{\Delta} \cdot B}{4 E I}}$$

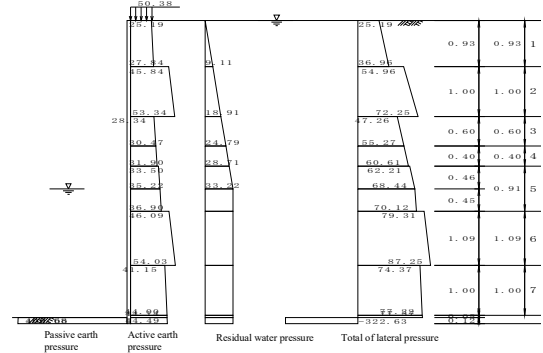
Material Name	10 H 950 -250 -16 -22 -18
Unit width	B = 1.0000 m
Corrosion margin	t ₁ = 1.00 mm (active side) t ₂ = 1.00 mm (passive side)
Corrosion rate	η = 0.86
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 688700 cm ⁴ (original condition)
Inertia sectional moment	I = 592282 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 592282 × 10 ⁻⁸ = 1.185 × 10 ⁶

3	1.93-2.53	14.27 15.70	18.91 24.79	— —	33.19 40.50
4	2.53-2.93	15.70 16.66	24.79 28.71	— —	40.50 45.37
5	2.93-3.39	17.55 19.83	28.71 37.63	— —	46.26 57.46
6	3.84-3.87	30.43 30.51	37.63 37.93	— —	68.06 68.44
7	3.87-4.93	30.51 33.53	37.93 37.93	— —	68.44 71.46
8	4.93-5.93	33.53 36.38	37.93 37.93	— —	71.46 74.31
9	5.93-5.98	36.38 36.53	37.93 37.93	— —	74.31 74.45
10	5.98-6.10	36.53 36.87	37.93 37.93	400.00 400.68	-325.55 -325.89

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure Ps = Pa + Pw - Pp

Imaginary riverbed Lk: 0.00 m (GL -5.98 m)

4.2 Seismic Condition



No	Depth, m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00-0.93	25.19 27.84	0.00 9.11	— —	25.19 36.96
2	0.93-1.93	45.84 53.34	9.11 18.91	— —	54.96 72.25

No	Depth, m	N Value	No	Depth, m	N Value
1	0.43	4	11	10.43	23
2	1.43	2	12	11.43	24
3	2.43	12	13	12.43	32
4	3.43	8	14	13.43	23
5	4.43	4	15	14.43	22
6	5.43	23	16	15.43	50
7	6.43	32			
8	7.43	33			
9	8.43	31			
10	9.43	21			

5.2 Normal Condition

Assuming Kh = 19548 kN/m³,

$$\beta = 4\sqrt{\frac{K_{\Delta} \cdot B}{4 E I}} = 0.253 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.95 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.98 m) to 3.95 m depth (GL -9.93 m).

No	Depth, m	Thickness, h, m	N Value, upper	N Value, lower	Area, A
1	5.98	0.45	28.0	32.0	13.49
2	6.43	1.00	32.0	33.0	32.50
3	7.43	1.00	33.0	31.0	32.00
4	8.43	1.00	31.0	21.0	26.00
5	9.43	0.50	21.0	22.0	10.66
L = Σ h = 3.95			Σ A = 114.65		

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

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

$$= \frac{114.65}{3.95}$$

$$= 29.06$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800\text{N}' = 2800 \times 29.06 = 81354 \text{ kN/m}^2$$

$$K_{\Delta 0} = \frac{1}{0.3} \times \alpha \times 81354 = 271180 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$K_{\Delta} = K_{\Delta 0} (B_{\Delta}/0.3)^{-1/4} = 271180 (10.00/0.3)^{-1/4} = 19548 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 19548 kN/m³.

5.3 Seismic Condition

Assuming Kh = 41150 kN/m3,

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0,305 \text{ m}^{-1}$$
$$L = \frac{1}{\beta} = 3,28 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.98 m) and 3.28 m depth (GL -9.26 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.98	0.45	28.0	32.0	13.40
2	6.43	1.00	32.0	33.0	32.50
3	7.43	1.00	33.0	31.0	32.00
4	8.43	0.83	31.0	22.7	22.19
L = Σh = 3.28					ΣA = 100.18

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

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$
$$= \frac{100,18}{3,28}$$
$$= 30,58$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 30,58 = 85628 \text{ kN/m}^2$$
$$K_{w0} = \frac{1}{0,3} \times \alpha \times 85628 = 570855 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition } =1, \text{ Seismi Condition } =2)$$
$$K_b = K_{w0} (B_u/0,3)^{-3/4} = 570855 (10,00/0,3)^{-3/4} = 41150 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 41150 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth. Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.93	0.93	17.57 29.34	8.17 13.64	5.67 5.36	46.33 73.12

4	2.53- 2.93	0.40	55.27 60.61	11.05 12.12	3.32 3.18	36.66 38.59
5	2.93- 3.39	0.46	62.21 68.44	14.31 15.74	2.90 2.74	41.45 43.18
6	3.39- 3.84	0.45	68.44 70.12	15.40 15.79	2.44 2.29	37.57 36.13
7	3.84- 4.93	1.09	79.31 87.25	43.22 47.55	1.78 1.41	76.79 67.21
8	4.93- 5.93	1.00	74.37 77.22	37.19 38.61	0.72 0.38	26.65 14.80
9	5.93- 5.98	0.05	77.22 77.37	1.93 1.93	0.03 0.02	0.06 0.03
Σ P = 378.10					Σ M = 980.71	

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

depth to acting position

moment

depth to acting position

Height from riverbed to top of coping

Depth of Imaginary riverbed from riverbed

$$P_t = 76.3 \text{ kN/m}$$
$$H_t = 0.00 \text{ m}$$
$$M_m = 58.5 \text{ kN} \cdot \text{m/m}$$
$$H_m = 0.00 \text{ m}$$
$$H = 5.98 \text{ m}$$
$$L_k = 0.00 \text{ m}$$

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 514.77 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure						
No	Depth. Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	3.39- 4.39	1.00	0.0 2.8	0.00 1.38	2.26 1.92	0.00 2.65
2	4.39- 5.39	1.00	2.8 3.9	1.38 1.95	1.26 0.92	1.73 1.80
3	5.39- 5.98	0.59	3.9 4.4	1.15 1.31	0.39 0.20	0.45 0.26
Σ P _{dw} = 7.17					Σ M _{dw} = 6.90	

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}}$$
$$= \frac{1502,39}{461,57} = 3,25 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 461,57}{5,98} = 154,37 \text{ kN/m}$$

2	0.93- 1.93	1.00	29.34 41.99	14.67 20.99	4.72 4.38	69.19 92.02
3	1.93- 2.53	0.60	33.19 40.50	9.96 12.15	3.85 3.65	38.33 44.34
4	2.53- 2.93	0.40	40.50 45.37	8.10 9.07	3.32 3.18	26.86 28.89
5	2.93- 3.84	0.91	46.26 57.46	21.05 26.15	2.75 2.44	57.82 63.88
6	3.84- 3.87	0.03	68.06 68.44	1.02 1.03	2.13 2.12	2.17 2.18
7	3.87- 4.93	1.06	68.44 71.46	36.27 37.87	1.76 1.40	63.72 53.15
8	4.93- 5.93	1.00	71.46 74.31	35.73 37.15	0.72 0.38	25.61 14.24
9	5.93- 5.98	0.05	74.31 74.45	1.86 1.86	0.03 0.02	0.06 0.03
Σ P = 296.75					Σ M = 701.95	

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

depth to acting position

moment

depth to acting position

Height from riverbed to top of coping

Depth of Imaginary riverbed from riverbed

$$P_t = 30.0 \text{ kN/m}$$
$$H_t = 0.0 \text{ m}$$
$$M_m = 0.00 \text{ kN} \cdot \text{m/m}$$
$$H_m = 0.00 \text{ m}$$
$$H = 5.98 \text{ m}$$
$$L_k = 0.00 \text{ m}$$

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 179.40 \text{ kN} \cdot \text{m}$$

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$
$$= \frac{881,35}{326,75} = 2,70 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 326,75}{5,98} = 109,28 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth. Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.93	0.93	25.19 36.96	11.71 17.18	5.67 5.36	66.42 92.11
2	0.93- 1.93	1.00	54.96 72.25	27.48 36.13	4.72 4.38	129.60 158.35
3	1.93- 2.53	0.60	47.26 55.27	14.18 16.58	3.85 3.65	54.58 60.52

6.2 Sectional Force

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

Material name 10 H _ H 950 -250 -16 -22 -18

Unit width B = 1.0000 m

Corrosion margin t_c = 1.00 mm (active side) t₂ = 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 I₀ = 688700 cm⁴ (original condition)

I = 592282 cm⁴ (after reduction by corrosion and section)

$$EI = 200000 \times 10^3 \times 592282 \times 10^{-8} = 1.185 \times 10^6$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$
$$\phi_x = \frac{\sqrt{(1+2 \beta h_0)^2+1}}{2 \beta h_0} \times \exp (-\tan ^{-1} \frac{1}{1+2 \beta h_0})$$
$$M_{\max }=M_0 \cdot \phi_x$$
$$l_n = \frac{1}{\beta} \times \tan ^{-1} \frac{1}{1+2 \beta h_0}$$
$$l_i = \frac{1}{\beta} \times \tan ^{-1} \frac{1+\beta h_0}{\beta h_0}$$
$$M_{(x)} = \frac{P_0}{\beta} \times \exp ^{-\beta x}(\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction

calculated value

resultant earth force (lateral)

height of acting position of load

moment

$$K_b = 19548 \text{ kN/m}^3$$
$$\beta = 0.25344 \text{ m}^{-1}$$
$$P_0 = 326.75 \text{ kN/m}$$
$$h_0 = 2.70 \text{ m}$$
$$M_0 = 881.35 \text{ kN} \cdot \text{m/m}$$

in consideration of ψ_m = 1.260,

maximum moment

depth of generated position of M_{max}

depth of 1st fixed point

$$M_{\max } = 1110.76 \text{ kN} \cdot \text{m/m}$$
$$l_m = 1.577 \text{ m}$$
$$l_i = 4.676 \text{ m}$$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction

calculated value

resultant earth force (lateral)

height of acting position of load

moment

$$K_b = 41150 \text{ kN/m}^3$$
$$\beta = 0.30527 \text{ m}^{-1}$$
$$P_0 = 461.57 \text{ kN/m}$$
$$h_0 = 3.25 \text{ m}$$
$$M_0 = 1502.39 \text{ kN} \cdot \text{m/m}$$

in consideration of ψ_m = 1.148,

maximum moment

depth of generated position of M_{max}

depth of 1st fixed point

$$M_{\max } = 1724.14 \text{ kN} \cdot \text{m/m}$$
$$l_m = 1.058 \text{ m}$$
$$l_i = 3.631 \text{ m}$$

6.3 Stress Intensity

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

Material Name	10 H _H 950 -250 -16 -22 -18
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 = 10570 cm ³ (original condition)
	Z = 9302 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

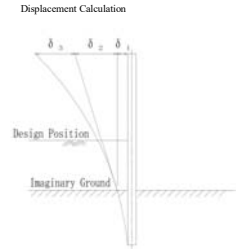
σ = M_{max} / Z = (1110.76 × 10⁵) / (9302 × 10³) = 119 N/mm² ≤ σ_s = 180 N/mm²

6.3.2 Seismic Condition

σ = M_{max} / Z = (1724.14 × 10⁵) / (9302 × 10³) = 185 N/mm² ≤ σ_s = 270 N/mm²

6.4 Displacement Calculation

6.4.1 Normal Condition

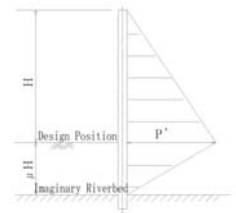


δ₁ = ((1 + β h₀) × P₀) / (2 E I β³) = ((1 + 0.2534 × 2.70) × 326.75) / (2 × 2.00 × 10⁹ × 592282 × 10⁻⁸ × 0.2534³) = 0.01426 m

δ₂ = ((1 + 2 β h₀) × P₀) / (2 E I β³) × (H + L_i) = ((1 + 2 × 0.2534 × 2.70) × 326.75) / (2 × 2.00 × 10⁹ × 592282 × 10⁻⁸ × 0.2534³) × (5.98 + 0.00) = 0.03040 m

δ₁ = ((1 + β h₀) × P₀) / (2 E I β³) = ((1 + 0.3053 × 3.25) × 461.57) / (2 × 2.00 × 10⁹ × 592282 × 10⁻⁸ × 0.3053³) = 0.01365 m

δ₂ = ((1 + 2 β h₀) × P₀) / (2 E I β³) × (H + L_i) = ((1 + 2 × 0.3053 × 3.25) × 461.57) / (2 × 2.00 × 10⁹ × 592282 × 10⁻⁸ × 0.3053³) × (5.98 + 0.00) = 0.03735 m



μ = L_k / H = 0.00 / 5.98 = 0.000

δ₃ = (P' H⁴) / (120 E I) × (4 + 20 μ + 40 μ² + 35 μ³ + 11 μ⁴) = (154.37 × 5.98⁴) / (120 × 2.00 × 10⁹ × 592282 × 10⁻⁸) × (4 + 20 × 0.000 + 40 × 0.000² + 35 × 0.000³ + 11 × 0.000⁴) = 0.00556 m

δ = δ₁ + δ₂ + δ₃ = 0.01365 + 0.03735 + 0.00556 = 0.05656 m

Size = 56.56 ≤ δ_a = 75.00 mm

Where,

δ₁ : Displacement at imaginary ground

δ₂ : Displacement by angle of inclination slope at imaginary ground

δ₃ : Displacement at higher part of imaginary ground as cantilever

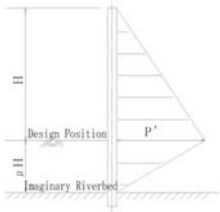
δ : Displacement at top of SSP

δ_a : Allowable displacement

7 Penetration Depth

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

Material Name	10 H _H 950 -250 -16 -22 -18
Unit width	B = 1.0000 m
Corrosion rate	η = 1.00
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²



μ = L_k / H = 0.00 / 5.98 = 0.000

δ₃ = (P' H⁴) / (120 E I) × (4 + 20 μ + 40 μ² + 35 μ³ + 11 μ⁴) = (109.28 × 5.98⁴) / (120 × 2.00 × 10⁹ × 592282 × 10⁻⁸) × (4 + 20 × 0.000 + 40 × 0.000² + 35 × 0.000³ + 11 × 0.000⁴) = 0.00393 m

δ = δ₁ + δ₂ + δ₃ = 0.01426 + 0.03040 + 0.00393 = 0.04859 m

Size = 48.59 ≤ δ_a = 50.00 mm

Where,

δ₁ : Displacement at imaginary ground

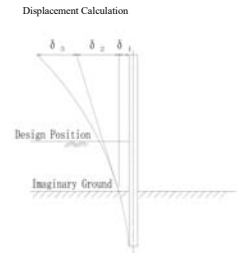
δ₂ : Displacement by angle of inclination slope at imaginary ground

δ₃ : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6.4.2 Seismic Condition



Inertia sectional moment	I ₀ = 688700 cm ⁴ (original condition)
	I = 688700 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 688700 × 10 ⁻⁸	= 1.377 × 10 ⁸

7.1 Penetration Depth and Whole Length of SSP (Chang)

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

D = L_i + 3 / β

L = H - H_{li} + D

β = √[(K_b × B) / (4 E I)]

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _b = 19548 kN/m ³
Calculated value	β = 0.24406 m ⁻¹
Penetration length of SSP	D = 0.00 + 3 / 0.244 = 12.29 m
Whole length of SSP	L = 5.98 - 0.40 + 12.29 = 17.87 m

7.1.1 Seismic Condition

Modules of lateral subgrade reaction	K _b = 41150 kN/m ³
Calculated value	β = 0.29398 m ⁻¹
Penetration length of SSP	D = 0.00 + 3 / 0.294 = 10.20 m
Whole length of SSP	L = 5.98 - 0.40 + 10.20 = 15.78 m

Therefore, the total length of the sheet pile is 18.00 m from the rounded length value of 0.50 m.

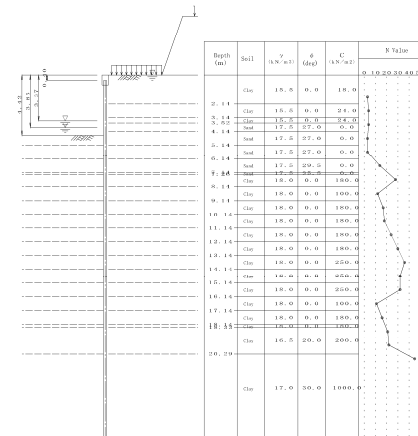
8 Calculation Result

SSP		10 H _H 950 -250 -16 -22 -18		Normal Condition	Seismic Condition
Inertia sectional moment	I	(cm ⁴)	688700		
Sectional Modulus	Z	(cm ³)	10570		
Maximum bending moment	M _{max}	(kN · m · m)		1110.76	1724.14
Stress intensity	σ	(N/mm ²)		119 (180)	185 (270)
Lateral displacement	δ	(mm)		48.59 (50.0)	56.56 (75.0)
Penetration depths	D	(m)		12.29	10.20
Whole length of SSP	L	(m)	18.00		

Block No. : L-15
Sta. : 9+800-9+900
Design Cross Section : Sta 9+820
Boring Name : BMLL-28
Specification : SSP SP-25H
(Combined) : H 1000-250-16-25-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 4.42$ m
Depth from coping top to rear side ground $H_b = 0.00$ m
Depth from coping top to SSP top $H_c = 0.40$ m
Landside WL $L_{ss} = 0.00$ m (Normal Condition)
 $L_{ss} = 0.00$ m (Seismic Condition)
Riverside WL $L_{sp} = 3.85$ m (Normal Condition)
 $L_{sp} = 3.37$ m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress
Penetration depths $L = \frac{P}{\beta}$

1.4 Design Constant

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 $P_h = 30.0$ kN/m (Normal Condition)
 $P_h = 76.3$ kN/m (Seismic Condition)
Depth of acting point $H_b = 0.0$ m (Normal Condition)
 $H_b = 0.0$ m (Seismic Condition)
Moment $M_a = 0.00$ kN·m/m (Normal Condition)
 $M_a = 58.5$ kN·m/m (Seismic Condition)
Depth of acting point $H_a = 0.00$ m (Normal Condition)
 $H_a = 0.00$ m (Seismic Condition)
(Depth means distance from top of coping)

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_a = 10$ degrees

Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1} \left(\frac{E \gamma \sin \theta}{2C} \right) + \tan \theta$

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

1.5 Modulus of Lateral Subgrade Reaction

Applied formula
 $K_{ul} = K_{ul} \left(\frac{B_u}{0.3} \right)^{1/4}$
 $K_{ul} = \frac{1}{0.3} \alpha E_s$ (α : Normal Condition =1, Seismic Condition =2)
 $B_u = 10.00$ m
 $E_s = 2800$ N

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	1.64	3	11	11.64	24
2	2.64	4	12	12.64	30
3	3.64	4	13	13.64	36
4	4.64	3	14	14.64	32
5	5.64	3	15	15.64	32
6	6.64	14	16	16.64	11
7	7.64	28	17	17.64	36
8	8.64	12	18	18.64	21
9	9.64	17	19	19.64	22
10	10.64	18	20	20.64	45

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 Modulus (kN/m ²)	Thickness (m)
1	2.14	2.14	2.14
2	3.14	1.00	1.00
3	3.52	0.38	0.38
4	4.14	0.62	0.62
5	5.14	1.00	1.00
6	6.14	1.00	1.00
7	7.14	1.00	1.00
8	7.56	0.12	0.12
9	8.14	0.11	0.11
10	9.14	1.00	1.00
11	10.14	1.00	1.00
12	11.14	1.00	1.00
13	12.14	1.00	1.00
14	13.14	1.00	1.00
15	14.14	1.00	1.00
16	15.14	1.00	1.00
17	16.14	1.00	1.00
18	17.14	1.00	1.00
19	18.14	1.00	1.00
20	19.25	0.19	0.19
21	20.25	1.00	1.00
22	21.25	4.91	4.91

No	Depth (m)	Soil Modulus (kN/m ²)	γ (kN/m ³)	γ' (kN/m ³)	ϕ (deg)	C (kN/m ²)	α	k ⁻¹	ζ (degrees)	Normal Condition	Seismic Condition
1	2.14	2.14	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto
2	3.14	1.00	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto
3	3.52	0.38	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto
4	4.14	0.62	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto
5	5.14	1.00	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto
6	6.14	1.00	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto
7	7.14	1.00	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto
8	7.56	0.12	18.0	16.0	0.0	0.00	0.200	Auto	Auto	Auto	Auto

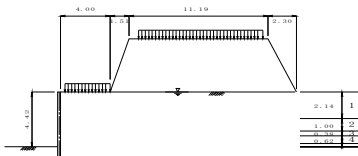
9	8.14	C	25.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
10	9.14	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
11	10.14	C	17.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
12	11.14	C	18.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
13	12.14	C	24.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
14	13.14	C	30.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
15	14.14	C	36.0	18.00	8.20	0.0	200.0	0.0	0.200	Asat	Asat
16	15.14	C	12.0	18.00	8.20	0.0	200.0	0.0	0.200	Asat	Asat
17	16.14	C	22.0	18.00	8.20	0.0	200.0	0.0	0.200	Asat	Asat
18	17.14	C	11.0	18.00	8.20	0.0	200.0	0.0	0.200	Asat	Asat
19	18.14	C	16.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
20	19.14	C	21.0	18.00	8.20	0.0	100.0	0.0	0.200	Asat	Asat
21	20.14	C	41.5	16.50	6.70	20.0	200.0	0.0	0.200	Asat	Asat
22	21.20	C	12.0	17.00	7.20	100.0	1000.0	0.0	0.200	Asat	Asat

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_u : 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 Condition	Seismic Condition
Active Pressure	15.00 °	10.00 °
	15.00 °	10.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No.	Soil	Backfill	Top Layer	Bottom Layer	h	Normal Condition	Seismic Condition	ϕ	ζ	Normal Condition	Seismic Condition
		Soil	m	m	m	kN/m ²	kN/m ²	degree	degree	degree	degree
1	Sand	4.00	5.51	16.78	10.00	4.20	10.0	10.0	15.0	0.0	Asat

Surcharge load acting on embankment

No.	Soil	Top Layer	Bottom Layer	h	Normal Condition	Seismic Condition
		m	m	m	kN/m ²	kN/m ²
1	Sand	4.00	5.51	16.78	10.0	4.20
2	Sand	4.00	5.51	16.78	10.0	4.20

Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

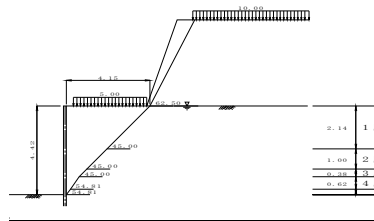
Material name : 25 H H 1000 250 -16 -25 -18
Young's modulus : $E = 200000 \text{ N/mm}^2$
Inertia sectional moment : $I_x = 935900 \text{ cm}^4$
Sectional factor : $Z_x = 12990 \text{ cm}^3$
Corrosion margin : $t_c = 1.00 \text{ mm}$ (riverside) $t_c = 1.00 \text{ mm}$ (landside)
Corrosion rate (to I_x) : $\eta = 0.87$
Corrosion rate (to Z_x) : $\eta = 0.89$
Section efficiency (to I_x) : $\mu = 1.00$
Section efficiency (to Z_x) : $\mu = 1.00$
Round unit of SSP length : 0.50 m
Allowable stress : $\sigma_a = 180 \text{ N/mm}^2$ (Normal)
 $\sigma'_a = 270 \text{ N/mm}^2$ (Seismic)
Allowable displacement : $\delta_a = 50.0 \text{ mm}$ (Normal)
 $\delta'_a = 75.0 \text{ mm}$ (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

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

2 Calculation of Acting Load

2.1 Normal Condition



2.1.1 Angle of Active Rupture

No.	Depth	Soil	ϕ	δ	C	$\Sigma \gamma \times h$	Q	γ value	Angle of Rupture
	m		degree	degree	kN/m ²	kN/m ²	kN/m ²	degree	degree
1	4.00-4.14	Sand	27.0	15.0	0.0	20.00	14.22	94.12	54.18
2	4.14-4.27	Sand	27.0	15.0	0.0	20.00	14.22	94.12	54.18
3	4.27-4.41	Clay	0.0	15.0	24.0	30.00	14.22	54.18	45.00
4	4.41-4.54	Clay	0.0	15.0	24.0	30.00	14.22	54.18	45.00
5	4.54-4.68	Clay	0.0	15.0	24.0	30.00	14.22	54.18	45.00
6	4.68-4.82	embankment	15.0	0.0	0.0	77.22	10.00	0.00	62.50

• Angle of active rupture of sandy soil

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

• Angle of active rupture of clayey soil

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

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

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)

2.1.2 Coordinates of Collapse Line

No.	Angle of Rupture	Thickness	bottom coordinate	top coordinate
	degree	m	X(m)	Y(m)
1	54.18	0.29	0.00	0.29
2	54.18	0.62	0.29	0.62
3	45.00	0.20	0.62	0.90
4	45.00	0.20	0.62	0.90
5	45.00	0.20	0.62	0.90
6	62.50	0.29	0.90	1.19

From the above table, the leading width (L) on the ground surface is 4.15 m.

2.1.3 Acting Load by Embankment

No.	γ	A	$\gamma \times A$
	kN/m ³	m ²	kN/m
1	18.0	2.21	39.97

Σ	39.97

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	L	$Q \times L$
	kN/m ²	m	kN/m
1	10.0	0.10	0.98
2	5.0	1.05	5.25
Σ			6.23

Q : width of surcharge load act by line of active rupture
 L : leading width of uniform load surrounded by main collapse line

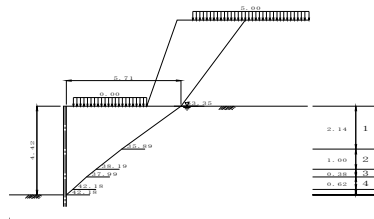
2.1.5 Calculated Load

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

$$= \frac{39.97 + 19.23 + 0.00}{4.15}$$

$$= 14.22 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No.	Depth	Soil	ϕ	δ	C	$\Sigma \gamma \times h$	Q	γ value	k	θ	Angle of Rupture
	m		degree	degree	kN/m ²	kN/m ²	kN/m ²	degree	degree	degree	degree
1	4.42-4.14	Sand	27.0	15.0	0.0	30.00	36.77	94.12	0.200	11.31	62.18
2	4.14-4.27	Sand	27.0	15.0	0.0	30.00	36.77	94.12	0.200	11.31	62.18
3	4.27-4.41	Clay	0.0	15.0	24.0	30.00	36.77	54.18	0.200	11.31	57.99
4	4.41-4.54	Clay	0.0	15.0	24.0	30.00	36.77	54.18	0.200	11.31	57.99

5	2.14-8.89	Clay	9.0	15.0	19.0	22.20	36.77	28.97	8.200	11.31	35.89
6		embankment	15.0	—	0.0	77.22	5.89	0.00	8.200	11.31	35.39

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

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

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)
- b : thickness of layer (m)
- Q : surcharge load (kN/m²)
- C : cohesive c force of soil (kN/m²)

2.2.2 Coordinates of Collapse Line

No	Angle of Rupture, ζ, degree	Thickness, z, m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	8.29	0.00	0.00	0.31	8.29
2	42.18	8.62	0.31	8.29	0.99	8.96
3	37.89	8.58	0.99	0.99	1.48	1.28
4	38.19	1.06	1.48	1.28	2.75	2.29
5	39.89	2.14	2.75	2.28	5.73	6.42
6	33.33	8.29	5.73	6.42	6.96	6.73

From the above table, the loading width (L) on the ground surface is 5.73 m.

2.2.3 Acting Load by Embankment

No	γ, kN/m ³	A, m ²	γ × A, kN/m
1	18.8	10.84	198.87
2			198.87

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	γ, m	Qγ, kN/m
1	5.0	5.63	28.18

5	3.82-4.14	Sand	7.7	27.0	—	36.829	0.3378	0.3389	39.862	0.3378	0.3389
6	4.14-6.42	Sand	7.7	27.0	—	39.862	0.3378	0.3389	41.218	0.3378	0.3389
7	4.42-5.14	Sand	7.7	27.0	—	41.218	0.3378	0.3389	46.762	0.3378	0.3389
8	5.14-6.14	Sand	7.7	27.0	—	46.762	0.3378	0.3389	54.462	0.3378	0.3389
9	6.14-7.14	Sand	7.7	28.5	—	54.462	0.33720	0.28614	62.162	0.24280	0.21612
10	7.14-7.28	Sand	7.7	18.5	—	62.162	0.24280	0.21612	63.588	0.24280	0.21612
11	7.28-8.14	Clay	8.2	—	188.0	63.588	—	—	68.762	—	—
12	8.14-8.14	Clay	8.2	—	188.0	70.382	—	—	70.382	—	—
13	8.14-10.14	Clay	8.2	—	188.0	70.382	—	—	70.382	—	—
14	10.14-11.14	Clay	8.2	—	188.0	80.762	—	—	80.762	—	—
15	11.14-12.14	Clay	8.2	—	188.0	89.382	—	—	89.382	—	—
16	12.14-13.14	Clay	8.2	—	188.0	103.382	—	—	103.382	—	—
17	13.14-14.14	Clay	8.2	—	270.0	111.382	—	—	111.382	—	—
18	14.14-15.14	Clay	8.2	—	270.0	119.382	—	—	119.382	—	—
19	15.14-16.14	Clay	8.2	—	270.0	127.762	—	—	127.762	—	—
20	16.14-17.14	Clay	8.2	—	188.0	137.962	—	—	137.962	—	—
21	17.14-18.14	Clay	8.2	—	188.0	146.382	—	—	146.382	—	—
22	18.14-18.31	Clay	8.2	—	188.0	152.382	—	—	152.382	—	—
23	18.31-20.29	Clay	6.7	—	280.0	157.888	—	—	160.982	—	—
24	20.29-22.20	Clay	7.2	—	1880.0	160.982	—	—	162.144	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= -15.00, β= 0.00, θ= 0.00

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ, kN/m ³	δ, degree	C', kN/m ²	Σ γ × h / Qp, kN/m ²	Kp, × cos δ	Kp, × cos δ
5	4.42-5.14	Sand	7.7	27.0	—	0.000	4.26889	4.11361

2	0.0	1.05	0.00
3			13.85

Q : width of surcharge load act by line of active rupture

1: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

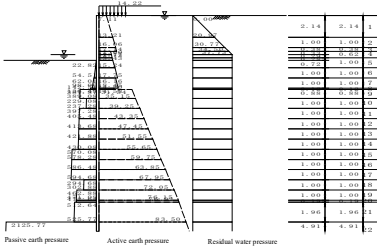
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{196.87 + 13.05 + 0.00}{5.71}$$

$$= 36.77 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ, kN/m ³	δ, degree	C', kN/m ²	Σ γ × Qp, kN/m ²	Ka, × cos δ	Ka, × cos δ
1	0.00-2.14	Clay	5.7	—	18.0	14.224	—	—
2	2.14-3.14	Clay	5.7	—	24.0	26.422	—	—
3	3.14-3.12	Clay	8.7	—	24.0	32.122	—	—
4	3.12-3.85	Sand	7.7	27.0	—	34.288	0.33789	0.33789

8	5.14-6.14	Sand	7.7	27.0	—	5.544	4.26889	4.11361
9	6.14-7.14	Sand	7.7	28.5	—	13.244	0.87132	0.88336
10	7.14-7.28	Sand	7.7	18.5	—	20.844	0.74695	0.53786
11	7.28-8.14	Clay	8.2	0.0	188.0	21.888	—	—
12	8.14-9.14	Clay	8.2	0.0	188.0	29.884	—	—
13	9.14-10.14	Clay	8.2	0.0	188.0	37.264	—	—
14	10.14-11.14	Clay	8.2	0.0	188.0	45.484	—	—
15	11.14-12.14	Clay	8.2	0.0	188.0	53.684	—	—
16	12.14-13.14	Clay	8.2	0.0	188.0	61.884	—	—
17	13.14-14.14	Clay	8.2	0.0	270.0	70.084	—	—
18	14.14-15.14	Clay	8.2	0.0	270.0	78.284	—	—
19	15.14-16.14	Clay	8.2	0.0	270.0	86.484	—	—
20	16.14-17.14	Clay	8.2	0.0	188.0	94.684	—	—
21	17.14-18.14	Clay	8.2	0.0	188.0	102.884	—	—
22	18.14-18.31	Clay	8.2	0.0	188.0	111.084	—	—
23	18.31-20.29	Clay	6.7	20.0	280.0	112.642	—	—
24	20.29-22.20	Clay	7.2	20.0	1880.0	123.774	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
δ= -15.00, β= 0.00, θ= 0.00

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

3.1.3 Lateral Forth

No	Depth, m	Soil	P12, kN/m ²	P2, kN/m ²	P3, kN/m ²	P4, kN/m ²	Water pressure, kN/m ²
1	0.00-2.14	—	-21.78	-9.28	13.21	11.21	0.00
2	2.14-3.14	—	-23.88	-13.21	14.80	16.86	36.97

3	3.18- 5.52	15.83 27.73	16.86 27.73	16.86 27.73	30.77 44.66	-----
4	3.52- 5.85	11.17 12.88	11.17 12.88	11.17 12.88	34.96 37.73	-----
5	3.85- 6.18	12.88 12.73	-----	12.88 12.73	37.73 37.73	-----
6	4.18- 6.52	12.73 12.45	-----	12.73 12.45	37.73 37.73	-----
7	4.52- 6.18	12.45 13.24	-----	12.45 13.24	37.73 37.73	0.00 22.82
8	5.18- 6.18	15.24 17.73	-----	15.24 17.73	37.73 37.73	22.82 44.61
9	6.18- 7.14	16.24 16.45	-----	16.24 16.45	37.73 37.73	42.81 46.86
10	7.18- 7.26	14.24 14.85	-----	14.24 14.85	37.73 37.73	136.49 142.51
11	7.26- 8.14	-296.35 -297.76	31.34 30.15	31.34 30.15	37.73 37.73	381.87 399.08
12	8.18- 9.14	-129.76 -131.56	30.15 30.25	30.15 30.25	37.73 37.73	329.08 337.28
13	9.18- 10.14	-281.56 -273.36	30.25 40.31	30.25 40.31	37.73 37.73	307.28 405.48
14	10.18- 11.14	-273.36 -268.36	40.31 47.45	40.31 47.45	37.73 37.73	405.48 431.68
15	11.18- 12.14	-268.36 -256.36	47.45 51.51	47.45 51.51	37.73 37.73	431.68 421.88
16	12.18- 13.14	-256.36 -246.76	51.51 55.65	51.51 55.65	37.73 37.73	421.88 409.08
17	13.18- 14.14	-246.76 -188.36	55.65 59.71	55.65 59.71	37.73 37.73	409.08 378.28
18	14.18- 15.14	-188.36 -172.36	59.71 65.81	59.71 65.81	37.73 37.73	378.28 356.48
19	15.18- 16.14	-172.36 -164.36	65.81 67.95	65.81 67.95	37.73 37.73	356.48 350.68
20	16.18- 17.14	-164.36 -85.96	67.95 72.01	67.95 72.01	37.73 37.73	350.68 302.88
21	17.18- 18.14	-85.96 -207.76	72.01 76.15	72.01 76.15	37.73 37.73	302.88 421.08
22	18.18- 19.13	-207.76 -206.14	76.15 76.91	76.15 76.91	37.73 37.73	421.08 472.64
23	19.13- 20.29	-206.14 -211.61	76.91 82.50	76.91 82.50	37.73 37.73	472.64 522.77
24	20.29- 21.29	-211.61 -207.68	82.50 101.17	82.50 101.17	37.73 37.73	522.77 2481.13

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(\phi - \beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a - Equilibrium coefficient of compression; 0.5
Larger of P_{a1} or P_{a2} is applied as active earth pressure (P_a)

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

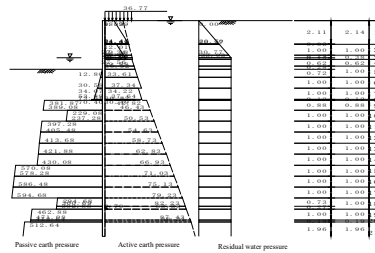
- Formula for passive earth pressure

$$\text{Sand } P_{p1} = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(\phi - \beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{p1} = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_{p1} = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ , kN/m ³	ϕ , degrees	C , kN/m ²	$\Sigma \gamma h + Q$, kN/m ²	$\gamma \cdot \tan \delta$, kN/m ²	δ , degrees	K_a	$K_a \cdot \cos \delta$	ζ , degrees
1	0.00-2.11	Clay	5.7	-----	18.0	36.78	0.00	0.200	11.31	-----	37.56
2	2.11-2.14	Clay	5.7	-----	18.0	40.07	39.97	0.200	11.31	-----	35.89
3	2.14-2.14	Clay	5.7	-----	24.0	40.07	39.97	0.200	11.31	-----	35.75
4	2.14-5.14	Clay	5.7	-----	24.0	54.07	39.77	0.200	11.31	-----	35.19
5	5.14-5.32	Clay	5.7	-----	24.0	57.58	35.85	0.200	11.31	-----	35.07
6	5.32-7.14	Sand	7.7	27.0	-----	56.84	34.98	0.200	11.31	0.50201	0.40400
7	7.14-8.14	Sand	7.7	27.0	-----	65.41	40.32	0.200	11.31	0.50201	0.40400
8	8.14-9.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
9	9.14-10.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
10	10.14-11.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
11	11.14-12.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
12	12.14-13.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
13	13.14-14.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
14	14.14-15.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
15	15.14-16.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
16	16.14-17.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
17	17.14-18.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
18	18.14-19.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
19	19.14-20.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
20	20.14-21.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
21	21.14-22.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
22	22.14-23.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
23	23.14-24.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
24	24.14-25.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
25	25.14-26.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
26	26.14-27.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
27	27.14-28.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
28	28.14-29.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
29	29.14-30.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
30	30.14-31.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
31	31.14-32.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
32	32.14-33.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
33	33.14-34.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
34	34.14-35.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
35	35.14-36.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
36	36.14-37.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
37	37.14-38.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
38	38.14-39.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
39	39.14-40.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
40	40.14-41.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
41	41.14-42.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
42	42.14-43.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
43	43.14-44.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
44	44.14-45.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
45	45.14-46.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
46	46.14-47.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
47	47.14-48.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
48	48.14-49.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
49	49.14-50.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
50	50.14-51.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
51	51.14-52.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
52	52.14-53.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
53	53.14-54.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
54	54.14-55.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
55	55.14-56.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
56	56.14-57.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
57	57.14-58.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
58	58.14-59.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
59	59.14-60.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
60	60.14-61.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
61	61.14-62.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
62	62.14-63.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
63	63.14-64.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
64	64.14-65.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
65	65.14-66.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
66	66.14-67.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
67	67.14-68.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
68	68.14-69.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
69	69.14-70.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
70	70.14-71.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
71	71.14-72.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400
72	72.14-73.14	Sand	7.7	27.0	-----	65.77	41.32	0.200	11.31	0.50201	0.40400

3	2.18- 3.14	12.01 19.15	24.49 27.34	28.49 27.54	28.97 30.97	-----
4	3.14- 3.37	18.16 24.94	27.14 27.89	27.54 27.99	30.77 33.03	-----
5	3.37- 3.52	24.84 21.55	27.89 26.42	27.99 26.42	33.03 33.03	-----
6	3.52- 4.14	27.56 26.89	-----	27.56 26.89	33.03 33.03	-----
7	4.14- 4.42	29.68 30.52	-----	29.68 30.52	33.03 33.03	-----
8	4.42- 5.14	30.52 33.61	-----	30.52 33.61	33.03 33.03	0.00 12.89
9	5.14- 6.14	33.61 37.54	-----	33.61 37.54	33.03 33.03	12.89 36.53
10	6.14- 7.14	34.22 37.64	-----	34.22 37.64	33.03 33.03	34.07 53.83
11	7.14- 7.26	36.49 36.52	-----	36.49 36.52	33.03 33.03	70.49 75.51
12	7.26- 8.14	326.65 -248.12	42.82 46.41	42.82 46.41	33.03 33.03	363.97 389.08
13	8.14- 9.14	47.72 -77.72	46.41 36.53	46.41 36.53	33.03 33.03	329.09 257.28
14	9.14- 10.14	-238.26 -238.27	56.53 54.65	56.53 54.65	33.03 33.03	397.28 405.48
15	10.14- 11.14	-229.27 -238.34	54.65 58.73	54.65 58.73	33.03 33.03	405.48 413.68
16	11.14- 12.14	-238.34 -238.46	58.73 62.83	58.73 62.83	33.03 33.03	413.68 421.89
17	12.14- 13.14	-238.46 -198.46	62.83 66.93	62.83 66.93	33.03 33.03	421.89 430.09
18	13.14- 14.14	-198.46 -128.46	66.93 71.03	66.93 71.03	33.03 33.03	430.09 438.28
19	14.14- 15.14	-128.46 -138.46	71.03 75.13	71.03 75.13	33.03 33.03	438.28 446.48
20	15.14- 16.14	-138.46 -188.46	75.13 79.23	75.13 79.23	33.03 33.03	446.48 454.68
21	16.14- 16.87	-7.46 6.89	79.23 82.23	79.23 82.23	33.03 33.03	294.68 300.09
22	16.87- 17.14	0.00 2.76	82.23 83.33	82.23 83.33	33.03 33.03	300.09 302.88
23	17.14- 18.14	-198.46 -146.42	83.33 87.43	83.33 87.43	33.03 33.03	402.88 471.08
24	18.14- 19.33	-146.42 -146.73	87.43 88.23	87.43 88.23	33.03 33.03	471.08 472.64
25	19.33- 20.29	-146.73 -176.02	88.23 94.77	88.23 94.77	33.03 33.03	472.64 522.77
26	20.29- 22.20	-176.02 -172.24	94.77 94.77	94.77 94.77	33.03 33.03	522.77 2125.77
27	22.20- 22.20	-172.24 -172.24	94.77 94.77	94.77 94.77	33.03 33.03	2125.77 2168.13

• Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of P_{a1} or P_{a2} is applied as active earth pressure (P_a)

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

• Formula for passive earth pressure

Sand $P_{p1} = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{p1} = \Sigma \gamma h + Q + 2C$
Mixed soil $P_{p1} = \left[K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p} \right] \cdot \cos \delta$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth z m	water level y m	p kN/m ²
1	3.37	0.00	0.00
2	4.37	1.00	1.76
3	4.42	1.03	1.80

$$p_{aw} = \pm \frac{7}{8} k_{aw} \gamma_w \sqrt{H' \cdot \gamma}$$

Where,

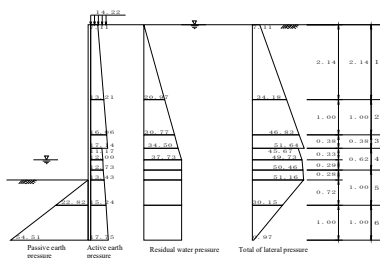
k_{aw} : design seismic coefficient
 γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



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

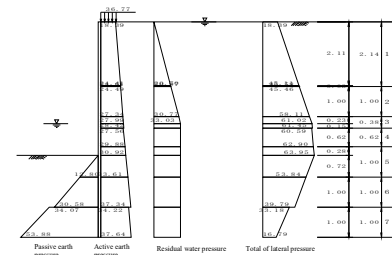


No	Depth z m	P_a kN/m ²	P_w kN/m ²	P_t kN/m ²
1	0.00- 2.14	7.11 13.21	0.00 20.97	7.11 34.18
2	2.14- 3.14	13.21 16.86	20.97 30.77	34.18 46.63
3	3.14- 3.52	16.86 17.14	30.77 34.96	46.63 51.84
4	3.52- 4.42	17.14 22.89	34.96 37.73	51.84 60.63
5	4.42- 6.14	22.89 12.89	37.73 33.73	60.63 46.63
6	6.14- 7.14	12.89 13.43	33.73 37.73	46.63 51.16
7	7.14- 8.14	13.43 15.29	37.73 37.73	51.16 55.02
8	8.14- 9.14	15.29 17.73	37.73 34.51	55.02 52.24
9	9.14- 10.14	17.73 16.97	34.51 30.00	52.24 46.97

P_a : Active earth pressure
 P_w : Residual water pressure
 P_t : Passive earth pressure
 $P_t = P_a + P_w + P_w$

Imaginary riverbed Lk: 1.72 m (GL -6.14 m)

4.2 Seismic Condition



No	Depth z m	P_a kN/m ²	P_w kN/m ²	P_t kN/m ²
1	0.00- 2.14	18.19 24.61	0.00 20.97	18.19 45.58
2	2.14- 3.14	24.61 24.61	20.97 30.77	45.58 55.38
3	3.14- 3.52	24.61 27.34	30.77 35.73	55.38 63.11
4	3.52- 4.42	27.34 31.07	35.73 37.73	63.11 68.80
5	4.42- 6.14	31.07 20.80	37.73 33.73	68.80 54.53
6	6.14- 7.14	20.80 21.44	33.73 37.73	54.53 59.17
7	7.14- 8.14	21.44 23.61	37.73 37.73	59.17 61.34
8	8.14- 9.14	23.61 25.80	37.73 34.51	61.34 56.31
9	9.14- 10.14	25.80 25.80	34.51 30.00	56.31 46.31
10	10.14- 11.14	25.80 25.80	30.00 25.80	46.31 46.31
11	11.14- 12.14	25.80 25.80	25.80 25.80	46.31 46.31

P_a : Active earth pressure
 P_w : Residual water pressure
 P_t : Passive earth pressure
 $P_t = P_a + P_w + P_w$

Imaginary riverbed Lk: 2.72 m (GL -7.14 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_u = K_{u0} \left(\frac{B_u}{0.3} \right)^{-0.4} \quad (B_u=10.0m)$$
$$K_{u0} = \frac{1}{0.3} \alpha E_s \quad (\alpha \text{ : Normal Condition } +1, \text{ Seimi Condition } +2)$$
$$E_s = 2800 N^2$$

where:

$$\beta = 4 \sqrt[4]{\frac{K_u \cdot B}{4 E I}}$$

Material Name	B	25 H_H 1000-250-16-25-18
Unit width	t ₁	= 1.0000 m
Corrosion margin	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	= 935900 cm ⁴ (original condition)
Inertia sectional moment	I	= 814233 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	= 200000 × 10 ³ × 814233 × 10 ⁴ = 1.628 × 10 ⁸

No.	Depth Z m	N-Value N	No.	Depth Z m	N-Value N
1	1.64	7	11	11.64	24
2	2.64	12	12	12.64	30
3	3.64	4	13	13.64	36
4	4.64	5	14	14.64	32
5	5.64	7	15	15.64	32
6	6.64	14	16	16.64	31
7	7.64	28	17	17.64	35
8	8.64	12	18	18.64	21
9	9.64	17	19	19.64	22
10	10.64	19	20	20.64	45

5.2 Normal Condition

Assuming $K_h = 11830 \text{ kN/m}^2$,

$$\beta = 4 \sqrt[4]{\frac{K_u \cdot B}{4 E I}} = 0.206 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.84 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.14 m) to 4.84 m depth (GL -10.98 m).

$$= \frac{74.45}{4.02}$$
$$= 18.51$$

K_h is recalculated from the calculated average N-value.

$$E_s = 2800 N^2 = 2800 \times 18.51 = 51837 \text{ kN/m}^2$$
$$K_{u0} = \frac{1}{0.3} \times \alpha \times 51837 = 345583 \text{ kN/m}^2 \quad (\alpha \text{ : Normal Condition } +1, \text{ Seimi Condition } +2)$$
$$K_u = K_{u0} (B_u/0.3)^{-0.4} = 345583 (10.00/0.3)^{-0.4} = 24911 \text{ kN/m}^2$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 24911 kN/m².

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No.	Depth Z m	Thickness b m	Lateral Forth P ₀ kN/m ²	Loads P kN	Actn length Y m	Moment M kN · m
1	0.00~ 2.14	2.14	7.11 36.38	7.61 36.38	8.41 6.75	41.39 172.39
2	2.14~ 3.14	1.00	36.38 46.51	17.89 23.42	3.67 3.11	62.67 79.05
3	3.14~ 5.52	0.38	46.51 71.65	8.89 8.91	2.67 2.75	25.57 26.89
4	5.52~ 6.52	0.33	46.51 46.73	7.14 8.21	2.51 2.49	18.91 19.69
5	6.52~ 8.14	0.29	46.73 36.46	7.21 7.12	2.18 2.19	15.82 15.54
6	8.14~ 9.42	0.28	36.46 51.38	7.86 7.16	1.91 1.83	12.47 12.99
7	9.42~ 1.14	0.72	51.38 30.15	18.42 18.93	1.46 1.24	27.26 13.46
8	1.14~ 6.14	1.00	30.15 9.97	15.88 8.49	0.67 0.97	10.05 8.09
Σ P = 192.75 Σ M = 554.08						

P_0 : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_0 \times b/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load P_0 = 30.0 kN/m

No.	Depth Z m	Thickness b m	N-Value		Area A
			upper	lower	
1	0.14	0.50	14.5	14.0	5.13
2	0.64	1.00	24.0	20.0	21.00
3	1.14	1.00	28.0	12.0	20.00
4	1.64	1.00	22.0	17.0	14.00
5	2.14	1.00	17.0	16.0	17.00
6	2.64	0.50	16.0	20.0	6.25

$$A: (\text{upper N-value} + \text{lower N-value}) \times b/2$$

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L}$$
$$= \frac{85.17}{4.84}$$
$$= 17.58$$

K_h is recalculated from the calculated average N-value.

$$E_s = 2800 N^2 = 2800 \times 17.58 = 49232 \text{ kN/m}^2$$
$$K_{u0} = \frac{1}{0.3} \times \alpha \times 49232 = 164107 \text{ kN/m}^2 \quad (\alpha \text{ : Normal Condition } +1, \text{ Seimi Condition } +2)$$
$$K_u = K_{u0} (B_u/0.3)^{-0.4} = 164107 (10.00/0.3)^{-0.4} = 11830 \text{ kN/m}^2$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 11830 kN/m².

5.3 Seismic Condition

Assuming $K_h = 24911 \text{ kN/m}^2$,

$$\beta = 4 \sqrt[4]{\frac{K_u \cdot B}{4 E I}} = 0.249 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.02 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -7.14 m) and 4.02 m depth (GL -11.16 m).

No.	Depth Z m	Thickness b m	N-Value		Area A
			upper	lower	
1	1.14	0.50	20.0	20.0	12.25
2	1.64	1.00	26.0	12.0	20.00
3	2.14	1.00	22.0	17.0	14.00
4	2.64	1.00	17.0	16.0	17.00
5	3.14	0.52	16.0	21.0	10.20

$$A: (\text{upper N-value} + \text{lower N-value}) \times b/2$$

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

depth to acting position H_u = 0.0 m
moment M_u = 0.00 kN·m/m
depth to acting position H_n = 0.00 m
Height from riverbed to top of coping H = 4.42 m
Depth of imaginary riverbed from riverbed L_n = 1.72 m

Moment M by arbitrary load is as below
 $M = P_0 (H + L_n - H_u) + M_u = 184.20 \text{ kN} \cdot \text{m}$
 h_0 : Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_u}{P_0} = \frac{\Sigma M_u + M_u}{222.73}$$
$$= \frac{738.28}{222.73} = 3.31 \text{ m}$$

6.1.2 Seismic Condition

No.	Depth Z m	Thickness b m	Lateral Forth P ₀ kN/m ²	Loads P kN	Actn length Y m	Moment M kN · m
1	0.00~ 2.11	2.11	18.39 45.11	18.42 47.64	6.44 5.75	124.88 275.07
2	2.11~ 2.14	0.03	45.11 45.58	0.02 0.03	5.92 5.91	0.14 0.16
3	2.14~ 3.14	1.00	45.46 59.11	22.75 39.40	4.67 4.51	106.07 125.98
4	3.14~ 3.37	0.23	59.11 61.02	6.48 7.02	1.92 1.95	26.22 26.99
5	3.37~ 3.72	0.15	61.02 61.45	4.58 4.61	1.72 1.67	17.02 16.91
6	3.72~ 4.14	0.62	60.59 62.96	16.76 19.30	1.41 1.21	64.11 62.53
7	4.14~ 4.42	0.28	62.96 63.95	8.33 8.95	1.51 1.61	25.68 24.19
8	4.42~ 5.14	0.72	63.95 53.84	23.02 19.30	2.48 2.26	57.89 45.61
9	5.14~ 6.14	1.00	53.84 39.79	26.32 19.00	1.67 1.31	44.66 26.53
10	6.14~ 7.14	1.00	39.79 16.79	16.59 8.35	0.67 0.51	11.06 4.29
Σ P = 113.21 Σ M = 1096.67						

P_0 : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_0 \times b/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load P_0 = 76.3 kN/m
depth to acting position H_u = 0.00 m
moment M_u = 58.5 kN·m/m
depth to acting position H_n = 0.00 m
Height from riverbed to top of coping H = 4.42 m
Depth of imaginary riverbed from riverbed L_n = 2.72 m
Moment M by arbitrary load is as below

M_o = P₁(H + L₁ - H₁) + M_o = 603.28 kN·m

Hydrodynamic Pressure

No.	Depth, z m	Thickness, h m	Hydrodynamic Pressure, p ₀ kPa	Load, P ₀ kN	Acting length, L m	Moment, M ₀ kN·m
1	2.22~ 4.27	1.00	0.0	0.00	2.44 3.10	0.00 2.73
2	4.27~ 6.42	0.05	1.0	0.04	2.53 2.78	0.12 0.12

h₁, Height of acting position of P₀ from imaginary riverbed

h₁ = $\frac{M_o}{P_o} = \frac{\sum M + M_o + \sum M_o}{\sum P + P_1 + \sum P_o}$
= $\frac{1692.90}{390.49} = 4.34 \text{ m}$

6.2 Sectional Force

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

Material name	25 H ₂ H 1000-250-16-25-18
Unit width	B = 1,000 mm
Corrosion margin	t _c = 1.00 mm (active side) t _p = 1.00 mm (passive side)
Corrosion rate	r _c = 0.87
Section efficiency	μ = 1.00
Young's modulus	E = 200,000 N/mm ²
Inertia sectional moment	I _o = 935,900 cm ⁴ (original condition) I = 814,233 cm ⁴ (after reduction by corrosion and section)
EI = 200,000 × 10 ³ × 814,233 × 10 ⁻⁸	= 1.628 × 10 ⁶

β = $\sqrt[4]{\frac{K_o + B}{4 E I}}$

φ_o = $\frac{\sqrt{(1+2 \beta h_o)^2+1}}{2 \beta h_o} \times \exp(-\tan^{-1} \frac{1}{1+2 \beta h_o})$

M_o = M_o × φ_o

l_o = $\frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2 \beta h_o}$

l₁ = $\frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_o}{\beta h_o}$

M_(x) = $\frac{P_o}{\beta} \times \exp^{-\beta x} (\beta h_o \cdot \cos \beta x + (1+\beta h_o) \sin \beta x)$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _o = 11830 kN/m ²
calculated value	β = 0.20643 m ⁻¹
resultant earth force (lateral)	P _o = 222.73 kN/m
height of acting position of load	h _o = 3.31 m

moment M_o = 738.28 kN·m/m

in consideration of φ_o = 1.260,

maximum moment	M _{max} = 930.19 kN·m/m
depth of generated position of M _{max}	l _o = 1.935 m
depth of 1° fixed point	l ₁ = 5.740 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _o = 24911 kN/m ²
calculated value	β = 0.24868 m ⁻¹
resultant earth force (lateral)	P _o = 390.49 kN/m
height of acting position of load	h _o = 4.34 m
moment	M _o = 1692.90 kN·m/m

in consideration of φ_o = 1.130,

maximum moment	M _{max} = 1912.60 kN·m/m
depth of generated position of M _{max}	l _o = 1.234 m
depth of 1° fixed point	l ₁ = 4.392 m

6.3 Stress Intensity

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

Material Name	25 H ₂ H 1000-250-16-25-18
Corrosion margin	t _c = 1.00 mm (active side) t _p = 1.00 mm (passive side)
Corrosion rate	r _c = 0.89
Section efficiency	μ = 1.00
Module of section	Z _o = 12980 cm ³ (original condition) Z = 11552 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

σ = $\frac{M_{max}}{Z} = \frac{930.19 \times 10^3}{11552 \times 10^3} = 81 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$

6.3.2 Seismic Condition

σ = $\frac{M_{max}}{Z} = \frac{1912.60 \times 10^3}{11552 \times 10^3} = 166 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No.	Depth, z m	Y m	α	ζ	P kN	Q kN
1	0.00~ 2.14	0.00 4.71	0.004 0.703	0.276 0.219	7.61 36.59	2.007 0.019
2	2.14~ 3.14	0.07 0.93	0.007 0.511	0.143 0.142	17.00 20.42	2.001 2.000
3	3.14~ 3.72	0.97 2.79	0.004 0.007	0.002 0.003	0.00 0.01	0.022 0.035
4	3.72~ 3.81	2.81 2.86	0.000 0.001	0.072 0.064	7.54 6.21	0.044 0.040

1	3.82~ 4.14	2.19 2.19	0.107 0.100	0.006 0.002	7.21 6.78	0.400 0.378
5	4.14~ 6.42	1.91 1.91	0.111 0.209	0.000 0.019	7.06 7.11	0.305 0.282
7	4.42~ 5.14	1.40 1.24	0.240 0.201	0.027 0.019	16.42 19.07	0.402 0.290
8	5.14~ 6.14	0.67 0.11	0.100 0.004	0.006 0.001	0.00 0.00	0.006 0.001

ΣQ = 30.285

Y : Height from imaginary riverbed to acting position

α : α = $\frac{Y}{H+L_1}$

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

Q : ζ × P

P : Lateral force

H : Depth to design position

L₁ : Depth from design position to imaginary ground

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.

P₁: horizontal load

Y₁: Height from the virtual ground plane to the point of horizontal load action

If

P₁ = 30.00

Y₁ = 6.14

α = 1.000

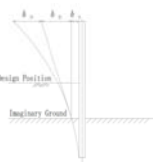
ζ = 0.333

Q = ζ × P = 10.000

Therefore, the deformation coefficient Q is expressed by

Q = 20.285 + 10.000 = 30.285

Displacement Calculation



δ₁ = $\frac{(1+\beta h_o) \times P_o}{2 E I \beta^2}$

= $\frac{(1+0.2064 \times 3.31) \times 222.73}{2 \times 2.00 \times 10^6 \times 814233 \times 10^{-8} \times 0.2064^2} = 0.01309 \text{ m}$

δ₂ = $\frac{(1+2 \beta h_o) \times P_o}{2 E I \beta^2} \times (H+L_1)$

コメントの追加 [h1] 日本語残り

= $\frac{(1+2 \times 0.2064 \times 3.31) \times 222.73}{2 \times 2.00 \times 10^6 \times 814233 \times 10^{-8} \times 0.2064^2} \times (4.42+1.72) = 0.02334 \text{ m}$

δ₃ = $\frac{Q \times (H+L_1)^3}{E I}$

= $\frac{30.28 \times (4.42+1.72)^3}{2.00 \times 10^6 \times 814233 \times 10^{-8}} = 0.00430 \text{ m}$

δ = δ₁ + δ₂ + δ₃
= 0.01309 + 0.02334 + 0.00430
= 0.04074 m
Size = 40.74 ≦ δ = 50.00 mm

Where,

δ₁ : Displacement at imaginary ground

δ₂ : Displacement by angle of inclination slope at imaginary ground

δ₃ : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ₄ : Allowable displacement

6.4.2 Seismic Condition

Modulus of deformation

No.	Depth, z m	Y m	α	ζ	P kN	Q kN
1	0.00~ 2.14	0.00 4.71	0.001 0.703	0.284 0.189	16.42 36.59	1.519 0.019
2	2.14~ 3.14	0.07 0.93	0.002 0.511	0.143 0.142	17.00 20.42	1.500 2.000
3	3.14~ 3.72	0.97 2.79	0.004 0.007	0.002 0.003	0.00 0.01	0.022 0.035
4	3.72~ 3.81	2.81 2.86	0.000 0.001	0.072 0.064	7.54 6.21	0.044 0.040
5	3.82~ 4.14	2.19 2.19	0.107 0.100	0.006 0.002	7.21 6.78	0.400 0.378
6	4.14~ 6.42	1.91 1.91	0.111 0.209	0.000 0.019	7.06 7.11	0.305 0.282
7	4.42~ 5.14	1.40 1.24	0.240 0.201	0.027 0.019	16.42 19.07	0.402 0.290
8	5.14~ 6.14	0.67 0.11	0.100 0.004	0.006 0.001	0.00 0.00	0.006 0.001

ΣQ = 30.610

Y : Height from imaginary riverbed to acting position

α : α = $\frac{Y}{H+L_1}$

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

Q : ζ × P

P : Lateral force

H : Depth to design position

L₁ : Depth from design position to imaginary ground

コメントの追加 [h2] 日本語残り

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.
P: horizontal load
Y: Height from the virtual ground plane to the point of horizontal load action

If
P = 76.30
Y = 7.14
a = 1.000
c = 0.333
Q = c × P = 25.433

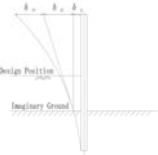
Therefore, the deformation coefficient Q is expressed by
Q = 35.615 + 25.433 = 61.049

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

No.	Depth m	Y m	a	c	P(kN)	Q(kN)
1	3.75	3.44	0.403	0.007	0.00	0.000
	4.37	3.10	0.433	0.003	0.00	0.071
2	4.25	2.75	0.386	0.003	0.00	0.003
3	4.42	2.34	0.303	0.004	0.05	0.003
Σ Q(kN) =						0.077

Therefore, the deformation coefficient Q is expressed by
Q = 61.049 + 0.077 = 61.125

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_1) \times P_e}{2 E I \beta^3}$$
$$= \frac{(1 + 0.2487 \times 4.34) \times 390.49}{2 \times 2.00 \times 10^9 \times 81.4233 \times 10^{-8} \times 0.2487^3} = 0.01620 \text{ m}$$
$$\delta_2 = \frac{(1 + 2 \beta h_2) \times P_e}{2 E I \beta^3} \times (H + L_1)$$
$$= \frac{(1 + 2 \times 0.2487 \times 4.34) \times 390.49}{2 \times 2.00 \times 10^9 \times 81.4233 \times 10^{-8} \times 0.2487^3} \times (4.42 + 2.72) = 0.04369 \text{ m}$$
$$\delta_3 = \frac{Q \times (H + L_1)^2}{E I}$$
$$= \frac{61.13 \times (4.42 + 2.72)^2}{2.00 \times 10^9 \times 81.4233 \times 10^{-8}} = 0.01366 \text{ m}$$

The displacement amount (δ) of the cantilever beam by the bending moment (Mm) is added.

$$\delta_m = \frac{M_e \cdot h}{2 E I} \times (2 L - h)$$
$$= \frac{58.50 \times 7.14}{2 \times 2.00 \times 10^9 \times 81.4233 \times 10^{-8}} \times (2 \times 7.14 - 7.14) = 0.00092 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= 0.01620 + 0.04369 + 0.01458$$
$$= 0.07447 \text{ m}$$
$$\delta_{\text{max}} = 74.47 \leq \delta_a = 75.00 \text{ mm}$$

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : 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:

Material Name	25 H _ H 1000 -250-16 -25 -18
Unit width	B = 1,000 mm
Corrosion rate	η = 1.00
Section efficiency	η = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 935900 cm ⁴ (original condition)
	I = 935900 cm ⁴ (after reduction by corrosion and section)
EI	EI = 200000 × 10 ³ × 935900 × 10 ⁻⁸ = 1.872 × 10 ⁶

7.1 Penetration Depth and Whole Length of SSP (Chang)

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

$$D = L_e + \frac{2}{\beta}$$
$$L = H + H_1 + D$$
$$\beta = \sqrt[4]{\frac{K_s + B}{4 E I}}$$

7.1.1 Normal Condition

Modulus of lateral subgrade reaction	K _s = 11830 kN/m ³
Calculated value	β = 0.19937 m ⁻¹
Penetration length of SSP	D = 1.72 + $\frac{3}{0.199}$ = 16.77 m
Whole length of SSP	L = 4.42 + 0.40 + 16.77 = 20.79 m

7.1.2 Seismic Condition

Modulus of lateral subgrade reaction	K _s = 24911 kN/m ³
Calculated value	β = 0.24017 m ⁻¹
Penetration length of SSP	D = 2.72 + $\frac{3}{0.240}$ = 15.21 m
Whole length of SSP	L = 4.42 + 0.40 + 15.21 = 19.23 m

Therefore, the total length of the sheet pile is 21.00 m from the rounded length value of 0.50 m.

8 Calculation Result

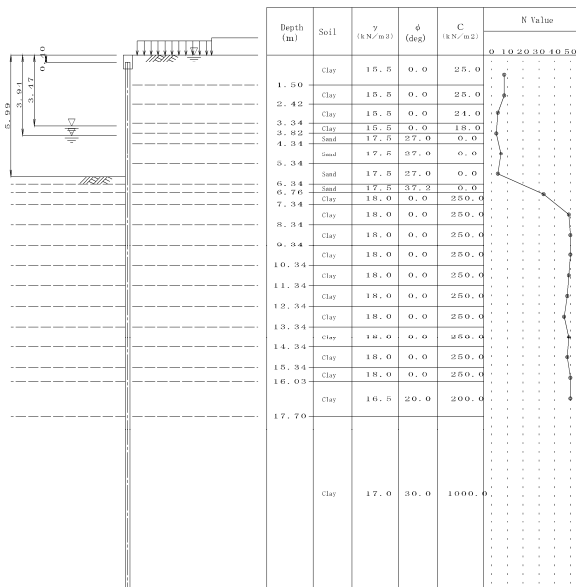
SSP		25 H _ H 1000 -250-16-25-18			
				Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	935900			
Sectional modulus	Z (cm ³)	12000			
Maximum bending moment	Mmax (kN × m × m)	929.19		929.19	1932.00
Bore capacity	φ (kN/cm ²)	15.1 (180)		15.1 (180)	15.1 (180)
Lateral displacement	δ (mm)	40.74 (25.0)		40.74 (25.0)	14.47 (7.5)
Penetration depth	D (m)	16.77		16.77	15.21
Whole length of SSP	L (m)	21.00			

Block No. : L-16
Sta. : 9+900~10+020

Design Cross Section : Sta 9+940
Boring Name : BDM-12

Specification : SSP SP-10H
(Combined) : H 750-250-14-22-18

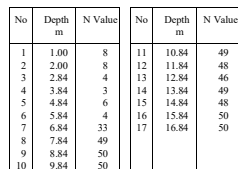
1.1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth from coping top to riverbed
Depth from coping top to rear side ground
Depth from coping top to SSP top
Landside WL

Riverside WL

H	=	5.99 m	
H ₀	=	0.00 m	
H _{lt}	=	0.40 m	
L _{wa}	=	0.00 m	(Normal Condition)
L _{wa} '	=	0.00 m	(Seismic Condition)
L _{wp}	=	3.94 m	(Normal Condition)
L _{wp} '	=	3.47 m	(Seismic Condition)



Vertical load on landside	calculated in consideration of embankment shape on landside
Vertical load on riverside	not considered

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.50	1.50
2	2.42	0.92
3	3.34	0.92
4	3.82	0.92
5	4.34	0.52
6	5.34	1.00
7	6.34	1.00
8	6.76	0.42
9	7.34	0.58
10	8.34	1.00
11	9.34	1.00
12	10.34	1.00
13	11.34	1.00
14	12.34	1.00
15	13.34	1.00
16	14.34	1.00
17	15.34	1.00
18	16.03	0.69
19	17.70	1.67
20	25.30	7.60

No	Depth m	earth Soil	N Value kN/m2	γ kN/m3	γ' kN/m3	ϕ degree	C kN/m2	a	k ²	ζ (degree)	
										Normal Condition	Seismic Condition
1	3.50	C	7.8	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
2	2.42	C	7.8	15.50	5.70	0.0	15.0	0.0	0.200	Auto	Auto
3	3.34	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto
4	3.82	C	3.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto
5	4.34	S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	5.34	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
7	6.34	S	10.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
8	6.76	S	33.0	17.50	7.70	37.2	0.0	0.0	0.200	Auto	Auto
9	7.34	C	33.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
10	8.00	C	40.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
11	9.34	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
12	10.34	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
13	11.34	C	40.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
14	12.34	C	48.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	13.34	C	46.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	14.34	C	49.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	15.34	C	48.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	16.00	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	17.00	C	63.5	18.00	8.20	20.0	200.0	0.0	0.200	Auto	Auto
20	25.30	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered

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

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

Applied formula	$K_b = K_{10} \left(\frac{B_0}{0.3} \right)^{-3/4}$ $K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$ $B_0 = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
Average N-value	calculated from average N-value between imaginary riverbed and depth as $1/\beta$

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

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

Technical drawing of a roof plan (Dachplan) showing a building footprint with dimensions and a table of values.

Dimensions (in meters):

- Top horizontal segments: 4.00, 10.91, 14.18
- Left vertical segment: 5.00

Table of values:

1.00	1
0.92	2
0.92	3
0.92	4
3.00	6

No	Soil	X Coordinate				Thickness		soil single weight γ		internal friction angle	stickiness	decay single ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	θ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree	
1	Sand	4.00	4.00	30.00	30.00	0.83	19.0	19.0	30.0	0.0	Auto	Auto	
2	Sand	14.91	15.82	30.00	30.00	1.79	19.0	19.0	30.0	0.0	Auto	Auto	

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.35	3.99	5.0	0.0

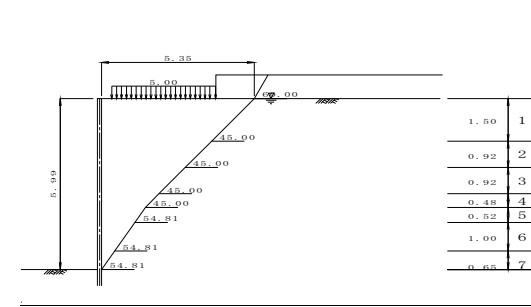
Angle of rapture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 750 -250 -14 -22 -18
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 414700 cm ⁴
Sectional factor	Z ₀	= 7640 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	= 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



2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	1.32	25.07
Σ			25.07

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

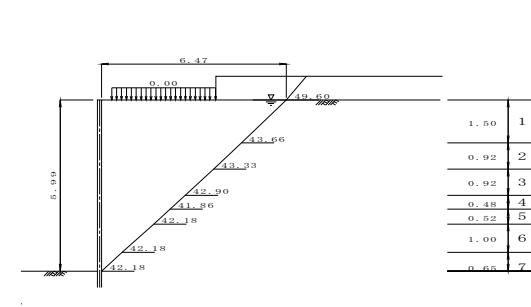
No	Q kN/m ²	l m	Q × l kN/m
1	5.0	3.64	18.20
Σ			18.20

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{25.07 + 18.20 + 0.00}{5.35}$$
$$= 8.09 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ w h kN/m ²	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	5.99 ~ 5.34	Sand	27.0	15.0	0.0	38.48	6.88	58.70	0.200	11.31	42.18

2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ w h kN/m ²	Angle of Rupture ζ degree
1	5.99 ~ 5.34	Sand	27.0	15.0	0.0	38.48	8.09	58.70	54.81
2	5.34 ~ 4.34	Sand	27.0	15.0	0.0	33.48	8.09	52.33	54.81
3	4.34 ~ 3.82	Sand	27.0	15.0	0.0	25.78	8.09	42.53	54.81
4	3.82 ~ 3.34	Clay	0.0	15.0	18.0	21.77	8.09	37.44	45.00
5	3.34 ~ 2.42	Clay	0.0	15.0	24.0	19.04	8.09	32.73	45.00
6	2.42 ~ 1.50	Clay	0.0	15.0	25.0	13.79	8.09	23.72	45.00
7	1.50 ~ 0.00	Clay	0.0	15.0	25.0	8.55	8.09	14.70	45.00
8		embankment	30.0	—	0.0	49.78	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 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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.81	0.65	0.00	0.00	0.46	0.65
2	54.81	1.00	0.46	0.65	1.16	1.65
3	54.81	0.52	1.16	1.65	1.53	2.17
4	45.00	0.48	1.53	2.17	2.01	2.65
5	45.00	0.92	2.01	2.65	2.93	3.57
6	45.00	0.92	2.93	3.57	3.85	4.49
7	45.00	1.50	3.85	4.49	5.35	5.99
8	60.00	0.83	5.35	5.99	5.83	6.82

From the above table, the loading width (L) on the ground surface is 5.35 m.

2	5.34 ~ 4.34	Sand	27.0	15.0	0.0	33.48	6.88	52.33	0.200	11.31	42.18
3	4.34 ~ 3.82	Sand	27.0	15.0	0.0	25.78	6.88	42.53	0.200	11.31	42.18
4	3.82 ~ 3.34	Clay	0.0	15.0	18.0	21.77	6.88	37.44	0.200	11.31	41.86
5	3.34 ~ 2.42	Clay	0.0	15.0	24.0	19.04	6.88	32.73	0.200	11.31	42.90
6	2.42 ~ 1.50	Clay	0.0	15.0	25.0	13.79	6.88	23.72	0.200	11.31	43.33
7	1.50 ~ 0.00	Clay	0.0	15.0	25.0	8.55	6.88	14.70	0.200	11.31	43.66
8		embankment	30.0	—	0.0	49.78	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	0.65	0.00	0.00	0.72	0.65
2	42.18	1.00	0.72	0.65	1.82	1.65
3	42.18	0.52	1.82	1.65	2.39	2.17
4	41.86	0.48	2.39	2.17	2.93	2.65
5	42.90	0.92	2.93	2.65	3.92	3.57
6	43.33	0.92	3.92	3.57	4.90	4.49
7	43.66	1.50	4.90	4.49	6.47	5.99
8	49.60	0.83	6.47	5.99	7.17	6.82

From the above table, the loading width (L) on the ground surface is 6.47 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	2.34	44.49

Σ			44.49

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	Qxl kN/m
1	0.0	3.64	0.00
Σ			0.00

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

l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

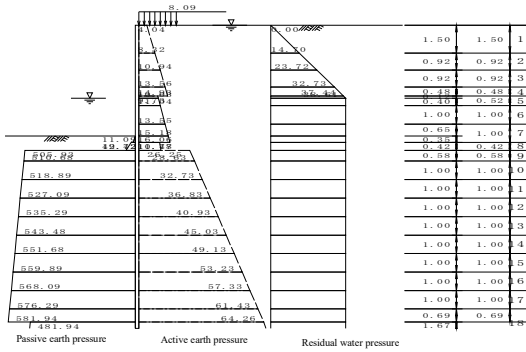
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{44.49 + 0.00 + 0.00}{6.47}$$

$$= 6.88 \text{ kN/m}^2$$

3 Lateral Forth

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	Σ γ h + Q _a kN/m ²	K _a	K _a × cos δ
1	0.00- 1.50	Clay	5.7	—	25.0 25.0	8.088 16.638	—	—

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	φ degree	C kN/m ²	Σ γ h + Q _p kN/m ²	K _p	K _p × cos δ
9	5.99- 6.34	Sand	7.7	27.0	—	0.000 2.695	4.26080 4.26080	4.11561 4.11561
10	6.34- 6.76	Sand	7.7	37.2	—	2.695 5.929	7.45965 7.45965	7.20546 7.20546
11	6.76- 7.34	Clay	8.2	0.0	250.0 250.0	5.929 10.685	—	—
12	7.34- 8.34	Clay	8.2	0.0	250.0 250.0	10.685 18.885	—	—
13	8.34- 9.34	Clay	8.2	0.0	250.0 250.0	18.885 27.085	—	—
14	9.34- 10.34	Clay	8.2	0.0	250.0 250.0	27.085 35.285	—	—
15	10.34- 11.34	Clay	8.2	0.0	250.0 250.0	35.285 43.485	—	—
16	11.34- 12.34	Clay	8.2	0.0	250.0 250.0	43.485 51.685	—	—
17	12.34- 13.34	Clay	8.2	0.0	250.0 250.0	51.685 59.885	—	—
18	13.34- 14.34	Clay	8.2	0.0	250.0 250.0	59.885 68.085	—	—
19	14.34- 15.34	Clay	8.2	0.0	250.0 250.0	68.085 76.285	—	—
20	15.34- 16.03	Clay	8.2	0.0	250.0 250.0	76.285 81.943	—	—
21	16.03- 17.70	Clay	6.7	20.0	200.0 200.0	81.943 93.132	—	—
22	17.70- 25.30	Clay	7.2	30.0	1000.0 1000.0	93.132 147.852	—	—

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

$$\delta = -15.00, \beta = 0.00, \theta = 0.00$$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.50	-41.91 -33.36	4.04 8.32	4.04 8.32	0.00 14.70	—
2	1.50- 2.42	-33.36 -28.12	8.32 10.94	8.32 10.94	14.70 23.72	—
3	2.42- 3.34	-28.12 -20.87	10.94 13.56	10.94 13.56	23.72 32.73	—
4	3.34- 3.82	-8.87 -6.14	13.56 14.93	13.56 14.93	32.73 37.44	—

2	1.50- 2.42	Clay	5.7	—	25.0 25.0	16.638 21.882	—	—
3	2.42- 3.34	Clay	5.7	—	24.0 24.0	21.882 27.126	—	—
4	3.34- 3.82	Clay	5.7	—	18.0 18.0	27.126 29.862	—	—
5	3.82- 3.94	Sand	7.7	27.0	—	29.862 30.786	0.33738 0.33738	0.32589 0.32589
6	3.94- 4.34	Sand	7.7	27.0	—	30.786 33.866	0.33738 0.33738	0.32589 0.32589
7	4.34- 5.34	Sand	7.7	27.0	—	33.866 41.566	0.33738 0.33738	0.32589 0.32589
8	5.34- 5.99	Sand	7.7	27.0	—	41.566 46.571	0.33738 0.33738	0.32589 0.32589
9	5.99- 6.34	Sand	7.7	27.0	—	46.571 49.266	0.33738 0.33738	0.32589 0.32589
10	6.34- 6.76	Sand	7.7	37.2	—	49.266 52.500	0.22641 0.22641	0.21870 0.21870
11	6.76- 7.34	Clay	8.2	—	250.0 250.0	52.500 57.256	—	—
12	7.34- 8.34	Clay	8.2	—	250.0 250.0	57.256 65.456	—	—
13	8.34- 9.34	Clay	8.2	—	250.0 250.0	65.456 73.656	—	—
14	9.34- 10.34	Clay	8.2	—	250.0 250.0	73.656 81.856	—	—
15	10.34- 11.34	Clay	8.2	—	250.0 250.0	81.856 90.056	—	—
16	11.34- 12.34	Clay	8.2	—	250.0 250.0	90.056 98.256	—	—
17	12.34- 13.34	Clay	8.2	—	250.0 250.0	98.256 106.456	—	—
18	13.34- 14.34	Clay	8.2	—	250.0 250.0	106.456 114.656	—	—
19	14.34- 15.34	Clay	8.2	—	250.0 250.0	114.656 122.856	—	—
20	15.34- 16.03	Clay	8.2	—	250.0 250.0	122.856 128.514	—	—
21	16.03- 17.70	Clay	6.7	—	200.0 200.0	128.514 139.703	—	—
22	17.70- 25.30	Clay	7.2	—	1000.0 1000.0	139.703 194.423	—	—

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

$$\delta = 15.00, \beta = 0.00, \theta = 0.00$$

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

5	3.82- 3.94	9.73 10.03	—	9.73 10.03	37.44 38.61	—	—
6	3.94- 4.34	10.03 11.04	—	10.03 11.04	38.61 38.61	—	—
7	4.34- 5.34	11.04 13.55	—	11.04 13.55	38.61 38.61	—	—
8	5.34- 5.99	13.55 15.18	—	13.55 15.18	38.61 38.61	—	—
9	5.99- 6.34	15.18 16.06	—	15.18 16.06	38.61 38.61	0.00 11.09	—
10	6.34- 6.76	16.06 17.77	—	16.06 17.77	38.61 38.61	19.42 42.72	—
11	6.76- 7.34	17.77 20.25	—	17.77 20.25	38.61 38.61	50.93 510.68	—
12	7.34- 8.34	20.25 23.73	—	20.25 23.73	38.61 38.61	510.68 518.89	—
13	8.34- 9.34	23.73 26.83	—	23.73 26.83	38.61 38.61	518.89 527.09	—
14	9.34- 10.34	26.83 29.86	—	26.83 29.86	38.61 38.61	527.09 535.29	—
15	10.34- 11.34	29.86 32.73	—	29.86 32.73	38.61 38.61	535.29 543.48	—
16	11.34- 12.34	32.73 35.23	—	32.73 35.23	38.61 38.61	543.48 551.68	—
17	12.34- 13.34	35.23 37.44	—	35.23 37.44	38.61 38.61	551.68 559.89	—
18	13.34- 14.34	37.44 39.54	—	37.44 39.54	38.61 38.61	559.89 568.09	—
19	14.34- 15.34	39.54 41.43	—	39.54 41.43	38.61 38.61	568.09 576.29	—
20	15.34- 16.03	41.43 42.26	—	41.43 42.26	38.61 38.61	576.29 581.94	—
21	16.03- 17.70	42.26 46.26	—	42.26 46.26	38.61 38.61	581.94 481.94	—
22	17.70- 25.30	46.26 49.21	—	46.26 49.21	38.61 38.61	481.94 2093.13	—

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a: Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

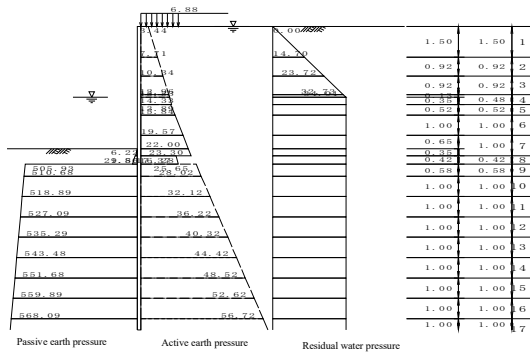
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



The dotted line in the figure shows the main earth pressure strength Pa2 using the consolidation equilibrium coefficient.

3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Ka	$Ka \times \cos \delta$	ζ degree
1	0.00-1.50	Clay	5.7	—	25.0	6.88	0.00	0.200	11.31	—	—	44.19
2	1.50-2.42	Clay	5.7	—	25.0	15.43	14.70	0.200	11.31	—	—	43.66
3	2.42-3.34	Clay	5.7	—	24.0	20.67	23.72	0.200	11.31	—	—	43.25
4	3.34-3.47	Clay	5.7	—	18.0	25.92	32.73	0.200	11.31	—	—	42.90
5	3.47-3.82	Clay	5.7	—	18.0	26.66	34.01	0.200	11.31	—	—	42.85
6	3.82-4.34	Sand	7.7	27.0	—	26.66	34.01	0.200	11.31	—	—	42.85
7	4.34-5.34	Sand	7.7	27.0	—	28.65	37.44	0.200	11.31	—	—	41.86
8	5.34-5.99	Sand	7.7	27.0	—	28.65	37.44	0.200	11.31	—	—	41.86
9	5.99-6.34	Sand	7.7	27.0	—	32.66	42.53	0.200	11.31	—	—	41.86
10	6.34-6.76	Sand	7.7	37.2	—	40.36	52.33	0.200	11.31	—	—	41.86
11	6.76-7.34	Clay	8.2	—	250.0	45.36	58.70	0.200	11.31	—	—	44.66
12	7.34-8.34	Clay	8.2	—	250.0	48.06	62.13	0.200	11.31	—	—	44.63

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active	Residual water pressure	Passive
1	0.00-1.50	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
2	1.50-2.42	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
3	2.42-3.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
4	3.34-3.47	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
5	3.47-3.82	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
6	3.82-4.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
7	4.34-5.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
8	5.34-5.99	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
9	5.99-6.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
10	6.34-6.76	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
11	6.76-7.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
12	7.34-8.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
13	8.34-9.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
14	9.34-10.34	Pa1 kN/m ² Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²

13	8.34-9.34	Clay	8.2	—	250.0	64.25	81.73	0.200	11.31	—	—	44.59
14	9.34-10.34	Clay	8.2	—	250.0	72.45	91.53	0.200	11.31	—	—	44.54
15	10.34-11.34	Clay	8.2	—	250.0	80.65	101.33	0.200	11.31	—	—	44.49
16	11.34-12.34	Clay	8.2	—	250.0	88.85	111.13	0.200	11.31	—	—	44.44
17	12.34-13.34	Clay	8.2	—	250.0	97.05	120.93	0.200	11.31	—	—	44.39
18	13.34-14.34	Clay	8.2	—	250.0	105.25	130.73	0.200	11.31	—	—	44.34
19	14.34-15.34	Clay	8.2	—	250.0	113.45	140.53	0.200	11.31	—	—	44.29
20	15.34-16.03	Clay	8.2	—	250.0	121.65	150.33	0.200	11.31	—	—	44.24
21	16.03-17.70	Clay	6.7	—	200.0	127.30	157.09	0.200	11.31	—	—	44.21
22	17.70-25.30	Clay	7.2	—	1000.0	138.49	173.46	0.200	11.31	—	—	44.01

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Qp$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Kp	$Kp \times \cos \delta$
9	5.99-6.34	Sand	7.70	27.0	—	0.000	0.00	3.43	0.200	2.30874	2.30874
10	6.34-6.76	Sand	7.70	37.2	—	2.695	3.43	7.55	0.200	3.63610	3.63610
11	6.76-7.34	Clay	8.20	0.0	250.0	5.929	7.55	13.23	0.200	—	—
12	7.34-8.34	Clay	8.20	0.0	250.0	10.685	13.23	23.03	0.200	—	—
13	8.34-9.34	Clay	8.20	0.0	250.0	18.885	23.03	32.83	0.200	—	—
14	9.34-10.34	Clay	8.20	0.0	250.0	27.085	32.83	42.63	0.200	—	—
15	10.34-11.34	Clay	8.20	0.0	250.0	35.285	42.63	52.43	0.200	—	—
16	11.34-12.34	Clay	8.20	0.0	250.0	43.485	52.43	62.23	0.200	—	—
17	12.34-13.34	Clay	8.20	0.0	250.0	51.685	62.23	72.03	0.200	—	—

15	10.34-11.34	-403.13	40.32	44.42	34.01	535.29	543.48
16	11.34-12.34	-393.13	44.42	48.52	34.01	551.68	551.68
17	12.34-13.34	-383.24	48.52	52.62	34.01	558.89	558.89
18	13.34-14.34	-373.35	52.62	56.72	34.01	568.09	568.09
19	14.34-15.34	-363.45	56.72	60.82	34.01	576.29	576.29
20	15.34-16.03	-353.55	60.82	64.92	34.01	584.49	584.49
21	16.03-17.70	-343.66	64.92	69.02	34.01	592.69	592.69
22	17.70-25.30	-1833.66	69.25	69.25	34.01	2093.13	2147.85

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$
$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression; 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

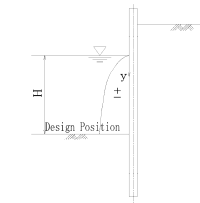
$$\text{Sand } P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$
$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$
$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth, Z, m	water level, y, m	pdw, kN/m ²
1	3.47	0.00	0.00
2	4.47	1.00	2.72
3	5.47	2.00	3.85
4	5.99	2.52	4.32

$$P_{dw} = \pm \frac{\gamma}{8} k_{hs} \cdot \gamma \cdot \sqrt{H \cdot y}$$

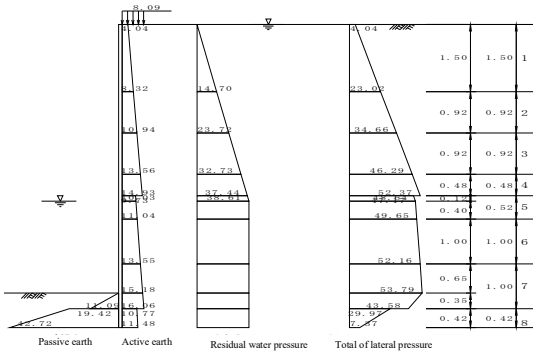
Where,
 k_{hs} : design seismic coefficient
 γ_w : unit weight of water
H: water depth of river side
y: depth from water surface to the point where active water pressure is calculated



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



No	Depth, m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00-1.50	4.04 8.32	0.00 14.70	— —	4.04 23.02
2	1.50-2.42	8.32 10.94	14.70 23.72	— —	23.02 34.66
3	2.42-3.34	10.94 13.56	23.72 32.73	— —	34.66 46.29
4	3.34-3.82	13.56 14.93	32.73 37.44	— —	46.29 52.37

3	2.42-3.34	10.34 12.96	23.72 32.73	— —	34.05 45.69
4	3.34-3.47	12.96 13.33	32.73 34.01	— —	45.69 47.33
5	3.47-3.82	13.33 14.33	34.01 34.01	— —	47.33 48.33
6	3.82-4.34	13.89 15.84	34.01 34.01	— —	47.90 49.84
7	4.34-5.34	15.84 19.57	34.01 34.01	— —	49.84 53.57
8	5.34-5.99	19.57 22.00	34.01 34.01	— —	53.57 56.00
9	5.99-6.34	22.00 23.30	34.01 6.22	0.00 —	56.00 59.09
10	6.34-6.76	16.28 17.37	34.01 21.56	9.80 —	40.48 29.82
11	6.76-7.34	25.65 28.02	34.01 510.68	505.93 —	446.28 448.66

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 : 0.77 m (GL -6.76 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = \frac{K_w}{0.3} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B=10.00m)$$

$$K_{w0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_0 = 2800N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

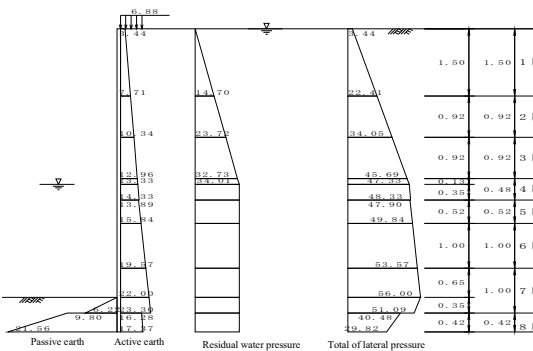
Material Name	10 H_H 750-250-14-22-18
Unit width	B = 1.0000 m
Corrosion margin	t ₁ = 1.00 mm (active side) t ₂ = 1.00 mm (passive side)
Corrosion rate	η = 0.86
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 414700 cm ⁴ (original condition)
	I = 355642 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 356642 × 10 ⁻⁸ = 7.135 × 10 ⁶

5	3.82-3.94	9.73 10.03	37.44 38.61	— —	47.17 48.64
6	3.94-4.34	10.03 11.04	38.61 38.61	— —	48.64 49.65
7	4.34-5.34	11.04 13.55	38.61 38.61	— —	49.65 52.16
8	5.34-5.99	13.55 15.18	38.61 38.61	— —	52.16 53.79
9	5.99-6.34	15.18 16.06	38.61 38.61	0.00 11.09	53.79 43.58
10	6.34-6.76	10.77 11.48	38.61 38.61	19.42 42.72	29.97 7.37
11	6.76-7.34	26.25 28.65	38.61 38.61	505.93 510.68	-441.07 -443.45

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 : 0.77 m (GL -6.76 m)

4.2 Seismic Condition



No	Depth, m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00-1.50	3.44 7.71	0.00 14.70	— —	3.44 22.41
2	1.50-2.42	7.71 10.34	14.70 23.72	— —	22.41 34.05

No	Depth, m	N Value	No	Depth, m	N Value
1	1.00	8	11	10.84	49
2	2.00	8	12	11.84	48
3	2.84	4	13	12.84	46
4	3.84	3	14	13.84	49
5	4.84	6	15	14.84	48
6	5.84	4	16	15.84	50
7	6.84	33	17	16.84	50
8	7.84	49			
9	8.84	50			
10	9.84	50			

5.2 Normal Condition

Assuming $K_h = 31256 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.324 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.09 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.76 m) to 3.09 m depth (GL -9.85 m).

No	Depth, m	Thickness, m	N Value, upper	N Value, lower	Area, A
1	6.76	0.08	30.7	33.0	2.55
2	6.84	1.00	33.0	49.0	41.00
3	7.84	1.00	49.0	50.0	49.50
4	8.84	1.00	50.0	50.0	50.00
5	9.84	0.01	50.0	50.0	0.55
L = 3.09					ΣA = 143.60

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

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

$$= \frac{143.60}{3.09}$$

$$= 46.46$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 46.46 = 130079 \text{ kN/m}^2$$

$$K_{w0} = \frac{1}{0.3} \times \alpha \times 130079 = 433598 \text{ kN/m}^2 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$K_b = K_{w0} (B/0.3)^{-3/4} = 433598 (10.00/0.3)^{-3/4} = 31256 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 31256 kN/m³.

5.3 Seismic Condition

Assuming Kh = 61629 kN/m3,

β = 4√(Ks · B / (4 E I)) = 0,383 m⁻¹

L = 1 / β = 2,61 m

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.76 m) and 2.61 m depth (GL -9.37 m).

No	Depth Z m	Thickness h m	N' Value		Area A
			upper	lower	
1	6.76	0.08	30.7	33.0	2.55
2	6.84	1.00	33.0	49.0	41.00
3	7.84	1.00	49.0	50.0	49.50
4	8.84	0.53	50.0	50.0	26.42
Σ h = 2.61			Σ A = 119.47		

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

Average N-value N' = (Σ A / L) = (119.47 / 2.61) = 45,80

Kh is recalculated from the calculated average N value.

Eo = 2800N' = 2800 × 45.80 = 128243 kN/m²
K10 = (1 / 0.3) × α × 128243 = 854953 kN/m² (α : Normal Condition =1, Seismi Condition =2)
K1 = K10 (B/0.3)^{-3/4} = 854953 (10.00/0.3)^{-3/4} = 61629 kN/m²

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 61629 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

2	1.50- 2.42	0.92	22.41 34.05	10.31 15.66	4.95 4.65	51.07 72.79
3	2.42- 3.34	0.92	34.05 45.69	15.66 21.02	4.03 3.73	63.18 78.32
4	3.34- 3.47	0.13	45.69 47.33	2.97 3.08	3.38 3.33	10.03 10.26
5	3.47- 3.82	0.35	47.33 48.33	8.28 8.46	3.17 3.06	26.29 25.85
6	3.82- 4.34	0.52	47.90 49.84	12.45 12.96	2.77 2.59	34.46 33.61
7	4.34- 5.34	1.00	49.84 53.57	24.92 26.79	2.09 1.75	52.00 46.97
8	5.34- 5.99	0.65	53.57 56.00	17.41 18.20	1.30 0.99	20.95 17.96
9	5.99- 6.34	0.35	56.00 51.09	9.80 8.94	0.65 0.54	6.40 4.80
10	6.34- 6.76	0.42	40.48 29.82	8.50 6.26	0.28 0.14	2.38 0.88
Σ P = 251.07			Σ M = 671.16			

P1 : active earth pressure + residual water pressure - passive earth pressure
P : load P1 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 P1 = 0.0 kN/m
depth to acting position H1 = 0.00 m
moment M1 = 0.0 kN·m/m
depth to acting position Hm = 0.00 m
Height from riverbed to top of coping H = 5.99 m
Depth of Imaginary riverbed from riverbed Lk = 0.77 m

Moment M1 by arbitrary load is as below
M1 = P1·(H + Lk - H1) + M1 = 0.00 kN·m

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure phw kN/m ²	Loads Pdw kN	Arm length Y m	Moment Mdw kN · m
1	3.47- 4.47	1.00	0.0 2.7	0.00 1.36	2.96 2.62	0.00 3.57
2	4.47- 5.47	1.00	2.7 3.9	1.36 1.93	1.96 1.62	2.66 3.13
3	5.47- 5.99	0.52	3.9 4.3	1.00 1.12	1.12 0.94	1.12 1.06
Σ Pdw = 6.77			Σ Mdw = 11.54			

h0, Height of acting position of P0 from imaginary riverbed
h0 = (M1 + M1 + Σ Mdw) / (P1 + P1 + Σ Pdw) = (0 + 0 + 11.54) / (0 + 0 + 6.77) = 1.71 m

No	Depth Z m	Thickness h m	Lateral Forth P1 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.50	1.50	4.04 23.02	17.26	3.03 5.76	18.99 99.44
2	1.50- 2.42	0.92	23.02 34.66	10.59 15.94	4.95 4.65	52.45 74.08
3	2.42- 3.34	0.92	34.66 46.29	15.94 21.30	4.03 3.73	64.30 79.36
4	3.34- 3.82	0.48	46.29 52.37	11.11 12.57	3.26 3.10	36.22 38.96
5	3.82- 3.94	0.12	47.17 48.64	2.83 2.92	2.90 2.86	8.21 8.35
6	3.94- 4.34	0.40	48.64 49.65	9.73 9.93	2.69 2.55	26.14 25.35
7	4.34- 5.34	1.00	49.65 52.16	24.82 26.08	2.09 1.75	51.80 45.72
8	5.34- 5.99	0.65	52.16 53.79	16.95 17.48	1.20 0.99	20.40 17.25
9	5.99- 6.34	0.35	53.79 43.58	9.41 7.63	0.65 0.54	6.15 4.09
10	6.34- 6.76	0.42	29.97 7.77	6.29 1.55	0.28 0.14	1.78 0.22
Σ P = 243.37			Σ M = 679.24			

P1 : active earth pressure + residual water pressure - passive earth pressure
P : load P1 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 P1 = 0.0 kN/m
depth to acting position H1 = 0.0 m
moment M1 = 0.00 kN·m/m
depth to acting position Hm = 0.00 m
Height from riverbed to top of coping H = 5.99 m
Depth of Imaginary riverbed from riverbed Lk = 0.77 m

Moment M1 by arbitrary load is as below
M1 = P1·(H + Lk - H1) + M1 = 0.00 kN·m
h0, Height of acting position of P0 from imaginary riverbed

h0 = (M1 + M1 + Σ Mdw) / (P1 + P1 + Σ Pdw) = (0 + 0 + 11.54) / (0 + 0 + 6.77) = 1.71 m

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P1 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.50	1.50	3.44 22.41	16.81	2.58 5.76	16.15 96.83

6.2 Sectional Force

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

Material name 10 H 750 -250 -14 -22 -18
Unit width B = 1.0000 m
Corrosion margin c = 1.00 mm (active side) t2 = 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 I0 = 414700 cm⁴ (original condition)
I = 356642 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 356642 × 10⁻⁸ = 7.135 × 10⁵

β = 4√(Ks · B / (4 E I))

φ1 = (√((1 + 2 β h0)² + 1) / (2 β h0)) × exp(-tan⁻¹ (1 / (1 + 2 β h0)))

Mmax = M0 · φ1

11 = (1 / β) × tan⁻¹ (1 / (1 + 2 β h0))

11 = (1 / β) × tan⁻¹ (1 + β h0 / β h0)

M10 = (P0 / β) × exp^{-β11} (β h0 · cos β11 + (1 + β h0) sin β11)

6.2.1 Normal Condition

modulus of lateral subgrade reaction Ks = 31256 kN/m³
calculated value β = 0.32352 m⁻¹
resultant earth force (lateral) P0 = 243.37 kN/m
height of acting position of load h0 = 2.79 m
moment M0 = 679.24 kN·m/m

in consideration of ψm = 1.171,
maximum moment Mmax = 795.58 kN·m/m
depth of generated position of Mmax lm = 1.058 m
depth of 1st fixed point li = 3.486 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction Ks = 61629 kN/m³
calculated value β = 0.38337 m⁻¹
resultant earth force (lateral) P0 = 257.84 kN/m
height of acting position of load h0 = 2.65 m
moment M0 = 682.69 kN·m/m

in consideration of ψm = 1.143
maximum moment Mmax = 780.15 kN·m/m
depth of generated position of Mmax lm = 0.832 m
depth of 1st fixed point li = 2.880 m

6.3 Stress Intensity

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

Material Name	10 H _H 750 -250 -14 -22 -18
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 = 7640 cm ³ (original condition)
	Z = 6723 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

σ = $\frac{M_{max}}{Z}$ = $\frac{795.58 \times 10^6}{6723 \times 10^3}$ = 118 N/mm² ≤ σ_s = 180 N/mm²

6.3.2 Seismic Condition

σ = $\frac{M_{max}}{Z}$ = $\frac{780.15 \times 10^6}{6723 \times 10^3}$ = 116 N/mm² ≤ σ_s = 270 N/mm²

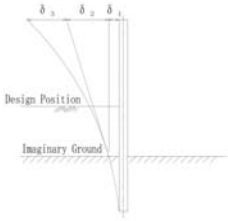
6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation							
No	Depth m	Y m	α	ζ	P kN	Q kN	
1	0.00- 1.50	6.26 5.76	0.926 0.852	0.296 0.260	3.03 17.26	0.899 4.467	
2	1.50- 2.42	4.95 4.65	0.733 0.687	0.203 0.182	10.59 15.94	2.148 2.903	
3	2.42- 3.34	4.03 3.73	0.597 0.551	0.143 0.124	15.94 21.30	2.273 2.641	
4	3.34- 3.82	3.26 3.10	0.482 0.459	0.098 0.089	11.11 12.57	1.084 1.120	
5	3.82- 3.94	2.90 2.86	0.429 0.423	0.079 0.077	2.83 2.92	0.223 0.234	
6	3.94- 4.34	2.69 2.55	0.397 0.378	0.069 0.062	9.73 9.93	0.667 0.619	
7	4.34- 5.34	2.09 1.75	0.309 0.259	0.043 0.031	24.82 26.08	1.061 0.801	
8	5.34- 5.99	1.29 0.99	0.178 0.146	0.015 0.010	16.95 17.48	0.233 0.177	
9	5.99- 6.34	0.65 0.54	0.097 0.079	0.005 0.003	9.41 7.63	0.043 0.023	
10	6.34- 6.76	0.28 0.14	0.041 0.021	0.001 0.000	6.29 1.55	0.005 0.000	
Σ Q =						21.653	

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

Displacement Calculation



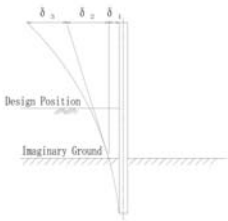
δ₁ = $\frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$
= $\frac{(1+0.3235 \times 2.79) \times 243.37}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.3235^3}$ = 0.00959 m
δ₂ = $\frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$
= $\frac{(1+2 \times 0.3235 \times 2.79) \times 243.37}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.3235^2} \times (5.99+0.77)$ = 0.03092 m
δ₃ = $\frac{Q \times (H+L_k)^3}{E I}$
= $\frac{21.65 \times (5.99+0.77)^3}{2.00 \times 10^8 \times 356642 \times 10^{-8}}$ = 0.00938 m

δ = δ₁ + δ₂ + δ₃
= 0.00959 + 0.03092 + 0.00938
= 0.04988 m
Size = 49.88 ≤ δ a = 50.00 mm

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : 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



δ₁ = $\frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$
= $\frac{(1+0.3834 \times 2.65) \times 257.84}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.3834^3}$ = 0.00646 m
δ₂ = $\frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$
= $\frac{(1+2 \times 0.3834 \times 2.65) \times 257.84}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.3834^2} \times (5.99+0.77)$ = 0.02519 m
δ₃ = $\frac{Q \times (H+L_k)^3}{E I}$
= $\frac{21.40 \times (5.99+0.77)^3}{2.00 \times 10^8 \times 356642 \times 10^{-8}}$ = 0.00927 m

δ = δ₁ + δ₂ + δ₃
= 0.00646 + 0.02519 + 0.00927
= 0.04092 m
Size = 40.92 ≤ δ a = 75.00 mm

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : 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:

Material Name	10 H _H 750 -250 -14 -22 -18
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 = 414700 cm ⁴ (original condition)
	I = 414700 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 414700 × 10 ⁻⁸	I = 8.294 × 10 ⁵

Y : Height from imaginary riverbed to acting position
α : α = $\frac{Y}{H+L_k}$
ζ : ζ = $\frac{(3-\alpha) \times \alpha^2}{6}$
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 _{sw} kN	Q _{sw} kN	
1	3.47- 4.47	2.96 2.62	0.437 0.388	0.082 0.066	0.00 1.36	0.000 0.089	
2	4.47- 5.47	1.96 1.62	0.289 0.240	0.038 0.027	1.36 1.93	0.052 0.051	
3	5.47- 5.99	1.12 0.94	0.165 0.140	0.013 0.009	1.00 1.12	0.013 0.010	
Σ Q _{sw} =						0.215	

Therefore, the deformation coefficient Q is expressed by
Q = 21.189 + 0.215 = 21.404

Displacement Calculation

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:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{11} + D$$
$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_b = 31256 \text{ kN/m}^3$
Calculated value $\beta = 0.31155 \text{ m}^{-1}$

Penetration length of SSP $D = 0.77 + \frac{3}{0.312} = 10.40 \text{ m}$
Whole length of SSP $L = 5.99 - 0.40 + 10.40 = 15.99 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 61629 \text{ kN/m}^3$
Calculated value $\beta = 0.36918 \text{ m}^{-1}$

Penetration length of SSP $D = 0.77 + \frac{3}{0.369} = 8.90 \text{ m}$
Whole length of SSP $L = 5.99 - 0.40 + 8.90 = 14.49 \text{ m}$

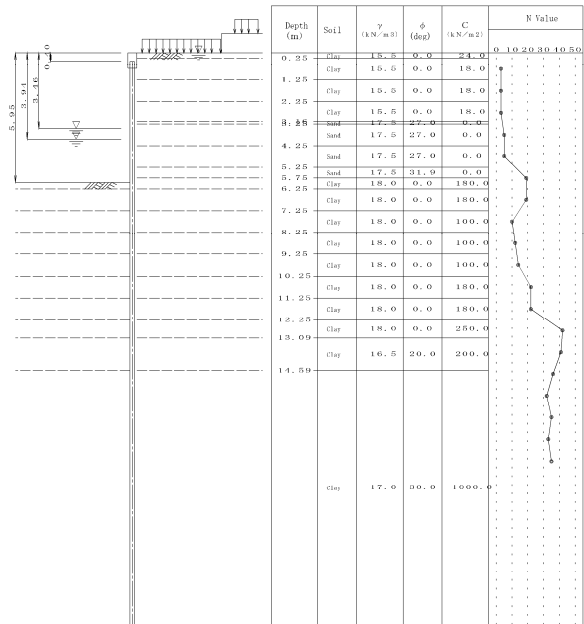
Therefore, the total length of the sheet pile is 16.00 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H _H 750 -250 -14 -22 -18			
Inertia sectional moment	I (cm ⁴)	414700	Normal Condition	Seismic Condition	
Sectional Modulus	Z (cm ³)	7640			
Maximum bending moment	Mmax (kN · m · m)		785.58	780.15	
Stress intensity	σ (N/mm ²)		118 (180)	116 (270)	
Lateral displacement	δ (mm)		49.88 (50.0)	40.92 (50.0)	
Penetration depths	D (m)		10.40	8.90	
Whole length of SSP	L (m)	16.00			

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 5.95 \text{ m}$
Depth from coping top to rear side ground $H_0 = 0.00 \text{ m}$
Depth from coping top to SSP top $H_R = 0.40 \text{ m}$
Landside WL $L_{wa} = 0.00 \text{ m}$ (Normal Condition)
 $L_{wa} = 0.00 \text{ m}$ (Seismic Condition)
Riverside WL $L_{wp} = 3.94 \text{ m}$ (Normal Condition)
 $L_{wp} = 3.46 \text{ m}$ (Seismic Condition)

Block No. : L-17
Sta. : 10+020~10+360

Design Cross Section : Sta 10+100
Boring Name : BMLL-29

Specification : SSP SP-10H
(Combined) : H 850-250-14-22-18

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered
Angle of rupture (clayey soil) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h^2 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_H = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

No	Depth m	N Value	No	Depth m	N Value
1	0.75	3	11	10.75	22
2	1.75	3	12	11.75	22
3	2.75	3	13	12.75	42
4	3.75	5	14	13.75	41
5	4.75	5	15	14.75	36
6	5.75	19	16	15.75	32
7	6.75	19	17	16.75	35
8	7.75	10	18	17.75	33
9	8.75	12	19	18.75	35
10	9.75	14			

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.7 Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	0.25	0.25
2	1.25	1.00
3	2.25	1.00
4	3.16	0.91
5	3.25	0.09
6	4.25	1.00
7	5.25	1.00
8	5.75	0.50
9	6.25	0.50
10	7.25	1.00
11	8.25	1.00
12	9.25	1.00
13	10.25	1.00
14	11.25	1.00
15	12.25	1.00
16	13.09	0.84
17	14.59	1.50
18	25.30	10.71

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C	a	k ¹	ζ (degree)	Normal Condition	Seismic Condition
1	0.25	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200		Auto	Auto
2	1.25	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200		Auto	Auto
3	2.25	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200		Auto	Auto
4	3.16	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200		Auto	Auto
5	4.25	S	7.0	17.50	7.70	27.0	0.0	0.0	0.200		Auto	Auto
6	4.25	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200		Auto	Auto
7	5.25	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200		Auto	Auto
8	5.25	S	19.0	17.50	7.70	31.9	0.0	0.0	0.200		Auto	Auto
9	6.25	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200		Auto	Auto
10	7.25	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200		Auto	Auto
11	8.25	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200		Auto	Auto
12	9.25	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200		Auto	Auto
13	10.25	C	14.0	18.00	8.20	0.0	100.0	0.0	0.200		Auto	Auto
14	11.25	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200		Auto	Auto
15	12.25	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200		Auto	Auto
16	13.25	C	42.0	18.00	8.20	0.0	200.0	0.0	0.200		Auto	Auto
17	14.99	C	63.5	18.00	7.70	28.0	200.0	0.0	0.200		Auto	Auto
18	25.30	C	121.5	17.00	7.20	38.0	1000.0	0.0	0.200		Auto	Auto

Figure 1: A technical drawing of a staircase layout. The drawing shows a staircase with a total height of 5.25 and a total width of 10.00. The staircase is divided into 8 steps, each with a height of 0.656 and a width of 1.25. The drawing includes a side view of the staircase and a top view showing the layout of the steps. The side view shows the staircase starting from a 'Floor' level and ending at a 'Roof' level. The top view shows the staircase layout with dimensions for each step and the total dimensions. The drawing is labeled 'Figure 1' and 'Figure 2'.

No	Depth. m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ_{str} kN/m ²	Angle of Rupture ζ degree
1	5.95 ~ 5.75	Clay	0.0	15.0	180.0	39.59	10.24	58.31	45.00

Section	Width (m)	Height (m)
1	4.00	11.90
2	36.00	11.90

No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	4.00	4.00	40.00	40.00	0.90	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	0.35	3.95	5.0	0.0
2	4.60	14.60	10.0	5.0

2	5.75 – 5.25	Sand	31.9	15.0	0.0	37.95	10.24	56.35	58.11
3	5.25 – 4.25	Sand	27.0	15.0	0.0	34.10	10.24	51.45	54.81
4	4.25 – 3.25	Sand	27.0	15.0	0.0	26.40	10.24	41.65	54.81
5	3.25 – 3.16	Sand	27.0	15.0	0.0	18.70	10.24	31.85	54.81
6	3.16 – 2.25	Clay	0.0	15.0	18.0	18.01	10.24	30.97	45.00
7	2.25 – 1.25	Clay	0.0	15.0	18.0	12.82	10.24	22.05	45.00
8	1.25 – 0.25	Clay	0.0	15.0	18.0	7.13	10.24	12.25	45.00
9	0.25 – 0.00	Clay	0.0	15.0	24.0	1.42	10.24	2.45	45.00
10		embankment	30.0	—	0.0	17.10	10.00	0.00	60.00

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

C cohesive force of soil (kN/m²)

No	Angle of Repose α degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.20	0.00	0.00	0.20	0.20
2	58.11	0.50	0.20	0.20	0.51	0.70
3	54.81	1.00	0.51	0.70	1.22	1.70
4	54.81	1.00	1.22	1.70	1.92	2.70
5	54.81	0.09	1.92	2.70	1.98	2.79
6	45.00	0.91	1.98	2.79	2.89	3.70
7	45.00	1.00	2.89	3.70	3.89	4.70
8	45.00	1.00	3.89	4.70	4.89	5.70
9	45.00	0.25	4.89	5.70	5.14	5.95
10	60.00	0.90	5.14	5.95	5.66	6.85

From the above table, the loading width (L) on the ground surface is 5.14 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	1.28	24.02
Σ			24.02

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

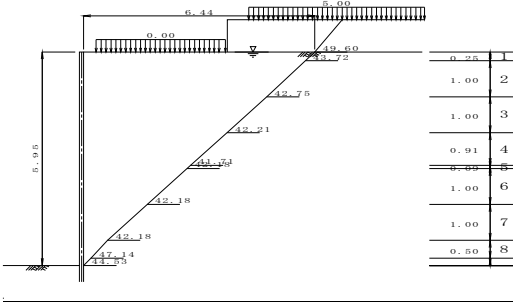
No	Q kN/m ²	l m	Qxl kN/m
1	5.0	3.60	18.00
2	10.0	1.06	10.65
Σ			28.65

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{24.02 + 28.65 + 0.00}{5.14}$$
$$= 10.24 \text{ kN/m}^2$$

2.2 Seismic 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	γ_{wet} kN/m ³	k (%)	θ degree	Angle of Rupture ζ degree
1	0.00	Clay	10.0	10.0	0.00	0.00	0.00	19.0	0.00	10.0	10.0
2	0.25	Sand	10.0	10.0	0.00	4.75	5.00	19.0	0.00	10.0	10.0
3	0.50	Sand	10.0	10.0	0.00	9.50	10.00	19.0	0.00	10.0	10.0
4	0.75	Sand	10.0	10.0	0.00	14.25	10.00	19.0	0.00	10.0	10.0
5	1.00	Sand	10.0	10.0	0.00	19.00	10.00	19.0	0.00	10.0	10.0
6	1.25	Sand	10.0	10.0	0.00	23.75	10.00	19.0	0.00	10.0	10.0
7	1.50	Sand	10.0	10.0	0.00	28.50	10.00	19.0	0.00	10.0	10.0
8	1.75	Sand	10.0	10.0	0.00	33.25	10.00	19.0	0.00	10.0	10.0
9	2.00	Sand	10.0	10.0	0.00	38.00	10.00	19.0	0.00	10.0	10.0
10	2.25	Sand	10.0	10.0	0.00	42.75	10.00	19.0	0.00	10.0	10.0

From the above table, the loading width (L) on the ground surface is 6.44 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	2.54	48.28
Σ			48.28

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	Qxl kN/m
1	0.0	3.60	0.00
2	5.0	2.61	13.05
Σ			13.05

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{48.28 + 13.03 + 0.00}{6.44}$$
$$= 9.52 \text{ kN/m}^2$$

1	5.95-5.75	Clay	0.0	15.0	180.0	39.59	9.52	58.31	0.200	11.31	44.53
2	5.75-5.25	Sand	31.9	15.0	0.0	37.95	9.52	56.35	0.200	11.31	47.14
3	5.25-4.25	Sand	27.0	15.0	0.0	34.10	9.52	51.45	0.200	11.31	42.18
4	4.25-3.25	Sand	27.0	15.0	0.0	26.40	9.52	41.65	0.200	11.31	42.18
5	3.25-3.16	Sand	27.0	15.0	0.0	18.70	9.52	31.85	0.200	11.31	42.18
6	3.16-2.25	Clay	0.0	15.0	18.0	18.01	9.52	30.97	0.200	11.31	41.71
7	2.25-1.25	Clay	0.0	15.0	18.0	12.82	9.52	22.05	0.200	11.31	42.21
8	1.25-0.25	Clay	0.0	15.0	18.0	7.13	9.52	12.25	0.200	11.31	42.75
9	0.25-0.00	Clay	0.0	15.0	24.0	1.42	9.52	2.45	0.200	11.31	43.72
10		embankment	30.0	—	0.0	17.10	5.00	0.00	0.200	11.31	49.60

Major collapse angle of Sand, intermediate soil, and split rock

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

Major collapse angle of cohesive soil

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

Where,

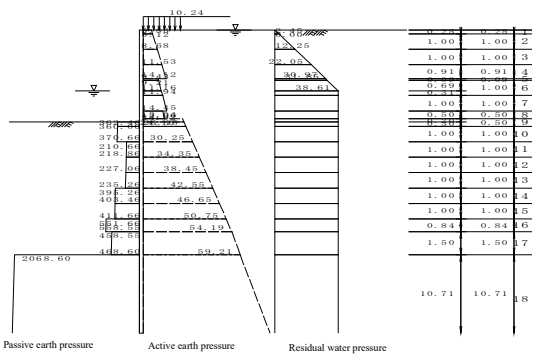
- ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)
- θ : earthquake combination angle (degree)
 $\theta = \tan^{-1} k$ or $\theta = \tan^{-1} k'$
- γ : unit weight of soil (kN/m³) (ascending force considered under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

2.2.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X(m)	Y(m)	X(m)	Y(m)
1	44.53	0.20	0.00	0.00	0.20	0.20
2	47.14	0.50	0.20	0.20	0.67	0.70
3	42.18	1.00	0.67	0.70	1.77	1.70
4	42.18	1.00	1.77	1.70	2.87	2.70
5	42.18	0.09	2.87	2.70	2.97	2.79
6	41.71	0.91	2.97	2.79	4.00	3.70
7	42.21	1.00	4.00	3.70	5.10	4.70
8	42.75	1.00	5.10	4.70	6.18	5.70
9	43.72	0.25	6.18	5.70	6.44	5.95
10	49.60	0.90	6.44	5.95	7.21	6.85

3 Lateral Forth

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	$\Sigma \gamma h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00-0.25	Clay	5.7	24.0	10.236	11.661	—
2	0.25-1.25	Clay	5.7	18.0	11.661	17.361	—
3	1.25-2.25	Clay	5.7	18.0	17.361	23.061	—
4	2.25-3.16	Clay	5.7	18.0	23.061	28.248	—
5	3.16-3.25	Sand	7.7	27.0	28.248	0.33738	0.32589
6	3.25-3.94	Sand	7.7	27.0	28.941	0.33738	0.32589
7	3.94-4.25	Sand	7.7	27.0	34.254	0.33738	0.32589
8	4.25-5.25	Sand	7.7	27.0	36.641	0.33738	0.32589
9	5.25-5.75	Sand	7.7	31.9	44.341	0.28015	0.27060
10	5.75-5.95	Clay	8.2	180.0	48.191	—	—
11	5.95-6.25	Clay	8.2	180.0	49.831	—	—
12	6.25-7.25	Clay	8.2	180.0	52.291	—	—

13	7.25-8.25	Clay	8.2	—	100.0 100.0	60.491 68.691	—	—
14	8.25-9.25	Clay	8.2	—	100.0 100.0	68.691 76.891	—	—
15	9.25-10.25	Clay	8.2	—	100.0 100.0	76.891 85.091	—	—
16	10.25-11.25	Clay	8.2	—	180.0 180.0	85.091 93.291	—	—
17	11.25-12.25	Clay	8.2	—	180.0 180.0	93.291 101.491	—	—
18	12.25-13.09	Clay	8.2	—	250.0 250.0	101.491 108.379	—	—
19	13.09-14.59	Clay	6.7	—	200.0 200.0	108.379 118.429	—	—
20	14.59-25.30	Clay	7.2	—	1000.0 1000.0	118.429 195.541	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma \cdot h + Q_p$ kN/m2	Kp	$K_p \times \cos \delta$
11	5.95-6.25	Clay	8.2	0.0	180.0 180.0	0.000 2.460	—	—
12	6.25-7.25	Clay	8.2	0.0	180.0 180.0	2.460 10.660	—	—
13	7.25-8.25	Clay	8.2	0.0	100.0 100.0	10.660 18.860	—	—
14	8.25-9.25	Clay	8.2	0.0	100.0 100.0	18.860 27.060	—	—
15	9.25-10.25	Clay	8.2	0.0	100.0 100.0	27.060 35.260	—	—
16	10.25-11.25	Clay	8.2	0.0	180.0 180.0	35.260 43.460	—	—
17	11.25-12.25	Clay	8.2	0.0	180.0 180.0	43.460 51.660	—	—
18	12.25-13.09	Clay	8.2	0.0	250.0 250.0	51.660 58.548	—	—
19	13.09-14.59	Clay	6.7	20.0	200.0 200.0	58.548 68.598	—	—
20	14.59-25.30	Clay	7.2	30.0	1000.0 1000.0	68.598 145.710	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active		Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pw kN/m2	Pw kN/m2	Pp kN/m2	
1	0.00-0.25	-37.76 -36.34	5.12 5.83	5.12 5.83	0.00 2.45	—	—
2	0.25-1.25	-24.34 -18.64	5.83 8.68	5.83 8.68	2.45 12.25	—	—
3	1.25-2.25	-18.64 -12.94	8.68 11.53	8.68 11.53	12.25 22.05	—	—
4	2.25-3.16	-12.94 -7.75	11.53 14.12	11.53 14.12	22.05 30.97	—	—
5	3.16-3.25	9.21 9.43	—	9.21 9.43	30.97 31.85	—	—
6	3.25-3.94	9.43 11.16	—	9.43 11.16	31.85 38.61	—	—
7	3.94-4.25	11.16 11.94	—	11.16 11.94	38.61 38.61	—	—
8	4.25-5.25	11.94 14.45	—	11.94 14.45	38.61 38.61	—	—
9	5.25-5.75	12.00 13.04	—	12.00 13.04	38.61 38.61	—	—
10	5.75-5.95	-311.81 -310.17	24.10 24.92	24.10 24.92	38.61 38.61	—	—
11	5.95-6.25	-310.17 -307.71	24.92 26.15	24.92 26.15	38.61 38.61	360.00 362.46	—
12	6.25-7.25	-307.71 -299.51	26.15 30.25	26.15 30.25	38.61 38.61	362.46 370.66	—
13	7.25-8.25	-139.51 -131.31	30.25 34.35	30.25 34.35	38.61 38.61	210.66 218.86	—
14	8.25-9.25	-131.31 -123.11	34.35 38.45	34.35 38.45	38.61 38.61	218.86 227.06	—
15	9.25-10.25	-123.11 -114.91	38.45 42.55	38.45 42.55	38.61 38.61	227.06 235.26	—
16	10.25-11.25	-274.91 -266.71	42.55 46.65	42.55 46.65	38.61 38.61	395.26 403.46	—
17	11.25-12.25	-266.71 -258.51	46.65 50.75	46.65 50.75	38.61 38.61	403.46 411.66	—
18	12.25-13.09	-398.51 -391.62	50.75 54.19	50.75 54.19	38.61 38.61	551.66 558.55	—
19	13.09-14.59	-291.62 -281.57	54.19 59.21	54.19 59.21	38.61 38.61	458.55 468.60	—
20	14.59-25.30	-1881.57 -1804.46	59.21 97.77	59.21 97.77	38.61 38.61	2008.60 2145.71	—

- Formula for active earth pressure

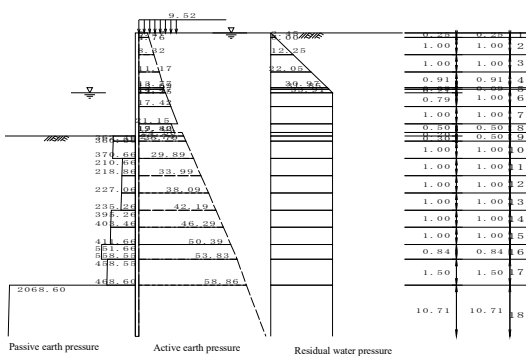
Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma \cdot h + Q - 2 \cdot C$
 $P_{a1} = K_a \cdot (\Sigma \gamma \cdot h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

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

3.2 Seismic Condition



The dotted line in the figure shows the main earth pressure strength Pa2 using the consolidation equilibrium coefficient.

3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma \cdot h + Q$ kN/m2	$\gamma \cdot h \cdot w$ kN/m2	k (k')	θ degree	Ka	$K_a \times \cos \delta$	ζ degree
1	0.00-0.25	Clay	5.7	—	24.0 24.0	9.52 10.95	0.00 2.45	0.200 0.200	11.31 11.31	—	—	43.82 43.72
2	0.25-1.25	Clay	5.7	—	18.0 18.0	10.95 16.65	2.45 12.25	0.200 0.200	11.31 11.31	—	—	43.27 42.75
3	1.25-2.25	Clay	5.7	—	18.0 18.0	16.65 22.35	12.25 22.05	0.200 0.200	11.31 11.31	—	—	42.75 42.21
4	2.25-3.16	Clay	5.7	—	18.0 18.0	22.35 27.53	22.05 30.97	0.200 0.200	11.31 11.31	—	—	42.21 41.71

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

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

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma \cdot h + Q_p$ kN/m2	$\gamma \cdot h \cdot w$ kN/m2	k (k')	θ degree	Kp	$K_p \times \cos \delta$
11	5.95-6.25	Clay	8.20	0.0	180.0 180.0	0.000 2.460	0.00 2.94	0.200 0.200	11.31 11.31	—	—
12	6.25-7.25	Clay	8.20	0.0	180.0 180.0	2.460 10.660	2.94 12.74	0.200 0.200	11.31 11.31	—	—

13	7.25- 8.25	Clay	8.20	0.0	100.0 100.0	10.660 18.860	12.74 22.54	0.200 0.200	11.31 11.31	=====	=====
14	8.25- 9.25	Clay	8.20	0.0	100.0 100.0	18.860 27.060	22.54 32.34	0.200 0.200	11.31 11.31	=====	=====
15	9.25- 10.25	Clay	8.20	0.0	100.0 100.0	27.060 35.260	32.34 42.14	0.200 0.200	11.31 11.31	=====	=====
16	10.25- 11.25	Clay	8.20	0.0	180.0 180.0	35.260 43.460	42.14 51.94	0.200 0.200	11.31 11.31	=====	=====
17	11.25- 12.25	Clay	8.20	0.0	180.0 180.0	43.460 51.660	51.94 61.74	0.200 0.200	11.31 11.31	=====	=====
18	12.25- 13.09	Clay	8.20	0.0	250.0 250.0	51.660 58.548	61.74 69.97	0.200 0.200	11.31 11.31	=====	=====
19	13.09- 14.59	Clay	6.70	20.0	200.0 200.0	58.548 68.598	69.97 84.67	0.200 0.200	11.31 11.31	=====	=====
20	14.59- 25.30	Clay	7.20	30.0	1000.0 1000.0	68.598 145.710	84.67 189.63	0.200 0.200	11.31 11.31	=====	=====

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2		
1	0.00- 0.25	-36.54 -34.81	4.76 5.47	4.76 5.47	0.00 2.45	=====		
2	0.25- 1.25	-22.80 -15.87	5.47 8.32	5.47 8.32	2.45 12.25	=====		
3	1.25- 2.25	-15.87 -8.90	8.32 11.17	8.32 11.17	12.25 22.05	=====		
4	2.25- 3.16	-8.90 -2.53	11.17 13.77	11.17 13.77	22.05 30.97	=====		
5	3.16- 3.25	13.35 13.69	=====	13.35 13.69	30.97 31.85	=====		
6	3.25- 3.46	13.69 14.47	=====	13.69 14.47	31.85 33.91	=====		
7	3.46- 4.25	14.47 17.42	=====	14.47 17.42	33.91 33.91	=====		
8	4.25- 5.25	17.42 21.15	=====	17.42 21.15	33.91 33.91	=====		
9	5.25- 5.75	17.82 19.40	=====	17.82 19.40	33.91 33.91	=====		
10	5.75- 5.95	-302.92 -300.95	23.74 24.56	23.74 24.56	33.91 33.91	=====		
11	5.95- 6.25	-300.95 -297.98	24.56 25.79	24.56 25.79	33.91 33.91	360.00 362.46		

12	6.25- 7.25	-297.98 -288.10	25.79 29.89	25.79 29.89	33.91 33.91	362.46 370.66		
13	7.25- 8.25	-227.96 -118.03	29.89 33.99	29.89 33.99	33.91 33.91	210.66 218.86		
14	8.25- 9.25	-118.03 -108.09	33.99 38.09	33.99 38.09	33.91 33.91	218.86 227.06		
15	9.25- 10.25	-108.09 -98.14	38.09 42.19	38.09 42.19	33.91 33.91	227.06 235.26		
16	10.25- 11.25	-258.42 -248.52	42.19 46.29	42.19 46.29	33.91 33.91	395.26 403.46		
17	11.25- 12.25	-248.52 -238.60	46.29 50.39	46.29 50.39	33.91 33.91	403.46 411.66		
18	12.25- 13.09	-378.74 -370.43	50.39 53.83	50.39 53.83	33.91 33.91	551.66 558.55		
19	13.09- 14.59	-270.33 -258.17	53.83 58.86	53.83 58.86	33.91 33.91	458.55 468.60		
20	14.59- 25.30	-1858.63 -1765.91	58.86 97.41	58.86 97.41	33.91 33.91	2968.60 2145.71		

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5

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

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

- Formula for passive earth pressure

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

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m2
1	3.46	0.00	0.00
2	4.46	1.00	2.71
3	5.46	2.00	3.83
4	5.95	2.49	4.27

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

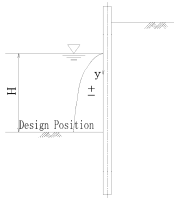
Where,

k_{hs} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

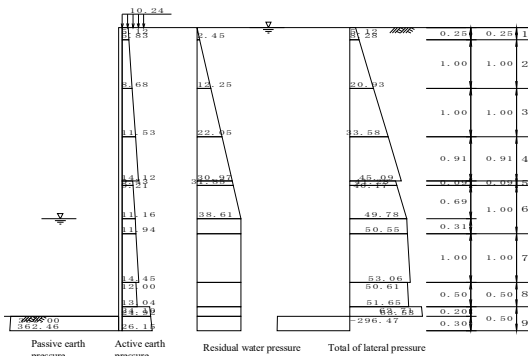
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

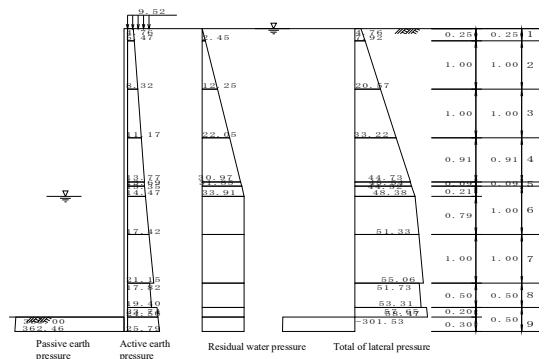
Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4.1 Normal Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.25	5.12 5.83	0.00 2.45	=====	5.12 8.28
2	0.25- 1.25	5.83 8.68	2.45 12.25	=====	8.28 20.93
3	1.25- 2.25	8.68 11.53	12.25 22.05	=====	20.93 33.58

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.25	4.76 5.47	0.00 2.45	=====	4.76 7.92
2	0.25- 1.25	5.47 8.32	2.45 12.25	=====	7.92 20.57

3	1.25- 2.25	8.32 11.17	12.25 22.65	———— ————	20.57 33.22
4	2.25- 3.16	11.17 13.77	22.65 30.97	———— ————	33.22 44.73
5	3.16- 3.25	13.35 13.69	30.97 31.85	———— ————	44.32 45.54
6	3.25- 3.46	13.69 14.47	31.85 33.91	———— ————	45.54 48.38
7	3.46- 4.25	14.47 17.42	33.91 33.91	———— ————	48.38 51.33
8	4.25- 5.25	17.42 21.15	33.91 33.91	———— ————	51.33 55.06
9	5.25- 5.75	17.82 19.40	33.91 33.91	———— ————	51.73 53.31
10	5.75- 5.95	23.74 24.56	33.91 33.91	———— ————	57.65 58.47
11	5.95- 6.25	24.56 25.79	33.91 33.91	360.00 362.46	301.53 302.76

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 : 0.00 m (GL -5.95 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{10} = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H = 10.00\text{m})$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

Material Name 10 H _H 850 -250 -14 -22 -18
Unit width $B = 1.0000 \text{ m}$
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.86$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 532300 \text{ cm}^4$ (original condition)
 $I = 457778 \text{ cm}^4$ (after reduction by corrosion and section)
Inertia sectional moment $EI = 200000 \times 10^3 \times 457778 \times 10^{-8} = 9.156 \times 10^6$

5.3 Seismic Condition

Assuming $K_h = 19021 \text{ kN/m}^3$,

$$\beta = 4 \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.268 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.73 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.95 m) and 3.73 m depth (GL -9.68 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.95	0.80	19.0	19.0	15.20
2	6.75	1.00	19.0	10.0	14.50
3	7.75	1.00	10.0	12.0	11.00
4	8.75	0.61	12.0	14.0	9.95
L = 3.73			Σ A =		52.66

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

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

$$= \frac{52.66}{3.73}$$

$$= 14.14$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 14.14 = 39581 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \alpha \times 39581 = 263872 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{10} (B/0.3)^{-3/4} = 263872 (10.00/0.3)^{-3/4} = 19021 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 19021 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth m	N Value	No	Depth m	N Value
1	0.75	3	11	10.75	22
2	1.75	3	12	11.75	22
3	2.75	3	13	12.75	42
4	3.75	5	14	13.75	41
5	4.75	5	15	14.75	36
6	5.75	19	16	15.75	32
7	6.75	19	17	16.75	35
8	7.75	10	18	17.75	33
9	8.75	12	19	18.75	35
10	9.75	14			

5.2 Normal Condition

Assuming $K_h = 9720 \text{ kN/m}^3$,

$$\beta = 4 \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.227 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.41 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.95 m) to 4.41 m depth (GL -10.36 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.95	0.80	19.0	19.0	15.20
2	6.75	1.00	19.0	10.0	14.50
3	7.75	1.00	10.0	12.0	11.00
4	8.75	1.00	12.0	14.0	13.00
5	9.75	0.61	14.0	18.8	9.95
L = 4.41			Σ A =		63.65

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

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

$$= \frac{63.65}{4.41}$$

$$= 14.45$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 14.45 = 40451 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \alpha \times 40451 = 134837 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{10} (B/0.3)^{-3/4} = 134837 (10.00/0.3)^{-3/4} = 9720 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 9720 kN/m³.

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.25	0.25	5.12 8.28	0.64 1.04	5.87 5.78	3.75 5.99
2	0.25- 1.25	1.00	8.28 20.93	4.14 10.47	5.37 5.03	22.22 52.68
3	1.25- 2.25	1.00	20.93 33.58	10.47 16.79	4.37 4.03	45.70 67.72
4	2.25- 3.16	0.91	33.58 45.09	15.28 20.52	3.40 3.09	51.90 63.47
5	3.16- 3.25	0.09	40.17 41.28	1.81 1.86	2.76 2.73	4.99 5.07
6	3.25- 3.94	0.69	41.28 49.78	14.24 17.17	2.47 2.24	35.18 38.47
7	3.94- 4.25	0.31	49.78 50.55	7.72 7.84	1.91 1.80	14.71 14.13
8	4.25- 5.25	1.00	50.55 53.06	25.28 26.53	1.37 1.05	34.54 27.42
9	5.25- 5.75	0.50	50.61 51.65	12.65 12.91	0.53 0.37	6.75 4.73
10	5.75- 5.95	0.20	62.71 63.53	6.27 6.35	0.13 0.07	0.84 0.42
Σ P =			219.96	Σ M =	500.67	

P_0 : active earth pressure + residual water pressure - passive earth pressure
P : load $P_s \times h/2 \times B$
B : unit width = 1.000 m
Y : height of acting position from imaginary riverbed
M : moment by load $P \times Y$

Arbitrary load lateral load $P_1 = 0.0 \text{ kN/m}$
depth to acting position $H_1 = 0.0 \text{ m}$
moment $M_0 = 0.00 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_m = 0.00 \text{ m}$
Height from riverbed to top of coping H = 5.95 m
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_0 by arbitrary load is as below
 $M_0 = P_1 \cdot (H + L_k - H_1) + M_0 = 0.00 \text{ kN} \cdot \text{m}$
 h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_0}{\Sigma P + P_1}$$

$$= \frac{500.67}{219.96} = 2.28 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.25	0.25	4.76 7.92	0.59 0.99	5.87 5.78	3.49 5.73
2	0.25- 1.25	1.00	7.92 20.57	3.96 10.29	5.37 5.03	21.26 51.77

3	1.25- 2.25	1.00	20.57 33.22	10.29 16.61	4.37 4.03	44.92 67.00
4	2.25- 3.16	0.91	33.22 44.73	15.12 20.35	3.40 3.09	51.34 62.96
5	3.16- 3.25	0.89	44.32 45.54	1.99 2.05	2.76 2.73	5.50 5.59
6	3.25- 3.46	0.21	45.54 48.38	4.78 5.08	2.63 2.56	12.57 13.00
7	3.46- 4.25	0.79	48.38 51.33	19.11 20.27	2.23 1.96	42.55 39.81
8	4.25- 5.25	1.00	51.33 55.06	25.66 27.53	1.37 1.03	35.07 28.45
9	5.25- 5.75	0.50	51.73 53.31	12.93 13.33	0.53 0.57	6.90 4.89
10	5.75- 5.95	0.20	57.65 58.47	5.76 5.85	0.13 0.07	0.77 0.39
$\Sigma P = 222.55$ $\Sigma M = 503.97$						

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

Arbitrary load lateral load $P_l = 0.0 \text{ kN/m}$
 depth to acting position $H_l = 0.00 \text{ m}$
 moment $M_m = 0.0 \text{ kN} \cdot \text{m/m}$
 depth to acting position $H_m = 0.00 \text{ m}$
 Height from riverbed to top of coping $H = 5.95 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_k = P_l \cdot (H + L_k - H_l) + M_m = 0.00 \text{ kN} \cdot \text{m}$

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hiv} kN/m ²	Loads P _{hiv} kN	Arm length Y m	Moment M _{hiv} kN · m
1	3.46- 4.46	1.00	0.0 2.7	0.00 1.35	2.16 1.82	0.00 2.47
2	4.46- 5.46	1.00	2.7 3.8	1.35 1.91	1.16 0.82	1.57 1.58
3	5.46- 5.95	0.49	3.8 4.3	0.94 1.05	0.33 0.16	0.31 0.17
$\Sigma P_{hiv} = 6.60$ $\Sigma M_{hiv} = 6.09$						

$$\begin{aligned}
 h_0 &= \text{Height of acting position of } P_0 \text{ from imaginary riverbed} \\
 h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{hiv}}{\Sigma P + P_i + \Sigma P_{hiv}} \\
 &= \frac{510.05}{229.16} = 2.23 \text{ m}
 \end{aligned}$$

6.2 Sectional Force

Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.88$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 8840 \text{ cm}^3$ (original condition)
 $Z = 7779 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{695.13 \times 10^6}{7779 \times 10^3} = 89 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{671.39 \times 10^6}{7779 \times 10^3} = 86 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 0.25	5.87 5.78	0.986 0.972	0.326 0.319	0.64 1.04	0.209 0.331
2	0.25- 1.25	5.37 5.03	0.902 0.846	0.284 0.257	4.14 10.47	1.178 2.689
3	1.25- 2.25	4.37 4.03	0.734 0.678	0.203 0.178	10.47 16.79	2.129 2.986
4	2.25- 3.16	3.40 3.09	0.571 0.520	0.112 0.112	15.28 20.52	2.016 2.292
5	3.16- 3.25	2.76 2.73	0.464 0.459	0.091 0.089	1.81 1.86	0.164 0.166
6	3.25- 3.94	2.47 2.24	0.415 0.376	0.074 0.062	14.24 17.17	1.057 1.064
7	3.94- 4.25	1.91 1.80	0.320 0.303	0.046 0.041	7.72 7.84	0.354 0.334
8	4.25- 5.25	1.37 1.03	0.230 0.174	0.024 0.014	25.28 26.53	0.616 0.377
9	5.25- 5.75	0.53 0.37	0.090 0.062	0.004 0.002	12.65 12.91	0.049 0.024
10	5.75- 5.95	0.13 0.07	0.022 0.011	0.000 0.000	6.27 6.35	0.002 0.000
$\Sigma Q = 18.026$						

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

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

Material name 10 H _ H 850 -250 -14 -22 -18
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.86$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 532300 \text{ cm}^4$ (original condition)
 $I = 457778 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 457778 \times 10^{-8} = 9.156 \times 10^5$

$$\begin{aligned}
 \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} \\
 \phi_a &= \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})
 \end{aligned}$$

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_b = 9720 \text{ kN/m}^3$
 calculated value $\beta = 0.22697 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 219.96 \text{ kN/m}$
 height of acting position of load $h_0 = 2.28 \text{ m}$
 moment $M_0 = 500.67 \text{ kN} \cdot \text{m/m}$

in consideration of $\psi_{\max} = 1.388$,
 maximum moment $M_{\max} = 695.13 \text{ kN} \cdot \text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 2.014 \text{ m}$
 depth of l^{st} fixed point $l_i = 5.474 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_b = 19021 \text{ kN/m}^3$
 calculated value $\beta = 0.26846 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 229.16 \text{ kN/m}$
 height of acting position of load $h_0 = 2.23 \text{ m}$
 moment $M_0 = 510.05 \text{ kN} \cdot \text{m/m}$

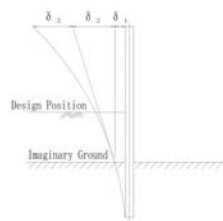
in consideration of $\psi_{\max} = 1.316$,
 maximum moment $M_{\max} = 671.39 \text{ kN} \cdot \text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 1.592 \text{ m}$
 depth of l^{st} fixed point $l_i = 4.518 \text{ m}$

6.3 Stress Intensity

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

Material Name 10 H _ H 850 -250 -14 -22 -18

Displacement Calculation



$$\begin{aligned}
 \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\
 &= \frac{(1 + 0.2270 \times 2.28) \times 219.96}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2270^3} = 0.01558 \text{ m} \\
 \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) \\
 &= \frac{(1 + 2 \times 0.2270 \times 2.28) \times 219.96}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2270^2} \times (5.95 + 0.00) = 0.02821 \text{ m} \\
 \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\
 &= \frac{18.03 \times (5.95 + 0.00)^3}{2.00 \times 10^8 \times 457778 \times 10^{-8}} = 0.00415 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 \delta &= \delta_1 + \delta_2 + \delta_3 \\
 &= 0.01558 + 0.02821 + 0.00415 \\
 &= 0.04794 \text{ m} \\
 \text{Size} &= 47.94 \leq \delta a = 50.00 \text{ mm}
 \end{aligned}$$

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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 0.25	5.87 5.78	0.986 0.972	0.326 0.319	0.59 0.99	0.194 0.316
2	0.25- 1.25	5.37 5.03	0.902 0.846	0.284 0.257	16.29 16.61	1.127 2.643
3	1.25- 2.25	4.37 4.03	0.734 0.678	0.203 0.178	10.29 16.61	2.092 2.954

4	2.25- 3.16	3.40 3.09	0.571 0.520	0.132 0.112	15.12 20.35	1.994 2.274
5	3.16- 3.25	2.76 2.73	0.464 0.459	0.091 0.089	1.99 2.05	0.181 0.183
6	3.25- 3.46	2.63 2.56	0.442 0.430	0.083 0.079	4.78 5.08	0.398 0.403
7	3.46- 4.25	2.23 1.96	0.374 0.330	0.061 0.048	19.11 20.27	1.171 0.982
8	4.25- 5.25	1.37 1.03	0.230 0.174	0.024 0.014	25.66 27.53	0.625 0.391
9	5.25- 5.75	0.53 0.37	0.090 0.062	0.004 0.002	12.93 13.33	0.030 0.025
10	5.75- 5.95	0.13 0.07	0.022 0.011	0.000 0.000	5.76 5.85	0.001 0.000
$\Sigma Q =$					18.007	

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

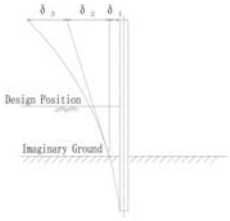
L_k : Depth from design position to imaginary ground

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

No	Depth m	Y m	α	ζ	Pkw kN	Qkw kN
1	3.46- 4.46	2.16 1.82	0.362 0.306	0.058 0.042	0.00 1.35	0.000 0.057
2	4.46- 5.46	1.16 0.82	0.194 0.138	0.018 0.009	1.35 1.91	0.024 0.017
3	5.46- 5.95	0.33 0.16	0.055 0.027	0.001 0.000	0.94 1.05	0.001 0.000
$\Sigma Qkw =$					0.100	

Therefore, the deformation coefficient Q is expressed by
Q = 18.007 + 0.100 = 18.107

Displacement Calculation



横方向地盤反力係数 K_h = 9720 kN/m³
特性値 β = 0.21858 m⁻¹

根入れ長 D = 0.00 + $\frac{3}{0.219}$ = 13.73 m
矢板全長 L = 5.95 - 0.40 + 13.73 = 19.28 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction K_h = 19021 kN/m³
Calculated value β = 0.25852 m⁻¹

Penetration length of SSP D = 0.00 + $\frac{3}{0.259}$ = 11.60 m
Whole length of SSP L = 5.95 - 0.40 + 11.60 = 17.15 m

Therefore, the total length of the sheet pile is 19.50 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H _ H 850 -250 -14 -22 -18			
				Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	532300			
Sectional Modulus	Z (cm ³)	8840			
Maximum bending moment	Mmax (kN · m · m)		695.13		671.39
Stress intensity	σ (N/mm ²)		89 (180)		86 (270)
Lateral displacement	δ (mm)		47.94 (50.0)		37.18 (35.0)
Penetration depths	D (m)		13.73		11.60
Whole length of SSP	L (m)	19.50			

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

$$= \frac{(1 + 0.2685 \times 2.23) \times 229.16}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2685^3} = 0.01033 \text{ m}$$

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

$$= \frac{(1 + 2 \times 0.2685 \times 2.23) \times 229.16}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2685^2} \times (5.95 + 0.00) = 0.02268 \text{ m}$$

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

$$= \frac{18.11 \times (5.95 + 0.00)^3}{2.00 \times 10^8 \times 457778 \times 10^{-8}} = 0.00417 \text{ m}$$

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

$$= 0.01033 + 0.02268 + 0.00417$$

$$= 0.03718 \text{ m}$$

$$\text{Size} = 37.18 \text{ mm} \leq \delta a = 75.00 \text{ mm}$$

Where,

δ₁ : Displacement at imaginary ground

δ₂ : Displacement by angle of inclination slope at imaginary ground

δ₃ : 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:

Material Name	10 H _ H 850 -250 -14 -22 -18
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 = 532300 cm ⁴ (original condition)
	I = 532300 cm ⁴ (after reduction by corrosion and section)
	EI = 200000 × 10 ³ × 532300 × 10 ⁻⁸ = 1.065 × 10 ⁶

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 follows:

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

$$L = H - H_{ik} + D$$

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction
Calculated value

Penetration length of SSP

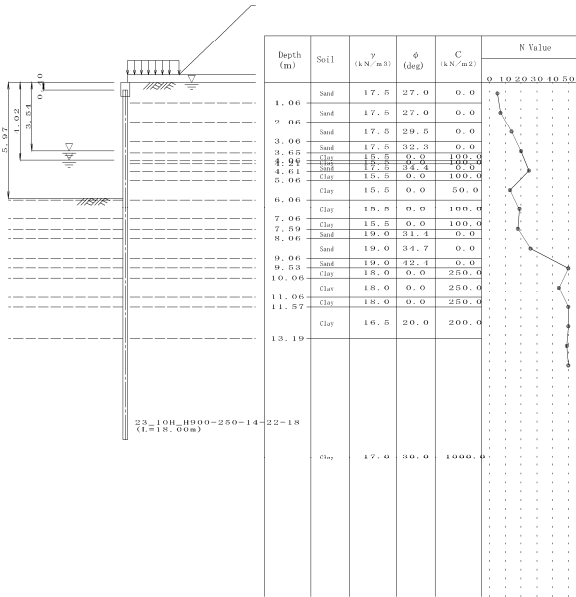
Block No. : L-18
Sta. : 10+360~10+520

Design Cross Section : Sta 10+420
Boring Name : BMLL-30

Specification : SSP SP-10H
(Combined) : H 900-250-14-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed
Depth from coping top to rear side ground
Depth from coping top to SSP top
Landside WL
Riverside WL

H = 5.97 m
H₀ = 0.00 m
H_h = 0.40 m
L_{wa} = 0.00 m (Normal Condition)
L_{wa} = 0.00 m (Seismic Condition)
L_{wp} = 4.02 m (Normal Condition)
L_{wp} = 3.54 m (Seismic Condition)

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	0.56	5	11	10.56	44
2	1.56	7	12	11.56	50
3	2.56	14	13	12.56	50
4	3.56	20	14	13.56	49
5	4.56	25	15	14.56	50
6	5.56	13			
7	6.56	19			
8	7.56	18			
9	8.56	26			
10	9.56	50			

1.6 Vertical Load

Vertical load on landside
Vertical load on riverside

calculated in consideration of embankment shape on landside
not considered

1.7 Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.06	1.06
2	2.06	1.00
3	3.06	1.00
4	3.65	0.59
5	4.06	0.41
6	4.21	0.15
7	4.61	0.40
8	5.06	0.45
9	6.06	1.00
10	7.06	1.00
11	7.59	0.53
12	8.06	0.47
13	9.06	1.00
14	9.53	0.47
15	10.06	0.53
16	11.06	1.00
17	11.57	0.51
18	13.19	1.62
19	25.40	12.21

No	Depth m	earth Soil	N Value	γ kN/m³	γ' kN/m³	φ degree	C kN/m²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.06	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	2.06	S	7.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	3.06	S	14.0	17.50	7.70	29.5	0.0	0.0	0.200	Auto	Auto
4	3.65	S	20.0	17.50	7.70	32.3	0.0	0.0	0.200	Auto	Auto
5	4.06	C	20.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
6	4.21	C	25.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
7	4.61	S	25.0	17.50	7.70	34.4	0.0	0.0	0.200	Auto	Auto
8	5.06	C	25.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
9	6.06	C	13.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto
10	7.06	C	19.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
11	7.59	C	18.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
12	8.06	S	18.0	19.00	9.20	31.4	0.0	0.0	0.200	Auto	Auto
13	9.06	S	26.0	19.00	9.20	34.7	0.0	0.0	0.200	Auto	Auto
14	9.53	S	50.0	19.00	9.20	42.4	0.0	0.0	0.200	Auto	Auto
15	10.06	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	11.06	C	44.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	11.57	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	13.19	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
19	25.40	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

Note) depth : from top of coping to bottom of the layer C₀ : soil adhesion

1.3 Applied Formula

Formula for generated stress
Penetration depths

Chang's formula
$$L = \frac{3}{\beta}$$

1.4 Design Constant

Unit weight of water
Type of water pressure
Lateral pressure
Study case
Design earthquake intensity
Dynamic water pressure due to earthquake considered as distributed load
Arbitrary load
Depth of acting point
Moment
Depth of acting point

γ_w = 9.8 kN/m³
trapezoidal water pressure
calculated in consideration of site conditions
- Normal Condition
- Seismic Condition
k = 0.200
Pt = 13.7 kN/m (Normal Condition)
Pt' = 38.7 kN/m (Seismic Condition)
Ht = 0.0 m (Normal Condition)
Ht' = 0.0 m (Seismic Condition)
Mm = 0.00 kN·m/m (Normal Condition)
Mm' = 17.5 kN·m/m (Seismic Condition)
Hm' = 0.00 m (Seismic Condition)
Hm = 0.00 m (Normal Condition)
(*Depth* means distance from top of coping)

Wind load, Impact load
Minimum angle of rupture
Rear side angle of slope
Angle of rupture (clayey soil)
Equilibrium factor of compression

not considered
ζ₀ = 10 degrees
not considered
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$$

K_c = 0.50 (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula
Average N-value

$$K_b = K_{10} \left(\frac{B_b}{0.3} \right)^{-3/4}$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

B_b = 10.00 m
E₀ = 2800N
calculated from average N-value between imaginary riverbed and depth as 1/β

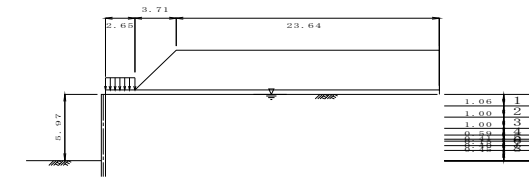
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil

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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m2	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m3	Seismic Condition kN/m3			Normal Condition degree	Seismic Condition degree
1	Sand	0.00	0.00	30.00	30.00	0.40	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	2.65	6.36	30.00	30.00	3.56	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m²	Seismic Condition kN/m²
1	0.00	2.65	5.0	0.0

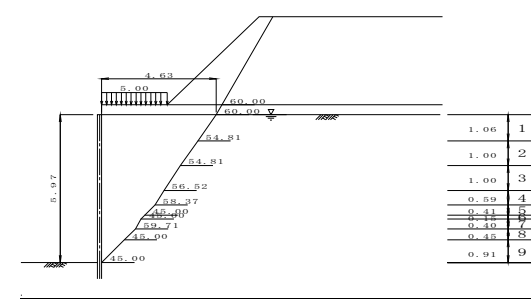
Angle of rupture in embankment
calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 900 -250 -14 -22 -18
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 597600 cm ⁴
Sectional factor	Z ₀	= 9470 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	= 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



8	54.81	1.00	3.18	3.91	3.88	4.91
9	54.81	1.06	3.88	4.91	4.63	5.97
10	60.00	0.40	4.63	5.97	4.86	6.37
11	60.00	3.56	4.86	6.37	6.92	9.93

From the above table, the loading width (L) on the ground surface is 4.63 m.

2.1.3 Acting Load by Embankment

No	γ, kN/m ³	A, m ²	γ × A, kN/m
1	19.0	1.90	36.07
2	19.0	4.93	93.65
Σ			129.72

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	Qxl, kN/m
1	5.0	2.65	13.25
Σ			13.25

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{129.72 + 13.25 + 0.00}{4.63}$$
$$= 30.87 \text{ kN/m}^2$$

2.1.1 Angle of Active Rupture

No	Depth, m	Soil	φ, degree	δ, degree	C, kN/m ²	Σ γ h, kN/m ²	Q, kN/m ²	γ wh, kN/m ²	Angle of Rupture, ζ, degree
1	5.97 ~ 5.06	Clay	0.0	15.0	50.0	42.13	30.87	58.51	45.00
2	5.06 ~ 4.61	Clay	0.0	15.0	100.0	36.94	30.87	49.59	45.00
3	4.61 ~ 4.21	Sand	34.4	15.0	0.0	34.38	30.87	45.18	59.71
4	4.21 ~ 4.06	Clay	0.0	15.0	100.0	31.30	30.87	41.26	45.00
5	4.06 ~ 3.65	Clay	0.0	15.0	100.0	30.44	30.87	39.79	45.00
6	3.65 ~ 3.06	Sand	32.3	15.0	0.0	28.11	30.87	35.77	58.37
7	3.06 ~ 2.06	Sand	29.5	15.0	0.0	23.56	30.87	29.99	56.52
8	2.06 ~ 1.06	Sand	27.0	15.0	0.0	15.86	30.87	20.19	54.81
9	1.06 ~ 0.00	Sand	27.0	15.0	0.0	8.16	30.87	10.39	54.81
10		embankment	30.0	—	0.0	75.24	0.00	0.00	60.00
11		embankment	30.0	—	0.0	67.64	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

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

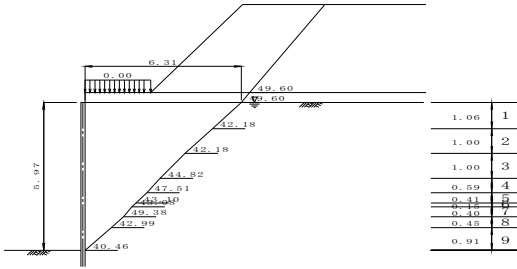
Angle of active rupture of clayey soil ζ is set as 45° since θ = 0°

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)
θ = tan⁻¹k or θ = tan⁻¹k'
γ: unit weight of soil (kN/m³) (ascending force considered under WL)
b: thickness of layer (m)
Q: surcharge load (kN/m²)
C: cohesive force of soil (kN/m²)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture, ζ, degree	Thickness, Z, m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.91	0.00	0.00	0.91	0.91
2	45.00	0.45	0.91	0.91	1.36	1.36
3	59.71	0.40	1.36	1.36	1.59	1.76
4	45.00	0.15	1.59	1.76	1.74	1.91
5	45.00	0.41	1.74	1.91	2.15	2.32
6	58.37	0.59	2.15	2.32	2.52	2.91
7	56.52	1.00	2.52	2.91	3.18	3.91

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ, degree	δ, degree	C, kN/m ²	Σ γ h, kN/m ²	Q, kN/m ²	γ wh, kN/m ²	θ (°)	θ, degree	Angle of Rupture, ζ, degree
1	5.97 ~ 5.06	Clay	0.0	15.0	50.0	42.13	47.05	58.51	0.200	11.31	40.46
2	5.06 ~ 4.61	Clay	0.0	15.0	100.0	36.94	47.05	49.59	0.200	11.31	42.99
3	4.61 ~ 4.21	Sand	34.4	15.0	0.0	34.38	47.05	45.18	0.200	11.31	49.38
4	4.21 ~ 4.06	Clay	0.0	15.0	100.0	31.30	47.05	41.26	0.200	11.31	43.08
5	4.06 ~ 3.65	Clay	0.0	15.0	100.0	30.44	47.05	39.79	0.200	11.31	43.10
6	3.65 ~ 3.06	Sand	32.3	15.0	0.0	28.11	47.05	35.77	0.200	11.31	47.51
7	3.06 ~ 2.06	Sand	29.5	15.0	0.0	23.56	47.05	29.99	0.200	11.31	44.82
8	2.06 ~ 1.06	Sand	27.0	15.0	0.0	15.86	47.05	20.19	0.200	11.31	42.18
9	1.06 ~ 0.00	Sand	27.0	15.0	0.0	8.16	47.05	10.39	0.200	11.31	42.18
10		embankment	30.0	—	0.0	75.24	0.00	0.00	0.200	11.31	49.60
11		embankment	30.0	—	0.0	67.64	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive 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 WL)
 h : thickness of layer (m)
 Q : surcharge load (kN/m²)
 C : cohesive force of soil (kN/m²)

2.2.2 Coordinates of Collapse Line

No	Angle of Rupture γ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	40.46	0.91	0.00	0.00	1.07	0.91
2	42.99	0.45	1.07	0.91	1.55	1.36
3	49.38	0.40	1.55	1.36	1.89	1.76
4	43.08	0.15	1.89	1.76	2.05	1.91
5	43.10	0.41	2.05	1.91	2.49	2.32
6	47.51	0.59	2.49	2.32	3.03	2.91
7	44.82	1.00	3.03	2.91	4.04	3.91
8	42.18	1.00	4.04	3.91	5.14	4.91
9	42.18	1.06	5.14	4.91	6.31	5.97
10	49.60	0.40	6.31	5.97	6.65	6.37
11	49.60	3.56	6.65	6.37	9.68	9.93

From the above table, the loading width (L) on the ground surface is 6.31 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	2.59	49.26
2	19.0	13.04	247.67
Σ			296.93

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/m ²	l m	Qxl kN/m
1	0.0	2.65	0.00
Σ			0.00

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

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

10	5.06- 5.97	Clay	5.7	—	50.0 50.0	67.816 73.003	—	—
11	5.97- 6.06	Clay	5.7	—	50.0 50.0	73.003 73.516	—	—
12	6.06- 7.06	Clay	5.7	—	100.0 100.0	73.516 79.216	—	—
13	7.06- 7.59	Clay	5.7	—	100.0 100.0	79.216 82.237	—	—
14	7.59- 8.06	Sand	9.2	31.4	—	82.237 86.561	0.28564 0.28564	0.27590 0.27590
15	8.06- 9.06	Sand	9.2	34.7	—	86.561 95.761	0.25078 0.25078	0.24223 0.24223
16	9.06- 9.53	Sand	9.2	42.4	—	95.761 100.085	0.18084 0.18084	0.17468 0.17468
17	9.53- 10.06	Clay	8.2	—	250.0 250.0	100.085 104.431	—	—
18	10.06- 11.06	Clay	8.2	—	250.0 250.0	104.431 112.631	—	—
19	11.06- 11.57	Clay	8.2	—	250.0 250.0	112.631 116.813	—	—
20	11.57- 13.19	Clay	6.7	—	200.0 200.0	116.813 127.667	—	—
21	13.19- 25.40	Clay	7.2	—	1000.0 1000.0	127.667 215.579	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

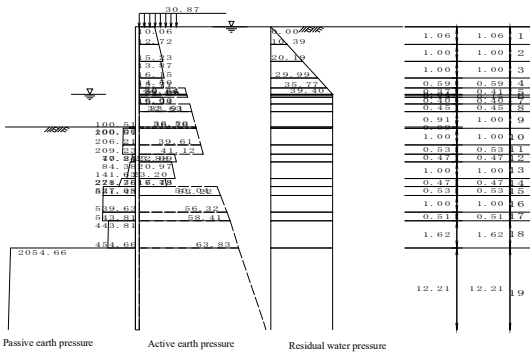
No	Depth. m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Qp$ kN/m ²	Kp	$Kp \times \cos \delta$
11	5.97- 6.06	Clay	5.7	0.0	50.0 50.0	0.000 0.513	—	—
12	6.06- 7.06	Clay	5.7	0.0	100.0 100.0	0.513 6.213	—	—
13	7.06- 7.59	Clay	5.7	0.0	100.0 100.0	6.213 9.234	—	—
14	7.59- 8.06	Sand	9.2	31.4	—	9.234 13.558	5.36321 5.36321	5.18047 5.18047
15	8.06- 9.06	Sand	9.2	34.7	—	13.558 22.758	6.44286 6.44286	6.22332 6.22332
16	9.06- 9.53	Sand	9.2	42.4	—	22.758 27.082	10.38845 10.38845	10.03447 10.03447
17	9.53- 10.06	Clay	8.2	0.0	250.0 250.0	27.082 31.428	—	—
18	10.06- 11.06	Clay	8.2	0.0	250.0 250.0	31.428 39.628	—	—
19	11.06- 11.57	Clay	8.2	0.0	250.0 250.0	39.628 43.810	—	—

$$= \frac{296.93 + 0.00 + 0.00}{6.31}$$

$$= 47.05 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma \cdot h + Qa$ kN/m ²	Ka	$Ka \times \cos \delta$
1	0.00- 1.06	Sand	7.7	27.0	—	30.874 39.036	0.33738 0.33738	0.32589 0.32589
2	1.06- 2.06	Sand	7.7	27.0	—	39.036 46.736	0.33738 0.33738	0.32589 0.32589
3	2.06- 3.06	Sand	7.7	29.5	—	46.736 54.436	0.30720 0.30720	0.29674 0.29674
4	3.06- 3.65	Sand	7.7	32.3	—	54.436 58.979	0.27581 0.27581	0.26641 0.26641
5	3.65- 4.02	Clay	5.7	—	100.0 100.0	58.979 61.088	—	—
6	4.02- 4.06	Clay	5.7	—	100.0 100.0	61.088 61.316	—	—
7	4.06- 4.21	Clay	5.7	—	100.0 100.0	61.316 62.171	—	—
8	4.21- 4.61	Sand	7.7	34.4	—	62.171 65.251	0.25382 0.25382	0.24517 0.24517
9	4.61- 5.06	Clay	5.7	—	100.0 100.0	65.251 67.816	—	—

20	11.57- 13.19	Clay	6.7	20.0	200.0 200.0	43.810 54.664	—	—
21	13.19- 25.40	Clay	7.2	30.0	1000.0 1000.0	54.664 142.576	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth. m	Active		Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.06	10.06 12.72	—	10.06 12.72	0.00 10.39
2	1.06- 2.06	12.72 15.23	—	12.72 15.23	10.39 20.19
3	2.06- 3.06	13.87 16.15	—	13.87 16.15	20.19 29.99
4	3.06- 3.65	14.50 15.71	—	14.50 15.71	29.99 35.77
5	3.65- 4.02	141.02 138.91	29.49 30.54	29.49 30.54	35.77 39.40
6	4.02- 4.06	138.91 138.68	30.54 30.66	30.54 30.66	39.40 39.40
7	4.06- 4.21	138.68 137.83	30.66 31.09	30.66 31.09	39.40 39.40
8	4.21- 4.61	15.24 16.00	—	15.24 16.00	39.40 39.40
9	4.61- 5.06	134.75 132.18	32.63 33.91	32.63 33.91	39.40 39.40
10	5.06- 5.97	32.18 27.00	33.91 36.50	33.91 36.50	39.40 39.40
11	5.97- 6.06	27.00 26.48	36.50 36.76	36.50 36.76	39.40 100.00
12	6.06- 7.06	126.48 120.78	36.76 39.61	36.76 39.61	200.51 206.21
13	7.06- 7.59	120.78 117.76	39.61 41.12	39.61 41.12	206.21 209.23
14	7.59- 8.06	22.69 23.88	—	22.69 23.88	39.40 39.40
15	8.06- 9.06	20.97 23.20	—	20.97 23.20	39.40 84.38
16	9.06- 9.53	16.73 17.48	—	16.73 17.48	39.40 273.75
17	9.53- 10.06	399.92 395.57	50.04 52.22	50.04 52.22	39.40 527.08

18	10.06- 11.06	-395.57 -387.37	52.22 56.32	52.22 56.32	39.40 39.40	531.43 539.63
19	11.06- 11.57	-287.37 -383.19	56.32 58.41	56.32 58.41	39.40 39.40	539.63 543.81
20	11.57- 13.19	-283.19 -272.33	58.41 63.83	58.41 63.83	39.40 39.40	543.81 554.66
21	13.19- 25.40	-1872.33 -1784.42	63.83 107.79	63.83 107.79	39.40 39.40	2054.66 2142.58

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5

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

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

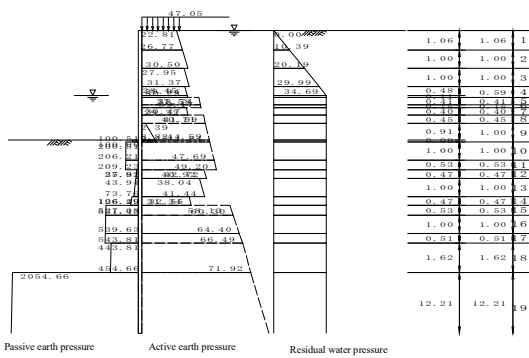
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



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

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
11	5.97- 6.06	Clay	5.70	0.0	50.0 50.0	0.000 0.513	0.00 0.88	0.200 0.200	11.31 11.31	— —	— —
12	6.06- 7.06	Clay	5.70	0.0	100.0 100.0	0.513 6.213	0.88 10.68	0.200 0.200	11.31 11.31	— —	— —
13	7.06- 7.59	Clay	5.70	0.0	100.0 100.0	6.213 9.234	10.68 15.88	0.200 0.200	11.31 11.31	— —	— —
14	7.59- 8.06	Sand	9.20	31.4	— —	9.234 13.558	15.88 20.48	0.200 0.200	11.31 11.31	2.79588 2.79588	2.79588 2.79588
15	8.06- 9.06	Sand	9.20	34.7	— —	13.558 22.758	20.48 30.28	0.200 0.200	11.31 11.31	3.24095 3.24095	3.24095 3.24095
16	9.06- 9.53	Sand	9.20	42.4	— —	22.758 27.082	30.28 34.89	0.200 0.200	11.31 11.31	4.67049 4.67049	4.67049 4.67049
17	9.53- 10.06	Clay	8.20	0.0	250.0 250.0	27.082 31.428	34.89 40.08	0.200 0.200	11.31 11.31	— —	— —
18	10.06- 11.06	Clay	8.20	0.0	250.0 250.0	31.428 39.628	40.08 49.88	0.200 0.200	11.31 11.31	— —	— —
19	11.06- 11.57	Clay	8.20	0.0	250.0 250.0	39.628 43.810	49.88 54.88	0.200 0.200	11.31 11.31	— —	— —
20	11.57- 13.19	Clay	6.70	20.0	200.0 200.0	43.810 54.664	54.88 70.76	0.200 0.200	11.31 11.31	— —	— —
21	13.19- 25.40	Clay	7.20	30.0	1000.0 1000.0	54.664 142.576	70.76 190.41	0.200 0.200	11.31 11.31	— —	— —

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.06	22.81 26.77	— —	22.81 26.77	0.00 10.39	— —
2	1.06- 2.06	26.77 30.50	— —	26.77 30.50	10.39 20.19	— —
3	2.06- 3.06	27.95 31.37	— —	27.95 31.37	20.19 29.99	— —
4	3.06- 3.54	28.45 29.94	— —	28.45 29.94	29.99 34.69	— —

3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Ka	Ka $\times \cos \delta$	ζ degree
1	0.00- 1.06	Sand	7.7	27.0	— —	47.05 55.21	0.00 10.39	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— —
2	1.06- 2.06	Sand	7.7	27.0	— —	55.21 62.91	10.39 20.19	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— —
3	2.06- 3.06	Sand	7.7	29.5	— —	62.91 70.61	20.19 29.99	0.200 0.200	11.31 11.31	0.45999 0.45999	0.44432 0.44432	— —
4	3.06- 3.54	Sand	7.7	32.3	— —	70.61 74.30	29.99 34.69	0.200 0.200	11.31 11.31	0.41711 0.41711	0.40290 0.40290	— —
5	3.54- 3.65	Sand	7.7	32.3	— —	74.30 75.15	34.69 35.77	0.200 0.200	11.31 11.31	0.41711 0.41711	0.40290 0.40290	— —
6	3.65- 4.06	Clay	5.7	—	100.0 100.0	75.15 77.49	35.77 39.79	0.200 0.200	11.31 11.31	— —	— —	43.13 43.10
7	4.06- 4.21	Clay	5.7	—	100.0 100.0	77.49 78.34	39.79 41.26	0.200 0.200	11.31 11.31	— —	— —	43.10 43.08
8	4.21- 4.61	Sand	7.7	34.4	— —	78.34 81.42	41.26 45.18	0.200 0.200	11.31 11.31	0.38741 0.38741	0.37421 0.37421	— —
9	4.61- 5.06	Clay	5.7	—	100.0 100.0	81.42 83.99	45.18 49.59	0.200 0.200	11.31 11.31	— —	— —	43.03 42.99
10	5.06- 5.97	Clay	5.7	—	50.0 50.0	83.99 89.18	49.59 58.51	0.200 0.200	11.31 11.31	— —	— —	40.66 40.46
11	5.97- 6.06	Clay	5.7	—	50.0 50.0	89.18 89.69	58.51 59.39	0.200 0.200	11.31 11.31	— —	— —	40.46 40.44
12	6.06- 7.06	Clay	5.7	—	100.0 100.0	89.69 95.39	59.39 69.19	0.200 0.200	11.31 11.31	— —	— —	42.90 42.80
13	7.06- 7.59	Clay	5.7	—	100.0 100.0	95.39 98.41	69.19 74.38	0.200 0.200	11.31 11.31	— —	— —	42.80 42.75
14	7.59- 8.06	Sand	9.2	31.4	— —	98.41 102.73	74.38 78.99	0.200 0.200	11.31 11.31	0.43046 0.43046	0.41579 0.41579	— —
15	8.06- 9.06	Sand	9.2	34.7	— —	102.73 111.93	78.99 88.79	0.200 0.200	11.31 11.31	0.38333 0.38333	0.37027 0.37027	— —
16	9.06- 9.53	Sand	9.2	42.4	— —	111.93 116.26	88.79 93.39	0.200 0.200	11.31 11.31	0.29883 0.29883	0.27995 0.27995	— —
17	9.53- 10.06	Clay	8.2	—	250.0 250.0	116.26 120.60	93.39 98.59	0.200 0.200	11.31 11.31	— —	— —	44.03 44.01
18	10.06- 11.06	Clay	8.2	—	250.0 250.0	120.60 128.80	98.59 108.39	0.200 0.200	11.31 11.31	— —	— —	44.01 43.96
19	11.06- 11.57	Clay	8.2	—	250.0 250.0	128.80 132.99	108.39 113.39	0.200 0.200	11.31 11.31	— —	— —	43.96 43.93
20	11.57- 13.19	Clay	6.7	—	200.0 200.0	132.99 143.84	113.39 129.26	0.200 0.200	11.31 11.31	— —	— —	43.65 43.56
21	13.19- 25.40	Clay	7.2	—	1000.0 1000.0	143.84 231.75	129.26 248.92	0.200 0.200	11.31 11.31	— —	— —	44.72 44.59

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

$$\delta = 15.00, \beta = 0.00, \theta = 0.00$$

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

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

5	3.54- 3.65	29.94 30.28	— —	29.94 30.28	34.69 34.69	— —
6	3.65- 4.06	-109.23 -106.39	37.58 38.74	37.58 38.74	34.69 34.69	— —
7	4.06- 4.21	-106.39 -105.35	38.74 39.17	38.74 39.17	34.69 34.69	— —
8	4.21- 4.61	29.32 30.47	— —	29.32 30.47	34.69 34.69	— —
9	4.61- 5.06	-101.61 -98.49	40.71 41.99	40.71 41.99	34.69 34.69	— —
10	5.06- 5.97	2.39 8.82	41.99 44.59	41.99 44.59	34.69 34.69	— —
11	5.97- 6.06	8.82 9.45	44.59 44.84	44.59 44.84	34.69 34.69	100.00 100.51
12	6.06- 7.06	-91.55 -84.40	44.84 47.69	44.84 47.69	34.69 34.69	200.51 206.21
13	7.06- 7.59	-84.40 -80.92	47.69 49.20	47.69 49.20	34.69 34.69	206.21 209.23
14	7.59- 8.06	40.92 42.72	— —	40.92 42.72	34.69 34.69	25.82 37.91
15	8.06- 9.06	38.04 41.44	— —	38.04 41.44	34.69 34.69	43.94 73.76
16	9.06- 9.53	31.34 32.55	— —	31.34 32.55	34.69 34.69	106.29 126.49
17	9.53- 10.06	-359.98 -354.73	58.13 60.30	58.13 60.30	34.69 34.69	527.08 531.43
18	10.06- 11.06	-354.73 -344.81	60.30 64.40	60.30 64.40	34.69 34.69	531.43 539.63
19	11.06- 11.57	-344.81 -339.75	64.40 66.49	64.40 66.49	34.69 34.69	539.63 543.81
20	11.57- 13.19	-239.58 -226.42	66.49 71.92	66.49 71.92	34.69 34.69	543.81 554.66
21	13.19- 25.40	-1827.21 -1721.44	71.92 115.88	71.92 115.88	34.69 34.69	2054.66 2142.58

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5

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

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z, m	water level y m	p _{dw} kN/m ²
1	3.54	0.00	0.00
2	4.54	1.00	2.67
3	5.54	2.00	3.78
4	5.97	2.43	4.17

$$p_{dw} = \pm \frac{7}{8} k_{10} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

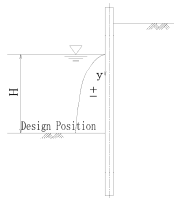
Where,

k₁₀: design seismic coefficient

γ_w: unit weight of water

H : water depth of riverside

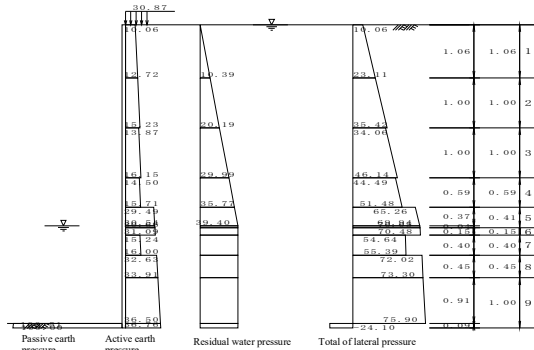
y : depth from water surface to the point where active water pressure is calculated



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



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.00	10.06 12.72	0.00 10.39	— —	10.06 23.11
2	1.06- 2.06	12.72 15.23	10.39 20.19	— —	23.11 35.42
3	2.06- 3.06	13.87 16.15	20.19 29.99	— —	34.06 46.14
4	3.06- 3.65	14.50 15.71	29.99 35.77	— —	44.49 51.48
5	3.65- 4.02	29.49 30.54	35.77 39.40	— —	65.26 69.94
6	4.02- 4.06	30.54 30.66	39.40 39.40	— —	69.94 70.05
7	4.06- 4.21	30.66 31.09	39.40 39.40	— —	70.05 70.48
8	4.21- 4.61	15.24 16.00	39.40 39.40	— —	54.64 55.39
9	4.61- 5.06	32.63 33.91	39.40 39.40	— —	72.02 73.30
10	5.06- 5.97	33.91 36.50	39.40 39.40	— —	73.30 75.90
11	5.97- 6.06	36.50 36.76	39.40 39.40	100.00 100.51	-24.10 -24.36

P_a : Active earth pressure

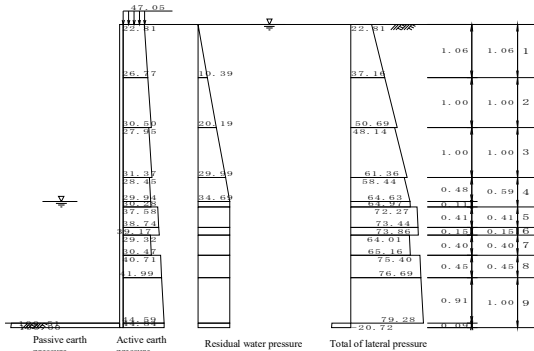
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure P_s = P_a + P_w - P_p

Imaginary riverbed L_k: 0.00 m (GL -5.97 m)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.06	22.81 26.77	0.00 10.39	— —	22.81 37.16
2	1.06- 2.06	26.77 30.50	10.39 20.19	— —	37.16 50.69
3	2.06- 3.06	27.95 31.37	20.19 29.99	— —	48.14 61.36
4	3.06- 3.54	28.45 29.94	29.99 34.69	— —	58.44 64.63
5	3.54- 3.65	29.94 30.28	34.69 34.69	— —	64.63 64.97
6	3.65- 4.06	37.58 38.74	34.69 34.69	— —	72.27 73.44
7	4.06- 4.21	38.74 39.17	34.69 34.69	— —	73.44 73.86
8	4.21- 4.61	29.32 30.47	34.69 34.69	— —	64.01 65.16
9	4.61- 5.06	40.71 41.99	34.69 34.69	— —	75.40 76.69
10	5.06- 5.97	41.99 44.59	34.69 34.69	— —	76.69 79.28
11	5.97- 6.06	44.59 44.84	34.69 34.69	100.00 100.51	-20.72 -20.98

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: 0.00 m (GL -5.97 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of U/β from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B_H}{0.3} \right)^{-0.14} \quad (B_H = 10.00m)$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_b = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H H 900 -250 -14 -22 -18
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 = 597600 cm ⁴ (original condition)
	I = 531336 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 513936 × 10 ⁻⁸ = 1.028 × 10 ⁶

No	Depth m	N Value	No	Depth m	N Value
1	0.56	5	11	10.56	44
2	1.56	7	12	11.56	50
3	2.56	14	13	12.56	50
4	3.56	20	14	13.56	49
5	4.56	25	15	14.56	50
6	5.56	13			
7	6.56	19			
8	7.56	18			
9	8.56	26			
10	9.56	50			

5.2 Normal Condition

Assuming K_b = 17895 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.257 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.89 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.97 m) to 3.89 m depth (GL -9.86 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.97	0.59	15.5	19.0	10.17
2	6.56	1.00	19.0	18.0	18.50
3	7.56	1.00	18.0	26.0	22.00
4	8.56	1.00	26.0	50.0	38.00
5	9.56	0.30	50.0	48.2	14.89
L = Σ h = 3.89			Σ A = 103.55		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{103.55}{3.89}$$

$$= 26.60$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 26.60 = 74474 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 74474 = 248248 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10} (B_u/0.3)^{-3/4} = 248248 (10.00/0.3)^{-3/4} = 17895 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 17895 kN/m³.

5.3 Seismic Condition

Assuming Kh = 31361 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.296 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.38 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.97 m) and 3.38 m depth (GL -9.35 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.97	0.59	15.5	19.0	10.17
2	6.56	1.00	19.0	18.0	18.50
3	7.56	1.00	18.0	26.0	22.00
4	8.56	0.79	26.0	45.1	28.20
L = Σ h = 3.38			Σ A = 78.87		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

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

Arbitrary load lateral load $P_t = 13.7 \text{ kN/m}$
depth to acting position $H_t = 0.0 \text{ m}$
moment $M_m = 0.00 \text{ kN}\cdot\text{m/m}$
depth to acting position $H_m = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 5.97 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 81.79 \text{ kN}\cdot\text{m}$$

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{694.01}{289.90} = 2.39 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _u kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.06	1.06	22.81 37.16	12.09 5.26	5.62 5.26	67.91 103.66
2	1.06- 2.06	1.00	37.16 50.69	18.58 25.35	4.58 4.24	85.03 107.55
3	2.06- 3.06	1.00	48.14 61.36	24.07 30.68	3.58 3.24	86.09 99.51
4	3.06- 3.54	0.48	58.44 64.63	14.02 15.51	2.75 2.59	38.57 40.17
5	3.54- 3.65	0.11	64.63 64.97	3.55 3.57	2.39 2.36	8.51 8.42
6	3.65- 4.06	0.41	72.27 73.44	14.81 15.05	2.18 2.05	32.35 30.81
7	4.06- 4.21	0.15	73.44 73.86	5.51 5.54	1.86 1.81	10.24 10.03
8	4.21- 4.61	0.40	64.01 65.16	12.80 13.03	1.63 1.49	20.82 19.46
9	4.61- 5.06	0.45	75.40 76.69	16.97 17.25	1.21 1.06	20.53 18.29
10	5.06- 5.97	0.91	76.69 79.28	34.89 36.07	0.61 0.30	21.17 10.94
Σ P = 339.06			Σ M = 840.05			

P_t : active earth pressure + residual water pressure - passive earth pressure

P : load $P_u \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

Arbitrary load lateral load $P_t = 38.7 \text{ kN/m}$
depth to acting position $H_t = 0.00 \text{ m}$
moment $M_m = 17.5 \text{ kN}\cdot\text{m/m}$
depth to acting position $H_m = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 5.97 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

$$= \frac{78.87}{3.38}$$

$$= 23.31$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 23.31 = 65258 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 65258 = 435053 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10} (B_u/0.3)^{-3/4} = 435053 (10.00/0.3)^{-3/4} = 31361 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 31361 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _u kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.06	1.06	10.06 23.11	5.33 12.25	5.62 5.26	29.95 64.46
2	1.06- 2.06	1.00	23.11 35.42	11.55 17.71	4.58 4.24	52.88 75.15
3	2.06- 3.06	1.00	34.06 46.14	17.03 23.07	3.58 3.24	60.90 74.83
4	3.06- 3.65	0.59	44.49 51.48	13.12 15.19	2.71 2.52	35.61 38.22
5	3.65- 4.02	0.37	65.26 69.94	12.07 12.94	2.20 2.07	26.52 26.83
6	4.02- 4.06	0.04	69.94 70.05	1.40 1.40	1.94 1.92	2.71 2.69
7	4.06- 4.21	0.15	70.05 70.48	5.25 5.29	1.86 1.81	9.77 9.57
8	4.21- 4.61	0.40	54.64 55.39	10.93 11.08	1.65 1.49	17.78 16.54
9	4.61- 5.06	0.45	72.02 73.30	16.20 16.49	1.21 1.06	19.61 17.48
10	5.06- 5.97	0.91	73.30 75.90	33.35 34.53	0.61 0.30	20.23 10.48
Σ P = 276.20			Σ M = 612.22			

P_u : active earth pressure + residual water pressure - passive earth pressure

P : load $P_u \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_m = 248.54 \text{ kN}\cdot\text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	3.54- 4.54	1.00	0.0 2.7	0.00 1.34	2.10 1.76	0.00 2.36
2	4.54- 5.54	1.00	2.7 3.8	1.34 1.89	1.10 0.76	1.47 1.44
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
3	5.54- 5.97	0.43	3.8 4.2	0.81 0.90	0.29 0.14	0.23 0.13
Σ P _{hw} = 6.27			Σ M _{hw} = 5.63			

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{hw}}{\Sigma P + P_t + \Sigma P_{hw}} = \frac{1094.22}{384.03} = 2.85 \text{ m}$$

6.2 Sectional Force

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

Material name $10 H_900-250-14-22-18$
Unit width $B = 1.0000 \text{ m}$
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.86$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 597600 \text{ cm}^4$ (original condition)
 $I = 513936 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 513936 \times 10^{-8} = 1.028 \times 10^6$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_b	=	17895	kN/m ³
calculated value	β	=	0.25685	m ⁻¹
resultant earth force (lateral)	P_0	=	289.90	kN/m
height of acting position of load	h_0	=	2.39	m
moment	M_0	=	694.01	kN·m/m

in consideration of $\psi_{lm} = 1.304$, maximum moment	$M_{\max}$	=	904.69	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	1.641	m
depth of 1 st fixed point	l_i	=	4.699	m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_b	=	31361	kN/m ³
calculated value	β	=	0.29553	m ⁻¹
resultant earth force (lateral)	P_0	=	384.03	kN/m
height of acting position of load	h_0	=	2.85	m
moment	M_0	=	1094.22	kN·m/m

in consideration of $\psi_{lm} = 1.191$, maximum moment	$M_{\max}$	=	1302.80	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	1.207	m
depth of 1 st fixed point	l_i	=	3.864	m

6.3 Stress Intensity

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

Material Name	10 H	H 900-250-14-22-18
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	= 9470 cm ³ (original condition)
	Z	= 8334 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{904.69 \times 10^6}{8334 \times 10^3} = 109 \text{ N/mm}^2 \leq \sigma_a = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{1302.80 \times 10^6}{8334 \times 10^3} = 156 \text{ N/mm}^2 \leq \sigma_a = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.06	5.62 5.26	0.941 0.882	0.304 0.274	5.33 12.25	1.620 3.361
2	1.06- 2.06	4.58 4.24	0.767 0.711	0.219 0.193	11.55 17.71	2.528 3.414
3	2.06- 3.06	3.58 3.24	0.599 0.543	0.144 0.121	17.03 23.07	2.446 2.788
4	3.06- 3.65	2.71 2.52	0.454 0.422	0.088 0.076	13.12 15.19	1.159 1.160
5	3.65- 4.02	2.20 2.07	0.368 0.347	0.059 0.053	12.07 12.94	0.717 0.690
6	4.02- 4.06	1.94 1.92	0.324 0.322	0.047 0.046	1.40 1.40	0.066 0.065
7	4.06- 4.21	1.86 1.81	0.312 0.303	0.043 0.041	5.25 5.29	0.229 0.218
8	4.21- 4.61	1.63 1.49	0.272 0.250	0.034 0.029	10.93 11.08	0.369 0.318
9	4.61- 5.06	1.21 1.06	0.203 0.178	0.019 0.015	16.20 16.49	0.310 0.245
10	5.06- 5.97	0.61 0.30	0.102 0.051	0.005 0.001	33.35 34.53	0.166 0.044
$\Sigma Q =$						21.902

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

$$Q : \zeta \times P$$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.

Pt: horizontal load

Yt: Height from the virtual ground plane to the point of horizontal load action

If

$$\begin{aligned} Pt &= 13.70 \\ Yt &= 5.97 \\ \alpha t &= 1.000 \\ \zeta t &= 0.333 \\ Qt &= \zeta t \times Pt = 4.567 \end{aligned}$$

Therefore, the deformation coefficient Q is expressed by

$$Q = 21.902 + 4.567 = 26.469$$

Displacement Calculation

5	3.54- 3.65	2.39 2.36	0.401 0.395	0.070 0.068	3.55 3.57	0.247 0.242
6	3.65- 4.06	2.18 2.05	0.366 0.343	0.059 0.052	14.81 15.05	0.870 0.784
7	4.06- 4.21	1.86 1.81	0.312 0.303	0.043 0.041	5.31 5.34	0.240 0.229
8	4.21- 4.61	1.63 1.49	0.272 0.250	0.034 0.029	12.80 13.03	0.432 0.374
9	4.61- 5.06	1.21 1.06	0.203 0.178	0.019 0.015	16.97 17.25	0.325 0.256
10	5.06- 5.97	0.61 0.30	0.102 0.051	0.005 0.001	34.89 36.07	0.174 0.046
$\Sigma Q =$						31.918

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

$$Q : \zeta \times P$$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.

Pt: horizontal load

Yt: Height from the virtual ground plane to the point of horizontal load action

If

$$\begin{aligned} Pt &= 38.70 \\ Yt &= 5.97 \\ \alpha t &= 1.000 \\ \zeta t &= 0.333 \\ Qt &= \zeta t \times Pt = 12.900 \end{aligned}$$

Therefore, the deformation coefficient Q is expressed by

$$Q = 31.918 + 12.900 = 44.818$$

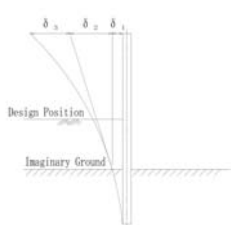
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth m	Y m	α	ζ	Pdw kN	Qdw kN
1	3.54- 4.54	2.10 1.76	0.351 0.285	0.054 0.039	0.00 1.34	0.000 0.053
2	4.54- 5.54	1.10 0.76	0.184 0.128	0.016 0.008	1.34 1.89	0.021 0.015
3	5.54- 5.97	0.29 0.14	0.048 0.024	0.001 0.000	0.81 0.90	0.001 0.000
$\Sigma Qdw =$						0.090

Therefore, the deformation coefficient Q is expressed by

$$Q = 44.818 + 0.090 = 44.907$$

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1+\beta h_0) \times P_0}{2 E I \beta^2} \\ &= \frac{(1+0.2569 \times 2.39) \times 289.90}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2569^2} = 0.01344 \text{ m} \\ \delta_2 &= \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k) \\ &= \frac{(1+2 \times 0.2569 \times 2.39) \times 289.90}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2569^2} \times (5.97+0.00) = 0.02845 \text{ m} \\ \delta_3 &= \frac{Q \times (H+L_k)^3}{E I} \\ &= \frac{26.47 \times (5.97+0.00)^3}{2.00 \times 10^8 \times 513936 \times 10^{-8}} = 0.00548 \text{ m} \\ \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01344 + 0.02845 + 0.00548 \\ &= 0.04737 \text{ m} \\ \text{Size} &= 47.37 \text{ mm} \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

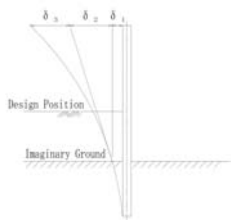
Where,

- 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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.06	5.62 5.26	0.941 0.882	0.304 0.274	12.09 19.69	3.673 5.405
2	1.06- 2.06	4.58 4.24	0.767 0.711	0.219 0.193	18.58 25.35	4.064 4.886
3	2.06- 3.06	3.58 3.24	0.599 0.543	0.144 0.121	24.07 30.68	3.457 3.708
4	3.06- 3.54	2.75 2.59	0.461 0.434	0.090 0.081	14.02 15.51	1.259 1.249



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

$$= \frac{(1 + 0.2955 \times 2.85) \times 384.03}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2955^3} = 0.01333 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_u)$$

$$= \frac{(1 + 2 \times 0.2955 \times 2.85) \times 384.03}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2955^3} \times (5.97 + 0.00) = 0.03427 \text{ m}$$

$$\delta_3 = \frac{Q \times (H + L_u)^3}{E I}$$

$$= \frac{44.91 \times (5.97 + 0.00)^3}{2.00 \times 10^8 \times 513936 \times 10^{-8}} = 0.00930 \text{ m}$$

The displacement amount (δ 3m) of the cantilever beam by the bending moment (Mm) is added.

$$\delta_{3a} = \frac{M_u \cdot h}{2 E I} \times (2 L - h)$$

$$= \frac{17.50 \times 5.97}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8}} \times (2 \times 5.97 - 5.97) = 0.00030 \text{ m}$$

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

$$= 0.01333 + 0.03427 + 0.00960$$

$$= 0.05721 \text{ m}$$

$$\text{Size} = 57.21 \text{ mm} \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name 10 H₂ H 900 -250 -14 -22 -18
Unit width B = 1.0000 m

Corrosion rate $\eta = 1.00$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 597600 \text{ cm}^4$ (original condition)
 $I = 597600 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 597600 \times 10^{-8} = 1.198 \times 10^6$

7.1 Penetration Depth and Whole Length of SSP (Chang)

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

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

$$L = H - H_{IC} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_b = 17895 \text{ kN/m}^3$
Calculated value $\beta = 0.24735 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.247} = 12.13 \text{ m}$
Whole length of SSP $L = 5.97 - 0.40 + 12.13 = 17.70 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 31361 \text{ kN/m}^3$
Calculated value $\beta = 0.28459 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.285} = 10.54 \text{ m}$
Whole length of SSP $L = 5.97 - 0.40 + 10.54 = 16.11 \text{ m}$

Therefore, the total length of the sheet pile is 18.00 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H ₂ H 900 -250 -14 -22 -18	
		Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	597600	
Sectional Modulus	Z (cm ³)	9470	
Maximum bending moment	Mmax (kN·m / m)		
Stress intensity	σ (N/mm ²)	904.69 109 (180)	1302.80 156 (270)
Lateral displacement	δ (mm)	47.37 (50.0)	57.21 (75.0)
Penetration depth	D (m)	12.13	10.54
Whole length of SSP	L (m)	18.00	

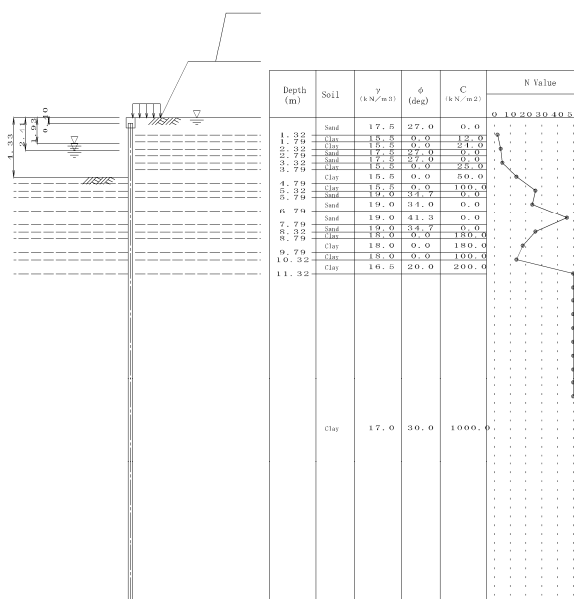
Block No. : L-19
Sta. : 10+520~10+580

Design Cross Section : Sta 10+560
Boring Name : DD-BH-L11

Specification : SSP SP-10H
(Combined) : H 750-250-14-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 4.33 \text{ m}$
Depth from coping top to rear side ground $H_0 = 0.00 \text{ m}$
Depth from coping top to SSP top $H_k = 0.40 \text{ m}$
Landside WL $L_{wa} = 0.00 \text{ m}$ (Normal Condition)
 $L_{ws} = 0.00 \text{ m}$ (Seismic Condition)
Riverside WL $L_{wp} = 2.41 \text{ m}$ (Normal Condition)
 $L_{ws} = 1.93 \text{ m}$ (Seismic Condition)

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 $P_t = 52.9 \text{ kN/m}$ (Normal Condition)
 $P_t' = 121.4 \text{ kN/m}$ (Seismic Condition)
 $H_t = 0.0 \text{ m}$ (Normal Condition)
 $H_t' = 0.0 \text{ m}$ (Seismic Condition)
 $M_m = 24.8 \text{ kN}\cdot\text{m/m}$ (Normal Condition)
 $M_m' = 163.5 \text{ kN}\cdot\text{m/m}$ (Seismic Condition)
 $H_m = 0.00 \text{ m}$ (Seismic Condition)
 $H_m = 0.00 \text{ m}$ (Normal Condition)
 ("Depth" means distance from top of coping)
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered
Angle of rupture (clayey soil) $\zeta = \tan^{-1} \left(1 - \frac{\sum \gamma h + 2Q}{2C} \right) \cdot \tan \theta$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

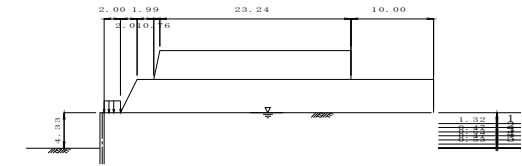
Applied formula $K_{\Delta} = K_{\Delta 0} \left(\frac{B_{\Delta}}{0.3} \right)^{-3/4}$
 $K_{\Delta 0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2)
 $B_{\Delta} = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

γ' : saturated unit weight of soil kh : modulus of subgrade reaction
 ϕ : internal friction angle of soil

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	dipity angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	2.00	4.01	40.00	40.00	4.02	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	6.00	6.76	30.00	30.00	3.54	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	2.00	5.0	0.0

Angle of rupture in embankment calculated in consideration of embankment conditions

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	1.29	2	11	11.29	50
2	2.29	4	12	12.29	50
3	3.29	5	13	13.29	50
4	4.29	14	14	14.29	50
5	5.29	26	15	15.29	50
6	6.29	24	16	16.29	50
7	7.29	46	17	17.29	50
8	8.29	26	18	18.29	50
9	9.29	18	19	19.29	50
10	10.29	14	20	20.29	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 (Include Projection Length)	Thickness m (excluding projected length)										
1	1.32	1.32										
2	1.79	1.79										
3	2.32	2.32										
4	2.79	2.79										
5	3.32	3.32										
6	3.79	3.79										
7	4.79	4.79										
8	5.32	5.32										
9	5.79	5.79										
10	6.79	6.79										
11	7.79	7.79										
12	8.32	8.32										
13	8.79	8.79										
14	9.79	9.79										
15	10.32	10.32										
16	11.32	11.32										
17	33.80	33.80										

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
1	1.32	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	1.79	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto
3	2.32	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto
4	2.79	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	3.32	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	3.79	C	5.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
7	4.79	C	14.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto
8	5.32	C	26.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
9	5.79	S	26.0	19.00	9.20	34.7	0.0	0.0	0.200	Auto	Auto
10	6.79	S	24.0	19.00	9.20	34.0	0.0	0.0	0.200	Auto	Auto
11	7.79	S	46.0	19.00	9.20	41.3	0.0	0.0	0.200	Auto	Auto
12	8.32	S	26.0	19.00	9.20	34.7	0.0	0.0	0.200	Auto	Auto
13	8.79	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	9.79	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	10.32	C	14.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
16	11.32	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
17	33.80	C	121.5	17.00	7.20	30.0	1000.0	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
 C_a : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
 ζ : angle of active rupture

1.9 Steel Sheet Pile (SSP)

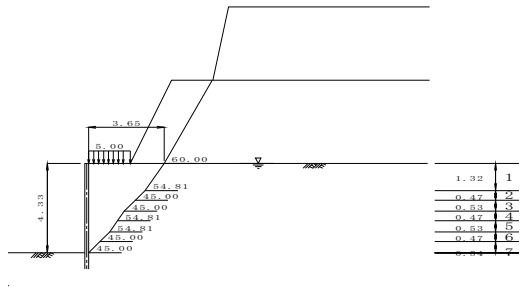
Material name 10 H H 750 -250 -14 -22 -18
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 414700 \text{ cm}^4$
Sectional factor $Z_0 = 7640 \text{ cm}^3$
Corrosion margin $t_1 = 1.00 \text{ mm}$ (riverside) $t_2 = 1.00 \text{ mm}$ (landside)
Corrosion rate (to I_0) $\eta = 0.86$
Corrosion rate (to Z_0) $\eta = 0.88$
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 $\sigma_a = 180 \text{ N/mm}$ (Normal)
 $\sigma_a' = 270 \text{ N/mm}$ (Seismic)
Allowable displacement $\delta_a = 50.0 \text{ mm}$ (Normal)
 $\delta_a' = 75.0 \text{ mm}$ (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	$\sum \gamma h$ kN/m ²	Q kN/m ²	γ value kN/m ²	Angle of Rupture ζ degree
1	4.33~3.79	Clay	0.0	15.0	30.0	29.32	40.48	42.43	45.00

2	3.79~3.32	Clay	0.0	15.0	25.0	26.24	40.48	37.14	45.00
3	3.32~2.79	Sand	27.0	15.0	0.0	23.56	40.48	32.54	54.81
4	2.79~2.32	Sand	27.0	15.0	0.0	19.48	40.48	27.34	54.81
5	2.32~1.79	Clay	0.0	15.0	24.0	15.86	40.48	22.74	45.00
6	1.79~1.32	Clay	0.0	15.0	12.0	12.84	40.48	17.54	45.00
7	1.32~0.00	Sand	27.0	15.0	0.0	10.16	40.48	12.94	54.81
8		embankment t	30.0	——	0.0	143.64	0.00	0.00	49.60

• Angle of active rupture of sandy soil

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

• 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 $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.54	0.00	0.00	0.54	0.54
2	45.00	0.47	0.54	0.54	1.01	1.01
3	54.81	0.53	1.01	1.01	1.38	1.54
4	54.81	0.47	1.38	1.54	1.72	2.01
5	45.00	0.53	1.72	2.01	2.25	2.54
6	45.00	0.47	2.25	2.54	2.72	3.01
7	54.81	1.32	2.72	3.01	3.65	4.33
8	60.00	4.02	3.65	4.33	5.97	8.35

From the above table, the loading width (L) on the ground surface is 3.65 m.

2.1.3 Acting Load by Embankment

No	γ kN/m^3	A m^2	$\gamma \times A$ kN/m
1	19.0	7.34	137.60

5	2.32~1.79	Clay	0.0	15.0	24.0	15.86	107.76	22.74	0.200	11.31	35.06
6	1.79~1.32	Clay	0.0	15.0	12.0	12.84	107.76	17.54	0.200	11.31	29.96
7	1.32~0.00	Sand	27.0	15.0	0.0	10.16	107.76	12.94	0.200	11.31	42.18
8		embankment t	30.0	——	0.0	143.64	0.00	0.00	0.200	11.31	49.60
9		embankment t	30.0	——	0.0	67.26	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	38.79	0.54	0.00	0.00	0.67	0.54
2	34.79	0.47	0.67	0.54	1.35	1.01
3	42.18	0.53	1.35	1.01	1.93	1.54
4	42.18	0.47	1.93	1.54	2.45	2.01
5	35.06	0.53	2.45	2.01	3.21	2.54
6	29.96	0.47	3.21	2.54	4.02	3.01
7	42.18	1.32	4.02	3.01	5.48	4.33
8	49.60	4.02	5.48	4.33	8.90	8.35
9	49.60	3.54	8.90	8.35	11.91	11.89

From the above table, the loading width (L) on the ground surface is 5.48 m.

2.2.3 Acting Load by Embankment

No	γ kN/m^3	A m^2	$\gamma \times A$ kN/m

Σ			137.60

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/m^2	l m	Qd kN/m
1	5.0	2.00	10.00
Σ			10.00

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

l: Loading width of uniform load surrounded by main collapse line

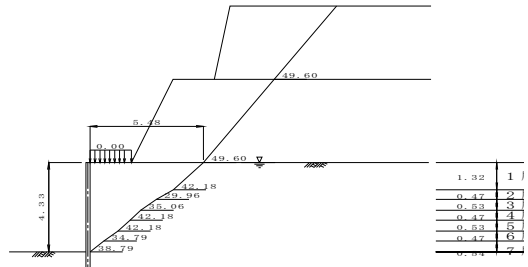
2.1.5 Calculated Load

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

$$= \frac{137.60 + 10.00 + 0.00}{3.65}$$

$$= 40.48 \text{ kN/m}^2$$

2.2 Seismic 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	$\gamma \text{ w/w}$ kN/m^2	k (k')	θ degree	Angle of Rupture ζ degree
1	4.33~3.79	Clay	0.0	15.0	80.0	29.32	107.76	42.43	0.200	11.31	38.79
2	3.79~3.32	Clay	0.0	15.0	25.0	26.24	107.76	37.14	0.200	11.31	34.79
3	3.32~2.79	Sand	27.0	15.0	0.0	23.56	107.76	32.54	0.200	11.31	42.18
4	2.79~2.32	Sand	27.0	15.0	0.0	19.48	107.76	27.34	0.200	11.31	42.18

1	19.0	16.82	319.64
2	19.0	14.25	270.82
Σ			590.46

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/m^2	l m	Qd kN/m
1	0.0	2.00	0.00
Σ			0.00

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

l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

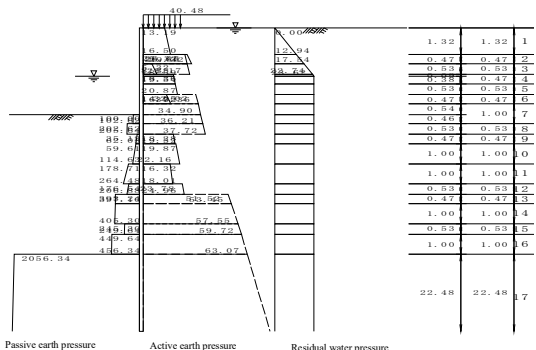
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{590.46 + 0.00 + 0.00}{5.48}$$

$$= 107.76 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Q_u$ kN/m ²	Ka	$K_a \times \cos \delta$
1	0.00- 1.32	Sand	7.7	27.0	—	40.482 50.646	0.33738 0.33738	0.32589 0.32589
2	1.32- 1.79	Clay	5.7	—	12.0 12.0	50.646 53.325	— —	— —
3	1.79- 2.32	Clay	5.7	—	24.0 24.0	53.325 56.346	— —	— —
4	2.32- 2.41	Sand	7.7	27.0	—	56.346 57.039	0.33738 0.33738	0.32589 0.32589
5	2.41- 2.79	Sand	7.7	27.0	—	57.039 59.965	0.33738 0.33738	0.32589 0.32589
6	2.79- 3.32	Sand	7.7	27.0	—	59.965 64.046	0.33738 0.33738	0.32589 0.32589
7	3.32- 3.79	Clay	5.7	—	25.0 25.0	64.046 66.725	— —	— —
8	3.79- 4.33	Clay	5.7	—	50.0 50.0	66.725 69.803	— —	— —
9	4.33- 4.79	Clay	5.7	—	50.0 50.0	69.803 72.425	— —	— —
10	4.79- 5.32	Clay	5.7	—	100.0 100.0	72.425 75.446	— —	— —
11	5.32- 5.79	Sand	9.2	34.7	—	75.446 79.770	0.25078 0.25078	0.24223 0.24223
12	5.79- 6.79	Sand	9.2	34.0	—	79.770 88.970	0.25791 0.25791	0.24912 0.24912
13	6.79- 7.79	Sand	9.2	41.3	—	88.970 98.170	0.18993 0.18993	0.18346 0.18346
14	7.79- 8.32	Sand	9.2	34.7	—	98.170 103.046	0.25078 0.25078	0.24223 0.24223
15	8.32- 8.79	Clay	8.2	—	180.0 180.0	103.046 106.900	— —	— —
16	8.79- 9.79	Clay	8.2	—	180.0 180.0	106.900 115.100	— —	— —
17	9.79- 10.32	Clay	8.2	—	100.0 100.0	115.100 119.446	— —	— —
18	10.32- 11.32	Clay	6.7	—	200.0 200.0	119.446 126.146	— —	— —
19	11.32- 33.80	Clay	7.2	—	1000.0 1000.0	126.146 288.002	— —	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	Kp	$K_p \times \cos \delta$
9	4.33- 4.79	Clay	5.7	0.0	50.0 50.0	0.000 2.622	— —	— —
10	4.79- 5.32	Clay	5.7	0.0	100.0 100.0	2.622 5.643	— —	— —
11	5.32- 5.79	Sand	9.2	34.7	—	5.643 9.967	6.44286 6.44286	6.22332 6.22332
12	5.79- 6.79	Sand	9.2	34.0	—	9.967 19.167	6.19149 6.19149	5.98052 5.98052
13	6.79- 7.79	Sand	9.2	41.3	—	19.167 28.367	9.65256 9.65256	9.32366 9.32366
14	7.79- 8.32	Sand	9.2	34.7	—	28.367 33.243	6.44286 6.44286	6.22332 6.22332
15	8.32- 8.79	Clay	8.2	0.0	180.0 180.0	33.243 37.097	— —	— —
16	8.79- 9.79	Clay	8.2	0.0	180.0 180.0	37.097 45.297	— —	— —
17	9.79- 10.32	Clay	8.2	0.0	100.0 100.0	45.297 49.643	— —	— —
18	10.32- 11.32	Clay	6.7	20.0	200.0 200.0	49.643 56.343	— —	— —
19	11.32- 33.80	Clay	7.2	30.0	1000.0 1000.0	56.343 218.199	— —	— —

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.32	13.19 16.50	— —	13.19 16.50	0.00 12.94	— —
2	1.32- 1.79	26.65 29.32	25.32 26.66	26.65 29.32	12.94 17.54	— —
3	1.79- 2.32	5.32 8.35	26.66 28.17	26.66 28.17	17.54 22.74	— —
4	2.32- 2.41	18.36 18.59	— —	18.36 18.59	22.74 23.62	— —
5	2.41- 2.79	18.59 19.54	— —	18.59 19.54	23.62 23.62	— —
6	2.79- 3.32	19.54 20.87	— —	19.54 20.87	23.62 23.62	— —
7	3.32- 3.79	14.05 16.72	32.02 33.36	32.02 33.36	23.62 23.62	— —

8	3.79- 4.33	-33.28 -30.20	33.36 34.90	33.36 34.90	23.62 23.62	— —
9	4.33- 4.79	-30.20 -27.58	34.90 36.21	34.90 36.21	23.62 23.62	100.00 102.62
10	4.79- 5.32	-127.58 -124.55	36.21 37.72	36.21 37.72	23.62 23.62	202.62 205.64
11	5.32- 5.79	18.28 19.32	— —	18.28 19.32	23.62 23.62	35.12 62.03
12	5.79- 6.79	19.87 22.16	— —	19.87 22.16	23.62 23.62	59.61 114.63
13	6.79- 7.79	16.32 18.01	— —	16.32 18.01	23.62 23.62	178.71 264.48
14	7.79- 8.32	23.78 24.96	— —	23.78 24.96	23.62 23.62	176.54 206.88
15	8.32- 8.79	-256.95 -253.10	51.52 53.45	51.52 53.45	23.62 23.62	393.24 397.10
16	8.79- 9.79	-253.10 -244.90	53.45 57.55	53.45 57.55	23.62 23.62	397.10 405.30
17	9.79- 10.32	-84.90 -80.55	57.55 59.72	57.55 59.72	23.62 23.62	245.30 249.64
18	10.32- 11.32	-280.55 -273.85	59.72 63.07	59.72 63.07	23.62 23.62	449.64 456.34
19	11.32- 33.80	-1873.85 -1712.00	63.07 144.00	63.07 144.00	23.62 23.62	2056.34 2218.20

- Formula for active earth pressure

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

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

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

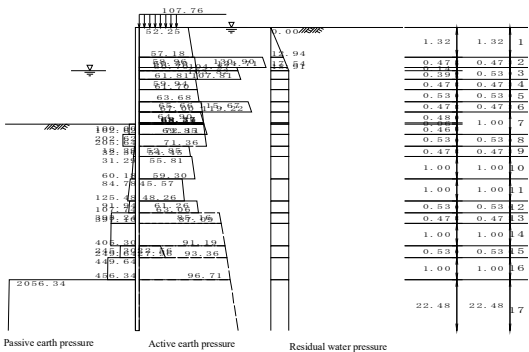
- Formula for passive earth pressure

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

Clay $P_p = \Sigma \gamma h + Q + 2C$

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/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{shw} kN/m ²	k (k ²)	θ degree	Ka	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.32	Sand	7.7	27.0	—	107.76 117.92	0.00 12.94	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— 30.14 29.96
2	1.32- 1.79	Clay	5.7	—	12.0 12.0	117.92 120.60	12.94 17.54	0.200 0.200	11.31 11.31	— —	— —	— 35.23 35.19
3	1.79- 1.93	Clay	5.7	—	24.0 24.0	120.60 121.40	17.54 18.91	0.200 0.200	11.31 11.31	— —	— —	— 35.19 35.06
4	1.93- 2.32	Clay	5.7	—	24.0 24.0	121.40 123.62	18.91 22.74	0.200 0.200	11.31 11.31	— —	— —	— 35.19 35.06
5	2.32- 2.79	Sand	7.7	27.0	—	123.62 127.24	22.74 27.34	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— — —
6	2.79- 3.32	Sand	7.7	27.0	—	127.24 131.32	27.34 32.54	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— — —
7	3.32- 3.79	Clay	5.7	—	25.0 25.0	131.32 134.00	32.54 37.14	0.200 0.200	11.31 11.31	— —	— —	34.93 34.79
8	3.79- 4.27	Clay	5.7	—	50.0 50.0	134.00 136.75	37.14 42.43	0.200 0.200	11.31 11.31	— —	— —	38.90
9	4.27- 4.33	Clay	5.7	—	50.0 50.0	136.75 137.08	42.43 46.94	0.200 0.200	11.31 11.31	— —	— —	38.79 38.69
10	4.33- 4.79	Clay	5.7	—	50.0 50.0	137.08 139.70	46.94 52.14	0.200 0.200	11.31 11.31	— —	— —	41.48 41.41
11	4.79- 5.32	Clay	5.7	—	100.0 100.0	139.70 142.72	46.94 56.74	0.200 0.200	11.31 11.31	— —	— —	— — —
12	5.32- 5.79	Sand	9.2	34.7	—	142.72 147.05	52.14 56.74	0.200 0.200	11.31 11.31	0.38333 0.38333	0.37027 0.37027	— — —
13	5.79- 6.79	Sand	9.2	34.0	—	147.05 156.25	56.74 66.54	0.200 0.200	11.31 11.31	0.39282 0.39282	0.37953 0.37953	— — —

14	6.79- 7.79	Sand	9.2	41.3	—	156.25 165.45	66.54 76.34	0.200 0.200	11.31 11.31	0.30197 0.30197	0.29168 0.29168	—
15	7.79- 8.32	Sand	9.2	34.7	—	165.45 170.32	76.34 81.54	0.200 0.200	11.31 11.31	0.30333 0.30333	0.37027 0.37027	—
16	8.32- 8.79	Clay	8.2	—	180.0 180.0	170.32 174.18	81.54 86.14	0.200 0.200	11.31 11.31	—	—	42.52 42.47
17	8.79- 9.79	Clay	8.2	—	180.0 180.0	174.18 182.38	86.14 95.94	0.200 0.200	11.31 11.31	—	—	42.47 42.36
18	9.79- 10.32	Clay	8.2	—	100.0 100.0	182.38 186.72	95.94 101.14	0.200 0.200	11.31 11.31	—	—	40.56 40.47
19	10.32- 11.32	Clay	6.7	—	200.0 200.0	186.72 193.42	101.14 110.94	0.200 0.200	11.31 11.31	—	—	42.55 42.47
20	11.32- 33.80	Clay	7.2	—	1000.0 1000.0	193.42 355.28	110.94 331.24	0.200 0.200	11.31 11.31	—	—	44.46 44.02

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

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

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

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

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degrees	C kN/m ²	$\sum \gamma h + Q_p$ kN/m ²	γ_{sub} kN/m ³	k (k ²)	θ degrees	Kp	Kp $\times \cos \delta$
10	4.33- 4.79	Clay	5.70	0.0	50.0 50.0	0.000 2.622	0.00 0.200	0.200 11.31	11.31	—	—
11	4.79- 5.32	Clay	5.70	0.0	100.0 100.0	2.622 5.643	4.51 9.70	0.200 0.200	11.31 11.31	—	—
12	5.32- 5.79	Sand	9.20	34.7	—	5.643 9.967	9.70 14.31	0.200 0.200	11.31 11.31	3.24095 3.24095	3.24095 3.24095
13	5.79- 6.79	Sand	9.20	34.0	—	9.967 19.167	14.31 24.11	0.200 0.200	11.31 11.31	3.13983 3.13983	3.13983 3.13983
14	6.79- 7.79	Sand	9.20	41.3	—	19.167 28.367	24.11 33.91	0.200 0.200	11.31 11.31	4.42329 4.42329	4.42329 4.42329
15	7.79- 8.32	Sand	9.20	34.7	—	28.367 33.243	33.91 39.10	0.200 0.200	11.31 11.31	3.24095 3.24095	3.24095 3.24095
16	8.32- 8.79	Clay	8.20	0.0	180.0 180.0	33.243 37.097	39.10 43.71	0.200 0.200	11.31 11.31	—	—
17	8.79- 9.79	Clay	8.20	0.0	180.0 180.0	37.097 45.297	43.71 53.51	0.200 0.200	11.31 11.31	—	—
18	9.79- 10.32	Clay	8.20	0.0	100.0 100.0	45.297 49.643	53.51 58.70	0.200 0.200	11.31 11.31	—	—
19	10.32- 11.32	Clay	6.70	20.0	200.0 200.0	49.643 56.343	58.70 68.50	0.200 0.200	11.31 11.31	—	—
20	11.32- 33.80	Clay	7.20	30.0	1000.0 1000.0	56.343 218.199	68.50 288.81	0.200 0.200	11.31 11.31	—	—

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00^\circ$ degrees, $\beta = 0.00^\circ$ degrees

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\sum \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m ²
1	1.93	0.00	0.00
2	2.93	1.00	2.66
3	3.93	2.00	3.78
4	4.33	2.40	4.12

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

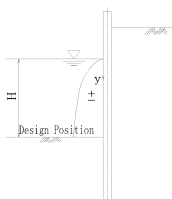
Where,

k_{dw} : 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



Seismic composite angle $\theta = \tan^{-1} k$

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

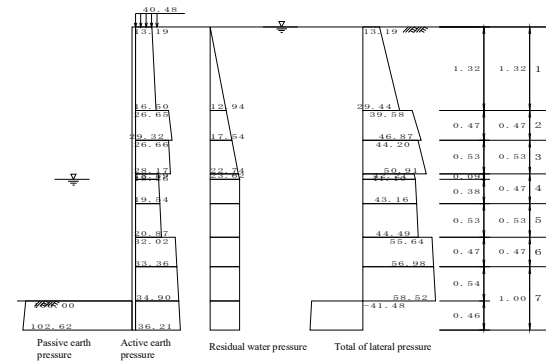
3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.32	52.25 57.18	—	52.25 57.18	0.00 12.94	—
2	1.32- 1.79	130.90 134.71	58.96 60.30	130.90 134.71	12.94 17.54	—
3	1.79- 1.93	103.82 104.87	60.30 60.70	103.82 104.87	17.54 18.91	—
4	1.93- 2.32	104.87 107.81	60.70 61.83	104.87 107.81	18.91 18.91	—
5	2.32- 2.79	59.94 61.70	—	59.94 61.70	18.91 18.91	—
6	2.79- 3.32	61.70 63.68	—	61.70 63.68	18.91 18.91	—
7	3.32- 3.79	115.67 119.22	63.68 67.00	115.67 119.22	18.91 18.91	—
8	3.79- 4.27	64.90 68.37	67.00 68.37	67.00 68.37	18.91 18.91	—
9	4.27- 4.33	68.37 68.79	68.37 68.54	68.37 68.79	18.91 18.91	—
10	4.33- 4.79	68.79 72.11	68.54 69.85	68.79 72.11	18.91 18.91	100.00 102.62
11	4.79- 5.32	30.22 26.49	69.85 71.36	69.85 71.36	18.91 18.91	202.62 205.64
12	5.32- 5.79	52.85 54.45	—	52.85 54.45	18.91 18.91	18.29 32.30
13	5.79- 6.79	55.81 59.30	—	55.81 59.30	18.91 18.91	31.29 60.18
14	6.79- 7.79	45.57 48.26	—	45.57 48.26	18.91 18.91	84.78 125.48
15	7.79- 8.32	61.26 63.06	—	61.26 63.06	18.91 18.91	91.94 107.74
16	8.32- 8.79	153.88 149.18	85.16 87.09	85.16 87.09	18.91 18.91	393.24 397.10
17	8.79- 9.79	149.18 139.16	87.09 91.19	87.09 91.19	18.91 18.91	397.10 403.30
18	9.79- 10.32	22.56 27.96	91.19 93.36	91.19 93.36	18.91 18.91	245.30 249.64
19	10.32- 11.32	174.06 165.88	93.36 96.71	93.36 96.71	18.91 18.91	449.64 456.34
20	11.32- 33.80	1767.51 1572.36	96.71 177.64	96.71 177.64	18.91 18.91	2056.34 2218.20

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



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 1.32	13.19 16.50	0.00 12.94	—	13.19 29.44
2	1.32- 1.79	26.65 29.32	12.94 17.54	—	39.58 46.87
3	1.79- 2.32	26.66 28.17	17.54 22.74	—	44.20 50.91
4	2.32- 2.41	18.36 18.59	22.74 23.62	—	41.10 42.21
5	2.41- 2.79	18.59 19.54	23.62 23.62	—	42.21 43.16
6	2.79- 3.32	19.54 20.87	23.62 23.62	—	43.16 44.49
7	3.32- 3.79	32.02 33.36	23.62 23.62	—	55.64 56.98
8	3.79- 4.33	33.36 34.90	23.62 23.62	—	56.98 58.52
9	4.33- 4.79	34.90 36.21	23.62 23.62	100.00 102.62	41.48 42.79

P_a : Active earth pressure

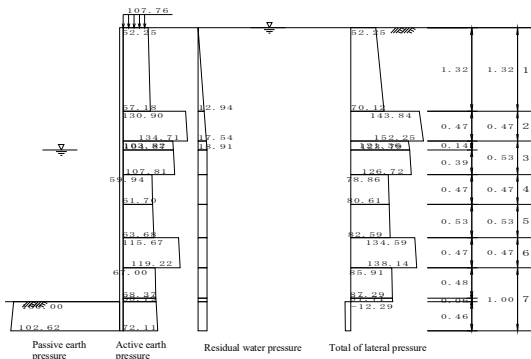
P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed L_A: 0.00 m (GL -4.33 m)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.32	52.25 57.18	0.00 12.94	—	52.25 70.12
2	1.32- 1.79	130.90 134.71	12.94 17.54	—	143.84 152.25
3	1.79- 1.93	103.82 104.87	17.54 18.91	—	121.36 123.79
4	1.93- 2.32	104.87 107.81	18.91 18.91	—	123.79 126.72
5	2.32- 2.79	59.94 61.70	18.91 18.91	—	78.86 80.61
6	2.79- 3.32	61.70 63.68	18.91 18.91	—	80.61 82.59
7	3.32- 3.79	115.67 119.22	18.91 18.91	—	134.59 138.14
8	3.79- 4.27	67.00 68.37	18.91 18.91	—	85.91 87.29
9	4.27- 4.33	68.37 68.79	18.91 18.91	—	87.29 87.71
10	4.33- 4.79	68.79 72.11	18.91 18.91	100.00 102.62	-12.29 -11.60

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

3.48 m depth (GL -7.81 m).

No	Depth Z m	Thickness h m	N Value upper lower	Area A
1	4.33	0.96	14.5 26.0	19.43
2	5.29	1.00	26.0 24.0	25.00
3	6.29	1.00	24.0 46.0	35.00
4	7.29	0.52	46.0 35.6	21.21
L = Σh = 3.48		ΣA = 100.64		

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

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{100.64}{3.48} = 28.92$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 28.92 = 80978 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 80978 = 269928 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition } =1, \text{ Seismic Condition } =2)$$

$$K_b = K_{10} (B_u/0.3)^{-3/4} = 269928 (10.00/0.3)^{-3/4} = 19458 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 19458 kN/m³.

5.3 Seismic Condition

Assuming Kh = 36265 kN/m³,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.336 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.98 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.33 m) and 2.98 m depth (GL -7.31 m).

No	Depth Z m	Thickness h m	N Value upper lower	Area A
1	4.33	0.96	14.5 26.0	19.43
2	5.29	1.00	26.0 24.0	25.00
3	6.29	1.00	24.0 46.0	35.00
4	7.29	0.02	46.0 45.6	0.84
L = Σh = 2.98		ΣA = 80.27		

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

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

Imaginary riverbed L_A: 0.00 m (GL -4.33 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B_u}{0.3} \right)^{-3/4} \quad (B_u = 10.00 \text{ m})$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition } =1, \text{ Seismic Condition } =2)$$

$$E_0 = 2800N'$$

where:

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H	H 750 -250 -14 -22 -18
Unit width	B	= 1.0000 m
Corrosion margin	t ₁	= 1.00 mm (active side)
Corrosion rate	η	= 0.86
Section efficiency	μ	= 1.00
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 414700 cm ⁴ (original condition)
	I	= 356642 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	= 200000 × 10 ³ × 356642 × 10 ⁻⁸ = 7.133 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	1.29	2	11	11.29	50
2	2.29	4	12	12.29	50
3	3.29	5	13	13.29	50
4	4.29	14	14	14.29	50
5	5.29	26	15	15.29	50
6	6.29	24	16	16.29	50
7	7.29	46	17	17.29	50
8	8.29	26	18	18.29	50
9	9.29	18	19	19.29	50
10	10.29	14	20	20.29	50

5.2 Normal Condition

Assuming Kh = 19458 kN/m³,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.287 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.48 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.33 m) to

$$= \frac{80.27}{2.98} = 26.95$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 26.95 = 75463 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 75463 = 503086 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition } =1, \text{ Seismic Condition } =2)$$

$$K_b = K_{10} (B_u/0.3)^{-3/4} = 503086 (10.00/0.3)^{-3/4} = 36265 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 36265 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.32	1.32	13.19 29.44	8.71 19.43	3.89 3.45	33.87 67.04
2	1.32- 1.79	0.47	39.58 46.87	9.30 11.01	2.85 2.70	26.54 29.70
3	1.79- 2.32	0.53	44.20 50.91	11.71 13.49	2.36 2.19	27.68 28.50
4	2.32- 2.41	0.09	41.10 42.21	1.85 1.90	1.98 1.95	3.66 3.70
5	2.41- 2.79	0.38	42.21 43.16	8.02 8.20	1.79 1.67	14.38 13.67
6	2.79- 3.32	0.53	43.16 44.49	11.44 11.79	1.36 1.19	15.29 13.99
7	3.32- 3.79	0.47	55.64 56.98	13.08 13.39	0.85 0.70	11.16 9.33
8	3.79- 4.33	0.54	56.98 58.52	15.38 15.80	0.36 0.18	5.54 2.84
			ΣP = 174.50	ΣM = 308.20		

P₀ : active earth pressure + residual water pressure - passive earth pressure

P : load P₀ × h/2 × B

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load P × Y

$$\text{Arbitrary load lateral load} \quad P_t = 52.9 \text{ kN/m}$$

$$\text{depth to acting position} \quad H_t = 0.0 \text{ m}$$

moment $M_m = 24.8 \text{ kN}\cdot\text{m/m}$
depth to acting position $H_m = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 4.33 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_m = 253.86 \text{ kN}\cdot\text{m}$$

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{\frac{P_0}{562.06}} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{227.40}{227.40} = 2.47 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Force P _h kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.32	1.32	52.25 70.12	34.49 46.28	3.89 3.45	134.15 159.66
2	1.32- 1.79	0.47	143.84 152.25	33.80 35.78	2.85 2.70	96.45 96.49
3	1.79- 1.93	0.14	121.36 123.79	8.50 8.67	2.49 2.45	21.18 21.20
4	1.93- 2.32	0.39	123.79 126.72	24.14 24.71	2.27 2.14	54.79 52.88
5	2.32- 2.79	0.47	78.86 80.61	18.53 18.94	1.85 1.70	34.35 32.14
6	2.79- 3.32	0.53	80.61 82.59	21.36 21.89	1.36 1.19	29.12 25.97
7	3.32- 3.79	0.47	134.59 138.14	31.63 32.46	0.85 0.70	26.99 22.62
8	3.79- 4.27	0.48	85.91 87.29	20.48 21.01	0.38 0.22	7.85 4.60
9	4.27- 4.33	0.06	87.29 87.71	2.56 2.57	0.04 0.02	0.10 0.05
			$\Sigma P =$	407.99	$\Sigma M =$	820.59

P_i : active earth pressure + residual water pressure - passive earth pressure

P : load $P_h \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

Arbitrary load lateral load

$$P_i = 121.4 \text{ kN/m}$$

$$H_i = 0.00 \text{ m}$$

$$M_m = 163.5 \text{ kN}\cdot\text{m/m}$$

$$H_m = 0.00 \text{ m}$$

$$H = 4.33 \text{ m}$$

$$L_k = 0.00 \text{ m}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_m = 689.16 \text{ kN}\cdot\text{m}$$

Hydrodynamic Pressure

$$\text{moment } M_0 = 562.06 \text{ kN}\cdot\text{m/m}$$

in consideration of $\psi_m = 1.246$,

maximum moment

depth of generated position of $M_{\max}$

depth of 1st fixed point

$$M_{\max} = 700.34 \text{ kN}\cdot\text{m/m}$$

$$l_m = 1.363 \text{ m}$$

$$l_i = 4.096 \text{ m}$$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction

$$K_h = 36265 \text{ kN/m}^3$$

calculated value

$$\beta = 0.33577 \text{ m}^3$$

resultant earth force (lateral)

$$P_0 = 535.50 \text{ kN/m}$$

height of acting position of load

$$h_0 = 2.83 \text{ m}$$

moment

$$M_0 = 1515.16 \text{ kN}\cdot\text{m/m}$$

in consideration of $\psi_m = 1.158$,

maximum moment

depth of generated position of $M_{\max}$

depth of 1st fixed point

$$M_{\max} = 1755.03 \text{ kN}\cdot\text{m/m}$$

$$l_m = 0.989 \text{ m}$$

$$l_i = 3.328 \text{ m}$$

6.3 Stress Intensity

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

Material Name 10 H _ H 750 -250 -14 -22 -18
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.88$
Section efficiency $\mu = 1.00$
Module of section $Z_0 = 7640 \text{ cm}^3$ (original condition)
 $Z = 6723 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{700.34 \times 10^6}{6723 \times 10^3} = 104 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{1755.03 \times 10^6}{6723 \times 10^3} = 261 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.32	3.89 3.45	0.898 0.797	0.283 0.233	8.71 19.43	2.461 4.530
2	1.32- 1.79	2.85 2.70	0.659 0.623	0.169 0.154	9.30 11.01	1.576 1.693
3	1.79- 2.32	2.36 2.19	0.546 0.505	0.122 0.106	11.71 13.49	1.427 1.431
4	2.32- 2.41	1.98 1.95	0.437 0.430	0.089 0.086	1.85 1.90	0.164 0.164

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	1.93- 2.93	1.00	0.0 2.7	0.00 1.33	2.67 1.73	0.00 2.30
2	2.93- 3.93	1.00	2.7 3.8	1.33 1.88	1.07 0.73	1.42 1.38
3	3.93- 4.33	0.40	3.8 4.1	0.75 0.82	0.27 0.13	0.20 0.11
			$\Sigma P_{hw} =$	6.11	$\Sigma M_{hw} =$	5.41

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{\frac{P_0}{1515.16}} = \frac{\Sigma M + M_i + \Sigma M_{dw}}{\Sigma P + P_i + \Sigma P_{dw}} = \frac{535.50}{535.50} = 2.83 \text{ m}$$

6.2 Sectional Force

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

Material name 10 H _ H 750 -250 -14 -22 -18
Unit width $B = 1.0000 \text{ m}$
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.86$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 414700 \text{ cm}^4$ (original condition)
 $I = 356642 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 356642 \times 10^8 = 7.133 \times 10^8$

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

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_h = 19458 \text{ kN/m}^3$
calculated value $\beta = 0.28737 \text{ m}^3$
resultant earth force (lateral) $P_0 = 277.40 \text{ kN/m}$
height of acting position of load $h_0 = 2.47 \text{ m}$

5	2.41- 2.79	1.79 1.67	0.414 0.385	0.074 0.065	8.02 8.20	0.593 0.530
6	2.79- 3.32	1.36 1.19	0.315 0.274	0.044 0.034	11.44 11.79	0.507 0.402
7	3.32- 3.79	0.85 0.70	0.197 0.161	0.018 0.012	13.08 13.39	0.237 0.164
8	3.79- 4.33	0.36 0.18	0.083 0.042	0.003 0.001	15.38 15.80	0.052 0.013
			$\Sigma Q =$	15.944		

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

$$Q : \zeta \times P$$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q .

P_t : horizontal load

Y_t : Height from the virtual ground plane to the point of horizontal load action

If

$$P_t = 52.90$$

$$Y_t = 4.33$$

$$\alpha_t = 1.000$$

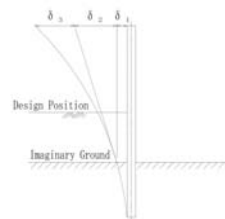
$$\zeta_t = 0.333$$

$$Q_t = \zeta_t \times P_t = 17.633$$

Therefore, the deformation coefficient Q is expressed by

$$Q = 15.944 + 17.633 = 33.577$$

Displacement Calculation



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

$$= \frac{(1+0.2874 \times 2.47) \times 277.40}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.2874^3} = 0.01149 \text{ m}$$

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

$$= \frac{(1+2 \times 0.2874 \times 2.47) \times 227.40}{2 \times 2.00 \times 10^9 \times 356642 \times 10^{-8} \times 0.2874^2} \times (4.33+0.00) = 0.02023 \text{ m}$$

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

$$= \frac{33.58 \times (4.33+0.00)^3}{2.00 \times 10^9 \times 356642 \times 10^{-8}} = 0.00382 \text{ m}$$

The displacement amount (δ_3) of the cantilever beam by the bending moment (Mm) is added.

$$\delta_{3a} = \frac{M_b \cdot h}{2 E I} \times (2 L - h) \quad (L=4.33 \text{ m}, h=L-H_a, H_a=0.00 \text{ m}, \text{ただし } h \leq L)$$

$$= \frac{24.80 \times 4.33}{2 \times 2.00 \times 10^9 \times 356642 \times 10^{-8}} \times (2 \times 4.33 - 4.33) = 0.00033 \text{ m}$$

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

$$= 0.01149 + 0.02023 + 0.00415$$

$$= 0.03587 \text{ m}$$

$$\text{Size} = 35.87 \leq \delta_a = 50.00 \text{ mm}$$

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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.32	3.89 3.45	0.898 0.797	0.283 0.233	34.49 46.28	9.749 10.788
2	1.32- 1.79	2.85 2.70	0.659 0.623	0.169 0.154	33.80 35.78	5.727 5.498
3	1.79- 1.93	2.49 2.45	0.576 0.565	0.134 0.130	8.50 8.67	1.138 1.123
4	1.93- 2.32	2.27 2.14	0.524 0.494	0.113 0.102	24.14 24.71	2.737 2.521
5	2.32- 2.79	1.85 1.70	0.428 0.392	0.079 0.067	18.53 18.94	1.455 1.264
6	2.79- 3.32	1.36 1.19	0.315 0.274	0.044 0.034	21.36 21.89	0.948 0.747
7	3.32- 3.79	0.85 0.70	0.197 0.161	0.018 0.012	31.63 32.46	0.574 0.398
8	3.79- 4.27	0.38 0.22	0.088 0.051	0.004 0.001	20.68 21.01	0.077 0.026
9	4.27- 4.33	0.04 0.02	0.009 0.005	0.000 0.000	2.56 2.57	0.000 0.000
$\Sigma Q = 44.771$						

$$\delta_2 = \frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.3358 \times 2.83) \times 535.50}{2 \times 2.00 \times 10^9 \times 356642 \times 10^{-8} \times 0.3358^2} \times (4.33+0.00) = 0.04181 \text{ m}$$

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

$$= \frac{85.39 \times (4.33+0.00)^3}{2.00 \times 10^9 \times 356642 \times 10^{-8}} = 0.00972 \text{ m}$$

The displacement amount (δ_3) of the cantilever beam by the bending moment (Mm) is added.

$$\delta_{3a} = \frac{M_b \cdot h}{2 E I} \times (2 L - h)$$

$$= \frac{**** \times 4.33}{2 \times 2.00 \times 10^9 \times 356642 \times 10^{-8}} \times (2 \times 4.33 - 4.33) = 0.00215 \text{ m}$$

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

$$= 0.01934 + 0.04181 + 0.01187$$

$$= 0.07302 \text{ m}$$

$$\text{Size} = 73.02 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	10 H ₂ H 750-250-14-22-18
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 = 414700 cm ⁴ (original condition) I = 414700cm ⁴ (after reduction by corrosion and section)
El = 200000 × 10 ³ × 414700 × 10 ⁻⁸	= 8.294 × 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:

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

$$L = H - H_{11} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

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

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.

Pt: horizontal load

Yt: Height from the virtual ground plane to the point of horizontal load action

If

$$P_t = 121.40$$

$$Y_t = 4.33$$

$$\alpha t = 1.000$$

$$\zeta t = 0.333$$

$$Q_t = \zeta t \times P_t = 40.467$$

Therefore, the deformation coefficient Q is expressed by

$$Q = 44.771 + 40.467 = 85.238$$

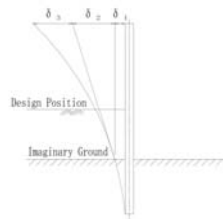
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth m	Y m	α	ζ	Pbw kN	Qbw kN
1	1.93- 2.93	2.07 1.73	0.477 0.400	0.096 0.069	0.00 1.33	0.000 0.092
2	2.93- 3.93	1.07 0.73	0.246 0.169	0.028 0.014	1.33 1.88	0.037 0.025
3	3.93- 4.33	0.27 0.13	0.062 0.031	0.002 0.000	0.75 0.82	0.001 0.000
$\Sigma Qbw =$						0.156

Therefore, the deformation coefficient Q is expressed by

$$Q = 85.238 + 0.156 = 85.394$$

Displacement Calculation



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

$$= \frac{(1+0.3358 \times 2.83) \times 535.50}{2 \times 2.00 \times 10^9 \times 356642 \times 10^{-8} \times 0.3358^3} = 0.01934 \text{ m}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction
Calculated value $K_b = 19458 \text{ kN/m}^3$
 $\beta = 0.27674 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.277} = 10.84 \text{ m}$
Whole length of SSP $L = 4.33 - 0.40 + 10.84 = 14.77 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction
Calculated value $K_b = 36265 \text{ kN/m}^3$
 $\beta = 0.32334 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.323} = 9.28 \text{ m}$
Whole length of SSP $L = 4.33 - 0.40 + 9.28 = 13.21 \text{ m}$

Therefore, the total length of the sheet pile is 15.00 m from the rounded length value of 0.50 m.

8 Calculation Result

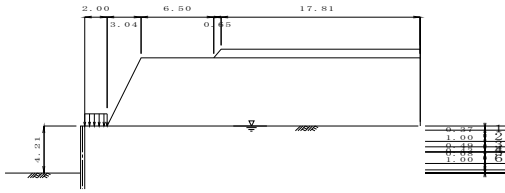
front sheet pile	10 H ₂ H 750-250-14-22-18		Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	414700		
Sectional Modulus	Z (cm ³)	7640		
Maximum bending moment	Mmax (kN · m · m)		700.34	1755.03
Stress intensity	σ (N/mm ²)		104 (180)	261 (270)
Lateral displacement	δ (mm)		35.87 (50.0)	73.02 (75.0)
Penetration depth	D (m)		10.84	9.28
Whole length of SSP	L (m)	15.00		

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_a : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	2.00	5.04	30.00	30.00	6.09	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	11.54	12.19	30.00	30.00	0.76	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	2.00	5.0	0.0

Angle of rupture in embankment calculated in consideration of embankment conditions

2	3.94 ~ 3.37	Sand	27.2	15.0	0.0	29.48	54.61	38.61	54.95
3	3.37 ~ 2.37	Sand	27.0	15.0	0.0	25.09	54.61	33.03	54.81
4	2.37 ~ 2.29	Sand	27.0	15.0	0.0	17.39	54.61	23.23	54.81
5	2.29 ~ 1.86	Clay	0.0	15.0	18.0	16.77	54.61	22.44	45.00
6	1.86 ~ 1.37	Sand	27.0	15.0	0.0	14.32	54.61	18.23	54.81
7	1.37 ~ 0.37	Sand	27.0	15.0	0.0	10.55	54.61	13.43	54.81
8	0.37 ~ 0.00	Sand	27.0	15.0	0.0	2.85	54.61	3.63	54.81
9	embankment	30.0	—	0.0	130.15	0.00	0.00	0.00	60.00

• Angle of active rupture of sandy soil

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

• Angle of active rupture of clayey soil

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

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

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.27	0.00	0.00	0.27	0.27
2	54.95	0.57	0.27	0.27	0.67	0.84
3	54.81	1.00	0.67	0.84	1.38	1.84
4	54.81	0.08	1.38	1.84	1.43	1.92
5	45.00	0.43	1.43	1.92	1.86	2.35
6	54.81	0.49	1.86	2.35	2.21	2.84
7	54.81	1.00	2.21	2.84	2.91	3.84
8	54.81	0.37	2.91	3.84	3.17	4.21
9	60.00	6.09	3.17	4.21	6.69	10.30

From the above table, the loading width (L) on the ground surface is 3.17 m.

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 700 -250 - 12-19-18
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 331300 \text{ cm}^4$
 Sectional factor $Z_0 = 6270 \text{ cm}^3$

Corrosion margin $t_1 = 1.00 \text{ mm (riverside)}$ $t_2 = 1.00 \text{ mm (landside)}$

Corrosion rate (to I_0) $\eta = 0.85$
 Corrosion rate (to Z_0) $\eta = 0.86$
 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 $\sigma_a = 180 \text{ N/mm (Normal)}$
 $\sigma_a' = 270 \text{ N/mm (Seismic)}$

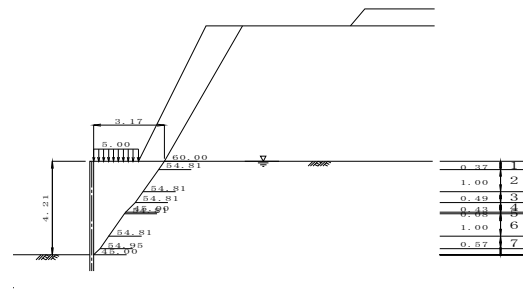
Allowable displacement $\delta_a = 50.0 \text{ mm (Normal)}$
 $\delta_a' = 75.0 \text{ mm (Seismic)}$

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	$\sum \gamma h$ kN/m ²	Q kN/m ²	γ when kN/m ²	Angle of Rupture ζ degree
1	4.21 ~ 3.94	Clay	0.0	15.0	50.0	31.02	54.61	41.26	45.00

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	8.59	163.28
Σ			163.28

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	Ql kN/m
1	5.0	2.00	10.00
Σ			10.00

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

l : Loading width of uniform load surrounded by main collapse line

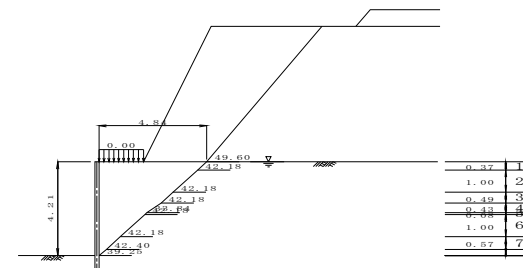
2.1.5 Calculated Load

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

$$= \frac{163.28 + 10.00 + 0.00}{3.17}$$

$$= 54.61 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth m	Soil	ϕ degree	δ degree	C kN/m ²	$\sum \gamma h$ kN/m ²	Q kN/m ²	γ when kN/m ²	k (k')	θ degree	Angle of Rupture ζ degree
1	4.21 ~ 3.94	Clay	0.0	15.0	50.0	31.02	93.51	41.26	0.200	11.31	39.25

2	3.94~3.37	Sand	27.2	15.0	0.0	29.48	93.51	38.61	0.200	11.31	42.40
3	3.37~2.37	Sand	27.0	15.0	0.0	25.09	93.51	33.03	0.200	11.31	42.18
4	2.37~2.29	Sand	27.0	15.0	0.0	17.39	93.51	23.23	0.200	11.31	42.18
5	2.29~1.86	Clay	0.0	15.0	18.0	16.77	93.51	22.44	0.200	11.31	33.84
6	1.86~1.37	Sand	27.0	15.0	0.0	14.32	93.51	18.23	0.200	11.31	42.18
7	1.37~0.37	Sand	27.0	15.0	0.0	10.55	93.51	13.43	0.200	11.31	42.18
8	0.37~0.00	Sand	27.0	15.0	0.0	2.85	93.51	3.63	0.200	11.31	42.18
9		embankment t	30.0	—	0.0	130.15	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\gamma h + Q}$$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.0^\circ$)
- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	39.25	0.27	0.00	0.00	0.33	0.27
2	42.40	0.57	0.33	0.27	0.95	0.84
3	42.18	1.00	0.95	0.84	2.06	1.84
4	42.18	0.08	2.06	1.84	2.15	1.92
5	33.84	0.43	2.15	1.92	2.79	2.35
6	42.18	0.49	2.79	2.35	3.33	2.84
7	42.18	1.00	3.33	2.84	4.43	3.84
8	42.18	0.37	4.43	3.84	4.84	4.21
9	49.60	6.09	4.84	4.21	10.02	10.30

From the above table, the loading width (L) on the ground surface is 4.84 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	23.82	452.65
Σ			452.65

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/m ²	l m	Qd kN/m
1	0.0	2.00	0.00
Σ			0.00

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

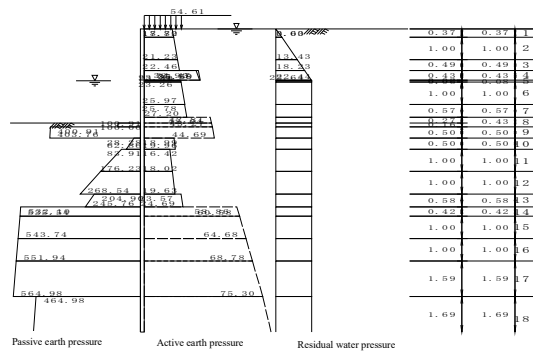
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L}$$

$$= \frac{452.65 + 0.00 + 0.00}{4.84}$$

$$= 93.51 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



6	2.31~ 2.37	23.31 23.46	————	23.31 23.46	22.64 22.64	————
7	2.37~ 3.37	23.46 25.97	————	23.46 25.97	22.64 22.64	————
8	3.37~ 3.94	25.78 27.20	————	25.78 27.20	22.64 22.64	————
9	3.94~ 4.21	-15.91 -14.37	42.04 42.81	42.04 42.81	22.64 22.64	————
10	4.21~ 4.37	-14.37 -13.46	42.81 43.27	42.81 43.27	22.64 22.64	100.00 100.91
11	4.37~ 4.87	-313.46 -310.61	43.27 44.69	43.27 44.69	22.64 22.64	400.91 403.76
12	4.87~ 5.37	18.99 19.96	————	18.99 19.96	22.64 22.64	28.28 62.86
13	5.37~ 6.37	16.42 18.02	————	16.42 18.02	22.64 22.64	83.91 176.23
14	6.37~ 7.37	18.02 19.63	————	18.02 19.63	22.64 22.64	176.23 268.54
15	7.37~ 7.95	21.57 24.69	————	21.57 24.69	22.64 22.64	204.90 345.76
16	7.95~ 8.37	-382.28 -378.83	58.86 60.58	58.86 60.58	22.64 22.64	532.10 535.54
17	8.37~ 9.37	-378.83 -370.63	60.58 64.68	60.58 64.68	22.64 22.64	535.54 543.74
18	9.37~ 10.37	-370.63 -362.43	64.68 68.78	64.68 68.78	22.64 22.64	543.74 551.94
19	10.37~ 11.96	-362.43 -349.39	68.78 75.30	68.78 75.30	22.64 22.64	551.94 564.98
20	11.96~ 13.65	-249.39 -238.07	75.30 80.96	75.30 80.96	22.64 22.64	464.98 476.30
21	13.65~ 33.70	-1838.07 -1693.71	80.96 153.14	80.96 153.14	22.64 22.64	2076.30 2220.66

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \sum \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\sum \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

Sand $P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_p = \sum \gamma h + Q + 2C$
Mixed soil $P_p = [K_p(\sum \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$

13	5.37~ 6.37	Sand	9.2	42.4	————	132.89 142.09	52.63 62.43	0.200 0.200	11.31 11.31	0.28983 0.28983	0.27995 0.27995	————
14	6.37~ 7.37	Sand	9.2	42.4	————	142.09 151.29	62.43 72.23	0.200 0.200	11.31 11.31	0.28983 0.28983	0.27995 0.27995	————
15	7.37~ 7.95	Sand	9.2	38.2	————	151.29 156.62	72.23 77.91	0.200 0.200	11.31 11.31	0.33826 0.33826	0.32674 0.32674	————
16	7.95~ 8.37	Clay	8.2	—	250.0 250.0	156.62 160.97	77.91 82.03	0.200 0.200	11.31 11.31	————	————	43.31 43.28
17	8.37~ 9.37	Clay	8.2	—	250.0 250.0	160.97 168.27	82.03 91.83	0.200 0.200	11.31 11.31	————	————	43.28 43.19
18	9.37~ 10.37	Clay	8.2	—	250.0 250.0	168.27 176.47	91.83 101.63	0.200 0.200	11.31 11.31	————	————	43.19 43.11
19	10.37~ 11.96	Clay	8.2	—	250.0 250.0	176.47 189.50	101.63 117.21	0.200 0.200	11.31 11.31	————	————	43.11 42.98
20	11.96~ 13.65	Clay	6.7	—	200.0 200.0	189.50 200.83	117.21 133.77	0.200 0.200	11.31 11.31	————	————	42.52 42.38
21	13.65~ 33.70	Clay	7.2	—	1000.0 1000.0	200.83 345.19	133.77 330.26	0.200 0.200	11.31 11.31	————	————	44.44 44.04

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

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

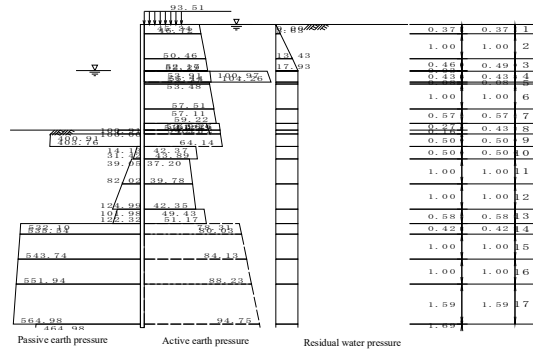
Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

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

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q_p$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Kp	$K_p \times \cos \delta$
10	4.21~ 4.37	Clay	5.70	0.0	50.0 50.0	0.000 0.912	0.00 1.57	0.200 0.200	11.31 11.31	————	————
11	4.37~ 4.87	Clay	5.70	0.0	200.0 200.0	0.912 3.762	1.57 6.47	0.200 0.200	11.31 11.31	————	————
12	4.87~ 5.37	Sand	9.20	37.9	————	3.762 8.362	6.47 11.37	0.200 0.200	11.31 11.31	3.75724 3.75724	3.75724 3.75724
13	5.37~ 6.37	Sand	9.20	42.4	————	8.362 17.562	11.37 21.17	0.200 0.200	11.31 11.31	4.67049 4.67049	4.67049 4.67049
14	6.37~ 7.37	Sand	9.20	42.4	————	17.562 26.762	21.17 30.97	0.200 0.200	11.31 11.31	4.67049 4.67049	4.67049 4.67049
15	7.37~ 7.95	Sand	9.20	38.2	————	26.762 32.098	30.97 36.65	0.200 0.200	11.31 11.31	3.81070 3.81070	3.81070 3.81070
16	7.95~ 8.37	Clay	8.20	0.0	250.0 250.0	32.098 35.542	36.65 40.77	0.200 0.200	11.31 11.31	————	————
17	8.37~ 9.37	Clay	8.20	0.0	250.0 250.0	35.542 43.742	40.77 50.57	0.200 0.200	11.31 11.31	————	————
18	9.37~ 10.37	Clay	8.20	0.0	250.0 250.0	43.742 51.942	50.57 60.37	0.200 0.200	11.31 11.31	————	————
19	10.37~ 11.96	Clay	8.20	0.0	250.0 250.0	51.942 64.980	60.37 75.95	0.200 0.200	11.31 11.31	————	————

3.2 Seismic Condition



The dotted line in the figure shows the main earth pressure strength Pa2 using the consolidation equilibrium coefficient.

3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00~ 0.37	Sand	7.7	27.0	————	93.51 96.36	0.00 3.63	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
2	0.37~ 1.37	Sand	7.7	27.0	————	96.36 104.06	3.63 13.43	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
3	1.37~ 1.83	Sand	7.7	27.0	————	104.06 107.60	13.43 17.93	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
4	1.83~ 1.86	Sand	7.7	27.0	————	107.60 107.83	17.93 18.23	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
5	1.86~ 2.29	Clay	5.7	—	18.0 18.0	107.83 110.28	18.23 22.44	0.200 0.200	11.31 11.31	————	————	34.00 33.84
6	2.29~ 2.37	Sand	7.7	27.0	————	110.28 110.90	22.44 23.23	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
7	2.37~ 3.37	Sand	7.7	27.0	————	110.90 118.60	23.23 33.03	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
8	3.37~ 3.94	Sand	7.7	27.2	————	118.60 122.99	33.03 38.61	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	————
9	3.94~ 4.21	Clay	5.7	—	50.0 50.0	122.99 124.52	38.61 41.26	0.200 0.200	11.31 11.31	————	————	39.31 39.25
10	4.21~ 4.37	Clay	5.7	—	50.0 50.0	124.52 125.44	41.26 42.83	0.200 0.200	11.31 11.31	————	————	39.25 39.22
11	4.37~ 4.87	Clay	5.7	—	200.0 200.0	125.44 128.29	42.83 47.73	0.200 0.200	11.31 11.31	————	————	43.31 43.27
12	4.87~ 5.37	Sand	9.2	37.9	————	128.29 132.89	47.73 52.63	0.200 0.200	11.31 11.31	0.34195 0.34195	0.33000 0.33000	————

The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00^\circ$ degrees, $\beta = 0.00^\circ$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00~ 0.37	45.34 46.72	————	46.72	0.00 3.63	————
2	0.37~ 1.37	46.72 50.46	————	46.72 50.46	3.63 13.43	————
3	1.37~ 1.83	50.46 52.17	————	50.46 52.17	13.43 17.93	————
4	1.83~ 1.86	52.17 52.29	————	52.17 52.29	17.93 17.93	————
5	1.86~ 2.29	100.97 104.26	53.91 55.14	100.97 104.26	17.93 17.93	————
6	2.29~ 2.37	53.48 53.77	————	53.48 53.77	17.93 17.93	————
7	2.37~ 3.37	53.77 57.51	————	53.77 57.51	17.93 17.93	————
8	3.37~ 3.94	57.51 59.22	————	57.51 59.22	17.93 17.93	————
9	3.94~ 4.21	51.02 52.96	61.49 62.26	61.49 62.26	17.93 17.93	————
10	4.21~ 4.37	52.96 54.11	62.26 62.72	62.26 62.72	17.93 17.93	100.00 100.91
11	4.37~ 4.87	-248.65 -245.19	62.72 64.14	62.72 64.14	17.93 17.93	400.91 403.76
12	4.87~ 5.37	42.37 43.89	————	42.37 43.89	17.93 17.93	14.13 31.42
13	5.37~ 6.37	37.20 39.78	————	37.20 39.78	17.93 17.93	39.05 82.02
14	6.37~ 7.37	39.78 42.35	————	39.78 42.35	17.93 17.93	82.02 124.99
15	7.37~ 7.95	49.43 51.17	————	49.43 51.17	17.93 17.93	101.98 122.32
16	7.95~ 8.37	-311.02 -306.84	78.31 80.03	78.31 80.03	17.93 17.93	532.10 535.54
17	8.37~ 9.37	-306.84 -296.88	80.03 84.13	80.03 84.13	17.93 17.93	535.54 543.74

18	9.37~ 10.37	-296.88 -286.92	84.13 88.23	84.13 88.23	17.93 17.93	543.74 551.94
19	10.37~ 11.96	-286.92 -271.07	88.23 94.75	88.23 94.75	17.93 17.93	551.94 564.98
20	11.96~ 13.65	-170.67 -156.83	94.75 100.41	94.75 100.41	17.93 17.93	464.98 476.30
21	13.65~ 33.70	-1758.60 -1584.55	100.41 172.59	100.41 172.59	17.93 17.93	2076.30 2220.66

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of P_{a1} or P_{a2} is applied as active earth pressure (P_a)

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

- Formula for passive earth pressure

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2C$
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	water level y m	paw kN/m2
1	1.83	0.00	0.00
2	2.83	1.00	2.65
3	3.83	2.00	3.74
4	4.21	2.38	4.08

$$p_{aw} = \pm \frac{7}{8} k_{10} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

k_{10} : 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

6	2.31~ 2.37	23.31 23.46	22.64 22.64	— —	45.95 46.10
7	2.37~ 3.37	23.46 25.97	22.64 22.64	— —	46.10 48.61
8	3.37~ 3.94	25.78 27.20	22.64 22.64	— —	48.42 49.84
9	3.94~ 4.21	42.04 42.81	22.64 22.64	— —	64.68 65.45
10	4.21~ 4.37	42.81 43.27	22.64 22.64	100.00 100.91	-34.55 -35.00

P_a : Active earth pressure

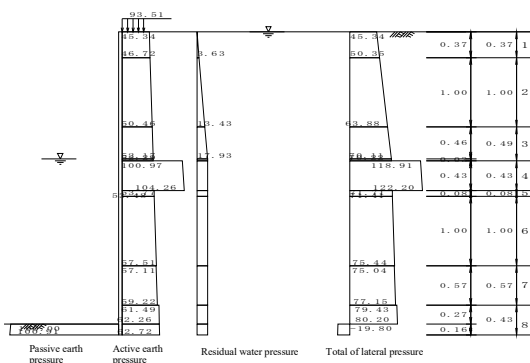
P_w : Residual water pressure

P_p : Passive earth pressure

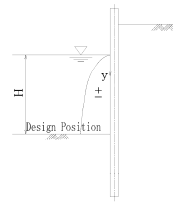
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 0.00 m (GL -4.21 m)

4.2 Seismic Condition



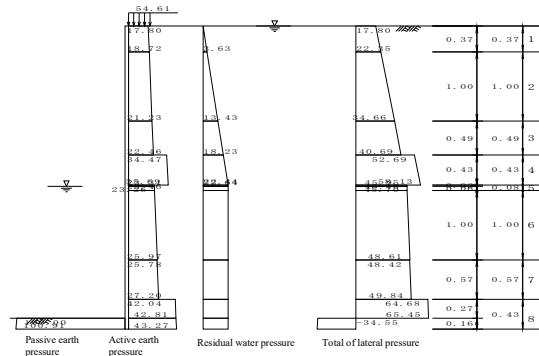
No	Depth m	P_a kN/m2	P_w kN/m2	P_p kN/m2	P_s kN/m2
1	0.00~ 0.37	45.34 46.72	0.00 3.63	— —	45.34 50.35
2	0.37~ 1.37	46.72 50.46	3.63 13.43	— —	50.35 63.88
3	1.37~ 1.83	50.46 52.17	13.43 17.93	— —	63.88 70.11
4	1.83~ 1.86	52.17 52.29	17.93 17.93	— —	70.11 70.22
5	1.86~ 2.29	100.97 104.26	17.93 17.93	— —	118.91 122.20



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



No	Depth m	P_a kN/m2	P_w kN/m2	P_p kN/m2	P_s kN/m2
1	0.00~ 0.37	17.80 18.72	0.00 3.63	— —	17.80 22.35
2	0.37~ 1.37	18.72 21.23	3.63 13.43	— —	22.35 34.66
3	1.37~ 1.86	21.23 22.46	13.43 18.23	— —	34.66 40.69
4	1.86~ 2.29	34.47 35.69	18.23 22.44	— —	52.69 58.13
5	2.29~ 2.31	22.26 23.31	22.44 22.64	— —	45.70 45.95

6	2.29~ 2.37	53.48 53.77	17.93 17.93	— —	71.41 71.71
7	2.37~ 3.37	53.77 57.51	17.93 17.93	— —	71.71 75.44
8	3.37~ 3.94	57.41 59.22	17.93 17.93	— —	75.04 77.15
9	3.94~ 4.21	61.49 62.26	17.93 17.93	— —	79.43 80.20
10	4.21~ 4.37	62.26 62.72	17.93 17.93	100.00 100.91	-19.80 -20.26

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed L_k : 0.00 m (GL -4.21 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B_{10}}{0.3} \right)^{-3/4} \quad (B_{10} = 10.00\text{m})$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_0 = 2800 \text{ N}'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H 700 -250 - 12-19-18
Unit width	B = 1.0000 m
Corrosion margin	$t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate	$\eta = 0.85$
Section efficiency	$\mu = 1.00$
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	$I_0 = 331300 \text{ cm}^4$ (original condition)
Inertia sectional moment	I = 281605 cm ⁴ (after reduction by corrosion and section)
	$EI = 200000 \times 10^3 \times 281605 \times 10^{-8} = 5.632 \times 10^5$

No	Depth m	N Value	No	Depth m	N Value
1	0.87	3	11	10.87	50
2	1.87	3	12	12.17	50
3	2.87	6			
4	3.87	10			
5	4.87	35			
6	5.87	50			
7	6.87	50			
8	7.87	36			
9	8.87	50			
10	9.87	50			

5.2 Normal Condition

Assuming $K_h = 28325 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.335 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.99 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.21 m) to 2.99 m depth (GL -7.20 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.21	0.66	18.5	35.0	17.65
2	4.87	1.00	35.0	50.0	42.50
3	5.87	1.00	50.0	50.0	50.00
4	6.87	0.33	50.0	45.4	15.57

$$L = \Sigma h = 2.99 \quad \Sigma A = 125.73$$

A: (upper N-value + lower N-value) $\times$ h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{125.73}{2.99}$$

$$= 42.10$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 42.10 = 117881 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 117881 = 392938 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10}(B_u/0.3)^{-3/4} = 392938(10.00/0.3)^{-3/4} = 28325 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 28325 kN/m^3 .

1	0.00- 0.37	0.37	17.80 22.35	3.29 4.13	4.09 3.96	13.45 16.39
2	0.37- 1.37	1.00	22.35 34.66	11.18 17.33	3.51 3.17	39.19 54.99
3	1.37- 1.86	0.49	34.66 40.69	8.49 9.97	2.68 2.51	22.73 25.06
4	1.86- 2.29	0.43	52.69 58.13	11.33 12.50	2.21 2.06	25.00 25.79
5	2.29- 2.31	0.02	45.70 45.95	0.46 0.46	1.91 1.91	0.87 0.88
6	2.31- 2.37	0.06	45.95 46.10	1.38 1.38	1.88 1.86	2.59 2.57
7	2.37- 3.37	1.00	46.10 48.61	23.05 24.31	1.51 1.17	34.73 28.52
8	3.37- 3.94	0.57	48.42 49.84	13.80 14.20	0.65 0.46	8.97 6.53
9	3.94- 4.21	0.27	64.68 65.45	8.73 8.84	0.18 0.09	1.57 0.80

$$\Sigma P = 174.83 \quad \Sigma M = 310.63$$

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

Arbitrary load lateral load $P_l = 52.9 \text{ kN/m}$
depth to acting position $H_l = 0.0 \text{ m}$
moment $M_m = 24.8 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_m = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 4.21 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_l) + M_m = 247.51 \text{ kN} \cdot \text{m}$$

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_l}{\Sigma P + P_l} = \frac{558.14}{227.73} = 2.45 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.37	0.37	45.34 50.35	8.39 9.31	4.09 3.96	34.28 36.92
2	0.37- 1.37	1.00	50.35 63.88	25.17 31.94	3.51 3.17	88.28 101.36
3	1.37- 1.83	0.46	63.88 70.11	14.69 16.13	2.69 2.53	39.48 40.85
4	1.83- 1.86	0.03	70.11 70.22	1.05 1.05	2.37 2.36	2.49 2.49

5.3 Seismic Condition

Assuming $K_h = 55121 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.396 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.53 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.21 m) and 2.53 m depth (GL -6.74 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.21	0.66	18.5	35.0	17.65
2	4.87	1.00	35.0	50.0	42.50
3	5.87	0.87	50.0	50.0	43.42

$$L = \Sigma h = 2.53 \quad \Sigma A = 103.58$$

A: (upper N-value + lower N-value) $\times$ h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{103.58}{2.53} = 40.96$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 40.96 = 114702 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 114702 = 764677 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10}(B_u/0.3)^{-3/4} = 764677(10.00/0.3)^{-3/4} = 55121 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 55121 kN/m^3 .

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
5	1.86- 2.29	0.43	118.91 122.20	25.57 26.27	2.21 2.06	56.41 54.21
6	2.29- 2.37	0.08	71.41 71.71	2.86 2.87	1.89 1.87	5.41 5.35
7	2.37- 3.37	1.00	71.71 75.44	35.85 37.72	1.51 1.17	54.02 44.26
8	3.37- 3.94	0.57	75.04 77.15	21.39 21.99	0.65 0.46	13.90 10.11
9	3.94- 4.21	0.27	79.43 80.20	10.72 10.83	0.18 0.09	1.93 0.97

$$\Sigma P = 303.80 \quad \Sigma M = 592.73$$

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

Arbitrary load lateral load $P_l = 121.4 \text{ kN/m}$
depth to acting position $H_l = 0.00 \text{ m}$
moment $M_m = 163.5 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_m = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 4.21 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_l) + M_m = 674.59 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	1.83- 2.83	1.00	0.0 2.6	0.00 1.32	2.05 1.71	0.00 2.27
2	2.83- 3.83	1.00	2.6 3.7	1.32 1.87	1.65 0.71	1.38 1.33
3	3.83- 4.21	0.38	3.7 4.1	0.71 0.78	0.25 0.15	0.18 0.10

$$\Sigma P_{dw} = 6.00 \quad \Sigma M_{dw} = 5.26$$

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_l + \Sigma M_{dw}}{\Sigma P + P_l + \Sigma P_{dw}} = \frac{1272.58}{431.21} = 2.95 \text{ m}$$

6.2 Sectional Force

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

Material name H H 700 -250 - 12-19-18
Unit width $B = 1.0000 \text{ m}$
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.85$

Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm ²
Inertia sectional moment	I ₀	=	331300 cm ⁴ (original condition)
	I	=	281605 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 281605 × 10 ⁻⁸		=	5.632 × 10 ⁵

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b	=	28325 kN/m ³
calculated value	β	=	0.33486 m ⁻¹
resultant earth force (lateral)	P ₀	=	227.73 kN/m
height of acting position of load	h ₀	=	2.485 m
moment	M ₀	=	558.14 kN·m/m

in consideration of $\psi_m = 1.198$, maximum moment	M _{max}	=	668.76 kN·m/m
depth of generated position of M _{max}	l _m	=	1.081 m
depth of 1 st fixed point	l _i	=	3.426 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b	=	55121 kN/m ³
calculated value	β	=	0.39550 m ⁻¹
resultant earth force (lateral)	P ₀	=	431.21 kN/m
height of acting position of load	h ₀	=	2.95 m
moment	M ₀	=	1272.58 kN·m/m

in consideration of $\psi_m = 1.114$, maximum moment	M _{max}	=	1418.05 kN·m/m
depth of generated position of M _{max}	l _m	=	0.737 m
depth of 1 st fixed point	l _i	=	2.723 m

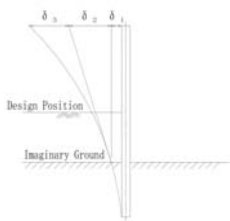
6.3 Stress Intensity

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

Material Name	10 H ₂ 700 -250 - 12-19-18
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
Module of section	Z ₀ = 6270 cm ³ (original condition)
	Z = 5392 cm ³ (after reduction by corrosion and section)

Therefore, the deformation coefficient Q is expressed by
Q = 16.825 + 17.633 = 34.458

Displacement Calculation



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

$$= \frac{(1+0.3349 \times 2.45) \times 227.73}{2 \times 2.00 \times 10^8 \times 281605 \times 10^{-8} \times 0.3349^3} = 0.00980 \text{ m}$$

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

$$= \frac{(1+2 \times 0.3349 \times 2.45) \times 227.73}{2 \times 2.00 \times 10^8 \times 281605 \times 10^{-8} \times 0.3349^2} \times (4.21+0.00) = 0.02005 \text{ m}$$

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

$$= \frac{34.46 \times (4.21+0.00)^3}{2.00 \times 10^8 \times 281605 \times 10^{-8}} = 0.00457 \text{ m}$$

The displacement amount (δ_3) of the cantilever beam by the bending moment (Mm) is added.

$$\delta_{3a} = \frac{M_m \cdot h}{2 E I} \times (2 L - h)$$

$$= \frac{24.80 \times 4.21}{2 \times 2.00 \times 10^8 \times 281605 \times 10^{-8}} \times (2 \times 4.21 - 4.21) = 0.00039 \text{ m}$$

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

$$= 0.00980 + 0.02005 + 0.00456$$

$$= 0.03481 \text{ m}$$

$$\text{Size} = 34.81 \leq \delta_a = 50.00 \text{ mm}$$

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

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{668.76 \times 10^6}{5392 \times 10^3} = 124 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{1418.05 \times 10^6}{5392 \times 10^3} = 263 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-0.37	4.09 3.96	0.971 0.941	0.319 0.304	3.29 4.13	1.049 1.257
2	0.37-1.37	3.51 3.17	0.833 0.754	0.251 0.213	11.18 17.33	2.800 3.686
3	1.37-1.86	2.68 2.51	0.636 0.597	0.159 0.143	8.49 9.97	1.353 1.423
4	1.86-2.29	2.21 2.06	0.524 0.490	0.113 0.100	11.33 12.50	1.284 1.256
5	2.29-2.31	1.91 1.91	0.454 0.453	0.088 0.087	0.46 0.46	0.040 0.040
6	2.31-2.37	1.88 1.86	0.447 0.442	0.085 0.083	1.38 1.38	0.117 0.115
7	2.37-3.37	1.51 1.17	0.358 0.279	0.056 0.035	23.05 24.31	1.300 0.856
8	3.37-3.94	0.65 0.46	0.154 0.109	0.011 0.006	13.80 14.20	0.156 0.082
9	3.94-4.21	0.18 0.09	0.043 0.021	0.001 0.000	8.73 8.84	0.008 0.002
$\Sigma Q =$						16.825

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.

Pt: horizontal load

Yt: Height from the virtual ground plane to the point of horizontal load action

If

$$Pt = 52.90$$

$$Yt = 4.21$$

$$\alpha t = 1.000$$

$$\zeta t = 0.333$$

$$Qt = \zeta t \times Pt = 17.633$$

6.4.2 Seismic Condition

Modulus of deformation

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-0.37	4.09 3.96	0.971 0.941	0.319 0.304	8.39 8.31	2.673 2.832
2	0.37-1.37	3.51 3.17	0.833 0.754	0.251 0.213	25.17 31.94	6.308 6.794
3	1.37-1.83	2.69 2.53	0.638 0.602	0.160 0.145	14.69 16.13	2.355 2.334
4	1.83-1.86	2.37 2.36	0.563 0.561	0.129 0.128	1.05 1.05	0.135 0.135
5	1.86-2.29	2.21 2.06	0.524 0.490	0.113 0.100	25.57 26.27	2.898 2.640
6	2.29-2.37	1.89 1.87	0.450 0.443	0.086 0.084	2.86 2.87	0.246 0.240
7	2.37-3.37	1.51 1.17	0.358 0.279	0.056 0.035	35.85 37.72	2.022 1.329
8	3.37-3.94	0.65 0.46	0.154 0.109	0.011 0.006	21.39 21.99	0.242 0.126
9	3.94-4.21	0.18 0.09	0.043 0.021	0.001 0.000	10.72 10.83	0.010 0.002
$\Sigma Q =$						33.322

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.

Pt: horizontal load

Yt: Height from the virtual ground plane to the point of horizontal load action

If

$$Pt = 121.40$$

$$Yt = 4.21$$

$$\alpha t = 1.000$$

$$\zeta t = 0.333$$

$$Qt = \zeta t \times Pt = 40.467$$

Therefore, the deformation coefficient Q is expressed by

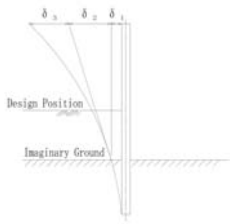
$$Q = 33.322 + 40.467 = 73.789$$

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

No	Depth, m	Y, m	α	ζ	Pdw, kN	Qdw, kN
1	1.83-2.83	2.05 1.71	0.486 0.407	0.099 0.072	0.00 1.32	0.000 0.095
2	2.83-3.83	1.05 0.71	0.249 0.169	0.028 0.014	1.32 1.87	0.038 0.025
3	3.83-4.21	0.25 0.13	0.060 0.030	0.002 0.000	0.71 0.76	0.001 0.000
$\Sigma Qdw =$						0.159

Therefore, the deformation coefficient Q is expressed by
 $Q = 73.789 + 0.159 = 73.948$

Displacement Calculation



$$\begin{aligned}\delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3955 \times 2.95) \times 431.21}{2 \times 2.00 \times 10^8 \times 281605 \times 10^{-8} \times 0.3955^3} = 0.01341 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_u) \\ &= \frac{(1 + 2 \times 0.3955 \times 2.95) \times 431.21}{2 \times 2.00 \times 10^8 \times 281605 \times 10^{-8} \times 0.3955^3} \times (4.21 + 0.00) = 0.03436 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_u)^3}{E I} \\ &= \frac{73.95 \times (4.21 + 0.00)^3}{2.00 \times 10^8 \times 281605 \times 10^{-8}} = 0.00980 \text{ m}\end{aligned}$$

The displacement amount (δ 3m) of the cantilever beam by the bending moment (Mm) is added.

$$\begin{aligned}\delta_{3a} &= \frac{M_{3a} \cdot h}{2 E I} \times (2 L - h) \\ &= \frac{**** \times 4.21}{2 \times 2.00 \times 10^8 \times 281605 \times 10^{-8}} \times (2 \times 4.21 - 4.21) = 0.00257 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01341 + 0.03436 + 0.01237 \\ &= 0.06014 \text{ m} \\ \text{Size} &= 60.14 \text{ mm} \leq \delta_a = 75.00 \text{ mm}\end{aligned}$$

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

8 Calculation Result

SSP		10 H_H 700-250-12-19-18			
			Normal Condition	Seismic Condition	
Inertia sectional moment	I (cm ⁴)	331300			
Sectional Modulus	Z (cm ³)	6270			
Maximum bending moment	Mmax (N · m · m)		608.76	1418.05	
Stress intensity	σ (N/mm ²)		124 (180)	263 (270)	
Lateral displacement	δ (mm)		34.81 (50.0)	60.14 (75.0)	
Penetration depth	D (m)		9.33	7.90	
Whole length of SSP	L (m)	13.50			

7 Penetration Depth

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

Material Name	10 H_H 700-250-12-19-18
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 = 331300 cm ⁴ (original condition)
	I = 331300 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 331300 × 10 ⁻⁸	= 6.626 × 10 ⁵

7.1 Penetration Depth and Whole Length of SSP (Chang)

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

$$\begin{aligned}D &= L_u + \frac{3}{\beta} \\ L &= H - H_{11} + D \\ \beta &= 4 \sqrt{\frac{K_{11} \cdot B}{4 E I}}\end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_{11} = 28325 kN/m ³
Calculated value	β = 0.32152 m ⁻¹
Penetration length of SSP	D = 0.00 + $\frac{3}{0.322}$ = 9.33 m
Whole length of SSP	L = 4.21 - 0.40 + 9.33 = 13.14 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_{11} = 55121 kN/m ³
Calculated value	β = 0.37975 m ⁻¹
Penetration length of SSP	D = 0.00 + $\frac{3}{0.380}$ = 7.90 m
Whole length of SSP	L = 4.21 - 0.40 + 7.90 = 11.71 m

Therefore, the total length of the sheet pile is 13.50 m from the rounded length value of 0.50 m.

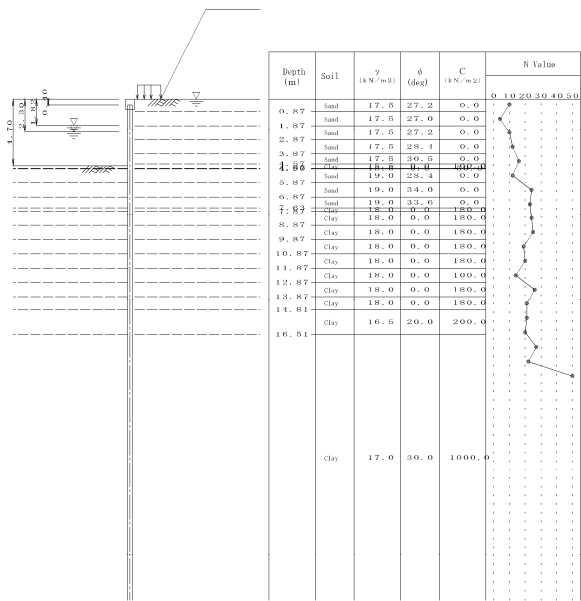
Block No. : L-21
Sta. : 10+640~10+760

Design Cross Section : Sta 10+700
Boring Name : DD-BH-L12

Specification : SSP SP-10H
(Combined) : H 900-250-14-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 4.70 m
Depth from coping top to rear side ground	H ₀ = 0.00 m
Depth from coping top to SSP top	H _B = 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} = 1.82 m (Seismic Condition)

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	0.37	10	11	10.37	19
2	1.37	4	12	11.37	20
3	2.37	10	13	12.37	14
4	3.37	12	14	13.37	26
5	4.37	16	15	14.37	21
6	5.37	12	16	15.37	21
7	6.37	24	17	16.37	20
8	7.37	23	18	17.37	27
9	8.37	24	19	18.37	22
10	9.37	25	20	19.37	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

Soil Modulus									
No	Depth m (Include Projection Length)	Thickness m (excluding projected length)							
1	0.87	0.87							
2	1.87	1.00							
3	2.87	1.00							
4	3.87	1.00							
5	4.87	0.70							
6	4.87	0.30							
7	4.90	0.03							
8	5.87	0.97							
9	6.87	1.00							
10	7.63	0.76							
11	7.87	0.24							
12	8.87	1.00							
13	9.87	1.00							
14	10.87	1.00							
15	11.87	1.00							
16	12.87	1.00							
17	13.87	1.00							
18	14.81	0.94							
19	16.51	1.70							
20	33.70	17.19							

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	φ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.87	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
2	1.87	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	2.87	S	10.0	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
4	3.87	S	12.0	17.50	7.70	26.4	0.0	0.0	0.200	Auto	Auto
5	4.87	S	16.0	17.50	7.70	30.5	0.0	0.0	0.200	Auto	Auto
6	4.87	C	16.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
7	4.90	C	12.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto
8	5.87	S	12.0	19.00	9.20	26.4	0.0	0.0	0.200	Auto	Auto
9	6.87	S	24.0	19.00	9.20	34.0	0.0	0.0	0.200	Auto	Auto
10	7.63	S	23.0	19.00	9.20	33.6	0.0	0.0	0.200	Auto	Auto

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$	
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	$P_t = 61.1 \text{ kN/m}$ (Normal Condition)
		$P_t' = 147.5 \text{ kN/m}$ (Seismic Condition)
	Depth of acting point	$H_t = 0.0 \text{ m}$ (Normal Condition)
		$H_t' = 0.0 \text{ m}$ (Seismic Condition)
	Moment	$M_m = 39.2 \text{ kN}\cdot\text{m/m}$ (Normal Condition)
		$M_m' = 234.9 \text{ kN}\cdot\text{m/m}$ (Seismic Condition)
	Depth of acting point	$H_m = 0.00 \text{ m}$ (Seismic Condition)
		$H_m = 0.00 \text{ m}$ (Normal Condition)
		(‘Depth’ means distance from top of coping)
Wind load, Impact load	not considered	
Minimum angle of rupture	$\zeta_\phi = 10 \text{ degrees}$	
Rear side angle of slope	not considered	
Angle of rupture (clayey soil)	$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$	
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)	

1.5 Modulus of Lateral Subgrade Reaction

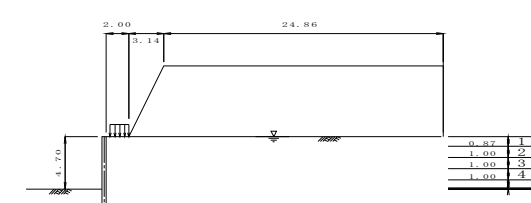
Applied formula	$K_b = K_{10} \left(\frac{B_B}{0.3} \right)^{-3/4}$ $K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$ $B_B = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
Average N-value	calculated from average N-value between imaginary riverbed and depth as $1/\beta$

11	7.87	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	8.87	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	9.87	C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	10.87	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	11.87	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	12.87	C	14.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
17	13.87	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
18	14.81	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
19	16.51	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
20	33.70	C	121.5	17.00	7.20	30.0	100.0	0.0	0.200	Auto	Auto

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

Angle of wall friction		
Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants											
No	Soil	X Coordinate			Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left	Top Left	Top Right	Bottom Right	b m	Normal Condition kN/m ³	Seismic Condition kN/m ³	φ degree	C kN/m ²	Normal Condition degree
1	Sand	2.00	5.14	30.00	30.00	6.28	19.0	19.0	30.0	0.0	Auto

Surcharge load acting on embankment				
No	load area		load strength	
		From m	End point m	Normal Condition kN/m ²
1	0.35	2.00	5.0	0.0

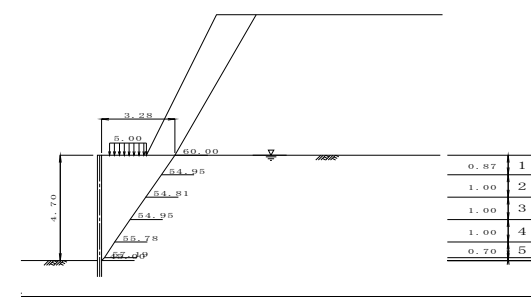
Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 900 -250 -14 -22 -18
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 597600 cm ⁴
Sectional factor	Z ₀	= 9470 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	= 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



2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	9.55	181.52
Σ			181.52

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

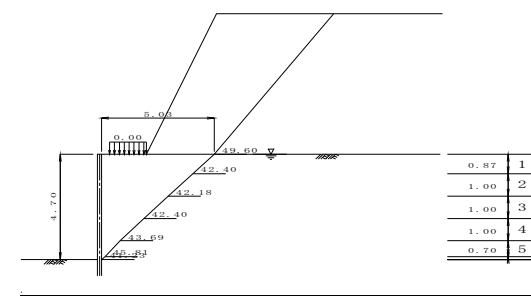
No	Q kN/m ²	l m	Q×l kN/m
1	5.0	1.65	8.25
Σ			8.25

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{181.52 + 8.25 + 0.00}{3.28}$$
$$= 57.88 \text{ kN/m}^2$$

2.2 Seismic Condition



2.1.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ when kN/m ²	Angle of Rupture ζ degree
1	4.70 ~ 4.57	Clay	0.0	15.0	100.0	35.93	57.88	46.06	45.00
2	4.57 ~ 3.87	Sand	30.5	15.0	0.0	35.19	57.88	44.79	57.19
3	3.87 ~ 2.87	Sand	28.4	15.0	0.0	29.80	57.88	37.93	55.78
4	2.87 ~ 1.87	Sand	27.2	15.0	0.0	22.10	57.88	28.13	54.95
5	1.87 ~ 0.87	Sand	27.0	15.0	0.0	14.40	57.88	18.33	54.81
6	0.87 ~ 0.00	Sand	27.2	15.0	0.0	6.70	57.88	8.53	54.95
7		embankment	30.0	—	0.0	119.32	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 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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.13	0.00	0.00	0.13	0.13
2	57.19	0.70	0.13	0.13	0.58	0.83
3	55.78	1.00	0.58	0.83	1.26	1.83
4	54.95	1.00	1.26	1.83	1.96	2.83
5	54.81	1.00	1.96	2.83	2.67	3.83
6	54.95	0.87	2.67	3.83	3.28	4.70
7	60.00	6.28	3.28	4.70	6.90	10.98

From the above table, the loading width (L) on the ground surface is 3.28 m.

2.2.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ when kN/m ²	k (k')	θ degree	Angle of Rupture ζ degree
1	4.70 ~ 4.57	Clay	0.0	15.0	100.0	35.93	98.01	46.06	0.200	11.31	41.23
2	4.57 ~ 3.87	Sand	30.5	15.0	0.0	35.19	98.01	44.79	0.200	11.31	45.81
3	3.87 ~ 2.87	Sand	28.4	15.0	0.0	29.80	98.01	37.93	0.200	11.31	43.69
4	2.87 ~ 1.87	Sand	27.2	15.0	0.0	22.10	98.01	28.13	0.200	11.31	42.40
5	1.87 ~ 0.87	Sand	27.0	15.0	0.0	14.40	98.01	18.33	0.200	11.31	42.18
6	0.87 ~ 0.00	Sand	27.2	15.0	0.0	6.70	98.01	8.53	0.200	11.31	42.40
7		embankment	30.0	—	0.0	119.32	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	41.23	0.13	0.00	0.00	0.15	0.13
2	45.81	0.70	0.15	0.13	0.83	0.83
3	43.69	1.00	0.83	0.83	1.88	1.83
4	42.40	1.00	1.88	1.83	2.97	2.83
5	42.18	1.00	2.97	2.83	4.07	3.83
6	42.40	0.87	4.07	3.83	5.03	4.70
7	49.60	6.28	5.03	4.70	10.37	10.98

From the above table, the loading width (L) on the ground surface is 5.03 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	25.93	492.69
Σ			492.69

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	Qxl kN/m
1	0.0	1.65	0.00
Σ			0.00

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

l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

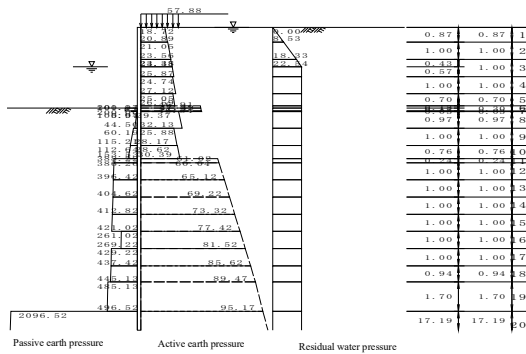
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{492.69 + 0.00 + 0.00}{5.03}$$

$$= 98.01 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Qx$ kN/m ²	Ka	$Ka \times \cos \delta$
1	0.00-0.87	Sand	7.7	27.2	57.885	0.33489	0.32348
2	0.87-1.87	Sand	7.7	27.0	64.584	0.33738	0.32589
3	1.87-2.30	Sand	7.7	27.2	72.284	0.33489	0.32348
4	2.30-2.87	Sand	7.7	27.2	75.595	0.33489	0.32348
5	2.87-3.87	Sand	7.7	28.4	79.984	0.33489	0.32348
6	3.87-4.57	Sand	7.7	30.5	87.684	0.32022	0.30931
7	4.57-5.7	Clay	5.7	—	97.084	0.29571	0.28563
8	5.7-6.87	Clay	5.7	—	100.0	0.29571	0.28563
9	6.87-7.63	Clay	5.7	—	100.0	0.29571	0.28563
10	7.63-8.87	Clay	5.7	—	100.0	0.29571	0.28563
11	8.87-9.87	Clay	5.7	—	100.0	0.29571	0.28563
12	9.87-10.87	Clay	5.7	—	100.0	0.29571	0.28563
13	10.87-11.87	Clay	5.7	—	100.0	0.29571	0.28563
14	11.87-12.87	Clay	5.7	—	100.0	0.29571	0.28563
15	12.87-13.87	Clay	5.7	—	100.0	0.29571	0.28563
16	13.87-14.81	Clay	5.7	—	100.0	0.29571	0.28563
17	14.81-16.51	Clay	5.7	—	100.0	0.29571	0.28563
18	16.51-33.70	Clay	5.7	—	100.0	0.29571	0.28563

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

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

3.1.3 Lateral Forth

No	Depth. m	Active			Residual water pressure	Passive
		Pa kN/m ²	Pa2 kN/m ²	Pa kN/m ²		
1	0.00- 0.87	18.72 20.89	— —	18.72 20.89	0.00 8.53	—
2	0.87- 1.87	21.05 23.56	— —	21.05 23.56	8.53 18.33	—
3	1.87- 2.30	23.38 24.45	— —	23.38 24.45	18.33 22.54	—
4	2.30- 2.87	24.45 25.87	— —	24.45 25.87	22.54 22.54	—
5	2.87- 3.87	24.74 27.12	— —	24.74 27.12	22.54 22.54	—
6	3.87- 4.57	25.05 26.59	— —	25.05 26.59	22.54 22.54	—
7	4.57- 4.70	-106.93 -106.19	46.54 46.91	46.54 46.91	22.54 22.54	—
8	4.70- 4.87	-106.19 -105.22	46.91 47.39	46.91 47.39	22.54 22.54	200.907
9	4.87- 4.90	-5.22 -5.05	47.39 47.48	47.39 47.48	22.54 22.54	100.97 101.14
10	4.90- 5.87	29.37 32.13	— —	29.37 32.13	22.54 22.54	5.04 44.50
11	5.87- 6.87	25.88 28.12	— —	25.88 28.12	22.54 22.54	60.19 115.21
12	6.87- 7.63	28.62 30.39	— —	28.62 30.39	22.54 22.54	112.64 153.53
13	7.63- 7.87	-239.93 -237.96	60.04 61.02	60.04 61.02	22.54 22.54	386.26 388.22
14	7.87- 8.87	-237.96 -229.76	61.02 65.12	61.02 65.12	22.54 22.54	388.22 396.42
15	8.87- 9.87	-229.76 -221.56	65.12 69.22	65.12 69.22	22.54 22.54	396.42 404.62
16	9.87- 10.87	-221.56 -213.36	69.22 73.32	69.22 73.32	22.54 22.54	404.62 412.82
17	10.87- 11.87	-213.36 -205.16	73.32 77.42	73.32 77.42	22.54 22.54	412.82 421.02
18	11.87- 12.87	-45.16 -36.96	77.42 81.52	77.42 81.52	22.54 22.54	260.02 269.22
19	12.87- 13.87	-196.96 -188.76	81.52 85.62	81.52 85.62	22.54 22.54	429.22 437.42
20	13.87- 14.81	-188.76 -181.05	85.62 89.47	85.62 89.47	22.54 22.54	437.42 445.13
21	14.81- 16.51	-221.05 -209.66	89.47 95.17	89.47 95.17	22.54 22.54	445.13 452.83
22	16.51- 33.70	-1809.66 -1685.90	95.17 157.05	95.17 157.05	22.54 22.54	2096.52 2220.29

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

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

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2 C$$

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

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

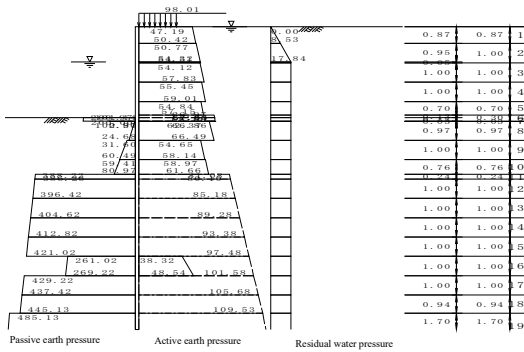
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2 C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-0.87	Sand	7.7	27.2	—	98.01 104.70	0.00 8.53	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
2	0.87-1.82	Sand	7.7	27.0	—	104.70 112.02	8.53 17.84	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
3	1.82-1.87	Sand	7.7	27.0	—	112.02 112.40	17.84 18.33	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
4	1.87-2.87	Sand	7.7	27.2	—	112.40 120.10	18.33 28.13	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
5	2.87-3.87	Sand	7.7	28.4	—	120.10 127.80	28.13 37.93	0.200 0.200	11.31 11.31	0.47800 0.47800	0.46172 0.46172	—

10	4.90-5.87	Sand	9.20	28.4	—	1.140 10.064	1.96 11.47	0.200 0.200	11.31 11.31	2.45242 2.45242	2.45242 2.45242	—
11	5.87-6.87	Sand	9.20	34.0	—	10.064 19.264	11.47 21.27	0.200 0.200	11.31 11.31	3.13983 3.13983	3.13983 3.13983	—
12	6.87-7.63	Sand	9.20	33.6	—	19.264 26.256	21.27 28.71	0.200 0.200	11.31 11.31	3.08376 3.08376	3.08376 3.08376	—
13	7.63-7.87	Clay	8.20	0.0	—	180.0 180.0	26.256 28.224	0.200 0.200	11.31 11.31	— —	— —	—
14	7.87-8.87	Clay	8.20	0.0	—	180.0 180.0	28.224 36.424	0.200 0.200	11.31 11.31	— —	— —	—
15	8.87-9.87	Clay	8.20	0.0	—	180.0 180.0	36.424 44.624	0.200 0.200	11.31 11.31	— —	— —	—
16	9.87-10.87	Clay	8.20	0.0	—	180.0 180.0	44.624 52.824	0.200 0.200	11.31 11.31	— —	— —	—
17	10.87-11.87	Clay	8.20	0.0	—	180.0 180.0	52.824 61.024	0.200 0.200	11.31 11.31	— —	— —	—
18	11.87-12.87	Clay	8.20	0.0	—	100.0 100.0	61.024 69.224	0.200 0.200	11.31 11.31	— —	— —	—
19	12.87-13.87	Clay	8.20	0.0	—	180.0 180.0	69.224 77.424	0.200 0.200	11.31 11.31	— —	— —	—
20	13.87-14.81	Clay	8.20	0.0	—	180.0 180.0	77.424 85.132	0.200 0.200	11.31 11.31	— —	— —	—
21	14.81-16.51	Clay	6.70	20.0	—	200.0 200.0	85.132 96.522	0.200 0.200	11.31 11.31	— —	— —	—
22	16.51-33.70	Clay	7.20	30.0	—	1000.0 1000.0	96.522 220.290	0.200 0.200	11.31 11.31	— —	— —	—

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Ps kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-0.87	47.19 50.42	—	47.19 50.42	0.00 8.53	—
2	0.87-1.82	50.77 54.32	—	50.77 54.32	8.53 17.84	—
3	1.82-1.87	54.32 54.51	—	54.32 54.51	17.84 17.84	—
4	1.87-2.87	54.12 57.83	—	54.12 57.83	17.84 17.84	—
5	2.87-3.87	—	—	55.45 59.01	17.84 17.84	—
6	3.87-4.57	54.84 57.15	—	54.84 57.15	17.84 17.84	—

6	3.87-4.57	Sand	7.7	30.5	—	127.80 133.19	37.93 44.79	0.200 0.200	11.31 11.31	0.44421 0.44421	0.42907 0.42907	—
7	4.57-4.70	Clay	5.7	—	—	100.0 100.0	133.19 133.94	44.79 46.06	0.200 0.200	11.31 11.31	— —	41.24 41.23
8	4.70-4.87	Clay	5.7	—	—	100.0 100.0	133.94 134.90	46.06 47.73	0.200 0.200	11.31 11.31	— —	41.23 41.21
9	4.87-4.90	Clay	5.7	—	—	50.0 50.0	134.90 135.08	47.73 48.02	0.200 0.200	11.31 11.31	— —	36.16 36.15
10	4.90-5.87	Sand	9.2	28.4	—	135.08 144.00	48.02 57.53	0.200 0.200	11.31 11.31	0.47800 0.47800	0.46172 0.46172	—
11	5.87-6.87	Sand	9.2	34.0	—	144.00 153.20	57.53 67.33	0.200 0.200	11.31 11.31	0.39292 0.39292	0.37953 0.37953	—
12	6.87-7.63	Sand	9.2	33.6	—	153.20 160.19	67.33 74.77	0.200 0.200	11.31 11.31	0.39850 0.39850	0.38492 0.38492	—
13	7.63-7.87	Clay	8.2	—	—	180.0 180.0	160.19 162.16	74.77 77.13	0.200 0.200	11.31 11.31	— —	42.78 42.77
14	7.87-8.87	Clay	8.2	—	—	180.0 180.0	162.16 170.36	77.13 86.93	0.200 0.200	11.31 11.31	— —	42.77 42.69
15	8.87-9.87	Clay	8.2	—	—	180.0 180.0	170.36 178.56	86.93 96.73	0.200 0.200	11.31 11.31	— —	42.69 42.61
16	9.87-10.87	Clay	8.2	—	—	180.0 180.0	178.56 186.76	96.73 106.53	0.200 0.200	11.31 11.31	— —	42.61 42.54
17	10.87-11.87	Clay	8.2	—	—	180.0 180.0	186.76 194.96	106.53 116.33	0.200 0.200	11.31 11.31	— —	42.54 42.46
18	11.87-12.87	Clay	8.2	—	—	100.0 100.0	194.96 203.16	116.33 126.13	0.200 0.200	11.31 11.31	— —	40.06 39.89
19	12.87-13.87	Clay	8.2	—	—	180.0 180.0	203.16 211.36	126.13 135.93	0.200 0.200	11.31 11.31	— —	42.38 42.30
20	13.87-14.81	Clay	8.2	—	—	180.0 180.0	211.36 219.07	135.93 145.14	0.200 0.200	11.31 11.31	— —	42.30 42.23
21	14.81-16.51	Clay	6.7	—	—	200.0 200.0	219.07 230.46	145.14 161.80	0.200 0.200	11.31 11.31	— —	42.53 42.43
22	16.51-33.70	Clay	7.2	—	—	1000.0 1000.0	230.46 354.23	161.80 330.26	0.200 0.200	11.31 11.31	— —	44.52 44.34

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Kp	$K_p \times \cos \delta$
8	4.70-4.87	Clay	5.70	0.0	100.0	0.000 0.969	0.00 1.67	0.200 0.200	11.31 11.31	— —	— —
9	4.87-4.90	Clay	5.70	0.0	50.0 50.0	0.969 1.140	1.67 1.96	0.200 0.200	11.31 11.31	— —	— —

7	4.57-4.70	—	-38.16 -37.24	66.60 66.97	66.60 66.97	17.84 17.84	—
8	4.70-4.87	—	-37.24 -36.05	66.97 67.45	66.97 67.45	17.84 17.84	200.00 200.97
9	4.87-4.90	—	66.96 67.08	67.45 67.54	67.45 67.54	17.84 17.84	100.97 101.14
10	4.90-5.87	—	62.37 66.49	—	62.37 66.49	17.84 17.84	2.80 24.68
11	5.87-6.87	—	54.65 58.14	—	54.65 58.14	17.84 17.84	31.60 60.49
12	6.87-7.63	—	58.97 61.66	—	58.97 61.66	17.84 17.84	59.41 80.97
13	7.63-7.87	—	-166.27 -163.87	80.10 81.08	80.10 81.08	17.84 17.84	386.26 388.22
14	7.87-8.87	—	-163.87 -153.88	81.08 85.18	81.08 85.18	17.84 17.84	388.22 396.42
15	8.87-9.87	—	-153.88 -143.88	85.18 89.28	85.18 89.28	17.84 17.84	396.42 404.62
16	9.87-10.87	—	-143.88 -133.87	89.28 93.38	89.28 93.38	17.84 17.84	404.62 412.82
17	10.87-11.87	—	-133.87 -123.85	93.38 97.48	93.38 97.48	17.84 17.84	412.82 421.02
18	11.87-12.87	—	38.32 48.54	97.48 101.58	97.48 101.58	17.84 17.84	261.02 269.22
19	12.87-13.87	—	-113.82 -103.79	101.58 105.68	101.58 105.68	17.84 17.84	429.22 437.42
20	13.87-14.81	—	-103.79 -94.35	105.68 109.53	105.68 109.53	17.84 17.84	437.42 445.13
21	14.81-16.51	—	-134.66 -120.74	109.53 115.23	109.53 115.23	17.84 17.84	485.13 496.52
22	16.51-33.70	—	-1722.95 -1573.81	115.23 177.11	115.23 177.11	17.84 17.84	2096.52 2220.29

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2 C$$

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

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2 C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	psh kN/m2
1	1.82	0.00	0.00
2	2.82	1.00	2.91
3	3.82	2.00	4.12
4	4.70	2.88	4.98

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

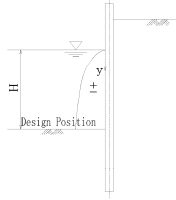
Where,

k_{sa} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

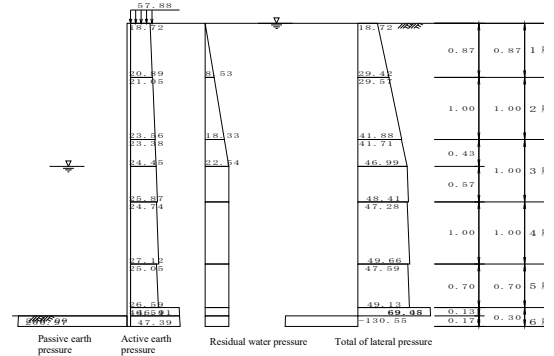
y : depth from water surface to the point where active water pressure is calculated



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



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.87	18.72 20.89	0.00 8.53	— —	18.72 29.42
2	0.87- 1.87	21.05 23.56	8.53 18.33	— —	29.57 41.88
3	1.87- 2.30	23.38 24.45	18.33 22.54	— —	41.71 46.99
4	2.30- 2.87	24.45 25.87	22.54 22.54	— —	46.99 48.41
5	2.87- 3.87	24.74 27.12	22.54 22.54	— —	47.28 49.66
6	3.87- 4.57	25.05 26.59	22.54 22.54	— —	47.59 49.13
7	4.57- 4.70	46.54 46.91	22.54 22.54	— —	69.08 69.45
8	4.70- 4.87	46.91 47.39	22.54 22.54	200.00 200.97	-130.55 -131.04

P_a : Active earth pressure

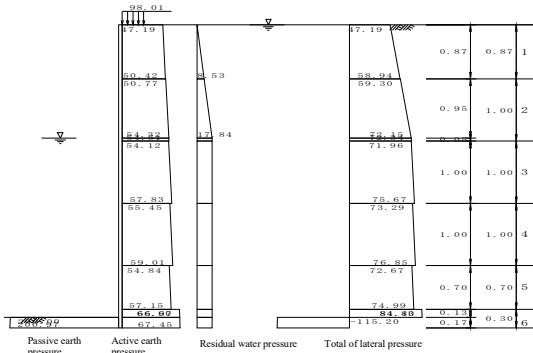
P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed L_k : 0.00 m (GL -4.70 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.87	47.19 50.42	0.00 8.53	— —	47.19 58.94
2	0.87- 1.82	50.77 54.32	8.53 17.84	— —	59.30 72.15
3	1.82- 1.87	54.32 54.51	17.84 17.84	— —	72.15 72.34
4	1.87- 2.87	54.12 57.83	17.84 17.84	— —	71.96 75.67
5	2.87- 3.87	55.45 59.01	17.84 17.84	— —	72.29 76.85
6	3.87- 4.57	54.84 57.15	17.84 17.84	— —	72.67 74.99
7	4.57- 4.70	66.60 66.97	17.84 17.84	— —	84.43 84.80
8	4.70- 4.87	66.97 67.45	17.84 17.84	200.00 200.97	-115.20 -115.68

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 : 0.00 m (GL -4.70 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B_0}{0.3} \right)^{-3/4} \quad (B_0 = 10.00m)$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_0 = 2800N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name

10 H H 900 -250 -14 -22 -18

Unit width

B = 1.0000 m

Corrosion margin

$t_1 = 1.00$ mm (active side)

Corrosion rate

$\eta = 0.86$

Section efficiency

$\mu = 1.00$

Young's modulus

E = 200000 N/mm²

Inertia sectional moment

$I_0 = 597600$ cm⁴(original condition)

Inertia sectional moment

I = 513936 cm⁴(after reduction by corrosion and section)

Inertia sectional moment

EI = 200000 × 10³ × 513936 × 10⁻⁸ = 1.028 × 10⁶

No	Depth m	N Value	No	Depth m	N Value
1	0.37	10	11	10.37	19
2	1.37	4	12	11.37	20
3	2.37	10	13	12.37	14
4	3.37	12	14	13.37	26
5	4.37	16	15	14.37	21
6	5.37	12	16	15.37	21
7	6.37	24	17	16.37	20
8	7.37	24	18	17.37	27
9	8.37	24	19	18.37	22
10	9.37	25	20	19.37	50

5.2 Normal Condition

Assuming $K_h = 13872$ kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.241 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.15 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.70 m) to 4.15 m depth (GL -8.85 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.70	0.67	14.7	12.0	8.94
2	5.37	1.00	12.0	24.0	18.00
3	6.37	1.00	24.0	23.0	23.50
4	7.37	1.00	23.0	24.0	23.50
5	8.37	0.48	24.0	24.5	11.62
L = Σ h = 4.15			Σ A = 85.55		

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

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{85.55}{4.15} \\ &= 20.62 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800 N' = 2800 \times 20.62 = 57733 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 57733 = 192444 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2) \\ K_b &= K_{10} (B_u/0.3)^{-3/4} = 192444 (10.00/0.3)^{-3/4} = 13872 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 13872 kN/m³.

5.3 Seismic Condition

Assuming Kh = 26887 kN/m³,

$$\begin{aligned} \beta &= 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.284 \text{ m}^{-1} \\ L &= \frac{1}{\beta} = 3.52 \text{ m} \end{aligned}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.70 m) and 3.52 m depth (GL -8.22 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.70	0.67	14.7	12.0	8.94
2	5.37	1.00	12.0	24.0	18.00
3	6.37	1.00	24.0	23.0	23.50
4	7.37	0.85	23.0	23.8	19.83
L = Σ h = 3.52			Σ A = 70.27		

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

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{70.27}{3.52} \end{aligned}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_0) + M_{in} = 326.67 \text{ kN} \cdot \text{m}$$

h_0 Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} \\ &= \frac{721.26}{255.35} = 2.82 \text{ m} \end{aligned}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.87	0.87	47.19 58.94	20.53 25.64	4.41 4.12	90.53 105.64
2	0.87~ 1.82	0.95	59.30 72.15	28.17 34.27	3.51 3.20	98.96 109.56
3	1.82~ 1.87	0.05	72.15 72.34	1.80 1.81	2.86 2.85	5.17 5.15
4	1.87~ 2.87	1.00	71.96 75.67	35.98 37.83	2.50 2.16	89.83 81.85
5	2.87~ 3.87	1.00	73.29 76.85	36.65 38.42	1.50 1.16	54.85 44.70
6	3.87~ 4.57	0.70	72.67 74.99	25.44 26.25	0.60 0.36	15.18 9.54
7	4.57~ 4.70	0.13	69.08 69.45	5.49 5.51	0.09 0.04	0.48 0.24
Σ P = 323.78			Σ M = 711.65			

P_s : active earth pressure + residual water pressure - passive earth pressure

P : load $P_s \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

Arbitrary load lateral load
depth to acting position
moment
depth to acting position
Height from riverbed to top of coping
Depth of Imaginary riverbed from riverbed

P_i = 147.5 kN/m
 H_i = 0.00 m
 M_{in} = 234.9 kN·m/m
 H_m = 0.0 m
 H = 4.70 m
 L_k = 0.00 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_0) + M_{in} = 928.15 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	1.82~ 2.82	1.00	0.0 2.9	0.00 1.46	2.55 2.21	0.00 3.22
2	2.82~ 3.82	1.00	2.9 4.1	1.46 2.06	1.55 1.21	2.25 2.50
3	3.82~ 4.70	0.88	4.1 4.9	1.81 2.17	0.59 0.29	1.06 0.64

$$= 19.98$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800 N' = 2800 \times 19.98 = 55949 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 55949 = 372991 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2) \\ K_b &= K_{10} (B_u/0.3)^{-3/4} = 372991 (10.00/0.3)^{-3/4} = 26887 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 26887 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.87	0.87	18.72 29.42	8.15 12.80	4.41 4.12	35.92 52.72
2	0.87~ 1.87	1.00	29.57 41.88	14.79 20.94	3.36 3.16	51.70 66.24
3	1.87~ 2.30	0.43	41.71 46.99	8.97 10.10	2.69 2.54	24.09 25.70
4	2.30~ 2.87	0.57	46.99 48.41	13.39 13.80	2.21 2.02	29.60 27.87
5	2.87~ 3.87	1.00	47.28 49.66	22.64 24.83	1.50 1.16	35.38 28.89
6	3.87~ 4.57	0.70	47.59 49.13	16.65 17.19	0.66 0.36	9.94 6.25
7	4.57~ 4.70	0.13	69.08 69.45	4.49 4.51	0.09 0.04	0.39 0.20
Σ P = 194.25			Σ M = 394.89			

P_s : active earth pressure + residual water pressure - passive earth pressure

P : load $P_s \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

Arbitrary load lateral load
depth to acting position
moment
depth to acting position
Height from riverbed to top of coping
Depth of Imaginary riverbed from riverbed

P_i = 61.1 kN/m
 H_i = 0.0 m
 M_{in} = 39.2 kN·m/m
 H_m = 0.00 m
 H = 4.70 m
 L_k = 0.00 m

Σ P _{hw} =	8.95	Σ M _{hw} =	9.67

h_0 Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{hw}}{\Sigma P + P_i + \Sigma P_{dw}} \\ &= \frac{1649.47}{480.24} = 3.43 \text{ m} \end{aligned}$$

6.2 Sectional Force

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

Material name	10 H ₂ H 900-250-14-22-18
Unit width	B = 1.0000 m
Corrosion margin	t _c = 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 = 597600 cm ⁴ (original condition)
	I = 513936 cm ⁴ (after reduction by corrosion and section)
	EI = 200000 × 10 ³ × 513936 × 10 ⁻⁸ = 1.028 × 10 ⁶

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 13872 kN/m ³
calculated value	β = 0.24101 m ⁻¹
resultant earth force (lateral)	P ₀ = 255.35 kN/m
height of acting position of load	h ₀ = 2.82 m
moment	M ₀ = 721.26 kN·m/m

in consideration of $\psi_{in} = 1.262$,

maximum moment	M _{max} = 910.15 kN·m/m
depth of generated position of M _{max}	l _m = 1.662 m
depth of 1° fixed point	l _i = 4.921 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b = 26887 kN/m ³
calculated value	β = 0.28437 m ⁻¹

resultant earth force (lateral) $P_0 = 480.24 \text{ kN/m}$
height of acting position of load $h_0 = 3.43 \text{ m}$
moment $M_0 = 1649.47 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{in} = 1.152$,
maximum moment $M_{max} = 1899.56 \text{ kN}\cdot\text{m/m}$
depth of generated position of M_{max} $l_m = 1.148 \text{ m}$
depth of l^a fixed point $l_i = 3.910 \text{ m}$

6.3 Stress Intensity

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

Material Name 10 H₂ H 900 -250 -14 -22 -18
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.88$
Section efficiency $\mu = 1.00$
Module of section $Z_0 = 9470 \text{ cm}^3$ (original condition)
 $Z = 8334 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{910.15 \times 10^6}{8334 \times 10^3} = 109 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{1899.56 \times 10^6}{8334 \times 10^3} = 228 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.87	4.41 4.12	0.938 0.877	0.303 0.272	8.15 12.80	2.464 3.480
2	0.87~ 1.87	3.50 3.16	0.744 0.673	0.298 0.176	14.79 20.94	3.077 3.679
3	1.87~ 2.30	2.69 2.54	0.572 0.541	0.132 0.120	8.97 10.10	1.186 1.212
4	2.30~ 2.87	2.21 2.02	0.470 0.430	0.093 0.079	13.39 13.80	1.249 1.092
5	2.87~ 3.87	1.50 1.16	0.318 0.248	0.045 0.028	23.64 24.83	1.071 0.698
6	3.87~ 4.57	0.60 0.36	0.127 0.077	0.008 0.003	16.65 17.19	0.129 0.050
7	4.57~ 4.70	0.09 0.04	0.018 0.009	0.000 0.000	4.49 4.51	0.001 0.000
$\Sigma Q =$					19.388	

$$= \frac{39.20 \times 4.70}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8}} \times (2 \times 4.70 - 4.70) = 0.00042 \text{ m}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01491 + 0.02373 + 0.00444 \\ &= 0.04308 \text{ m} \\ \text{Size} &= 43.08 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.87	4.41 4.12	0.938 0.877	0.303 0.272	20.53 25.64	6.210 6.973
2	0.87~ 1.82	3.51 3.20	0.748 0.680	0.210 0.179	28.17 34.27	5.909 6.130
3	1.82~ 1.87	2.86 2.85	0.609 0.606	0.148 0.146	1.80 1.81	0.267 0.265
4	1.87~ 2.87	2.50 2.16	0.531 0.460	0.116 0.090	35.98 37.83	4.178 3.393
5	2.87~ 3.87	1.50 1.16	0.318 0.248	0.045 0.028	36.65 38.42	1.661 1.080
6	3.87~ 4.57	0.60 0.36	0.127 0.077	0.008 0.003	25.44 26.25	0.196 0.076
7	4.57~ 4.70	0.09 0.04	0.018 0.009	0.000 0.000	5.49 5.51	0.001 0.000
$\Sigma Q =$					36.338	

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

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.
Pt: horizontal load
Yt: Height from the virtual ground plane to the point of horizontal load action

If
Pt = 147.50
Yt = 4.70
 $\alpha t = 1.000$
 $\zeta t = 0.333$
Qt = $\zeta t \times Pt = 49.167$

Therefore, the deformation coefficient Q is expressed by
Q = 36.338 + 49.167 = 85.505

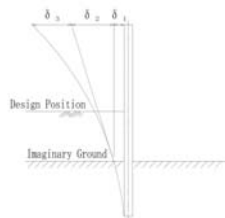
Y : Height from imaginary riverbed to acting position
 $\alpha : \alpha = \frac{Y}{H+L_k}$
 $\zeta : \zeta = \frac{(3-\alpha) \times \alpha^2}{6}$
Q : $\zeta \times P$
P : Lateral force
H : Depth to design position
 L_k : Depth from design position to imaginary ground

Since a horizontal load acts at a position deeper than the sheet pile head, it is added to the deformation coefficient Q.
Pt: horizontal load
Yt: Height from the virtual ground plane to the point of horizontal load action

If
Pt = 61.10
Yt = 4.70
 $\alpha t = 1.000$
 $\zeta t = 0.333$
Qt = $\zeta t \times Pt = 20.367$

Therefore, the deformation coefficient Q is expressed by
Q = 19.388 + 20.367 = 39.755

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2410 \times 2.82) \times 255.35}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2410^3} = 0.01491 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.2410 \times 2.82) \times 255.35}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2410^2} \times (4.70 + 0.00) = 0.02373 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\ &= \frac{39.75 \times (4.70 + 0.00)^3}{2.00 \times 10^8 \times 513936 \times 10^{-8}} = 0.00402 \text{ m} \end{aligned}$$

The displacement amount (δ 3m) of the cantilever beam by the bending moment (Mm) is added.

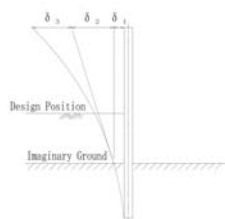
$$\delta_{3a} = \frac{M_k \cdot h}{2 E I} \times (2 L - h)$$

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

No	Depth m	Y m	α	ζ	Pdw kN	Qdw kN
1	1.82~ 2.82	2.55 2.21	0.542 0.471	0.120 0.093	0.00 1.46	0.000 0.136
2	2.82~ 3.82	1.55 1.21	0.329 0.258	0.048 0.030	1.46 2.06	0.070 0.063
3	3.82~ 4.70	0.59 0.29	0.125 0.062	0.007 0.002	1.81 2.17	0.014 0.004
$\Sigma Q_{dw} =$					0.287	

Therefore, the deformation coefficient Q is expressed by
Q = 85.505 + 0.287 = 85.791

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2844 \times 3.43) \times 480.24}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2844^3} = 0.02008 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.2844 \times 3.43) \times 480.24}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2844^2} \times (4.70 + 0.00) = 0.04010 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\ &= \frac{85.79 \times (4.70 + 0.00)^3}{2.00 \times 10^8 \times 513936 \times 10^{-8}} = 0.00867 \text{ m} \end{aligned}$$

The displacement amount (δ 3m) of the cantilever beam by the bending moment (Mm) is added.

$$\delta_{3a} = \frac{M_k \cdot h}{2 E I} \times (2 L - h)$$

$$= \frac{**** \times 4.70}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8}} \times (2 \times 4.70 - 4.70) = 0.00252 \text{ m}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.02008 + 0.04010 + 0.01119 \\ &= 0.07137 \text{ m} \\ \text{Size} &= 71.37 \text{ mm} \leq \delta_a = 75.00 \text{ mm} \end{aligned}$$

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:

Material Name	10 H ₂ H 900 -250 -14 -22 -18
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 = 597600 cm ⁴ (original condition)
	I = 597600 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 597600 × 10 ⁻⁸	= 1.195 × 10 ⁶

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 follows:

$$\begin{aligned} D &= L_k + \frac{3}{\beta} \\ L &= H - H_{it} + D \\ \beta &= 4\sqrt{\frac{K_b \cdot B}{4EI}} \end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 13872 kN/m ³
Calculated value	β = 0.23209 m ⁻¹
Penetration length of SSP	D = 0.00 + $\frac{3}{0.232}$ = 12.93 m
Whole length of SSP	L = 4.70 - 0.40 + 12.93 = 17.23 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_b = 26887 kN/m ³
Calculated value	β = 0.27385 m ⁻¹
Penetration length of SSP	D = 0.00 + $\frac{3}{0.274}$ = 10.95 m
Whole length of SSP	L = 4.70 - 0.40 + 10.95 = 15.25 m

Therefore, the total length of the sheet pile is 17.50 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H ₂ H 900 -250 -14 -22 -18		Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	597600			
Sectional Modulus	Z (cm ³)	9470			
Maximum bending moment	Mmax (kN × m × m)			910.15	1899.56
Stress intensity	σ (N/mm ²)			109 (180)	228 (270)
Lateral displacement	δ (mm)			43.08 (50.0)	71.37 (75.0)
Penetration depth	D (m)			12.93	10.95
Whole length of SSP	L (m)	17.50			

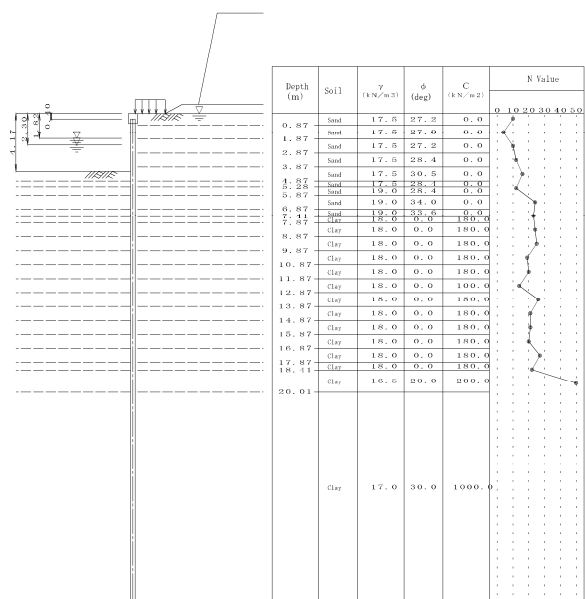
Block No. : L-22
Sta. : 10+760~11+040

Design Cross Section : Sta 10+800
Boring Name : DD-BH-L12

Specification : SSP SP-10H
(Combined) : H 850-250-14-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log

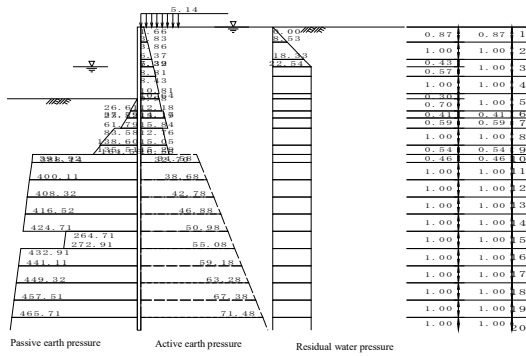


1.2 Dimensions of Structure

Depth from coping top to riverbed	H	= 4.17 m
Depth from coping top to rear side ground	H ₀	= 0.00 m
Depth from coping top to SSP top	H _b	= 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'}	= 1.82 m (Seismic Condition)

3 Lateral Forth

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	$\Sigma \gamma h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00~ 0.87	Sand	7.7	27.2	—	5.140 11.839	0.33489 0.33489	0.32348 0.32348
2	0.87~ 1.87	Sand	7.7	27.0	—	11.839 18.539	0.33738 0.33738	0.32589 0.32589
3	1.87~ 2.30	Sand	7.7	27.2	—	19.539 22.850	0.33489 0.33489	0.32348 0.32348
4	2.30~ 2.87	Sand	7.7	27.2	—	22.850 27.239	0.33489 0.33489	0.32348 0.32348
5	2.87~ 3.87	Sand	7.7	28.4	—	27.239 34.939	0.32022 0.32022	0.30931 0.30931
6	3.87~ 4.17	Sand	7.7	30.5	—	34.939 37.449	0.29571 0.29571	0.28563 0.28563
7	4.17~ 4.87	Sand	7.7	30.5	—	37.449 42.639	0.29571 0.29571	0.28563 0.28563
8	4.87~ 5.28	Sand	7.7	28.4	—	42.639 45.796	0.32022 0.32022	0.30931 0.30931
9	5.28~ 5.87	Sand	9.2	28.4	—	45.796 51.224	0.32022 0.32022	0.30931 0.30931
10	5.87~ 6.87	Sand	9.2	34.0	—	51.224 60.424	0.25791 0.25791	0.24912 0.24912
11	6.87~ 7.41	Sand	9.2	33.6	—	60.424 65.392	0.26205 0.26205	0.25312 0.25312
12	7.41~ 7.87	Clay	8.2	—	180.0 180.0	65.392 69.164	—	—

13	7.87~ 8.87	Clay	8.2	—	180.0 180.0	69.164 77.364	—	—
14	8.87~ 9.87	Clay	8.2	—	180.0 180.0	77.364 85.564	—	—
15	9.87~ 10.87	Clay	8.2	—	180.0 180.0	85.564 93.764	—	—
16	10.87~ 11.87	Clay	8.2	—	180.0 180.0	93.764 101.964	—	—
17	11.87~ 12.87	Clay	8.2	—	100.0 100.0	101.964 110.164	—	—
18	12.87~ 13.87	Clay	8.2	—	180.0 180.0	110.164 118.364	—	—
19	13.87~ 14.87	Clay	8.2	—	180.0 180.0	118.364 126.564	—	—
20	14.87~ 15.87	Clay	8.2	—	180.0 180.0	126.564 134.764	—	—
21	15.87~ 16.87	Clay	8.2	—	180.0 180.0	134.764 142.964	—	—
22	16.87~ 17.87	Clay	8.2	—	180.0 180.0	142.964 151.164	—	—
23	17.87~ 18.41	Clay	8.2	—	180.0 180.0	151.164 155.592	—	—
24	18.41~ 20.01	Clay	6.7	—	200.0 200.0	155.592 166.312	—	—
25	20.01~ 33.70	Clay	7.2	—	1000.0 1000.0	166.312 264.880	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	K_p	$K_p \times \cos \delta$
7	4.17~ 4.87	Sand	7.7	30.5	—	0.000 5.390	5.11035 5.11035	4.95622 4.95622
8	4.87~ 5.28	Sand	7.7	28.4	—	5.390 8.547	4.57728 4.57728	4.42131 4.42131
9	5.28~ 5.87	Sand	9.2	28.4	—	8.547 13.975	4.57728 4.57728	4.42131 4.42131
10	5.87~ 6.87	Sand	9.2	34.0	—	13.975 23.175	6.19149 6.19149	5.98052 5.98052
11	6.87~ 7.41	Sand	9.2	33.6	—	23.175 28.143	6.05364 6.05364	5.84737 5.84737
12	7.41~ 7.87	Clay	8.2	0.0	180.0 180.0	28.143 31.915	—	—
13	7.87~ 8.87	Clay	8.2	0.0	180.0 180.0	31.915 40.115	—	—
14	8.87~ 9.87	Clay	8.2	0.0	180.0 180.0	40.115 48.315	—	—

15	9.87~ 10.87	Clay	8.2	0.0	180.0 180.0	48.315 56.515	—	—
16	10.87~ 11.87	Clay	8.2	0.0	180.0 180.0	56.515 64.715	—	—
17	11.87~ 12.87	Clay	8.2	0.0	100.0 100.0	64.715 72.915	—	—
18	12.87~ 13.87	Clay	8.2	0.0	180.0 180.0	72.915 81.115	—	—
19	13.87~ 14.87	Clay	8.2	0.0	180.0 180.0	81.115 89.315	—	—
20	14.87~ 15.87	Clay	8.2	0.0	180.0 180.0	89.315 97.515	—	—
21	15.87~ 16.87	Clay	8.2	0.0	180.0 180.0	97.515 105.715	—	—
22	16.87~ 17.87	Clay	8.2	0.0	180.0 180.0	105.715 113.915	—	—
23	17.87~ 18.41	Clay	8.2	0.0	180.0 180.0	113.915 118.343	—	—
24	18.41~ 20.01	Clay	6.7	20.0	200.0 200.0	118.343 129.063	—	—
25	20.01~ 33.70	Clay	7.2	30.0	1000.0 1000.0	129.063 227.631	—	—

Coefficient of passive earth pressure of sandy soil K_p is calculated by the formula below;
 $\delta = -15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure Pw kN/m ²	Passive Pp kN/m ²
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²		
1	0.00~ 0.87	1.66 3.83	—	1.66 3.83	0.00 8.53	—
2	0.87~ 1.87	3.86 6.37	—	3.86 6.37	8.53 18.33	—
3	1.87~ 2.30	6.32 7.39	—	6.32 7.39	18.33 22.54	—
4	2.30~ 2.87	7.39 8.81	—	7.39 8.81	22.54 22.54	—
5	2.87~ 3.87	8.83 10.81	—	8.83 10.81	22.54 22.54	—
6	3.87~ 4.17	9.98 10.64	—	9.98 10.64	22.54 22.54	—
7	4.17~ 4.87	10.64 12.18	—	10.64 12.18	22.54 22.54	0.00 26.61
8	4.87~ 5.28	13.19 14.17	—	13.19 14.17	22.54 22.54	23.83 37.79

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

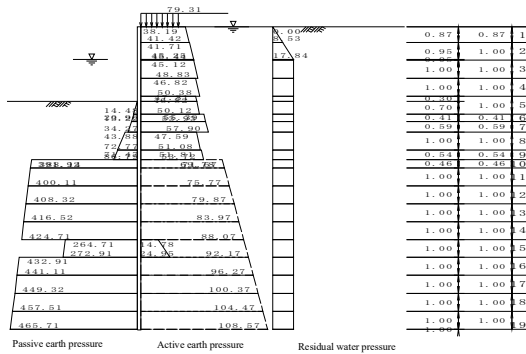
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{shw} kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00~0.87	Sand	7.7	27.2	—	79.31 80.01	0.00 8.53	0.200 0.200	11.31	0.49850 0.49850	0.48152 0.48152	—
2	0.87~1.82	Sand	7.7	27.0	—	86.01 93.33	8.53 17.84	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
3	1.82~1.87	Sand	7.7	27.0	—	93.33 93.71	17.84 18.33	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
4	1.87~2.87	Sand	7.7	27.2	—	93.71 101.41	18.33 28.13	0.200 0.200	11.31	0.49850 0.49850	0.48152 0.48152	—
5	2.87~3.87	Sand	7.7	28.4	—	101.41 109.11	28.13 37.93	0.200 0.200	11.31	0.47800 0.47800	0.46072 0.46072	—
6	3.87~4.17	Sand	7.7	30.5	—	109.11 111.42	37.93 40.87	0.200 0.200	11.31	0.44421 0.44421	0.42907 0.42907	—
7	4.17~4.87	Sand	7.7	30.5	—	111.42 116.81	40.87 47.73	0.200 0.200	11.31	0.44421 0.44421	0.42907 0.42907	—
8	4.87~5.28	Sand	7.7	28.4	—	116.81 119.97	47.73 51.74	0.200 0.200	11.31	0.47800 0.47800	0.46072 0.46072	—
9	5.28~5.87	Sand	9.2	28.4	—	119.97 125.40	51.74 57.53	0.200 0.200	11.31	0.47800 0.47800	0.46072 0.46072	—
10	5.87~6.87	Sand	9.2	34.0	—	125.40 134.60	57.53 67.33	0.200 0.200	11.31	0.39292 0.39292	0.37953 0.37953	—
11	6.87~7.41	Sand	9.2	33.6	—	134.60 139.56	67.33 72.62	0.200 0.200	11.31	0.39850 0.39850	0.38402 0.38402	—
12	7.41~7.87	Clay	8.2	—	180.0 180.0	139.56 143.34	72.62 77.13	0.200 0.200	11.31	—	—	43.14 43.11
13	7.87~8.87	Clay	8.2	—	180.0 180.0	143.34 151.54	77.13 86.93	0.200 0.200	11.31	—	—	43.11 43.08

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure, kN/m ²	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Ps kN/m ²		
1	0.00~0.87	38.19 41.42	—	38.19 41.42	0.00 8.53	—
2	0.87~1.82	41.71 45.25	—	41.71 45.25	8.53 17.84	—
3	1.82~1.87	45.25 45.44	—	45.25 45.44	17.84 17.84	—
4	1.87~2.87	45.12 48.83	—	45.12 48.83	17.84 17.84	—
5	2.87~3.87	46.82 50.38	—	46.82 50.38	17.84 17.84	—
6	3.87~4.17	46.82 47.81	—	46.82 47.81	17.84 17.84	—

14	8.87~9.87	Clay	8.2	—	180.0 180.0	151.54 159.74	86.93 96.73	0.200 0.200	11.31 11.31	—	—	43.04 42.96
15	9.87~10.87	Clay	8.2	—	180.0 180.0	159.74 167.94	96.73 106.53	0.200 0.200	11.31 11.31	—	—	42.96 42.89
16	10.87~11.87	Clay	8.2	—	180.0 180.0	167.94 176.14	106.53 116.33	0.200 0.200	11.31 11.31	—	—	42.89 42.81
17	11.87~12.87	Clay	8.2	—	100.0 100.0	176.14 184.34	116.33 126.13	0.200 0.200	11.31 11.31	—	—	40.79 40.63
18	12.87~13.87	Clay	8.2	—	180.0 180.0	184.34 192.54	126.13 135.93	0.200 0.200	11.31 11.31	—	—	42.73 42.66
19	13.87~14.87	Clay	8.2	—	180.0 180.0	192.54 200.74	135.93 145.73	0.200 0.200	11.31 11.31	—	—	42.66 42.58
20	14.87~15.87	Clay	8.2	—	180.0 180.0	200.74 208.94	145.73 155.53	0.200 0.200	11.31 11.31	—	—	42.58 42.50
21	15.87~16.87	Clay	8.2	—	180.0 180.0	208.94 217.14	155.53 165.33	0.200 0.200	11.31 11.31	—	—	42.50 42.43
22	16.87~17.87	Clay	8.2	—	180.0 180.0	217.14 225.34	165.33 175.13	0.200 0.200	11.31 11.31	—	—	42.43 42.35
23	17.87~18.41	Clay	8.2	—	180.0 180.0	225.34 229.76	175.13 180.42	0.200 0.200	11.31 11.31	—	—	42.35 42.31
24	18.41~20.01	Clay	6.7	—	200.0 200.0	229.76 240.48	180.42 196.10	0.200 0.200	11.31 11.31	—	—	42.60 42.53
25	20.01~33.70	Clay	7.2	—	1000.0 1000.0	240.48 339.05	196.10 330.26	0.200 0.200	11.31 11.31	—	—	44.53 44.39

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{shw} kN/m ²	k (k ²)	θ degree	K_p	$K_p \times \cos \delta$
7	4.17~4.87	Sand	7.70	30.5	—	0.000 5.390	0.00 6.86	0.200 0.200	11.31	2.68732 2.68732	2.68732 2.68732
8	4.87~5.28	Sand	7.70	28.4	—	5.390 8.547	6.86 10.88	0.200 0.200	11.31	2.45242 2.45242	2.45242 2.45242
9	5.28~5.87	Sand	9.20	28.4	—	8.547 13.975	10.88 16.66	0.200 0.200	11.31	2.45242 2.45242	2.45242 2.45242
10	5.87~6.87	Sand	9.20	34.0	—	13.975 23.175	16.66 26.46	0.200 0.200	11.31	3.13983 3.13983	3.13983 3.13983
11	6.87~7.41	Sand	9.20	33.6	—	23.175 28.143	26.46 31.75	0.200 0.200	11.31	3.08376 3.08376	3.08376 3.08376
12	7.41~7.87	Clay	8.20	0.0	180.0 180.0	28.143 31.915	31.75 36.26	0.200 0.200	11.31 11.31	—	—

7	4.17~4.87	47.81 50.12	—	—	47.81 50.12	17.84 17.84	0.00 14.48	—	—	—	—
8	4.87~5.28	53.93 55.39	—	—	53.93 55.39	17.84 17.84	13.22 20.96	—	—	—	—
9	5.28~5.87	55.39 57.90	—	—	55.39 57.90	17.84 17.84	20.96 34.27	—	—	—	—
10	5.87~6.87	47.59 51.08	—	—	47.59 51.08	17.84 17.84	43.88 72.77	—	—	—	—
11	6.87~7.41	51.81 53.72	—	—	51.81 53.72	17.84 17.84	71.47 86.79	—	—	—	—
12	7.41~7.87	-191.41 -186.82	69.78 71.67	—	69.78 71.67	17.84 17.84	388.14 391.92	—	—	—	—
13	7.87~8.87	-186.82 -176.85	71.67 75.77	—	71.67 75.77	17.84 17.84	391.92 400.11	—	—	—	—
14	8.87~9.87	-176.85 -166.87	75.77 79.87	—	75.77 79.87	17.84 17.84	400.11 408.32	—	—	—	—
15	9.87~10.87	-166.87 -156.88	79.87 83.97	—	79.87 83.97	17.84 17.84	408.32 416.52	—	—	—	—
16	10.87~11.87	-156.88 -146.89	83.97 88.07	—	83.97 88.07	17.84 17.84	416.52 424.71	—	—	—	—
17	11.87~12.87	14.78 24.95	88.07 92.17	—	88.07 92.17	17.84 17.84	264.71 272.91	—	—	—	—
18	12.87~13.87	-136.89 -126.88	92.17 96.27	—	92.17 96.27	17.84 17.84	432.91 441.11	—	—	—	—
19	13.87~14.87	-126.88 -116.86	96.27 100.37	—	96.27 100.37	17.84 17.84	441.11 449.32	—	—	—	—
20	14.87~15.87	-116.86 -106.84	100.37 104.47	—	100.37 104.47	17.84 17.84	449.32 457.51	—	—	—	—
21	15.87~16.87	-106.84 -96.81	104.47 108.57	—	104.47 108.57	17.84 17.84	457.51 465.71	—	—	—	—
22	16.87~17.87	-96.81 -86.77	108.57 112.67	—	108.57 112.67	17.84 17.84	465.71 473.91	—	—	—	—
23	17.87~18.41	-86.77 -81.34	112.67 114.88	—	112.67 114.88	17.84 17.84	473.91 478.34	—	—	—	—
24	18.41~20.01	-121.67 -108.56	114.88 120.34	—	114.88 120.34	17.84 17.84	518.34 529.06	—	—	—	—
25	20.01~33.70	-1710.89 -1592.13	120.34 160.53	—	120.34 160.53	17.84 17.84	2129.06 2227.63	—	—	—	—

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2C$
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	water level y m	p _{dw} kN/m ²
1	1.82	0.00	0.00
2	2.82	1.00	2.63
3	3.82	2.00	3.72
4	4.17	2.35	4.03

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

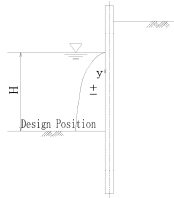
Where,

k_{is}: design seismic coefficient

γ_w: unit weight of water

H: water depth of riverside

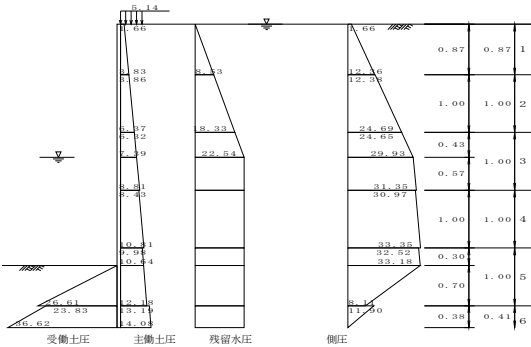
y: depth from water surface to the point where active water pressure is calculated



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



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00~ 0.87	1.66 3.83	0.00 8.53	— —	1.66 12.36
2	0.87~ 1.87	3.86 6.37	8.53 18.33	— —	12.38 24.69
3	1.87~ 2.30	6.32 7.39	18.33 22.54	— —	24.65 29.93
4	2.30~ 2.87	7.39 8.81	22.54 22.54	— —	29.93 31.35
5	2.87~ 3.87	8.83 10.81	22.54 22.54	— —	30.97 33.35
6	3.87~ 4.17	9.98 10.64	22.54 22.54	— —	32.52 33.18
7	4.17~ 4.87	10.64 12.18	22.54 22.54	0.00 26.61	33.18 8.11
8	4.87~ 5.25	13.19 14.08	22.54 22.54	23.83 36.62	11.90 0.00
9	5.25~ 5.28	14.08 14.17	22.54 22.54	36.62 37.79	0.00 -1.08

P_a: Active earth pressure

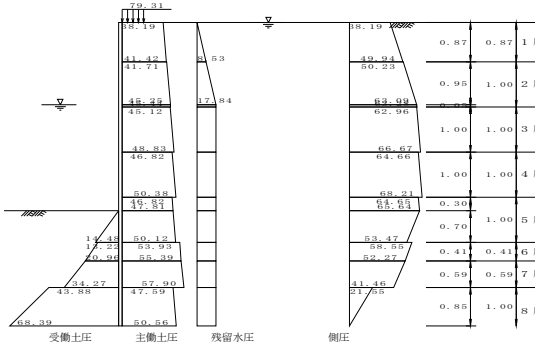
P_w: Residual water pressure

P_p: Passive earth pressure

P_s: Lateral pressure P_s = P_a + P_w - P_p

Imaginary riverbed L_k: 0.00 m (GL -5.25 m)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00~ 0.87	38.19 41.42	0.00 8.53	— —	38.19 49.94
2	0.87~ 1.82	41.71 45.25	8.53 17.84	— —	50.23 63.09
3	1.82~ 1.87	45.25 45.44	17.84 17.84	— —	63.09 63.28
4	1.87~ 2.87	45.12 48.83	17.84 17.84	— —	62.96 66.67
5	2.87~ 3.87	46.82 50.38	17.84 17.84	— —	64.66 68.21
6	3.87~ 4.17	46.82 47.81	17.84 17.84	— —	64.65 65.64
7	4.17~ 4.87	47.81 50.12	17.84 17.84	0.00 14.48	65.64 53.47
8	4.87~ 5.28	53.93 55.39	17.84 17.84	13.22 20.96	58.55 52.27
9	5.28~ 5.87	55.39 57.90	17.84 17.84	20.96 34.27	52.27 41.46
10	5.87~ 6.72	47.59 50.56	17.84 17.84	43.88 68.39	21.55 0.00
11	6.72~ 6.87	50.56 51.08	17.84 17.84	68.39 72.77	0.00 -3.85

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: 2.55 m (GL -6.72 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of 1/β from the virtual ground surface.

Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B \geq 10.00 \text{ m})$$
$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$
$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H - H 850 -250 -14 -22 -18
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 = 532300 cm ⁴ (original condition)
	I = 457778 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 2457778 × 10 ⁻⁸ = 9.156 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.37	10	11	10.37	19
2	1.37	4	12	11.37	20
3	2.37	10	13	12.37	14
4	3.37	12	14	13.37	26
5	4.37	16	15	14.37	21
6	5.37	12	16	15.37	21
7	6.37	24	17	16.37	20
8	7.37	22	18	17.37	27
9	8.37	24	19	18.37	22
10	9.37	25	20	19.37	50

5.2 Normal Condition

Assuming Kh = 14773 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.252 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.97 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.25 m) to 3.97 m depth (GL -9.21 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.25	0.12	12.5	12.0	1.52
2	5.37	1.00	12.0	24.0	18.00
3	6.37	1.00	24.0	23.0	23.50
4	7.37	1.00	24.0	24.0	23.50
5	8.37	0.84	24.0	24.8	20.61
L = $\Sigma h = 3.97$			$\Sigma A = 87.13$		

A: (upper N-value + lower N-value) $\times$ h/2

$$\begin{aligned}\text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{87.13}{3.97} \\ &= 21.96\end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned}E_0 &= 2800N' = 2800 \times 21.96 = 61482 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 61482 = 204938 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 204938(10.00/0.3)^{-3/4} = 14773 \text{ kN/m}^3\end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 14773 kN/m³.

5.3 Seismic Condition

Assuming Kh = 31892 kN/m³,

$$\begin{aligned}\beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.305 \text{ m}^{-1} \\ L &= \frac{1}{\beta} = 3.27 \text{ m}\end{aligned}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.72 m) and 3.27 m depth (GL -9.99 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.72	0.65	23.7	23.0	15.20
2	7.37	1.00	23.0	24.0	23.50
3	8.37	1.00	24.0	25.0	24.50
4	9.37	0.62	25.0	21.3	14.39
L = $\Sigma h = 3.27$			$\Sigma A = 77.59$		

A: (upper N-value + lower N-value) $\times$ h/2

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

Height from riverbed to top of coping H = 4.17 m
Depth of Imaginary riverbed from riverbed L_k = 1.08 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 0.00 \text{ kN}\cdot\text{m}$$

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned}h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} \\ &= \frac{267.19}{112.53} = 2.37 \text{ m}\end{aligned}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.87	0.87	38.19 49.94	16.61 6.14	6.43 6.14	106.80 133.36
2	0.87- 1.82	0.95	50.23 63.09	23.86 29.97	5.53 5.22	132.00 156.29
3	1.82- 1.87	0.05	63.09 63.28	1.58 1.58	4.88 4.87	7.70 7.70
4	1.87- 2.87	1.00	62.96 66.67	31.48 33.33	4.52 4.18	142.14 139.40
5	2.87- 3.87	1.00	64.66 68.21	32.33 34.11	3.52 3.18	113.65 108.53
6	3.87- 4.17	0.30	64.65 65.64	9.70 9.85	2.75 2.65	26.66 26.08
7	4.17- 4.87	0.70	65.64 53.47	22.98 18.72	2.32 2.08	53.19 38.96
8	4.87- 5.28	0.41	58.55 52.27	12.00 10.71	1.71 1.58	20.55 16.88
9	5.28- 5.87	0.59	52.27 41.46	15.42 12.23	1.24 1.05	19.15 12.78
10	5.87- 6.72	0.85	21.55 0.00	9.14 0.00	0.57 0.28	5.17 0.00
$\Sigma P = 347.32$			$\Sigma M = 1266.97$			

P_i : active earth pressure + residual water pressure - passive earth pressure
P : load P_x 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_i = 0.0 kN/m
depth to acting position H_i = 0.00 m
moment M_{in} = 0.0 kN·m/m
depth to acting position H_{in} = 0.00 m
Height from riverbed to top of coping H = 4.17 m
Depth of Imaginary riverbed from riverbed L_k = 2.55 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 0.00 \text{ kN}\cdot\text{m}$$

$$\begin{aligned}&= \frac{77.59}{3.27} \\ &= 23.70\end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned}E_0 &= 2800N' = 2800 \times 23.70 = 66363 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 66363 = 442421 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 442421(10.00/0.3)^{-3/4} = 31892 \text{ kN/m}^3\end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 31892 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.87	0.87	1.66 12.36	0.72 5.37	4.96 4.67	3.58 25.08
2	0.87- 1.87	1.00	12.38 24.69	6.19 12.35	4.04 3.71	25.03 45.80
3	1.87- 2.30	0.43	24.65 29.93	5.30 6.44	3.23 3.09	17.13 19.88
4	2.30- 2.87	0.57	29.93 31.35	8.53 8.94	2.76 2.57	23.51 22.93
5	2.87- 3.87	1.00	30.97 33.35	15.48 16.67	2.04 1.71	31.62 28.50
6	3.87- 4.17	0.30	32.52 33.18	4.88 4.98	1.28 1.18	6.22 5.85
7	4.17- 4.87	0.70	32.18 8.11	11.61 2.84	0.84 0.61	9.78 1.73
8	4.87- 5.25	0.38	11.90 0.00	2.24 0.00	0.25 0.13	0.56 0.00
$\Sigma P = 112.53$			$\Sigma M = 267.19$			

P_i : active earth pressure + residual water pressure - passive earth pressure

P : load P_x 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_i = 0.0 kN/m
depth to acting position H_i = 0.0 m
moment M_{in} = 0.0 kN·m/m
depth to acting position H_{in} = 0.00 m

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	1.82- 2.82	1.00	0.0 2.6	0.00 1.31	4.57 4.25	0.00 5.56
2	2.82- 3.82	1.00	2.6 3.7	1.31 1.86	3.57 3.23	4.69 6.01
3	3.82- 4.17	0.35	3.7 4.0	0.65 0.71	2.78 2.67	1.81 1.88
$\Sigma P_{0w} = 5.84$			$\Sigma M_{0w} = 19.95$			

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned}h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0w}}{\Sigma P + P_i + \Sigma P_{0w}} \\ &= \frac{1286.91}{353.17} = 3.64 \text{ m}\end{aligned}$$

6.2 Sectional Force

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

Material name 10 H₂ H 850-250-14-22-18
Unit width B = 1.0000 m
Corrosion margin t_i = 1.00 mm (active side) t₂ = 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 I₀ = 532300 cm⁴ (original condition)
I = 457778 cm⁴ (after reduction by corrosion and section)
EI = 200000 $\times$ 10³ $\times$ 457778 $\times$ 10⁻⁶ = 9.156 $\times$ 10⁵

$$\begin{aligned}\beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} \\ \phi_a &= \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})\end{aligned}$$

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction K_b = 14773 kN/m³
calculated value β = 0.25202 m⁻¹
resultant earth force (lateral) P₀ = 112.53 kN/m
height of acting position of load h₀ = 2.37 m

moment $M_0 = 267.19 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_m = 1.316$,
maximum moment $M_{\max} = 351.54 \text{ kN}\cdot\text{m/m}$
depth of generated position of $M_{\max}$ $l_m = 1.695 \text{ m}$
depth of 1st fixed point $l_i = 4.812 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_0 = 31892 \text{ kN/m}^3$
calculated value $\beta = 0.30548 \text{ m}^3$
resultant earth force (lateral) $P_0 = 353.17 \text{ kN/m}$
height of acting position of load moment $h_0 = 3.64 \text{ m}$
 $M_0 = 1286.91 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_m = 1.123$,
maximum moment $M_{\max} = 1445.63 \text{ kN}\cdot\text{m/m}$
depth of generated position of $M_{\max}$ $l_m = 0.984 \text{ m}$
depth of 1st fixed point $l_i = 3.555 \text{ m}$

6.3 Stress Intensity

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

Material Name 10 H₂ H 850 -250 -14 -22 -18
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.88$
Section efficiency $\mu = 1.00$
Module of section $Z_0 = 8840 \text{ cm}^3$ (original condition)
 $Z = 7779 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{351.54 \times 10^6}{7779 \times 10^3} = 45 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{1445.63 \times 10^6}{7779 \times 10^3} = 186 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.87	4.96 4.67	0.945 0.889	0.306 0.278	0.72 5.37	0.221 1.466
2	0.87~ 1.87	4.04 3.71	0.771 0.707	0.221 0.191	6.19 12.35	1.366 2.339
3	1.87~ 2.30	3.23 3.09	0.616 0.589	0.151 0.139	5.30 6.44	0.799 0.897
4	2.30~ 2.87	2.76 2.57	0.525 0.489	0.114 0.100	8.53 8.94	0.971 0.895

$$\text{Size} = 19.06 \leq \delta_a = 50.00 \text{ mm}$$

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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.87	6.43 6.14	0.957 0.914	0.312 0.290	16.61 21.72	5.179 6.306
2	0.87~ 1.82	5.53 5.22	0.823 0.776	0.246 0.223	23.86 29.97	5.868 6.692
3	1.82~ 1.87	4.88 4.87	0.727 0.724	0.200 0.199	1.58 1.58	0.316 0.315
4	1.87~ 2.87	4.52 4.18	0.672 0.622	0.175 0.154	31.48 33.33	5.516 5.117
5	2.87~ 3.87	3.52 3.18	0.523 0.474	0.113 0.094	32.33 34.11	3.653 3.221
6	3.87~ 4.17	2.75 2.65	0.489 0.394	0.072 0.067	9.70 9.85	0.701 0.665
7	4.17~ 4.87	2.32 2.08	0.345 0.310	0.053 0.043	22.98 18.72	1.207 0.806
8	4.87~ 5.28	1.71 1.58	0.255 0.234	0.030 0.025	12.00 10.71	0.357 0.271
9	5.28~ 5.87	1.26 1.05	0.185 0.156	0.016 0.011	15.42 12.23	0.247 0.140
10	5.87~ 6.72	0.57 0.28	0.084 0.042	0.003 0.001	9.14 0.00	0.032 0.000
$\Sigma Q =$					46.611	

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

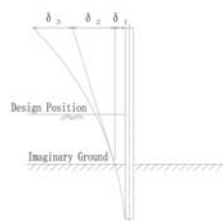
Dynamic water pressure due to earthquake is added to modulus of deformation Q

No	Depth m	Y m	α	ζ	P+Q kN	Q+Q _{dw} kN
1	1.82~ 2.82	4.57 4.23	0.679 0.630	0.179 0.157	0.00 1.31	0.000 0.206
2	2.82~ 3.82	3.57 3.23	0.531 0.481	0.116 0.097	1.31 1.86	0.152 0.181
3	3.82~ 4.17	2.78 2.67	0.414 0.397	0.074 0.068	0.65 0.71	0.048 0.048
$\Sigma Q_{dw} =$					0.635	

5	2.87~ 3.87	2.04 1.71	0.389 0.326	0.066 0.047	15.48 16.67	1.021 0.789
6	3.87~ 4.17	1.28 1.18	0.243 0.224	0.027 0.023	4.88 4.98	0.133 0.116
7	4.17~ 4.87	0.84 0.61	0.161 0.116	0.012 0.006	11.61 2.84	0.142 0.016
8	4.87~ 5.25	0.25 0.13	0.048 0.024	0.001 0.000	2.24 0.00	0.003 0.000
$\Sigma Q =$					11.234	

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

Displacement Calculation

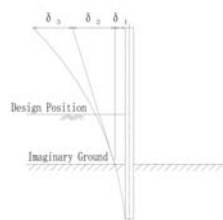


$$\begin{aligned} \delta_1 &= \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1+0.2520 \times 2.37) \times 112.53}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2520^3} = 0.00614 \text{ m} \\ \delta_2 &= \frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k) \\ &= \frac{(1+2 \times 0.2520 \times 2.37) \times 112.53}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2520^2} \times (4.17+1.08) = 0.01115 \text{ m} \\ \delta_3 &= \frac{Q \times (H+L_k)^3}{E I} \\ &= \frac{11.22 \times (4.17+1.08)^3}{2.00 \times 10^8 \times 457778 \times 10^{-8}} = 0.00177 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00614 + 0.01115 + 0.00177 \\ &= 0.01906 \text{ m} \end{aligned}$$

Therefore, the deformation coefficient Q is expressed by
 $Q = 46.611 + 0.635 = 47.246$

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1+0.3055 \times 3.64) \times 353.17}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.3055^3} = 0.01430 \text{ m} \\ \delta_2 &= \frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k) \\ &= \frac{(1+2 \times 0.3055 \times 3.64) \times 353.17}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.3055^2} \times (4.17+2.55) = 0.04480 \text{ m} \\ \delta_3 &= \frac{Q \times (H+L_k)^3}{E I} \\ &= \frac{47.25 \times (4.17+2.55)^3}{2.00 \times 10^8 \times 457778 \times 10^{-8}} = 0.01565 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01430 + 0.04480 + 0.01565 \\ &= 0.07475 \text{ m} \\ \text{Size} &= 74.75 \leq \delta_a = 75.00 \text{ mm} \end{aligned}$$

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:

Material Name 10 H₂ H 850 -250 -14 -22 -18
Unit width $B = 1.0000 \text{ m}$
Corrosion rate $\eta = 1.00$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 532300 \text{ cm}^4$ (original condition)
 $I = 532300 \text{ cm}^4$ (after reduction by corrosion and section)

$$EI = 200000 \times 10^3 \times 532300 \times 10^{-8} = 1.065 \times 10^6$$

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:

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

$$L = H - H_{iv} + D$$

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_b = 14773 \text{ kN/m}^3$
Calculated value $\beta = 0.24269 \text{ m}^{-1}$

Penetration length of SSP $D = 1.08 + \frac{3}{0.243} = 13.44 \text{ m}$
Whole length of SSP $L = 4.17 - 0.40 + 13.44 = 17.21 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 31892 \text{ kN/m}^3$
Calculated value $\beta = 0.29418 \text{ m}^{-1}$

Penetration length of SSP $D = 2.55 + \frac{3}{0.294} = 12.75 \text{ m}$
Whole length of SSP $L = 4.17 - 0.40 + 12.75 = 16.52 \text{ m}$

Therefore, the total length of the sheet pile is 17.50 m from the rounded length value of 0.50 m.

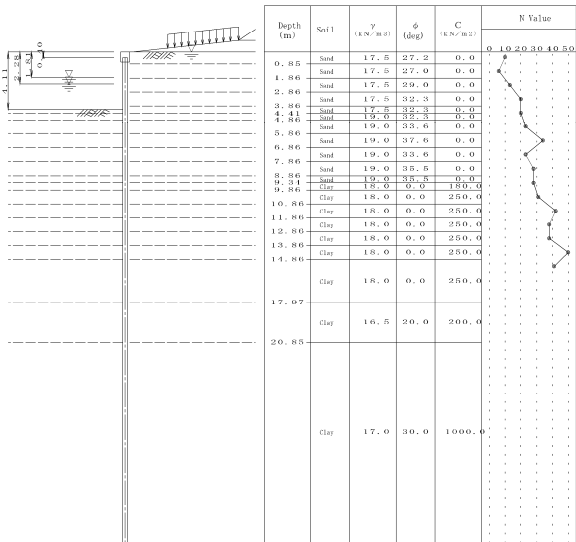
8 Calculation Result

front sheet pile 10 H 850 -250-14-22-18

			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	532300		
Sectional Modulus	Z (cm ³)	8840		
Maximum bending moment	Mmax (kN · m · m)		351.54	1445.63
Stress intensity	σ (N/mm ²)		45 (180)	186 (270)
Lateral displacement	δ (mm)		19.06 (50.0)	74.75 (75.0)
Penetration depth	D (m)		13.44	12.75
Whole length of SSP	L (m)	17.50		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 4.11 \text{ m}$
Depth from coping top to rear side ground $H_0 = 0.00 \text{ m}$
Depth from coping top to SSP top $H_k = 0.40 \text{ m}$
Landside WL $L_{wa} = 0.00 \text{ m}$ (Normal Condition)
 $L_{ws} = 0.00 \text{ m}$ (Seismic Condition)
Riverside WL $L_{wp} = 2.28 \text{ m}$ (Normal Condition)
 $L_{wp} = 1.81 \text{ m}$ (Seismic Condition)

Block No. : L-23
Sta. : 11+040~11+180

Design Cross Section : Sta 11+040
Boring Name : BMLL-32

Specification : SSP SP-10H
(Combined) : H 400-200-9-12-13

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered
Angle of rupture (clayey soil) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h^2 2Q}{2C} \cdot \tan \theta}$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{b0} \left(\frac{B_0}{0.3} \right)^{-3/4}$
 $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_0 = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
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	0.36	10	11	10.36	31
2	1.36	6	12	11.36	42
3	2.36	13	13	12.36	38
4	3.36	20	14	13.36	38
5	4.36	20	15	14.36	50
6	5.36	23	16	15.36	41
7	6.36	34			
8	7.36	23			
9	8.36	28			
10	9.36	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 (Include Projection Length)	Thickness m (excluding projected length)
1	0.85	0.85
2	1.86	1.01
3	2.86	1.00
4	3.86	1.00
5	4.41	0.55
6	4.86	0.45
7	5.86	1.00
8	6.86	1.00
9	7.86	1.00
10	8.86	1.00
11	9.34	0.48
12	9.86	0.52
13	10.86	1.00
14	11.86	1.00
15	12.86	1.00
16	13.86	1.00
17	14.86	1.00
18	17.97	3.11
19	20.85	2.88
20	33.70	12.85

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	2.89	7.97	5.0	0.0

Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 400 -200 -9 -12 -13
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 87800 cm⁴
Sectional factor Z₀ = 2320 cm³

Corrosion margin t₁ = 1.00 mm (riverside) t₂ = 1.00 mm (landside)

Corrosion rate (to I₀) η = 0.80
Corrosion rate (to Z₀) η = 0.81
Section efficiency (to I₀) μ = 1.00
Section efficiency (to Z₀) μ = 1.00

Round unit of SSP length 0.50 m

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

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

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I₀ applied to calculation of penetration depth
Reduced: I₀ applied to calculation of section forces and displacement
Reduced: Z₀ applied to calculation of stresses

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	φ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.85	S	10.0	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
2	1.86	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	2.86	S	13.0	17.50	7.70	29.0	0.0	0.0	0.200	Auto	Auto
4	3.86	S	20.0	17.50	7.70	32.3	0.0	0.0	0.200	Auto	Auto
5	4.41	S	20.0	17.50	7.70	32.3	0.0	0.0	0.200	Auto	Auto
6	4.86	S	20.0	19.00	9.20	32.3	0.0	0.0	0.200	Auto	Auto
7	5.86	S	23.0	19.00	9.20	33.6	0.0	0.0	0.200	Auto	Auto
8	6.86	S	34.0	19.00	9.20	37.6	0.0	0.0	0.200	Auto	Auto
9	7.86	S	23.0	19.00	9.20	33.6	0.0	0.0	0.200	Auto	Auto
10	8.86	S	28.0	19.00	9.20	35.5	0.0	0.0	0.200	Auto	Auto
11	9.34	S	28.0	19.00	9.20	35.5	0.0	0.0	0.200	Auto	Auto
12	9.86	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	10.86	C	31.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
14	11.86	C	42.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	12.86	C	38.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	13.86	C	38.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	14.86	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	17.97	C	41.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	20.85	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
20	33.70	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

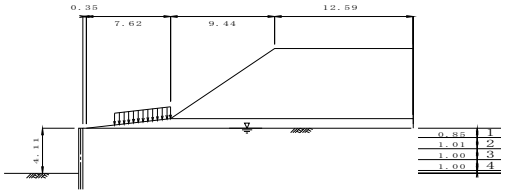
Note) depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ' : saturated unit weight of soil
φ : internal friction angle of soil

C₀ : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside

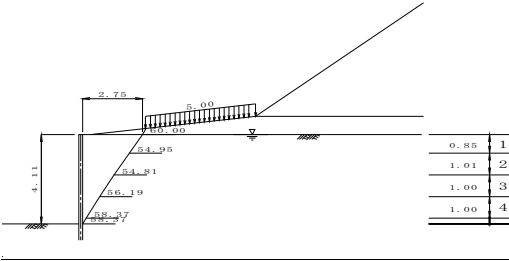


Fill shape and soil constants

No	Soil	Bottom Left m	Top Left m	Top Right m	Bottom Right m	Thickness h m	soil single weight γ Normal Condition kN/m ³	internal friction angle φ degree	stickiness C kN/m ²	decay angle ζ Normal Condition degree	Seismic Condition degree
1	Sand	0.35	7.97	30.00	30.00	0.85	19.0	30.0	0.0	Auto	Auto
2	Sand	7.97	17.41	30.00	30.00	6.38	19.0	30.0	0.0	Auto	Auto

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	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	Angle of Rupture ζ degree
1	4.11~3.86	Sand	32.3	15.0	0.0	31.65	2.41	40.28	58.37
2	3.86~2.86	Sand	32.3	15.0	0.0	29.72	2.41	37.83	58.37
3	2.86~1.86	Sand	29.0	15.0	0.0	22.02	2.41	28.03	56.19
4	1.86~0.85	Sand	27.0	15.0	0.0	14.32	2.41	18.23	54.81
5	0.85~0.00	Sand	27.2	15.0	0.0	6.55	2.41	8.33	54.95
6	embankment t		30.0	——	0.0	137.37	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

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

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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	58.37	0.25	0.00	0.00	0.15	0.25
2	58.37	1.00	0.15	0.25	0.77	1.25
3	56.19	1.00	0.77	1.25	1.44	2.25
4	54.81	1.01	1.44	2.25	2.15	3.26
5	54.95	0.85	2.15	3.26	2.75	4.11
6	60.00	0.29	2.75	4.11	2.91	4.40

From the above table, the loading width (L) on the ground surface is 2.75 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.34	6.51
Σ			6.51

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/m ²	l m	Q × l kN/m
1	5.0	0.02	0.12
Σ			0.12

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

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

$$= \frac{6.51 + 0.12 + 0.00}{2.75}$$

$$= 2.41 \text{ kN/m}^2$$

C : cohesive force of soil (kN/m²)

2.2.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	47.51	0.25	0.00	0.00	0.23	0.25
2	47.51	1.00	0.23	0.25	1.15	1.25
3	44.31	1.00	1.15	1.25	2.17	2.25
4	42.18	1.01	2.17	2.25	3.28	3.26
5	42.40	0.85	3.28	3.26	4.21	4.11
6	49.60	0.48	4.21	4.11	4.62	4.59

From the above table, the loading width (L) on the ground surface is 4.21 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.92	17.49
Σ			17.49

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 × l kN/m
1	0.0	1.73	0.00
Σ			0.00

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

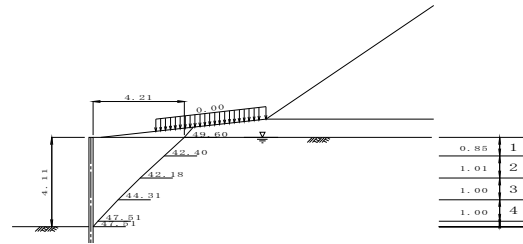
2.2.5 Calculated Load

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

$$= \frac{17.49 + 0.00 + 0.00}{4.21}$$

$$= 4.15 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ w h kN/m ²	k (k)	θ degree	Angle of Rupture ζ degree
1	4.11 ~ 3.86	Sand	32.3	15.0	0.0	31.65	4.15	40.28	0.200	11.31	47.51
2	3.86 ~ 2.86	Sand	32.3	15.0	0.0	29.72	4.15	37.83	0.200	11.31	47.51
3	2.86 ~ 1.86	Sand	29.0	15.0	0.0	22.02	4.15	28.03	0.200	11.31	44.31
4	1.86 ~ 0.85	Sand	27.0	15.0	0.0	14.32	4.15	18.23	0.200	11.31	42.18
5	0.85 ~ 0.00	Sand	27.2	15.0	0.0	6.55	4.15	8.33	0.200	11.31	42.40
6		embankment t	30.0	—	0.0	137.37	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

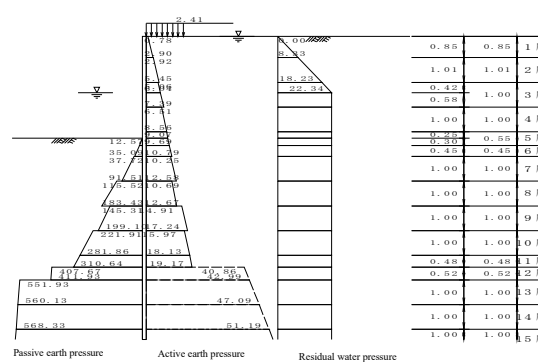
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

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⁻¹ k or θ = 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)

3 Lateral Forth

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	Σ γ h + Q _a kN/m ²	K _a	K _a × cos δ
1	0.00-0.85	Sand	7.7	—	2.413	0.33489	0.32348
					8.958	0.33489	0.32348
2	0.85-1.86	Sand	7.7	27.0	8.958	0.33738	0.32589
					16.735	0.33738	0.32589
3	1.86-2.28	Sand	7.7	29.0	16.735	0.31307	0.30240
					19.969	0.31307	0.30240
4	2.28-2.86	Sand	7.7	29.0	19.969	0.31307	0.30240
					24.435	0.31307	0.30240
5	2.86-3.86	Sand	7.7	32.3	24.435	0.27581	0.26641
					32.135	0.27581	0.26641
6	3.86-4.11	Sand	7.7	32.3	32.135	0.27581	0.26641
					34.060	0.27581	0.26641
7	4.11-4.41	Sand	7.7	32.3	34.060	0.27581	0.26641
					36.370	0.27581	0.26641
8	4.41-4.86	Sand	9.2	32.3	36.370	0.27581	0.26641
					40.510	0.27581	0.26641
9	4.86-5.86	Sand	9.2	33.6	40.510	0.26205	0.25312
					49.710	0.26205	0.25312
10	5.86-6.86	Sand	9.2	37.6	49.710	0.22267	0.21508
					58.910	0.22267	0.21508
11	6.86-7.86	Sand	9.2	33.6	58.910	0.26205	0.25312
					68.110	0.26205	0.25312

12	7.86- 8.86	Sand	9.2	35.3	250.0 250.0	68.110 77.310	0.24280 0.24280	0.23452 0.23452
13	8.86- 9.34	Sand	9.2	35.3	250.0 250.0	77.310 81.726	0.24280 0.24280	0.23452 0.23452
14	9.34- 9.86	Clay	8.2	—	180.0 180.0	81.726 85.990	—	—
15	9.86- 10.86	Clay	8.2	—	250.0 250.0	85.990 94.190	—	—
16	10.86- 11.86	Clay	8.2	—	250.0 250.0	94.190 102.390	—	—
17	11.86- 12.86	Clay	8.2	—	250.0 250.0	102.390 110.590	—	—
18	12.86- 13.86	Clay	8.2	—	250.0 250.0	110.590 118.790	—	—
19	13.86- 14.86	Clay	8.2	—	250.0 250.0	118.790 126.990	—	—
20	14.86- 17.97	Clay	8.2	—	250.0 250.0	126.990 152.492	—	—
21	17.97- 20.85	Clay	6.7	—	200.0 200.0	152.492 171.788	—	—
22	20.85- 33.70	Clay	7.2	—	1000.0 1000.0	171.788 264.308	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	Kp	Kp $\times \cos \delta$
7	4.11- 4.41	Sand	7.7	32.3	—	0.000 2.310	5.63255 5.63255	5.44062 5.44062
8	4.41- 4.86	Sand	9.2	32.3	—	2.310 6.450	5.63255 5.63255	5.44062 5.44062
9	4.86- 5.86	Sand	9.2	33.6	—	6.450 15.650	6.05364 6.05364	5.84737 5.84737
10	5.86- 6.86	Sand	9.2	37.6	—	15.650 24.850	7.64187 7.64187	7.38148 7.38148
11	6.86- 7.86	Sand	9.2	33.6	—	24.850 34.050	6.05364 6.05364	5.84737 5.84737
12	7.86- 8.86	Sand	9.2	35.5	—	34.050 43.250	6.74695 6.74695	6.51706 6.51706
13	8.86- 9.34	Sand	9.2	35.5	—	43.250 47.666	6.74695 6.74695	6.51706 6.51706
14	9.34- 9.86	Clay	8.2	0.0	180.0 180.0	47.666 51.930	—	—
15	9.86- 10.86	Clay	8.2	0.0	250.0 250.0	51.930 60.130	—	—
16	10.86- 11.86	Clay	8.2	0.0	250.0 250.0	60.130 68.330	—	—

14	9.34- 9.86	-278.27 -274.01	40.86 42.99	40.86 42.99	22.34 22.34	407.67 411.93
15	9.86- 10.86	-414.01 -405.81	42.99 47.09	42.99 47.09	22.34 22.34	531.93 560.13
16	10.86- 11.86	-405.81 -397.61	47.09 51.19	47.09 51.19	22.34 22.34	560.13 568.33
17	11.86- 12.86	-397.61 -389.41	51.19 55.29	51.19 55.29	22.34 22.34	568.33 576.53
18	12.86- 13.86	-389.41 -381.21	55.29 59.39	55.29 59.39	22.34 22.34	576.53 584.73
19	13.86- 14.86	-381.21 -373.01	59.39 63.49	59.39 63.49	22.34 22.34	584.73 592.93
20	14.86- 17.97	-373.01 -347.51	63.49 76.25	63.49 76.25	22.34 22.34	592.93 618.43
21	17.97- 20.85	-247.51 -228.21	76.25 85.89	76.25 85.89	22.34 22.34	518.43 537.73
22	20.85- 33.70	-1828.21 -1735.69	85.89 132.15	85.89 132.15	22.34 22.34	2137.73 2230.25

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

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

17	11.86- 12.86	Clay	8.2	0.0	250.0 250.0	68.330 76.530	—	—
18	12.86- 13.86	Clay	8.2	0.0	250.0 250.0	76.530 84.730	—	—
19	13.86- 14.86	Clay	8.2	0.0	250.0 250.0	84.730 92.930	—	—
20	14.86- 17.97	Clay	8.2	0.0	250.0 250.0	92.930 118.432	—	—
21	17.97- 20.85	Clay	6.7	20.0	200.0 200.0	118.432 137.728	—	—
22	20.85- 33.70	Clay	7.2	30.0	1000.0 1000.0	137.728 230.248	—	—

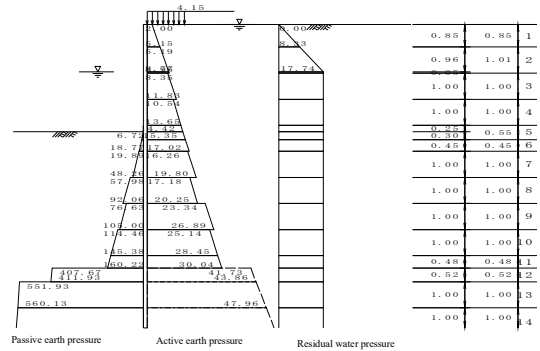
Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pv kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 0.85	0.78 2.90	—	0.78 2.90	0.00 8.33	—
2	0.85- 1.86	2.92 5.45	—	2.92 5.45	8.33 18.23	—
3	1.86- 2.28	5.06 6.04	—	5.06 6.04	18.23 22.34	—
4	2.28- 2.86	6.04 7.30	—	6.04 7.30	22.34 22.34	—
5	2.86- 3.86	6.51 8.56	—	6.51 8.56	22.34 22.34	—
6	3.86- 4.11	8.56 9.07	—	8.56 9.07	22.34 22.34	—
7	4.11- 4.41	9.07 9.69	—	9.07 9.69	22.34 22.34	0.00 12.57
8	4.41- 4.86	9.69 10.79	—	9.69 10.79	22.34 22.34	12.57 35.99
9	4.86- 5.86	10.25 12.58	—	10.25 12.58	22.34 22.34	37.72 91.51
10	5.86- 6.86	10.69 12.67	—	10.69 12.67	22.34 22.34	115.52 183.43
11	6.86- 7.86	14.91 17.24	—	14.91 17.24	22.34 22.34	145.31 199.10
12	7.86- 8.86	15.97 18.13	—	15.97 18.13	22.34 22.34	221.91 281.86
13	8.86- 9.34	18.13 19.17	—	18.13 19.17	22.34 22.34	281.86 310.64

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Ka	Ka $\times \cos \delta$	ζ degree
1	0.00- 0.85	Sand	7.7	27.2	—	4.15 10.69	0.00 8.33	0.200 0.200	11.31	0.49850 0.49850	0.48152 0.48152	—
2	0.85- 1.81	Sand	7.7	27.0	—	10.69 18.09	8.33 17.74	0.200 0.200	11.31	0.50201 0.49850	0.48490 0.48490	—
3	1.81- 1.86	Sand	7.7	27.0	—	18.09 18.47	17.74 18.23	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
4	1.86- 2.86	Sand	7.7	29.0	—	18.47 26.17	18.23 28.03	0.200 0.200	11.31	0.46809 0.46809	0.45214 0.45214	—
5	2.86- 3.86	Sand	7.7	32.3	—	26.17 33.87	28.03 37.83	0.200 0.200	11.31	0.41711 0.41711	0.40290 0.40290	—
6	3.86- 4.11	Sand	7.7	32.3	—	33.87 35.80	37.83 40.28	0.200 0.200	11.31	0.41711 0.41711	0.40290 0.40290	—
7	4.11- 4.41	Sand	7.7	32.3	—	35.80 38.11	40.28 45.22	0.200 0.200	11.31	0.41711 0.41711	0.40290 0.40290	—
8	4.41- 4.86	Sand	9.2	32.3	—	38.11 42.25	45.22 47.63	0.200 0.200	11.31	0.41711 0.41711	0.40290 0.40290	—
9	4.86- 5.86	Sand	9.2	33.6	—	42.25 51.45	47.63 57.43	0.200 0.200	11.31	0.39850 0.39850	0.38492 0.38492	—
10	5.86- 6.86	Sand	9.2	37.6	—	51.45 60.65	57.43 67.23	0.200 0.200	11.31	0.34567 0.34567	0.33389 0.33389	—
11	6.86- 7.86	Sand	9.2	33.6	—	60.65 69.85	67.23 77.03	0.200 0.200	11.31	0.39850 0.39850	0.38492 0.38492	—
12	7.86- 8.86	Sand	9.2	35.5	—	69.85 79.05	77.03 86.83	0.200 0.200	11.31	0.37261 0.37261	0.35992 0.35992	—
13	8.86- 9.34	Sand	9.2	35.5	—	79.05 83.46	86.83 91.53	0.200 0.200	11.31	0.37261 0.37261	0.35992 0.35992	—

14	9.34- 9.86	Clay	8.2	—	180.0 180.0	83.46 87.73	91.53 96.63	0.200 0.200	11.31 11.31	—	—	44.29 44.25
15	9.86- 10.86	Clay	8.2	—	250.0 250.0	87.73 95.93	96.63 106.43	0.200 0.200	11.31 11.31	—	—	44.46 44.41
16	10.86- 11.86	Clay	8.2	—	250.0 250.0	95.93 104.13	106.43 116.23	0.200 0.200	11.31 11.31	—	—	44.41 44.37
17	11.86- 12.86	Clay	8.2	—	250.0 250.0	104.13 112.33	116.23 126.03	0.200 0.200	11.31 11.31	—	—	44.37 44.32
18	12.86- 13.86	Clay	8.2	—	250.0 250.0	112.33 120.53	126.03 135.83	0.200 0.200	11.31 11.31	—	—	44.32 44.27
19	13.86- 14.86	Clay	8.2	—	250.0 250.0	120.53 128.73	135.83 145.63	0.200 0.200	11.31 11.31	—	—	44.27 44.22
20	14.86- 17.97	Clay	8.2	—	250.0 250.0	128.73 154.23	145.63 176.11	0.200 0.200	11.31 11.31	—	—	44.22 44.06
21	17.97- 20.85	Clay	6.7	—	200.0 200.0	154.23 173.52	176.11 204.33	0.200 0.200	11.31 11.31	—	—	43.82 43.67
22	20.85- 33.70	Clay	7.2	—	1000.0 1000.0	173.52 266.04	204.33 330.26	0.200 0.200	11.31 11.31	—	—	44.74 44.61

• The principal earth pressure coefficient (Ka) of Sand is calculated by the following equation.
 $\delta = 15.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

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

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degrees	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{ultw} kN/m ²	k (k ⁻¹)	θ degrees	Kp	Kp $\times \cos \beta$
7	4.11- 4.41	Sand	7.70	32.3	—	0.000 2.310	0.00 2.94	0.200 0.200	11.31 11.31	2.90961 2.90961	2.90961 2.90961
8	4.41- 4.86	Sand	9.20	32.3	—	2.310 6.450	2.94 7.35	0.200 0.200	11.31 11.31	2.90961 2.90961	2.90961 2.90961
9	4.86- 5.86	Sand	9.20	33.6	—	6.450 15.650	7.35 17.15	0.200 0.200	11.31 11.31	3.08376 3.08376	3.08376 3.08376
10	5.86- 6.86	Sand	9.20	37.6	—	15.650 24.850	17.15 26.95	0.200 0.200	11.31 11.31	3.70472 3.70472	3.70472 3.70472
11	6.86- 7.86	Sand	9.20	33.6	—	24.850 34.050	26.95 36.75	0.200 0.200	11.31 11.31	3.08376 3.08376	3.08376 3.08376
12	7.86- 8.86	Sand	9.20	35.5	—	34.050 43.250	36.75 46.55	0.200 0.200	11.31 11.31	3.36140 3.36140	3.36140 3.36140
13	8.86- 9.34	Sand	9.20	35.5	—	43.250 47.666	46.55 51.25	0.200 0.200	11.31 11.31	3.36140 3.36140	3.36140 3.36140
14	9.34- 9.86	Clay	8.20	0.0	180.0 180.0	47.666 51.930	51.25 56.35	0.200 0.200	11.31 11.31	— —	— —

12	7.86- 8.86	25.14 28.45	— —	25.14 28.45	17.74 17.74	114.46 145.38
13	8.86- 9.34	28.45 30.04	— —	28.45 30.04	17.74 17.74	145.38 160.22
14	9.34- 9.86	-259.54 -254.39	41.73 43.86	41.73 43.86	17.74 17.74	407.67 411.93
15	9.86- 10.86	-394.48 -384.60	43.86 47.96	43.86 47.96	17.74 17.74	551.93 560.13
16	10.86- 11.86	-384.60 -374.70	47.96 52.06	47.96 52.06	17.74 17.74	560.13 568.33
17	11.86- 12.86	-374.70 -364.81	52.06 56.16	52.06 56.16	17.74 17.74	568.33 576.53
18	12.86- 13.86	-364.81 -354.91	56.16 60.26	56.16 60.26	17.74 17.74	576.53 584.73
19	13.86- 14.86	-354.91 -345.00	60.26 64.36	60.26 64.36	17.74 17.74	584.73 592.93
20	14.86- 17.97	-345.00 -314.17	64.36 77.11	64.36 77.11	17.74 17.74	592.93 618.43
21	17.97- 20.85	-213.97 -190.55	77.11 86.76	77.11 86.76	17.74 17.74	618.43 537.73
22	20.85- 33.70	-1791.54 -1680.20	86.76 133.02	86.76 133.02	17.74 17.74	2137.73 2230.25

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	1.81	0.00	0.00
2	2.81	1.00	2.60
3	3.81	2.00	3.68
4	4.11	2.30	3.94

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

15	9.86- 10.86	Clay	8.20	0.0	250.0 250.0	51.930 60.130	56.35 66.15	0.200 0.200	11.31 11.31	—	—
16	10.86- 11.86	Clay	8.20	0.0	250.0 250.0	60.130 68.330	66.15 75.95	0.200 0.200	11.31 11.31	—	—
17	11.86- 12.86	Clay	8.20	0.0	250.0 250.0	68.330 76.530	75.95 85.75	0.200 0.200	11.31 11.31	—	—
18	12.86- 13.86	Clay	8.20	0.0	250.0 250.0	76.530 84.730	85.75 95.55	0.200 0.200	11.31 11.31	—	—
19	13.86- 14.86	Clay	8.20	0.0	250.0 250.0	84.730 92.930	95.55 105.35	0.200 0.200	11.31 11.31	—	—
20	14.86- 17.97	Clay	8.20	0.0	250.0 250.0	92.930 118.432	105.35 135.83	0.200 0.200	11.31 11.31	—	—
21	17.97- 20.85	Clay	6.70	20.0	200.0 200.0	118.432 137.728	135.83 164.05	0.200 0.200	11.31 11.31	—	—
22	20.85- 33.70	Clay	7.20	30.0	1000.0 1000.0	137.728 230.248	164.05 289.98	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive
		Pa1 kN/m ²	Pa2 kN/m ²	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	
1	0.00- 0.85	2.00 5.15	— —	2.00 5.15	0.00 8.33	— —	— —
2	0.85- 1.81	5.19 8.77	— —	5.19 8.77	8.33 17.74	— —	— —
3	1.81- 1.86	8.77 8.96	— —	8.77 8.96	17.74 17.74	— —	— —
4	1.86- 2.86	8.35 11.83	— —	8.35 11.83	17.74 17.74	— —	— —
5	2.86- 3.86	10.54 13.65	— —	10.54 13.65	17.74 17.74	— —	— —
6	3.86- 4.11	13.65 14.42	— —	13.65 14.42	17.74 17.74	— —	— —
7	4.11- 4.41	14.42 15.35	— —	14.42 15.35	17.74 17.74	0.00 6.72	— —
8	4.41- 4.86	15.35 17.02	— —	15.35 17.02	17.74 17.74	6.72 18.77	— —
9	4.86- 5.86	16.26 19.80	— —	16.26 19.80	17.74 17.74	19.89 48.26	— —
10	5.86- 6.86	17.18 20.25	— —	17.18 20.25	17.74 17.74	57.98 92.06	— —
11	6.86- 7.86	23.34 26.89	— —	23.34 26.89	17.74 17.74	76.63 105.00	— —

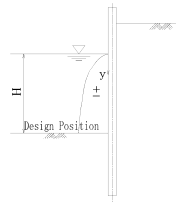
Where,

k_{dw} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

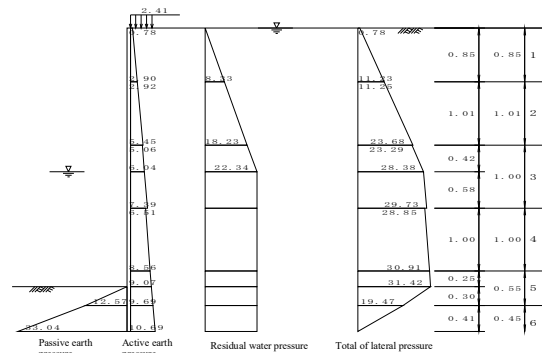
y : depth from water surface to the point where active water pressure is calculated



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



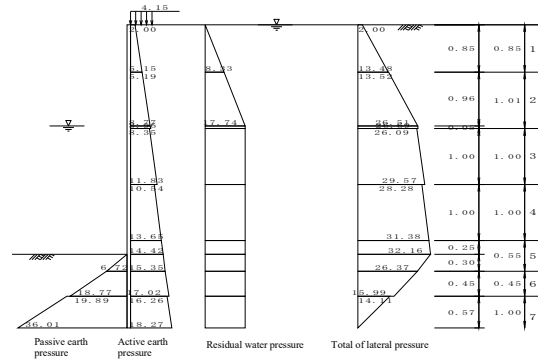
No	Depth m	Pa kN/m ²	Pw kN/m ²	Pt kN/m ²	Pt kN/m ²
1	0.00- 0.85	0.78 2.90	0.00 8.33	— —	0.78 11.23

2	0.85- 1.86	2.92 5.45	8.33 18.23	————	11.25 23.68
3	1.86- 2.28	5.06 6.04	18.23 22.34	————	23.29 28.38
4	2.28- 2.86	6.04 7.39	22.34 22.34	————	28.38 29.73
5	2.86- 3.86	6.51 8.56	22.34 22.34	————	28.85 30.91
6	3.86- 4.11	8.56 9.07	22.34 22.34	————	30.91 31.42
7	4.11- 4.41	9.07 9.69	22.34 22.34	0.00 12.57	31.42 19.47
8	4.41- 4.82	9.69 10.69	22.34 22.34	12.57 33.04	19.47 0.00
9	4.82- 4.86	10.69 10.79	22.34 22.34	33.04 35.09	0.00 -1.96

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 : 0.00 m (GL -4.82 m)

4.2 Seismic Condition



No	Depth m	P_a kN/m²	P_w kN/m²	P_p kN/m²	P_s kN/m²
1	0.00- 0.85	2.00 5.15	0.00 8.33	———— ————	2.00 13.48
2	0.85- 1.81	5.19 8.77	8.33 17.74	———— ————	13.52 26.51
3	1.81- 1.86	8.77 8.96	17.74 17.74	———— ————	26.51 26.69
4	1.86- 2.86	8.35 11.83	17.74 17.74	———— ————	26.09 29.57
5	2.86- 3.86	10.34 13.65	17.74 17.74	———— ————	28.28 31.38
6	3.86- 4.11	13.65 14.42	17.74 17.74	———— ————	31.38 32.16
7	4.11- 4.41	14.42 15.35	17.74 17.74	0.00 6.72	32.16 26.37
8	4.41- 4.86	15.35 17.02	17.74 17.74	6.72 18.77	26.37 15.99
9	4.86- 5.43	16.26 18.27	17.74 17.74	18.77 36.01	14.11 0.00
10	5.43- 5.86	18.27 19.80	17.74 17.74	36.01 48.26	0.00 -10.72

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 : 1.32 m (GL -5.43 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_h = K_{50} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H = 10.00 \text{ m})$$

$$K_{50} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}}$$

Material Name	10 H _ H 400 -200 -9 -12 -13
Unit width	B = 1.0000 m
Corrosion margin	$t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate	$\eta = 0.80$
Section efficiency	$\mu = 1.00$
Young's modulus	E = 200000 N/mm²
Inertia sectional moment	$I_0 = 87800 \text{ cm}^4$ (original condition) $I = 70240 \text{ cm}^4$ (after reduction by corrosion and section)
Inertia sectional moment	El = $200000 \times 10^3 \times 70240 \times 10^{-8} = 1.405 \times 10^5$

No	Depth m	N Value	No	Depth m	N Value
1	0.36	10	11	10.36	31
2	1.36	6	12	11.36	42
3	2.36	13	13	12.36	38
4	3.36	20	14	13.36	38
5	4.36	20	15	14.36	50
6	5.36	23	16	15.36	41
7	6.36	34			
8	7.36	23			
9	8.36	28			
10	9.36	28			

5.2 Normal Condition

Assuming $K_h = 18440 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}} = 0.426 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.35 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.82 m) to 2.35 m depth (GL -7.17 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.82	0.54	21.4	23.0	12.01
2	5.36	1.00	23.0	34.0	28.50
3	6.36	0.81	34.0	25.1	23.89
L = $\Sigma h = 2.35$			$\Sigma A =$		64.40

A: (upper N-value + lower N-value) $\times h/2$

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

$$= \frac{64.40}{2.35}$$

$$= 27.41$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 27.41 = 76745 \text{ kN/m}^2$$

$$K_{50} = \frac{1}{0.3} \times \alpha \times 76745 = 255817 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_h = K_{50} (B_H/0.3)^{-3/4} = 255817 (10.00/0.3)^{-3/4} = 18440 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 18440 kN/m³.

5.3 Seismic Condition

Assuming $K_h = 38504 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}} = 0.512 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 1.95 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.43 m) and 1.95 m depth (GL -7.38 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.43	0.93	23.8	34.0	26.90
2	6.36	1.00	34.0	23.0	28.50
3	7.36	0.02	23.0	23.1	0.53
L = $\Sigma h = 1.95$			$\Sigma A =$		55.93

A: (upper N-value + lower N-value) $\times h/2$

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

$$= \frac{55.93}{1.95}$$

$$= 28.62$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 28.62 = 80123 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 80123 = 534155 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10} (B/0.3)^{-3/4} = 534155 (10.00/0.3)^{-3/4} = 38504 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 38504 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.85	0.85	0.78 11.23	0.33 4.77	4.54 4.25	1.50 20.29
2	0.85~ 1.86	1.01	11.25 23.68	5.68 11.96	3.63 3.30	20.63 39.41
3	1.86~ 2.28	0.42	23.29 26.38	4.89 5.96	2.82 2.68	13.79 15.97
4	2.28~ 2.86	0.58	28.38 29.73	8.23 8.62	2.35 2.15	19.31 18.56
5	2.86~ 3.86	1.00	28.85 30.91	14.43 15.45	1.63 1.29	23.45 19.97
6	3.86~ 4.11	0.25	30.91 31.42	3.86 3.93	0.88 0.79	3.28 3.11
7	4.11~ 4.41	0.30	31.42 19.47	4.71 2.92	0.61 0.51	2.87 1.49
8	4.41~ 4.82	0.41	19.47 0.00	3.98 0.00	0.27 0.14	1.08 0.00
$\Sigma P = 99.73 \quad \Sigma M = 204.81$						

Ps : active earth pressure + residual water pressure - passive earth pressure
P : load Ps 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 Pt = 0.0 kN/m
depth to acting position Ht = 0.0 m
moment Mt = 0.0 kN·m/m
depth to acting position Hm = 0.00 m
Height from riverbed to top of coping H = 4.11 m
Depth of Imaginary riverbed from riverbed Lk = 0.71 m

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	1.81~ 2.81	1.00	0.0 2.6	0.00 1.30	3.28 2.95	0.00 3.84
2	2.81~ 3.81	1.00	2.6 3.7	1.30 1.84	2.28 1.95	2.97 3.59
3	3.81~ 4.11	0.30	3.7 3.9	0.53 0.59	1.52 1.42	0.84 0.84
$\Sigma P_{hw} = 5.58 \quad \Sigma M_{hw} = 12.08$						

h₀ Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{hw}}{\Sigma P + P_t + \Sigma P_{hw}} \\ &= \frac{304.37}{120.63} = 2.52 \text{ m} \end{aligned}$$

6.2 Sectional Force

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

Material name 10 H _ H 400 -200 -9 -12 -13
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.80
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 87800 cm⁴ (original condition)
I = 70240 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 70240 × 10⁻⁸ = 1.405 × 10⁵

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction K_b = 18440 kN/m³
calculated value β = 0.42562 m⁻¹
resultant earth force (lateral) P₀ = 99.73 kN/m
height of acting position of load h₀ = 2.05 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_{ta} = 0.00 \text{ kN} \cdot \text{m}$$

h₀ Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} \\ &= \frac{204.81}{99.73} = 2.05 \text{ m} \end{aligned}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.85	0.85	2.00 13.48	0.85 5.73	5.14 4.86	4.37 27.85
2	0.85~ 1.81	0.96	13.52 26.51	6.49 12.72	4.26 3.94	27.63 50.11
3	1.81~ 1.86	0.65	26.51 26.69	0.66 0.67	3.60 3.58	2.39 2.39
4	1.86~ 2.86	1.00	26.09 29.57	13.04 14.79	3.23 2.90	42.20 42.90
5	2.86~ 3.86	1.00	28.28 31.38	14.14 15.69	2.23 1.90	31.60 29.84
6	3.86~ 4.11	0.25	31.38 32.16	3.92 4.02	1.48 1.40	5.83 5.63
7	4.11~ 4.41	0.30	32.16 26.37	4.82 3.96	1.22 1.12	5.88 4.42
8	4.41~ 4.86	0.45	26.37 15.99	5.93 3.60	0.87 0.72	5.15 2.58
9	4.86~ 5.43	0.57	14.11 0.00	4.01 0.00	0.38 0.19	1.52 0.00
$\Sigma P = 115.05 \quad \Sigma M = 292.30$						

Ps : active earth pressure + residual water pressure - passive earth pressure

P : load Ps 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 Pt = 0.0 kN/m
depth to acting position Ht = 0.00 m
moment Mt = 0.0 kN·m/m
depth to acting position Hm = 0.00 m
Height from riverbed to top of coping H = 4.11 m
Depth of Imaginary riverbed from riverbed Lk = 1.32 m

Moment M_t by arbitrary load is as below

$$M_t = P_t \cdot (H + L_k - H_t) + M_{ta} = 0.00 \text{ kN} \cdot \text{m}$$

$$\text{moment} \quad M_0 = 204.81 \text{ kN} \cdot \text{m/m}$$

in consideration of ψ_{hs} = 1.180,

$$\begin{aligned} \text{maximum moment} \quad M_{max} &= 241.69 \text{ kN} \cdot \text{m/m} \\ \text{depth of generated position of } M_{max} \quad l_m &= 0.820 \text{ m} \\ \text{depth of 1st fixed point} \quad l_i &= 2.665 \text{ m} \end{aligned}$$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction K_b = 38504 kN/m³
calculated value β = 0.51163 m⁻¹
resultant earth force (lateral) P₀ = 120.63 kN/m
height of acting position of load h₀ = 2.52 m
moment M₀ = 304.37 kN·m/m

in consideration of ψ_{hs} = 1.097,

$$\begin{aligned} \text{maximum moment} \quad M_{max} &= 333.92 \text{ kN} \cdot \text{m/m} \\ \text{depth of generated position of } M_{max} \quad l_m &= 0.532 \text{ m} \\ \text{depth of 1st fixed point} \quad l_i &= 2.067 \text{ m} \end{aligned}$$

6.3 Stress Intensity

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

Material Name 10 H _ H 400 -200 -9 -12 -13
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.81
Section efficiency μ = 1.00
Module of section Z₀ = 2320 cm³ (original condition)
Z = 1879 cm³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{241.69 \times 10^6}{1879 \times 10^3} = 129 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{333.92 \times 10^6}{1879 \times 10^3} = 178 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.85	4.54 4.25	0.941 0.882	0.304 0.275	0.33 4.77	0.101 1.311
2	0.85~ 1.86	3.63 3.30	0.754 0.684	0.213 0.181	5.68 11.96	1.208 2.159
3	1.86~ 2.28	2.82 2.68	0.585 0.556	0.138 0.126	4.89 5.96	0.674 0.750

4	2.28- 2.86	2.35 2.15	0.487 0.447	0.099 0.085	8.23 8.62	0.817 0.732
5	2.86- 3.86	1.63 1.29	0.337 0.268	0.051 0.033	14.43 15.45	0.729 0.506
6	3.86- 4.11	0.88 0.79	0.182 0.164	0.016 0.013	3.86 3.93	0.060 0.050
7	4.11- 4.41	0.61 0.51	0.126 0.106	0.008 0.005	4.71 2.92	0.036 0.016
8	4.41- 4.82	0.27 0.14	0.057 0.028	0.002 0.000	3.98 0.00	0.006 0.000
$\Sigma Q =$						9.155

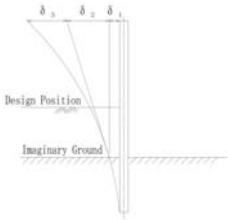
Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

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

Displacement Calculation



$$\delta_1 = \frac{(1+\beta h_a) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.4256 \times 2.05) \times 99.73}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4256^3} = 0.00863 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_a) \times P_0}{2 E I \beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.4256 \times 2.05) \times 99.73}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4256^2} \times (4.11+0.71) = 0.02595 \text{ m}$$

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

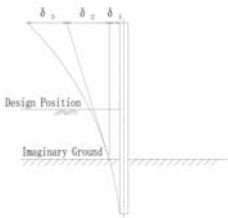
$$= \frac{9.15 \times (4.11+0.71)^3}{2.00 \times 10^8 \times 70240 \times 10^{-8}} = 0.00729 \text{ m}$$

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

$$= 0.00863 + 0.02595 + 0.00729$$

$$Q = 12.147 + 0.399 = 12.546$$

Displacement Calculation



$$\delta_1 = \frac{(1+\beta h_a) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.5116 \times 2.52) \times 120.63}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.5116^3} = 0.00734 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_a) \times P_0}{2 E I \beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.5116 \times 2.52) \times 120.63}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.5116^2} \times (4.11+1.32) = 0.03189 \text{ m}$$

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

$$= \frac{12.55 \times (4.11+1.32)^3}{2.00 \times 10^8 \times 70240 \times 10^{-8}} = 0.01429 \text{ m}$$

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

$$= 0.00734 + 0.03189 + 0.01429$$

$$= 0.05352 \text{ m}$$

$$\text{Size} = 53.52 \text{ mm} \leq \delta a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	10 H ₂ H 400 -200 -9 -12 -13
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 = 87800 cm ⁴ (original condition)
	I = 87800 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 87800 × 10 ⁻⁸	= 1.756 × 10 ⁹

$$= 0.04187 \text{ m}$$

$$\text{Size} = 41.87 \text{ mm} \leq \delta a = 50.00 \text{ mm}$$

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

No	Depth. m	Y m	α	ζ	P kN	Q kN
1	0.00- 0.85	5.14 4.86	0.948 0.896	0.307 0.281	0.85 5.73	0.261 1.612
2	0.85- 1.81	4.26 3.94	0.784 0.726	0.227 0.200	6.49 12.72	1.474 2.539
3	1.81- 1.86	3.60 3.58	0.663 0.660	0.171 0.170	0.66 0.67	0.114 0.114
4	1.86- 2.86	3.23 2.90	0.596 0.535	0.142 0.117	13.04 14.79	1.856 1.736
5	2.86- 3.86	2.23 1.90	0.412 0.350	0.073 0.054	14.14 15.69	1.034 0.850
6	3.86- 4.11	1.48 1.40	0.274 0.258	0.034 0.030	3.92 4.02	0.133 0.122
7	4.11- 4.41	1.22 1.12	0.224 0.206	0.023 0.020	4.82 3.96	0.112 0.078
8	4.41- 4.86	0.87 0.72	0.160 0.132	0.012 0.008	5.93 3.60	0.072 0.030
9	4.86- 5.43	0.38 0.19	0.070 0.035	0.002 0.001	4.01 0.00	0.010 0.000
$\Sigma Q =$						12.147

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

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	1.81- 2.81	3.28 2.95	0.605 0.544	0.146 0.121	0.00 1.30	0.000 0.157
2	2.81- 3.81	2.28 1.95	0.421 0.360	0.076 0.057	1.30 1.84	0.099 0.105
3	3.81- 4.11	1.52 1.42	0.280 0.261	0.035 0.031	0.55 0.59	0.020 0.016
$\Sigma Q_{dw} =$						0.399

Therefore, the deformation coefficient Q is expressed by

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 follows:

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

$$L = H - H_{1/3} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction
Calculated value $K_b = 18440 \text{ kN/m}^3$
 $\beta = 0.40253 \text{ m}^{-1}$

Penetration length of SSP $D = 0.71 + \frac{3}{0.403} = 8.16 \text{ m}$
Whole length of SSP $L = 4.11 - 0.40 + 8.16 = 11.87 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction
Calculated value $K_b = 38504 \text{ kN/m}^3$
 $\beta = 0.48387 \text{ m}^{-1}$

Penetration length of SSP $D = 1.32 + \frac{3}{0.484} = 7.52 \text{ m}$
Whole length of SSP $L = 4.11 - 0.40 + 7.52 = 11.23 \text{ m}$

Therefore, the total length of the sheet pile is 12.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP		10 H ₂ H 400 -200 -9 -12 -13		Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	87800			
Sectional Modulus	Z (cm ³)	2320			
Maximum bending moment	M _{max} (kN · m · m)			241.69	333.92
Stress intensity	σ (N/mm ²)			129 (180)	178 (270)
Lateral displacement	δ (mm)			41.87 (50.0)	53.52 (75.0)
Penetration depth	D (m)			8.16	7.52
Whole length of SSP	L (m)	12.00			

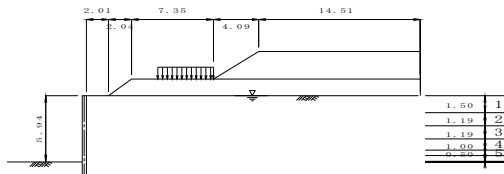
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.50	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
2	2.69	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
3	3.88	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
4	4.88	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	5.38	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	5.88	C	2.0	18.00	8.20	0.0	16.0	0.0	0.200	Auto	Auto
7	6.88	C	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
8	7.88	C	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	8.88	C	13.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
10	9.88	C	15.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
11	10.88	C	15.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
12	11.88	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	12.88	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
14	13.88	C	39.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	14.88	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	15.88	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
17	16.88	C	47.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	18.83	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	21.56	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
20	35.60	C	121.5	17.00	7.20	30.0	1000.0	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 (underwater)
 ζ : angle of active rupture
 kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



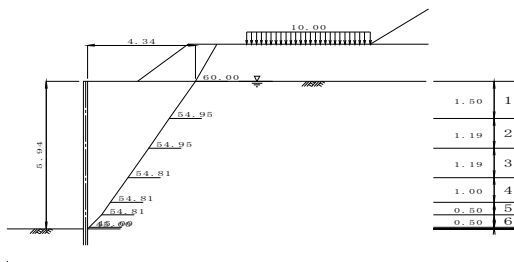
Fill shape and soil constants

No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	2.01	4.05	30.00	30.00	1.50	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	11.40	15.49	30.00	30.00	2.47	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

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	$\gamma \times A$ kN/m	Angle of Rupture ζ degree
1	5.94~5.88	Clay	0.0	15.0	100.0	46.02	11.46	58.21	45.00
2	5.88~5.38	Clay	0.0	15.0	16.0	45.53	11.46	57.62	45.00
3	5.38~4.88	Sand	27.0	15.0	0.0	41.43	11.46	52.72	54.81
4	4.88~3.88	Sand	27.0	15.0	0.0	37.58	11.46	47.82	54.81
5	3.88~2.69	Sand	27.0	15.0	0.0	29.88	11.46	38.02	54.81
6	2.69~1.50	Sand	27.2	15.0	0.0	20.71	11.46	26.36	54.95
7	1.50~0.00	Sand	27.2	15.0	0.0	11.55	11.46	14.70	54.95
8	embankment		30.0	—	0.0	75.43	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 $\theta = 0^\circ$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	6.41	11.40	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 900 -250 -14 -22 -18
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 597600 \text{ cm}^4$
 Sectional factor $Z_0 = 9470 \text{ cm}^3$

Corrosion margin $t_1 = 1.00 \text{ mm}$ (riverside) $t_2 = 1.00 \text{ mm}$ (landside)

Corrosion rate (to I_0) $\eta = 0.86$
 Corrosion rate (to Z_0) $\eta = 0.88$
 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 $\sigma_a = 180 \text{ N/mm}$ (Normal)
 $\sigma'_a = 270 \text{ N/mm}$ (Seismic)

Allowable displacement $\delta_a = 50.0 \text{ mm}$ (Normal)
 $\delta'_a = 75.0 \text{ mm}$ (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

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.06	0.00	0.00	0.06	0.06
2	45.00	0.50	0.06	0.06	0.56	0.56
3	54.81	0.50	0.56	0.56	0.91	1.06
4	54.81	1.00	0.91	1.06	1.62	2.06
5	54.81	1.19	1.62	2.06	2.46	3.25
6	54.95	1.19	2.46	3.25	3.29	4.44
7	54.95	1.50	3.29	4.44	4.34	5.94
8	60.00	1.50	4.34	5.94	5.21	7.44

From the above table, the loading width (L) on the ground surface is 4.34 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	2.62	49.79
Σ			49.79

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

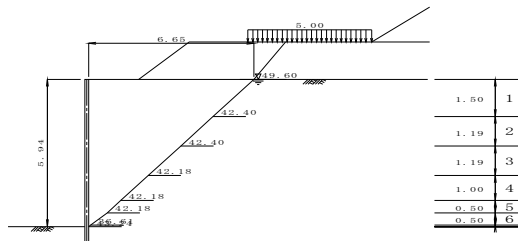
2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{49.79 + 0.00 + 0.00}{4.34}$$

$$= 11.46 \text{ kN/m}^2$$

2.2 Seismic 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	γ when h=1m, kN/m ²	k, (kN/m ²)	θ , degree	Angle of Repose α , degree
1	5.94 - 5.88	Clay	0.0	15.0	100.0	46.02	19.39	58.21	0.200	11.31	43.24
2	5.88 - 5.38	Clay	0.0	15.0	16.0	45.53	19.39	57.62	0.200	11.31	36.61
3	5.38 - 4.88	Sand	27.0	15.0	0.0	41.43	19.39	52.72	0.200	11.31	42.18
4	4.88 - 3.88	Sand	27.0	15.0	0.0	37.58	19.39	47.82	0.200	11.31	42.18
5	3.88 - 2.69	Sand	27.0	15.0	0.0	29.88	19.39	38.02	0.200	11.31	42.18
6	2.69 - 1.50	Sand	27.2	15.0	0.0	20.71	19.39	26.36	0.200	11.31	42.40
7	1.50 - 0.00	Sand	27.2	15.0	0.0	11.55	19.39	14.70	0.200	11.31	42.40
8	embankment	embankment	30.0	—	0.0	75.43	0.00	0.00	0.200	11.31	49.60

- Major collapse angle of Sand, intermediate soil, and split rock

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

- Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

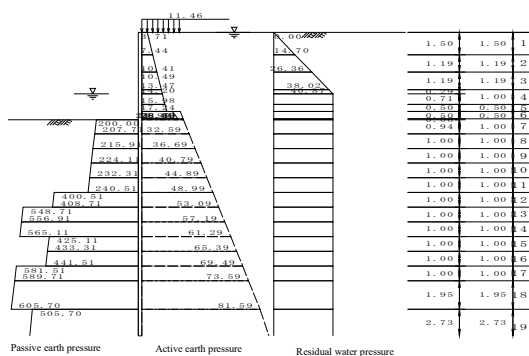
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

Where,

ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)
 ϕ : internal friction angle (degree)

3 Lateral Forth

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	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	Ka	$K_a \times \cos \phi$
1	0.00– 1.50	Sand	7.7	27.2	—	11.462 23.012	0.33489 0.33489	0.32348 0.32348
2	1.50– 2.69	Sand	7.7	27.2	—	23.012 32.175	0.33489 0.33489	0.32348 0.32348
3	2.69– 3.88	Sand	7.7	27.0	—	32.175 41.338	0.33738 0.33738	0.32889 0.32889
4	3.88– 4.17	Sand	7.7	27.0	—	41.338 43.571	0.33738 0.33738	0.32889 0.32889
5	4.17– 4.88	Sand	7.7	27.0	—	43.571 49.038	0.33738 0.33738	0.32889 0.32889
6	4.88– 5.38	Sand	7.7	27.0	—	49.038 52.808	0.33738 0.33738	0.32889 0.32889
7	5.38– 5.88	Clay	8.2	—	16.0 16.0	52.808 56.968	—	—
8	5.88– 5.94	Clay	8.2	—	100.0 100.0	56.968 57.480	—	—
9	5.94– 6.88	Clay	8.2	—	100.0 100.0	57.480 65.188	—	—
10	6.88– 7.88	Clay	8.2	—	100.0 100.0	65.188 73.388	—	—
11	7.88– 8.88	Clay	8.2	—	100.0 100.0	73.388 81.588	—	—
12	8.88– 9.88	Clay	8.2	—	100.0 100.0	81.588 89.788	—	—

 δ : wall friction angle (degree)

θ : earthquake combination angle (degree)

$$\theta = \tan^{-1}k \text{ or } \theta = \tan^{-1}k'$$
 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 Collapse Line

No	Angle of Rotation ζ degree	Thickness Z mm	bottom coordinate		top coordinate	
			X (mm)	Y (mm)	X (mm)	Y (mm)
1	43.24	0.06	0.00	0.00	0.06	0.06
2	36.61	0.80	0.06	0.06	0.74	0.56
3	42.18	0.50	0.74	0.56	1.29	1.06
4	42.18	1.00	1.29	1.06	2.39	2.06
5	42.18	1.19	2.39	2.06	3.71	3.25
6	42.40	1.19	3.71	3.25	5.01	4.44
7	42.40	1.50	5.01	4.44	6.65	5.94
8	49.60	1.50	6.65	5.94	7.93	7.44

From the above table, the loading width (L) on the ground surface is 6.65 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	6.39	121.40
Σ			121.40

 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/m ²	l m	Qxl kN/m
1	5.0	1.52	7.59
Σ			7.59

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

1: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

$$\begin{aligned} Q &= \frac{\Sigma(\gamma \times A) + \Sigma(Q \times l) + \Sigma P}{L} \\ &= \frac{121.40 + 7.59 + 0.00}{6.65} \\ &= 19.39 \text{ kN/m}^2 \end{aligned}$$

13	9.88- 10.88	Clay	8.2	—	100.0 100.0	89.788 97.988	—	—	—
14	10.88- 11.88	Clay	8.2	—	180.0 180.0	97.988 106.188	—	—	—
15	11.88- 12.88	Clay	8.2	—	250.0 250.0	106.188 114.388	—	—	—
16	12.88- 13.88	Clay	8.2	—	250.0 250.0	114.388 122.588	—	—	—
17	13.88- 14.88	Clay	8.2	—	180.0 180.0	122.588 130.788	—	—	—
18	14.88- 15.88	Clay	8.2	—	180.0 180.0	130.788 138.988	—	—	—
19	15.88- 16.88	Clay	8.2	—	250.0 250.0	138.988 147.188	—	—	—
20	16.88- 18.83	Clay	8.2	—	250.0 250.0	147.188 163.178	—	—	—
21	18.83- 21.56	Clay	6.7	—	200.0 200.0	163.178 181.469	—	—	—
22	21.56- 35.60	Clay	7.2	—	1000.0 1000.0	181.469 282.557	—	—	—

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

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	δ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	Kp	Kp $\times \cos \delta$
9	5.94- 6.88	Clay	8.2	0.0	100.0 100.0	0.000 7.708	_____	_____
10	6.88- 7.88	Clay	8.2	0.0	100.0 100.0	7.708 15.908	_____	_____
11	7.88- 8.88	Clay	8.2	0.0	100.0 100.0	15.908 24.108	_____	_____
12	8.88- 9.88	Clay	8.2	0.0	100.0 100.0	24.108 32.308	_____	_____
13	9.88- 10.88	Clay	8.2	0.0	100.0 100.0	32.308 40.508	_____	_____
14	10.88- 11.88	Clay	8.2	0.0	180.0 180.0	40.508 48.708	_____	_____
15	11.88- 12.88	Clay	8.2	0.0	250.0 250.0	48.708 56.908	_____	_____
16	12.88- 13.88	Clay	8.2	0.0	250.0 250.0	56.908 65.108	_____	_____
17	13.88- 14.88	Clay	8.2	0.0	180.0 180.0	65.108 73.308	_____	_____
18	14.88- 15.88	Clay	8.2	0.0	180.0 180.0	73.308 81.508	_____	_____
19	15.88- 16.88	Clay	8.2	0.0	250.0 250.0	81.508 89.708	_____	_____

20	16.88- 18.83	Clay	8.2	0.0	250.0 250.0	89.708 105.698	=====	=====
21	18.83- 21.56	Clay	6.7	20.0	200.0 200.0	105.698 123.989	=====	=====
22	21.56- 35.60	Clay	7.2	30.0	1000.0 1000.0	123.989 225.077	=====	=====

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2		Pp kN/m2	
1	0.00- 1.50	3.71 7.44	=====	3.71 7.44	0.00 14.70		=====	
2	1.50- 2.69	7.44 10.41	=====	7.44 10.41	14.70 26.36		=====	
3	2.69- 3.88	10.49 13.47	=====	10.49 13.47	26.36 38.02		=====	
4	3.88- 4.17	13.47 14.20	=====	13.47 14.20	38.02 40.87		=====	
5	4.17- 4.88	14.20 15.98	=====	14.20 15.98	40.87 40.87		=====	
6	4.88- 5.38	15.98 17.24	=====	15.98 17.24	40.87 40.87		=====	
7	5.38- 5.88	20.89 24.99	26.44 28.49	26.44 28.49	40.87 40.87		=====	
8	5.88- 5.94	-143.01 -142.52	28.49 28.74	28.49 28.74	40.87 40.87		=====	
9	5.94- 6.88	-142.52 -134.81	28.74 32.59	28.74 32.59	40.87 40.87	200.00 207.71		
10	6.88- 7.88	-134.81 -126.61	32.59 36.69	32.59 36.69	40.87 40.87	207.71 215.91		
11	7.88- 8.88	-126.61 -118.41	36.69 40.79	36.69 40.79	40.87 40.87	215.91 224.11		
12	8.88- 9.88	-118.41 -110.21	40.79 44.89	40.79 44.89	40.87 40.87	224.11 232.31		
13	9.88- 10.88	-110.21 -102.01	44.89 48.99	44.89 48.99	40.87 40.87	232.31 240.51		
14	10.88- 11.88	-262.01 -253.81	48.99 53.09	48.99 53.09	40.87 40.87	400.51 408.71		
15	11.88- 12.88	-393.81 -385.61	53.09 57.19	53.09 57.19	40.87 40.87	548.71 556.91		
16	12.88- 13.88	-385.61 -377.41	57.19 61.29	57.19 61.29	40.87 40.87	556.91 565.11		

17	13.88- 14.88	-237.41 -229.21	61.29 65.39	61.29 65.39	40.87 40.87	425.11 433.31		
18	14.88- 15.88	-229.21 -221.01	65.39 69.49	65.39 69.49	40.87 40.87	433.31 441.51		
19	15.88- 16.88	-361.01 -352.81	69.49 73.59	69.49 73.59	40.87 40.87	581.51 589.71		
20	16.88- 18.83	-352.81 -336.82	73.59 81.59	73.59 81.59	40.87 40.87	589.71 605.70		
21	18.83- 21.56	-236.82 -218.53	81.59 90.73	81.59 90.73	40.87 40.87	505.70 523.99		
22	21.56- 35.60	-1818.53 -1717.44	90.73 141.28	90.73 141.28	40.87 40.87	2123.99 2225.08		

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5

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

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

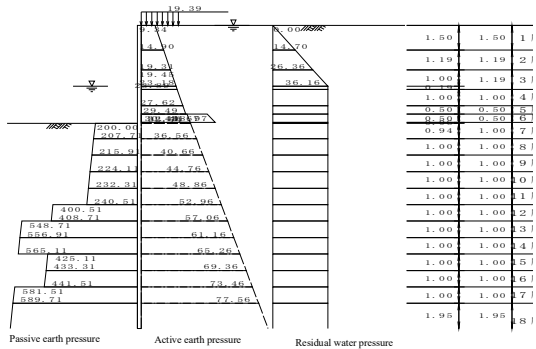
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	$\gamma \text{ wtm}$ kN/m2	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.50	Sand	7.7	27.2	=====	19.39 30.94	0.00 14.70	0.200 0.200	11.31	0.49850 0.49850	0.48152 0.48152	=====
2	1.50- 2.69	Sand	7.7	27.2	=====	30.94 40.11	14.70 26.36	0.200 0.200	11.31	0.49850 0.49850	0.48152 0.48152	=====
3	2.69- 3.69	Sand	7.7	27.0	=====	40.11 47.81	26.36 36.16	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	=====
4	3.69- 3.88	Sand	7.7	27.0	=====	47.81 49.27	36.16 38.02	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	=====
5	3.88- 4.88	Sand	7.7	27.0	=====	49.27 56.97	38.02 47.82	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	=====
6	4.88- 5.38	Sand	7.7	27.0	=====	56.97 60.82	47.82 52.72	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	=====
7	5.38- 5.88	Clay	8.2	=====	16.0 16.0	60.82 64.92	52.72 57.62	0.200 0.200	11.31	=====	=====	37.01 36.61
8	5.88- 5.94	Clay	8.2	=====	100.0 100.0	64.92 65.41	57.62 58.21	0.200 0.200	11.31	=====	=====	43.25 43.24
9	5.94- 6.88	Clay	8.2	=====	100.0 100.0	65.41 73.12	58.21 67.42	0.200 0.200	11.31	=====	=====	43.24 43.05
10	6.88- 7.88	Clay	8.2	=====	100.0 100.0	73.12 81.32	67.42 77.22	0.200 0.200	11.31	=====	=====	43.05 42.84
11	7.88- 8.88	Clay	8.2	=====	100.0 100.0	81.32 89.52	77.22 87.02	0.200 0.200	11.31	=====	=====	42.84 42.64
12	8.88- 9.88	Clay	8.2	=====	100.0 100.0	89.52 97.72	87.02 96.82	0.200 0.200	11.31	=====	=====	42.64 42.45
13	9.88- 10.88	Clay	8.2	=====	100.0 100.0	97.72 105.92	96.82 106.62	0.200 0.200	11.31	=====	=====	42.45 42.25
14	10.88- 11.88	Clay	8.2	=====	180.0 180.0	105.92 114.12	106.62 116.42	0.200 0.200	11.31	=====	=====	43.41 43.29
15	11.88- 12.88	Clay	8.2	=====	250.0 250.0	114.12 122.32	116.42 126.22	0.200 0.200	11.31	=====	=====	43.75 43.66
16	12.88- 13.88	Clay	8.2	=====	250.0 250.0	122.32 130.52	126.22 136.02	0.200 0.200	11.31	=====	=====	43.66 43.58
17	13.88- 14.88	Clay	8.2	=====	180.0 180.0	130.52 138.72	136.02 145.82	0.200 0.200	11.31	=====	=====	43.06 42.95
18	14.88- 15.88	Clay	8.2	=====	180.0 180.0	138.72 146.92	145.82 155.62	0.200 0.200	11.31	=====	=====	42.95 42.84
19	15.88- 16.88	Clay	8.2	=====	250.0 250.0	146.92 155.12	155.62 165.42	0.200 0.200	11.31	=====	=====	43.41 43.33
20	16.88- 18.83	Clay	8.2	=====	250.0 250.0	155.12 171.11	165.42 184.53	0.200 0.200	11.31	=====	=====	43.33 43.16
21	18.83- 21.56	Clay	6.7	=====	200.0 200.0	171.11 189.40	184.53 211.29	0.200 0.200	11.31	=====	=====	42.74 42.52
22	21.56- 35.60	Clay	7.2	=====	1000.0 1000.0	189.40 290.49	211.29 348.88	0.200 0.200	11.31	=====	=====	44.47 44.19

- The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$\delta = 15.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

- The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

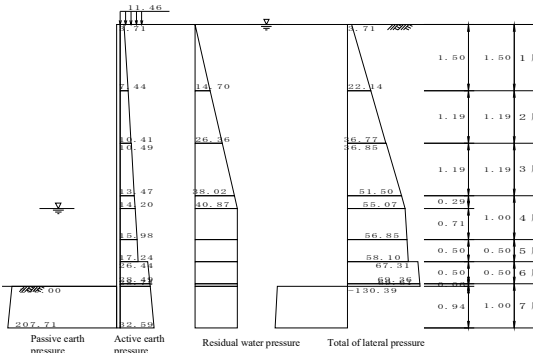
$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2		
1	0.00-1.50	9.34 14.90	———— ————	9.34 14.90	0.00 14.70	———— ————
2	1.50-2.69	14.90 19.31	———— ————	14.90 19.31	14.70 26.36	———— ————
3	2.69-3.69	19.45 23.18	———— ————	19.45 23.18	26.36 36.16	———— ————
4	3.69-4.88	23.18 27.62	———— ————	23.18 27.62	36.16 36.16	———— ————
5	4.88-5.38	27.62 29.49	———— ————	27.62 29.49	36.16 36.16	———— ————
7	5.38-5.88	43.67 48.97	30.41 32.46	43.67 48.97	36.16 36.16	———— ————
8	5.88-5.94	-121.65 -121.06	32.46 32.71	32.46 32.71	36.16 36.16	———— ————
9	5.94-6.88	-121.06 -111.69	32.71 36.56	32.71 36.56	36.16 36.56	200.00 207.71
10	6.88-7.88	-111.69 -101.71	36.56 40.66	36.56 40.66	36.16 36.16	207.71 215.91
11	7.88-8.88	-101.71 -91.72	40.66 44.76	40.66 44.76	36.16 36.16	215.91 224.11
12	8.88-9.88	-91.72 -81.71	44.76 48.86	44.76 48.86	36.16 36.16	224.11 232.31
13	9.88-10.88	-81.71 -71.69	48.86 52.96	48.86 52.96	36.16 36.16	232.31 240.51
14	10.88-11.88	-71.69 -62.52	52.96 57.06	52.96 57.06	36.16 36.16	400.51 408.71
15	11.88-12.88	-62.52 -52.59	57.06 61.16	57.06 61.16	36.16 36.16	548.71 556.91
16	12.88-13.88	-52.59 -42.67	61.16 65.26	61.16 65.26	36.16 36.16	556.91 565.11
17	13.88-14.88	-42.67 -32.74	65.26 69.36	65.26 69.36	36.16 36.16	425.11 433.31
18	14.88-15.88	-32.74 -22.82	69.36 73.46	69.36 73.46	36.16 36.16	433.31 441.51
19	15.88-16.88	-22.82 -12.89	73.46 77.56	73.46 77.56	36.16 36.16	581.51 589.71
20	16.88-18.83	-12.89 -290.43	77.56 85.55	77.56 85.55	36.16 36.16	589.71 605.70
21	18.83-21.56	-290.43 -170.79	85.55 94.70	85.55 94.70	36.16 36.16	505.70 523.99
22	21.56-35.60	-170.79 -1630.55	94.70 145.24	94.70 145.24	36.16 36.16	2123.99 2225.08

- Formula for active earth pressure

4.1 Normal Condition



No	Depth, m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00-1.50	3.71 7.44	0.00 14.70	———— ————	3.71 22.14
2	1.50-2.69	7.44 10.41	14.70 26.36	———— ————	22.14 36.77
3	2.69-3.88	10.41 13.47	26.36 38.02	———— ————	36.85 51.50
4	3.88-4.17	13.47 14.20	38.02 40.87	———— ————	51.50 55.07
5	4.17-4.88	14.20 15.98	40.87 40.87	———— ————	55.07 56.85
6	4.88-5.38	15.98 17.24	40.87 40.87	———— ————	56.85 58.10
7	5.38-5.88	26.44 28.49	40.87 40.87	———— ————	67.31 69.36
8	5.88-5.94	28.49 28.74	40.87 40.87	———— ————	69.36 69.61
9	5.94-6.88	28.74 32.59	40.87 40.87	200.00 207.71	-130.29 -134.25

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure Ps = Pa + Pw - Pp
Imaginary riverbed Lk: 0.00 m (GL -5.94 m)

Sand $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

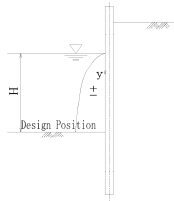
- Formula for passive earth pressure

Sand $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2C$
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

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

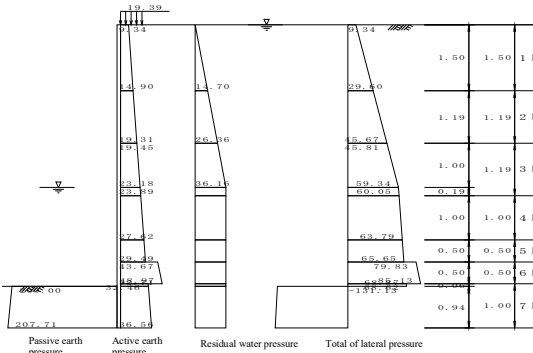
Where,
k_{dw}: design seismic coefficient
γ_w: unit weight of water
H: water depth of riverside
y: depth from water surface to the point where active water pressure is calculated



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.

4.2 Seismic Condition



No	Depth, m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00-1.50	9.34 14.90	0.00 14.70	———— ————	9.34 29.60
2	1.50-2.69	14.90 19.31	14.70 26.36	———— ————	29.60 45.67
3	2.69-3.69	19.45 23.18	26.36 36.16	———— ————	45.81 59.34
4	3.69-4.88	23.18 27.62	36.16 36.16	———— ————	59.34 60.05
5	4.88-5.38	27.62 29.49	36.16 36.16	———— ————	60.05 63.79
6	5.38-5.88	43.67 48.97	36.16 36.16	———— ————	63.79 79.83
7	5.88-5.94	48.97 52.96	36.16 36.16	———— ————	79.83 85.13
8	5.94-6.88	52.96 57.06	36.16 36.16	200.00 207.71	68.62 68.87
9	6.88-7.88	57.06 61.16	36.16 36.16	200.00 207.71	-131.13 -134.99

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure Ps = Pa + Pw - Pp
Imaginary riverbed Lk: 0.00 m (GL -5.94 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B_u}{0.3} \right)^{-3/4} \quad (B_u = 10.00m)$$
$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$E_0 = 2800N'$$

where:

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H_H 900 -250 -14 -22 -18
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 = 597600 cm ⁴ (original condition)
	I = 513936 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 513936 × 10 ⁻⁸ = 1.028 × 10 ⁶

No	Depth m	N Value	No	Depth m	N Value
1	1.00	10	11	11.38	19
2	2.00	10	12	12.38	34
3	3.38	2	13	13.38	39
4	4.38	2	14	14.38	16
5	5.38	2	15	15.38	28
6	6.38	10	16	16.38	47
7	7.38	10	17	17.38	50
8	8.38	13			
9	9.38	15			
10	10.38	15			

5.2 Normal Condition

Assuming Kh = 8333 kN/m3,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.212 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.71 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.94 m) to 4.71 m depth (GL -10.65 m).

Average N-value $N' = \frac{\sum A}{L}$
$$= \frac{47.59}{4.00}$$

$$= 11.88$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 11.88 = 33278 \text{ kN/m}^2$$
$$K_{10} = \frac{1}{0.3} \times \alpha \times 33278 = 221850 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$K_b = K_{10} (B_u/0.3)^{-3/4} = 221850 (10.00/0.3)^{-3/4} = 15992 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 15992 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.50	1.50	3.71 22.14	2.78 16.61	5.44 4.94	15.13 82.04
2	1.50- 2.69	1.19	22.14 36.77	13.18 21.88	4.04 3.65	53.27 79.78
3	2.69- 3.88	1.19	36.85 51.50	21.92 30.64	2.85 2.46	62.56 75.27
4	3.88- 4.17	0.29	51.50 55.07	7.47 7.98	1.96 1.87	14.66 14.90
5	4.17- 4.88	0.71	55.07 56.85	19.55 20.18	1.53 1.30	29.97 26.17
6	4.88- 5.38	0.50	56.85 58.10	14.21 14.53	0.89 0.73	12.70 10.56
7	5.38- 5.88	0.50	67.31 69.36	16.83 17.34	0.39 0.23	6.62 3.93
8	5.88- 5.94	0.06	69.36 69.61	2.08 2.09	0.04 0.02	0.08 0.04
			Σ P =	229.26	Σ M =	487.68

P_t : 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

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.94	0.44	6.5	10.0	3.63
2	6.38	1.00	10.0	10.0	10.00
3	7.38	1.00	10.0	13.0	11.50
4	8.38	1.00	13.0	15.0	14.00
5	9.38	1.00	15.0	15.0	15.00
6	10.38	0.27	15.0	16.1	4.25
L = Σ h = 4.71			Σ A =		58.37

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

Average N-value $N' = \frac{\sum A}{L}$
$$= \frac{58.37}{4.71}$$

$$= 12.39$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 12.39 = 34678 \text{ kN/m}^2$$
$$K_{10} = \frac{1}{0.3} \times \alpha \times 34678 = 115594 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$K_b = K_{10} (B_u/0.3)^{-3/4} = 115594 (10.00/0.3)^{-3/4} = 8333 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 8333 kN/m3.

5.3 Seismic Condition

Assuming Kh = 15992 kN/m3,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.250 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.00 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.94 m) and 4.00 m depth (GL -9.94 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.94	0.44	6.5	10.0	3.63
2	6.38	1.00	10.0	10.0	10.00
3	7.38	1.00	10.0	13.0	11.50
4	8.38	1.00	13.0	15.0	14.00
5	9.38	0.56	15.0	15.0	8.46
L = Σh = 4.00			ΣA = 47.59		

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

depth to acting position H_t = 0.0 m
moment M_a = 0.0 kN·m/m
depth to acting position H_a = 0.00 m
Height from riverbed to top of coping H = 5.94 m
Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_t by arbitrary load is as below
M_t = P_t·(H + L_k - H_t) + M_a = 0.00 kN·m
h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\sum M + M_t}{\sum P + P_t}$$
$$= \frac{487.68}{229.26} = 2.13 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.50	1.50	9.34 29.60	7.00 22.20	5.44 4.94	38.10 109.67
2	1.50- 2.69	1.19	29.60 45.67	17.61 27.18	4.04 3.65	71.21 99.10
3	2.69- 3.69	1.00	45.81 59.34	22.90 29.67	2.92 2.58	66.81 76.65
4	3.69- 3.88	0.19	59.34 60.05	5.64 5.70	2.19 2.12	12.33 12.11
5	3.88- 4.88	1.00	60.05 63.79	30.03 31.89	1.73 1.39	51.85 44.44
6	4.88- 5.38	0.50	63.79 65.65	15.95 16.41	0.89 0.73	14.25 11.93
7	5.38- 5.88	0.50	79.83 85.13	19.96 21.28	0.39 0.23	7.85 4.82
8	5.88- 5.94	0.06	68.62 68.87	2.06 2.07	0.04 0.02	0.08 0.04
			Σ P =	277.55	Σ M =	621.23

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 = 0.0 kN/m
depth to acting position H_t = 0.00 m
moment M_a = 0.0 kN·m/m
depth to acting position H_a = 0.00 m
Height from riverbed to top of coping H = 5.94 m
Depth of Imaginary riverbed from riverbed L_k = 0.00 m

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

Hydrodynamic Pressure

No	Depth, Z m	Thickness, h m	Hydrodynamic Pressure, p ₀ kN/m ²	Loads, P ₀ kN	Arm length, Y m	Moment, M ₀ kN · m
1	3.69- 4.69	1.00	0.0 2.6	0.00 1.29	1.92 1.58	0.00 2.04
2	4.69- 5.69	1.00	2.6 3.6	1.29 1.82	0.92 0.58	1.18 1.06
3	5.69- 5.94	0.25	3.6 3.9	0.45 0.48	0.17 0.08	0.08 0.04
Σ P ₀ = 5.33 Σ M ₀ = 4.39						

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{av}}{\Sigma P + P_i + \Sigma P_{av}} = \frac{625.62}{282.88} = 2.21 \text{ m}$$

6.2 Sectional Force

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

Material name	10 H _ H 900 -250 -14 -22 -18
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 = 597600 cm ⁴ (original condition) I = 513936 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 513936 × 10 ⁻⁸	= 1.028 × 10 ⁶

$$\beta = \sqrt[4]{\frac{K_s \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _s = 8333 kN/m ³
calculated value	β = 0.21217 m ⁻¹
resultant earth force (lateral)	P ₀ = 229.26 kN/m

height of acting position of load	h ₀ = 2.13 m
moment	M ₀ = 229.26 kN·m/m

in consideration of ψ _m = 1468,	M _{max} = 715.78 kN·m/m
maximum moment	l _m = 2.281 m
depth of generated position of M _{max}	l _i = 5.982 m
depth of 1 st fixed point	

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _s = 15992 kN/m ³
calculated value	β = 0.24973 m ⁻¹
resultant earth force (lateral)	P ₀ = 282.88 kN/m
height of acting position of load	h ₀ = 2.21 m
moment	M ₀ = 625.62 kN·m/m

in consideration of ψ _m = 1.354,	M _{max} = 846.91 kN·m/m
maximum moment	l _m = 1.776 m
depth of generated position of M _{max}	l _i = 4.921 m
depth of 1 st fixed point	

6.3 Stress Intensity

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

Material Name	10 H _ H 900 -250 -14 -22 -18
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 = 9470 cm ³ (original condition) Z = 8334 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{715.78 \times 10^6}{8334 \times 10^3} = 86 \text{ N/mm}^2 \leq \sigma_a = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{846.91 \times 10^6}{8334 \times 10^3} = 102 \text{ N/mm}^2 \leq \sigma_a = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00- 1.50	5.44 4.94	0.916 0.832	0.291 0.250	2.78 16.61	0.810 4.151
2	1.50- 2.69	4.04 3.65	0.681 0.614	0.179 0.150	13.18 21.88	2.360 3.279
3	2.69- 3.88	2.85 2.46	0.480 0.414	0.097 0.074	21.92 30.64	2.124 2.259

$$= 0.04842 \text{ m}$$

$$\text{Size} = 48.42 \leq \delta a = 50.00 \text{ mm}$$

Where,

- δ₁ : Displacement at imaginary ground
- δ₂ : Displacement by angle of inclination slope at imaginary ground
- δ₃ : 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

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00- 1.50	5.44 4.94	0.916 0.832	0.291 0.250	7.00 22.20	2.040 5.549
2	1.50- 2.69	4.04 3.65	0.681 0.614	0.179 0.150	17.61 27.18	3.154 4.073
3	2.69- 3.69	2.92 2.58	0.491 0.435	0.101 0.081	22.90 29.67	2.349 2.299
4	3.69- 3.88	2.19 2.12	0.368 0.357	0.059 0.056	5.64 5.70	0.335 0.321
5	3.88- 4.88	1.73 1.39	0.291 0.235	0.038 0.025	30.03 31.89	1.146 0.809
6	4.88- 5.38	0.89 0.73	0.150 0.122	0.011 0.007	15.95 16.41	0.171 0.118
7	5.38- 5.88	0.39 0.23	0.066 0.038	0.002 0.001	19.96 21.28	0.043 0.015
8	5.88- 5.94	0.04 0.02	0.007 0.003	0.000 0.000	2.06 2.07	0.000 0.000
Σ Q = 22.483						

$$Y : \text{Height from imaginary riverbed to acting position}$$

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

$$Q : \zeta \times P$$

$$P : \text{Lateral force}$$

$$H : \text{Depth to design position}$$

$$L_k : \text{Depth from design position to imaginary ground}$$

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

No	Depth, m	Y, m	α	ζ	P ₀ , kN	Q ₀ , kN
1	3.69- 4.69	1.92 1.58	0.323 0.267	0.046 0.032	0.00 1.29	0.000 0.042
2	4.69- 5.69	0.92 0.58	0.154 0.098	0.011 0.005	1.29 1.82	0.015 0.008
3	5.69- 5.94	0.17 0.08	0.028 0.014	0.000 0.000	0.45 0.48	0.000 0.000
Σ Q ₀ = 0.065						

Therefore, the deformation coefficient Q is expressed by
Q = 22.483 + 0.065 = 22.548

Displacement Calculation

4	3.88- 4.17	1.96 1.87	0.331 0.314	0.049 0.044	7.47 7.98	0.363 0.353
5	4.17- 4.88	1.53 1.30	0.258 0.218	0.030 0.022	19.55 20.18	0.595 0.446
6	4.88- 5.38	0.89 0.73	0.150 0.122	0.011 0.007	14.21 14.53	0.153 0.104
7	5.38- 5.88	0.39 0.23	0.066 0.038	0.002 0.001	16.83 17.34	0.036 0.012
8	5.88- 5.94	0.04 0.02	0.007 0.003	0.000 0.000	2.08 2.09	0.000 0.000
Σ Q = 17.046						

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

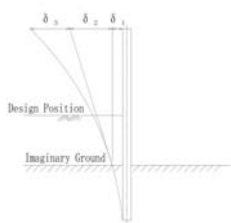
Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement Calculation



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

$$= \frac{(1+0.2122 \times 2.13) \times 229.26}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2122^3} = 0.01695 \text{ m}$$

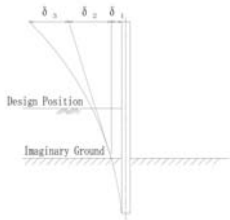
$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.2122 \times 2.13) \times 229.26}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2122^2} \times (5.94+0.00) = 0.02800 \text{ m}$$

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

$$= \frac{17.05 \times (5.94+0.00)^3}{2.00 \times 10^8 \times 513936 \times 10^{-8}} = 0.00348 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01695 + 0.02800 + 0.00348$$



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

$$= \frac{(1 + 0.2497 \times 2.21) \times 282.88}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2497^2} = 0.01371 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u)$$

$$= \frac{(1 + 2 \times 0.2497 \times 2.21) \times 282.88}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2497^2} \times (5.94 + 0.00) = 0.02758 \text{ m}$$

$$\delta_3 = \frac{Q \times (H + L_u)^3}{E I}$$

$$= \frac{22.55 \times (5.94 + 0.00)^3}{2.00 \times 10^8 \times 513936 \times 10^{-8}} = 0.00460 \text{ m}$$

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

$$= 0.01371 + 0.02758 + 0.00460$$

$$= 0.04590 \text{ m}$$

$$\text{Size} = 45.90 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	10 H ₂ H 900 -250 -14 -22 -18
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 = 597600 cm ⁴ (original condition)
	I = 597600 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 597600 × 10 ⁻⁸	= 1.195 × 10 ⁸

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is L_k, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

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

$$L = H - H_{IC} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 8333 kN/m ³
Calculated value	β = 0.20432 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.204}$ = 14.68 m
Whole length of SSP	L = 5.94 - 0.40 + 14.68 = 20.22 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_b = 15992 kN/m ³
Calculated value	β = 0.24049 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.240}$ = 12.47 m
Whole length of SSP	L = 5.94 - 0.40 + 12.47 = 18.01 m

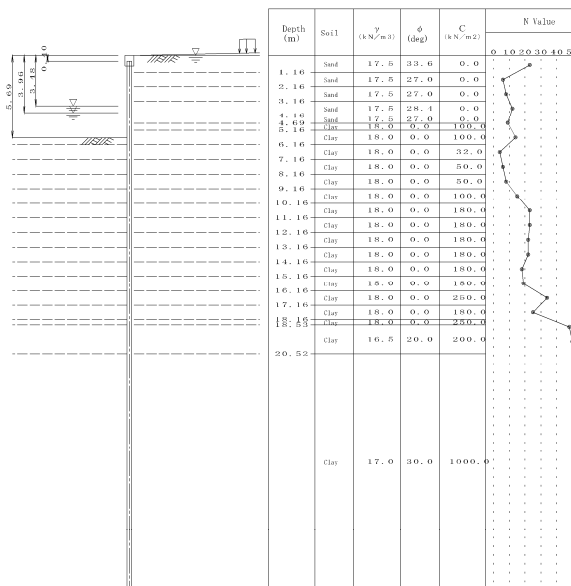
Therefore, the total length of the sheet pile is 20.50 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H ₂ H 900 -250 -14 -22 -18	
		Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	597600	
Sectional Modulus	Z (cm ³)	9470	
Maximum bending moment	Mmax (kN · m · m)		
Stress intensity	σ (N/mm ²)	715.78 86 (180)	846.91 102 (270)
Lateral displacement	δ (mm)	48.42 (50.0)	45.90 (50.0)
Penetration depth	D (m)	14.68	12.47
Whole length of SSP	L (m)	20.50	

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	= 5.69 m
Depth from coping top to rear side ground	H ₀	= 0.00 m
Depth from coping top to SSP top	H _b	= 0.40 m
Landside WL	L _{wa}	= 0.00 m (Normal Condition)
	L _{wa'}	= 0.00 m (Seismic Condition)
Riverside WL	L _{wp}	= 3.96 m (Normal Condition)
	L _{wp'}	= 3.48 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered
Wind load, Impact load	not considered
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope	not considered
Angle of rupture (clayey soil)	$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_h = K_{h0} \left(\frac{B_u}{0.3} \right)^{-3/4}$ $K_{h0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2) $B_u = 10,00 \text{ m}$ $E_0 = 2800 \text{ N}$
Average N-value	calculated from average N-value between imaginary riverbed and depth as 1/3

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	0.66	23	11	10.66	23
2	1.66	6	12	11.66	23
3	2.66	8	13	12.66	22
4	3.66	12	14	13.66	22
5	4.66	9	15	14.66	18
6	5.66	14	16	15.66	19
7	6.66	4	17	16.66	34
8	7.66	6	18	17.66	25
9	8.66	8	19	18.66	48
10	9.66	15	20	19.66	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 (Include Projection Length)	Thickness m (excluding projected length)
1	1.16	1.16
2	2.16	1.00
3	3.16	1.00
4	4.16	1.00
5	4.69	0.53
6	5.16	0.47
7	6.16	1.00
8	7.16	1.00
9	8.16	1.00
10	9.16	1.00
11	10.16	1.00
12	11.16	1.00
13	12.16	1.00
14	13.16	1.00
15	14.16	1.00
16	15.16	1.00
17	16.16	1.00
18	17.16	1.00
19	18.16	1.00
20	18.53	0.37
21	20.52	1.99
22	35.40	14.88

No	Depth m	earth Soil	N Value	γ kN/m3	γ' kN/m3	ϕ degree	C kN/m2	a	k'	ζ (degree) Normal Condition Seismic Condition
1	1.16	S	23.0	17.50	7.70	33.6	0.0	0.0	0.200	Auto Auto
2	2.16	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto Auto
3	3.16	S	8.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto Auto
4	4.16	S	12.0	17.50	7.70	28.4	0.0	0.0	0.200	Auto Auto
5	4.69	S	9.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto Auto
6	5.16	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto Auto
7	6.16	C	14.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto Auto
8	7.16	C	4.0	18.00	8.20	0.0	32.0	0.0	0.200	Auto Auto

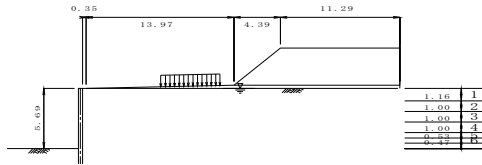
No	Depth m	earth Soil	N Value	γ kN/m3	γ' kN/m3	ϕ degree	C kN/m2	a	k'	ζ (degree) Normal Condition Seismic Condition
9	8.16	C	6.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto Auto
10	9.16	C	8.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto Auto
11	10.16	C	15.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto Auto
12	11.16	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto Auto
13	12.16	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto Auto
14	13.16	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto Auto
15	14.16	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto Auto
16	15.16	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto Auto
17	16.16	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto Auto
18	17.16	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto Auto
19	18.16	C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto Auto
20	18.53	C	48.0	18.00	8.20	0.0	290.0	0.0	0.200	Auto Auto
21	20.52	C	63.5	16.50	7.30	20.0	200.0	0.0	0.200	Auto Auto
22	35.40	C	121.5	17.00	7.20	30.0	1000.0	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 (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	Bottom Left m	Top Left m	Bottom Right m	Thickness h m	Normal Condition kN/m3	Seismic Condition kN/m3	internal friction angle ϕ degree	stickness C kN/m2	Normal Condition degree	Seismic Condition degree
1	Sand	0.35	14.32	30.00	0.30	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	14.32	18.71	30.00	3.52	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	7.41	12.99	10.0	5.0

Angle of rupture in embankment calculated in consideration of embankment conditions

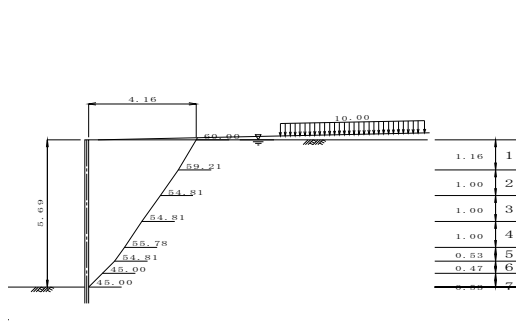
1.9 Steel Sheet Pile (SSP)

Material name	10 H _ H 800 -250 -14 -22 -18
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 471700 cm ⁴
Sectional factor	Z ₀ = 8240cm ³
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)	$\eta = 0.88$
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	$\sigma_a = 180 \text{ N/mm}$ (Normal) $\sigma'_a = 270 \text{ N/mm}$ (Seismic)
Allowable displacement	$\delta_a = 50.0 \text{ mm}$ (Normal) $\delta'_a = 75.0 \text{ mm}$ (Seismic)

Bending of cantilever beam calculated as distributed load of each layer
Reduction of material modulus Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I₀ applied to calculation of penetration depth
Reduced: I₀ 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	Σ γ h kN/m2	Q kN/m2	γ whw kN/m2	Angle of Rupture ζ degree
1	5.69~5.16	Clay	0.0	15.0	100.0	44.31	0.72	56.90	45.00
2	5.16~4.69	Clay	0.0	15.0	100.0	39.97	0.72	51.60	45.00
3	4.69~4.16	Sand	27.0	15.0	0.0	36.11	0.72	46.90	54.81
4	4.16~3.16	Sand	28.4	15.0	0.0	32.03	0.72	41.60	55.78
5	3.16~2.16	Sand	27.0	15.0	0.0	24.33	0.72	31.60	54.81
6	2.16~1.16	Sand	27.0	15.0	0.0	16.63	0.72	21.60	54.81
7	1.16~0.00	Sand	33.6	15.0	0.0	8.93	0.72	11.60	59.21
8		embankment	30.0	—	—	72.58	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 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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.53	0.00	0.00	0.53	0.53
2	45.00	0.47	0.53	0.53	1.00	1.00
3	54.81	0.53	1.00	1.00	1.37	1.53
4	55.78	1.00	1.37	1.53	2.05	2.53
5	54.81	1.00	2.05	2.53	2.76	3.53
6	54.81	1.00	2.76	3.53	3.46	4.53
7	59.21	1.16	3.46	4.53	4.16	5.69
8	60.00	0.08	4.16	5.69	4.20	5.77

From the above table, the loading width (L) on the ground surface is 4.16 m.

7	1.16 ~ 0.00	Sand	33.6	15.0	0.0	8.93	1.08	11.60	0.200	11.31	48.68
8		embankment	30.0	——	0.0	72.58	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	44.32	0.53	0.00	0.00	0.54	0.53
2	44.38	0.47	0.54	0.53	1.02	1.00
3	42.18	0.53	1.02	1.00	1.61	1.53
4	43.69	1.00	1.61	1.53	2.65	2.53
5	42.18	1.00	2.65	2.53	3.76	3.53
6	42.18	1.00	3.76	3.53	4.86	4.53
7	48.68	1.16	4.86	4.53	5.88	5.69
8	49.60	0.12	5.88	5.69	5.98	5.81

From the above table, the loading width (L) on the ground surface is 5.88 m.

2.2.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.33	6.36
Σ			6.36

γ : unit weight of embankment soil

A: sectional area of embankment enclosed by line of active rupture

2.1.3 Acting Load by Embankment

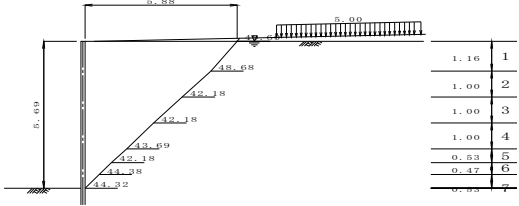
No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.16	2.99
Σ			2.99

γ : unit weight of embankment soil

A: sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$\begin{aligned} Q &= \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L} \\ &= \frac{2.99 + 0.00 + 0.00}{4.16} \\ &= 0.72 \text{ kN/m}^2 \end{aligned}$$



2.2 Seismic Condition

2.2.1 Angle of Active Rupture

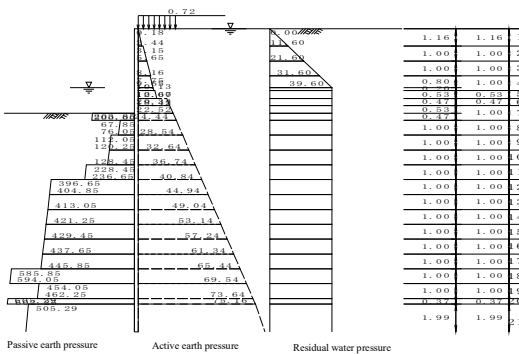
No	Depth, m	Soil	φ degree	δ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ whw kN/m2	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	5.69~5.16	Clay	0.0	15.0	100.0	44.31	1.08	56.90	0.200	11.31	44.32
2	5.16~4.69	Clay	0.0	15.0	100.0	39.97	1.08	51.60	0.200	11.31	44.38
3	4.69~4.16	Sand	27.0	15.0	0.0	36.11	1.08	46.90	0.200	11.31	42.18
4	4.16~3.16	Sand	28.4	15.0	0.0	32.03	1.08	41.60	0.200	11.31	43.69
5	3.16~2.16	Sand	27.0	15.0	0.0	24.33	1.08	31.60	0.200	11.31	42.18
6	2.16~1.16	Sand	27.0	15.0	0.0	16.63	1.08	21.60	0.200	11.31	42.18

2.2.4 Calculated Load

$$\begin{aligned} Q &= \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L} \\ &= \frac{6.36 + 0.00 + 0.00}{5.88} \\ &= 1.08 \text{ kN/m}^2 \end{aligned}$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

Depth, m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qa kN/m2	Ka	Ka × cos δ
1	0.00~1.16	Sand	7.7	33.6	0.720 9.652	0.26205 0.26205	0.25312 0.25312
2	1.16~2.16	Sand	7.7	27.0	9.652 17.352	0.33738 0.33738	0.32589 0.32589
3	2.16~3.16	Sand	7.7	27.0	17.352 25.052	0.33738 0.33738	0.32589 0.32589
4	3.16~3.96	Sand	7.7	28.4	25.052 31.212	0.32022 0.32022	0.30901 0.30901
5	3.96~4.16	Sand	7.7	28.4	31.212 32.752	0.32022 0.32022	0.30901 0.30901
6	4.16~4.69	Sand	7.7	27.0	32.752 36.833	0.33738 0.33738	0.32589 0.32589
7	4.69~5.16	Clay	8.2	—	100.0 100.0	— —	— —

8	5.16- 5.69	Clay	8.2	—	100.0 100.0	40.687 45.033	—	—
9	5.69- 6.16	Clay	8.2	—	100.0 100.0	45.033 48.887	—	—
10	6.16- 7.16	Clay	8.2	—	32.0 32.0	48.887 57.087	—	—
11	7.16- 8.16	Clay	8.2	—	50.0 50.0	57.087 65.287	—	—
12	8.16- 9.16	Clay	8.2	—	50.0 50.0	65.287 73.487	—	—
13	9.16- 10.16	Clay	8.2	—	100.0 100.0	73.487 81.687	—	—
14	10.16- 11.16	Clay	8.2	—	180.0 180.0	81.687 89.887	—	—
15	11.16- 12.16	Clay	8.2	—	180.0 180.0	89.887 98.087	—	—
16	12.16- 13.16	Clay	8.2	—	180.0 180.0	98.087 106.287	—	—
17	13.16- 14.16	Clay	8.2	—	180.0 180.0	106.287 114.487	—	—
18	14.16- 15.16	Clay	8.2	—	180.0 180.0	114.487 122.687	—	—
19	15.16- 16.16	Clay	8.2	—	180.0 180.0	122.687 130.887	—	—
20	16.16- 17.16	Clay	8.2	—	250.0 250.0	130.887 139.087	—	—
21	17.16- 18.16	Clay	8.2	—	180.0 180.0	139.087 147.287	—	—
22	18.16- 18.53	Clay	8.2	—	250.0 250.0	147.287 150.321	—	—
23	18.53- 20.52	Clay	6.7	—	200.0 200.0	150.321 163.654	—	—
24	20.52- 35.40	Clay	7.2	—	1000.0 1000.0	163.654 270.790	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth. m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma \cdot h + Q_p$ kN/m2	Kp	$K_p \times \cos \delta$
9	5.69- 6.16	Clay	8.2	0.0	100.0 100.0	0.000 3.854	—	—
10	6.16- 7.16	Clay	8.2	0.0	32.0 32.0	3.854 12.054	—	—
11	7.16- 8.16	Clay	8.2	0.0	50.0 50.0	12.054 20.254	—	—
12	8.16- 9.16	Clay	8.2	0.0	50.0 50.0	20.254 28.454	—	—

8	5.16- 5.69	-159.31 -154.97	20.34 22.52	20.34 22.52	39.60 39.60	—
9	5.69- 6.16	-154.97 -151.11	22.52 24.44	22.52 24.44	39.60 39.60	200.00 203.85
10	6.16- 7.16	-15.11 -6.91	24.44 28.54	24.44 28.54	39.60 39.60	67.85 76.05
11	7.16- 8.16	-42.91 -34.71	28.54 32.64	28.54 32.64	39.60 39.60	112.05 120.25
12	8.16- 9.16	-34.71 -26.51	32.64 36.74	32.64 36.74	39.60 39.60	120.25 128.45
13	9.16- 10.16	-126.51 -118.31	36.74 40.84	36.74 40.84	39.60 39.60	228.45 236.65
14	10.16- 11.16	-278.31 -270.11	40.84 44.94	40.84 44.94	39.60 39.60	396.65 404.85
15	11.16- 12.16	-270.11 -261.91	44.94 49.04	44.94 49.04	39.60 39.60	404.85 413.05
16	12.16- 13.16	-261.91 -253.71	49.04 53.14	49.04 53.14	39.60 39.60	413.05 421.25
17	13.16- 14.16	-253.71 -245.51	53.14 57.24	53.14 57.24	39.60 39.60	421.25 429.45
18	14.16- 15.16	-245.51 -237.31	57.24 61.34	57.24 61.34	39.60 39.60	429.45 437.65
19	15.16- 16.16	-237.31 -229.11	61.34 65.44	61.34 65.44	39.60 39.60	437.65 445.85
20	16.16- 17.16	-369.11 -360.91	65.44 69.54	65.44 69.54	39.60 39.60	585.85 594.05
21	17.16- 18.16	-228.91 -212.71	69.54 73.64	69.54 73.64	39.60 39.60	454.05 462.25
22	18.16- 18.53	-352.71 -340.68	73.64 75.16	73.64 75.16	39.60 39.60	602.25 605.29
23	18.53- 20.52	-249.68 -236.35	75.16 81.83	75.16 81.83	39.60 39.60	505.29 518.62

No	Depth. m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
24	20.52- 35.40	-1836.25 -1729.21	81.83 135.39	81.83 135.39	39.60 39.60	2118.62 2225.76

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma \cdot h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma \cdot h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma \cdot h + Q + 2C$$

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

13	9.16- 10.16	Clay	8.2	0.0	100.0 100.0	28.454 36.654	—	—
14	10.16- 11.16	Clay	8.2	0.0	180.0 180.0	36.654 44.854	—	—
15	11.16- 12.16	Clay	8.2	0.0	180.0 180.0	44.854 53.054	—	—
16	12.16- 13.16	Clay	8.2	0.0	180.0 180.0	53.054 61.254	—	—
17	13.16- 14.16	Clay	8.2	0.0	180.0 180.0	61.254 69.454	—	—
18	14.16- 15.16	Clay	8.2	0.0	180.0 180.0	69.454 77.654	—	—
19	15.16- 16.16	Clay	8.2	0.0	180.0 180.0	77.654 85.854	—	—
20	16.16- 17.16	Clay	8.2	0.0	250.0 250.0	85.854 94.054	—	—
21	17.16- 18.16	Clay	8.2	0.0	180.0 180.0	94.054 102.254	—	—
22	18.16- 18.53	Clay	8.2	0.0	250.0 250.0	102.254 105.288	—	—
23	18.53- 20.52	Clay	6.7	20.0	200.0 200.0	105.288 118.621	—	—
24	20.52- 35.40	Clay	7.2	30.0	1000.0 1000.0	118.621 225.757	—	—

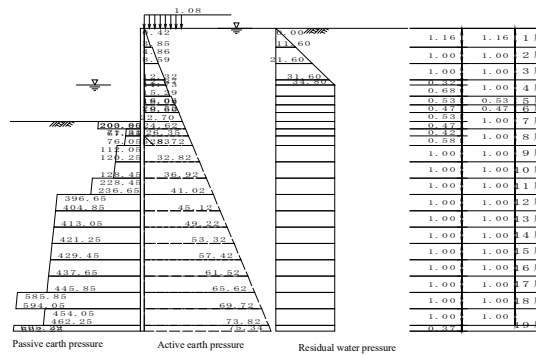
Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth. m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00- 1.16	0.18 2.44	—	0.18 2.44	0.00 11.60	—
2	1.16- 2.16	—	3.15 5.65	—	3.15 21.60	—
3	2.16- 3.16	—	5.65 8.16	—	5.65 31.60	—
4	3.16- 3.96	—	7.75 9.65	—	7.75 39.60	—
5	3.96- 4.16	—	9.65 10.13	—	9.65 10.13	39.60 39.60
6	4.16- 4.69	—	10.67 12.00	—	10.67 12.00	39.60 39.60
7	4.69- 5.16	—	-163.17 -159.31	18.42 20.34	18.42 20.34	39.60 39.60

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth. m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma \cdot h + Q$ kN/m2	$\gamma \cdot \text{whw}$ kN/m2	k (k')	θ degree	Ka	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.16	Sand	7.7	33.6	—	1.08 10.01	0.00 11.60	0.200 0.200	11.31	0.39850 0.39850	0.38492 0.38492	—
2	1.16- 2.16	Sand	7.7	27.0	—	16.01 17.71	11.60 21.60	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
3	2.16- 3.16	Sand	7.7	27.0	—	17.71 25.41	21.60 31.60	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
4	3.16- 3.48	Sand	7.7	28.4	—	25.41 27.88	31.60 34.80	0.200 0.200	11.31	0.47800 0.47800	0.46172 0.46172	—
5	3.48- 4.16	Sand	7.7	28.4	—	27.88 33.11	34.80 41.60	0.200 0.200	11.31	0.47800 0.47800	0.46172 0.46172	—
6	4.16- 4.69	Sand	7.7	27.0	—	33.11 37.19	41.60 46.90	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
7	4.69- 5.16	Clay	8.2	—	100.0	37.19 41.05	46.90 51.60	0.200 0.200	11.31	—	—	44.44 44.38
8	5.16- 5.69	Clay	8.2	—	100.0	41.05 45.39	51.60 56.90	0.200 0.200	11.31	—	—	44.38 44.32
9	5.69- 6.16	Clay	8.2	—	100.0	45.39 49.25	56.90 61.60	0.200 0.200	11.31	—	—	44.32 44.26
10	6.16- 6.58	Clay	8.2	—	32.0 32.0	49.25 52.71	61.60 66.90	0.200	11.31	—	—	42.55
11	6.58- 7.16	Clay	8.2	—	32.0 32.0	52.71 57.45	66.90 71.60	0.200	11.31	—	—	42.11
12	7.16- 8.16	Clay	8.2	—	50.0 50.0	57.45 65.65	71.60 81.60	0.200 0.200	11.31	—	—	43.22 42.95

13	8.16- 9.16	Clay	8.2	—	50.0 50.0	65.65 73.85	81.60 91.60	0.200 0.200	11.31 11.31	—	—	42.95 42.68
14	9.16- 10.16	Clay	8.2	—	100.0 100.0	73.85 82.05	91.60 101.60	0.200 0.200	11.31 11.31	—	—	43.98 43.76
15	10.16- 11.16	Clay	8.2	—	180.0 180.0	82.05 90.25	101.60 111.60	0.200 0.200	11.31 11.31	—	—	44.32 44.25
16	11.16- 12.16	Clay	8.2	—	180.0 180.0	90.25 98.45	111.60 121.60	0.200 0.200	11.31 11.31	—	—	44.25 44.19
17	12.16- 13.16	Clay	8.2	—	180.0 180.0	98.45 106.65	121.60 131.60	0.200 0.200	11.31 11.31	—	—	44.19 44.12
18	13.16- 14.16	Clay	8.2	—	180.0 180.0	106.65 114.85	131.60 141.60	0.200 0.200	11.31 11.31	—	—	44.12 44.05
19	14.16- 15.16	Clay	8.2	—	180.0 180.0	114.85 123.05	141.60 151.60	0.200 0.200	11.31 11.31	—	—	44.05 43.98
20	15.16- 16.16	Clay	8.2	—	180.0 180.0	123.05 131.25	151.60 161.60	0.200 0.200	11.31 11.31	—	—	43.98 43.91
21	16.16- 17.16	Clay	8.2	—	250.0 250.0	131.25 139.45	161.60 171.60	0.200 0.200	11.31 11.31	—	—	44.22 44.17
22	17.16- 18.16	Clay	8.2	—	180.0 180.0	139.45 147.65	171.60 181.60	0.200 0.200	11.31 11.31	—	—	43.84 43.77
23	18.16- 18.53	Clay	8.2	—	250.0 250.0	147.65 150.68	181.60 185.30	0.200 0.200	11.31 11.31	—	—	44.12 44.10
24	18.53- 20.52	Clay	6.7	—	200.0 200.0	150.68 164.02	185.30 205.20	0.200 0.200	11.31 11.31	—	—	43.87 43.77
25	20.52- 35.40	Clay	7.2	—	1000.0 1000.0	164.02 271.15	205.20 354.00	0.200 0.200	11.31 11.31	—	—	44.76 44.60

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$\delta = 15.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

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

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{sub} kN/m ²	k (ϕ')	θ degree	K _p	K _p $\times \cos \delta$
9	5.69- 6.16	Clay	8.20	0.0	100.0 100.0	0.000 3.854	0.00 4.70	0.200 0.200	11.31 11.31	—	—
10	6.16- 6.58	Clay	8.20	0.0	32.0 32.0	3.854 7.314	4.70 —	0.200 —	11.31 —	—	—
11	6.58- 7.16	Clay	8.20	0.0	32.0 32.0	7.314 12.054	— 14.70	— 0.200	— 11.31	—	—
12	7.16- 8.16	Clay	8.20	0.0	50.0 50.0	12.054 20.254	14.70 24.70	0.200 0.200	11.31 11.31	—	—

7	4.69- 5.16	-155.26 -150.61	18.60 20.52	18.60 20.52	34.80 34.80	—	—
8	5.16- 5.69	-150.61 -145.37	20.52 22.70	20.52 22.70	34.80 34.80	—	—
9	5.69- 6.16	-145.37 -140.71	22.70 24.62	22.70 24.62	34.80 34.80	200.00 203.85	—
10	6.16- 6.58	-4.26 0.00	24.62 26.35	24.62 26.35	34.80 34.80	67.85 71.31	—
11	6.58- 7.16	0.00 5.83	26.35 28.72	26.35 28.72	34.80 34.80	71.31 76.05	—
12	7.16- 8.16	-30.52 -20.50	28.72 32.82	28.72 32.82	34.80 34.80	112.05 120.25	—
13	8.16- 9.16	-20.50 -10.46	32.82 36.92	32.82 36.92	34.80 34.80	120.25 128.45	—
14	9.16- 10.16	-110.95 -101.00	36.92 41.02	36.92 41.02	34.80 34.80	228.45 236.65	—
15	10.16- 11.16	-261.25 -251.35	41.02 45.12	41.02 45.12	34.80 34.80	396.65 404.85	—
16	11.16- 12.16	-251.35 -241.44	45.12 49.22	45.12 49.22	34.80 34.80	404.85 413.05	—
17	12.16- 13.16	-241.44 -231.53	49.22 53.32	49.22 53.32	34.80 34.80	413.05 421.25	—
18	13.16- 14.16	-231.53 -221.60	53.32 57.42	53.32 57.42	34.80 34.80	421.25 429.45	—
19	14.16- 15.16	-221.60 -211.68	57.42 61.52	57.42 61.52	34.80 34.80	429.45 437.65	—
20	15.16- 16.16	-211.68 -201.74	61.52 65.62	61.52 65.62	34.80 34.80	437.65 445.85	—
21	16.16- 17.16	-241.96 -232.05	65.62 69.72	65.62 69.72	34.80 34.80	585.85 594.05	—
22	17.16- 18.16	-191.80 -181.86	69.72 73.82	69.72 73.82	34.80 34.80	454.05 462.25	—
23	18.16- 18.53	-322.14 -318.47	73.82 75.34	73.82 75.34	34.80 34.80	602.25 605.29	—
24	18.53- 20.52	-218.28 -202.11	75.34 82.01	75.34 82.01	34.80 34.80	505.29 518.62	—
25	20.52- 35.40	-1802.98 -1674.06	82.01 135.58	82.01 135.58	34.80 34.80	2118.62 2225.76	—

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

13	8.16- 9.16	Clay	8.20	0.0	50.0 50.0	20.254 28.454	24.70 34.70	0.200 0.200	11.31 11.31	—	—
14	9.16- 10.16	Clay	8.20	0.0	100.0 100.0	28.454 36.654	34.70 44.70	0.200 0.200	11.31 11.31	—	—
15	10.16- 11.16	Clay	8.20	0.0	180.0 180.0	36.654 44.854	44.70 54.70	0.200 0.200	11.31 11.31	—	—
16	11.16- 12.16	Clay	8.20	0.0	180.0 180.0	44.854 53.054	54.70 64.70	0.200 0.200	11.31 11.31	—	—
17	12.16- 13.16	Clay	8.20	0.0	180.0 180.0	53.054 61.254	64.70 74.70	0.200 0.200	11.31 11.31	—	—
18	13.16- 14.16	Clay	8.20	0.0	180.0 180.0	61.254 69.454	74.70 84.70	0.200 0.200	11.31 11.31	—	—
19	14.16- 15.16	Clay	8.20	0.0	180.0 180.0	69.454 77.654	84.70 94.70	0.200 0.200	11.31 11.31	—	—
20	15.16- 16.16	Clay	8.20	0.0	180.0 180.0	77.654 85.854	94.70 104.70	0.200 0.200	11.31 11.31	—	—
21	16.16- 17.16	Clay	8.20	0.0	250.0 250.0	85.854 94.054	104.70 114.70	0.200 0.200	11.31 11.31	—	—
22	17.16- 18.16	Clay	8.20	0.0	180.0 180.0	94.054 102.254	114.70 124.70	0.200 0.200	11.31 11.31	—	—
23	18.16- 18.53	Clay	8.20	0.0	250.0 250.0	102.254 105.288	124.70 128.40	0.200 0.200	11.31 11.31	—	—
24	18.53- 20.52	Clay	6.70	20.0	200.0 200.0	105.288 118.621	128.40 148.30	0.200 0.200	11.31 11.31	—	—
25	20.52- 35.40	Clay	7.20	30.0	1000.0 1000.0	118.621 225.757	148.30 297.10	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.16	0.42 3.85	—	0.42 3.85	0.00 11.60	—
2	1.16- 2.16	4.86 8.59	—	4.86 8.59	11.60 21.60	—
3	2.16- 3.16	8.59 12.32	—	8.59 12.32	21.60 31.60	—
4	3.16- 3.48	11.73 12.87	—	11.73 12.87	31.60 34.80	—
5	3.48- 4.16	—	—	12.87 15.29	34.80 34.80	—
6	4.16- 4.69	—	—	16.06 18.04	34.80 34.80	—

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	3.48	0.00	0.00
2	4.48	1.00	2.60
3	5.48	2.00	3.68
4	5.69	2.21	3.87

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

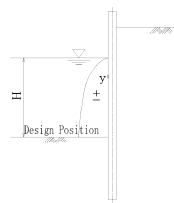
Where,

k_{sa} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

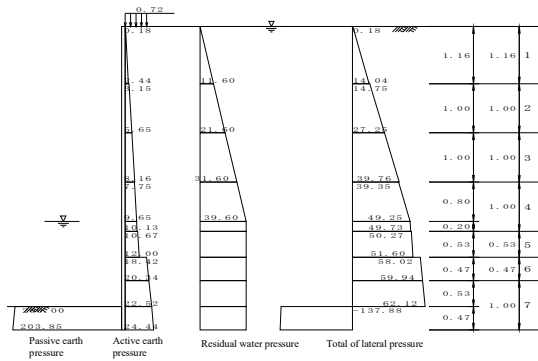
y : depth from water surface to the point where active water pressure is calculated



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

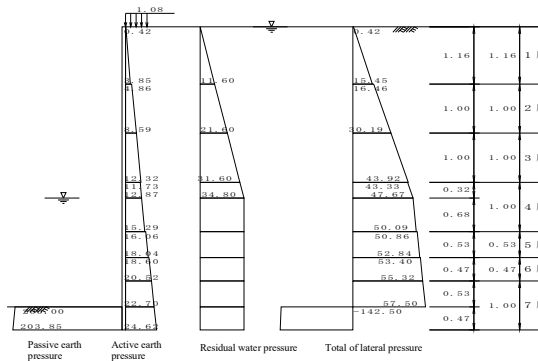


No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.16	0.18 2.44	0.00 11.60	—	0.18 14.04
2	1.16- 2.16	3.15 5.65	11.60 21.60	—	14.75 27.25
3	2.16- 3.16	5.65 8.16	21.60 31.60	—	27.25 39.76
4	3.16- 3.96	7.75 9.65	31.60 39.60	—	39.35 49.25
5	3.96- 4.16	9.65 10.13	39.60 39.60	—	49.25 49.73
6	4.16- 4.69	10.67 12.00	39.60 39.60	—	50.27 51.60
7	4.69- 5.16	18.42 20.34	39.60 39.60	—	58.02 59.94
8	5.16- 5.69	20.34 22.52	39.60 39.60	—	59.94 62.12
9	5.69- 6.16	22.52 24.44	39.60 39.60	200.00 203.85	-137.88 -139.81

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_A: 0.00 m (GL -5.69)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.16	0.42 3.85	0.00 11.60	—	0.42 15.45
2	1.16- 2.16	4.86 8.59	11.60 21.60	—	16.46 30.19
3	2.16- 3.16	8.59 12.32	21.60 31.60	—	30.19 43.92
4	3.16- 3.48	11.73 12.87	31.60 34.80	—	43.33 47.67
5	3.48- 4.16	12.87 15.29	34.80 34.80	—	47.67 50.09
6	4.16- 4.69	16.06 18.04	34.80 34.80	—	50.86 52.84
7	4.69- 5.16	18.60 20.52	34.80 34.80	—	53.40 55.32
8	5.16- 5.69	20.52 22.70	34.80 34.80	—	55.32 57.50
9	5.69- 6.16	22.70 24.62	34.80 34.80	200.00 203.85	-142.50 -144.43

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_A: 0.00 m (GL -5.69 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of 1/β from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_h = K_{50} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H=10.00\text{m})$$
$$K_{50} = \frac{1}{0.3} \alpha E_0 \quad (\alpha:\text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$E_0 = 2800 N'$$

where:

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

Material Name 10 H _ H 800 -250 -14 -22 -18
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 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 I₀ = 471700 cm⁴(original condition)
I = 405662 cm⁴(after reduction by corrosion and section)
Inertia sectional moment EI = 200000 × 10³ × 405662 × 10⁻⁸ = 8.113 × 10⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.66	23	11	10.66	23
2	1.66	6	12	11.66	23
3	2.66	8	13	12.66	22
4	3.66	12	14	13.66	22
5	4.66	9	15	14.66	18
6	5.66	14	16	15.66	19
7	6.66	4	17	16.66	34
8	7.66	6	18	17.66	25
9	8.66	8	19	18.66	48
10	9.66	15	20	19.66	50

5.2 Normal Condition

Assuming Kh = 6507 kN/m³,

$$\beta = 4 \sqrt[4]{\frac{K_h \cdot B}{4 E I}} = 0.212 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.73 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.69 m) to 4.73 m depth (GL -10.42 m).

5.3 Seismic Condition

Assuming Kh = 11247 kN/m³,

$$\beta = 4 \sqrt[4]{\frac{K_h \cdot B}{4 E I}} = 0.243 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.12 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.69 m) and 4.12 m depth (GL -9.81 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.69	0.97	13.7	4.0	8.58
2	6.66	1.00	4.0	6.0	5.00
3	7.66	1.00	6.0	8.0	7.00
4	8.66	1.00	8.0	15.0	11.50
5	9.66	0.15	15.0	16.2	2.36
L = $\Sigma h = 4.12$			$\Sigma A = 34.45$		

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

$$\begin{aligned} \text{Average N-value} \quad N' &= \frac{\Sigma A}{L} \\ &= \frac{34.45}{4.12} \\ &= 8.36 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_o &= 2800N' = 2800 \times 8.36 = 23403 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 23403 = 156020 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_{10} &= K_{10}(B_o/0.3)^{-3/4} = 156020(10.00/0.3)^{-3/4} = 11247 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 11247 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.16	1.16	0.18 14.04	0.11 8.14	5.30 4.92	0.56 40.05
2	1.16- 2.16	1.00	14.75 27.25	7.37 13.63	4.20 3.86	30.94 52.65
3	2.16- 3.16	1.00	27.25 39.76	13.63 19.88	3.20 2.86	43.56 56.93
4	3.16- 3.96	0.80	39.35 49.25	15.74 19.70	2.26 2.00	35.62 39.34
5	3.96- 4.16	0.20	49.25 49.73	4.93 4.97	1.66 1.60	8.19 7.94
6	4.16- 4.69	0.53	50.27 51.60	13.32 13.67	1.35 1.18	18.03 16.09
7	4.69- 5.16	0.47	58.02 59.94	13.63 14.09	0.84 0.69	11.50 9.67
8	5.16- 5.69	0.53	59.94 62.12	15.89 16.46	0.35 0.18	5.61 2.91
		ΣP =		195.16	ΣM =	379.59

Ps : active earth pressure + residual water pressure - passive earth pressure
P : load Ps 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 P1 = 0.0 kN/m

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	3.48- 4.48	1.00	0.0 2.6	0.00 1.30	1.88 1.54	0.00 2.01
2	4.48- 5.48	1.00	2.6 3.7	1.30 1.84	0.88 0.54	1.14 1.00
3	5.48- 5.69	0.21	3.7 3.9	0.39 0.41	0.14 0.07	0.05 0.03
		Σ P _{hw} =		5.23	Σ M _{hw} =	4.23

$$\begin{aligned} h_o, \text{ Height of acting position of } P_0 \text{ from imaginary riverbed} \\ h_o = \frac{M_o}{P_o} = \frac{\Sigma M + M_1 + \Sigma M_{hw}}{\Sigma P + P_1 + \Sigma P_{hw}} \\ = \frac{412.19}{205.54} = 2.01 \text{ m} \end{aligned}$$

6.2 Sectional Force

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

Material name	10 H _ H 800 -250 -14 -22 -18
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 _o = 471700 cm ⁴ (original condition) I = 405662 cm ⁴ (after reduction by corrosion and section)
	EI = 200000 × 10 ³ × 405662 × 10 ⁻⁸ = 8.113 × 10 ⁵

$$\begin{aligned} \beta &= \sqrt[4]{\frac{K_s \cdot B}{4 E I}} \\ \phi_s &= \frac{\sqrt{(1+2 \beta h_o)^2+1}}{2 \beta h_o} \times \exp(-\tan^{-1} \frac{1}{1+2 \beta h_o}) \\ M_{\max} &= M_o \cdot \phi_s \\ l_s &= \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2 \beta h_o} \\ l_i &= \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_o}{\beta h_o} \\ M_{(x)} &= -\frac{P_o}{\beta} \times \exp^{-\beta x} (\beta h_o \cdot \cos \beta x + (1+\beta h_o) \sin \beta x) \end{aligned}$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _s = 6507 kN/m ³
calculated value	β = 0.21161 m ⁻¹
resultant earth force (lateral)	P _o = 195.16 kN/m

depth to acting position	H _i = 0.0 m
moment	M _o = 0.0 kN·m/m
depth to acting position	H _o = 0.00 m
Height from riverbed to top of coping	H = 5.69 m
Depth of Imaginary riverbed from riverbed	L _k = 0.00 m

Moment M_i by arbitrary load is as below
M_i = P₁·(H + L_k - H_i) + M_o = 0.00 kN·m
h_o, Height of acting position of P_o from imaginary riverbed

$$\begin{aligned} h_o &= \frac{M_o}{P_o} = \frac{\Sigma M + M_1}{\Sigma P + P_1} \\ &= \frac{379.59}{195.16} = 1.94 \text{ m} \end{aligned}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.16	1.16	0.42 15.45	0.24 8.96	0.24 4.92	1.28 44.07
2	1.16- 2.16	1.00	16.46 30.19	8.23 15.09	4.20 3.86	34.53 58.32
3	2.16- 3.16	1.00	30.19 43.92	15.09 21.96	3.20 2.86	48.25 62.88
4	3.16- 3.48	0.32	43.33 47.67	6.93 7.63	2.42 2.32	16.80 17.67
5	3.48- 4.16	0.68	47.67 50.09	16.21 17.03	1.98 1.76	32.15 29.92
6	4.16- 4.69	0.53	50.86 52.84	13.48 14.00	1.35 1.18	18.24 16.48
7	4.69- 5.16	0.47	53.40 55.32	12.55 13.00	0.84 0.69	10.58 8.93
8	5.16- 5.69	0.53	55.32 57.50	14.66 15.24	0.35 0.18	5.18 2.69
		ΣP =		200.31	ΣM =	407.96

Ps : active earth pressure + residual water pressure - passive earth pressure
P : load Ps 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 ₁ = 0.0 kN/m
depth to acting position	H _i = 0.00 m
moment	M _o = 0.0 kN·m/m
depth to acting position	H _o = 0.00 m
Height from riverbed to top of coping	H = 5.69 m
Depth of Imaginary riverbed from riverbed	L _k = 0.00 m

Moment M_i by arbitrary load is as below
M_i = P₁·(H + L_k - H_i) + M_o = 0.00 kN·m

height of acting position of load	h _o = 1.94 m
moment	M _o = 379.59 kN·m/m

in consideration of ψ_{sa} = 1.530,
maximum moment M_{max} = 580.62 kN·m/m
depth of generated position of M_{max} l_m = 2.371 m
depth of 1st fixed point l_i = 6.082 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _s = 11247 kN/m ³
calculated value	β = 0.24263 m ⁻¹
resultant earth force (lateral)	P _o = 205.54 kN/m
height of acting position of load	h _o = 2.01 m
moment	M _o = 412.19 kN·m/m

in consideration of ψ_{sa} = 1.422,
maximum moment M_{max} = 586.15 kN·m/m
depth of generated position of M_{max} l_m = 1.933 m
depth of 1st fixed point l_i = 5.170 m

6.3 Stress Intensity

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

Material Name	10 H _ H 800 -250 -14 -22 -18
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 _o = 8240 cm ³ (original condition) Z = 7251 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{580.62 \times 10^6}{7251 \times 10^3} = 80 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{586.15 \times 10^6}{7251 \times 10^3} = 81 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

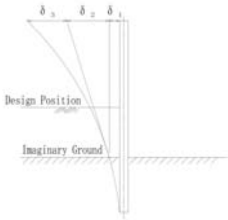
Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.16	5.30 4.92	0.932 0.864	0.299 0.266	0.11 8.14	0.032 2.165
2	1.16- 2.16	4.30 3.86	0.738 0.679	0.205 0.178	7.37 13.63	1.512 2.430
3	2.16- 3.16	3.20 2.86	0.562 0.503	0.128 0.105	13.63 19.88	1.748 2.095

4	3.16- 3.96	2.26 2.00	0.398 0.351	0.069 0.054	15.74 19.70	1.080 1.071
5	3.96- 4.16	1.66 1.60	0.292 0.281	0.039 0.036	4.93 4.97	0.190 0.177
6	4.16- 4.69	1.35 1.18	0.238 0.207	0.026 0.020	13.32 13.67	0.347 0.272
7	4.69- 5.16	0.84 0.69	0.148 0.121	0.010 0.007	13.63 14.09	0.142 0.098
8	5.16- 5.69	0.35 0.18	0.062 0.031	0.002 0.000	15.89 16.46	0.030 0.008
$\Sigma Q =$						13.398

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

Displacement Calculation



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

$$= \frac{(1+0.2116 \times 1.94) \times 195.16}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.2116^3} = 0.01792 \text{ m}$$

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

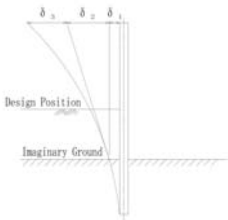
$$= \frac{(1+2 \times 0.2116 \times 1.94) \times 195.16}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.2116^2} \times (5.69+0.00) = 0.02786 \text{ m}$$

$$\delta_3 = \frac{Q \times (H+L_k)^2}{E I}$$

$$= \frac{13.40 \times (5.69+0.00)^3}{2.00 \times 10^8 \times 405662 \times 10^{-8}} = 0.00304 \text{ m}$$

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

$$= 0.01792 + 0.02786 + 0.00304$$



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

$$= \frac{(1+0.2426 \times 2.01) \times 205.54}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.2426^3} = 0.01318 \text{ m}$$

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

$$= \frac{(1+2 \times 0.2426 \times 2.01) \times 205.54}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.2426^2} \times (5.69+0.00) = 0.02416 \text{ m}$$

$$\delta_3 = \frac{Q \times (H+L_k)^2}{E I}$$

$$= \frac{14.72 \times (5.69+0.00)^3}{2.00 \times 10^8 \times 405662 \times 10^{-8}} = 0.00334 \text{ m}$$

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

$$= 0.01318 + 0.02416 + 0.00334$$

$$= 0.04068 \text{ m}$$

$$\text{Size} = 40.68 \leq \delta a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	10 H ₈ H 800-250-14-22-18
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 = 471700 cm ⁴ (original condition)
	I = 471700 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 471700 × 10 ⁻⁸	= 9.434 × 10 ⁵

$$= 0.04882 \text{ m}$$

$$\text{Size} = 48.82 \leq \delta a = 50.00 \text{ mm}$$

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

No	Depth, m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.16	5.30 4.92	0.932 0.864	0.299 0.266	0.24 8.96	0.072 2.382
2	1.16- 2.16	4.20 3.86	0.738 0.679	0.205 0.178	9.23 15.09	1.688 2.692
3	2.16- 3.16	3.20 2.86	0.562 0.503	0.128 0.105	15.09 21.96	1.936 2.314
4	3.16- 3.48	2.42 2.32	0.426 0.407	0.078 0.072	6.93 7.63	0.540 0.546
5	3.48- 4.16	1.98 1.76	0.349 0.309	0.054 0.043	16.21 17.03	0.870 0.728
6	4.16- 4.69	1.35 1.18	0.228 0.207	0.026 0.020	13.48 14.00	0.351 0.279
7	4.69- 5.16	0.84 0.69	0.148 0.121	0.010 0.007	12.55 13.00	0.131 0.091
8	5.16- 5.69	0.35 0.18	0.062 0.031	0.002 0.000	14.66 15.24	0.028 0.007
$\Sigma Q =$						14.655

Y : Height from imaginary riverbed to acting position
 $\alpha : \alpha = \frac{Y}{H+L_k}$
 $\zeta : \zeta = \frac{(3-\alpha) \times \alpha^2}{6}$
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	3.48- 4.48	1.88 1.54	0.330 0.271	0.048 0.033	0.00 1.30	0.000 0.044
2	4.48- 5.48	0.88 0.54	0.154 0.095	0.011 0.004	1.30 1.84	0.015 0.008
3	5.48- 5.69	0.14 0.07	0.025 0.012	0.000 0.000	0.39 0.41	0.000 0.000
$\Sigma Q_{dw} =$						0.066

Therefore, the deformation coefficient Q is expressed by
Q = 14.655 + 0.066 = 14.722

Displacement Calculation

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is L_k, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

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

$$L = H - H_{11} + D$$

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction
Calculated value $K_b = 6507 \text{ kN/m}^3$
 $\beta = 0.20378 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.204} = 14.72 \text{ m}$
Whole length of SSP $L = 5.69 - 0.40 + 14.72 = 20.01 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction
Calculated value $K_b = 11247 \text{ kN/m}^3$
 $\beta = 0.23365 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.234} = 12.84 \text{ m}$
Whole length of SSP $L = 5.69 - 0.40 + 12.84 = 18.13 \text{ m}$

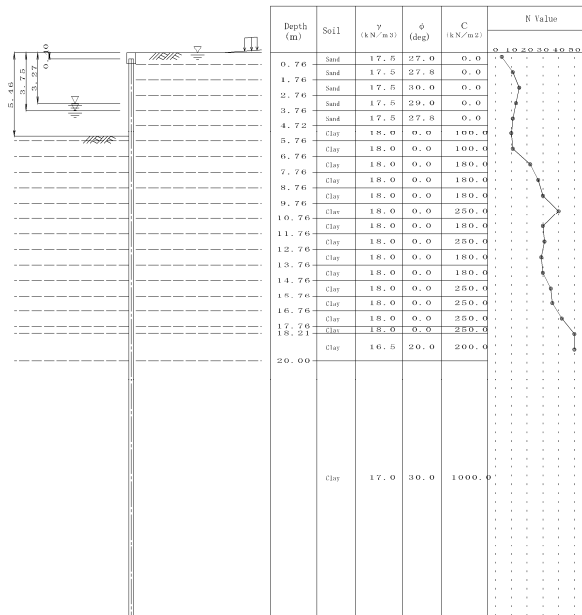
Therefore, the total length of the sheet pile is 20.50 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H ₈ H 800-250-14-22-18			
				Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	471700			
Sectional Modulus	Z (cm ³)	8240			
Maximum bending moment	M _{max} (kN × m)			580.62	586.15
Stress intensity	σ (N/mm ²)			80 (180)	81 (270)
Lateral displacement	δ (mm)			48.82 (50.0)	40.68 (75.0)
Penetration depth	D (m)			14.72	12.84
Whole length of SSP	L (m)	20.50			

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	= 5.46 m
Depth from coping top to rear side ground	H ₀	= 0.00 m
Depth from coping top to SSP top	H _b	= 0.40 m
Landside WL	L _{wa}	= 0.00 m (Normal Condition)
	L _{wa'}	= 0.00 m (Seismic Condition)
Riverside WL	L _{wp}	= 3.75 m (Normal Condition)
	L _{wp'}	= 3.27 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$
Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered
Wind load, Impact load	not considered
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope	not considered
Angle of rupture (clayey soil)	$\zeta = \tan^{-1} \left(1 - \frac{\sum \gamma h + 2Q}{2C} \right) \cdot \tan \theta$
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_h = K_{h0} \left(\frac{B_H}{0.3} \right)^{-3/4}$ $K_{h0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$ $B_H = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
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	0.26	4	11	10.26	40
2	1.26	11	12	11.26	30
3	2.26	15	13	12.26	31
4	3.26	13	14	13.26	29
5	4.26	11	15	14.26	30
6	5.26	10	16	15.26	35
7	6.26	11	17	16.26	36
8	7.26	22	18	17.26	42
9	8.26	27	19	18.26	50
10	9.26	30	20	19.26	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

Soil Modulus									
No	Depth m (include Projection Length)	Thickness m (excluding projected length)							
1	0.76	0.76							
2	1.76	1.00							
3	2.76	1.00							
4	3.76	1.00							
5	4.72	0.96							
6	5.76	1.04							
7	6.76	1.00							
8	7.76	1.00							
9	8.76	1.00							
10	9.76	1.00							
11	10.76	1.00							
12	11.76	1.00							
13	12.76	1.00							
14	13.76	1.00							
15	14.76	1.00							
16	15.76	1.00							
17	16.76	1.00							
18	17.76	1.00							
19	18.21	0.45							
20	20.00	1.79							
21	35.20	15.20							

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.76	S	4.0	17.20	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	1.76	S	11.0	17.50	7.70	27.8	0.0	0.0	0.200	Auto	Auto
3	2.76	S	15.0	17.50	7.70	30.0	0.0	0.0	0.200	Auto	Auto
4	3.76	S	13.0	17.50	7.70	29.0	0.0	0.0	0.200	Auto	Auto
5	4.72	S	11.0	17.50	7.70	27.8	0.0	0.0	0.200	Auto	Auto
6	5.76	C	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
7	6.76	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
8	7.76	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
9	8.76	C	27.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto

C cohesive force of soil (kN/m²)

2.2.2 Coordinates of Collapse Line

No	Angle of Rotation ° degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	44.38	0.74	0.00	0.00	0.76	0.74
2	43.05	0.96	0.76	0.74	1.78	1.70
3	44.31	1.00	1.78	1.70	2.81	2.70
4	45.32	1.00	2.81	2.70	3.80	3.70
5	43.05	1.00	3.80	3.70	4.87	4.70
6	42.18	0.76	4.87	4.70	5.71	5.46

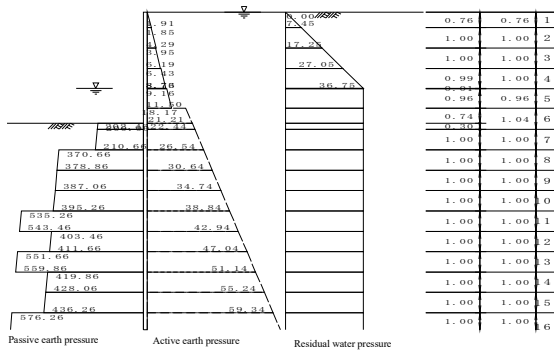
From the above table, the loading width (L) on the ground surface is 5.71 m.

2.2.3 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{0.00 + 0.00 + 0.00}{5.71}$$
$$= 0.00 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	K_p	$K_p \times \cos \delta$
8	5.46- 5.76	Clay	8.2	0.0	100.0	0.000	—	—
9	5.76- 6.76	Clay	8.2	0.0	100.0	2.460	—	—
10	6.76- 7.76	Clay	8.2	0.0	180.0	10.660	—	—
11	7.76- 8.76	Clay	8.2	0.0	180.0	18.860	—	—
12	8.76- 9.76	Clay	8.2	0.0	180.0	27.060	—	—
13	9.76- 10.76	Clay	8.2	0.0	250.0	35.260	—	—
14	10.76- 11.76	Clay	8.2	0.0	180.0	43.460	—	—
15	11.76- 12.76	Clay	8.2	0.0	250.0	51.660	—	—
16	12.76- 13.76	Clay	8.2	0.0	180.0	59.860	—	—
17	13.76- 14.76	Clay	8.2	0.0	180.0	68.060	—	—
18	14.76- 15.76	Clay	8.2	0.0	250.0	76.260	—	—
19	15.76- 16.76	Clay	8.2	0.0	250.0	84.460	—	—
20	16.76- 17.76	Clay	8.2	0.0	250.0	92.660	—	—
21	17.76- 18.21	Clay	8.2	0.0	250.0	100.860	—	—
22	18.21- 20.00	Clay	6.7	20.0	200.0	104.550	—	—
23	20.00- 35.20	Clay	7.2	30.0	1000.0	116.543	—	—

Coefficient of passive earth pressure of sandy soil K_p is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.1 Soil Modulus of Active Side

	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00- 0.76	Sand	7.7	27.0	—	0.000	0.33738	0.32589
2	0.76- 1.76	Sand	7.7	27.8	—	5.852	0.32749	0.31633
3	1.76- 2.76	Sand	7.7	30.0	—	13.552	0.30142	0.29115
4	2.76- 3.75	Sand	7.7	29.0	—	21.252	0.31307	0.30240
5	3.75- 3.76	Sand	7.7	29.0	—	28.875	0.31307	0.30240
6	3.76- 4.72	Sand	7.7	27.8	—	28.952	0.32749	0.31633
7	4.72- 5.46	Clay	8.2	—	100.0	36.344	—	—
8	5.46- 5.76	Clay	8.2	—	100.0	42.412	—	—
9	5.76- 6.76	Clay	8.2	—	100.0	44.872	—	—
10	6.76- 7.76	Clay	8.2	—	180.0	53.072	—	—
11	7.76- 8.76	Clay	8.2	—	180.0	61.272	—	—
12	8.76- 9.76	Clay	8.2	—	180.0	69.472	—	—
13	9.76- 10.76	Clay	8.2	—	250.0	77.672	—	—
14	10.76- 11.76	Clay	8.2	—	180.0	85.872	—	—
15	11.76- 12.76	Clay	8.2	—	250.0	94.072	—	—
16	12.76- 13.76	Clay	8.2	—	180.0	102.272	—	—
17	13.76- 14.76	Clay	8.2	—	180.0	110.472	—	—
18	14.76- 15.76	Clay	8.2	—	250.0	118.672	—	—
19	15.76- 16.76	Clay	8.2	—	250.0	126.872	—	—
20	16.76- 17.76	Clay	8.2	—	250.0	135.072	—	—
21	17.76- 18.21	Clay	8.2	—	250.0	143.272	—	—
22	18.21- 20.00	Clay	6.7	—	200.0	146.982	—	—
23	20.00- 35.20	Clay	7.2	—	1000.0	158.955	—	—

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive
		P_{a1} kN/m ²	P_{a2} kN/m ²	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	
1	0.00- 0.76	0.00	1.91	0.00	0.00	7.45	—
2	0.76- 1.76	1.85	4.29	1.85	4.29	17.25	—
3	1.76- 2.76	3.95	6.19	3.95	6.19	27.05	—
4	2.76- 3.75	6.43	8.73	6.43	8.73	27.05	—
5	3.75- 3.76	8.73	8.76	8.73	8.76	36.75	—
6	3.76- 4.72	9.16	11.50	9.16	11.50	36.75	—
7	4.72- 5.46	-163.66	-157.59	18.17	21.21	36.75	—
8	5.46- 5.76	-157.59	-155.13	21.21	22.44	36.75	200.00
9	5.76- 6.76	-155.13	-146.93	22.44	26.54	36.75	202.46
10	6.76- 7.76	-306.93	-298.73	26.54	30.64	36.75	370.66
11	7.76- 8.76	-298.73	-290.53	30.64	34.74	36.75	378.86
12	8.76- 9.76	-290.53	-282.33	34.74	38.84	36.75	387.06
13	9.76- 10.76	-422.33	-414.13	38.84	42.94	36.75	535.26
14	10.76- 11.76	-274.13	-265.93	42.94	47.04	36.75	543.46
15	11.76- 12.76	-405.93	-397.73	47.04	51.14	36.75	603.46
16	12.76- 13.76	-257.73	-249.53	51.14	55.24	36.75	559.86
17	13.76- 14.76	-249.53	-241.33	55.24	59.34	36.75	419.86
18	14.76- 15.76	-381.33	-373.13	59.34	63.44	36.75	428.06
19	15.76- 16.76	-373.13	-364.93	63.44	67.54	36.75	436.26
20	16.76- 17.76	-364.93	-356.73	67.54	71.64	36.75	576.26
21	17.76- 18.21	-356.73	-353.04	71.64	73.48	36.75	584.46
22	18.21- 20.00	-253.04	-241.05	73.48	79.48	36.75	600.86
23	20.00- 35.20	-1841.05	-1731.60	79.48	134.20	36.75	604.55

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

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

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

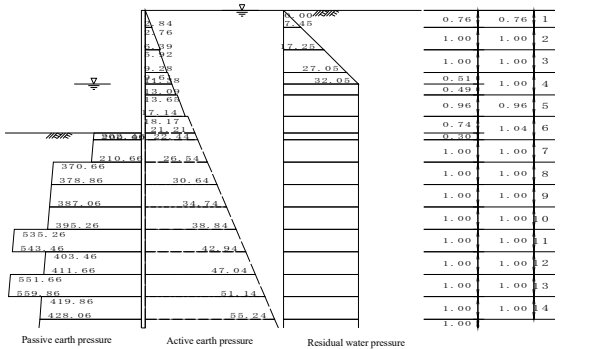
- Formula for passive earth pressure

Sand $P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_p = \sum \gamma h + Q + 2 C$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \beta$	ζ degree
1	0.00-0.76	Sand	7.7	27.0	—	0.00	0.200	11.31	0.50201	0.48490	0.48490	—
2	0.76-1.76	Sand	7.7	27.8	—	5.85	7.45	0.200	11.31	0.48814	0.47151	—
3	1.76-2.76	Sand	7.7	30.0	—	13.55	17.25	0.200	11.31	0.45203	0.43663	—
4	2.76-3.27	Sand	7.7	29.0	—	21.25	27.05	0.200	11.31	0.46809	0.45214	—
5	3.27-3.76	Sand	7.7	29.0	—	25.18	32.05	0.200	11.31	0.46809	0.45214	—

6	3.76-4.72	Sand	7.7	27.8	—	28.95	36.85	0.200	11.31	0.48814	0.47151	—
7	4.72-5.46	Clay	8.2	—	100.0	36.34	46.26	0.200	11.31	—	—	44.47
8	5.46-5.76	Clay	8.2	—	100.0	42.41	53.51	0.200	11.31	—	—	44.38
9	5.76-6.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.38
10	6.76-7.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.34
11	7.76-8.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.22
12	8.76-9.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.50
13	9.76-10.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.50
14	10.76-11.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.30
15	11.76-12.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.23
16	12.76-13.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.45
17	13.76-14.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.40
18	14.76-15.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.16
19	15.76-16.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.09
20	16.76-17.76	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.02
21	17.76-18.21	Clay	8.2	—	100.0	44.87	56.45	0.200	11.31	—	—	44.30
22	18.21-20.00	Clay	6.7	—	200.0	158.96	178.46	0.200	11.31	—	—	44.25
23	20.00-35.20	Clay	7.2	—	1000.0	158.96	196.00	0.200	11.31	—	—	44.25

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$\delta = 15.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

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

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q_p$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Kp	$K_p \times \cos \beta$
8	5.46-5.76	Clay	8.20	0.0	100.0	0.000	0.00	0.200	11.31	—	—
9	5.76-6.76	Clay	8.20	0.0	100.0	2.460	2.94	0.200	11.31	—	—
10	6.76-7.76	Clay	8.20	0.0	180.0	10.660	12.74	0.200	11.31	—	—
11	7.76-8.76	Clay	8.20	0.0	180.0	18.860	22.54	0.200	11.31	—	—
12	8.76-9.76	Clay	8.20	0.0	180.0	27.060	32.34	0.200	11.31	—	—
13	9.76-10.76	Clay	8.20	0.0	180.0	35.260	42.14	0.200	11.31	—	—
14	10.76-11.76	Clay	8.20	0.0	180.0	43.460	51.94	0.200	11.31	—	—
15	11.76-12.76	Clay	8.20	0.0	180.0	51.660	61.74	0.200	11.31	—	—
16	12.76-13.76	Clay	8.20	0.0	180.0	59.860	71.54	0.200	11.31	—	—
17	13.76-14.76	Clay	8.20	0.0	180.0	68.060	81.34	0.200	11.31	—	—
18	14.76-15.76	Clay	8.20	0.0	250.0	76.260	91.14	0.200	11.31	—	—
19	15.76-16.76	Clay	8.20	0.0	250.0	84.460	100.94	0.200	11.31	—	—
20	16.76-17.76	Clay	8.20	0.0	250.0	92.660	110.74	0.200	11.31	—	—
21	17.76-18.21	Clay	8.20	0.0	250.0	100.860	120.54	0.200	11.31	—	—
22	18.21-20.00	Clay	6.70	20.0	200.0	104.550	124.95	0.200	11.31	—	—
23	20.00-35.20	Clay	7.20	30.0	1000.0	116.543	142.49	0.200	11.31	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-0.76	0.00	—	0.00	0.00	—

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	3.27	0.00	0.00
2	4.27	1.00	2.54
3	5.27	2.00	3.59
4	5.46	2.19	3.76

$$p_{dw} = \pm \frac{7}{8} k_{10} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

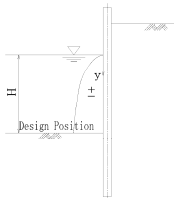
Where,

k_{10} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

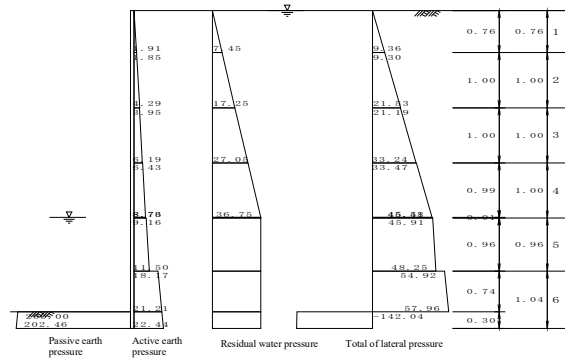
y : depth from water surface to the point where active water pressure is calculated



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



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Pt kN/m ²
1	0.00- 0.76	0.00 1.91	0.00 7.45	— —	0.00 9.36
2	0.76- 1.76	1.85 4.26	7.45 17.25	— —	9.30 21.53
3	1.76- 2.76	3.95 6.19	17.25 27.05	— —	21.19 33.24
4	2.76- 3.75	6.43 8.73	27.05 36.75	— —	33.47 45.48
5	3.75- 3.76	8.73 8.76	36.75 36.75	— —	45.48 45.51
6	3.76- 4.72	9.16 11.50	36.75 36.75	— —	45.91 48.25
7	4.72- 5.46	18.17 21.21	36.75 36.75	— —	54.92 57.96
8	5.46- 5.76	21.21 22.44	36.75 36.75	200.00 202.46	-142.04 -143.27

P_a : Active earth pressure

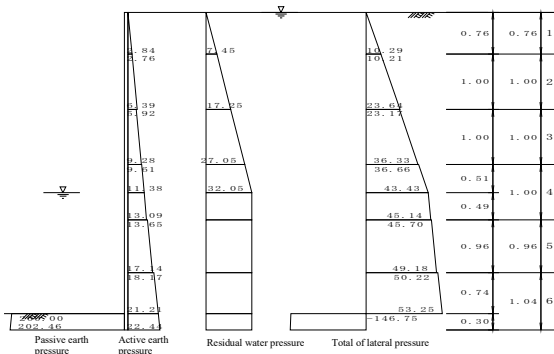
P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed Lk: 0.00 m (GL -5.46 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Pt kN/m ²
1	0.00- 0.76	0.00 2.84	0.00 7.45	— —	0.00 10.29
2	0.76- 1.76	2.76 6.39	7.45 17.25	— —	10.21 23.64
3	1.76- 2.76	5.92 9.28	17.25 27.05	— —	23.17 36.33
4	2.76- 3.27	9.61 11.38	27.05 32.05	— —	36.66 43.43
5	3.27- 3.76	11.38 13.09	32.05 32.05	— —	43.43 45.14
6	3.76- 4.72	13.65 17.14	32.05 32.05	— —	45.70 49.18
7	4.72- 5.46	18.17 21.21	32.05 32.05	— —	50.22 53.25
8	5.46- 5.76	21.21 22.44	32.05 32.05	200.00 202.46	-146.75 -147.98

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed Lk: 0.00 m (GL -5.46 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B=10.00\text{m})$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_b = 2800\text{N}'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H - H 600 -200 - 12-16-13
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 = 0.83
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 208200 cm ⁴ (original condition)
	I = 172806 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 172806 × 10 ⁻⁸ = 3.456 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.26	4	11	10.26	40
2	1.26	11	12	11.26	30
3	2.26	15	13	12.26	31
4	3.26	13	14	13.26	29
5	4.26	11	15	14.26	30
6	5.26	10	16	15.26	35
7	6.26	11	17	16.26	36
8	7.26	22	18	17.26	42
9	8.26	27	19	18.26	50
10	9.26	30	20	19.26	50

5.2 Normal Condition

Assuming $K_h = 12773 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.310 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.23 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.46 m) to 3.23 m depth (GL -8.69 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.46	0.80	10.2	11.0	8.48
2	6.26	1.00	11.0	22.0	16.50
3	7.26	1.00	22.0	27.0	24.50
4	8.26	0.63	27.0	28.3	11.76
L = Σ h = 3.23			Σ A = 61.24		

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

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{61.24}{3.23} = 18.99$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 18.99 = 53160 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 53160 = 177201 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10}(B/0.3)^{-3/4} = 177201(10.00/0.3)^{-3/4} = 12773 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 12773 kN/m³.

5.3 Seismic Condition

Assuming Kh = 23624 kN/m³,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.362 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.77 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.46 m) and 2.77 m depth (GL -8.23 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.46	0.80	10.2	11.0	8.48
2	6.26	1.00	11.0	22.0	16.50
3	7.26	0.97	22.0	26.8	23.58
L = Σ h = 2.77			Σ A = 48.56		

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

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

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{ia} = 0.00 \text{ kN} \cdot \text{m}$$

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{323.67}{172.68} = 1.87 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.76	0.76	0.00 10.29	0.00 3.91	5.21 4.95	0.00 19.36
2	0.76- 1.76	1.00	10.21 23.64	5.10 11.82	4.37 4.03	22.29 47.67
3	1.76- 2.76	1.00	23.17 36.33	11.58 18.16	3.37 3.03	38.99 55.10
4	2.76- 3.27	0.51	36.66 43.43	9.35 11.07	2.53 2.36	23.65 26.14
5	3.27- 3.76	0.49	43.43 45.14	10.64 11.06	2.03 1.86	21.56 20.61
6	3.76- 4.72	0.96	45.70 49.18	21.93 23.61	1.38 1.06	30.27 25.02
7	4.72- 5.46	0.74	50.22 53.25	18.58 19.70	0.49 0.25	9.17 4.86
Σ P = 176.52			Σ M = 344.68			

P_i : active earth pressure + residual water pressure - passive earth pressure

P : load P_0 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

$$\begin{aligned} \text{Arbitrary load lateral load } P_i &= 0.0 \text{ kN/m} \\ \text{depth to acting position } H_i &= 0.00 \text{ m} \\ \text{moment } M_{ia} &= 0.0 \text{ kN} \cdot \text{m/m} \\ \text{depth to acting position } H_{ia} &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 5.46 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.00 \text{ m} \end{aligned}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{ia} = 0.00 \text{ kN} \cdot \text{m}$$

$$\begin{aligned} &= \frac{48.56}{2.77} \\ &= 17.56 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 17.56 = 49159 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 49159 = 327729 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10}(B/0.3)^{-3/4} = 327729(10.00/0.3)^{-3/4} = 23624 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 23624 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.76	0.76	0.00 9.36	0.00 3.55	5.21 4.95	0.00 17.61
2	0.76- 1.76	1.00	9.30 21.53	4.65 10.77	4.37 4.03	20.30 43.43
3	1.76- 2.76	1.00	21.19 33.24	10.60 16.62	3.37 3.03	35.68 50.41
4	2.76- 3.72	0.99	33.47 45.48	16.57 22.51	2.37 2.04	39.27 45.93
5	3.72- 3.76	0.01	45.48 45.51	0.23 0.23	1.71 1.70	0.39 0.39
6	3.76- 4.72	0.96	45.91 48.25	22.04 23.16	1.38 1.06	30.41 24.55
7	4.72- 5.46	0.74	54.02 57.96	20.32 21.44	0.49 0.25	10.03 5.29
Σ P = 172.68			Σ M = 323.67			

P_i : active earth pressure + residual water pressure - passive earth pressure

P : load P_0 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

$$\begin{aligned} \text{Arbitrary load lateral load } P_i &= 0.0 \text{ kN/m} \\ \text{depth to acting position } H_i &= 0.0 \text{ m} \\ \text{moment } M_{ia} &= 0.0 \text{ kN} \cdot \text{m/m} \\ \text{depth to acting position } H_{ia} &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 5.46 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.00 \text{ m} \end{aligned}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p_{dw} kN/m ²	Loads P_{dw} kN	Arm length Y m	Moment M_{dw} kN · m
1	3.27- 4.27	1.00	0.0 2.5	0.00 1.27	1.86 1.52	0.00 1.93
2	4.27- 5.27	1.00	2.5 3.6	1.27 1.79	0.86 0.52	1.09 0.94
3	5.27- 5.46	0.19	3.6 3.8	0.34 0.36	0.13 0.06	0.04 0.02
Σ P_{dw} = 5.03			Σ M_{dw} = 4.03			

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i + \Sigma P_{dw}} = \frac{348.71}{181.55} = 1.92 \text{ m}$$

6.2 Sectional Force

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

$$\begin{aligned} \text{Material name } 10 \text{ H } &= \text{H 600-200-12-16-13} \\ \text{Unit width } B &= 1.0000 \text{ m} \\ \text{Corrosion margin } t_1 &= 1.00 \text{ mm (active side)} \quad t_2 = 1.00 \text{ mm (passive side)} \\ \text{Corrosion rate } \eta &= 0.83 \\ \text{Section efficiency } \mu &= 1.00 \\ \text{Young's modulus } E &= 200000 \text{ N/mm}^2 \\ \text{Inertia sectional moment } I_0 &= 208200 \text{ cm}^4 \text{ (original condition)} \\ &= 172806 \text{ cm}^4 \text{ (after reduction by corrosion and section)} \\ EI &= 200000 \times 10^3 \times 172806 \times 10^{-8} \\ &= 3.456 \times 10^7 \end{aligned}$$

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

$$M_{ia} = M_0 \cdot \phi_a$$

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

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

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

6.2.1 Normal Condition

$$\begin{aligned} \text{modulus of lateral subgrade reaction } K_b &= 12773 \text{ kN/m}^3 \\ \text{calculated value } \beta &= 0.31004 \text{ m}^{-1} \\ \text{resultant earth force (lateral) } P_0 &= 172.68 \text{ kN/m} \end{aligned}$$

height of acting position of load	h_0	=	1.87	m
moment	M_0	=	323.67	kN·m/m
in consideration of $\psi_{lm} = 1.329$, maximum moment	M_{max}	=	430.20	kN·m/m
depth of generated position of M_{max}	l_m	=	1.397	m
depth of 1 st fixed point	l_i	=	3.930	m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_s	=	23624	kN/m ³
calculated value	β	=	0.36156	m ³
resultant earth force (lateral)	P_0	=	181.55	kN/m
height of acting position of load	h_0	=	1.92	m
moment	M_0	=	348.71	kN·m/m
in consideration of $\psi_{lm} = 1.254$, maximum moment	M_{max}	=	437.40	kN·m/m
depth of generated position of M_{max}	l_m	=	1.096	m
depth of 1 st fixed point	l_i	=	3.269	m

6.3 Stress Intensity

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

Material Name	10 H - H 600 -200 - 12-16-13			
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	=	4270 cm ³ (original condition)	
	Z	=	3630 cm ³ (after reduction by corrosion and section)	

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{430.20 \times 10^6}{3630 \times 10^3} = 119 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{437.40 \times 10^6}{3630 \times 10^3} = 121 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.76	5.21 4.95	0.954 0.907	0.310 0.287	0.00 3.55	0.000 1.021
2	0.76~ 1.76	4.37 4.03	0.800 0.739	0.235 0.206	4.65 10.77	1.091 2.214
3	1.76~ 2.76	3.37 3.03	0.617 0.556	0.151 0.126	10.60 16.62	1.600 2.090

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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.76	5.21 4.95	0.954 0.907	0.310 0.287	0.00 3.91	0.000 1.122
2	0.76~ 1.76	4.37 4.03	0.800 0.739	0.235 0.206	5.10 11.82	1.197 2.431
3	1.76~ 2.76	3.37 3.03	0.617 0.556	0.151 0.126	11.58 18.16	1.749 2.284
4	2.76~ 3.27	2.53 2.36	0.463 0.432	0.091 0.080	9.35 11.07	0.849 0.885
5	3.27~ 3.78	2.03 1.86	0.371 0.341	0.060 0.052	10.64 11.06	0.642 0.571
6	3.78~ 4.72	1.38 1.06	0.253 0.194	0.029 0.018	21.93 23.61	0.642 0.416
7	4.72~ 5.46	0.49 0.25	0.090 0.045	0.004 0.001	18.58 19.70	0.074 0.020
$\Sigma Q =$						12.881

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	3.27~ 4.27	1.86 1.52	0.340 0.279	0.051 0.035	0.00 1.27	0.000 0.045
2	4.27~ 5.27	0.86 0.52	0.157 0.096	0.012 0.004	1.27 1.79	0.015 0.008
3	5.27~ 5.46	0.13 0.06	0.022 0.012	0.000 0.000	0.34 0.36	0.000 0.000
$\Sigma Q_{dw} =$						0.068

Therefore, the deformation coefficient Q is expressed by
Q = 12.881 + 0.068 = 12.949

Displacement Calculation

4	2.76~ 3.75	2.37 2.04	0.434 0.374	0.081 0.061	16.57 22.51	1.335 1.376
5	3.75~ 3.76	1.71 1.70	0.313 0.312	0.044 0.044	0.23 0.23	0.010 0.010
6	3.76~ 4.72	1.38 1.06	0.253 0.194	0.029 0.018	22.04 23.16	0.645 0.406
7	4.72~ 5.46	0.49 0.25	0.090 0.045	0.004 0.001	20.32 21.44	0.080 0.022
$\Sigma Q =$						11.900

Y : Height from imaginary riverbed to acting position

α : $\alpha = \frac{Y}{H+L_k}$

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

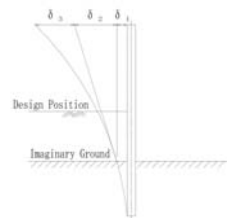
Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

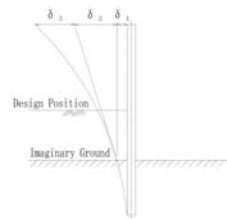
L_k : Depth from design position to imaginary ground

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3100 \times 1.87) \times 172.68}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.3100^3} = 0.01325 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3100 \times 1.87) \times 172.68}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.3100^2} \times (5.46 + 0.00) = 0.03068 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\ &= \frac{11.90 \times (5.46 + 0.00)^3}{2.00 \times 10^8 \times 172806 \times 10^{-8}} = 0.00560 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01325 + 0.03068 + 0.00560 \\ &= 0.04954 \text{ m} \\ \text{Size} &= 49.54 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3616 \times 1.92) \times 181.55}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.3616^3} = 0.00942 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3616 \times 1.92) \times 181.55}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.3616^2} \times (5.46 + 0.00) = 0.02621 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\ &= \frac{12.95 \times (5.46 + 0.00)^3}{2.00 \times 10^8 \times 172806 \times 10^{-8}} = 0.00610 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00942 + 0.02621 + 0.00610 \\ &= 0.04172 \text{ m} \\ \text{Size} &= 41.72 \leq \delta_a = 75.00 \text{ mm} \end{aligned}$$

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:

Material Name	10 H - H 600 -200 - 12-16-13			
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	=	208200 cm ⁴ (original condition)	
	I	=	208200 cm ⁴ (after reduction by corrosion and section)	
$EI = 200000 \times 10^3 \times 208200 \times 10^{-8}$				$= 4.164 \times 10^5$

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is Lk, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

D = Lk + 3/β
L = H - H1 + D
β = √(Kb · B / 4 E I)

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _b = 12773 kN/m ³
Calculated value	β = 0.29593 m ⁻¹
Penetration length of SSP	D = 0.00 + 3/0.296 = 10.14 m
Whole length of SSP	L = 5.46 - 0.40 + 10.14 = 15.20 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K _b = 23624 kN/m ³
Calculated value	β = 0.34510 m ⁻¹
Penetration length of SSP	D = 0.00 + 3/0.345 = 8.69 m
Whole length of SSP	L = 5.46 - 0.40 + 8.69 = 13.75 m

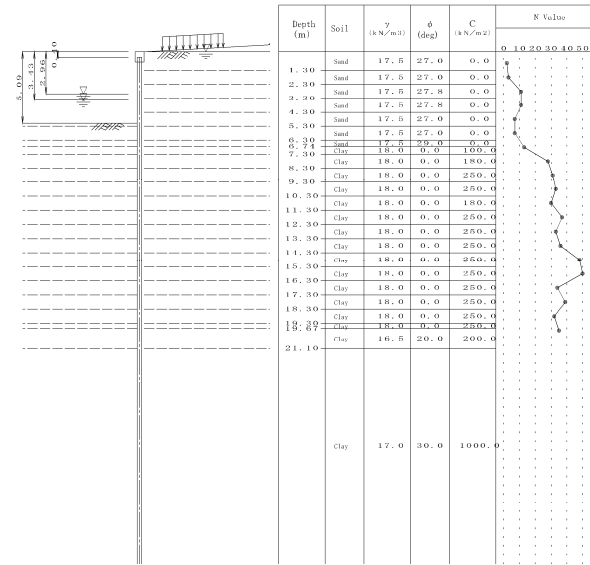
Therefore, the total length of the sheet pile is 15.50 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H _ H 600 -200 - 12-16-13		
Inertia sectional moment	I (cm ⁴)	208200	Normal Condition	Seismic Condition
Sectional Modulus	Z (cm ³)	4270		
Maximum bending moment	Mmax (kN · m · m)		430.20	437.40
Stress intensity	σ (N/mm ²)		119 (180)	121 (270)
Lateral displacement	δ (mm)		49.54 (50.0)	41.72 (75.0)
Penetration depth	D (m)		10.14	8.69
Whole length of SSP	L (m)	15.50		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 5.09 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} = 3.43 m (Normal Condition)
	L _{wp} = 2.96 m (Seismic Condition)

Block No. : L-27
Sta. : 11+800~12+040

Design Cross Section : Sta 11+940
Boring Name : BMLL-35

Specification : SSP SP-10H
(Combined) : H 750-250-14-22-18

1.3 Applied Formula
Formula for generated stress : Chang's formula
Penetration depths : $L = \frac{3}{\beta}$

1.4 Design Constant
Unit weight of water : $\gamma_w = 9.8 \text{ kN/m}^3$
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 : not considered
Wind load, Impact load : not considered
Minimum angle of rupture : $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope : not considered
Angle of rupture (clayey soil) : $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression : $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction
Applied formula : $K_b = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2)
 $B_H = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
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	0.80	2	11	10.80	30
2	1.80	3	12	11.80	37
3	2.80	11	13	12.80	33
4	3.80	11	14	13.80	36
5	4.80	7	15	14.80	48
6	5.80	7	16	15.80	50
7	6.80	13	17	16.80	34
8	7.80	28	18	17.80	39
9	8.80	31	19	18.80	32
10	9.80	33	20	19.80	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

Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.30	1.30
2	2.30	1.00
3	3.30	1.00
4	4.30	1.00
5	5.30	1.00
6	6.30	1.00
7	6.74	0.44
8	7.30	0.56
9	8.30	1.00
10	9.30	1.00
11	10.30	1.00
12	11.30	1.00
13	12.30	1.00
14	13.30	1.00
15	14.30	1.00
16	15.30	1.00
17	16.30	1.00
18	17.30	1.00
19	18.30	1.00
20	19.30	1.00
21	19.67	0.37
22	21.10	1.43
23	34.90	13.80

No	Depth m	earth Soil	N Value	γ	γ '	φ	C	a	k'	ζ (degree)	
			kN/m ³	kN/m ³	degree		kN/m ²			Normal Condition	Seismic Condition
1	1.30	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	2.30	S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	3.30	S	11.0	17.50	7.70	27.8	0.0	0.0	0.200	Auto	Auto
4	4.30	S	11.0	17.50	7.70	27.8	0.0	0.0	0.200	Auto	Auto
5	5.30	S	7.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	6.30	S	7.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
7	6.74	S	13.0	17.50	7.70	29.0	0.0	0.0	0.200	Auto	Auto

1	1.45	5.77	10.0	5.0

Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name 10 H₂ H 750 -250 -14 -22 -18
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 414700 cm⁴
Sectional factor Z₀ = 7640 cm³

Corrosion margin t₁ = 1.00 mm (riverside) t₂ = 1.00 mm (landside)

Corrosion rate (to I₀) η = 0.86
Corrosion rate (to Z₀) η = 0.88
Section efficiency (to I₀) μ = 1.00
Section efficiency (to Z₀) μ = 1.00

Round unit of SSP length 0.50 m

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

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

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I₀ applied to calculation of penetration depth
Reduced: I₀ applied to calculation of section forces and displacement
Reduced: Z₀ applied to calculation of stresses

1.10 Construction Time

Construction Time not considered

No	Depth m	earth Soil	N Value	γ	γ '	φ	C	a	k'	ζ (degree)	
			kN/m ³	kN/m ³	degree		kN/m ²			Normal Condition	Seismic Condition
8	7.30	C	13.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	8.30	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
10	9.30	C	31.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
11	10.30	C	33.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
12	11.30	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	12.30	C	37.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
14	13.30	C	33.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	14.30	C	36.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	15.30	C	48.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	16.30	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	17.30	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	18.30	C	39.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
20	19.30	C	32.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
21	19.67	C	35.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
22	21.10	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
23	34.90	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

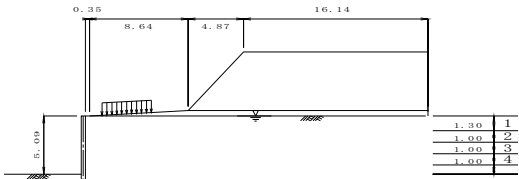
Note) depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
γ : wet unit weight of soil
γ ' : saturated unit weight of soil
φ : internal friction angle of soil

C_s : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

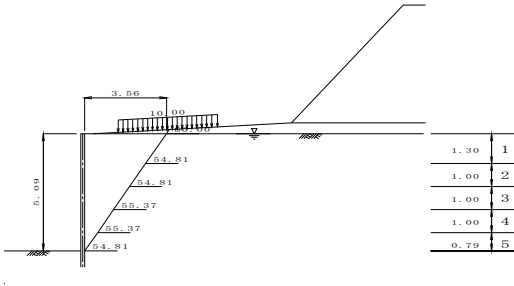
No	Soil	X Coordinate				Thickness	soil single weight γ	internal friction angle	stickiness	decay angle ζ		
		Bottom Left	Top Left	Top Right	Bottom Right					h	Normal Condition	Seismic Condition
		m	m	m	m	m	kN/m3	kN/m3	degree	kN/m2	degree	degree
1	Sand	0.35	8.99	30.00	30.00	0.48	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	8.99	13.86	30.00	30.00	5.13	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2

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	Σ γ h kN/m ²	Q kN/m ²	γ wh kN/m ²	Angle of Rupture ζ degree
1	5.09 ~ 4.30	Sand	27.0	15.0	0.0	39.19	7.80	49.88	54.81
2	4.30 ~ 3.30	Sand	27.8	15.0	0.0	33.11	7.80	42.14	55.37
3	3.30 ~ 2.30	Sand	27.8	15.0	0.0	25.41	7.80	32.34	55.37
4	2.30 ~ 1.30	Sand	27.0	15.0	0.0	17.71	7.80	22.54	54.81
5	1.30 ~ 0.00	Sand	27.0	15.0	0.0	10.01	7.80	12.74	54.81
6	embankment	t	30.0	—	0.0	106.59	0.00	0.00	60.00

• Angle of active rupture of sandy soil

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

• Angle of active rupture of clayey soil

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

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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.81	0.79	0.00	0.00	0.56	0.79
2	55.37	1.00	0.56	0.79	1.25	1.79
3	55.37	1.00	1.25	1.79	1.94	2.79
4	54.81	1.00	1.94	2.79	2.64	3.79
5	54.81	1.30	2.64	3.79	3.56	5.09
6	60.00	0.18	3.56	5.09	3.67	5.27

From the above table, the loading width (L) on the ground surface is 3.56 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.30	5.62
Σ			5.62

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 × l kN/m
1	10.0	2.22	22.17
Σ			22.17

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

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

$$= \frac{5.62 + 22.17 + 0.00}{3.56}$$

$$= 7.80 \text{ kN/m}^2$$

C : cohesive force of soil (kN/m²)

2.2.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	0.79	0.00	0.00	0.87	0.79
2	43.05	1.00	0.87	0.79	1.94	1.79
3	43.05	1.00	1.94	1.79	3.01	2.79
4	42.18	1.00	3.01	2.79	4.12	3.79
5	42.18	1.30	4.12	3.79	5.55	5.09
6	49.60	0.30	5.55	5.09	5.81	5.39

From the above table, the loading width (L) on the ground surface is 5.55 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.79	14.99
Σ			14.99

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 × l kN/m
1	5.0	4.32	21.60
Σ			21.60

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

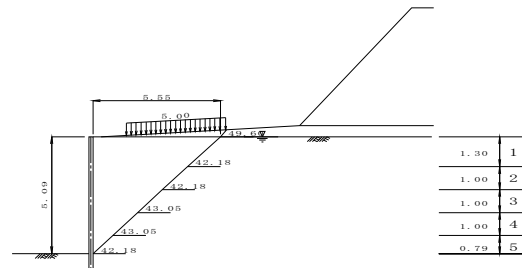
2.2.5 Calculated Load

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

$$= \frac{14.99 + 21.60 + 0.00}{5.55}$$

$$= 6.59 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ w h w kN/m ²	k (k)	θ degree	Angle of Rupture ζ degree
1	5.09 ~ 4.30	Sand	27.0	15.0	0.0	39.19	6.59	49.88	0.200	11.31	42.18
2	4.30 ~ 3.30	Sand	27.8	15.0	0.0	33.11	6.59	42.14	0.200	11.31	43.05
3	3.30 ~ 2.30	Sand	27.8	15.0	0.0	25.41	6.59	32.34	0.200	11.31	43.05
4	2.30 ~ 1.30	Sand	27.0	15.0	0.0	17.71	6.59	22.54	0.200	11.31	42.18
5	1.30 ~ 0.00	Sand	27.0	15.0	0.0	10.01	6.59	12.74	0.200	11.31	42.18
6		embankment	30.0	—	0.0	106.59	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

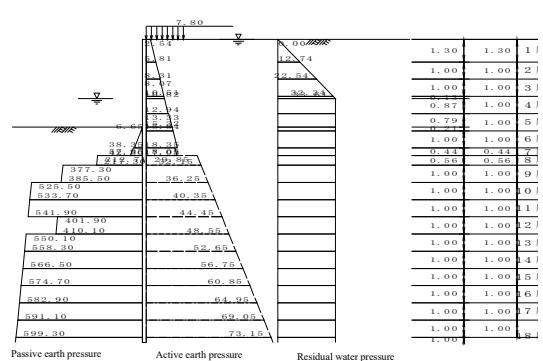
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

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⁻¹ k or θ = 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)

3 Lateral Forth

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	Σ γ h + Q _s kN/m ²	K _a	K _a × cos δ
1	0.00 ~ 1.30	Sand	7.7	—	7.805 17.815	0.33738 0.33738	0.32589 0.32589
2	1.30 ~ 2.30	Sand	7.7	—	17.815 25.515	0.33738 0.33738	0.32589 0.32589
3	2.30 ~ 3.30	Sand	7.7	—	25.515 33.215	0.32749 0.32749	0.31633 0.31633
4	3.30 ~ 3.43	Sand	7.7	—	33.215 34.216	0.32749 0.32749	0.31633 0.31633
5	3.43 ~ 4.30	Sand	7.7	—	34.216 40.915	0.32749 0.32749	0.31633 0.31633
6	4.30 ~ 5.09	Sand	7.7	—	40.915 46.998	0.33738 0.33738	0.32589 0.32589
7	5.09 ~ 5.30	Sand	7.7	—	46.998 48.615	0.33738 0.33738	0.32589 0.32589
8	5.30 ~ 6.30	Sand	7.7	—	48.615 56.315	0.33738 0.33738	0.32589 0.32589
9	6.30 ~ 6.74	Sand	7.7	—	56.315 59.703	0.31307 0.31307	0.30240 0.30240
10	6.74 ~ 7.30	Clay	8.2	—	100.0 100.0	— —	— —
11	7.30 ~ 8.30	Clay	8.2	—	180.0 180.0	— —	— —
12	8.30 ~ 9.30	Clay	8.2	—	250.0 250.0	— —	— —

13	9.30-10.30	Clay	8.2	—	250.0 250.0	80.695 88.895	—	—
14	10.20-11.30	Clay	8.2	—	180.0 180.0	88.895 97.095	—	—
15	11.20-12.30	Clay	8.2	—	250.0 250.0	97.095 105.295	—	—
16	12.20-13.30	Clay	8.2	—	250.0 250.0	105.295 113.495	—	—
17	13.20-14.30	Clay	8.2	—	250.0 250.0	113.495 121.695	—	—
18	14.20-15.30	Clay	8.2	—	250.0 250.0	121.695 129.895	—	—
19	15.20-16.30	Clay	8.2	—	250.0 250.0	129.895 138.095	—	—
20	16.20-17.30	Clay	8.2	—	250.0 250.0	138.095 146.295	—	—
21	17.20-18.30	Clay	8.2	—	250.0 250.0	146.295 154.495	—	—
22	18.20-19.30	Clay	8.2	—	250.0 250.0	154.495 162.695	—	—
23	19.20-19.67	Clay	8.2	—	250.0 250.0	162.695 165.729	—	—
24	19.67-21.10	Clay	6.7	—	200.0 200.0	165.729 175.310	—	—
25	21.10-34.90	Clay	7.2	—	1000.0 1000.0	175.310 274.670	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	Kp	$K_p \times \cos \delta$
7	5.09-5.30	Sand	7.7	27.0	—	0.000 1.617	4.26800 4.26800	4.11561 4.11561
8	5.30-6.30	Sand	7.7	27.0	—	1.617 9.317	4.26800 4.26800	4.11561 4.11561
9	6.30-6.74	Sand	7.7	29.0	—	9.317 12.705	4.72202 4.72202	4.56112 4.56112
10	6.74-7.30	Clay	8.2	0.0	100.0 100.0	12.705 17.297	—	—
11	7.30-8.30	Clay	8.2	0.0	180.0 180.0	17.297 25.497	—	—
12	8.30-9.30	Clay	8.2	0.0	250.0 250.0	25.497 33.697	—	—
13	9.30-10.30	Clay	8.2	0.0	250.0 250.0	33.697 41.897	—	—
14	10.30-11.30	Clay	8.2	0.0	180.0 180.0	41.897 50.097	—	—

10	6.74-7.30	-140.30 -135.71	29.85 32.15	29.85 32.15	33.61 33.61	212.71 217.30
11	7.30-8.30	-295.71 -287.51	32.15 36.25	32.15 36.25	33.61 33.61	377.30 385.50
12	8.30-9.30	-427.51 -419.31	36.25 40.35	36.25 40.35	33.61 33.61	525.50 533.70
13	9.30-10.30	-419.31 -411.11	40.35 44.45	40.35 44.45	33.61 33.61	533.70 541.90
14	10.30-11.30	-271.11 -262.91	44.45 48.55	44.45 48.55	33.61 33.61	401.90 410.10
15	11.30-12.30	-402.91 -394.71	48.55 52.65	48.55 52.65	33.61 33.61	550.10 558.30
16	12.30-13.30	-394.71 -386.51	52.65 56.75	52.65 56.75	33.61 33.61	558.30 566.50
17	13.30-14.30	-386.51 -378.31	56.75 60.85	56.75 60.85	33.61 33.61	566.50 574.70
18	14.30-15.30	-378.31 -370.11	60.85 64.95	60.85 64.95	33.61 33.61	574.70 582.90
19	15.30-16.30	-370.11 -361.91	64.95 69.05	64.95 69.05	33.61 33.61	582.90 591.10
20	16.30-17.30	-361.91 -353.71	69.05 73.15	69.05 73.15	33.61 33.61	591.10 599.30
21	17.30-18.30	-353.71 -345.51	73.15 77.25	73.15 77.25	33.61 33.61	599.30 607.50
22	18.30-19.30	-345.51 -337.31	77.25 81.35	77.25 81.35	33.61 33.61	607.50 615.70
23	19.30-19.67	-337.31 -334.27	81.35 82.86	81.35 82.86	33.61 33.61	615.70 618.73
24	19.67-21.10	-234.27 -228.69	82.86 87.65	82.86 87.65	33.61 33.61	518.73 528.31
25	21.10-34.90	-1824.69 -1725.33	87.65 137.33	87.65 137.33	33.61 33.61	2128.31 2227.67

- Formula for active earth pressure

$$\begin{aligned} \text{Sand} \quad P_{a1} &= K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_{a1} &= \Sigma \gamma h + Q - 2C \\ P_{a2} &= K_a \cdot (\Sigma \gamma h + Q) \\ K_a &: \text{Equilibrium coefficient of compression: 0.5} \\ &\text{Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)} \end{aligned}$$

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

- Formula for passive earth pressure

$$\begin{aligned} \text{Sand} \quad P_p &= K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_p &= \Sigma \gamma h + Q + 2C \\ \text{Mixed soil} \quad P_p &= [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta \end{aligned}$$

15	11.30-12.30	Clay	8.2	0.0	250.0 250.0	50.097 58.297	—	—
16	12.20-13.30	Clay	8.2	0.0	250.0 250.0	58.297 66.497	—	—
17	13.20-14.30	Clay	8.2	0.0	250.0 250.0	66.497 74.697	—	—
18	14.20-15.30	Clay	8.2	0.0	250.0 250.0	74.697 82.897	—	—
19	15.20-16.30	Clay	8.2	0.0	250.0 250.0	82.897 91.097	—	—
20	16.20-17.30	Clay	8.2	0.0	250.0 250.0	91.097 99.297	—	—
21	17.20-18.30	Clay	8.2	0.0	250.0 250.0	99.297 107.497	—	—
22	18.20-19.30	Clay	8.2	0.0	250.0 250.0	107.497 115.697	—	—
23	19.20-19.67	Clay	8.2	0.0	250.0 250.0	115.697 118.731	—	—
24	19.67-21.10	Clay	6.7	20.0	200.0 200.0	118.731 128.312	—	—
25	21.10-34.90	Clay	7.2	30.0	1000.0 1000.0	128.312 227.672	—	—

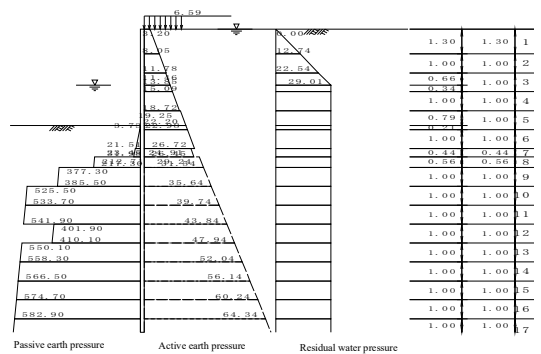
Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pv kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-1.30	2.54 5.81	—	5.81	2.54 12.74	0.00 —
2	1.30-2.30	5.81 8.31	—	8.31	12.74 22.54	—
3	2.30-3.30	8.07 10.51	—	8.07 10.51	22.54 32.34	—
4	3.30-3.43	10.51 10.82	—	10.51 10.82	32.34 33.61	—
5	3.43-4.30	10.82 12.94	—	10.82 12.94	33.61 —	—
6	4.30-5.09	13.33 15.32	—	13.33 15.32	33.61 —	—
7	5.09-5.30	15.32 15.84	—	15.32 15.84	33.61 6.65	0.00
8	5.30-6.30	15.84 18.35	—	15.84 18.35	33.61 38.35	6.65
9	6.30-6.74	17.03 18.05	—	17.03 18.05	33.61 —	42.50 57.95

3.2 Seismic Condition



The dotted line in the figure shows the main earth pressure strength Pa2 using the consolidation equilibrium coefficient.

3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k')	θ degree	Ka	$K_a \times \cos \delta$	ζ degree
1	0.00-1.30	Sand	7.7	27.0	—	6.59 16.60	0.00 12.74	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
2	1.30-2.30	Sand	7.7	27.0	—	16.60 24.30	12.74 22.54	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
3	2.30-2.96	Sand	7.7	27.8	—	24.30 29.38	22.54 29.01	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	—
4	2.96-3.30	Sand	7.7	27.8	—	29.38 32.00	29.01 32.34	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	—
5	3.30-4.30	Sand	7.7	27.8	—	32.00 39.70	32.34 42.14	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	—
6	4.30-5.09	Sand	7.7	27.0	—	39.70 45.78	42.14 49.88	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
7	5.09-5.30	Sand	7.7	27.0	—	45.78 47.40	49.88 51.94	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
8	5.30-6.30	Sand	7.7	27.0	—	47.40 55.10	51.94 61.74	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
9	6.30-6.74	Sand	7.7	29.0	—	55.10 58.49	61.74 66.05	0.200 0.200	11.31 11.31	0.46089 0.46089	0.45214 0.45214	—
10	6.74-7.30	Clay	8.2	—	100.0 100.0	58.49 71.54	66.05 71.54	0.200 0.200	11.31 11.31	—	—	44.04 43.97
11	7.30-8.30	Clay	8.2	—	180.0 180.0	63.08 71.28	71.54 81.34	0.200 0.200	11.31 11.31	—	—	44.41 44.37
12	8.30-9.30	Clay	8.2	—	250.0 250.0	71.28 79.48	81.34 91.14	0.200 0.200	11.31 11.31	—	—	44.55 44.50

13	9.30-10.30	Clay	8.2	—	250.0	79.48 87.68	91.14 100.94	0.200	11.31	—	—	44.50 44.45
14	10.30-11.30	Clay	8.2	—	180.0	87.68 100.0	100.94 110.74	0.200	11.31	—	—	44.25 44.16
15	11.30-12.30	Clay	8.2	—	250.0	95.88 250.0	110.74 120.54	0.200	11.31	—	—	44.40 44.30
16	12.30-13.30	Clay	8.2	—	250.0	104.08 250.0	120.54 130.34	0.200	11.31	—	—	44.35 44.30
17	13.30-14.30	Clay	8.2	—	250.0	112.28 250.0	130.34 140.14	0.200	11.31	—	—	44.30 44.25
18	14.30-15.30	Clay	8.2	—	250.0	120.48 250.0	140.14 149.94	0.200	11.31	—	—	44.25 44.20
19	15.30-16.30	Clay	8.2	—	250.0	128.68 250.0	149.94 159.74	0.200	11.31	—	—	44.20 44.15
20	16.30-17.30	Clay	8.2	—	250.0	136.88 250.0	159.74 169.54	0.200	11.31	—	—	44.15 44.10
21	17.30-18.30	Clay	8.2	—	250.0	145.08 250.0	169.54 179.34	0.200	11.31	—	—	44.10 44.05
22	18.30-19.30	Clay	8.2	—	250.0	153.28 250.0	179.34 189.14	0.200	11.31	—	—	44.05 44.00
23	19.30-19.67	Clay	8.2	—	250.0	161.48 250.0	189.14 197.77	0.200	11.31	—	—	44.00 43.98
24	19.67-21.10	Clay	6.7	—	200.0	164.52 200.0	192.77 206.78	0.200	11.31	—	—	43.72 43.64
25	21.10-34.90	Clay	7.2	—	1000.0	174.10 273.46	206.78 342.02	0.200	11.31	—	—	44.74 44.59

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.
 $\delta = 15.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

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

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	δ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ when kN/m ²	k (k ⁻¹)	θ degree	K _p	K _p $\times \cos \beta$
7	5.09-5.30	Sand	7.70	27.0	—	0.000 1.617	0.00 2.06	0.200	11.31	2.30874 2.30874	2.30874 2.30874
8	5.30-6.30	Sand	7.70	27.0	—	1.617 9.317	2.06 11.86	0.200	11.31	2.30874 2.30874	2.30874 2.30874
9	6.30-6.74	Sand	7.70	29.0	—	9.317 12.705	11.86 16.17	0.200	11.31	2.51705 2.51705	2.51705 2.51705
10	6.74-7.30	Clay	8.20	0.0	100.0 100.0	12.705 17.297	16.17 21.66	0.200	11.31	—	—

5	3.30-4.30	15.09 18.72	—	15.09 18.72	29.01 29.01	—
6	4.30-5.09	19.25 22.20	—	19.25 22.20	29.01 29.01	—
7	5.09-5.30	22.20 22.08	—	22.20 22.08	29.01 29.01	0.00 3.73
8	5.30-6.30	22.08 26.72	—	22.08 26.72	29.01 29.01	3.73 21.51
9	6.30-6.74	24.91 26.45	—	24.91 26.45	29.01 29.01	23.45 31.98
10	6.74-7.30	-129.53 -123.97	29.24 31.54	29.24 31.54	29.01 29.01	212.71 217.30
11	7.30-8.30	-284.12 -279.23	31.54 35.64	31.54 35.64	29.01 29.01	377.30 385.50
12	8.30-9.30	-414.30 -404.42	35.64 39.74	35.64 39.74	29.01 29.01	525.50 533.70
13	9.30-10.30	-404.42 -394.54	39.74 43.84	39.74 43.84	29.01 29.01	533.70 541.90
14	10.30-11.30	-254.44 -244.53	43.84 47.94	43.84 47.94	29.01 29.01	401.90 410.10
15	11.30-12.30	-384.65 -374.75	47.94 52.04	47.94 52.04	29.01 29.01	550.10 558.30
16	12.30-13.30	-374.75 -364.86	52.04 56.14	52.04 56.14	29.01 29.01	558.30 566.50
17	13.30-14.30	-364.86 -354.96	56.14 60.24	56.14 60.24	29.01 29.01	566.50 574.70
18	14.30-15.30	-354.96 -345.05	60.24 64.34	60.24 64.34	29.01 29.01	574.70 582.90
19	15.30-16.30	-345.05 -335.14	64.34 68.44	64.34 68.44	29.01 29.01	582.90 591.10
20	16.30-17.30	-335.14 -325.23	68.44 72.54	68.44 72.54	29.01 29.01	591.10 599.30
21	17.30-18.30	-325.23 -315.31	72.54 76.64	72.54 76.64	29.01 29.01	599.30 607.50
22	18.30-19.30	-315.31 -305.38	76.64 80.74	76.64 80.74	29.01 29.01	607.50 615.70
23	19.30-19.67	-305.38 -301.71	80.74 82.26	80.74 82.26	29.01 29.01	615.70 618.73
24	19.67-21.10	-301.48 -189.85	82.26 87.05	82.26 87.05	29.01 29.01	618.73 528.31
25	21.10-34.90	-1790.85 -1671.27	87.05 136.73	87.05 136.73	29.01 29.01	2128.31 2227.67

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
 Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

11	7.30-8.30	Clay	8.20	0.0	180.0 180.0	17.297 25.497	21.66 31.46	0.200 0.200	11.31 11.31	—	—
12	8.30-9.30	Clay	8.20	0.0	250.0 250.0	25.497 33.697	31.46 41.26	0.200 0.200	11.31 11.31	—	—
13	9.30-10.30	Clay	8.20	0.0	250.0 250.0	33.697 41.897	41.26 51.06	0.200 0.200	11.31 11.31	—	—
14	10.30-11.30	Clay	8.20	0.0	180.0 180.0	41.897 50.097	51.06 60.86	0.200 0.200	11.31 11.31	—	—
15	11.30-12.30	Clay	8.20	0.0	250.0 250.0	50.097 58.297	60.86 70.66	0.200 0.200	11.31 11.31	—	—
16	12.30-13.30	Clay	8.20	0.0	250.0 250.0	58.297 66.497	70.66 80.46	0.200 0.200	11.31 11.31	—	—
17	13.30-14.30	Clay	8.20	0.0	250.0 250.0	66.497 74.697	80.46 90.26	0.200 0.200	11.31 11.31	—	—
18	14.30-15.30	Clay	8.20	0.0	250.0 250.0	74.697 82.897	90.26 100.06	0.200 0.200	11.31 11.31	—	—
19	15.30-16.30	Clay	8.20	0.0	250.0 250.0	82.897 91.097	100.06 109.86	0.200 0.200	11.31 11.31	—	—
20	16.30-17.30	Clay	8.20	0.0	250.0 250.0	91.097 99.297	109.86 119.66	0.200 0.200	11.31 11.31	—	—
21	17.30-18.30	Clay	8.20	0.0	250.0 250.0	99.297 107.497	119.66 129.46	0.200 0.200	11.31 11.31	—	—
22	18.30-19.30	Clay	8.20	0.0	250.0 250.0	107.497 115.697	129.46 139.26	0.200 0.200	11.31 11.31	—	—
23	19.30-19.67	Clay	8.20	0.0	250.0 250.0	115.697 118.731	139.26 142.88	0.200 0.200	11.31 11.31	—	—
24	19.67-21.10	Clay	6.70	20.0	200.0 200.0	118.731 128.312	142.88 156.90	0.200 0.200	11.31 11.31	—	—
25	21.10-34.90	Clay	7.20	30.0	1000.0 1000.0	128.312 227.672	156.90 292.14	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	P ₀ kN/m ²	P _w kN/m ²	P _p kN/m ²
1	0.00-1.30	3.20 8.05	—	3.20 8.05	0.00 12.74	—
2	1.30-2.30	8.05 11.78	—	8.05 11.78	12.74 22.54	—
3	2.30-2.96	—	—	—	22.54 29.01	—
4	2.96-3.30	—	—	—	—	—

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
 Clay $P_p = \Sigma \gamma h + Q + 2C$
 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	water level y, m	pdw kN/m ²
1	2.96	0.00	0.00
2	3.96	1.00	2.50
3	4.96	2.00	3.54
4	5.09	2.13	3.65

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

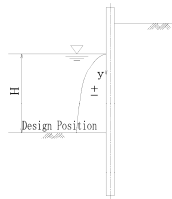
Where,

k_{hs} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

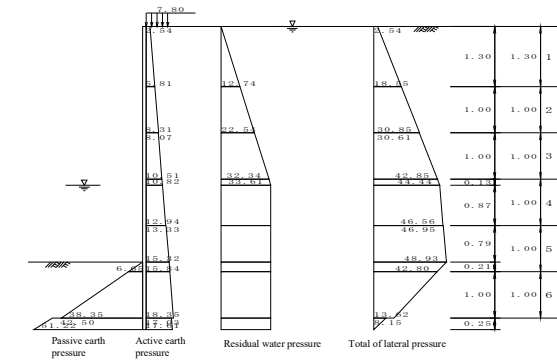
y : depth from water surface to the point where active water pressure is calculated



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

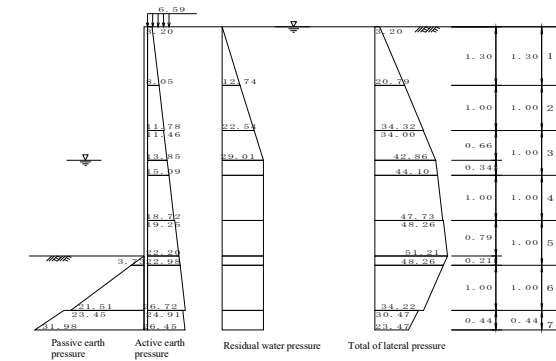


No	Depth m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00~ 1.30	2.24 5.81	0.00 12.74	——— ———	2.24 18.55
2	1.30~ 2.30	5.81 8.31	12.74 22.54	——— ———	18.55 30.85
3	2.30~ 3.30	8.07 10.51	22.54 32.34	——— ———	30.61 42.85
4	3.30~ 3.43	10.51 10.82	32.34 33.61	——— ———	42.85 44.44
5	3.43~ 4.30	10.82 12.94	33.61 33.61	——— ———	44.44 46.56
6	4.30~ 5.09	13.33 15.32	33.61 33.61	——— ———	46.95 48.93
7	5.09~ 5.30	15.32 15.84	33.61 33.61	0.00 6.65	48.93 42.80
8	5.30~ 6.30	15.84 18.35	33.61 33.61	6.65 38.35	42.80 13.62
9	6.30~ 6.55	17.03 17.61	33.61 33.61	42.50 51.22	8.15 0.00
10	6.55~ 6.74	17.61 18.05	33.61 33.61	51.22 57.95	0.00 -6.28

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 : 1.46 m (GL -6.55 m)

4.2 Seismic Condition



No	Depth m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00~ 1.30	3.20 8.05	0.00 12.74	——— ———	3.20 20.79
2	1.30~ 2.30	8.05 11.78	12.74 22.54	——— ———	20.79 34.32
3	2.30~ 2.96	11.46 13.85	22.54 29.01	——— ———	34.00 42.86
4	2.96~ 3.30	13.85 15.09	29.01 29.01	——— ———	42.86 44.10
5	3.30~ 4.30	15.09 18.72	29.01 29.01	——— ———	44.10 47.73
6	4.30~ 5.09	19.25 22.20	29.01 29.01	——— ———	48.26 51.21
7	5.09~ 5.30	22.20 22.98	29.01 29.01	0.00 3.73	51.21 48.26
8	5.30~ 6.30	22.98 26.72	29.01 29.01	3.73 21.51	48.26 34.22
9	6.30~ 6.74	24.91 26.45	29.01 29.01	23.45 31.98	30.47 23.47
10	6.74~ 7.30	29.24 31.54	29.01 29.01	212.71 217.30	-154.45 -156.75

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 : 1.65 m (GL -6.74 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_h = K_{h0} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H=10, 00m)$$
$$K_{h0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$E_0 = 2800 N'$$

where:

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

Material Name	10 H _H 750 -250 -14 -22 -18
Unit width	B = 1.0000 m
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 0.86$
Section efficiency	$\mu = 1.00$
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	$I_0 = 414700 \text{ cm}^4$ (original condition)
Inertia sectional moment	I = 356642 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	El = 200000 × 10 ³ × 356642 × 10 ⁻⁸ = 7.133 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.80	2	11	10.80	30
2	1.80	3	12	11.80	37
3	2.80	11	13	12.80	33
4	3.80	11	14	13.80	36
5	4.80	7	15	14.80	48
6	5.80	7	16	15.80	50
7	6.80	13	17	16.80	34
8	7.80	28	18	17.80	39
9	8.80	31	19	18.80	32
10	9.80	33	20	19.80	35

5.2 Normal Condition

Assuming $K_h = 17965 \text{ kN/m}^3$,

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4 E I}} = 0.282 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.55 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.55 m) to 3.55 m depth (GL -10.10 m).

5.3 Seismic Condition

Assuming $K_h = 36184 \text{ kN/m}^3$,

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4 E I}} = 0.336 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.98 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.74 m) and 2.98 m depth (GL -9.72 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.74	0.06	12.6	13.0	0.77
2	6.80	1.00	13.0	28.0	20.50
3	7.80	1.00	28.0	31.0	29.50
4	8.80	0.92	31.0	32.8	29.36
L = 2h = 2.98 Σ A = 80.13					

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

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

$$= \frac{80.13}{2.98}$$

$$= 26.89$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 26.89 = 75295 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 75295 = 501965 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_h = K_{10} (B_u / 0.3)^{-3/4} = 501965 (10.00 / 0.3)^{-3/4} = 36184 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 36184 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.30	1.30	2.54 18.55	1.65 12.05	6.12 5.68	10.11 68.49
2	1.30- 2.30	1.00	18.55 30.85	9.27 15.43	4.92 4.58	45.58 70.69
3	2.30- 3.30	1.00	30.61 42.85	15.31 21.42	3.92 3.58	59.92 76.73
4	3.30- 3.43	0.13	42.85 44.44	2.79 2.89	3.21 3.16	8.93 9.13
5	3.43- 4.30	0.87	44.44 46.56	19.33 20.25	2.83 2.54	54.68 51.41
6	4.30- 5.09	0.79	46.95 48.93	18.54 19.33	1.99 1.72	36.81 33.28
7	5.09- 5.30	0.21	48.93 42.80	5.14 4.49	1.39 1.32	7.13 5.93
8	5.30- 6.30	1.00	42.80 13.62	21.40 6.81	0.92 0.58	19.58 3.96
9	6.30- 6.55	0.25	8.15 0.00	1.01 0.00	0.17 0.00	0.17 0.00
			ΣP =	197.12	ΣM =	562.53

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_i = 0.0 kN/m

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	2.96- 3.96	1.00	0.0 2.5	0.00 1.25	3.45 3.11	0.00 3.90
2	3.96- 4.96	1.00	2.5 3.5	1.25 1.77	2.45 2.11	3.06 3.74
3	4.96- 5.09	0.13	3.5 3.7	0.23 0.24	1.74 1.69	0.40 0.40
			Σ P _{hw} =	4.74	Σ M _{hw} =	11.50

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{hw}}{\Sigma P + P_i + \Sigma P_{hw}}$$

$$= \frac{669.93}{236.79} = 2.83 \text{ m}$$

6.2 Sectional Force

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

Material name	10 H _ H 750 -250 -14 -22 -18
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 = 414700 cm ⁴ (original condition) I = 356642 cm ⁴ (after reduction by corrosion and section) = 7.133 × 10 ⁵

$$EI = 200000 \times 10^3 \times 356642 \times 10^{-8}$$

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

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

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

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

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

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

$$\begin{aligned} \text{depth to acting position} & H_i = 0.0 \text{ m} \\ \text{moment} & M_0 = 0.0 \text{ kN} \cdot \text{m/m} \\ \text{depth to acting position} & H_m = 0.00 \text{ m} \\ \text{Height from riverbed to top of coping} & H = 5.09 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed} & L_k = 0.00 \text{ m} \end{aligned}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_0 = 0.00 \text{ kN} \cdot \text{m}$$

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i}$$

$$= \frac{562.53}{197.12} = 2.85 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.30	1.30	3.20 20.79	2.08 13.51	6.31 5.87	13.10 79.37
2	1.30- 2.30	1.00	20.79 34.32	10.39 17.16	5.11 4.77	53.08 81.92
3	2.30- 2.96	0.66	34.00 42.86	11.22 14.14	4.22 4.00	47.35 56.58
4	2.96- 3.30	0.34	42.86 44.10	7.29 7.50	3.67 3.55	26.72 26.64
5	3.30- 4.30	1.00	44.10 47.73	22.05 23.86	3.11 2.77	68.50 66.18
6	4.30- 5.09	0.79	48.26 51.21	19.06 20.23	2.18 1.91	41.49 38.70
7	5.09- 5.30	0.21	51.21 48.26	5.38 5.07	1.58 1.51	8.50 7.65
8	5.30- 6.30	1.00	48.26 34.22	24.13 17.11	1.11 0.77	26.70 13.23
9	6.30- 6.74	0.44	30.47 23.47	6.70 5.16	0.29 0.15	1.97 0.76
			ΣP =	232.05	ΣM =	658.43

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_i = 0.0 kN/m
depth to acting position H_i = 0.00 m
moment M₀ = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 5.09 m
Depth of Imaginary riverbed from riverbed L_k = 1.65 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_0 = 0.00 \text{ kN} \cdot \text{m}$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction K_h = 17965 kN/m³
calculated value β = 0.28169 m⁻¹
resultant earth force (lateral) P₀ = 197.12 kN/m
height of acting position of load h₀ = 2.85 m
moment M₀ = 562.53 kN·m/m

in consideration of ψ₀ = 1.205,
maximum moment M_{max} = 677.57 kN·m/m
depth of generated position of M_{max} l_m = 1.300 m
depth of 1st fixed point l_i = 4.088 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction K_h = 36184 kN/m³
calculated value β = 0.33558 m⁻¹
resultant earth force (lateral) P₀ = 236.79 kN/m
height of acting position of load h₀ = 2.83 m
moment M₀ = 669.93 kN·m/m

in consideration of ψ₀ = 1.158,
maximum moment M_{max} = 776.09 kN·m/m
depth of generated position of M_{max} l_m = 0.990 m
depth of 1st fixed point l_i = 3.330 m

6.3 Stress Intensity

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

Material Name	10 H _ H 750 -250 -14 -22 -18
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 = 7640 cm ³ (original condition) Z = 6723 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{677.57 \times 10^6}{6723 \times 10^3} = 101 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{776.09 \times 10^6}{6723 \times 10^3} = 115 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

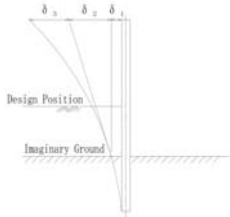
Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.30	6.12 5.68	0.934 0.868	0.300 0.208	1.65 12.05	0.496 3.225

2	1.30- 2.30	4.92 4.58	0.751 0.700	0.211 0.188	9.27 15.43	1.958 2.896
3	2.30- 3.30	3.92 3.58	0.598 0.547	0.143 0.122	15.31 21.42	2.190 2.620
4	3.30- 4.30	3.21 3.16	0.489 0.403	0.100 0.098	2.79 2.89	0.279 0.283
5	3.43- 4.30	2.83 2.54	0.432 0.388	0.080 0.065	19.33 20.25	1.544 1.325
6	4.30- 5.09	1.99 1.72	0.303 0.263	0.041 0.032	18.54 19.33	0.766 0.610
7	5.09- 5.30	1.39 1.32	0.212 0.201	0.021 0.019	5.14 4.49	0.107 0.085
8	5.30- 6.30	0.92 0.58	0.140 0.089	0.009 0.004	21.40 6.81	0.199 0.026
9	6.30- 6.55	0.17 0.08	0.025 0.013	0.000 0.000	1.01 0.00	0.000 0.000
Σ Q = 18.010						

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

Displacement Calculation



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

$$= \frac{(1+0.2817 \times 2.85) \times 197.12}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.2817^3} = 0.01115 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^3} \times (H+L_k)$$

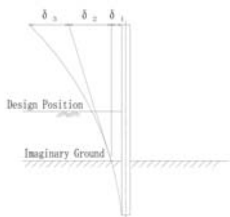
$$= \frac{(1+2 \times 0.2817 \times 2.85) \times 197.12}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.2817^3} \times (5.09+1.46) = 0.02974 \text{ m}$$

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

No	Depth m	Y m	α	ζ	Pdw kN	Qdw kN
1	2.96- 3.96	3.45 3.11	0.511 0.462	0.108 0.090	0.00 1.25	0.000 0.113
2	3.96- 4.96	2.45 2.11	0.363 0.314	0.058 0.044	1.25 1.77	0.072 0.078
3	4.96- 5.09	1.74 1.69	0.238 0.231	0.030 0.029	0.23 0.24	0.007 0.007
Σ Qdw = 0.277						

Therefore, the deformation coefficient Q is expressed by
Q = 21.291 + 0.277 = 21.568

Displacement Calculation



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

$$= \frac{(1+0.3356 \times 2.83) \times 236.79}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.3356^3} = 0.00856 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^3} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.3356 \times 2.83) \times 236.79}{2 \times 2.00 \times 10^8 \times 356642 \times 10^{-8} \times 0.3356^3} \times (5.09+1.65) = 0.02880 \text{ m}$$

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

$$= \frac{21.57 \times (5.09+1.65)^3}{2.00 \times 10^8 \times 356642 \times 10^{-8}} = 0.00926 \text{ m}$$

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

$$= 0.00856 + 0.02880 + 0.00926$$

$$= 0.04662 \text{ m}$$

$$\text{Size} = 46.62 \text{ mm} \leq \delta_a = 75.00 \text{ mm}$$

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

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

$$= \frac{18.61 \times (5.09+1.46)^3}{2.00 \times 10^8 \times 356642 \times 10^{-8}} = 0.00733 \text{ m}$$

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

$$= 0.01115 + 0.02974 + 0.00733$$

$$= 0.04821 \text{ m}$$

$$\text{Size} = 48.21 \text{ mm} \leq \delta_a = 50.00 \text{ mm}$$

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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.30	6.31 5.87	0.936 0.871	0.301 0.269	2.08 13.51	0.626 3.640
2	1.30- 2.30	5.11 4.77	0.758 0.708	0.215 0.192	10.39 17.16	2.230 3.288
3	2.30- 2.96	4.22 4.00	0.626 0.593	0.135 0.141	11.22 14.14	1.740 1.998
4	2.96- 3.30	3.67 3.55	0.544 0.527	0.121 0.115	7.29 7.50	0.883 0.859
5	3.30- 4.30	3.11 2.77	0.461 0.411	0.090 0.073	22.05 23.86	1.982 1.743
6	4.30- 5.09	2.18 1.91	0.323 0.284	0.047 0.036	19.06 20.23	0.887 0.738
7	5.09- 5.30	1.58 1.51	0.234 0.224	0.025 0.023	5.38 5.07	0.136 0.118
8	5.30- 6.30	1.11 0.77	0.164 0.115	0.013 0.006	24.13 17.11	0.307 0.108
9	6.30- 6.74	0.29 0.15	0.044 0.022	0.001 0.000	6.70 5.16	0.006 0.001
Σ Q = 21.291						

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

δ_a : Allowable displacement

7 Penetration Depth

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

Material Name	10 H ₂ H 750 -250 -14 -22 -18
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 = 414700 cm ⁴ (original condition)
	I = 414700 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 414700 × 10 ⁻⁸	I = 8.294 × 10 ⁵

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is L_k, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

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

$$L = H - H_{ik} + D$$

$$\beta = \sqrt[4]{\frac{K_s \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _s = 17965 kN/m ³
Calculated value	β = 0.27127 m ⁻¹

Penetration length of SSP	D = 1.46 + $\frac{3}{0.271}$ = 12.52 m
Whole length of SSP	L = 5.09 - 0.40 + 12.52 = 17.21 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K _s = 36184 kN/m ³
Calculated value	β = 0.32316 m ⁻¹

Penetration length of SSP	D = 1.65 + $\frac{3}{0.323}$ = 10.93 m
Whole length of SSP	L = 5.09 - 0.40 + 10.93 = 15.62 m

Therefore, the total length of the sheet pile is 17.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP		10 H _H 750-250-14-22-18		
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm4)	414700		
Sectional Modulus	Z (cm3)	7640		
Maximum bending moment	Mmax (kN · m · m)		677.57	776.09
Stress intensity	σ (N/mm2)		101 (180)	115 (270)
Lateral displacement	δ (mm)		48.21 (50.0)	46.62 (75.0)
Penetration depths	D (m)		12.52	10.93
Whole length of SSP	L (m)	17.50		

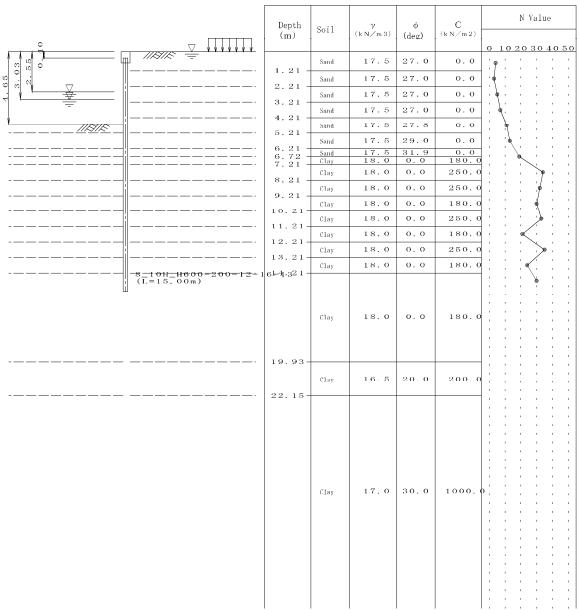
Block No. : L-28
Sta. : 12+040~12+280

Design Cross Section : Sta 12+080
Boring Name : BL-15

Specification : SSP SP-10H
(Combined) : H 600-200-12-16-13

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	= 4.65 m
Depth from coping top to rear side ground	H ₀	= 0.00 m
Depth from coping top to SSP top	H _B	= 0.40 m
Landside WL	L _{wa}	= 0.00 m (Normal Condition)
	L _{wd}	= 0.00 m (Seismic Condition)
Riverside WL	L _{wp}	= 3.03 m (Normal Condition)
	L _{wp}	= 2.55 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress : Chang's formula
Penetration depths : $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water : $\gamma_w = 9.8 \text{ kN/m}^3$
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 : not considered
Wind load, Impact load : not considered
Minimum angle of rupture : $\zeta_B = 10 \text{ degrees}$
Rear side angle of slope : not considered
Angle of rupture (clayey soil) : $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression : $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula : $K_b = K_{10} \left(\frac{B_B}{0.3} \right)^{-3/4}$
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_B = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
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	0.71	4	11	10.71	33
2	1.71	3	12	11.71	21
3	2.71	5	13	12.71	35
4	3.71	7	14	13.71	24
5	4.71	11	15	14.71	30
6	5.71	13			
7	6.71	19			
8	7.71	34			
9	8.71	32			
10	9.71	30			

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

Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.21	1.21
2	2.21	1.00
3	3.21	1.00
4	4.21	1.00
5	5.21	1.00
6	6.21	1.00
7	6.72	0.51
8	7.21	0.49
9	8.21	1.00
10	9.21	1.00
11	10.21	1.00
12	11.21	1.00
13	12.21	1.00
14	13.21	1.00
15	14.21	1.00
16	19.93	5.72
17	22.15	2.22
18	34.50	12.35

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.21	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	2.21	S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	3.21	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
4	4.21	S	7.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	5.21	S	11.0	17.50	7.70	27.8	0.0	0.0	0.200	Auto	Auto
6	6.21	S	13.0	17.50	7.70	29.0	0.0	0.0	0.200	Auto	Auto
7	6.72	S	19.0	17.50	7.70	31.9	0.0	0.0	0.200	Auto	Auto
8	7.21	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
9	8.21	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
10	9.21	C	32.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
11	10.21	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	11.21	C	33.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 600 -200 - 12-16-13

Young's modulus E = 200000 N/mm²

Inertia sectional moment I₀ = 208200 cm⁴

Sectional factor Z₀ = 4270 cm³

Corrosion margin t₁ = 1.00 mm (riverside) t₂ = 1.00 mm (landside)

Corrosion rate (to I₀) η = 0.83

Corrosion rate (to Z₀) η = 0.85

Section efficiency (to I₀) μ = 1.00

Section efficiency (to Z₀) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_s = 180 N/mm (Normal)

σ_s' = 270 N/mm (Seismic)

Allowable displacement δ_s = 50.0 mm (Normal)

δ_s' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction

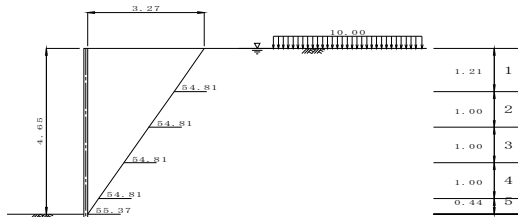
 Not reduced: I₀ applied to calculation of penetration depth

 Reduced: I₀ applied to calculation of section forces and displacement

 Reduced: Z₀ applied to calculation of stresses

2 Calculation of Acting Load

2.1 Normal Condition



No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
13	12.21	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	13.21	C	35.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	14.21	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	19.93	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
17	22.15	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
18	34.50	C	121.5	17.00	7.20	30.0	1000.0	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

C₀ : soil adhesion

a : slope of soil adhesion

k' : design seismic coefficient (underwater)

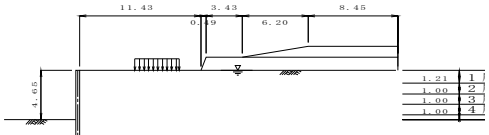
ζ : angle of active rupture

kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate			Thickness Bottom Right m	soil single weight γ Normal Condition kN/m ³	Seismic Condition kN/m ³	internal friction angle ϕ degree	stickiness C kN/m ²	Normal Condition degree	Seismic Condition degree
		Bottom Left m	Top Left m	Top Right m							
1	Sand	11.43	11.92	30.00	30.00	1.23	19.0	19.0	30.0	0.0	Auto
2	Sand	15.35	21.55	30.00	30.00	1.02	19.0	19.0	30.0	0.0	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	5.21	9.38	10.0	5.0

Angle of rupture in embankment calculated in consideration of embankment conditions

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	γ value kN/m ³	Angle of Rupture ζ degree
1	4.65~4.21	Sand	27.8	15.0	0.0	35.81	0.00	45.57	55.37
2	4.21~3.21	Sand	27.0	15.0	0.0	32.42	0.00	41.26	54.81
3	3.21~2.21	Sand	27.0	15.0	0.0	24.72	0.00	31.46	54.81
4	2.21~1.21	Sand	27.0	15.0	0.0	17.02	0.00	21.66	54.81
5	1.21~0.00	Sand	27.0	15.0	0.0	9.32	0.00	11.86	54.81

• 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 $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	55.37	0.44	0.00	0.00	0.30	0.44
2	54.81	1.00	0.30	0.44	1.01	1.44
3	54.81	1.00	1.01	1.44	1.71	2.44
4	54.81	1.00	1.71	2.44	2.42	3.44
5	54.81	1.21	2.42	3.44	3.27	4.65

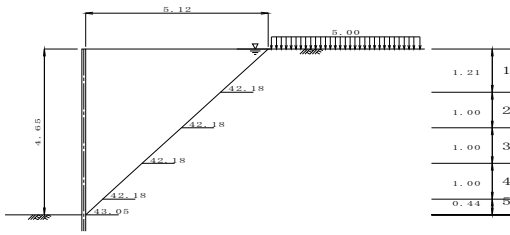
From the above table, the loading width (L) on the ground surface is 3.27 m.

2.1.3 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{0.00 + 0.00 + 0.00}{3.27}$$
$$= 0.00 \text{ kN/m}^2$$

C cohesive force of soil (kN/m²)

2.2 Seismic 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	γ when kN/m ²	k (k ²)	θ degree	Angle of Rupture ζ degree
1	4.65-4.21	Sand	27.8	15.0	0.0	35.81	0.00	45.57	0.200	11.31	43.05
2	4.21-3.21	Sand	27.0	15.0	0.0	32.42	0.00	41.26	0.200	11.31	42.18
3	3.21-2.21	Sand	27.0	15.0	0.0	24.72	0.00	31.46	0.200	11.31	42.18
4	2.21-1.21	Sand	27.0	15.0	0.0	17.02	0.00	21.66	0.200	11.31	42.18
5	1.21-0.00	Sand	27.0	15.0	0.0	9.32	0.00	11.86	0.200	11.31	42.18

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive 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/m³) (ascending force considered under L)
- h : thickness of layer (m)
- Q : surcharge load (kN/m²)

3.1.1 Soil Modulus of Active Side

	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	Ka	$K_a \times \cos \delta$
1	0.00-1.21	Sand	7.7	27.0	—	0.000 9.317	0.33738 0.33738	0.32589 0.32589
2	1.21-2.21	Sand	7.7	27.0	—	9.317 17.017	0.33738 0.33738	0.32589 0.32589
3	2.21-3.03	Sand	7.7	27.0	—	17.017 23.331	0.33738 0.33738	0.32589 0.32589
4	3.03-3.21	Sand	7.7	27.0	—	23.331 24.717	0.33738 0.33738	0.32589 0.32589
5	3.21-4.21	Sand	7.7	27.0	—	24.717 32.417	0.33738 0.33738	0.32589 0.32589
6	4.21-4.65	Sand	7.7	27.8	—	32.417 35.805	0.32749 0.32749	0.31633 0.31633
7	4.65-5.21	Sand	7.7	27.8	—	35.805 40.117	0.32749 0.32749	0.31633 0.31633
8	5.21-6.21	Sand	7.7	29.0	—	40.117 47.817	0.31307 0.31307	0.30240 0.30240
9	6.21-6.72	Sand	7.7	31.9	—	47.817 51.744	0.28015 0.28015	0.27060 0.27060
10	6.72-7.21	Clay	8.2	—	180.0 180.0	51.744 55.762	—	—
11	7.21-8.21	Clay	8.2	—	250.0 250.0	55.762 63.962	—	—
12	8.21-9.21	Clay	8.2	—	250.0 250.0	63.962 72.162	—	—
13	9.21-10.21	Clay	8.2	—	180.0 180.0	72.162 80.362	—	—
14	10.21-11.21	Clay	8.2	—	250.0 250.0	80.362 88.562	—	—
15	11.21-12.21	Clay	8.2	—	180.0 180.0	88.562 96.762	—	—
16	12.21-13.21	Clay	8.2	—	250.0 250.0	96.762 104.962	—	—
17	13.21-14.21	Clay	8.2	—	180.0 180.0	104.962 113.162	—	—
18	14.21-19.93	Clay	8.2	—	180.0 180.0	113.162 160.066	—	—
19	19.93-22.15	Clay	6.7	—	200.0 200.0	160.066 174.940	—	—
20	22.15-34.50	Clay	7.2	—	1000.0 1000.0	174.940 263.860	—	—

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

$\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

2.2.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.05	0.44	0.00	0.00	0.47	0.44
2	42.18	1.00	0.47	0.44	1.57	1.44
3	42.18	1.00	1.57	1.44	2.68	2.44
4	42.18	1.00	2.68	2.44	3.78	3.44
5	42.18	1.21	3.78	3.44	5.12	4.65

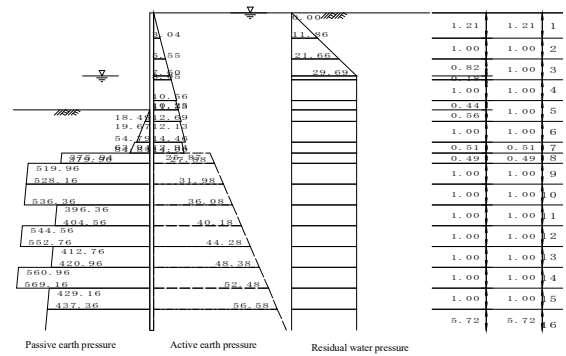
From the above table, the loading width (L) on the ground surface is 5.12 m.

2.2.3 Calculated Load

$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$
$$= \frac{0.00 + 0.00 + 0.00}{5.12}$$
$$= 0.00 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	Kp	$K_p \times \cos \delta$
7	4.65-5.21	Sand	7.7	27.8	—	0.000 4.312	4.43813 4.43813	4.28690 4.28690
8	5.21-6.21	Sand	7.7	29.0	—	4.312 12.012	4.72202 4.72202	4.56112 4.56112
9	6.21-6.72	Sand	7.7	31.9	—	12.012 15.939	5.51072 5.51072	5.32295 5.32295
10	6.72-7.21	Clay	8.2	0.0	180.0 180.0	15.939 19.957	—	—
11	7.21-8.21	Clay	8.2	0.0	250.0 250.0	19.957 28.157	—	—
12	8.21-9.21	Clay	8.2	0.0	250.0 250.0	28.157 36.357	—	—
13	9.21-10.21	Clay	8.2	0.0	180.0 180.0	36.357 44.557	—	—
14	10.21-11.21	Clay	8.2	0.0	250.0 250.0	44.557 52.757	—	—
15	11.21-12.21	Clay	8.2	0.0	180.0 180.0	52.757 60.957	—	—
16	12.21-13.21	Clay	8.2	0.0	250.0 250.0	60.957 69.157	—	—
17	13.21-14.21	Clay	8.2	0.0	180.0 180.0	69.157 77.357	—	—
18	14.21-19.93	Clay	8.2	0.0	180.0 180.0	77.357 124.261	—	—
19	19.93-22.15	Clay	6.7	20.0	200.0 200.0	124.261 139.135	—	—
20	22.15-34.50	Clay	7.2	30.0	1000.0 1000.0	139.135 228.055	—	—

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

$\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure		Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	
1	0.00-1.21	0.00 3.04	—	0.00 3.04	0.00 11.86	—	—
2	1.21-2.21	3.04 5.55	—	3.04 5.55	11.86 21.66	—	—
3	2.21-3.03	5.55 7.60	—	5.55 7.60	21.66 29.69	—	—
4	3.03-3.21	7.60 8.05	—	7.60 8.05	29.69 29.69	—	—

5	3.21- 4.21	8.05 10.56	————	8.05 10.56	29.69 29.69	————
6	4.21- 4.65	10.25 11.33	————	10.25 11.33	29.69 29.69	————
7	4.65- 5.21	11.33 12.69	————	11.33 12.69	29.69 29.69	0.00 18.49
8	5.21- 6.21	12.13 14.46	————	12.13 14.46	29.69 29.69	19.67 54.79
9	6.21- 6.72	12.94 14.00	————	12.94 14.00	29.69 29.69	63.94 84.84
10	6.72- 7.21	-308.26 -304.24	25.87 27.88	25.87 27.88	29.69 29.69	375.94 379.96
11	7.21- 8.21	-444.24 -436.04	27.88 31.98	27.88 31.98	29.69 29.69	519.96 528.16
12	8.21- 9.21	-436.04 -427.84	31.98 36.08	31.98 36.08	29.69 29.69	528.16 536.36
13	9.21- 10.21	-297.84 -279.64	36.08 40.18	36.08 40.18	29.69 29.69	396.36 404.56
14	10.21- 11.21	-419.64 -411.44	40.18 44.28	40.18 44.28	29.69 29.69	544.56 552.76
15	11.21- 12.21	-271.44 -263.24	44.28 48.38	44.28 48.38	29.69 29.69	412.76 420.96
16	12.21- 13.21	-403.24 -395.04	48.38 52.48	48.38 52.48	29.69 29.69	560.96 569.16
17	13.21- 14.21	-255.04 -246.84	52.48 56.58	52.48 56.58	29.69 29.69	429.16 437.36
18	14.21- 19.93	-246.84 -199.93	56.58 80.03	56.58 80.03	29.69 29.69	437.36 484.26
19	19.93- 22.15	-239.93 -225.06	80.03 87.47	80.03 87.47	29.69 29.69	524.26 539.14
20	22.15- 34.50	-1825.06 -1736.14	87.47 131.93	87.47 131.93	29.69 29.69	2139.14 2228.05

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\sum \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

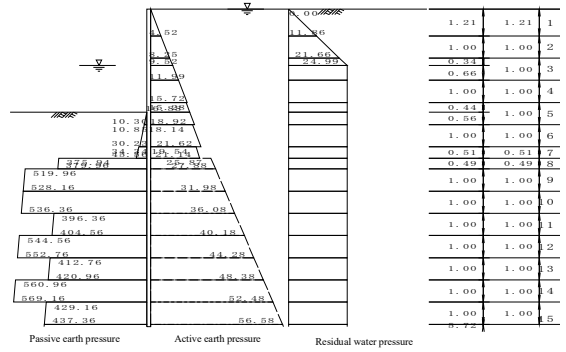
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma h + Q + 2C$$

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

3.2 Seismic Condition



The dotted line in the figure shows the main earth pressure strength Pa2 using the consolidation equilibrium coefficient.

3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q$ kN/m ²	γ_{sub} kN/m ²	k	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.21	Sand	7.7	27.0	—	0.00 9.32	0.00 11.86	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
2	1.21- 2.21	Sand	7.7	27.0	—	9.32 17.02	11.86 21.66	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
3	2.21- 2.55	Sand	7.7	27.0	—	17.02 19.64	21.66 24.99	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
4	2.55- 5.21	Sand	7.7	27.0	—	19.64 24.72	24.99 31.46	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
5	3.21- 4.21	Sand	7.7	27.0	—	24.72 32.42	31.46 41.26	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
6	4.21- 4.65	Sand	7.7	27.8	—	32.42 35.81	41.26 45.57	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	—
7	4.65- 5.21	Sand	7.7	27.8	—	35.81 40.12	45.57 51.06	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	—
8	5.21- 6.21	Sand	7.7	29.0	—	40.12 47.82	51.06 60.86	0.200 0.200	11.31 11.31	0.46809 0.46809	0.45214 0.45214	—
9	6.21- 6.72	Sand	7.7	31.9	—	47.82 51.74	60.86 65.86	0.200 0.200	11.31 11.31	0.42299 0.42299	0.40858 0.40858	—
10	6.72- 7.21	Clay	8.2	—	180.0	51.74 180.0	65.86 70.66	0.200 0.200	11.31 11.31	—	—	44.58 44.55
11	7.21- 8.21	Clay	8.2	—	250.0	55.76 250.0	70.66 80.46	0.200 0.200	11.31 11.31	—	—	44.68 44.63
12	8.21- 9.21	Clay	8.2	—	250.0	63.96 250.0	80.46 90.26	0.200 0.200	11.31 11.31	—	—	44.63 44.58

13	9.21- 10.21	Clay	8.2	—	180.0 180.0	72.16 80.36	90.26 100.06	0.200 0.200	11.31 11.31	—	—	44.41 44.35
14	10.21- 11.21	Clay	8.2	—	250.0 250.0	80.36 88.56	100.06 109.86	0.200 0.200	11.31 11.31	—	—	44.53 44.48
15	11.21- 12.21	Clay	8.2	—	180.0 180.0	88.56 96.76	109.86 119.66	0.200 0.200	11.31 11.31	—	—	44.28 44.21
16	12.21- 13.21	Clay	8.2	—	250.0 250.0	96.76 104.96	119.66 129.46	0.200 0.200	11.31 11.31	—	—	44.43 44.39
17	13.21- 14.21	Clay	8.2	—	180.0 180.0	104.96 113.16	129.46 139.26	0.200 0.200	11.31 11.31	—	—	44.14 44.07
18	14.21- 19.93	Clay	8.2	—	180.0 180.0	113.16 160.07	139.26 195.31	0.200 0.200	11.31 11.31	—	—	44.07 43.67
19	19.93- 22.15	Clay	6.7	—	200.0 200.0	160.07 174.94	195.31 217.07	0.200 0.200	11.31 11.31	—	—	43.81 43.69
20	22.15- 34.50	Clay	7.2	—	1000.0 1000.0	174.94 263.86	217.07 338.10	0.200 0.200	11.31 11.31	—	—	44.75 44.62

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.
 $\delta = 15.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

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

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q_p$ kN/m ²	γ_{sub} kN/m ²	k	θ degree	K_p	$K_p \times \cos \delta$
7	4.65- 5.21	Sand	7.70	27.8	—	0.000 4.312	0.00 5.49	0.200 0.200	11.31 11.31	2.38966 2.38966	2.38966 2.38966
8	5.21- 6.21	Sand	7.70	29.0	—	4.312 12.012	5.49 15.29	0.200 0.200	11.31 11.31	2.51705 2.51705	2.51705 2.51705
9	6.21- 6.72	Sand	7.70	31.9	—	12.012 15.939	15.29 20.29	0.200 0.200	11.31 11.31	2.85840 2.85840	2.85840 2.85840
10	6.72- 7.21	Clay	8.20	0.0	180.0 180.0	15.939 19.957	20.29 25.09	0.200 0.200	11.31 11.31	—	—
11	7.21- 8.21	Clay	8.20	0.0	250.0 250.0	19.957 28.157	25.09 34.89	0.200 0.200	11.31 11.31	—	—
12	8.21- 9.21	Clay	8.20	0.0	250.0 250.0	28.157 36.357	34.89 44.69	0.200 0.200	11.31 11.31	—	—
13	9.21- 10.21	Clay	8.20	0.0	180.0 180.0	36.357 44.557	44.69 54.49	0.200 0.200	11.31 11.31	—	—
14	10.21- 11.21	Clay	8.20	0.0	250.0 250.0	44.557 52.757	54.49 64.29	0.200 0.200	11.31 11.31	—	—
15	11.21- 12.21	Clay	8.20	0.0	180.0 180.0	52.757 60.957	64.29 74.09	0.200 0.200	11.31 11.31	—	—

3.2.3 Lateral Forth

No	Depth, m	Active		Residual water pressure		Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	
1	0.00-1.21	0.00 4.52	— —	0.00 4.52	0.00 11.86	— —
2	1.21-2.21	4.52 8.25	— —	4.52 8.25	11.86 21.66	— —
3	2.21-2.55	8.25 9.52	— —	8.25 9.52	21.66 24.99	— —
4	2.55-3.21	9.52 11.99	— —	9.52 11.99	24.99 24.99	— —
5	3.21-4.21	11.99 15.72	— —	11.99 15.72	24.99 24.99	— —
6	4.21-4.65	15.28 16.88	— —	15.28 16.88	24.99 24.99	— —
7	4.65-5.21	16.88 18.92	— —	16.88 18.92	24.99 24.99	0.00 10.30
8	5.21-6.21	18.14 21.62	— —	18.14 21.62	24.99 24.99	10.83 30.23
9	6.21-6.72	19.54 21.14	— —	19.54 21.14	24.99 24.99	34.34 45.56
10	6.72-7.21	297.79 292.95	25.87 27.88	25.87 27.88	24.99 24.99	375.94 379.96
11	7.21-8.21	432.99 423.12	27.88 31.98	27.88 31.98	24.99 24.99	519.96 528.16
12	8.21-9.21	423.12 413.25	31.98 36.08	31.98 36.08	24.99 24.99	528.16 536.36
13	9.21-10.21	273.18 263.29	36.08 40.18	36.08 40.18	24.99 24.99	396.36 404.56
14	10.21-11.21	403.37 393.48	44.28 48.18	40.18 44.28	24.99 24.99	544.56 552.76

15	11.21- 12.21	-253.39 -243.48	44.28 48.38	44.28 48.38	24.99 24.99	412.76 420.96
16	12.21- 13.21	-283.60 -273.71	48.38 52.48	48.38 52.48	24.99 24.99	500.96 509.16
17	13.21- 14.21	-233.57 -223.65	52.48 56.58	52.48 56.58	24.99 24.99	429.16 437.36
18	14.21- 19.93	-223.65 -166.79	56.58 80.03	56.58 80.03	24.99 24.99	437.36 484.26
19	19.93- 22.15	-206.91 -188.85	80.03 87.47	80.03 87.47	24.99 24.99	524.26 539.14
20	22.15- 34.50	-1789.84 -1082.84	87.47 131.93	87.47 131.93	24.99 24.99	2139.14 2228.05

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\sum \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m2
1	2.55	0.00	0.00
2	3.55	1.00	2.49
3	4.55	2.00	3.51
4	4.65	2.10	3.60

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

Where,

k_{is} : 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

6	4.21- 4.65	10.25 11.33	29.69 29.69	— —	39.95 41.02
7	4.65- 5.21	11.33 12.69	29.69 29.69	0.00 18.49	41.02 23.90
8	5.21- 5.89	12.13 13.70	29.69 29.69	19.67 43.40	22.16 0.00
9	5.89- 6.21	13.70 14.46	29.69 29.69	43.40 54.79	0.00 -10.63

P_a : Active earth pressure

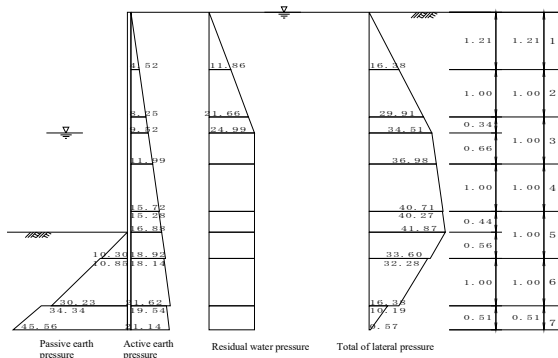
P_w : Residual water pressure

P_p : Passive earth pressure

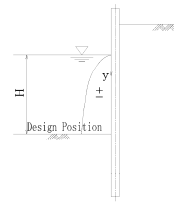
P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 1.24 m (GL -5.89 m)

4.2 Seismic Condition



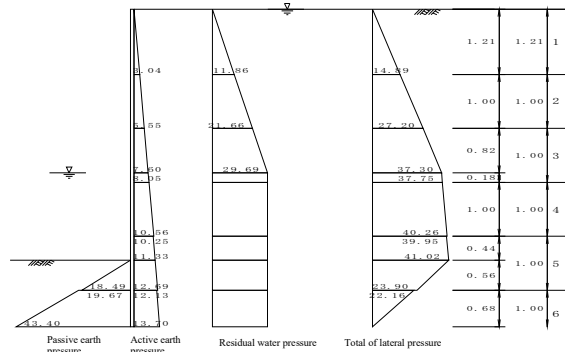
No	Depth m	P_a kN/m2	P_w kN/m2	P_p kN/m2	P_s kN/m2
1	0.00- 1.21	0.00 4.52	0.00 11.86	— —	0.00 16.38
2	1.21- 2.21	4.52 8.25	11.86 21.66	— —	16.38 29.91
3	2.21- 2.55	8.25 9.52	21.66 24.99	— —	29.91 34.51
4	2.55- 3.21	9.52 11.99	24.99 24.99	— —	34.51 36.98
5	3.21- 4.21	11.99 15.72	24.99 24.99	— —	36.98 40.71
6	4.21- 4.65	15.28 16.88	24.99 24.99	— —	40.27 41.87



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



No	Depth m	P_a kN/m2	P_w kN/m2	P_p kN/m2	P_s kN/m2
1	0.00- 1.21	0.00 3.04	0.00 11.86	— —	0.00 14.89
2	1.21- 2.21	3.04 5.55	11.86 21.66	— —	14.89 27.20
3	2.21- 3.03	5.55 7.60	21.66 29.69	— —	27.20 37.30
4	3.03- 3.21	7.60 8.05	29.69 29.69	— —	37.30 37.75
5	3.21- 4.21	8.05 10.56	29.69 29.69	— —	37.75 40.26

7	4.65- 5.21	16.88 18.92	24.99 24.99	0.00 10.30	41.87 33.60
8	5.21- 6.21	18.14 21.62	24.99 24.99	10.85 30.23	32.28 16.38
9	6.21- 6.72	19.54 21.14	24.99 24.99	34.34 45.56	10.19 0.57
10	6.72- 7.21	25.87 27.88	24.99 24.99	375.94 379.96	-325.08 -327.09

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 : 2.07 m (GL -6.72 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{10} = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H = 10, 00m)$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha = \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_{10} \cdot B}{4 E I}}$$

Material Name

Unit width

Corrosion margin

Corrosion rate

Section efficiency

Young's modulus

Inertia sectional moment

Inertia sectional moment

10 H - H 600 - 200 - 12-16-13

B = 1.0000 m

$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)

$\eta = 0.83$

$\mu = 1.00$

E = 200000 N/mm²

$I_0 = 208200$ cm⁴(original condition)

I = 172806 cm⁴(after reduction by corrosion and section)

EI = 200000 × 10³ × 172806 × 10⁻⁸ = 3.456 × 10⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.71	4	11	10.71	33
2	1.71	3	12	11.71	21
3	2.71	5	13	12.71	35
4	3.71	7	14	13.71	24
5	4.71	11	15	14.71	30
6	5.71	13			
7	6.71	19			
8	7.71	34			
9	8.71	32			
10	9.71	30			

5.2 Normal Condition

Assuming Kh = 17623 kN/m3,

$$\beta = \sqrt[4]{\frac{K_s \cdot B}{4 E I}} = 0,336 \text{ m}^{-1}$$
$$L = \frac{1}{\beta} = 2,98 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.89 m) to 2.98 m depth (GL -8.86 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.89	0.82	14.1	19.0	13.62
2	6.71	1.00	19.0	34.0	26.50
3	7.71	1.00	34.0	32.0	33.00
4	8.71	0.15	32.0	31.7	4.85
L = Σh = 2.98		ΣA =		77.96	

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

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{77,96}{2,98} = 26,19$$

Kh is recalculated from the calculated average N value.

$$E_o = 2800N' = 2800 \times 26,19 = 73344 \text{ kN/m}^2$$
$$K_{10} = \frac{1}{0,3} \times \alpha \times 73344 = 244481 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$K_s = K_{10}(B_o/0,3)^{-3/4} = 244481(10,00/0,3)^{-3/4} = 17623 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 17623 kN/m3.

5.3 Seismic Condition

Assuming Kh = 40523 kN/m3,

$$\beta = \sqrt[4]{\frac{K_s \cdot B}{4 E I}} = 0,414 \text{ m}^{-1}$$
$$L = \frac{1}{\beta} = 2,42 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.72 m) and 2.42 m depth (GL -9.14 m).

8	5.21~ 5.89	0.68	22.16 0.00	7.49 0.00	0.45 0.23	3.37 0.00
ΣP= 145.74 ΣM= 368.87						

P_i : active earth pressure + residual water pressure - passive earth pressure
P : load P_x 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_i = 0.0 kN/m
depth to acting position H_i = 0.0 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 = 4.65 m
Depth of Imaginary riverbed from riverbed L_k = 1.24 m

Moment M_i by arbitrary load is as below
M_i = P_i·(H + L_k - H_i) + M_m = 0.00 kN·m
h₀, Height of acting position of P₀ from imaginary riverbed

$$h_o = \frac{M_o}{P_o} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{368,87}{145,74} = 2,53 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 1.21	1.21	0.00 16.38	0.00 9.91	6.32 5.91	0.00 58.59
2	1.21~ 2.21	1.00	16.38 29.91	8.19 14.95	5.18 4.84	42.39 72.43
3	2.21~ 2.55	0.34	29.91 34.51	5.08 5.87	4.40 4.28	22.36 25.13
4	2.55~ 3.21	0.66	34.51 36.98	11.39 12.20	3.95 3.73	44.99 45.51
5	3.21~ 4.21	1.00	36.98 40.71	18.49 20.35	3.18 2.84	58.73 57.87
6	4.21~ 4.65	0.44	40.27 41.87	8.86 9.21	2.36 2.22	20.94 20.42
7	4.65~ 5.21	0.56	41.87 33.60	11.72 9.41	1.88 1.70	22.08 15.96
8	5.21~ 6.21	1.00	32.28 16.38	16.14 8.19	1.18 0.84	18.99 6.90
9	6.21~ 6.72	0.51	10.19 0.57	2.60 0.15	0.34 0.17	0.88 0.02
		ΣP =		172.71		ΣM = 534.20

P_i : active earth pressure + residual water pressure - passive earth pressure
P : load P_x 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

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.72	0.99	19.1	34.0	26.31
2	7.71	1.00	34.0	32.0	33.00
3	8.71	0.43	32.0	31.1	13.47
L = Σh = 2.42		ΣA =		72.78	

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

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{72,78}{2,42} = 30,12$$

Kh is recalculated from the calculated average N value.

$$E_o = 2800N' = 2800 \times 30,12 = 84325 \text{ kN/m}^2$$
$$K_{10} = \frac{1}{0,3} \times \alpha \times 84325 = 562167 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$K_s = K_{10}(B_o/0,3)^{-3/4} = 562167(10,00/0,3)^{-3/4} = 40523 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 40523 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 1.21	1.21	0.00 14.89	0.00 9.01	5.48 5.08	0.00 45.77
2	1.21~ 2.21	1.00	14.89 27.20	7.45 13.60	4.34 4.01	32.34 54.53
3	2.21~ 3.03	0.82	27.20 37.30	11.15 15.29	3.40 3.13	37.95 47.85
4	3.03~ 3.21	0.18	37.30 37.75	3.36 3.40	2.80 2.74	9.38 9.29
5	3.21~ 4.21	1.00	37.75 40.26	18.87 20.13	2.34 2.01	44.21 40.44
6	4.21~ 4.65	0.44	39.95 41.02	8.79 9.02	1.53 1.38	13.44 12.48
7	4.65~ 5.21	0.56	41.02 23.90	11.49 6.69	1.05 0.86	12.05 5.77

Arbitrary load lateral load P_i = 0.0 kN/m
depth to acting position H_i = 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 = 4.65 m
Depth of Imaginary riverbed from riverbed L_k = 2.07 m

Moment M_i by arbitrary load is as below
M_i = P_i·(H + L_k - H_i) + M_m = 0.00 kN·m

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m2	Loads P _{0w} kN	Arm length Y m	Moment M _{0w} kN · m
1	2.55~ 3.55	1.00	0.0 2.5	0.00 1.24	3.84 3.50	0.00 4.35
2	3.55~ 4.55	1.00	2.5 3.5	1.24 1.76	2.84 2.50	3.52 4.40
3	4.55~ 4.65	0.10	3.5 3.6	0.18 0.18	2.14 2.10	0.38 0.38
		Σ P _{0w} =		4.60		Σ M _{0w} = 13.03

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_o = \frac{M_o}{P_o} = \frac{\Sigma M + M_i + \Sigma M_{0w}}{\Sigma P + P_i + \Sigma P_{0w}} = \frac{547,23}{177,31} = 3,09 \text{ m}$$

6.2 Sectional Force

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

Material name 10 H _H 600 -200 - 12-16-13
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.83
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 208200 cm⁴ (original condition)
I = 172806 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 172806 × 10⁻⁸ = 3.456 × 10⁵

$$\beta = \sqrt[4]{\frac{K_a \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_a	=	17623	kN/m ³
calculated value	β	=	0.33602	m ⁻¹
resultant earth force (lateral)	P_0	=	145.74	kN/m
height of acting position of load	h_0	=	2.53	m
moment	M_0	=	368.87	kN·m/m

in consideration of $\psi_m = 1.188$, maximum moment	$M_{\max}$	=	438.12	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	1.055	m
depth of 1 st fixed point	l_i	=	3.393	m

6.2.2 Seismic Condition

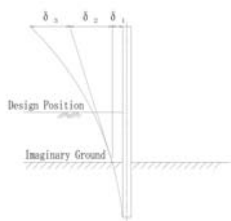
modulus of lateral subgrade reaction	K_a	=	40523	kN/m ³
calculated value	β	=	0.41378	m ⁻¹
resultant earth force (lateral)	P_0	=	177.31	kN/m
height of acting position of load	h_0	=	3.09	m
moment	M_0	=	547.23	kN·m/m

in consideration of $\psi_m = 1.099$, maximum moment	$M_{\max}$	=	601.30	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	0.663	m
depth of 1 st fixed point	l_i	=	2.561	m

6.3 Stress Intensity

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

Material Name	10 H ₂ H 600 -200 - 12-16-13		
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	=	4270 cm ³ (original condition)
	Z	=	3630 cm ³ (after reduction by corrosion and section)



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

$$= \frac{(1+0.3360 \times 2.53) \times 145.74}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.3360^2} = 0.01028 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^3} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.3360 \times 2.53) \times 145.74}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.3360^3} \times (4.65+1.24) = 0.02969 \text{ m}$$

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

$$= \frac{13.37 \times (4.65+1.24)^3}{2.00 \times 10^8 \times 172806 \times 10^{-8}} = 0.00789 \text{ m}$$

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

$$= 0.01028 + 0.02969 + 0.00789$$

$$= 0.04786 \text{ m}$$

$$\text{Size} = 47.86 \leq \delta_a = 50.00 \text{ mm}$$

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

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-1.21	6.32 5.91	0.940 0.880	0.303 0.274	0.00 9.91	0.000 2.711
2	1.21-2.21	5.18 4.84	0.770 0.721	0.221 0.197	8.19 14.95	1.806 2.951
3	2.21-2.55	4.40 4.28	0.654 0.637	0.167 0.160	5.08 5.87	0.851 0.939
4	2.55-3.21	3.95 3.73	0.588 0.555	0.139 0.126	11.39 12.20	1.582 1.532

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{438.12 \times 10^6}{3630 \times 10^3} = 121 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{601.30 \times 10^6}{3630 \times 10^3} = 166 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-1.21	5.48 5.08	0.931 0.863	0.299 0.265	0.00 9.01	0.000 2.390
2	1.21-2.21	4.34 4.01	0.738 0.681	0.205 0.179	7.45 13.60	1.528 2.439
3	2.21-3.03	3.40 3.13	0.578 0.532	0.135 0.116	11.15 15.29	1.504 1.778
4	3.03-3.21	2.80 2.74	0.475 0.465	0.095 0.091	3.36 3.40	0.319 0.310
5	3.21-4.21	2.34 2.01	0.398 0.341	0.069 0.052	18.87 20.13	1.296 1.039
6	4.21-4.65	1.53 1.38	0.260 0.235	0.031 0.025	8.79 9.02	0.271 0.229
7	4.65-5.21	1.05 0.86	0.178 0.147	0.015 0.010	11.49 6.69	0.172 0.068
8	5.21-5.89	0.45 0.23	0.077 0.038	0.003 0.001	7.49 0.00	0.021 0.000
$\Sigma Q =$					13.36	

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

$$Q : \zeta \times P$$

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement Calculation

5	3.21-4.21	3.18 2.84	0.473 0.423	0.094 0.077	18.49 20.35	1.740 1.565
6	4.21-4.65	2.36 2.22	0.352 0.330	0.055 0.048	8.86 9.21	0.484 0.446
7	4.65-5.21	1.88 1.70	0.280 0.252	0.036 0.029	11.72 9.41	0.417 0.275
8	5.21-6.21	1.18 0.84	0.175 0.126	0.014 0.008	16.14 8.19	0.233 0.062
9	6.21-6.72	0.34 0.17	0.051 0.025	0.001 0.000	2.60 0.15	0.003 0.000
$\Sigma Q =$					17.996	

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

$$Q : \zeta \times P$$

P : Lateral force

H : Depth to design position

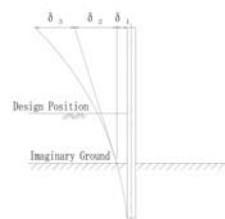
L_k : Depth from design position to imaginary ground

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

No	Depth, m	Y, m	α	ζ	Pdw, kN	Qdw, kN
1	2.55-3.55	3.84 3.50	0.571 0.521	0.132 0.112	0.00 1.24	0.000 0.140
2	3.55-4.55	2.84 2.50	0.422 0.373	0.077 0.061	1.24 1.76	0.095 0.107
3	4.55-4.65	2.14 2.10	0.318 0.313	0.045 0.044	0.18 0.18	0.008 0.008
$\Sigma Qdw =$					0.357	

Therefore, the deformation coefficient Q is expressed by
Q = 17.996 + 0.357 = 17.953

Displacement Calculation



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

$$= \frac{(1+0.4138 \times 3.09) \times 177.31}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.4138^3} = 0.00824 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2EI\beta^2} \times (H+L_0)$$
$$= \frac{(1+2 \times 0.4138 \times 3.09) \times 177.31}{2 \times 2.00 \times 10^8 \times 172806 \times 10^{-8} \times 0.4138^2} \times (4.65+2.07) = 0.03578 \text{ m}$$
$$\delta_3 = \frac{Q \times (H+L_0)^3}{EI}$$
$$= \frac{17.95 \times (4.65+2.07)^3}{2.00 \times 10^8 \times 172806 \times 10^{-8}} = 0.01576 \text{ m}$$
$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= 0.00824 + 0.03578 + 0.01576$$
$$= 0.05979 \text{ m}$$
$$\text{Size} = 59.79 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	10 H_H 600 -200 - 12-16-13
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 = 208200 cm ⁴ (original condition)
	I = 208200 cm ⁴ (after reduction by corrosion and section)
El = 200000 × 10 ³ × 208200 × 10 ⁻⁸	= 4.164 × 10 ⁵

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is Lk, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

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

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_h = 17623 \text{ kN/m}^3$
Calculated value $\beta = 0.32072 \text{ m}^{-1}$

Penetration length of SSP $D = 1.24 + \frac{3}{0.321} = 10.59 \text{ m}$
Whole length of SSP $L = 4.65 - 0.40 + 10.59 = 14.84 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 40523 \text{ kN/m}^3$
Calculated value $\beta = 0.39494 \text{ m}^{-1}$

Penetration length of SSP $D = 2.07 + \frac{3}{0.395} = 9.67 \text{ m}$
Whole length of SSP $L = 4.65 - 0.40 + 9.67 = 13.92 \text{ m}$

Therefore, the total length of the sheet pile is 15.00 m from the rounded length value of 0.50 m.

8 Calculation Result

10 H_H 600 -200 - 12-16-13				
front sheet pile			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	208200		
Sectional Modulus	Z (cm ³)	4270		
Maximum bending moment	Mmax (kN · m · m)		438.12	601.30
Stress intensity	σ (N/mm ²)		121 (180)	166 (270)
Lateral displacement	δ (mm)		47.86 (50.0)	59.79 (75.0)
Penetration depth	D (m)		10.59	9.67
Whole length of SSP	L (m)	15.00		

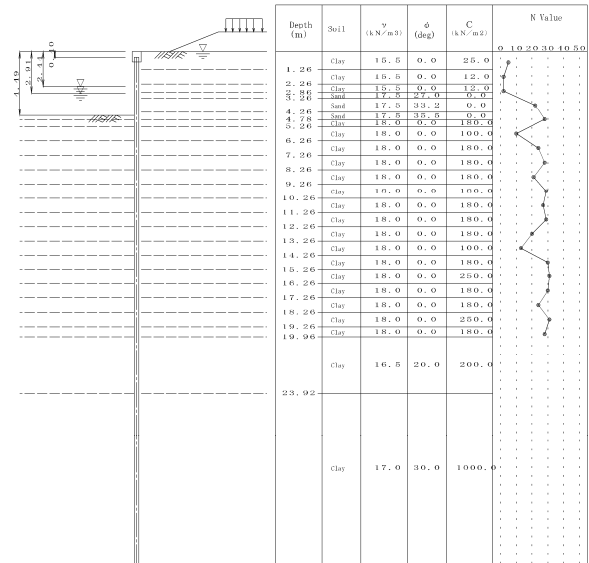
Block No. : L-29
Sta. : 12+280~12+520

Design Cross Section : Sta 12+320
Boring Name : BMLL-36

Specification : SSP SP-10H
(Combined) : H 400-200-9-16-13

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered
Wind load, Impact load	not considered
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$
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 Modulus of Lateral Subgrade Reaction

Applied formula	$K_{\lambda} = K_{\lambda 0} \left(\frac{B_{\lambda}}{0.3} \right)^{-3/4}$
	$K_{\lambda 0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$
	$B_{\lambda} = 10.00 \text{ m}$
	$E_0 = 2800 \text{ N}$
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	0.76	5	11	10.76	27
2	1.76	2	12	11.76	29
3	2.76	2	13	12.76	20
4	3.76	22	14	13.76	13
5	4.76	28	15	14.76	30
6	5.76	10	16	15.76	31
7	6.76	24	17	16.76	30
8	7.76	28	18	17.76	24
9	8.76	21	19	18.76	31
10	9.76	29	20	19.76	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

Soil Modulus		Depth m (Include Projection Length)		Thickness m (excluding projected length)	
No					
1		1.26		1.26	
2		2.26		1.00	
3		2.86		0.60	
4		3.26		0.40	
5		4.26		1.00	
6		4.78		0.52	
7		5.26		0.48	
8		6.26		1.00	
9		7.26		1.00	
10		8.26		1.00	
11		9.26		1.00	
12		10.26		1.00	
13		11.26		1.00	
14		12.26		1.00	
15		13.26		1.00	
16		14.26		1.00	
17		15.26		1.00	
18		16.26		1.00	
19		17.26		1.00	
20		18.26		1.00	
21		19.26		1.00	
22		19.96		0.70	
23		23.92		3.96	
24		34.40		10.48	

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.26	C	5.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
2	2.26	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto
3	2.86	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto
4	3.26	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	4.26	S	22.0	17.50	7.70	33.2	0.0	0.0	0.200	Auto	Auto
6	4.78	S	28.0	17.50	7.70	35.5	0.0	0.0	0.200	Auto	Auto

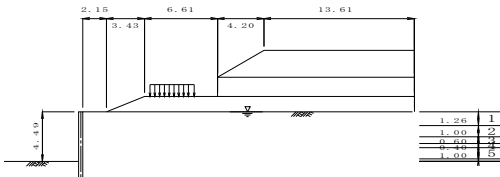
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
7	5.26	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
8	6.26	C	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	7.26	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
10	8.26	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
11	9.26	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	10.26	C	29.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	11.26	C	27.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	12.26	C	29.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	13.26	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	14.26	C	13.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
17	15.26	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
18	16.26	C	31.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	17.26	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
20	18.26	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
21	19.26	C	31.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
22	19.96	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
23	23.92	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
24	34.40	C	121.5	17.00	7.20	30.0	1000.0	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 (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness		soil single weight γ	internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³				Normal Condition degree	Seismic Condition degree
1	Sand	2.15	5.58	30.00	30.00	1.37	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	12.19	12.19	30.00	30.00	1.76	19.0	19.0	30.0	0.0	Auto	Auto
3	Sand	12.19	16.39	30.00	30.00	2.42	19.0	19.0	30.0	0.0	Auto	Auto

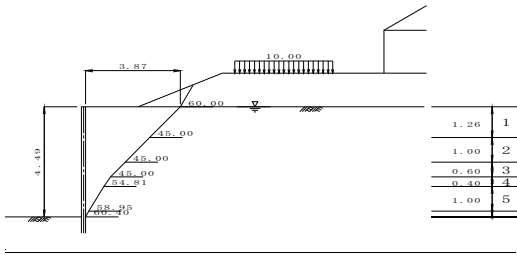
Surcharge load acting on embankment

No	load area	load strength

2 Calculation of Acting Load

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 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	γ when kN/m ²	Angle of Rupture ζ degree
1	4.49~4.26	Sand	35.5	15.0	0.0	28.85	3.79	44.00	60.40
2	4.26~3.26	Sand	33.2	15.0	0.0	27.08	3.79	41.75	58.95
3	3.26~2.86	Sand	27.0	15.0	0.0	19.38	3.79	31.95	54.81
4	2.86~2.26	Clay	0.0	15.0	12.0	16.30	3.79	28.03	45.00
5	2.26~1.26	Clay	0.0	15.0	12.0	12.88	3.79	22.15	45.00
6	1.26~0.00	Clay	0.0	15.0	25.0	7.18	3.79	12.35	45.00
7		embankment	30.0		0.0	105.45	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

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

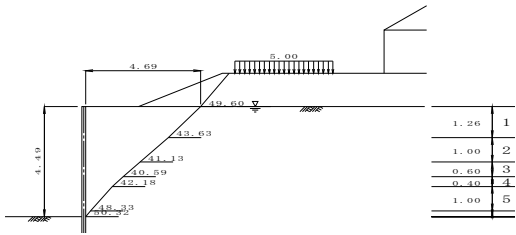
Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0^\circ$

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 $\theta = \tan^{-1}k'$

2.2 Seismic Condition

Q : surcharge load (kN/m²)
 C : cohesive force of soil (kN/m²)



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	γ when kN/m ²	k (δ°)	θ degree	Angle of Rupture ζ degree
1	4.49~4.26	Sand	35.5	15.0	0.0	28.85	7.81	44.00	0.200	11.31	50.32
2	4.26~3.26	Sand	33.2	15.0	0.0	27.08	7.81	41.75	0.200	11.31	48.33
3	3.26~2.86	Sand	27.0	15.0	0.0	19.38	7.81	31.95	0.200	11.31	42.18
4	2.86~2.26	Clay	0.0	15.0	12.0	16.30	7.81	28.03	0.200	11.31	40.59
5	2.26~1.26	Clay	0.0	15.0	12.0	12.88	7.81	22.15	0.200	11.31	41.13
6	1.26~0.00	Clay	0.0	15.0	25.0	7.18	7.81	12.35	0.200	11.31	43.63
7		embankment	30.0		0.0	105.45	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive 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/m³) (ascending force considered under WL)
- h : thickness of layer (m)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	60.40	0.23	0.00	0.00	0.13	0.23
2	58.95	1.00	0.13	0.23	0.73	1.23
3	54.81	0.40	0.73	1.23	1.01	1.63
4	45.00	0.60	1.01	1.63	1.61	2.23
5	45.00	1.00	1.61	2.23	2.61	3.23
6	45.00	1.26	2.61	3.23	3.87	4.49
7	60.00	0.90	3.87	4.49	4.39	5.39

From the above table, the loading width (L) on the ground surface is 3.87 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.77	14.67
Σ			14.67

γ : unit weight of embankment soil

A: sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{14.67 + 0.00 + 0.00}{3.87}$$
$$= 3.79 \text{ kN/m}^2$$

2.2.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	50.32	0.23	0.00	0.00	0.19	0.23
2	48.33	1.00	0.19	0.23	1.08	1.23
3	42.18	0.40	1.08	1.23	1.52	1.63
4	40.59	0.60	1.52	1.63	2.22	2.23
5	41.13	1.00	2.22	2.23	3.37	3.23
6	43.63	1.26	3.37	3.23	4.69	4.49
7	49.60	1.37	4.69	4.49	5.86	5.86

From the above table, the loading width (L) on the ground surface is 4.69 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	1.93	36.64
Σ			36.64

γ : unit weight of embankment soil

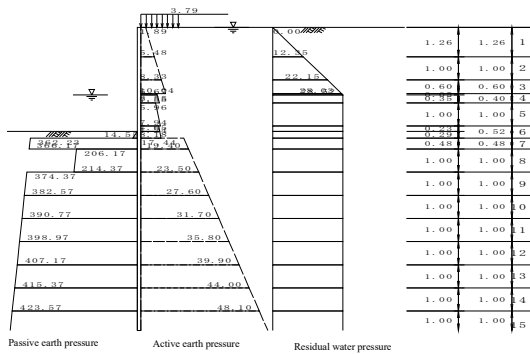
A: sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{36.64 + 0.00 + 0.00}{4.69}$$
$$= 7.81 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ, kN/m³	φ, degree	C, kN/m²	Σ γ h + Qa, kN/m²	Ka	Ka × cos δ
1	0.00-1.26	Clay	5.7	—	25.0	10.968	—	—
2	1.26-2.26	Clay	5.7	—	12.0	10.968	—	—
3	2.26-2.86	Clay	5.7	—	12.0	16.668	—	—
4	2.86-2.91	Sand	7.7	27.0	—	20.088	0.33738	0.32589
5	2.91-3.26	Sand	7.7	27.0	—	20.473	0.33738	0.32589
6	3.26-4.26	Sand	7.7	33.2	—	23.168	0.26623	0.25716
7	4.26-4.49	Sand	7.7	35.5	—	30.868	0.24280	0.23452
8	4.49-4.78	Sand	7.7	35.5	—	32.639	0.24280	0.23452
9	4.78-5.26	Clay	8.2	—	180.0	34.872	—	—
10	5.26-6.26	Clay	8.2	—	100.0	38.808	—	—
11	6.26-7.26	Clay	8.2	—	180.0	47.008	—	—
12	7.26-8.26	Clay	8.2	—	180.0	55.208	—	—

13	8.26-9.26	Clay	8.2	—	180.0	63.408	—	—
14	9.26-10.26	Clay	8.2	—	180.0	71.608	—	—
15	10.26-11.26	Clay	8.2	—	180.0	79.808	—	—
16	11.26-12.26	Clay	8.2	—	180.0	88.008	—	—
17	12.26-13.26	Clay	8.2	—	180.0	96.208	—	—
18	13.26-14.26	Clay	8.2	—	100.0	104.408	—	—
19	14.26-15.26	Clay	8.2	—	180.0	112.608	—	—
20	15.26-16.26	Clay	8.2	—	250.0	120.808	—	—
21	16.26-17.26	Clay	8.2	—	180.0	129.008	—	—
22	17.26-18.26	Clay	8.2	—	180.0	137.208	—	—
23	18.26-19.26	Clay	8.2	—	250.0	145.408	—	—
24	19.26-19.96	Clay	8.2	—	180.0	153.608	—	—
25	19.96-23.92	Clay	6.7	—	200.0	159.348	—	—
26	23.92-34.40	Clay	7.2	—	1000.0	185.880	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 15.00, β= 0.00, θ= 0.00

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ, kN/m³	φ, degree	C, kN/m²	Σ γ h + Qp, kN/m²	Kp	Kp × cos δ
8	4.49-4.78	Sand	7.7	35.5	—	0.000	6.74695	6.51706
9	4.78-5.26	Clay	8.2	0.0	180.0	2.233	6.169	—
10	5.26-6.26	Clay	8.2	0.0	100.0	6.169	14.369	—
11	6.26-7.26	Clay	8.2	0.0	180.0	14.369	22.569	—
12	7.26-8.26	Clay	8.2	0.0	180.0	22.569	30.769	—
13	8.26-9.26	Clay	8.2	0.0	180.0	30.769	38.969	—
14	9.26-10.26	Clay	8.2	0.0	180.0	38.969	47.169	—

15	10.26-11.26	Clay	8.2	0.0	180.0	47.169	—	—
16	11.26-12.26	Clay	8.2	0.0	180.0	55.369	—	—
17	12.26-13.26	Clay	8.2	0.0	180.0	63.569	—	—
18	13.26-14.26	Clay	8.2	0.0	100.0	71.769	—	—
19	14.26-15.26	Clay	8.2	0.0	180.0	79.969	—	—
20	15.26-16.26	Clay	8.2	0.0	250.0	88.169	—	—
21	16.26-17.26	Clay	8.2	0.0	180.0	96.369	—	—
22	17.26-18.26	Clay	8.2	0.0	180.0	104.569	—	—
23	18.26-19.26	Clay	8.2	0.0	250.0	112.769	—	—
24	19.26-19.96	Clay	8.2	0.0	180.0	120.969	—	—
25	19.96-23.92	Clay	6.7	20.0	200.0	126.709	—	—
26	23.92-34.40	Clay	7.2	30.0	1000.0	153.241	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
δ= -15.00, β= 0.00, θ= 0.00

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

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure		Passive
		Pa1, kN/m²	Pa2, kN/m²	Pa, kN/m²	Pw, kN/m²	Pp, kN/m²	
1	0.00-1.26	-46.21 -39.03	1.89 5.48	1.89 5.48	0.00 12.35	—	—
2	1.26-2.26	-13.03 -7.33	5.48 8.33	5.48 8.33	12.35 22.15	—	—
3	2.26-2.86	-7.33 -3.91	8.33 10.04	8.33 10.04	22.15 26.03	—	—
4	2.86-2.91	6.55 6.67	—	6.55 6.67	26.03 28.52	—	—
5	2.91-3.26	6.67 7.55	—	6.67 7.55	28.52 28.52	—	—
6	3.26-4.26	5.96 7.94	—	5.96 7.94	28.52 28.52	—	—
7	4.26-4.49	7.24 7.65	—	7.24 7.65	28.52 28.52	—	—
8	4.49-4.78	7.65 8.18	—	7.65 8.18	28.52 28.52	0.00 14.55	—

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

Kc : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

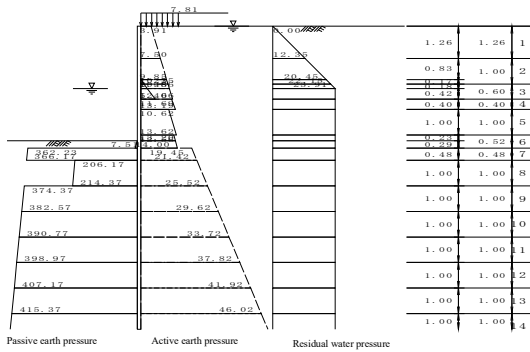
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{sub} kN/m ²	k (k ²)	θ degree	K _a	K _a $\times \cos \delta$	ζ degree
1	0.00- 1.26	Clay	5.7	—	25.0 25.0	7.81 15.00	0.00 12.35	0.200 0.200	11.31 11.31	— —	— —	44.08 43.63
2	1.26- 2.09	Clay	5.7	—	12.0 12.0	15.00 19.71	12.35 —	0.200 —	11.31 —	— —	— —	41.99
3	2.09- 2.26	Clay	5.7	—	12.0 12.0	19.71 20.70	— 22.15	0.200 0.200	11.31 11.31	— —	— —	41.13
4	2.26- 2.44	Clay	5.7	—	12.0 12.0	20.70 21.72	22.15 23.91	0.200 0.200	11.31 11.31	— —	— —	41.13 40.97
5	2.44- 2.86	Clay	5.7	—	12.0 12.0	21.72 24.12	23.91 28.03	0.200 0.200	11.31 11.31	— —	— —	40.97 40.59
6	2.86- 3.26	Sand	7.7	27.0	— —	24.12 27.20	28.03 31.95	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— —
7	3.26- 4.26	Sand	7.7	33.2	— —	27.20 34.90	31.95 41.75	0.200 0.200	11.31 11.31	0.40414 0.40414	0.39037 0.39037	— —
8	4.26- 4.49	Sand	7.7	35.5	— —	34.90 36.67	41.75 44.00	0.200 0.200	11.31 11.31	0.37261 0.37261	0.35992 0.35992	— —
9	4.49- 4.78	Sand	7.7	35.5	— —	36.67 46.84	44.00 46.84	0.200 0.200	11.31 11.31	0.37261 0.37261	0.35992 0.35992	— —
10	4.78- 5.26	Clay	8.2	—	180.0 180.0	38.90 42.84	46.84 51.55	0.200 0.200	11.31 11.31	— —	— —	44.62 44.59
11	5.26- 6.26	Clay	8.2	—	100.0 100.0	42.84 51.04	51.55 61.35	0.200 0.200	11.31 11.31	— —	— —	44.26 44.13
12	6.26- 7.26	Clay	8.2	—	180.0 180.0	51.04 59.24	61.35 71.15	0.200 0.200	11.31 11.31	— —	— —	44.52 44.46
13	7.26- 8.26	Clay	8.2	—	180.0 180.0	59.24 67.44	71.15 80.95	0.200 0.200	11.31 11.31	— —	— —	44.46 44.39

13	7.26- 8.26	Clay	8.20	0.0	180.0 180.0	22.569 30.769	27.15 36.95	0.200 0.200	11.31 11.31	— —	— —	— —
14	8.26- 9.26	Clay	8.20	0.0	180.0 180.0	30.769 38.969	36.95 46.75	0.200 0.200	11.31 11.31	— —	— —	— —
15	9.26- 10.26	Clay	8.20	0.0	180.0 180.0	38.969 47.169	46.75 56.55	0.200 0.200	11.31 11.31	— —	— —	— —
16	10.26- 11.26	Clay	8.20	0.0	180.0 180.0	47.169 55.369	56.55 66.35	0.200 0.200	11.31 11.31	— —	— —	— —
17	11.26- 12.26	Clay	8.20	0.0	180.0 180.0	55.369 63.569	66.35 76.15	0.200 0.200	11.31 11.31	— —	— —	— —
18	12.26- 13.26	Clay	8.20	0.0	180.0 180.0	63.569 71.769	76.15 85.95	0.200 0.200	11.31 11.31	— —	— —	— —
19	13.26- 14.26	Clay	8.20	0.0	100.0 100.0	71.769 79.969	85.95 95.75	0.200 0.200	11.31 11.31	— —	— —	— —
20	14.26- 15.26	Clay	8.20	0.0	180.0 180.0	79.969 88.169	95.75 105.55	0.200 0.200	11.31 11.31	— —	— —	— —
21	15.26- 16.26	Clay	8.20	0.0	250.0 250.0	88.169 96.369	105.55 115.35	0.200 0.200	11.31 11.31	— —	— —	— —
22	16.26- 17.26	Clay	8.20	0.0	180.0 180.0	96.369 104.569	115.35 125.15	0.200 0.200	11.31 11.31	— —	— —	— —
23	17.26- 18.26	Clay	8.20	0.0	180.0 180.0	104.569 112.769	125.15 134.95	0.200 0.200	11.31 11.31	— —	— —	— —
24	18.26- 19.26	Clay	8.20	0.0	250.0 250.0	112.769 120.969	134.95 144.75	0.200 0.200	11.31 11.31	— —	— —	— —
25	19.26- 19.96	Clay	8.20	0.0	180.0 180.0	120.969 126.709	144.75 151.61	0.200 0.200	11.31 11.31	— —	— —	— —
26	19.96- 23.92	Clay	6.70	20.0	200.0 200.0	126.709 153.241	151.61 190.41	0.200 0.200	11.31 11.31	— —	— —	— —
27	23.92- 34.40	Clay	7.20	30.0	1000.0 1000.0	153.241 228.097	190.41 293.12	0.200 0.200	11.31 11.31	— —	— —	— —

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.26	-40.60 -31.92	3.91 7.50	3.91 7.50	0.00 12.35	— —
2	1.26- 2.09	-5.81 0.00	7.50 9.85	7.50 9.85	12.35 20.45	— —
3	2.09- 2.26	0.00 1.21	9.85 10.35	9.85 10.35	20.45 22.15	— —
4	2.26- 2.44	1.21 2.48	10.35 10.86	10.35 10.86	22.15 23.91	— —

14	8.26- 9.26	Clay	8.2	—	180.0 180.0	67.44 75.64	80.95 90.75	0.200 0.200	11.31 11.31	— —	— —	44.39 44.32
15	9.26- 10.26	Clay	8.2	—	180.0 180.0	75.64 83.84	90.75 100.55	0.200 0.200	11.31 11.31	— —	— —	44.32 44.25
16	10.26- 11.26	Clay	8.2	—	180.0 180.0	83.84 92.04	100.55 110.35	0.200 0.200	11.31 11.31	— —	— —	44.25 44.18
17	11.26- 12.26	Clay	8.2	—	180.0 180.0	92.04 100.24	110.35 120.15	0.200 0.200	11.31 11.31	— —	— —	44.18 44.11
18	12.26- 13.26	Clay	8.2	—	180.0 180.0	100.24 108.44	120.15 129.95	0.200 0.200	11.31 11.31	— —	— —	44.11 44.04
19	13.26- 14.26	Clay	8.2	—	100.0 100.0	108.44 116.64	129.95 139.75	0.200 0.200	11.31 11.31	— —	— —	44.04 43.97
20	14.26- 15.26	Clay	8.2	—	180.0 180.0	116.64 124.84	139.75 149.55	0.200 0.200	11.31 11.31	— —	— —	43.97 43.90
21	15.26- 16.26	Clay	8.2	—	250.0 250.0	124.84 133.04	149.55 159.35	0.200 0.200	11.31 11.31	— —	— —	44.22 44.17
22	16.26- 17.26	Clay	8.2	—	180.0 180.0	133.04 141.24	159.35 169.15	0.200 0.200	11.31 11.31	— —	— —	44.17 44.10
23	17.26- 18.26	Clay	8.2	—	180.0 180.0	141.24 149.44	169.15 178.95	0.200 0.200	11.31 11.31	— —	— —	44.10 44.03
24	18.26- 19.26	Clay	8.2	—	250.0 250.0	149.44 157.64	178.95 188.75	0.200 0.200	11.31 11.31	— —	— —	44.03 44.02
25	19.26- 19.96	Clay	8.2	—	180.0 180.0	157.64 163.38	188.75 195.61	0.200 0.200	11.31 11.31	— —	— —	44.02 43.97
26	19.96- 23.92	Clay	6.7	—	200.0 200.0	163.38 189.91	195.61 234.42	0.200 0.200	11.31 11.31	— —	— —	43.97 43.51
27	23.92- 34.40	Clay	7.2	—	1000.0 1000.0	189.91 265.36	234.42 337.12	0.200 0.200	11.31 11.31	— —	— —	44.71 44.60

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.
 $\delta = 15.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

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

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Qp$ kN/m ²	γ_{sub} kN/m ²	k (k ²)	θ degree	K _p	K _p $\times \cos \delta$
9	4.49- 4.78	Sand	7.70	35.5	— —	0.000 2.233	0.00 2.84	0.200 0.200	11.31 11.31	3.36140 3.36140	3.36140 3.36140
10	4.78- 5.26	Clay	8.20	0.0	180.0 180.0	2.233 6.169	2.84 7.55	0.200 0.200	11.31 11.31	— —	— —
11	5.26- 6.26	Clay	8.20	0.0	100.0 100.0	6.169 14.369	7.55 17.35	0.200 0.200	11.31 11.31	— —	— —
12	6.26- 7.26	Clay	8.20	0.0	180.0 180.0	14.369 22.569	17.35 27.15	0.200 0.200	11.31 11.31	— —	— —

5	2.44- 2.86	2.48 5.46	10.86 12.06	10.86 12.06	23.91 23.91	— —
6	2.86- 3.26	11.69 13.19	— —	11.69 13.19	23.91 23.91	— —
7	3.26- 4.26	10.62 13.62	— —	10.62 13.62	23.91 23.91	— —
8	4.26- 4.49	12.56 13.20	— —	12.56 13.20	23.91 23.91	— —
9	4.49- 4.78	13.20 14.00	— —	13.20 14.00	23.91 23.91	0.00 7.51
10	4.78- 5.26	-113.25 -308.51	19.45 21.42	19.45 21.42	23.91 23.91	362.23 366.17
11	5.26- 6.26	-148.44 -138.54	21.42 25.52	21.42 25.52	23.91 23.91	206.17 214.37
12	6.26- 7.26	-298.64 -288.76	25.52 29.62	25.52 29.62	23.91 23.91	374.37 382.57
13	7.26- 8.26	-288.76 -278.87	29.62 33.72	29.62 33.72	23.91 23.91	382.57 390.77
14	8.26- 9.26	-278.87 -268.98	33.72 37.82	33.72 37.82	23.91 23.91	390.77 398.97
15	9.26- 10.26	-268.98 -259.08	37.82 41.92	37.82 41.92	23.91 23.91	398.97 407.17
16	10.26- 11.26	-259.08 -249.17	41.92 46.02	41.92 46.02	23.91 23.91	407.17 415.37
17	11.26- 12.26	-249.17 -239.26	46.02 50.12	46.02 50.12	23.91 23.91	415.37 423.57
18	12.26- 13.26	-239.26 -229.34	50.12 54.22	50.12 54.22	23.91 23.91	423.57 431.77
19	13.26- 14.26	-88.88 -58.88	54.22 58.32	54.22 58.32	23.91 23.91	271.77 279.97
20	14.26- 15.26	-219.42 -209.49	58.32 62.42	58.32 62.42	23.91 23.91	439.97 448.17
21	15.26- 16.26	-349.69 -339.79	62.42 66.52	62.42 66.52	23.91 23.91	588.17 596.37
22	16.26- 17.26	-199.55 -189.61	66.52 70.62	66.52 70.62	23.91 23.91	456.37 464.57
23	17.26- 18.26	-189.61 -179.66	70.62 74.72	70.62 74.72	23.91 23.91	464.57 472.77
24	18.26- 19.26	-319.96 -310.03	74.72 78.82	74.72 78.82	23.91 23.91	612.77 620.97
25	19.26- 19.96	-169.70 -162.73	78.82 81.69	78.82 81.69	23.91 23.91	480.97 486.71
26	19.96- 23.92	-202.86 -1681.02	81.69 94.95	81.69 94.95	23.91 23.91	526.71 553.24
27	23.92- 34.40	-1771.83 -1268.68	94.95 132.68	94.95 132.68	23.91 23.91	2153.24 2228.74

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
 Clay $P_{a1} = \Sigma \gamma h + Q - 2 C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
 Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

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

Clay $P_p = \Sigma \gamma h + Q + 2 C$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m2
1	2.44	0.00	0.00
2	3.44	1.00	2.46
3	4.44	2.00	3.47
4	4.49	2.05	3.52

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

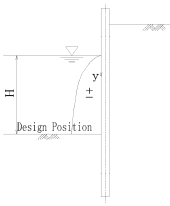
Where,

k_{is} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

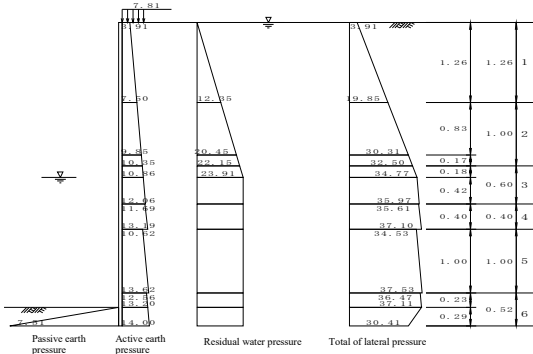
y : depth from water surface to the point where active water pressure is calculated



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.

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Ps kN/m2
1	0.00- 1.26	3.91 7.50	0.00 12.35	3.91 19.85
2	1.26- 2.09	7.50 9.85	12.35 20.45	19.85 30.31
3	2.09- 2.26	9.85 10.35	20.45 22.15	30.31 32.50
4	2.26- 2.44	10.35 10.86	22.15 23.91	32.50 34.77
5	2.44- 2.86	10.86 12.06	23.91 23.91	34.77 35.97
6	2.86- 3.26	11.69 13.19	23.91 23.91	35.61 37.10
7	3.26- 4.26	10.62 13.62	23.91 23.91	34.53 37.53
8	4.26- 4.49	12.56 13.20	23.91 23.91	36.47 37.11
9	4.49- 4.78	13.20 14.00	23.91 23.91	37.11 30.41
10	4.78- 5.26	19.45 21.42	23.91 23.91	362.23 -320.84

Pa : Active earth pressure

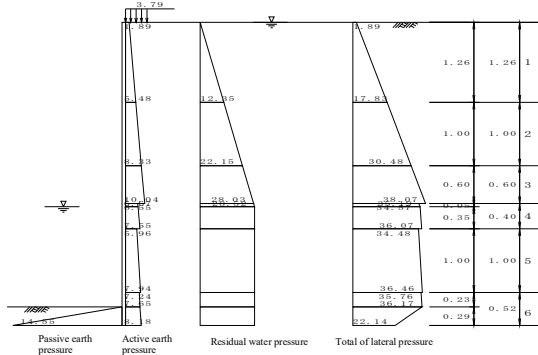
Pw : Residual water pressure

Pp : Passive earth pressure

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

Imaginary riverbed Lk: 0.29 m (GL -4.78 m)

4.1 Normal Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 1.26	1.89 5.48	0.00 12.35	— —	1.89 17.83
2	1.26- 2.26	5.48 8.33	12.35 22.15	— —	17.83 30.48
3	2.26- 2.86	8.33 10.04	22.15 28.03	— —	30.48 38.07
4	2.86- 2.91	6.55 6.67	28.03 28.52	— —	34.57 35.19
5	2.91- 3.26	6.67 7.55	28.52 28.52	— —	35.19 36.07
6	3.26- 4.26	5.96 7.04	28.52 28.52	— —	34.48 36.46
7	4.26- 4.49	7.24 7.65	28.52 28.52	— —	35.76 36.17
8	4.49- 4.78	7.65 8.18	28.52 28.52	0.00 14.55	36.17 22.14
9	4.78- 5.26	17.44 19.40	28.52 28.52	362.23 366.17	-318.28 -318.25

Pa : Active earth pressure

Pw : Residual water pressure

Pp : Passive earth pressure

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

Imaginary riverbed Lk: 0.29 m (GL -4.78 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

Average N-value is calculated depending on the sectional data. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B=10.00m)$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_b = 2800N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H H 400 -200 -9 -16 -13
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 = 98700 cm ⁴ (original condition)
	I = 80934 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 80934 × 10 ⁻⁸ = 1.619 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.76	5	11	10.76	27
2	1.76	2	12	11.76	29
3	2.76	2	13	12.76	30
4	3.76	22	14	13.76	13
5	4.76	28	15	14.76	30
6	5.76	10	16	15.76	31
7	6.76	24	17	16.76	30
8	7.76	28	18	17.76	24
9	8.76	21	19	18.76	21
10	9.76	29	20	19.76	28

5.2 Normal Condition

Assuming Kh = 13294 kN/m3,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.379 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.64 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.78 m) to 2.64 m depth (GL -7.42 m).

No	Depth Z	Thickness h	N Value	Area A

	m		m	upper	lower	
1	4.78	0.98	27.6	10.0	18.44	
2	5.76	1.00	10.0	24.0	17.00	
3	6.76	0.66	24.0	26.6	16.76	
L ~ Σ h = 2.64			Σ A ~ 52.20			

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

$$\begin{aligned}\text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{52.20}{2.64} \\ &= 19.76\end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned}E_0 &= 2800N' = 2800 \times 19.76 = 55329 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 55329 = 184429 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10} (B/0.3)^{-3/4} = 184429 (10.00/0.3)^{-3/4} = 13294 \text{ kN/m}^3\end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 13294 kN/m³.

5.3 Seismic Condition

Assuming Kh = 25167 kN/m³,

$$\begin{aligned}\beta &= 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.444 \text{ m}^{-1} \\ L &= \frac{1}{\beta} = 2.25 \text{ m}\end{aligned}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.78 m) and 2.25 m depth (GL -7.03 m).

No	Depth Z m	Thickness h m	N Value upper	lower	Area A
1	4.78	0.98	27.6	10.0	18.44
2	5.76	1.00	10.0	24.0	17.00
3	6.76	0.27	24.0	25.1	6.08
L ~ Σ h = 2.25			Σ A ~ 42.12		

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

$$\begin{aligned}\text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{42.12}{2.25} \\ &= 18.70\end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned}E_0 &= 2800N' = 2800 \times 18.70 = 52371 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 52371 = 349137 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10} (B/0.3)^{-3/4} = 349137 (10.00/0.3)^{-3/4} = 25167 \text{ kN/m}^3\end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 25167 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.26	1.26	1.89 17.83	1.19 11.23	4.36 3.94	5.20 44.26
2	1.26- 2.26	1.00	17.83 30.48	8.92 15.24	3.19 2.85	28.41 43.49
3	2.26- 2.86	0.60	30.48 38.07	9.14 11.42	2.32 2.12	21.22 24.21
4	2.86- 2.91	0.05	34.57 35.19	0.86 0.88	1.90 1.89	1.65 1.66
5	2.91- 3.26	0.35	35.19 36.07	6.16 6.31	1.75 1.64	10.80 10.33
6	3.26- 4.26	1.00	34.48 36.46	17.24 18.23	1.19 0.85	20.46 15.55
7	4.26- 4.49	0.23	35.76 36.17	4.11 4.16	0.44 0.37	1.82 1.53
8	4.49- 4.78	0.29	36.17 22.14	5.25 3.21	0.19 0.10	1.01 0.31
Σ P = 123.56			Σ M = 231.91			

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

Arbitrary load lateral load P_t = 0.0 kN/m
depth to acting position H_t = 0.0 m
moment M_{ta} = 0.0 kN·m/m
depth to acting position H_{ta} = 0.00 m
Height from riverbed to top of coping H = 4.49 m
Depth of Imaginary riverbed from riverbed L_k = 0.29 m

Moment M_t by arbitrary load is as below
M_t = P_t · (H + L_k - H_t) + M_{ta} = 0.00 kN·m

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned}h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} \\ &= \frac{231.91}{123.56} = 1.88 \text{ m}\end{aligned}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.26	1.26	3.91 19.85	2.46 12.50	4.36 3.94	10.73 49.26
2	1.26- 2.09	0.83	19.85 30.31	8.21 12.53	3.24 2.97	26.63 37.21
3	2.09- 2.26	0.17	30.31 32.50	2.62 2.81	2.64 2.58	6.91 7.24
4	2.26- 2.44	0.18	32.50 34.77	2.92 3.13	2.46 2.40	7.19 7.51
5	2.44- 2.86	0.42	34.77 35.97	7.30 7.55	2.20 2.06	16.06 15.56
6	2.86- 3.26	0.40	35.61 37.10	7.12 7.42	1.79 1.65	12.72 12.27
7	3.26- 4.26	1.00	34.53 37.53	17.26 18.77	1.19 0.85	20.49 16.01
8	4.26- 4.49	0.23	36.47 37.11	4.19 4.27	0.44 0.37	1.86 1.56
9	4.49- 4.78	0.29	37.11 30.41	5.38 4.41	0.19 0.10	1.04 0.43
Σ P = 130.87			Σ M = 250.68			

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

Arbitrary load lateral load P_t = 0.0 kN/m
depth to acting position H_t = 0.00 m
moment M_{ta} = 0.0 kN·m/m
depth to acting position H_{ta} = 0.00 m
Height from riverbed to top of coping H = 4.49 m
Depth of Imaginary riverbed from riverbed L_k = 0.29 m

Moment M_t by arbitrary load is as below
M_t = P_t · (H + L_k - H_t) + M_{ta} = 0.00 kN·m

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	2.44- 3.44	1.00	0.0 2.5	0.00 1.23	2.01 1.67	0.00 2.05
2	3.44- 4.44	1.00	2.5 3.5	1.23 1.74	1.01 0.67	1.24 1.17
3	4.44- 4.49	0.05	3.5 3.5	0.09 0.09	0.22 0.31	0.03 0.03
Σ P _{hw} = 4.37			Σ M _{hw} = 4.51			

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned}h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{hw}}{\Sigma P + P_t + \Sigma P_{hw}} \\ &= \frac{255.20}{135.23} = 1.89 \text{ m}\end{aligned}$$

6.2 Sectional Force

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

Material name 10 H H 400-200-9-16-13
Unit width B = 1.0000 m
Corrosion margin t_c = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.82
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 98700 cm⁴ (original condition)
I = 8943 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 80943 × 10⁻⁸
= 1.619 × 10⁷

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

$$M_{100} = M_0 \cdot \phi_a$$

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

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

$$M_{10} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _a	=	13294	kN/m ³
calculated value	β	=	0.37854	m ⁻¹
resultant earth force (lateral)	P ₀	=	123.56	kN/m
height of acting position of load	h ₀	=	1.88	m
moment	M ₀	=	231.91	kN·m/m
in consideration of ψ _m = 1.246,				
maximum moment	M _{max}	=	288.94	kN·m/m
depth of generated position of M _{max}	l _m	=	1.035	m
depth of 1 st fixed point	l _i	=	3.110	m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _a	=	25167	kN/m ³
calculated value	β	=	0.44402	m ⁻¹
resultant earth force (lateral)	P ₀	=	135.23	kN/m
height of acting position of load	h ₀	=	1.89	m
moment	M ₀	=	255.20	kN·m/m
in consideration of ψ _m = 1.192,				
maximum moment	M _{max}	=	304.21	kN·m/m
depth of generated position of M _{max}	l _m	=	0.805	m
depth of 1 st fixed point	l _i	=	2.574	m

6.3 Stress Intensity

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

Material Name	10 H ₂	H 400 -200 -9 -16 -13
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
Module of section	Z ₀	= 2700 cm ³ (original condition)
	Z	= 2268 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

σ = $\frac{M_{max}}{Z}$ = $\frac{288.94 \times 10^6}{2268 \times 10^3}$ = 127 N/mm² ≤ σ_s = 180 N/mm²

6.3.2 Seismic Condition

σ = $\frac{M_{max}}{Z}$ = $\frac{304.21 \times 10^6}{2268 \times 10^3}$ = 134 N/mm² ≤ σ_s = 270 N/mm²

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation						
No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-1.26	4.36 3.94	0.912 0.824	0.290 0.246	1.19 11.23	0.345 2.768

= $\frac{10.29 \times (4.49+0.29)^3}{2.00 \times 10^8 \times 80934 \times 10^{-8}}$ = 0.00695 m

δ = δ₁ + δ₂ + δ₃
= 0.01204 + 0.03082 + 0.00695
= 0.04980 m
Size = 49.80 ≤ δ_a = 50.00 mm

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6.4.2 Seismic Condition

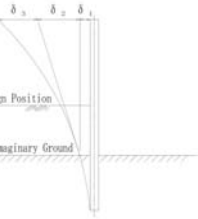
Modulus of deformation						
No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-1.26	4.36 3.94	0.912 0.824	0.290 0.246	2.46 12.50	0.713 3.080
2	1.26-2.09	3.24 2.97	0.679 0.621	0.178 0.153	8.21 12.53	1.463 1.917
3	2.09-2.26	2.64 2.58	0.351 0.339	0.124 0.119	2.62 2.81	0.328 0.355
4	2.26-2.44	2.46 2.40	0.515 0.502	0.110 0.105	2.92 3.13	0.321 0.328
5	2.44-2.86	2.20 2.06	0.460 0.431	0.090 0.080	7.30 7.55	0.655 0.601
6	2.86-3.26	1.79 1.65	0.374 0.346	0.061 0.053	7.12 7.42	0.435 0.393
7	3.26-4.26	1.19 0.85	0.248 0.179	0.028 0.015	17.26 18.77	0.488 0.281
8	4.26-4.49	0.44 0.37	0.093 0.077	0.004 0.003	4.19 4.27	0.017 0.012
9	4.49-4.78	0.19 0.10	0.040 0.020	0.001 0.000	5.38 4.41	0.004 0.001
ΣQ = 11.369						

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

2	1.26-2.26	3.19 2.85	0.667 0.597	0.173 0.143	8.92 15.24	1.541 2.175
3	2.26-2.86	2.32 2.12	0.485 0.444	0.099 0.084	9.14 11.42	0.903 0.957
4	2.86-2.91	1.90 1.89	0.398 0.395	0.069 0.068	0.86 0.88	0.059 0.060
5	2.91-3.26	1.75 1.64	0.367 0.342	0.059 0.052	6.16 6.31	0.364 0.328
6	3.26-4.26	1.19 0.85	0.248 0.179	0.028 0.015	17.24 18.23	0.487 0.273
7	4.26-4.49	0.44 0.37	0.093 0.077	0.004 0.003	4.11 4.16	0.017 0.012
8	4.49-4.78	0.19 0.10	0.040 0.020	0.001 0.000	5.25 3.21	0.004 0.001
ΣQ = 10.294						

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

Displacement Calculation



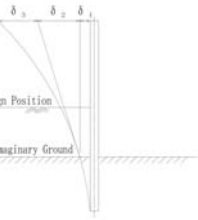
δ₁ = $\frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$
= $\frac{(1+0.3785 \times 1.88) \times 123.56}{2 \times 2.00 \times 10^8 \times 80934 \times 10^{-8} \times 0.3785^3}$ = 0.01204 m
δ₂ = $\frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$
= $\frac{(1+2 \times 0.3785 \times 1.88) \times 123.56}{2 \times 2.00 \times 10^8 \times 80934 \times 10^{-8} \times 0.3785^2} \times (4.49+0.29)$ = 0.03082 m
δ₃ = $\frac{Q \times (H+L_k)^3}{E I}$

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	2.44-3.44	2.01 1.67	0.420 0.350	0.076 0.054	0.00 1.23	0.000 0.066
2	3.44-4.44	1.01 0.67	0.211 0.141	0.021 0.009	1.23 1.74	0.025 0.016
3	4.44-4.49	0.32 0.31	0.068 0.064	0.002 0.002	0.09 0.09	0.000 0.000
Σ Q _{dw} = 0.109						

Therefore, the deformation coefficient Q is expressed by
Q = 11.369 + 0.109 = 11.478

Displacement Calculation



δ₁ = $\frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$
= $\frac{(1+0.4440 \times 1.89) \times 135.23}{2 \times 2.00 \times 10^8 \times 80934 \times 10^{-8} \times 0.4440^3}$ = 0.00877 m
δ₂ = $\frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$
= $\frac{(1+2 \times 0.4440 \times 1.89) \times 135.23}{2 \times 2.00 \times 10^8 \times 80934 \times 10^{-8} \times 0.4440^2} \times (4.49+0.29)$ = 0.02710 m
δ₃ = $\frac{Q \times (H+L_k)^3}{E I}$
= $\frac{11.48 \times (4.49+0.29)^3}{2.00 \times 10^8 \times 80934 \times 10^{-8}}$ = 0.00774 m

δ = δ₁ + δ₂ + δ₃
= 0.00877 + 0.02710 + 0.00774
= 0.04361 m
Size = 43.61 ≤ δ_a = 75.00 mm

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP

δ_s : Allowable displacement

7 Penetration Depth

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

Material Name	10 H 400-200-9-16-13
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 = 98700 cm ⁴ (original condition)
	I = 98700 cm ⁴ (after reduction by corrosion and section)
	EI = 200000 × 10 ³ × 98700 × 10 ⁻⁸ = 1.974 × 10 ⁶

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is Lk, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{11} + D$$
$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 13294 kN/m ³
Calculated value	β = 0.36022 m ⁻¹

Penetration length of SSP	$D = 0.29 + \frac{3}{0.360} = 8.62$ m
Whole length of SSP	$L = 4.49 - 0.40 + 8.62 = 12.71$ m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_b = 25167 kN/m ³
Calculated value	β = 0.42253 m ⁻¹

Penetration length of SSP	$D = 0.29 + \frac{3}{0.423} = 7.39$ m
Whole length of SSP	$L = 4.49 - 0.40 + 7.39 = 11.48$ m

Therefore, the total length of the sheet pile is 13.00 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H 400-200-9-16-13			
			Normal Condition	Seismic Condition	
Inertia sectional moment	I (cm ⁴)	98700			
Sectional Modulus	Z (cm ³)	2700			
Maximum bending moment	Mmax (kN · m · m)		288.94	304.21	
Stress intensity	σ (N/mm ²)		127 (180)	134 (270)	
Lateral displacement	δ (mm)		49.80 (50.0)	43.61 (75.0)	
Penetration depths	D (m)		8.62	7.39	
Whole length of SSP	L (m)	13.00			

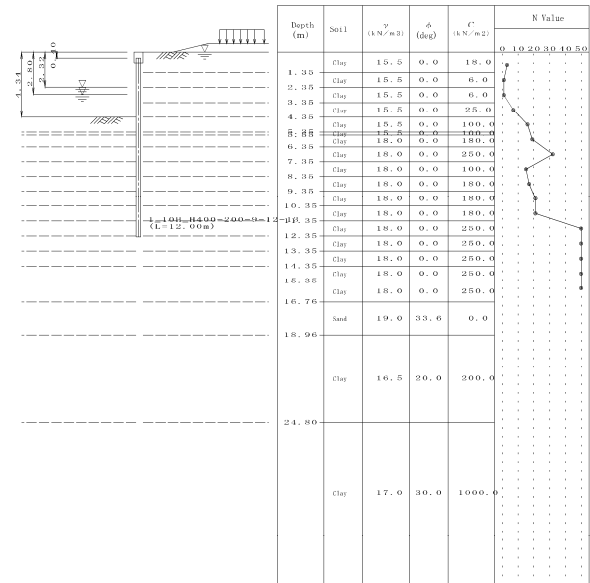
Block No. : L-30
Sta. : 12+520~12+820

Design Cross Section : Sta 12+540
Boring Name : BMLL-37

Specification : SSP SP-10H
(Combined) : H 400-200-9-12-13

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 4.34 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} = 2.80 m (Normal Condition)
	L _{wp} ' = 2.32 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress Chang's formula

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

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$

Rear side angle of slope not considered

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

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

1.5 Modulus of Lateral Subgrade Reaction

$$\text{Applied formula} \quad K_{10} = K_{10} \left(\frac{B_{10}}{0.3} \right)^{-3/4}$$

$$K_{100} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$B_{10} = 10.00 \text{ m}$$

$$E_0 = 2800 \text{ N}$$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

N-value distribution

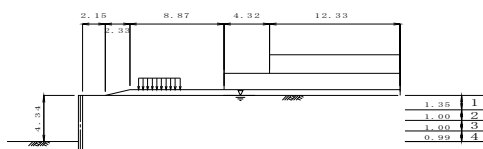
No	Depth m	N Value	No	Depth m	N Value
1	0.85	3	11	10.85	21
2	1.85	1	12	11.85	50
3	2.85	1	13	12.85	50
4	3.85	7	14	13.85	50
5	4.85	16	15	14.85	50
6	5.85	19	16	15.85	50
7	6.85	32			
8	7.85	15			
9	8.85	17			
10	9.85	21			

1.6 Vertical Load

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

Vertical load on riverside not considered

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	2.15	4.48	30.00	30.00	0.56	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	13.35	13.35	30.00	30.00	1.53	19.0	19.0	30.0	0.0	Auto	Auto
3	Mixed Soil	17.67	17.67	30.00	30.00	1.77	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	5.29	9.22	10.0	5.0

Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 400-200-9-12-13
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 87800 \text{ cm}^4$
Sectional factor $Z_0 = 2320 \text{ cm}^3$

Corrosion margin $t_1 = 1.00 \text{ mm}$ (riverside) $t_2 = 1.00 \text{ mm}$ (landside)

Corrosion rate (to I_0) $\eta = 0.80$
Corrosion rate (to Z_0) $\eta = 0.81$
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 $\sigma_a = 180 \text{ N/mm}$ (Normal)
 $\sigma'_a = 270 \text{ N/mm}$ (Seismic)

Allowable displacement $\delta_a = 50.0 \text{ mm}$ (Normal)
 $\delta'_a = 75.0 \text{ mm}$ (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

1.7 Soil Modulus

Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.35	1.35
2	2.35	1.00
3	3.35	1.00
4	4.35	1.00
5	5.35	1.00
6	5.55	0.20
7	6.35	0.80
8	7.35	1.00
9	8.35	1.00
10	9.25	1.00
11	10.35	1.00
12	11.35	1.00
13	12.35	1.00
14	13.35	1.00
15	14.35	1.00
16	15.35	1.00
17	16.76	1.41
18	18.96	2.20
19	24.80	5.84
20	34.30	9.50

No	Depth m	earth Soil	N Value kN/m ³	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.35	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200	Auto	Auto
2	2.35	C	1.0	15.50	5.70	0.0	6.0	0.0	0.200	Auto	Auto
3	3.35	C	1.0	15.50	5.70	0.0	6.0	0.0	0.200	Auto	Auto
4	4.35	C	7.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
5	5.35	C	16.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
6	5.55	C	19.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto
7	6.35	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
8	7.35	C	32.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
9	8.35	C	15.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
10	9.35	C	17.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto

No	Depth m	earth Soil	N Value kN/m ³	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
11	10.35	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	11.35	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	12.35	C	80.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
14	13.35	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	14.35	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	15.35	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	16.76	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	18.96	S	23.0	19.00	9.20	33.6	0.0	0.0	0.200	Auto	Auto
19	24.80	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
20	34.30	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

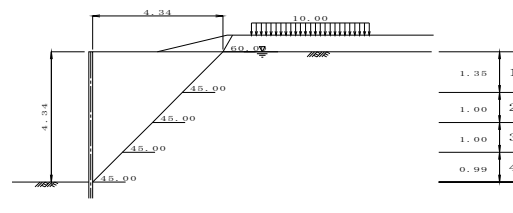
Note) depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
 γ : wet unit weight of soil
 γ' : saturated unit weight of soil
 ϕ : internal friction angle of soil
 C_0 : soil adhesion
a : slope of soil adhesion
k' : design seismic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

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

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	γ value kN/m ³	Angle of Rupture ζ degree
1	4.34-3.35	Clay	0.0	15.0	25.0	24.74	2.91	42.53	45.00
2	3.35-2.35	Clay	0.0	15.0	6.0	19.09	2.91	32.83	45.00
3	2.35-1.35	Clay	0.0	15.0	6.0	13.39	2.91	23.03	45.00
4	1.35-0.00	Clay	0.0	15.0	18.0	7.69	2.91	13.23	45.00
5		embankment t	30.0		0.0	73.34	0.00	0.00	60.00

• Angle of active rupture of sandy soil

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

• 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 $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.99	0.00	0.00	0.99	0.99
2	45.00	1.00	0.99	0.99	1.99	1.99
3	45.00	1.00	1.99	1.99	2.99	2.99
4	45.00	1.35	2.99	2.99	4.34	4.34
5	60.00	0.56	4.34	4.34	4.66	4.90

From the above table, the loading width (L) on the ground surface is 4.34 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.66	12.63
Σ			12.63

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

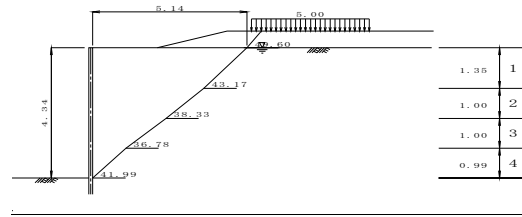
2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{12.63 + 0.00 + 0.00}{4.34}$$

$$= 2.91 \text{ kN/m}^2$$

2.2 Seismic 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	γ when kN/m ³	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	4.34 ~ 3.35	Clay	0.0	15.0	25.0	24.74	4.59	42.55	0.200	11.31	41.99
2	3.35 ~ 2.35	Clay	0.0	15.0	6.0	19.09	4.59	32.83	0.200	11.31	36.78
3	2.35 ~ 1.35	Clay	0.0	15.0	6.0	13.39	4.59	23.05	0.200	11.31	38.33
4	1.35 ~ 0.00	Clay	0.0	15.0	18.0	7.69	4.59	13.23	0.200	11.31	43.17
5		embankment	30.0	—	0.0	73.34	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	41.99	0.99	0.00	0.00	1.10	0.99
2	36.78	1.00	1.10	0.99	2.44	1.99
3	38.33	1.00	2.44	1.99	3.70	2.99
4	43.17	1.35	3.70	2.99	5.14	4.34
5	49.60	0.56	5.14	4.34	5.62	4.90

From the above table, the loading width (L) on the ground surface is 5.14 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	1.16	21.97
Σ			21.97

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	Ql kN/m
1	5.0	0.33	1.64
Σ			1.64

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

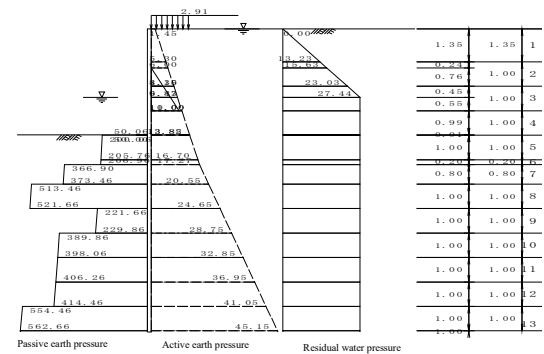
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{21.97 + 1.64 + 0.00}{5.14}$$

$$= 4.59 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Q_0$ kN/m ²	Ka	Ka $\times \cos \delta$
1	0.00-1.35	Clay	5.7	18.0	2.909	10.604	
2	1.35-1.59	Clay	5.7	6.0	10.604	12.000	
3	1.59-2.35	Clay	5.7	6.0	12.000	16.304	
4	2.35-2.80	Clay	5.7	6.0	16.304	18.869	
5	2.80-3.35	Clay	5.7	6.0	18.869	22.004	
6	3.35-4.34	Clay	5.7	25.0	22.004	27.647	
7	4.34-4.35	Clay	5.7	25.0	27.647	27.704	
8	4.35-5.35	Clay	5.7	100.0	27.704	33.404	
9	5.35-5.55	Clay	5.7	100.0	33.404	34.544	
10	5.55-6.35	Clay	8.2	180.0	34.544	41.104	
11	6.35-7.35	Clay	8.2	250.0	41.104	49.304	
12	7.35-8.35	Clay	8.2	100.0	49.304	57.504	

13	8.35- 9.35	Clay	8.2	—	180.0 180.0	57.504 65.704	—	—
14	9.35- 10.35	Clay	8.2	—	180.0 180.0	65.704 73.904	—	—
15	10.35- 11.35	Clay	8.2	—	180.0 180.0	73.904 82.104	—	—
16	11.35- 12.35	Clay	8.2	—	250.0 250.0	82.104 90.304	—	—
17	12.35- 13.35	Clay	8.2	—	250.0 250.0	90.304 98.504	—	—
18	13.35- 14.35	Clay	8.2	—	250.0 250.0	98.504 106.704	—	—
19	14.35- 15.35	Clay	8.2	—	250.0 250.0	106.704 114.904	—	—
20	15.35- 16.76	Clay	8.2	—	250.0 250.0	114.904 126.466	—	—
21	16.76- 18.96	Sand	9.2	33.6	—	126.466 146.706	0.26205 0.26205	0.25312 0.25312
22	18.96- 24.80	Clay	6.7	—	200.0 200.0	146.706 185.834	—	—
23	24.80- 34.30	Clay	7.2	—	1000.0 1000.0	185.834 254.234	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	K_p	$K_p \times \cos \delta$
7	4.34- 4.35	Clay	5.7	0.0	25.0 25.0	0.000 0.057	—	—
8	4.35- 5.35	Clay	5.7	0.0	100.0 100.0	0.057 5.757	—	—
9	5.35- 5.55	Clay	5.7	0.0	100.0 100.0	5.757 6.897	—	—
10	5.55- 6.35	Clay	8.2	0.0	180.0 180.0	6.897 13.457	—	—
11	6.35- 7.35	Clay	8.2	0.0	250.0 250.0	13.457 21.657	—	—
12	7.35- 8.35	Clay	8.2	0.0	100.0 100.0	21.657 29.857	—	—
13	8.35- 9.35	Clay	8.2	0.0	180.0 180.0	29.857 38.057	—	—
14	9.35- 10.35	Clay	8.2	0.0	180.0 180.0	38.057 46.257	—	—
15	10.35- 11.35	Clay	8.2	0.0	180.0 180.0	46.257 54.457	—	—
16	11.35- 12.35	Clay	8.2	0.0	250.0 250.0	54.457 62.657	—	—

14	9.35- 10.35	-294.30 -286.10	32.85 36.95	32.85 36.95	27.44 27.44	398.06 406.26
15	10.35- 11.35	-286.10 -277.90	36.95 41.05	36.95 41.05	27.44 27.44	406.26 414.46
16	11.35- 12.35	-417.90 -409.70	41.05 45.15	41.05 45.15	27.44 27.44	554.46 562.66
17	12.35- 13.35	-409.70 -401.50	45.15 49.25	45.15 49.25	27.44 27.44	562.66 570.86
18	13.35- 14.35	-401.50 -393.30	49.25 53.35	49.25 53.35	27.44 27.44	570.86 579.06
19	14.35- 15.35	-393.30 -385.10	53.35 57.45	53.35 57.45	27.44 27.44	579.06 587.26
20	15.35- 16.76	-385.10 -373.53	57.45 63.23	57.45 63.23	27.44 27.44	587.26 598.82
21	16.76- 18.96	32.01 37.13	—	32.01 37.13	27.44 27.44	577.83 686.18
22	18.96- 24.80	-253.29 -214.17	73.35 92.92	73.35 92.92	27.44 27.44	519.06 558.19
23	24.80- 34.30	-1814.17 -1745.77	92.92 127.12	92.92 127.12	27.44 27.44	2158.19 2226.59

- Formula for active earth pressure

$$\begin{aligned} \text{Sand} \quad P_{a1} &= K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_{a1} &= \Sigma \gamma h + Q - 2C \\ P_{a1} &= K_a \cdot (\Sigma \gamma h + Q) \\ K_a &: \text{Equilibrium coefficient of compression: } 0.5 \\ &\text{Larger of } Pa1 \text{ or } Pa2 \text{ is applied as active earth pressure (Pa)} \end{aligned}$$

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

- Formula for passive earth pressure

$$\begin{aligned} \text{Sand} \quad P_p &= K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_p &= \Sigma \gamma h + Q + 2C \\ \text{Mixed soil} \quad P_p &= [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta \end{aligned}$$

17	12.35- 13.35	Clay	8.2	0.0	250.0 250.0	62.657 70.857	—	—
18	13.35- 14.35	Clay	8.2	0.0	250.0 250.0	70.857 79.057	—	—
19	14.35- 15.35	Clay	8.2	0.0	250.0 250.0	79.057 87.257	—	—
20	15.35- 16.76	Clay	8.2	0.0	250.0 250.0	87.257 98.819	—	—
21	16.76- 18.96	Sand	9.2	33.6	—	98.819 119.059	6.05364 6.05364	5.84737 5.84737
22	18.96- 24.80	Clay	6.7	20.0	200.0 200.0	119.059 158.187	—	—
23	24.80- 34.30	Clay	7.2	30.0	1000.0 1000.0	158.187 226.587	—	—

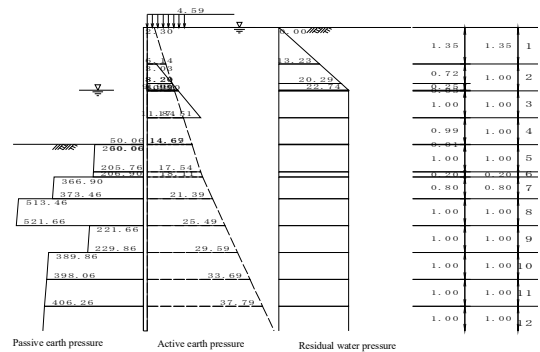
Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m ²	Pa2 kN/m ²	Pu kN/m ²	Pw kN/m ²	Pp kN/m ²		
1	0.00- 1.35	-33.09 -25.40	1.45 5.30	1.45 5.30	0.00 13.23	—		
2	1.35- 1.59	-1.40 0.00	5.30 6.00	5.30 6.00	13.23 15.63	—		
3	1.59- 2.35	0.00 4.30	6.00 8.15	6.00 8.15	15.63 23.03	—		
4	2.35- 2.80	4.30 6.87	8.15 9.43	8.15 9.43	23.03 27.44	—		
5	2.80- 3.35	6.87 10.00	9.43 11.00	9.43 11.00	27.44 27.44	—		
6	3.35- 4.34	-28.00 -22.35	11.00 13.82	11.00 13.82	27.44 27.44	—		
7	4.34- 4.35	-22.35 -22.30	13.82 13.85	13.82 13.85	27.44 27.44	50.00 50.06		
8	4.35- 5.35	-172.30 -166.60	13.85 16.70	13.85 16.70	27.44 27.44	200.06 205.76		
9	5.35- 5.55	-166.60 -165.46	16.70 17.27	16.70 17.27	27.44 27.44	205.76 206.90		
10	5.55- 6.35	-325.46 -318.90	17.27 20.55	17.27 20.55	27.44 27.44	366.90 373.46		
11	6.35- 7.35	-458.90 -450.70	20.55 24.65	20.55 24.65	27.44 27.44	513.46 521.66		
12	7.35- 8.35	-450.70 -142.50	24.65 28.75	24.65 28.75	27.44 27.44	221.66 229.86		
13	8.35- 9.35	-302.50 -294.30	28.75 32.85	28.75 32.85	27.44 27.44	389.86 398.06		

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γw_{sat} kN/m ²	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.35	Clay	5.7	—	18.0 18.0	4.59 12.29	0.00 13.23	0.200 0.200	11.31 11.31	—	—	44.29 43.17
2	1.35- 2.07	Clay	5.7	—	6.0 6.0	12.29 16.39	13.23 16.39	0.200 0.200	11.31 11.31	—	—	40.11
3	2.07- 2.32	Clay	5.7	—	6.0 6.0	16.39 17.82	16.39 17.82	0.200 0.200	11.31 11.31	—	—	38.38
4	2.32- 2.35	Clay	5.7	—	6.0 6.0	17.82 17.99	22.74 23.03	0.200 0.200	11.31 11.31	—	—	38.38 38.33
5	2.35- 3.35	Clay	5.7	—	6.0 6.0	17.99 21.69	23.03 32.83	0.200 0.200	11.31 11.31	—	—	38.33 36.78
6	3.35- 4.34	Clay	5.7	—	25.0 25.0	21.69 29.33	32.83 42.53	0.200 0.200	11.31 11.31	—	—	42.52 41.99
7	4.34- 4.35	Clay	5.7	—	25.0 25.0	29.33 29.39	42.53 42.63	0.200 0.200	11.31 11.31	—	—	41.99 41.98
8	4.35- 5.35	Clay	5.7	—	100.0 100.0	29.39 35.09	42.63 52.43	0.200 0.200	11.31 11.31	—	—	44.18 44.03
9	5.35- 5.55	Clay	5.7	—	100.0 100.0	35.09 36.23	52.43 54.39	0.200 0.200	11.31 11.31	—	—	44.03 44.00
10	5.55- 6.35	Clay	8.2	—	180.0 180.0	36.23 42.79	54.39 62.23	0.200 0.200	11.31 11.31	—	—	44.43 44.33
11	6.35- 7.35	Clay	8.2	—	250.0 250.0	42.79 50.99	62.23 72.03	0.200 0.200	11.31 11.31	—	—	44.52 44.43
12	7.35- 8.35	Clay	8.2	—	100.0 100.0	50.99 59.19	72.03 81.83	0.200 0.200	11.31 11.31	—	—	43.61 43.40
13	8.35- 9.35	Clay	8.2	—	180.0 180.0	59.19 67.39	81.83 91.63	0.200 0.200	11.31 11.31	—	—	44.09 43.97

14	9.35-10.35	Clay	8.2	—	180.0	67.39	91.63	0.200	11.31	—	—	43.97	43.85
					180.0	75.59	101.43	0.200	11.31	—	—	43.85	43.73
15	10.35-11.35	Clay	8.2	—	180.0	83.79	111.23	0.200	11.31	—	—	44.07	43.98
					250.0	91.99	121.03	0.200	11.31	—	—	44.07	43.98
16	11.35-12.35	Clay	8.2	—	250.0	91.99	121.03	0.200	11.31	—	—	43.98	43.90
					250.0	100.19	130.83	0.200	11.31	—	—	43.98	43.90
17	12.35-13.35	Clay	8.2	—	250.0	100.19	130.83	0.200	11.31	—	—	43.90	43.81
					250.0	108.39	140.63	0.200	11.31	—	—	43.90	43.81
18	13.35-14.35	Clay	8.2	—	250.0	108.39	140.63	0.200	11.31	—	—	43.81	43.72
					250.0	116.59	150.43	0.200	11.31	—	—	43.81	43.72
19	14.35-15.35	Clay	8.2	—	250.0	116.59	150.43	0.200	11.31	—	—	43.72	43.66
					250.0	128.15	164.25	0.200	11.31	—	—	43.72	43.66
20	15.35-16.76	Clay	8.2	—	250.0	128.15	164.25	0.200	11.31	—	—	43.66	43.60
					250.0	148.39	185.81	0.200	11.31	0.39850	0.38492	—	—
21	16.76-18.96	Sand	9.2	33.6	—	128.15	164.25	0.200	11.31	0.39850	0.38492	—	—
					—	148.39	185.81	0.200	11.31	—	—	—	—
22	18.96-24.80	Clay	6.7	—	200.0	148.39	185.81	0.200	11.31	—	—	43.02	42.54
					200.0	187.52	243.04	0.200	11.31	—	—	43.02	42.54
23	24.80-34.30	Clay	7.2	—	1000.0	187.52	243.04	0.200	11.31	—	—	44.47	44.29
					1000.0	255.92	336.14	0.200	11.31	—	—	44.47	44.29

• The principal earth pressure coefficient (Ka) of Sand is calculated by the following equation.
 $\delta = 15.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γ ulw kN/m2	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
7	4.34-4.35	Clay	5.70	0.0	25.0	0.000	0.00	0.00	11.31	—	—
					25.0	0.057	0.10	0.200	11.31	—	—
8	4.35-5.35	Clay	5.70	0.0	100.0	0.057	0.10	0.200	11.31	—	—
					100.0	5.757	9.90	0.200	11.31	—	—
9	5.35-5.55	Clay	5.70	0.0	100.0	5.757	9.90	0.200	11.31	—	—
					100.0	6.897	11.86	0.200	11.31	—	—
10	5.55-6.35	Clay	8.20	0.0	180.0	6.897	11.86	0.200	11.31	—	—
					180.0	13.457	19.70	0.200	11.31	—	—
11	6.35-7.35	Clay	8.20	0.0	250.0	13.457	19.70	0.200	11.31	—	—
					250.0	21.657	29.50	0.200	11.31	—	—
12	7.35-8.35	Clay	8.20	0.0	100.0	21.657	29.50	0.200	11.31	—	—
					100.0	29.857	39.30	0.200	11.31	—	—

9	5.35-5.55	-157.77	17.54	17.54	22.74	205.76
		-156.39	18.11	18.11	22.74	206.90
10	5.55-6.35	-316.45	18.11	18.11	22.74	366.90
		-308.55	21.39	21.39	22.74	373.46
11	6.35-7.35	-448.58	21.39	21.39	22.74	513.66
		-438.71	25.49	25.49	22.74	521.66
12	7.35-8.35	-138.54	25.49	25.49	22.74	221.66
		-128.61	29.59	29.59	22.74	229.86
13	8.35-9.35	-288.77	29.59	29.59	22.74	389.86
		-278.87	33.69	33.69	22.74	398.06
14	9.35-10.35	-278.87	33.69	33.69	22.74	398.06
		-268.97	37.79	37.79	22.74	406.26
15	10.35-11.35	-268.97	37.79	37.79	22.74	406.26
		-259.05	41.89	41.89	22.74	414.46
16	11.35-12.35	-399.17	41.89	41.89	22.74	554.46
		-389.27	45.99	45.99	22.74	562.66
17	12.35-13.35	-389.27	45.99	45.99	22.74	562.66
		-379.36	50.09	50.09	22.74	570.86
18	13.35-14.35	-379.36	50.09	50.09	22.74	570.86
		-369.45	54.19	54.19	22.74	579.06
19	14.35-15.35	-369.45	54.19	54.19	22.74	579.06
		-359.53	58.29	58.29	22.74	587.26
20	15.35-16.76	-359.53	58.29	58.29	22.74	587.26
		-345.53	64.07	64.07	22.74	598.82
21	16.76-18.96	49.33	—	49.33	22.74	304.73
		57.12	—	57.12	22.74	367.15
22	18.96-24.80	-220.76	74.19	74.19	22.74	519.06
		-173.09	93.76	93.76	22.74	558.19
23	24.80-34.30	-1774.62	93.76	93.76	22.74	2158.19
		-1692.23	127.96	127.96	22.74	2206.39

• Formula for active earth pressure

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

Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

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

Clay $P_p = \Sigma \gamma h + Q + 2C$

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

13	8.35-9.35	Clay	8.20	0.0	180.0	29.857	39.30	0.200	11.31	—	—	—	—
					180.0	38.057	49.10	0.200	11.31	—	—	—	—
14	9.35-10.35	Clay	8.20	0.0	180.0	38.057	49.10	0.200	11.31	—	—	—	—
					180.0	46.257	58.90	0.200	11.31	—	—	—	—
15	10.35-11.35	Clay	8.20	0.0	180.0	46.257	58.90	0.200	11.31	—	—	—	—
					180.0	54.457	68.70	0.200	11.31	—	—	—	—
16	11.35-12.35	Clay	8.20	0.0	250.0	54.457	68.70	0.200	11.31	—	—	—	—
					250.0	62.657	78.50	0.200	11.31	—	—	—	—
17	12.35-13.35	Clay	8.20	0.0	250.0	62.657	78.50	0.200	11.31	—	—	—	—
					250.0	70.857	88.30	0.200	11.31	—	—	—	—
18	13.35-14.35	Clay	8.20	0.0	250.0	70.857	88.30	0.200	11.31	—	—	—	—
					250.0	79.057	98.10	0.200	11.31	—	—	—	—
19	14.35-15.35	Clay	8.20	0.0	250.0	79.057	98.10	0.200	11.31	—	—	—	—
					250.0	87.257	107.90	0.200	11.31	—	—	—	—
20	15.35-16.76	Clay	8.20	0.0	250.0	87.257	107.90	0.200	11.31	—	—	—	—
					250.0	98.819	121.72	0.200	11.31	—	—	—	—
21	16.76-18.96	Sand	9.20	33.6	—	98.819	121.72	0.200	11.31	3.08376	3.08376	—	—
					—	119.059	143.28	0.200	11.31	3.08376	3.08376	—	—
22	18.96-24.80	Clay	6.70	20.0	200.0	119.059	143.28	0.200	11.31	—	—	—	—
					200.0	138.187	200.51	0.200	11.31	—	—	—	—
23	24.80-34.30	Clay	7.20	30.0	1000.0	138.187	200.51	0.200	11.31	—	—	—	—
					1000.0	226.587	293.61	0.200	11.31	—	—	—	—

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00-1.35	-30.48	2.80	2.80	0.00	—
		-21.17	6.14	6.14	13.23	—
2	1.35-2.07	3.03	6.14	6.14	13.23	—
		8.20	8.20	8.20	20.29	—
3	2.07-2.32	8.20	8.20	8.20	20.29	—
		9.99	8.91	9.99	22.74	—
4	2.32-2.35	9.99	8.91	9.99	22.74	—
		10.20	8.99	10.20	22.74	—
5	2.35-3.35	10.20	8.99	10.20	22.74	—
		17.51	11.84	17.51	22.74	—
6	3.35-4.34	-21.33	11.84	11.84	22.74	—
		-14.43	14.67	14.67	22.74	—
7	4.34-4.35	-14.43	14.67	14.67	22.74	50.00
		-14.36	14.69	14.69	22.74	50.06
8	4.35-5.35	-164.65	14.69	14.69	22.74	200.06
		-157.77	17.54	17.54	22.74	205.76

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth, m	water level, y, m	pdw, kN/m2
1	2.32	0.00	0.00
2	3.32	1.00	2.44
3	4.32	2.00	3.45
4	4.34	2.02	3.46

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

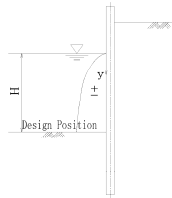
Where,

k_{dw} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

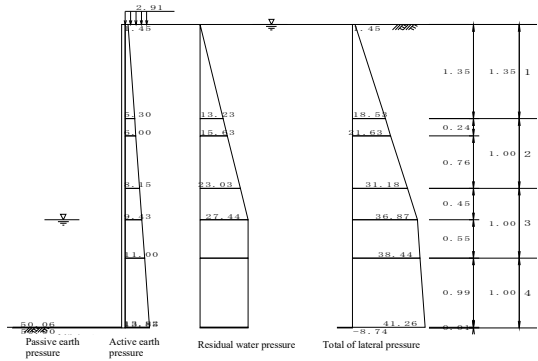
y : depth from water surface to the point where active water pressure is calculated



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

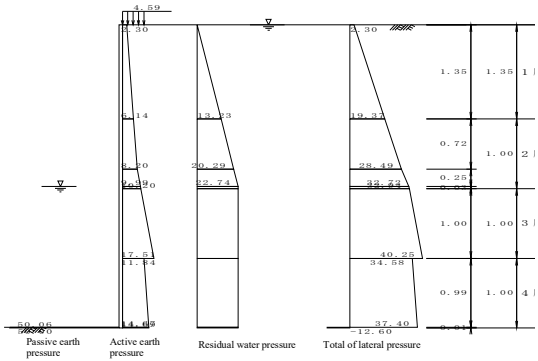


No	Depth m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00- 1.35	1.45 5.30	0.00 13.23	——— ———	1.45 18.53
2	1.35- 1.60	5.30 6.00	13.23 15.63	——— ———	18.53 21.63
3	1.60- 2.35	6.00 8.15	15.63 23.03	——— ———	21.63 31.18
4	2.35- 2.80	8.15 9.43	23.03 27.44	——— ———	31.18 36.87
5	2.80- 3.35	9.43 11.00	27.44 27.44	——— ———	36.87 38.44
6	3.35- 4.34	11.00 13.82	27.44 27.44	——— ———	38.44 41.26
7	4.34- 4.35	13.82 13.85	27.44 27.44	50.00 50.06	-8.74 -8.76

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_A : 0.00 m (GL -4.34 m)

4.2 Seismic Condition



No	Depth m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00- 1.35	2.30 6.14	0.00 13.23	——— ———	2.30 19.37
2	1.35- 2.07	6.14 8.20	13.23 20.29	——— ———	19.37 28.49
3	2.07- 2.32	8.20 9.99	20.29 22.74	——— ———	28.49 32.72
4	2.32- 2.35	9.99 10.20	22.74 22.74	——— ———	32.72 32.94
5	2.35- 3.35	10.20 17.51	22.74 22.74	——— ———	32.94 40.25
6	3.35- 4.34	11.84 14.67	22.74 22.74	——— ———	34.58 37.40
7	4.34- 4.35	14.67 14.69	22.74 22.74	50.00 50.06	-12.60 -12.63

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_A : 0.00 m (GL -4.34 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

Average N-value $N' = \frac{\sum A}{L}$
 $= \frac{50.95}{2.54}$
 $= 20.06$

K_h is recalculated from the calculated average N value.

$E_0 = 2800N' = 2800 \times 20.06 = 56160 \text{ kN/m}^2$
 $K_{10} = \frac{1}{0.3} \times \alpha \times 56160 = 187198 \text{ kN/m}^3$ (α : Normal Condition =1, Seismic Condition =2)
 $K_h = K_{10}(B_H/0.3)^{-3/4} = 187198(10.00/0.3)^{-3/4} = 13494 \text{ kN/m}^3$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 13494 kN/m³.

5.3 Seismic Condition

Assuming $K_h = 24787 \text{ kN/m}^3$,

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.458 \text{ m}^{-1}$

$L = \frac{1}{\beta} = 2.18 \text{ m}$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.34 m) and 2.18 m depth (GL -6.52 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.34	0.51	11.4	16.0	6.99
2	4.85	1.00	16.0	19.0	17.50
3	5.85	0.67	19.0	27.7	15.70
L = $\sum h = 2.18$			$\sum A = 40.19$		

A: (upper N-value + lower N-value) $\times h/2$

Average N-value $N' = \frac{\sum A}{L}$
 $= \frac{40.19}{2.18}$
 $= 18.42$

K_h is recalculated from the calculated average N value.

$E_0 = 2800N' = 2800 \times 18.42 = 51578 \text{ kN/m}^2$
 $K_{10} = \frac{1}{0.3} \times \alpha \times 51578 = 343855 \text{ kN/m}^3$ (α : Normal Condition =1, Seismic Condition =2)
 $K_h = K_{10}(B_H/0.3)^{-3/4} = 343855(10.00/0.3)^{-3/4} = 24787 \text{ kN/m}^3$

5.2 Normal Condition

Assuming $K_h = 13494 \text{ kN/m}^3$,

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.394 \text{ m}^{-1}$

$L = \frac{1}{\beta} = 2.54 \text{ m}$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.34 m) to 2.54 m depth (GL -6.88 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.34	0.51	11.4	16.0	6.99
2	4.85	1.00	16.0	19.0	17.50
3	5.85	1.00	19.0	32.0	25.50
4	6.85	0.03	32.0	31.5	0.96
L = $\sum h = 2.54$			$\sum A = 50.95$		

A: (upper N-value + lower N-value) $\times h/2$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 24787 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth, Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.35	1.35	1.45 18.53	0.98 12.51	3.89 3.44	3.82 43.03
2	1.35- 1.59	0.24	18.53 21.63	2.27 2.65	2.91 2.83	6.60 7.49
3	1.59- 2.35	0.76	21.63 31.18	8.17 11.77	2.49 2.24	20.36 26.39
4	2.35- 2.80	0.45	31.18 36.87	7.02 8.30	1.84 1.69	12.91 14.62
5	2.80- 3.35	0.55	36.87 38.44	10.14 10.57	1.36 1.17	13.76 12.40
6	3.35- 4.34	0.99	38.44 41.26	19.03 20.43	0.66 0.33	12.56 6.74
			ΣP= 113.83	ΣM= 180.08		

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_i = 0.0 kN/m
depth to acting position H_i = 0.0 m
moment M_{in} = 0.0 kN·m/m
depth to acting position H_{in} = 0.00 m
Height from riverbed to top of coping H = 4.34 m
Depth of Imaginary riverbed from riverbed L_k = 0.29 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 0.00 \text{ kN} \cdot \text{m}$$

h₀ Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{\frac{P_0}{113.83}} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = 1.58 \text{ m}$$

6.1.2 Seismic Condition

No	Depth, Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.35	1.35	2.30 19.37	1.55 13.08	3.89 3.44	6.03 44.99
2	1.35- 2.07	0.72	19.37 28.49	6.98 10.26	2.75 2.51	19.19 25.75
3	2.07- 2.32	0.25	28.49 32.72	3.55 4.08	2.19 2.10	7.77 8.59
4	2.32- 2.35	0.03	32.72 32.94	0.49 0.49	2.01 2.00	0.99 0.99
5	2.35- 3.35	1.00	32.94 40.25	16.47 20.12	1.66 1.32	27.29 26.63
6	3.35- 4.34	0.99	34.58 37.40	17.12 18.51	0.66 0.35	11.30 6.11
			ΣP= 112.72	ΣM= 185.62		

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_i = 0.0 kN/m
depth to acting position H_i = 0.00 m
moment M_{in} = 0.0 kN·m/m
depth to acting position H_{in} = 0.00 m
Height from riverbed to top of coping H = 4.34 m
Depth of Imaginary riverbed from riverbed L_k = 0.29 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 0.00 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth, Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	2.32- 3.32	1.00	0.0 2.4	0.00 1.22	1.69 1.35	0.00 1.65
2	3.32- 4.32	1.00	2.4 3.4	1.22 1.72	0.69 0.35	0.84 0.61
3	4.32- 4.34	0.02	3.4 3.5	0.03 0.03	0.01 0.01	0.00 0.00
			ΣP _{dw} = 4.21	ΣM _{dw} = 3.10		

h₀ Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{\frac{P_0}{188.71}} = \frac{\Sigma M + M_i + \Sigma M_{dw}}{\Sigma P + P_i + \Sigma P_{dw}} = 1.61 \text{ m}$$

6.2 Sectional Force

Material Name 10 H H 400 -200 -9 -12 -13
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.81
Section efficiency μ = 1.00
Module of section Z₀ = 2320 cm³ (original condition)
Z = 1879 cm³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{233.76 \times 10^6}{1879 \times 10^3} = 124 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{232.45 \times 10^6}{1879 \times 10^3} = 124 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth, m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.35	3.89 3.44	0.096 0.793	0.282 0.231	0.98 12.51	0.277 2.891
2	1.35- 1.59	2.91 2.83	0.670 0.651	0.174 0.166	2.27 2.65	0.396 0.440
3	1.59- 2.35	2.49 2.24	0.575 0.517	0.133 0.110	8.17 11.77	1.090 1.300
4	2.35- 2.80	1.84 1.69	0.424 0.389	0.077 0.066	7.02 8.30	0.541 0.547
5	2.80- 3.35	1.36 1.17	0.313 0.270	0.084 0.033	10.14 10.57	0.444 0.352
6	3.35- 4.34	0.66 0.33	0.152 0.076	0.011 0.003	19.03 20.43	0.209 0.058
			ΣQ= 8.544			

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{H + L_k}{(3 - \alpha) \times \alpha^2}$$

$$\zeta : \zeta = \frac{P}{6}$$

Q : ζ x P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement Calculation

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

Material name 10 H H 400 -200 -9 -12 -13
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.80
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 87800 cm⁴ (original condition)
I = 70240 cm⁴ (after reduction by corrosion and section)
EI = 200000 x 10³ x 70240 x 10⁻⁸ = 1.405 x 10⁵

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction K_h = 13494 kN/m³
calculated value β = 0.39366 m⁻¹
resultant earth force (lateral) P₀ = 113.83 kN/m
height of acting position of load h₀ = 1.58 m
moment M₀ = 180.08 kN·m/m

in consideration of ψ₀ = 1.298,

maximum moment M_{max} = 233.76 kN·m/m
depth of generated position of M_{max} l_m = 1.064 m
depth of lst fixed point l_i = 3.059 m

6.2.2 Seismic Condition

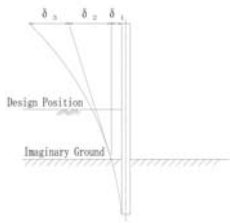
modulus of lateral subgrade reaction K_h = 24787 kN/m³
calculated value β = 0.45828 m⁻¹
resultant earth force (lateral) P₀ = 116.95 kN/m
height of acting position of load h₀ = 1.61 m
moment M₀ = 188.71 kN·m/m

in consideration of ψ₀ = 1.232,

maximum moment M_{max} = 232.45 kN·m/m
depth of generated position of M_{max} l_m = 0.837 m
depth of lst fixed point l_i = 2.550 m

6.3 Stress Intensity

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



$$\begin{aligned}\delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3937 \times 1.58) \times 113.83}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3937^3} = 0.01078 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3937 \times 1.58) \times 113.83}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3937^3} \times (4.34 + 0.00) = 0.02548 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\ &= \frac{8.54 \times (4.34 + 0.00)^3}{2.00 \times 10^8 \times 70240 \times 10^{-8}} = 0.00497 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01078 + 0.02548 + 0.00497 \\ &= 0.04123 \text{ m} \\ \text{Size} &= 41.23 \text{ mm} \leq \delta_a = 50.00 \text{ mm}\end{aligned}$$

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

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-1.35	3.89 3.44	0.896 0.793	0.282 0.231	1.55 13.08	0.437 3.023
2	1.35-2.07	2.75 2.51	0.634 0.578	0.158 0.135	6.98 10.26	1.105 1.385
3	2.07-2.32	2.19 2.10	0.504 0.485	0.106 0.098	3.55 4.08	0.375 0.402
4	2.32-2.35	2.01 2.00	0.463 0.461	0.091 0.090	0.49 0.49	0.045 0.044

$$\begin{aligned}&= \frac{(1 + 2 \times 0.4583 \times 1.61) \times 116.95}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4583^2} \times (4.34 + 0.00) = 0.02132 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\ &= \frac{9.02 \times (4.34 + 0.00)^3}{2.00 \times 10^8 \times 70240 \times 10^{-8}} = 0.00525 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00752 + 0.02132 + 0.00525 \\ &= 0.03409 \text{ m} \\ \text{Size} &= 34.09 \text{ mm} \leq \delta_a = 75.00 \text{ mm}\end{aligned}$$

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:

Material Name	10 H ₁ H 400 -200 -9 -12 -13
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 = 87800 cm ⁴ (original condition)
	I = 87800 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 87800 × 10 ⁻⁸	= 1.756 × 10 ⁷

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is L_k, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

$$\begin{aligned}D &= L_k + \frac{3}{\beta} \\ L &= H - H_{Lk} + D \\ \beta &= 4\sqrt{\frac{K_b \cdot B}{4 E I}}\end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 13494 kN/m ³
Calculated value	β = 0.37230 m ⁻¹

$$\begin{aligned}\text{Penetration length of SSP} \quad D &= 0.00 + \frac{3}{0.372} = 8.06 \text{ m} \\ \text{Whole length of SSP} \quad L &= 4.34 - 0.40 + 8.06 = 12.00 \text{ m}\end{aligned}$$

5	2.35-3.35	1.66 1.32	0.382 0.305	0.064 0.042	16.47 20.12	1.047 0.840
6	3.35-4.34	0.66 0.33	0.152 0.076	0.011 0.003	17.12 18.51	0.188 0.052
$\Sigma Q =$					8.943	

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H + L_k} = \frac{(3 - \alpha) \times \alpha^2}{6}$$

$$\zeta : \zeta = \frac{\zeta \times P}{6}$$

$$Q : \zeta \times P$$

$$P : \text{Lateral force}$$

$$H : \text{Depth to design position}$$

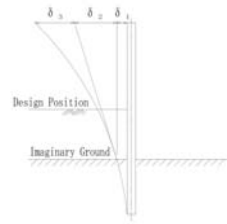
$$L_k : \text{Depth from design position to imaginary ground}$$

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

No	Depth, m	Y, m	α	ζ	Pdw, kN	Qdw, kN
1	2.32-3.32	1.69 1.35	0.389 0.312	0.066 0.044	0.00 1.22	0.000 0.053
2	3.32-4.32	0.69 0.35	0.158 0.081	0.012 0.003	1.22 1.72	0.014 0.006
3	4.32-4.34	0.01 0.01	0.003 0.002	0.000 0.000	0.03 0.03	0.000 0.000
$\Sigma Qdw =$					0.073	

Therefore, the deformation coefficient Q is expressed by
Q = 8.943 + 0.073 = 9.016

Displacement Calculation



$$\begin{aligned}\delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.4583 \times 1.61) \times 116.95}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4583^3} = 0.00752 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k)\end{aligned}$$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_b = 24787 kN/m ³
Calculated value	β = 0.43342 m ⁻¹

$$\begin{aligned}\text{Penetration length of SSP} \quad D &= 0.00 + \frac{3}{0.433} = 6.92 \text{ m} \\ \text{Whole length of SSP} \quad L &= 4.34 - 0.40 + 6.92 = 10.86 \text{ m}\end{aligned}$$

Therefore, the total length of the sheet pile is 12.00 m from the rounded length value of 0.50 m.

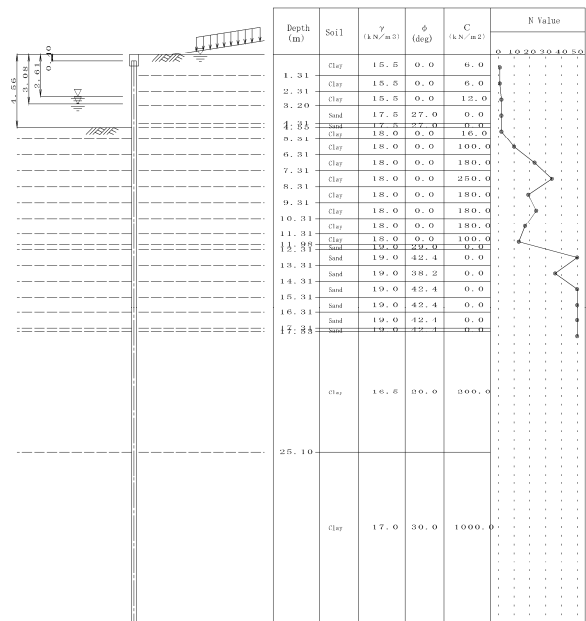
8 Calculation Result

front sheet pile 10 H₁ H 400 -200 -9 -12 -13

			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	87800		
Sectional Modulus	Z (cm ³)	2320		
Maximum bending moment	Mmax (kN × m × m)		233.76	232.45
Stress intensity	σ (N/mm ²)		124 (180)	124 (170)
Lateral displacement	δ (mm)		41.23 (50.0)	34.09 (75.0)
Penetration depths	D (m)		8.06	6.92
Whole length of SSP	L (m)	12.00		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 4.56$ m
Depth from coping top to rear side ground $H_0 = 0.00$ m
Depth from coping top to SSP top $H_h = 0.40$ m
Landside WL $L_{wa} = 0.00$ m (Normal Condition)
 $L_{wa}' = 0.00$ m (Seismic Condition)
Riverside WL $L_{wp} = 3.08$ m (Normal Condition)
 $L_{wp}' = 2.61$ m (Seismic Condition)

Block No. : L-31
Sta. : 12+820~13+000

Design Cross Section : Sta 12+840
Boring Name : BMLL-38

Specification : SSP SP-10H
(Combined) : H 500-200-12-16-13

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

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 not considered
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) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{b0} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_H = 10.00$ m
 $E_0 = 2800$ N
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	0.81	1	11	10.81	17
2	1.81	1	12	11.81	13
3	2.81	2	13	12.81	50
4	3.81	2	14	13.81	36
5	4.81	2	15	14.81	50
6	5.81	10	16	15.81	50
7	6.81	23	17	16.81	50
8	7.81	34	18	17.81	50
9	8.81	19			
10	9.81	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

Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.31	1.31
2	2.31	1.00
3	3.20	0.89
4	4.31	1.11
5	4.55	0.24
6	5.31	0.76
7	6.31	1.00
8	7.31	1.00
9	8.31	1.00
10	9.31	1.00
11	10.31	1.00
12	11.31	1.00
13	11.98	0.67
14	12.31	0.33
15	13.31	1.00
16	14.31	1.00
17	15.31	1.00
18	16.31	1.00
19	17.31	1.00
20	17.53	0.22
21	25.10	7.57
22	34.60	8.50

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.31	C	1.0	15.50	5.70	0.0	6.0	0.0	0.200	Auto	Auto
2	2.31	C	1.0	15.50	5.70	0.0	6.0	0.0	0.200	Auto	Auto
3	3.20	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto
4	4.31	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	4.55	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	5.31	C	2.0	18.00	8.20	0.0	16.0	0.0	0.200	Auto	Auto
7	6.31	C	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
8	7.31	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto

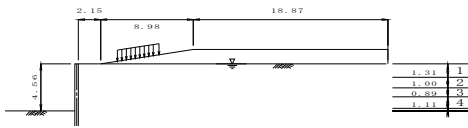
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
9	8.31	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
10	9.31	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
11	10.31	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	11.31	C	17.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	11.98	C	13.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
14	12.31	S	13.0	19.00	9.20	29.0	0.0	0.0	0.200	Auto	Auto
15	13.31	S	50.0	19.00	9.20	42.4	0.0	0.0	0.200	Auto	Auto
16	14.31	S	36.0	19.00	9.20	38.2	0.0	0.0	0.200	Auto	Auto
17	15.31	S	50.0	19.00	9.20	42.4	0.0	0.0	0.200	Auto	Auto
18	16.31	S	50.0	19.00	9.20	42.4	0.0	0.0	0.200	Auto	Auto
19	17.31	S	50.0	19.00	9.20	42.4	0.0	0.0	0.200	Auto	Auto
20	17.53	S	50.0	19.00	9.20	42.4	0.0	0.0	0.200	Auto	Auto
21	25.10	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
22	34.60	C	121.5	17.00	7.20	30.0	1000.0	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 (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	2.15	11.13	30.00	30.00	1.40	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	3.78	7.80	10.0	5.0

Angle of rupture in embankment

calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H H 500 -200 -12-16-13
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 149900 cm ⁴
Sectional factor	Z ₀ = 3540 cm ³

Corrosion margin	t ₁ = 1.00 mm (riverside)	t ₂ = 1.00 mm (landside)

Corrosion rate (to I ₀)	η = 0.83
Corrosion rate (to Z ₀)	η = 0.85
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)

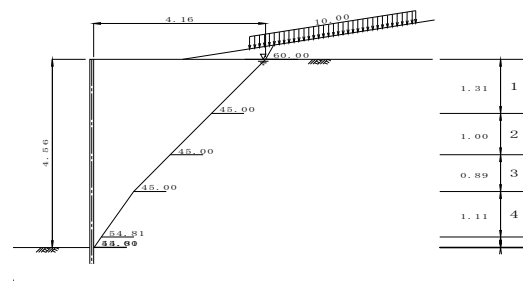
Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus

Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I₀ applied to calculation of penetration depth
Reduced: I₀ 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/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ value kN/m ³	Angle of Rupture ζ degree
1	4.56 ~ 4.55	Clay	0.0	15.0	16.0	28.72	2.98	44.69	45.00

2.1.4 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qd kN/m
1	10.0	0.58	5.81
Σ			5.81

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

l: Loading width of uniform load surrounded by main collapse line

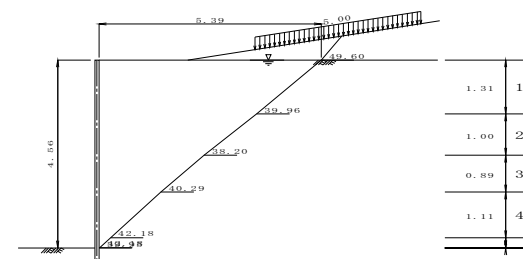
2.1.5 Calculated Load

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

$$= \frac{6.59 + 5.81 + 0.00}{4.16}$$

$$= 2.98 \text{ kN/m}^2$$

2.2 Seismic 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	γ value kN/m ³	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	4.56 ~ 4.55	Clay	0.0	15.0	16.0	28.72	5.27	44.69	0.200	11.31	39.95
2	4.55 ~ 4.31	Sand	27.0	15.0	0.0	28.64	5.27	44.59	0.200	11.31	42.18
3	4.31 ~ 3.20	Sand	27.0	15.0	0.0	26.79	5.27	42.24	0.200	11.31	42.18
4	3.20 ~ 2.31	Clay	0.0	15.0	12.0	18.24	5.27	31.36	0.200	11.31	40.29
5	2.31 ~ 1.31	Clay	0.0	15.0	6.0	13.17	5.27	22.64	0.200	11.31	38.20
6	1.31 ~ 0.00	Clay	0.0	15.0	6.0	7.47	5.27	12.84	0.200	11.31	39.96
7		embankment	30.0	—	0.0	26.60	0.00	0.00	0.200	11.31	49.60

2	4.55 ~ 4.31	Sand	27.0	15.0	0.0	28.64	2.98	44.59	54.81
3	4.31 ~ 3.20	Sand	27.0	15.0	0.0	26.79	2.98	42.24	54.81
4	3.20 ~ 2.31	Clay	0.0	15.0	12.0	18.24	2.98	31.36	45.00
5	2.31 ~ 1.31	Clay	0.0	15.0	6.0	13.17	2.98	22.64	45.00
6	1.31 ~ 0.00	Clay	0.0	15.0	6.0	7.47	2.98	12.84	45.00
7		embankment	30.0	—	0.0	26.60	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 $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z' m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.01	0.00	0.00	0.01	0.01
2	54.81	0.24	0.01	0.01	0.18	0.25
3	54.81	1.11	0.18	0.25	0.96	1.36
4	45.00	0.89	0.96	1.36	1.85	2.25
5	45.00	1.00	1.85	2.25	2.85	3.25
6	45.00	1.21	2.85	3.25	4.16	4.56
7	60.00	0.34	4.16	4.56	4.36	4.90

From the above table, the loading width (L) on the ground surface is 4.16 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.35	6.59
Σ			6.59

γ : unit weight of embankment soil

A: sectional area of embankment enclosed by line of active rupture

* Major collapse angle of Sand, intermediate soil, and split rock

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

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	39.95	0.01	0.00	0.00	0.01	0.01
2	42.18	0.24	0.01	0.01	0.28	0.25
3	42.18	1.11	0.28	0.25	1.50	1.36
4	40.29	0.89	1.50	1.36	2.55	2.25
5	38.20	1.00	2.55	2.25	3.82	3.25
6	39.96	1.31	3.82	3.25	5.39	4.56
7	49.60	0.58	5.39	4.56	5.88	5.14

From the above table, the loading width (L) on the ground surface is 5.39 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.94	17.88
Σ			17.88

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/m ²	l m	Qxl kN/m
1	5.0	2.10	10.51
Σ			10.51

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

l: Loading width of uniform load surrounded by main collapse line

7	4.31~4.55	Sand	7.7	27.0	—	29.766 31.614	0.33738 0.33738	0.32589 0.32589
8	4.55~4.56	Clay	8.2	—	16.0 16.0	31.614 31.696	— —	— —
9	4.56~4.60	Clay	8.2	—	16.0 16.0	31.696 32.000	— —	— —
10	4.60~5.31	Clay	8.2	—	16.0 16.0	32.000 37.446	— —	— —
11	5.31~6.31	Clay	8.2	—	100.0 100.0	37.446 46.046	— —	— —
12	6.31~7.31	Clay	8.2	—	180.0 180.0	46.046 54.246	— —	— —
13	7.31~8.31	Clay	8.2	—	250.0 250.0	54.246 62.446	— —	— —
14	8.31~9.31	Clay	8.2	—	180.0 180.0	62.446 70.646	— —	— —
15	9.31~10.31	Clay	8.2	—	180.0 180.0	70.646 78.846	— —	— —
16	10.31~11.31	Clay	8.2	—	180.0 180.0	78.846 87.046	— —	— —
17	11.31~11.98	Clay	8.2	—	100.0 100.0	87.046 92.540	— —	— —
18	11.98~12.31	Sand	9.2	28.0	—	92.540 95.576	0.31307 0.31307	0.30240 0.30240
19	12.31~13.31	Sand	9.2	42.4	—	95.576 104.776	0.18084 0.18084	0.17468 0.17468
20	13.31~14.31	Sand	9.2	38.2	—	104.776 113.976	0.21713 0.21713	0.20973 0.20973
21	14.31~15.31	Sand	9.2	42.4	—	113.976 123.176	0.18084 0.18084	0.17468 0.17468
22	15.31~16.31	Sand	9.2	42.4	—	123.176 132.376	0.18084 0.18084	0.17468 0.17468
23	16.31~17.31	Sand	9.2	42.4	—	132.376 141.576	0.18084 0.18084	0.17468 0.17468
24	17.31~17.53	Sand	9.2	42.4	—	141.576 143.600	0.18084 0.18084	0.17468 0.17468
25	17.53~25.10	Clay	6.7	—	200.0 200.0	143.600 194.319	— —	— —
26	25.10~34.60	Clay	7.2	—	1000.0 1000.0	194.319 262.719	— —	— —

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	K_p	$K_p \times \cos \delta$
9	4.56~4.60	Clay	8.2	0.0	16.0 16.0	0.000 0.304	— —	— —

2.2.5 Calculated Load

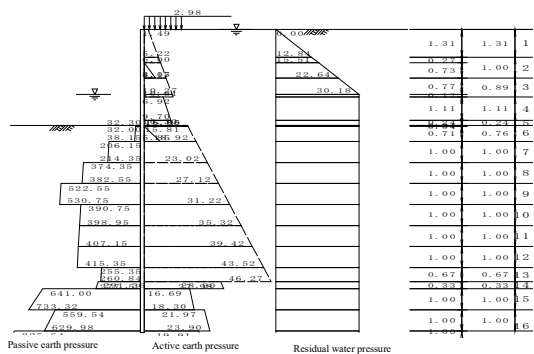
$$Q = \frac{\Sigma(\gamma \times A) + \Sigma(Q \times 1) + \Sigma P}{L}$$

$$= \frac{17.88 + 10.51 + 0.00}{5.39}$$

$$= 5.27 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00~1.31	Clay	5.7	—	6.0	2.979 10.446	—
2	1.31~1.58	Clay	5.7	—	6.0	10.446 12.000	—
3	1.58~2.31	Clay	5.7	—	6.0	12.000 16.146	—
4	2.31~3.08	Clay	5.7	—	12.0	16.146 20.535	—
5	3.08~3.20	Clay	5.7	—	12.0	20.535 21.219	—
6	3.20~4.31	Sand	7.7	27.0	—	21.219 29.766	0.33738 0.33738

10	4.60~5.31	Clay	8.2	0.0	16.0 16.0	0.304 6.150	— —	— —
11	5.31~6.31	Clay	8.2	0.0	100.0 100.0	6.150 14.350	— —	— —
12	6.31~7.31	Clay	8.2	0.0	180.0 180.0	14.350 22.550	— —	— —
13	7.31~8.31	Clay	8.2	0.0	250.0 250.0	22.550 30.750	— —	— —
14	8.31~9.31	Clay	8.2	0.0	180.0 180.0	30.750 38.950	— —	— —
15	9.31~10.31	Clay	8.2	0.0	180.0 180.0	38.950 47.150	— —	— —
16	10.31~11.31	Clay	8.2	0.0	180.0 180.0	47.150 55.350	— —	— —
17	11.31~11.98	Clay	8.2	0.0	100.0 100.0	55.350 60.844	— —	— —
18	11.98~12.31	Sand	9.2	29.0	—	60.844 63.880	4.72202 4.72202	4.56112 4.56112
19	12.31~13.31	Sand	9.2	42.4	—	63.880 73.080	10.3845 10.3845	10.0347 10.0347
20	13.31~14.31	Sand	9.2	38.2	—	73.080 82.280	7.92661 7.92661	7.65652 7.65652
21	14.31~15.31	Sand	9.2	42.4	—	82.280 91.480	10.3845 10.3845	10.0347 10.0347
22	15.31~16.31	Sand	9.2	42.4	—	91.480 100.680	10.3845 10.3845	10.0347 10.0347
23	16.31~17.31	Sand	9.2	42.4	—	100.680 109.880	10.3845 10.3845	10.0347 10.0347
24	17.31~17.53	Sand	9.2	42.4	—	109.880 111.904	10.3845 10.3845	10.0347 10.0347
25	17.53~25.10	Clay	6.7	20.0	200.0 200.0	111.904 162.623	— —	— —
26	25.10~34.60	Clay	7.2	30.0	1000.0 1000.0	162.623 231.023	— —	— —

Coefficient of passive earth pressure of sandy soil K_p is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		P_{a1} kN/m ²	P_{a2} kN/m ²	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²
1	0.00~1.31	-9.02 -1.55	1.49 5.22	1.49 5.22	0.00 12.84	— —
2	1.31~1.58	-1.55 0.00	5.22 6.00	5.22 6.00	12.84 15.51	— —
3	1.58~2.31	0.00 4.15	6.00 8.07	6.00 8.07	15.51 22.64	— —

4	2.31- 3.08	-7.85 -3.47	8.07 10.27	8.07 10.27	22.64 30.18	—
5	3.08- 3.20	-3.47 -2.78	10.27 10.61	10.27 10.61	30.18 30.18	—
6	3.20- 4.31	6.92 9.70	—	6.92 9.70	30.18 30.18	—
7	4.31- 4.55	—	—	9.70 10.30	30.18 30.18	—
8	4.55- 4.56	-0.39 -0.30	15.81 15.85	15.81 15.85	30.18 30.18	—
9	4.56- 4.60	-0.20 0.00	15.85 16.00	15.85 16.00	30.18 30.18	32.00 32.30
10	4.60- 5.31	0.00 5.85	16.00 18.92	16.00 18.92	30.18 30.18	32.30 38.15
11	5.31- 6.31	-162.15 -153.95	18.92 23.02	18.92 30.18	30.18	206.15 214.35
12	6.31- 7.31	-313.95 -305.75	23.02 27.12	23.02 30.18	30.18	374.35 382.55
13	7.31- 8.31	-445.75 -437.55	27.12 31.22	27.12 30.18	30.18	522.55 530.75
14	8.31- 9.31	-297.55 -289.35	31.22 35.32	31.22 30.18	30.18	390.75 398.95
15	9.31- 10.31	-289.35 -281.15	35.32 39.42	35.32 30.18	30.18	398.95 407.15
16	10.31- 11.31	-281.15 -272.95	39.42 43.52	39.42 30.18	30.18	407.15 415.35
17	11.31- 11.98	-112.95 -107.46	43.52 46.27	43.52 30.18	30.18	255.35 260.84
18	11.98- 12.31	27.98 28.90	—	27.98 28.90	30.18	277.52 291.36
19	12.31- 13.31	16.69 18.30	—	16.69 30.18	30.18	641.00 733.32
20	13.31- 14.31	21.97 23.90	—	21.97 30.18	30.18	599.54 629.98
21	14.31- 15.31	19.91 21.52	—	19.91 30.18	30.18	825.64 917.95
22	15.31- 16.31	21.52 23.12	—	21.52 30.18	30.18	917.95 1010.27
23	16.31- 17.31	—	—	23.12 30.18	30.18	1010.27 1102.59
24	17.31- 17.53	24.73 25.08	—	24.73 30.18	30.18	1102.59 1122.90
25	17.53- 25.10	-256.40 -205.08	71.80 97.16	71.80 30.18	30.18	511.90 562.62
26	25.10- 34.60	-1805.68 -1737.28	97.16 131.36	97.16 30.18	30.18	2162.62 2231.02

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

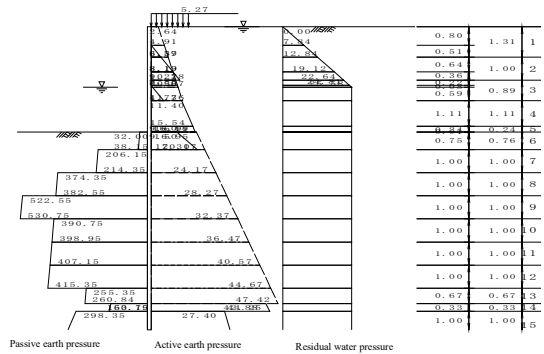
- Formula for passive earth pressure

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

Clay $P_p = \Sigma \gamma h + Q + 2C$

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/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-0.80	Clay	5.7	—	6.0	5.27	0.00	0.200	11.31	—	—	42.68
2	0.80-1.31	Clay	5.7	—	6.0	9.83	12.84	0.200	11.31	—	—	39.96
3	1.31-1.95	Clay	5.7	—	6.0	12.74	12.84	0.200	11.31	—	—	39.96
4	1.95-2.31	Clay	5.7	—	6.0	16.39	15.44	0.200	11.31	—	—	38.20
5	2.31-2.53	Clay	5.7	—	12.0	18.44	19.70	0.200	11.31	—	—	41.17

6	2.53-2.61	Clay	5.7	—	12.0	19.70	20.15	—	11.31	—	—	40.87
7	2.61-3.20	Clay	5.7	—	12.0	20.15	25.58	0.200	11.31	—	—	40.87
8	3.20-4.31	Sand	7.7	27.0	—	22.51	31.36	0.200	11.31	0.50201	0.48490	—
9	4.31-4.55	Sand	7.7	27.0	—	32.06	42.24	0.200	11.31	0.50201	0.48490	—
10	4.55-4.56	Clay	8.2	—	16.0	33.91	44.59	0.200	11.31	—	—	39.96
11	4.56-5.31	Clay	8.2	—	16.0	33.99	44.69	0.200	11.31	—	—	39.95
12	5.31-6.31	Clay	8.2	—	100.0	40.14	52.04	0.200	11.31	—	—	39.95
13	6.31-7.31	Clay	8.2	—	180.0	48.34	61.84	0.200	11.31	—	—	43.89
14	7.31-8.31	Clay	8.2	—	180.0	56.54	71.64	0.200	11.31	—	—	43.68
15	8.31-9.31	Clay	8.2	—	250.0	64.74	81.44	0.200	11.31	—	—	44.25
16	9.31-10.31	Clay	8.2	—	250.0	72.94	91.24	0.200	11.31	—	—	44.28
17	10.31-11.31	Clay	8.2	—	180.0	81.14	101.04	0.200	11.31	—	—	43.88
18	11.31-11.98	Clay	8.2	—	180.0	89.34	110.84	0.200	11.31	—	—	43.76
19	11.98-12.31	Sand	9.2	29.0	—	94.83	117.40	0.200	11.31	0.46809	0.45214	—
20	12.31-13.31	Sand	9.2	42.4	—	97.87	120.64	0.200	11.31	0.46809	0.45214	—
21	13.31-14.31	Sand	9.2	38.2	—	107.07	130.44	0.200	11.31	0.28983	0.27995	—
22	14.31-15.31	Sand	9.2	42.4	—	116.27	140.24	0.200	11.31	0.28983	0.27995	—
23	15.31-16.31	Sand	9.2	42.4	—	125.47	150.04	0.200	11.31	0.28983	0.27995	—
24	16.31-17.31	Sand	9.2	42.4	—	134.67	159.84	0.200	11.31	0.28983	0.27995	—
25	17.31-17.53	Sand	9.2	42.4	—	143.87	169.64	0.200	11.31	0.28983	0.27995	—
26	17.53-25.10	Clay	6.7	—	200.0	143.87	171.79	0.200	11.31	0.28983	0.27995	—
27	25.10-34.60	Clay	7.2	—	200.0	196.61	245.98	0.200	11.31	—	—	43.05

- The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$\delta = 15.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

- Angle (ζ) between the collapse surface and the horizontal in cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	K_p	$K_p \times \cos \delta$
11	4.56-5.31	Clay	8.20	0.0	16.0	6.000	0.00	0.200	11.31	—	—
12	5.31-6.31	Clay	8.20	0.0	100.0	6.150	7.35	0.200	11.31	—	—
13	6.31-7.31	Clay	8.20	0.0	180.0	14.350	17.15	0.200	11.31	—	—
14	7.31-8.31	Clay	8.20	0.0	250.0	22.550	26.95	0.200	11.31	—	—
15	8.31-9.31	Clay	8.20	0.0	180.0	30.750	36.75	0.200	11.31	—	—
16	9.31-10.31	Clay	8.20	0.0	180.0	38.950	46.55	0.200	11.31	—	—
17	10.31-11.31	Clay	8.20	0.0	180.0	47.150	56.35	0.200	11.31	—	—
18	11.31-11.98	Clay	8.20	0.0	100.0	55.350	66.15	0.200	11.31	—	—
19	11.98-12.31	Sand	9.20	29.0	—	60.844	72.72	0.200	11.31	2.51705	2.51705
20	12.31-13.31	Sand	9.20	42.4	—	63.880	75.95	0.200	11.31	4.67049	4.67049
21	13.31-14.31	Sand	9.20	38.2	—	63.880	85.75	0.200	11.31	4.67049	4.67049
22	14.31-15.31	Sand	9.20	42.4	—	73.080	85.75	0.200	11.31	3.81070	3.81070
23	15.31-16.31	Sand	9.20	42.4	—	82.280	95.55	0.200	11.31	4.67049	4.67049
24	16.31-17.31	Sand	9.20	42.4	—	91.480	105.35	0.200	11.31	4.67049	4.67049
25	17.31-17.53	Sand	9.20	42.4	—	100.680	115.15	0.200	11.31	4.67049	4.67049
26	17.53-25.10	Clay	6.70	20.0	200.0	111.904	127.11	0.200	11.31	—	—
27	25.10-34.60	Clay	7.20	30.0	1000.0	162.623	201.29	0.200	11.31	—	—

- The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active		Residual water pressure		Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00-0.80	-5.63 0.00	2.64 4.91	2.64 4.91	0.00 7.84	-----
2	0.80-1.31	0.00 3.59	4.91 6.37	4.91 6.37	7.84 12.84	-----
3	1.31-1.95	3.59 8.19	6.37 8.19	6.37 8.19	12.84 19.12	-----
4	1.95-2.31	8.19 10.78	8.19 9.22	8.19 10.78	19.12 22.64	-----
5	2.31-2.53	-1.56 0.00	9.22 9.85	9.22 9.85	22.64 24.81	-----
6	2.53-2.61	0.00 0.55	9.85 10.07	9.85 10.07	24.81 25.58	-----
7	2.61-3.20	0.55 4.73	10.07 11.76	10.07 11.76	25.58 25.58	-----
8	3.20-4.31	11.40 15.54	-----	11.40 15.54	25.58 25.58	-----
9	4.31-4.55	15.54 16.44	-----	15.54 16.44	25.58 25.58	-----
10	4.55-4.56	9.50 9.60	16.95 16.99	16.95 16.99	25.58 25.58	-----
11	4.56-5.31	9.60 17.31	16.99 20.07	16.99 20.07	25.58 25.58	32.00
12	5.31-6.31	-151.67 -141.75	20.07 24.17	20.07 24.17	25.58 25.58	206.15 214.35
13	6.31-7.31	-301.86 -291.97	24.17 28.27	24.17 28.27	25.58 25.58	374.35 382.55
14	7.31-8.31	-452.02 -422.14	28.27 32.37	28.27 32.37	25.58 25.58	522.55 530.75
15	8.31-9.31	-282.07 -272.17	32.37 36.47	32.37 36.47	25.58 25.58	390.75 398.95
16	9.31-10.31	-272.17 -262.25	36.47 40.57	36.47 40.57	25.58 25.58	398.95 407.15
17	10.31-11.31	-262.25 -252.33	40.57 44.67	40.57 44.67	25.58 25.58	407.15 415.35
18	11.31-11.98	-91.94 -85.24	44.67 47.42	44.67 47.42	25.58 25.58	255.35 260.84
19	11.98-12.31	42.88 44.25	-----	42.88 44.25	25.58 25.58	153.15 160.79
20	12.31-13.31	27.40 29.97	-----	27.40 29.97	25.58 25.58	298.35 341.32
21	13.31-14.31	34.98 37.99	-----	34.98 37.99	25.58 25.58	278.49 313.54

22	14.31-15.31	32.55 35.13	-----	32.55 35.13	25.58 25.58	384.29 427.26
23	15.31-16.31	35.13 37.70	-----	35.13 37.70	25.58 25.58	427.26 470.22
24	16.31-17.31	37.70 40.28	-----	37.70 40.28	25.58 25.58	470.22 513.19
25	17.31-17.53	40.28 40.84	-----	40.28 40.84	25.58 25.58	513.19 522.65
26	17.53-25.10	-223.80 -161.99	72.95 98.31	72.95 98.31	25.58 25.58	511.90 562.62
27	25.10-34.60	-1763.67 -1681.27	98.31 132.51	98.31 132.51	25.58 25.58	2162.62 2231.02

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2 C$$

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

K_a : Equilibrium coefficient of compression: 0.5

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

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

- Formula for passive earth pressure

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

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2 C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m2
1	2.61	0.00	0.00
2	3.61	1.00	2.39
3	4.56	1.95	3.34

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

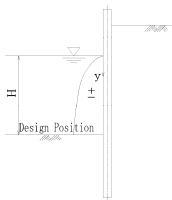
Where,

k_{hw} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

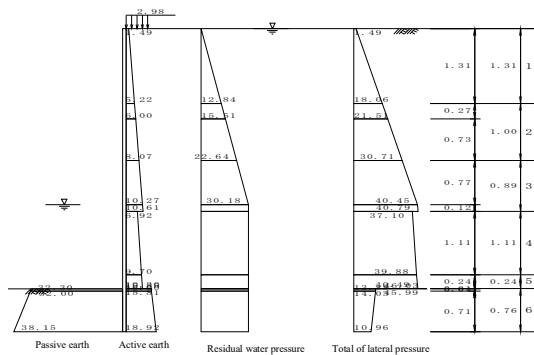
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

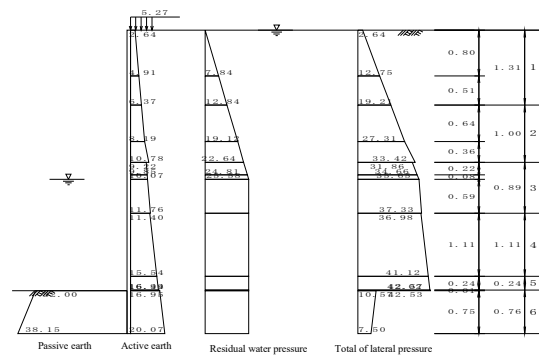
Imaginary ground level Lk is calculated as the elevation level that the sum of active earth pressure and residual water pressure are balanced with passive earth pressure.

4.1 Normal Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00-1.31	1.49 5.22	0.00 12.84	-----	1.49 18.06
2	1.31-1.58	5.22 6.00	12.84 15.51	-----	18.06 21.51
3	1.58-2.31	6.00 8.07	15.51 22.64	-----	21.51 30.71
4	2.31-3.08	8.07 10.27	22.64 30.18	-----	30.71 40.45

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00-0.80	2.64 4.91	0.00 7.84	-----	2.64 12.75
2	0.80-1.31	4.91 6.37	7.84 12.84	-----	12.75 19.21
3	1.31-1.95	6.37 8.19	12.84 19.12	-----	19.21 27.31

4	1.95- 2.31	8.19 10.78	19.12 22.64	———— ————	27.31 33.42
5	2.31- 2.53	9.22 9.85	22.64 24.81	———— ————	31.86 34.66
6	2.53- 2.61	9.85 10.07	24.81 25.58	———— ————	34.66 35.65
7	2.61- 3.20	10.07 11.76	25.58 25.58	———— ————	35.65 37.33
8	3.20- 4.31	11.40 15.54	25.58 25.58	———— ————	36.98 41.12
9	4.31- 4.55	15.54 16.44	25.58 25.58	———— ————	41.12 42.02
10	4.55- 4.56	16.95 16.99	25.58 25.58	———— ————	42.53 42.57
11	4.56- 5.31	16.99 20.07	25.58 25.58	32.00 38.15	10.57 7.50
12	5.31- 6.31	20.07 24.17	25.58 25.58	206.15 214.35	-160.50 -164.60

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 : 0.75 m (GL -5.31 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{10} = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H = 10.00\text{m})$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$E_0 = 2800N'$$

where:

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name 10 H₁₆ H 500 -200 -12-16-13
Unit width $B = 1.0000\text{ m}$
Corrosion margin $t_1 = 1.00\text{ mm}$ (active side) $t_2 = 1.00\text{ mm}$ (passive side)
Corrosion rate $\eta = 0.83$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000\text{ N/mm}^2$
Inertia sectional moment $I_0 = 149900\text{ cm}^4$ (original condition)
Inertia sectional moment $I = 124417\text{ cm}^4$ (after reduction by corrosion and section)
Inertia sectional moment $EI = 200000 \times 10^3 \times 124417 \times 10^{-8} = 2.488 \times 10^6$

5.3 Seismic Condition

Assuming $K_h = 26232\text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.403\text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.48\text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.31 m) and 2.48 m depth (GL -7.79 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.31	0.50	6.0	10.0	4.00
2	5.81	1.00	10.0	23.0	16.50
3	6.81	0.98	23.0	33.8	27.89
L = Σh = 2.48			ΣA =		48.39

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

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{48.39}{2.48} = 19.50$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 19.50 = 54587\text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \alpha \times 54587 = 363911\text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_b = K_{10} (B/0.3)^{-3/4} = 363911 (10.00/0.3)^{-3/4} = 26232\text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 26232 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.31	1.31	1.49 18.06	0.98 11.83	4.87 4.44	4.75 52.49

No	Depth m	N Value	No	Depth m	N Value
1	0.81	1	11	10.81	17
2	1.81	1	12	11.81	13
3	2.81	2	13	12.81	50
4	3.81	2	14	13.81	36
5	4.81	2	15	14.81	50
6	5.81	10	16	15.81	50
7	6.81	23	17	16.81	50
8	7.81	34	18	17.81	50
9	8.81	19			
10	9.81	24			

5.2 Normal Condition

Assuming $K_h = 14232\text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.346\text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.89\text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.31 m) to 2.89 m depth (GL -8.20 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.31	0.50	6.0	10.0	4.00
2	5.81	1.00	10.0	23.0	16.50
3	6.81	1.00	23.0	34.0	28.50
4	7.81	0.39	34.0	28.1	12.17
L = Σh = 2.89			ΣA =		61.17

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

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{61.17}{2.89} = 21.15$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 21.15 = 59229\text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \alpha \times 59229 = 197431\text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_b = K_{10} (B/0.3)^{-3/4} = 197431 (10.00/0.3)^{-3/4} = 14232\text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 14232 kN/m³.

2	1.31- 1.58	0.27	18.06 21.51	2.46 2.93	3.91 3.82	9.62 11.20
3	1.58- 2.31	0.73	21.51 30.71	7.82 11.17	3.48 3.24	27.26 36.22
4	2.31- 3.08	0.77	30.71 40.45	11.82 15.57	2.78 2.49	32.44 38.73
5	3.08- 3.20	0.12	40.45 40.79	2.43 2.45	2.19 2.15	5.32 5.26
6	3.20- 4.31	1.11	37.10 39.88	20.59 22.14	1.74 1.37	35.83 30.33
7	4.31- 4.55	0.24	39.88 40.49	4.79 4.86	0.92 0.84	4.40 4.08
8	4.55- 4.56	0.01	40.99 40.93	0.23 0.23	0.76 0.75	0.17 0.17
9	4.56- 4.60	0.04	14.03 13.88	0.26 0.26	0.74 0.75	0.19 0.19
10	4.60- 5.31	0.71	13.88 10.96	4.95 3.91	0.48 0.24	2.35 0.93
ΣP =			151.67	ΣM =	301.92	

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

Arbitrary load lateral load $P_1 = 0.0\text{ kN/m}$
depth to acting position $H_1 = 0.0\text{ m}$
moment $M_1 = 0.0\text{ kN} \cdot \text{m/m}$
depth to acting position $H_2 = 0.00\text{ m}$
Height from riverbed to top of coping $H = 4.56\text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.75\text{ m}$

Moment M_0 by arbitrary load is as below
 $M_0 = P_1 \cdot (H + L_k - H_1) + M_1 = 0.00\text{ kN} \cdot \text{m}$
 h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_1}{\Sigma P + P_1} = \frac{301.92}{131.67} = 2.29\text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.80	0.80	2.64 12.75	1.05 5.10	5.04 4.78	5.31 24.36
2	0.80- 1.31	0.51	12.75 19.21	3.25 8.75	4.34 4.17	14.12 20.44
3	1.31- 1.95	0.64	19.21 27.31	6.15 8.75	3.79 3.57	23.30 31.26
4	1.95- 2.31	0.36	27.31 33.42	4.91 6.00	3.24 3.12	15.89 18.73

5	2.31~ 2.53	0.22	31.86 34.66	3.53 3.84	2.93 2.85	10.33 10.95
6	2.53~ 2.61	0.08	34.66 35.65	1.36 1.40	2.75 2.73	3.74 3.81
7	2.61~ 3.20	0.59	35.65 37.33	10.52 11.01	2.50 2.31	26.33 25.40
8	3.20~ 4.31	1.11	36.98 41.12	20.52 22.82	1.74 1.37	35.71 31.27
9	4.31~ 4.55	0.24	41.12 42.02	4.93 5.04	0.92 0.84	4.54 4.24
10	4.55~ 4.56	0.01	42.53 42.57	0.21 0.21	0.76 0.75	0.16 0.16
11	4.56~ 5.31	0.75	10.57 7.50	3.96 2.81	0.50 0.25	1.98 0.70
			ΣP= 132.30	ΣM= 312.73		

P_a : active earth pressure + residual water pressure - passive earth pressure

P : load P_a 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_i = 0.0 kN/m
depth to acting position H_i = 0.00 m
moment M_{ia} = 0.0 kN·m/m
depth to acting position H_{ia} = 0.00 m
Height from riverbed to top of coping H = 4.56 m
Depth of Imaginary riverbed from riverbed L_k = 0.75 m

Moment M_i by arbitrary load is as below
M_i = P_i·(H + L_k - H_i) + M_{ia} = 0.00 kN·m

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Leads P _{dw} kN	Arm length Y m	Moment M _{dw} kN·m
1	2.61~ 3.61	1.00	0.0 2.4	0.00 1.20	2.37 2.03	0.00 2.43
2	3.61~ 4.56	0.95	2.4 3.3	1.14 1.59	1.38 1.07	1.57 1.69
			Σ P _{dw} = 3.92	Σ M _{dw} = 5.70		

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0i}}{\Sigma P + P_i + \Sigma P_{0i}} = \frac{318.43}{136.22} = 2.34 \text{ m}$$

6.2 Sectional Force

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

Material name 10 H _H 500 -200 - 12-16-13
Unit width B = 1.0000 m

$$Z = 3009 \text{ cm}^2 \text{ (after reduction by corrosion and section)}$$

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{364.95 \times 10^6}{3009 \times 10^3} = 121 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{369.53 \times 10^6}{3009 \times 10^3} = 123 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 1.31	4.87 4.44	0.918 0.836	0.292 0.252	0.98 11.83	0.285 2.979
2	1.31~ 1.58	3.91 3.82	0.736 0.719	0.204 0.197	2.46 2.93	0.503 0.576
3	1.58~ 2.31	3.48 3.24	0.656 0.611	0.168 0.148	7.82 11.17	1.316 1.658
4	2.31~ 3.08	2.74 2.60	0.517 0.468	0.110 0.093	11.82 15.57	1.306 1.441
5	3.08~ 3.20	2.19 2.15	0.412 0.405	0.073 0.071	2.43 2.45	0.178 0.174
6	3.20~ 4.31	1.74 1.37	0.328 0.258	0.048 0.030	20.59 22.14	0.985 0.673
7	4.31~ 4.55	0.92 0.84	0.173 0.158	0.014 0.012	4.79 4.86	0.008 0.058
8	4.55~ 4.56	0.76 0.75	0.143 0.142	0.010 0.010	0.23 0.23	0.002 0.002
9	4.56~ 4.60	0.74 0.73	0.139 0.137	0.009 0.009	0.26 0.26	0.002 0.002
10	4.60~ 5.31	0.48 0.24	0.090 0.045	0.004 0.001	4.95 3.91	0.019 0.004
			Σ Q = 12.233			

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H + L_k}$$

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

Q : ζ × P

P : Lateral force

H : Depth to design position

L_k : Depth from design position to imaginary ground

Displacement Calculation

Corrosion margin t_i = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.83
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 149900 cm⁴ (original condition)
I = 124417 cm⁴ (after reduction by corrosion and section)
EI = 20000 × 10³ × 124417 × 10⁻⁸ = 2.488 × 10⁶

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction K_b = 14232 kN/m³
calculated value β = 0.34580 m⁻¹
resultant earth force (lateral) P₀ = 131.67 kN/m
height of acting position of load h₀ = 2.29 m
moment M₀ = 301.92 kN·m/m

in consideration of ψ_{sa} = 1.209,
maximum moment M_{max} = 364.95 kN·m/m
depth of generated position of M_{max} l_m = 1.067 m
depth of 1st fixed point l_i = 3.338 m

6.2.2 Seismic Condition

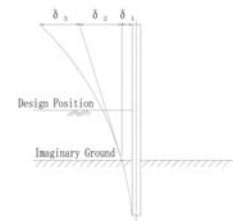
modulus of lateral subgrade reaction K_b = 26232 kN/m³
calculated value β = 0.40292 m⁻¹
resultant earth force (lateral) P₀ = 136.22 kN/m
height of acting position of load h₀ = 2.34 m
moment M₀ = 318.43 kN·m/m

in consideration of ψ_{sa} = 1.160,
maximum moment M_{max} = 369.53 kN·m/m
depth of generated position of M_{max} l_m = 0.828 m
depth of 1st fixed point l_i = 2.778 m

6.3 Stress Intensity

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

Material Name 10 H _H 500 -200 - 12-16-13
Corrosion margin t_i = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.85
Section efficiency μ = 1.00
Module of section Z₀ = 3540 cm³ (original condition)



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3458 \times 2.29) \times 131.67}{2 \times 2.00 \times 10^6 \times 124417 \times 10^{-8} \times 0.3458^3} = 0.01147 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3458 \times 2.29) \times 131.67}{2 \times 2.00 \times 10^6 \times 124417 \times 10^{-8} \times 0.3458^3} \times (4.56 + 0.75) = 0.03038 \text{ m} \\ \delta_3 &= \frac{Q \times (H + L_k)^3}{E I} \\ &= \frac{12.23 \times (4.56 + 0.75)^3}{2.00 \times 10^6 \times 124417 \times 10^{-8}} = 0.00736 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01147 + 0.03038 + 0.00736 \\ &= 0.04921 \text{ m} \\ \text{Size} &= 49.21 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

Where,

δ₁ : Displacement at imaginary ground

δ₂ : Displacement by angle of inclination slope at imaginary ground

δ₃ : 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

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00~ 0.80	5.04 4.78	0.950 0.900	0.308 0.283	1.05 5.10	0.325 1.445
2	0.80~ 1.31	4.34 4.17	0.817 0.785	0.243 0.228	3.25 4.90	0.791 1.116
3	1.31~ 1.95	3.79 3.57	0.713 0.673	0.194 0.176	6.15 8.75	1.192 1.536
4	1.95~ 2.31	3.24 3.12	0.610 0.588	0.148 0.139	4.91 6.00	0.727 0.833

5	2.31~ 2.53	2.93 2.85	0.551 0.537	0.124 0.118	3.53 3.84	0.437 0.455
6	2.53~ 2.61	2.75 2.73	0.518 0.513	0.111 0.109	1.36 1.40	0.151 0.153
7	2.61~ 3.20	2.50 2.31	0.471 0.434	0.094 0.081	10.52 11.01	0.985 0.889
8	3.20~ 4.31	1.74 1.37	0.328 0.258	0.048 0.030	20.52 22.82	0.981 0.694
9	4.31~ 4.55	0.92 0.84	0.173 0.158	0.014 0.012	4.93 5.04	0.070 0.060
10	4.55~ 4.56	0.76 0.75	0.143 0.142	0.010 0.010	0.21 0.21	0.002 0.002
11	4.56~ 5.31	0.50 0.25	0.094 0.047	0.004 0.001	3.96 2.81	0.017 0.003
$\Sigma Q =$						12.864

Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

Q : $\zeta \times P$

P : Lateral force

H : Depth to design position

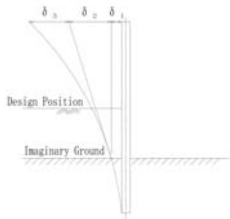
L_k : Depth from design position to imaginary ground

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

No	Depth m	Y m	α	ζ	Pkw kN	Qdw kN
1	2.61~ 3.61	2.37 2.03	0.446 0.383	0.085 0.064	0.00 1.20	0.000 0.077
2	3.61~ 4.56	1.38 1.07	0.261 0.201	0.031 0.019	1.14 1.59	0.035 0.030
$\Sigma Qdw =$						0.142

Therefore, the deformation coefficient Q is expressed by
Q=12.864+0.142=13.006

Displacement Calculation



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

$$= \frac{(1 + 0.4029 \times 2.34) \times 136.22}{2 \times 2.00 \times 10^8 \times 124417 \times 10^{-8} \times 0.4029^3} = 0.00813 \text{ m}$$

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

$$= \frac{(1 + 2 \times 0.4029 \times 2.34) \times 136.22}{2 \times 2.00 \times 10^8 \times 124417 \times 10^{-8} \times 0.4029^2} \times (4.56 + 0.75) = 0.02582 \text{ m}$$

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

$$= \frac{13.01 \times (4.56 + 0.75)^3}{2.00 \times 10^8 \times 124417 \times 10^{-8}} = 0.00783 \text{ m}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00813 + 0.02582 + 0.00783 \\ &= 0.04177 \text{ m} \\ \text{Size} &= 41.77 \text{ mm} \leq \delta_a = 75.00 \text{ mm} \end{aligned}$$

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

Material Name	10 H _ H 500 -200 - 12-16-13
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 = 149900 cm ⁴ (original condition)
	I = 149900 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 149900 × 10 ⁻⁸	= 2.998 × 10 ⁵

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is L_k, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

$$\begin{aligned} D &= L_k + \frac{3}{\beta} \\ L &= H - H_{it} + D \\ \beta &= 4 \sqrt{\frac{K_h \times B}{4 E I}} \end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_h = 14232 \text{ kN/m}^3$
Calculated value $\beta = 0.33006 \text{ m}^{-1}$

$$\text{Penetration length of SSP} \quad D = 0.75 + \frac{3}{0.330} = 9.84 \text{ m}$$

$$\text{Whole length of SSP} \quad L = 4.56 - 0.40 + 9.84 = 14.00 \text{ m}$$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_h = 26232 \text{ kN/m}^3$
Calculated value $\beta = 0.38458 \text{ m}^{-1}$

$$\text{Penetration length of SSP} \quad D = 0.75 + \frac{3}{0.385} = 8.55 \text{ m}$$

$$\text{Whole length of SSP} \quad L = 4.56 - 0.40 + 8.55 = 12.71 \text{ m}$$

Therefore, the total length of the sheet pile is 14.00 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		10 H _ H 500 -200 - 12-16-13			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)			149900		
Sectional Modulus	Z (cm ³)			3540		
Maximum bending moment	Mmax (kN · m · m)				364.95	369.53
Stress intensity	σ (N/mm ²)				121 (180)	123 (270)
Lateral displacement	δ (mm)				49.21 (50.0)	41.77 (75.0)
Penetration depth	D (m)				9.84	8.55
Whole length of SSP	L (m)			14.00		

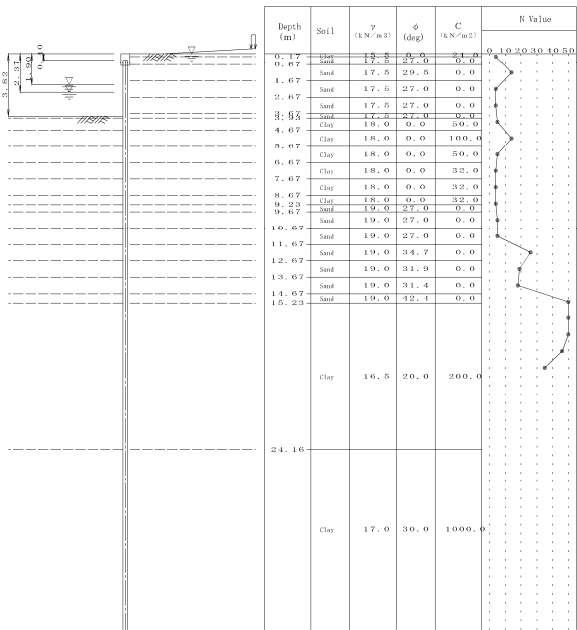
Block No. : L-32
Sta. : 13+000~13+320

Design Cross Section : Sta 13+020
Boring Name : BMLL-39

Specification : SSP SP-50H

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 3.82$ m
Depth from coping top to rear side ground $H_0 = 0.00$ m
Depth from coping top to SSP top $H_h = 0.40$ m
Landside WL $L_{wa} = 0.00$ m (Normal Condition)
 $L_{ws} = 0.00$ m (Seismic Condition)
Riverside WL $L_{wp} = 2.37$ m (Normal Condition)
 $L_{wp} = 1.90$ m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress Chang's formula

Vertical load on riverside not considered

1.7 Soil Modulus

Soil Modulus											
No	Depth m (Include Projection Length)	Thickness m (excluding projected length)									
1	0.17	0.17									
2	0.67	0.50									
3	1.67	1.00									
4	2.67	1.00									
5	3.67	1.00									
6	3.93	0.26									
7	4.67	0.74									
8	5.67	1.00									
9	6.67	1.00									
10	7.67	1.00									
11	8.67	1.00									
12	9.23	0.56									
13	9.67	0.44									
14	10.67	1.00									
15	11.67	1.00									
16	12.67	1.00									
17	13.67	1.00									
18	14.67	1.00									
19	15.23	0.56									
20	24.16	8.93									
21	33.90	9.74									

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)		
											Normal Condition	Seismic Condition
1	0.17	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto	
2	0.67	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	
3	1.67	S	14.0	17.50	7.70	29.5	0.0	0.0	0.200	Auto	Auto	
4	2.67	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	
5	3.67	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	
6	3.93	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	
7	4.67	C	5.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto	
8	5.67	C	14.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	
9	6.67	C	5.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto	

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)		
											Normal Condition	Seismic Condition
10	7.67	C	4.0	18.00	8.20	0.0	32.0	0.0	0.200	Auto	Auto	
11	8.67	C	4.0	18.00	8.20	0.0	32.0	0.0	0.200	Auto	Auto	
12	9.23	C	4.0	18.00	8.20	0.0	32.0	0.0	0.200	Auto	Auto	
13	9.67	S	4.0	19.00	9.20	27.0	0.0	0.0	0.200	Auto	Auto	
14	10.67	S	4.5	19.00	9.20	27.0	0.0	0.0	0.200	Auto	Auto	
15	11.67	S	5.0	19.00	9.20	27.0	0.0	0.0	0.200	Auto	Auto	
16	12.67	S	26.0	19.00	9.20	34.7	0.0	0.0	0.200	Auto	Auto	
17	13.67	S	19.0	19.00	9.20	31.9	0.0	0.0	0.200	Auto	Auto	
18	14.67	S	18.0	19.00	9.20	31.4	0.0	0.0	0.200	Auto	Auto	
19	15.23	S	50.0	19.00	9.20	42.4	0.0	0.0	0.200	Auto	Auto	
20	24.16	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto	
21	33.90	C	121.5	17.00	7.20	30.0	1000.0	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 (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

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

1.4 Design Constant

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 not considered
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) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_{ls} = K_{ls} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{ls} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2)
 $B_H = 10.00$ m
 $E_0 = 2800$ N
Average N-value calculated from average N-value between imaginary riverbed and depth as 1/β
N-value distribution

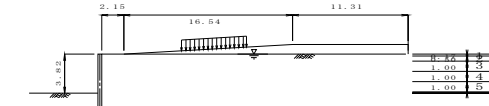
No	Depth m	N Value	No	Depth m	N Value
1	0.17	4	11	10.17	5
2	1.17	14	12	11.17	5
3	2.17	4	13	12.17	26
4	3.17	4	14	13.17	19
5	4.17	5	15	14.17	18
6	5.17	14	16	15.17	50
7	6.17	5	17	16.17	50
8	7.17	4	18	17.17	50
9	8.17	4	19	18.17	46
10	9.17	4	20	19.17	35

1.6 Vertical Load

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

Angle of wall friction		
Normal Condition	Seismic Condition	
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants												
No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	2.15	18.69	30.00	30.00	0.95	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	7.80	14.17	10.0	0.0

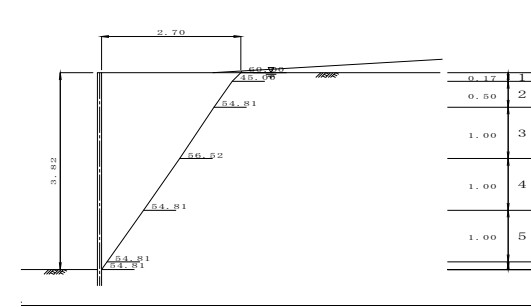
Angle of rapture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	Hat steel sheet pile SP -50 H		
Young's modulus	E	=	200000 N/mm ²
Inertia sectional moment	I ₀	=	51100 cm ⁴
Sectional factor	Z ₀	=	2760 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	=	0.87
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	=	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



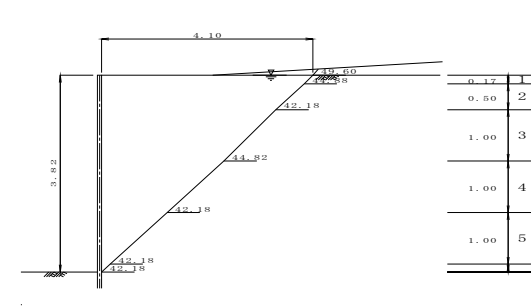
2.1.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	Angle of Rupture ζ degree
1	3.82~3.67	Sand	27.0	15.0	0.0	29.07	0.06	37.44	54.81

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{0.17 + 0.00 + 0.00}{2.70}$$
$$= 0.06 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	3.82~3.67	Sand	27.0	15.0	0.0	29.07	0.53	37.44	0.200	11.31	42.18
2	3.67~2.67	Sand	27.0	15.0	0.0	27.92	0.53	35.97	0.200	11.31	42.18
3	2.67~1.67	Sand	27.0	15.0	0.0	20.22	0.53	26.17	0.200	11.31	42.18
4	1.67~0.67	Sand	29.5	15.0	0.0	12.52	0.53	16.37	0.200	11.31	44.82
5	0.67~0.17	Sand	27.0	15.0	0.0	4.82	0.53	6.57	0.200	11.31	42.18
6	0.17~0.00	Clay	0.0	15.0	24.0	0.97	0.53	1.67	0.200	11.31	44.88
7		embankment	30.0	—	0.0	18.05	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

2	3.67~2.67	Sand	27.0	15.0	0.0	27.92	0.06	35.97	54.81
3	2.67~1.67	Sand	27.0	15.0	0.0	20.22	0.06	26.17	54.81
4	1.67~0.67	Sand	29.5	15.0	0.0	12.52	0.06	16.37	56.52
5	0.67~0.17	Sand	27.0	15.0	0.0	4.82	0.06	6.57	54.81
6	0.17~0.00	Clay	0.0	15.0	24.0	0.97	0.06	1.67	45.00
7		embankment	30.0	—	0.0	18.05	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 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)
- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.81	0.15	0.00	0.00	0.11	0.15
2	54.81	1.00	0.11	0.15	0.81	1.15
3	54.81	1.00	0.81	1.15	1.52	2.15
4	56.52	1.00	1.52	2.15	2.18	3.15
5	54.81	0.50	2.18	3.15	2.53	3.65
6	45.00	0.17	2.53	3.65	2.70	3.82
7	60.00	0.03	2.70	3.82	2.72	3.85

From the above table, the loading width (L) on the ground surface is 2.70 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.01	0.17
Σ			0.17

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

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

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	0.15	0.00	0.00	0.17	0.15
2	42.18	1.00	0.17	0.15	1.27	1.15
3	42.18	1.00	1.27	1.15	2.37	2.15
4	44.82	1.00	2.37	2.15	3.38	3.15
5	42.18	0.50	3.38	3.15	3.93	3.65
6	44.88	0.17	3.93	3.65	4.10	3.82
7	49.60	0.12	4.10	3.82	4.20	3.94

From the above table, the loading width (L) on the ground surface is 4.10 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.12	2.19
Σ			2.19

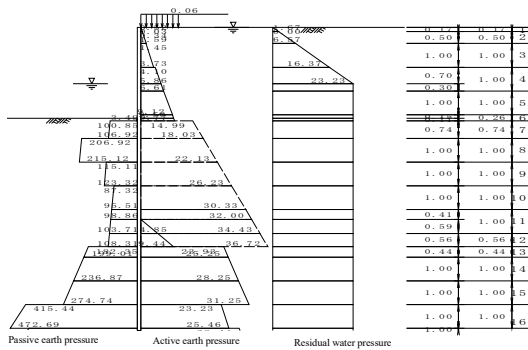
γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{2.19 + 0.00 + 0.00}{4.10}$$
$$= 0.53 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

	Depth- m	Soil	γ kN/m ³	θ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00- 0.17	Clay	5.7	—	24.0 24.0	0.063 0.032	—	—
2	0.17- 0.67	Sand	7.7	27.0	—	1.032 4.862	0.33738 0.33738	0.32589 0.32589
3	0.67- 1.67	Sand	7.7	28.5	—	4.882 12.582	0.30720 0.30720	0.29674 0.29674
4	1.67- 2.37	Sand	7.7	27.0	—	12.582 17.972	0.33738 0.33738	0.32589 0.32589
5	2.37- 2.67	Sand	7.7	27.0	—	17.972 20.282	0.33738 0.33738	0.32589 0.32589
6	2.67- 3.67	Sand	7.7	27.0	—	20.282 27.962	0.33738 0.33738	0.32589 0.32589
7	3.67- 3.82	Sand	7.7	27.0	—	27.962 29.137	0.33738 0.33738	0.32589 0.32589
8	3.82- 3.93	Sand	7.7	27.0	—	29.137 29.984	0.33738 0.33738	0.32589 0.32589
9	3.93- 4.67	Clay	8.2	—	50.0 50.0	29.984 36.052	—	—
10	4.67- 5.67	Clay	8.2	—	100.0 100.0	36.052 44.252	—	—
11	5.67- 6.67	Clay	8.2	—	50.0 50.0	44.252 52.452	—	—
12	6.67- 7.67	Clay	8.2	—	32.0 32.0	52.452 60.652	—	—

17	9.67- 10.67	Sand	9.2	27.0	—	48.355 57.555	4.26080 4.26080	4.11561 4.11561
18	10.67- 11.67	Sand	9.2	27.0	—	57.555 66.755	4.26080 4.26080	4.11561 4.11561
19	11.67- 12.67	Sand	9.2	34.7	—	66.755 75.955	6.44286 6.44286	6.22332 6.22332
20	12.67- 13.67	Sand	9.2	31.9	—	75.955 85.155	5.51072 5.51072	5.32295 5.32295
21	13.67- 14.67	Sand	9.2	31.4	—	85.155 94.355	5.36321 5.36321	5.18047 5.18047
22	14.67- 15.23	Sand	9.2	42.4	—	94.355 99.507	10.38845 10.38845	10.03447 10.03447
23	15.23- 24.16	Clay	6.7	20.0	200.0 200.0	99.507 159.338	—	—
24	24.16- 33.90	Clay	7.2	30.0	1000.0 1000.0	159.338 229.466	—	—

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth- m	Active				Residual water pressure Pw kN/m ²	Passive Pp kN/m ²
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Po kN/m ²		
1	0.00- 0.17	-47.94 -46.97	0.03 0.52	0.03 1.67	0.00 1.67	—	—
2	0.17- 0.67	0.34 1.59	—	0.34 1.59	1.67 6.57	—	—
3	0.67- 1.67	1.45 3.73	—	1.45 3.73	6.57 16.37	—	—
4	1.67- 2.37	4.10 5.86	—	4.10 5.86	16.37 23.23	—	—
5	2.37- 2.67	5.86 6.61	—	5.86 6.61	23.23 23.23	—	—
6	2.67- 3.67	6.61 9.12	—	6.61 9.12	23.23 23.23	—	—
7	3.67- 3.82	9.12 9.50	—	9.12 9.50	23.23 23.23	—	—
8	3.82- 3.93	9.50 9.77	—	9.50 9.77	23.23 23.23	0.00 3.49	—
9	3.93- 4.67	-70.02 -63.95	14.99 18.03	14.99 18.03	23.23 23.23	100.85 106.92	—
10	4.67- 5.67	-163.95 -155.75	18.03 22.13	18.03 22.13	23.23 23.23	206.92 215.12	—
11	5.67- 6.67	-55.75 -47.55	22.13 26.23	22.13 26.23	23.23 23.23	115.11 123.32	—

13	7.67- 8.08	Clay	8.2	—	32.0 32.0	60.652 64.000	—	—
14	8.08- 8.67	Clay	8.2	—	32.0 32.0	64.000 68.852	—	—
15	8.67- 9.23	Clay	8.2	—	32.0 32.0	68.852 73.444	—	—
16	9.23- 9.67	Sand	9.2	27.0	—	73.444 77.492	0.33738 0.33738	0.32589 0.32589
17	9.67- 10.67	Sand	9.2	27.0	—	77.492 86.692	0.33738 0.33738	0.32589 0.32589
18	10.67- 11.67	Sand	9.2	27.0	—	86.692 95.892	0.33738 0.33738	0.32589 0.32589
19	11.67- 12.67	Sand	9.2	34.7	—	95.892 105.092	0.25078 0.25078	0.24223 0.24223
20	12.67- 13.67	Sand	9.2	31.9	—	105.092 114.292	0.28015 0.28015	0.27060 0.27060
21	13.67- 14.67	Sand	9.2	31.4	—	114.292 123.492	0.28564 0.28564	0.27590 0.27590
22	14.67- 15.23	Sand	9.2	42.4	—	123.492 128.644	0.13084 0.13084	0.17868 0.17868
23	15.23- 24.16	Clay	6.7	—	200.0 200.0	128.644 188.475	—	—
24	24.16- 33.90	Clay	7.2	—	1000.0 1000.0	188.475 258.603	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.2 Soil Modulus of Passive Side

No	Depth- m	Soil	γ kN/m ³	θ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	K_p	$K_p \times \cos \delta$
8	3.82- 3.93	Sand	7.7	27.0	—	0.000 0.847	4.26080 4.26080	4.11561 4.11561
9	3.93- 4.67	Clay	8.2	0.0	50.0 50.0	0.847 6.915	—	—
10	4.67- 5.67	Clay	8.2	0.0	100.0 100.0	6.915 15.115	—	—
11	5.67- 6.67	Clay	8.2	0.0	50.0 50.0	15.115 23.315	—	—
12	6.67- 7.67	Clay	8.2	0.0	32.0 32.0	23.315 31.515	—	—
13	7.67- 8.08	Clay	8.2	0.0	32.0 32.0	31.515 34.863	—	—
14	8.08- 8.67	Clay	8.2	0.0	32.0 32.0	34.863 39.715	—	—
15	8.67- 9.23	Clay	8.2	0.0	32.0 32.0	39.715 44.307	—	—
16	9.23- 9.67	Sand	9.2	27.0	—	44.307 48.355	4.26080 4.26080	4.11561 4.11561

12	6.67- 7.67	—	-11.55 -3.35	26.23 30.33	26.23 30.33	23.23 23.23	87.32 95.51
13	7.67- 8.08	—	-3.35 0.00	30.33 32.00	30.33 32.00	23.23 23.23	95.51 98.86
14	8.08- 8.67	—	0.00 4.85	32.00 34.43	32.00 34.43	23.23 23.23	98.86 103.71
15	8.67- 9.23	—	4.85 9.44	34.43 36.72	34.43 36.72	23.23 23.23	103.71 108.31
16	9.23- 9.67	—	23.93 25.25	—	23.93 25.25	23.23 23.23	182.35 199.01
17	9.67- 10.67	—	25.25 28.25	—	25.25 28.25	23.23 23.23	199.01 226.87
18	10.67- 11.67	—	28.25 31.25	—	28.25 31.25	23.23 23.23	226.87 274.74
19	11.67- 12.67	—	23.23 25.46	—	23.23 25.46	23.23 23.23	415.44 472.69
20	12.67- 13.67	—	28.44 30.93	—	28.44 30.93	23.23 23.23	404.30 453.28
21	13.67- 14.67	—	31.53 34.07	—	31.53 34.07	23.23 23.23	441.14 488.80
22	14.67- 15.23	—	21.57 22.47	—	21.57 22.47	23.23 23.23	946.80 998.50
23	15.23- 24.16	—	-271.36 -211.52	64.32 94.24	64.32 94.24	23.23 23.23	499.51 559.34
24	24.16- 33.90	—	-1811.52 -1741.40	94.24 129.30	94.24 129.30	23.23 23.23	2159.34 2229.47

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

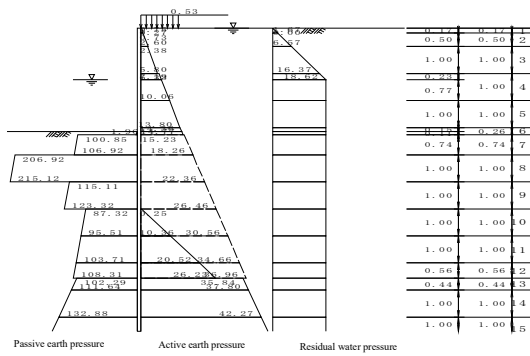
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Ka	Ka $\times \cos \delta$	ζ degree
1	0.00-0.17	Clay	5.7	—	24.0 24.0	0.53 1.50	0.00 1.67	0.200 0.200	11.31 11.31	— —	— —	44.94 44.88
2	0.17-0.67	Sand	7.7	27.0	—	1.50 5.35	1.67 6.57	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
3	0.67-1.67	Sand	7.7	29.5	—	5.35 13.05	6.57 16.37	0.200 0.200	11.31 11.31	0.45999 0.45999	0.44432 0.44432	—
4	1.67-1.90	Sand	7.7	27.0	—	13.05 14.82	16.37 18.62	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
5	1.90-2.67	Sand	7.7	27.0	—	14.82 20.75	18.62 26.17	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
6	2.67-3.67	Sand	7.7	27.0	—	20.75 28.45	26.17 35.97	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
7	3.67-3.82	Sand	7.7	27.0	—	28.45 29.61	35.97 37.44	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
8	3.82-3.93	Sand	7.7	27.0	—	29.61 30.45	37.44 38.51	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
9	3.93-4.67	Clay	8.2	—	50.0 50.0	30.45 36.52	38.51 45.77	0.200 0.200	11.31 11.31	— —	— —	44.08 43.90
10	4.67-5.67	Clay	8.2	—	100.0 100.0	36.52 44.72	45.77 55.57	0.200 0.200	11.31 11.31	— —	— —	44.46 44.34
11	5.67-6.67	Clay	8.2	—	50.0 50.0	44.72 52.92	55.57 63.37	0.200 0.200	11.31 11.31	— —	— —	43.64 43.38
12	6.67-7.67	Clay	8.2	—	32.0 32.0	52.92 61.12	63.37 75.17	0.200 0.200	11.31 11.31	— —	— —	42.39 41.94
13	7.67-8.67	Clay	8.2	—	32.0 32.0	61.12 69.32	75.17 84.97	0.200 0.200	11.31 11.31	— —	— —	41.94 41.48
14	8.67-9.23	Clay	8.2	—	32.0 32.0	69.32 73.91	84.97 90.45	0.200 0.200	11.31 11.31	— —	— —	41.48 41.22

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-0.17	-47.36 -46.20	0.27 0.75	0.27 0.75	0.00 1.67	— —
2	0.17-0.67	0.73 2.60	— —	0.73 2.60	1.67 6.57	— —
3	0.67-1.67	2.38 5.80	— —	2.38 5.80	6.57 16.37	— —
4	1.67-1.90	6.33 7.19	— —	6.33 7.19	16.37 18.62	— —
5	1.90-2.67	7.19 10.06	— —	7.19 10.06	18.62 18.62	— —
6	2.67-3.67	10.06 13.80	— —	10.06 13.80	18.62 18.62	— —
7	3.67-3.82	13.80 14.36	— —	13.80 14.36	18.62 18.62	— —
8	3.82-3.93	14.36 14.77	— —	14.36 14.77	18.62 18.62	0.00 1.96
9	3.93-4.67	-63.31 -55.96	15.23 18.26	15.23 18.26	18.62 18.62	100.85 100.92
10	4.67-5.67	-156.07 -146.18	18.26 22.36	18.26 22.36	18.62 18.62	206.92 215.12
11	5.67-6.67	-46.01 -36.04	22.36 26.46	22.36 26.46	18.62 18.62	115.11 123.32

15	9.23-9.67	Sand	9.2	27.0	—	73.91 77.96	90.45 94.77	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
16	9.67-10.67	Sand	9.2	27.0	—	77.96 87.16	94.77 104.57	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
17	10.67-11.67	Sand	9.2	27.0	—	87.16 96.36	104.57 114.37	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
18	11.67-12.67	Sand	9.2	34.7	—	96.36 105.56	114.37 124.17	0.200 0.200	11.31 11.31	0.38333 0.38333	0.37027 0.37027	—
19	12.67-13.67	Sand	9.2	31.9	—	105.56 114.76	124.17 133.97	0.200 0.200	11.31 11.31	0.42299 0.42299	0.40858 0.40858	—
20	13.67-14.67	Sand	9.2	31.4	—	114.76 123.96	133.97 143.77	0.200 0.200	11.31 11.31	0.43046 0.43046	0.41579 0.41579	—
21	14.67-15.23	Sand	9.2	42.4	—	123.96 129.11	143.77 149.25	0.200 0.200	11.31 11.31	0.28983 0.28983	0.27995 0.27995	—
22	15.23-24.16	Clay	6.7	—	—	200.0 288.95	129.11 236.77	0.200 0.200	11.31 11.31	— —	— —	44.04 43.57
23	24.16-33.90	Clay	7.2	—	—	1000.0 188.95	236.77 332.22	0.200 0.200	11.31 11.31	— —	— —	44.73 44.62

• The principal earth pressure coefficient (Ka) of Sand is calculated by the following equation.
 $\delta = 15.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

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

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
8	3.82-3.93	Sand	7.70	27.0	—	0.000 0.847	0.00 1.08	0.200 0.200	11.31 11.31	2.30874 2.30874	2.30874 2.30874
9	3.93-4.67	Clay	8.20	0.0	50.0 50.0	0.847 6.915	1.08 8.33	0.200 0.200	11.31 11.31	— —	— —
10	4.67-5.67	Clay	8.20	0.0	100.0 100.0	6.915 15.115	8.33 18.13	0.200 0.200	11.31 11.31	— —	— —
11	5.67-6.67	Clay	8.20	0.0	50.0 50.0	15.115 23.315	18.13 27.93	0.200 0.200	11.31 11.31	— —	— —
12	6.67-7.67	Clay	8.20	0.0	32.0 32.0	23.315 31.515	27.93 37.73	0.200 0.200	11.31 11.31	— —	— —
13	7.67-8.67	Clay	8.20	0.0	32.0 32.0	31.515 39.715	37.73 47.53	0.200 0.200	11.31 11.31	— —	— —
14	8.67-9.23	Clay	8.20	0.0	32.0 32.0	39.715 44.307	47.53 53.02	0.200 0.200	11.31 11.31	— —	— —
15	9.23-9.67	Sand	9.20	27.0	—	44.307 48.355	53.02 57.53	0.200 0.200	11.31 11.31	2.30874 2.30874	2.30874 2.30874

12	6.67-7.67	0.25 10.36	26.46 30.56	26.46 30.56	18.62 18.62	87.32 95.51
13	7.67-8.67	10.36 20.52	30.56 34.66	30.56 34.66	18.62 18.62	95.51 103.71
14	8.67-9.23	20.52 26.23	34.66 36.96	34.66 36.96	18.62 18.62	103.71 108.31
15	9.23-9.67	35.84 37.80	— —	35.84 37.80	18.62 18.62	102.29 111.64
16	9.67-10.67	37.80 42.27	— —	37.80 42.27	18.62 18.62	111.64 132.88
17	10.67-11.67	42.27 46.73	— —	42.27 46.73	18.62 18.62	132.88 154.12
18	11.67-12.67	35.08 39.09	— —	35.08 39.09	18.62 18.62	216.35 246.17
19	12.67-13.67	43.13 46.89	— —	43.13 46.89	18.62 18.62	217.11 243.41
20	13.67-14.67	47.72 51.54	— —	47.72 51.54	18.62 18.62	238.08 263.80
21	14.67-15.23	34.70 36.15	— —	34.70 36.15	18.62 18.62	440.68 464.75
22	15.23-24.16	-244.41 -171.63	64.56 94.47	64.56 94.47	18.62 18.62	499.51 539.34
23	24.16-33.90	-1772.99 -1688.60	94.47 129.54	94.47 129.54	18.62 18.62	2159.34 2229.47

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z, m	water level y, m	pdw, kN/m ²
1	1.90	0.00	0.00
2	2.90	1.00	2.38
3	3.82	1.92	3.29

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

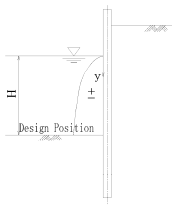
Where,

k_{is} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

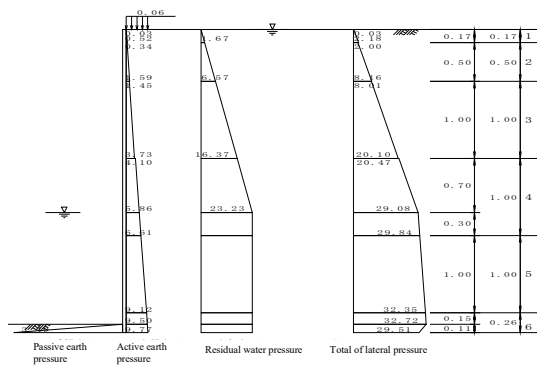
y : depth from water surface to the point where active water pressure is calculated



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



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.17	0.27 0.75	0.00 1.67	— —	0.27 2.42
2	0.17- 0.67	0.73 2.60	1.67 6.57	— —	2.39 9.16
3	0.67- 1.67	2.38 5.80	6.57 16.37	— —	8.94 22.17
4	1.67- 1.90	6.33 7.19	16.37 18.62	— —	22.69 25.81
5	1.90- 2.67	7.19 10.06	18.62 18.62	— —	25.81 28.68
6	2.67- 3.67	10.06 13.80	18.62 18.62	— —	28.68 32.42
7	3.67- 3.82	13.80 14.36	18.62 18.62	— —	32.42 32.98
8	3.82- 3.93	14.36 14.77	18.62 18.62	0.00 1.96	32.98 31.43
9	3.93- 4.67	15.23 18.26	18.62 18.62	100.85 106.92	-67.00 -70.03

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed Lk: 0.11 m (GL -3.93 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Calculation formula of lateral ground reaction coefficient

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{L0} = K_{L0} \left(\frac{B_0}{0.3} \right)^{-3/4} \quad (B_0 = 10.00m)$$

$$K_{L0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.17	0.03 0.52	0.00 1.67	— —	0.03 2.18
2	0.17- 0.67	0.34 1.39	1.67 6.57	— —	2.00 8.16
3	0.67- 1.67	1.45 3.73	6.57 16.37	— —	8.01 20.10
4	1.67- 2.37	4.10 5.86	16.37 23.23	— —	20.47 29.08
5	2.37- 2.67	5.86 6.61	23.23 23.23	— —	29.08 29.84
6	2.67- 3.67	6.61 9.12	23.23 23.23	— —	29.84 32.35
7	3.67- 3.82	9.12 9.50	23.23 23.23	— —	32.35 32.72
8	3.82- 3.93	9.50 9.77	23.23 23.23	0.00 3.49	32.72 29.51
9	3.93- 4.67	14.99 18.03	23.23 23.23	100.85 106.92	-62.63 -65.66

P_a : Active earth pressure

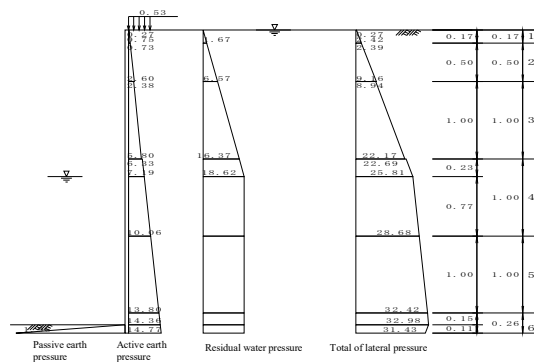
P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed Lk: 0.11 m (GL -3.93 m)

4.2 Seismic Condition



Material Name

Hat steel sheet pile SP -50 H

Unit width

B = 1.0000 m

Corrosion margin

$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)

Corrosion rate

$\eta = 0.87$

Section efficiency

$\eta = 1.00$

Young's modulus

E = 200000 N/mm²

Inertia sectional moment

$I_0 = 51100$ cm⁴ (original condition)

Inertia sectional moment

I = 44457 cm⁴ (after reduction by corrosion and section)

Inertia sectional moment

El = $200000 \times 10^3 \times 44457 \times 10^{-8} = 8.891 \times 10^5$

No	Depth m	N Value	No	Depth m	N Value
1	0.17	4	11	10.17	5
2	1.17	14	12	11.17	5
3	2.17	4	13	12.17	26
4	3.17	4	14	13.17	19
5	4.17	5	15	14.17	18
6	5.17	14	16	15.17	50
7	6.17	5	17	16.17	50
8	7.17	4	18	17.17	50
9	8.17	4	19	18.17	46
10	9.17	4	20	19.17	35

5.2 Normal Condition

Assuming Kh = 5444 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.352 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.84 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) to 2.84 m depth (GL -6.77 m).

No	Depth Z m	Thickness h m	N Value upper	N Value lower	Area A
1	3.93	0.24	4.8	5.0	1.17
2	4.17	1.00	5.0	14.0	9.50
3	5.17	1.00	14.0	5.0	9.50
4	6.17	0.60	5.0	4.4	2.83

$L = 2.8 - 2.84 \quad \Sigma A = 23.00$

A: (upper N-value + lower N-value) $\times$ h/2

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{23.00}{2.84} = 8.09$$

Kh is recalculated from the calculated average N value.

E₀ = 2800N' = 2800×8, 09 = 22655 kN/m²
K_{u0}= 1 / 0.3 × α × 22655 = 75518 kN/m³ (α :Normal Condition =1, Seismi Condition =2)
K_b = K_{u0}(B_u/0. 3)^{-3/4} = 75518(10. 00/0. 3)^{-3/4} = 5444 kN/m²

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 5444 kN/m².

5.3 Seismic Condition

Assuming Kh = 11886 kN/m²,

β = 4√(K_b · B / 4 E I) = 0. 428 m⁻¹
L = 1 / β = 2. 34 m

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -3.93 m) and 2.34 m depth (GL -6.27 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	3.93	0.24	4.8	5.0	1.17
2	4.17	1.00	5.0	14.0	9.50
3	5.17	1.00	14.0	5.0	9.50
4	6.17	0.10	5.0	4.9	0.49
L = Σ h = 2.34			Σ A = 20.66		

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

Average N-value N' = Σ A / L
= 20. 66 / 2. 34
= 8. 83

Kh is recalculated from the calculated average N value.

E₀ = 2800N' = 2800×8, 83 = 24733 kN/m²
K_{u0}= 1 / 0.3 × α × 24733 = 164890 kN/m³ (α :Normal Condition =1, Seismi Condition =2)
K_b = K_{u0}(B_u/0. 3)^{-3/4} = 164890(10. 00/0. 3)^{-3/4} = 11886 kN/m²

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 11886 kN/m².

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.17	0.17	0.02 2.42	0.02 0.21	3.87 3.82	0.09 0.78
2	0.17- 0.67	0.50	2.39 9.16	0.60 2.29	3.59 3.43	2.15 7.85
3	0.67- 1.67	1.00	8.94 22.17	4.47 11.08	2.93 2.59	13.09 28.74
4	1.67- 1.90	0.23	22.69 25.81	2.61 2.97	2.18 2.11	5.70 6.25
5	1.90- 2.67	0.77	25.81 28.68	9.84 11.04	1.77 1.52	17.62 16.75
6	2.67- 3.67	1.00	28.68 32.42	14.34 16.21	0.93 0.59	13.29 9.62
7	3.67- 3.82	0.15	32.42 32.98	2.43 2.47	0.21 0.16	0.51 0.40
8	3.82- 3.93	0.11	32.98 31.43	1.81 1.73	0.07 0.04	0.13 0.06
Σ P = 84.22			Σ M = 123.03			

P_i : 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_i = 0.0 kN/m
depth to acting position H_i = 0.00 m
moment M_{in} = 0.0 kN·m/m
depth to acting position H_{in} = 0.00 m
Height from riverbed to top of coping H = 3.82 m
Depth of Imaginary riverbed from riverbed L_k = 0.11 m

Moment M_i by arbitrary load is as below
M_i = P_i·(H + L_k - H_i) + M_{in} = 0.00 kN·m

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m2	Loads p _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	1.90- 2.90	1.00	0.0 2.4	0.00 1.19	1.70 1.36	0.00 1.62
2	2.90- 3.82	0.92	2.4 3.3	1.09 1.51	0.72 0.42	0.79 0.63
Σ P _{dw} = 3.80			Σ M _{dw} = 3.04			

h₀, Height of acting position of P₀ from imaginary riverbed

h₀ = M₀ / (Σ M + M_i + Σ M_{dw})
= P₀ / (Σ P + P_i + Σ P_{dw})
= 126. 07 / 88. 02 = 1. 43 m

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.17	0.17	0.03 2.18	0.00 0.19	3.87 3.82	0.01 0.71
2	0.17- 0.67	0.50	2.00 8.16	0.50 2.04	3.59 3.43	1.80 6.99
3	0.67- 1.67	1.00	8.01 20.10	4.01 10.05	2.93 2.59	11.73 26.06
4	1.67- 2.37	0.70	20.47 29.08	7.16 10.18	2.03 1.79	14.52 18.25
5	2.37- 2.67	0.30	29.08 29.84	4.26 4.48	1.46 1.36	6.37 6.09
6	2.67- 3.67	1.00	29.84 32.35	14.92 16.17	0.93 0.59	13.82 9.60
7	3.67- 3.82	0.15	32.35 32.72	2.43 2.45	0.21 0.16	0.51 0.39
8	3.82- 3.93	0.11	32.72 29.51	1.80 1.62	0.07 0.04	0.13 0.06
Σ P = 82.36			Σ M = 117.04			

P_i : 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_i = 0.0 kN/m
depth to acting position H_i = 0.0 m
moment M_{in} = 0.0 kN·m/m
depth to acting position H_{in} = 0.00 m
Height from riverbed to top of coping H = 3.82 m
Depth of Imaginary riverbed from riverbed L_k = 0.11 m

Moment M_i by arbitrary load is as below
M_i = P_i·(H + L_k - H_i) + M_{in} = 0.00 kN·m
h₀, Height of acting position of P₀ from imaginary riverbed

h₀ = M₀ / (Σ M + M_i)
= P₀ / (Σ P + P_i)
= 117. 04 / 82. 36 = 1. 42 m

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

P' = (2 × P₀) / (H + L_k) = (2 × 88. 02) / 3. 93 = 44. 79 kN/m

6.2 Sectional Force

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

Material name	Hat steel sheet pile SP -50 H
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 = 51100 cm ⁴ (original condition) I = 44457 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 44457 × 10 ⁻⁸	= 8.891 × 10 ⁴

β = 4√(K_b · B / 4 E I)
φ_a = √((1 + 2 β h₀)² + 1) / (2 β h₀) × exp(-tan⁻¹ (1 / (1 + 2 β h₀)))
M_{max} = M₀ · φ_a
l_a = 1 / β × tan⁻¹ (1 / (1 + 2 β h₀))
l_i = 1 / β × tan⁻¹ (1 + β h₀ / β h₀)
M_(z) = - P₀ / β × exp^{-β z} (β h₀ · cos β x + (1 + β h₀) sin β x)

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 5444 kN/m³
calculated value	β = 0.35174 m ⁻¹
resultant earth force (lateral)	P ₀ = 82.36 kN/m
height of acting position of load	h ₀ = 1.42 m
moment	M ₀ = 117.04 kN·m/m

in consideration of ψ_{0a} = 1.407,
maximum moment M_{max} = 166.63 kN·m/m
depth of generated position of M_{max} l_m = 1.318 m
depth of 1st fixed point l_i = 3.551 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b = 11886 kN/m³
calculated value	β = 0.42756 m ⁻¹
resultant earth force (lateral)	P ₀ = 88.02 kN/m
height of acting position of load	h ₀ = 1.43 m
moment	M ₀ = 126.07 kN·m/m

in consideration of $\psi_{m1} = 1.305$,
maximum moment $M_{max} = 164.57 \text{ kN}\cdot\text{m/m}$
depth of generated position of M_{max} $l_m = 0.988 \text{ m}$
depth of l^a fixed point $l_i = 2.825 \text{ m}$

6.3 Stress Intensity

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

Material Name Hat steel sheet pile SP -50 H
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.87$
Section efficiency $\mu = 1.00$
Module of section $Z_0 = 2760 \text{ cm}^3$ (original condition)
 $Z = 2401 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{164.63 \times 10^6}{2401 \times 10^3} = 69 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

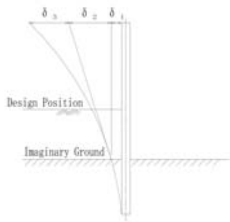
6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{164.57 \times 10^6}{2401 \times 10^3} = 69 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

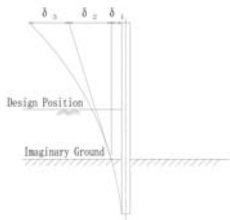
Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1 + 0.3517 \times 1.42) \times 82.36}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.3517^3} = 0.01596 \text{ m}$$

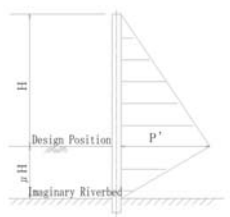
6.4.2 Seismic Condition

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1 + 0.4276 \times 1.43) \times 88.02}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.4276^3} = 0.01021 \text{ m}$$

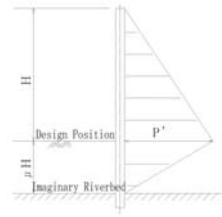
$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) = \frac{(1 + 2 \times 0.4276 \times 1.43) \times 88.02}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.4276^2} \times (3.82 + 0.11) = 0.02367 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.11}{3.82} = 0.029$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) = \frac{44.79 \times 3.82^4}{120 \times 2.00 \times 10^8 \times 44457 \times 10^{-8}} (4 + 20 \times 0.029 + 40 \times 0.029^2 + 35 \times 0.029^3 + 11 \times 0.029^4) = 0.00412 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) = \frac{(1 + 2 \times 0.3517 \times 1.42) \times 82.36}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.3517^2} \times (3.82 + 0.11) = 0.02942 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.11}{3.82} = 0.029$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) = \frac{41.91 \times 3.82^4}{120 \times 2.00 \times 10^8 \times 44457 \times 10^{-8}} (4 + 20 \times 0.029 + 40 \times 0.029^2 + 35 \times 0.029^3 + 11 \times 0.029^4) = 0.00386 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01596 + 0.02942 + 0.00386 = 0.04924 \text{ m}$$

$$\text{Size} = 49.24 \leq \delta_a = 50.00 \text{ mm}$$

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

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01021 + 0.02367 + 0.00412 = 0.03800 \text{ m}$$

$$\text{Size} = 38.00 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Material Name Hat steel sheet pile SP -50 H
Unit width $B = 1.0000 \text{ m}$
Corrosion rate $\eta = 1.00$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 51100 \text{ cm}^4$ (original condition)
 $I = 51100 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 51100 \times 10^{-8} = 1.022 \times 10^9$

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is L_k , the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

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

$$L = H - H_{11} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_b = 5444 \text{ kN/m}^3$
Calculated value $\beta = 0.33970 \text{ m}^{-1}$

Penetration length of SSP $D = 0.11 + \frac{3}{0.340} = 8.94 \text{ m}$
Whole length of SSP $L = 3.82 - 0.40 + 8.94 = 12.36 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 11886 \text{ kN/m}^3$
Calculated value $\beta = 0.41293 \text{ m}^{-1}$

Penetration length of SSP $D = 0.11 + \frac{3}{0.413} = 7.38 \text{ m}$
Whole length of SSP $L = 3.82 - 0.40 + 7.38 = 10.80 \text{ m}$

Therefore, the total length of the sheet pile is 12.50 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile		Hat steel sheet pile SP-50 H		
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	51100		
Sectional Modulus	Z (cm ³)	2760		
Maximum bending moment	Mmax (kN · m · m)		164.63	164.57
Stress intensity	σ (N/mm ²)		69 (180)	69 (270)
Lateral displacement	δ (mm)		49.24 (50.0)	38.00 (75.0)
Penetration depths	D (m)		8.94	7.38
Whole length of SSP	L (m)	12.50		

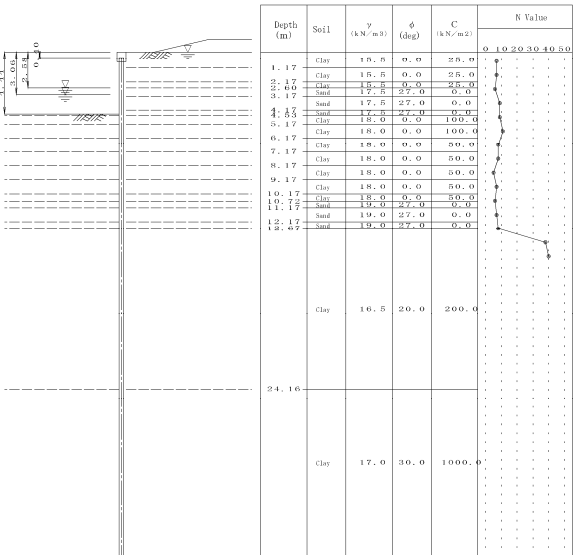
Block No. : L-33
Sta. : 13+320~13+360

Design Cross Section : Sta 13+340
Boring Name : BMLL-40

Specification : SSP SP-10H
(Combined) : H 450-200-9-19-13

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed H = 4.44 m
Depth from coping top to rear side ground H₀ = 0.00 m
Depth from coping top to SSP top H_h = 0.40 m
Landside WL L_{wa} = 0.00 m (Normal Condition)
L_{wa} = 0.00 m (Seismic Condition)
Riverside WL L_{wp} = 3.06 m (Normal Condition)
L_{wp} = 2.58 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{b0} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_H = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$

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	0.67	7	11	10.67	6
2	1.67	7	12	11.67	7
3	2.67	6	13	12.67	8
4	3.67	9	14	13.67	38
5	4.67	9	15	14.67	40
6	5.67	11			
7	6.67	8			
8	7.67	8			
9	8.67	5			
10	9.67	7			

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

Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.17	1.17
2	2.17	1.00
3	2.60	0.43
4	3.17	0.57
5	4.17	1.00
6	4.53	0.36
7	5.17	0.64
8	6.17	1.00
9	7.17	1.00
10	8.17	1.00
11	9.17	1.00
12	10.17	1.00
13	10.72	0.55
14	11.17	0.45
15	12.17	1.00
16	12.67	0.50
17	24.16	11.49
18	34.60	10.44

No	Depth m	soil Soil	N Value	γ kN/m3	γ' kN/m3	φ degree	C kNm2	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.17	C	7.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
2	2.17	C	7.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
3	2.60	C	6.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
4	3.17	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	4.17	S	9.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	4.53	S	9.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
7	5.17	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
8	6.17	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	7.17	C	8.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto
10	8.17	C	8.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto
11	9.17	C	5.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto
12	10.17	C	7.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto
13	10.72	C	6.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto
14	11.17	S	6.0	19.00	9.20	27.0	0.0	0.0	0.200	Auto	Auto
15	12.17	S	7.0	19.00	9.20	27.0	0.0	0.0	0.200	Auto	Auto
16	12.67	S	8.0	19.00	9.20	27.0	0.0	0.0	0.200	Auto	Auto
17	24.16	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
18	34.60	C	121.5	17.00	7.20	30.0	1000.0	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_a : 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

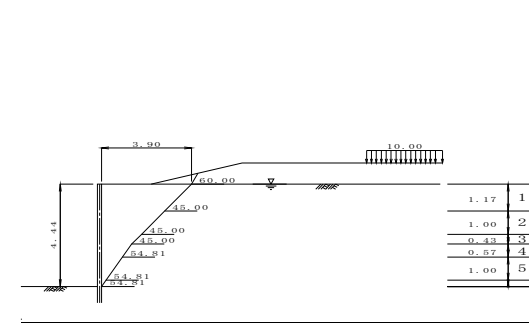
Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.9 Steel Sheet Pile (SSP)

Material name	10 H H 450 -200 -9 -19 -13
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 128300 cm ⁴
Sectional factor	Z ₀ = 3280 cm ³
Corrosion margin	t ₁ = 1.00 mm (riverside) t ₂ = 1.00 mm (landside)
Corrosion rate (to I ₀)	η ₁ = 0.83
Corrosion rate (to Z ₀)	η ₂ = 0.85
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

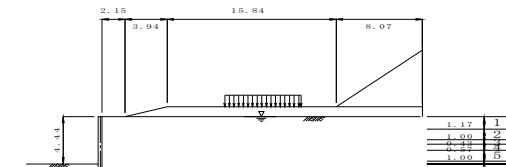
2.1 Normal Condition



2.1.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	ζ degree	C kNm2	Σ γ h kN/m2	Q kN/m2	γ when kN/m2	Angle of Rupture ζ degree
1	4.44 ~ 4.17	Sand	27.0	15.0	0.0	28.99	2.01	43.51	54.81

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		h m	Normal Condition kN/m ³			Seismic Condition kN/m ³	ϕ degree
1	Sand	2.15	6.09	30.00	30.00	0.92	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	21.93	30.00	30.00	30.00	5.30	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	11.49	18.63	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

2	4.17 ~ 3.17	Sand	27.0	15.0	0.0	26.91	2.01	40.87	54.81
3	3.17 ~ 2.60	Sand	27.0	15.0	0.0	19.21	2.01	31.07	54.81
4	2.60 ~ 2.17	Clay	0.0	15.0	25.0	14.82	2.01	25.48	45.00
5	2.17 ~ 1.17	Clay	0.0	15.0	25.0	12.37	2.01	21.27	45.00
6	1.17 ~ 0.00	Clay	0.0	15.0	25.0	6.67	2.01	11.47	45.00
7		embankment t	30.0	——	0.0	118.18	0.00	0.00	60.00

• Angle of active rupture of sandy soil

• Angle of active rupture of clayey soil

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

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)
- θ = tan⁻¹ k or θ = 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.81	0.27	0.00	0.00	0.19	0.27
2	54.81	1.00	0.19	0.27	0.90	1.27
3	54.81	0.57	0.90	1.27	1.30	1.84
4	45.00	0.43	1.30	1.84	1.73	2.27
5	45.00	1.00	1.73	2.27	2.73	3.27
6	45.00	1.17	2.73	3.27	3.90	4.44
7	60.00	0.47	3.90	4.44	4.17	4.91

From the above table, the loading width (L) on the ground surface is 3.90 m.

2.1.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.41	7.83
Σ			7.83

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

2.1.4 Calculated Load

Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (7.83 + 0.00 + 0.00) / 3.90

= 2.01 kN/m²

2.2 Seismic Condition

ζ = tan⁻¹ √(1 - (Σ γ h + 2Q) / 2C) · tan θ

- 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⁻¹ k or θ = 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	0.27	0.00	0.00	0.30	0.27
2	42.18	1.00	0.30	0.27	1.40	1.27
3	42.18	0.57	1.40	1.27	2.03	1.84
4	43.64	0.43	2.03	1.84	2.48	2.27
5	43.80	1.00	2.48	2.27	3.52	3.27
6	44.15	1.17	3.52	3.27	4.73	4.44
7	49.60	0.75	4.73	4.44	5.37	5.19

From the above table, the loading width (L) on the ground surface is 4.73 m.

2.2.1 Angle of Active Rupture

No	Depth m	Soil	δ degree	φ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ wlm kN/m2	k (k')	θ degree	Angle of Rupture ζ degree
1	4.44 ~ 4.17	Sand	27.0	15.0	0.0	28.99	3.90	43.51	0.200	11.31	42.18
2	4.17 ~ 3.17	Sand	27.0	15.0	0.0	26.91	3.90	40.87	0.200	11.31	42.18
3	3.17 ~ 2.60	Sand	27.0	15.0	0.0	19.21	3.90	31.07	0.200	11.31	42.18
4	2.60 ~ 2.17	Clay	0.0	15.0	25.0	14.82	3.90	25.48	0.200	11.31	43.64
5	2.17 ~ 1.17	Clay	0.0	15.0	25.0	12.37	3.90	21.27	0.200	11.31	43.80
6	1.17 ~ 0.00	Clay	0.0	15.0	25.0	6.67	3.90	11.47	0.200	11.31	44.15
7		embankment	30.0	—	0.0	118.18	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

ζ = 90 - tan⁻¹ [sin(φ + θ) / (cos(δ + θ) · sin(φ + δ) / sin(φ - θ))]

• Major collapse angle of cohesive soil

2.2.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.97	18.43
Σ			18.43

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

2.2.4 Calculated Load

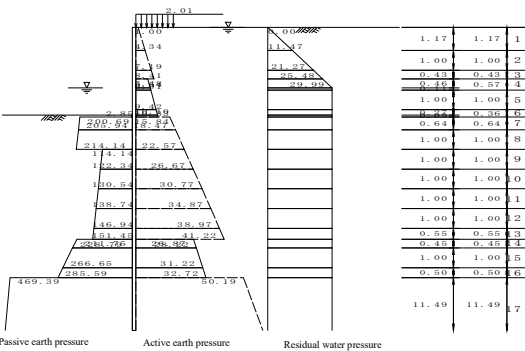
Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (18.43 + 0.00 + 0.00) / 4.73

= 3.90 kN/m²

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Q ₀ kN/m2	K _a	K _a × cos δ
1	0.00 ~ 1.17	Clay	5.7	—	25.0	2.809	—	—
2	1.17 ~ 2.17	Clay	5.7	—	25.0	8.678	—	—
3	2.17 ~ 2.60	Clay	5.7	—	25.0	14.378	—	—
4	2.60 ~ 3.06	Sand	7.7	27.0	—	16.829	0.3378	0.32589
5	3.06 ~ 3.17	Sand	7.7	27.0	—	20.371	0.3378	0.32589
6	3.17 ~ 4.17	Sand	7.7	27.0	—	21.218	0.3378	0.32589
7	4.17 ~ 4.44	Sand	7.7	27.0	—	28.918	0.3378	0.32589
8	4.44 ~ 4.53	Sand	7.7	27.0	—	30.997	0.3378	0.32589
9	4.53 ~ 5.17	Clay	8.2	—	100.0	31.690	—	—
10	5.17 ~ 6.17	Clay	8.2	—	100.0	36.938	—	—
11	6.17 ~ 7.17	Clay	8.2	—	50.0	45.138	—	—
12	7.17 ~ 8.17	Clay	8.2	—	50.0	53.338	—	—

13	8.17 ~ 9.17	Clay	8.2	—	50.0	61.538	—	—
14	9.17 ~ 10.17	Clay	8.2	—	50.0	69.738	—	—
15	10.17 ~ 10.72	Clay	8.2	—	50.0	77.938	—	—
16	10.72 ~ 11.17	Sand	9.2	27.0	—	82.448	0.3378	0.32589
17	11.17 ~ 12.17	Sand	9.2	27.0	—	86.588	0.3378	0.32589
18	12.17 ~ 12.67	Sand	9.2	27.0	—	86.588	0.3378	0.32589
19	12.67 ~ 24.16	Clay	6.7	—	200.0	100.388	—	—
20	24.16 ~ 34.60	Clay	7.2	—	1000.0	177.371	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
δ = 15.00, β = 0.00, θ = 0.00

K_a = cos²(φ - θ) / (cos θ · cos(δ + θ) · [1 + (sin(φ + δ) · sin(φ - β - θ) / cos(δ + θ) · cos(-β))²])

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Q ₀ kN/m2	K _p	K _p × cos δ
8	4.44 ~ 4.53	Sand	7.7	27.0	—	0.693	4.26080	4.11561
9	4.53 ~ 5.17	Clay	8.2	0.0	100.0	0.693	—	—
10	5.17 ~ 6.17	Clay	8.2	0.0	100.0	5.941	—	—
11	6.17 ~ 7.17	Clay	8.2	0.0	50.0	14.141	—	—
12	7.17 ~ 8.17	Clay	8.2	0.0	50.0	22.341	—	—
13	8.17 ~ 9.17	Clay	8.2	0.0	50.0	30.541	—	—
14	9.17 ~ 10.17	Clay	8.2	0.0	50.0	38.741	—	—
15	10.17 ~ 10.72	Clay	8.2	0.0	50.0	46.941	—	—
16	10.72 ~ 11.17	Sand	9.2	27.0	—	51.451	4.26080	4.11561
17	11.17 ~ 12.17	Sand	9.2	27.0	—	55.591	4.26080	4.11561
18	12.17 ~ 12.67	Sand	9.2	27.0	—	64.791	4.26080	4.11561
19	12.67 ~ 24.16	Clay	6.7	20.0	200.0	69.391	—	—
20	24.16 ~ 34.60	Clay	7.2	30.0	1000.0	146.374	—	—

Coefficient of passive earth pressure of sandy soil K_p is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2		
1	0.00- 1.17	-47.99 -41.32	1.00 4.34	1.00 4.34	0.00 11.47	—
2	1.17- 2.17	-41.32 -35.62	4.34 7.19	4.34 7.19	11.47 21.27	—
3	2.17- 2.60	-35.62 -33.17	7.19 8.41	7.19 8.41	21.27 25.48	—
4	2.60- 3.06	-5.48 6.64	—	5.48 6.64	25.48 29.99	—
5	3.06- 3.17	6.64 6.91	—	6.64 6.91	29.99 29.99	—
6	3.17- 4.17	—	—	6.91 9.42	29.99 29.99	—
7	4.17- 4.44	—	—	9.42 10.10	29.99 29.99	—
8	4.44- 4.53	—	—	10.10 10.33	29.99 29.99	0.00 2.85
9	4.53- 5.17	-168.31 -163.06	15.84 18.47	15.84 18.47	29.99 29.99	200.69 205.94
10	5.17- 6.17	-163.06 -154.86	18.47 22.57	18.47 22.57	29.99 29.99	205.94 214.14
11	6.17- 7.17	-54.86 -46.66	22.57 26.67	22.57 26.67	29.99 29.99	114.14 122.34
12	7.17- 8.17	-46.66 -38.46	26.67 30.77	26.67 30.77	29.99 29.99	122.34 130.54
13	8.17- 9.17	-38.46 -30.26	30.77 34.87	30.77 34.87	29.99 29.99	130.54 138.74
14	9.17- 10.17	-30.26 -22.06	34.87 38.97	34.87 38.97	29.99 29.99	138.74 146.94
15	10.17- 10.72	-22.06 -17.55	38.97 41.22	38.97 41.22	29.99 29.99	146.94 151.45
16	10.72- 11.17	—	—	26.87 28.22	29.99 29.99	211.75 228.79
17	11.17- 12.17	—	—	28.22 31.22	29.99 29.99	228.79 266.65
18	12.17- 12.67	—	—	31.22 32.72	29.99 29.99	266.65 285.59
19	12.67- 24.16	-299.61 -222.63	50.19 88.69	50.19 88.69	29.99 29.99	469.39 546.37
20	24.16- 34.60	-1822.63 -1747.46	88.69 126.27	88.69 126.27	29.99 29.99	2146.37 2221.54

- Formula for active earth pressure

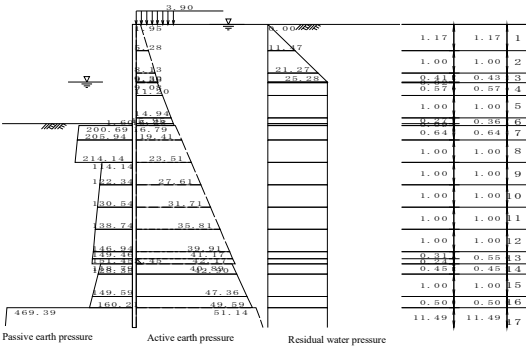
Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2C$
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/m2	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γwhw kN/m2	k (δ)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.17	Clay	5.7	—	25.0	3.90 10.56	0.00 11.47	0.200 0.200	11.31	—	—	44.55 44.15
2	1.17- 2.17	Clay	5.7	—	25.0	10.56 16.26	11.47 21.27	0.200 0.200	11.31	—	—	44.15 43.80
3	2.17- 2.58	Clay	5.7	—	25.0	16.26 18.49	21.27 25.28	0.200 0.200	11.31	—	—	43.80 43.65
4	2.58- 2.60	Clay	5.7	—	25.0	18.49 18.72	25.28 25.48	0.200 0.200	11.31	—	—	43.65 43.64

5	2.60- 3.17	Sand	7.7	27.0	—	18.72 23.11	25.48 31.07	0.200 0.200	11.31	0.50201	0.48490	—
6	3.17- 4.17	Sand	7.7	27.0	—	23.11 30.81	31.07 40.87	0.200 0.200	11.31	0.50201	0.48490	—
7	4.17- 4.44	Sand	7.7	27.0	—	30.81 32.88	40.87 44.39	0.200 0.200	11.31	0.50201	0.48490	—
8	4.44- 4.53	Sand	7.7	27.0	—	32.88 33.58	44.39 44.39	0.200 0.200	11.31	0.50201	0.48490	—
9	4.53- 5.17	Clay	8.2	—	—	100.0 100.0	44.39 50.67	0.200 0.200	11.31	—	—	44.45 44.37
10	5.17- 6.17	Clay	8.2	—	—	100.0 100.0	50.67 47.02	0.200 0.200	11.31	—	—	44.37 44.25
11	6.17- 7.17	Clay	8.2	—	—	50.0 50.0	47.02 55.22	0.200 0.200	11.31	—	—	43.86 43.20
12	7.17- 8.17	Clay	8.2	—	—	50.0 50.0	55.22 63.42	0.200 0.200	11.31	—	—	43.20 42.93
13	8.17- 9.17	Clay	8.2	—	—	50.0 50.0	63.42 71.62	0.200 0.200	11.31	—	—	42.93 42.66
14	9.17- 10.17	Clay	8.2	—	—	50.0 50.0	71.62 79.82	0.200 0.200	11.31	—	—	42.66 42.38
15	10.17- 10.48	Clay	8.2	—	—	50.0 50.0	79.82 82.34	0.200 0.200	11.31	—	—	42.38 —
16	10.48- 10.72	Clay	8.2	—	—	50.0 50.0	82.34 84.33	0.200 0.200	11.31	—	—	— 42.22
17	10.72- 11.17	Sand	9.2	27.0	—	84.33 88.47	105.06 109.47	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
18	11.17- 12.17	Sand	9.2	27.0	—	88.47 97.67	109.47 119.27	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
19	12.17- 12.67	Sand	9.2	27.0	—	97.67 102.27	119.27 124.17	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
20	12.67- 24.16	Clay	6.7	—	—	200.0 200.0	102.27 179.26	0.200 0.200	11.31	—	—	44.22 43.62
21	24.16- 34.60	Clay	7.2	—	—	1000.0 1000.0	179.26 254.43	0.200 0.200	11.31	—	—	44.74 44.63

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

No	Depth m	Soil	γ kN/m2	ϕ degree	C kN/m2	$\Sigma \gamma h + Q_p$ kN/m2	γwhw kN/m2	k (δ)	θ degree	K_p	$K_p \times \cos \delta$
8	4.44- 4.53	Sand	7.70	27.0	—	0.000 0.693	0.00 0.88	0.200 0.200	11.31	2.30874 2.30874	2.30874 2.30874
9	4.53- 5.17	Clay	8.20	0.0	100.0	0.693 5.941	0.88 7.15	0.200 0.200	11.31	—	—

No	Depth m	N Value	No	Depth m	N Value
1	0.67	7	11	10.67	6
2	1.67	7	12	11.67	7
3	2.67	6	13	12.67	8
4	3.67	9	14	13.67	38
5	4.67	9	15	14.67	40
6	5.67	11			
7	6.67	8			
8	7.67	8			
9	8.67	5			
10	9.67	7			

5.2 Normal Condition

Assuming $K_h = 6067 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.291 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.44 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.53 m) to 3.44 m depth (GL -7.97 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.53	0.14	9.0	9.0	1.26
2	4.67	1.00	9.0	11.0	10.00
3	5.67	1.00	11.0	8.0	9.50
4	6.67	1.00	8.0	8.0	8.00
5	7.67	0.30	8.0	7.1	2.28
L = $\Sigma h=3.44$			$\Sigma A=$		31.04

A: (upper N-value + lower N-value) $\times$ h/2

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{31.04}{3.44} \\ &= 9.02 \end{aligned}$$

K_h is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800 N' = 2800 \times 9.02 = 25249 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 25249 = 84162 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2) \\ K_b &= K_{10} (B_u/0.3)^{-3/4} = 84162 (10.00/0.3)^{-3/4} = 6067 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 6067 kN/m³.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.17	1.17	1.00 15.80	0.59 9.25	4.14 3.75	2.43 34.67
2	1.17- 2.17	1.00	15.80 28.45	7.90 14.23	3.03 2.69	23.92 38.32
3	2.17- 2.60	0.43	28.45 33.89	6.12 7.29	2.22 2.07	13.56 15.11
4	2.60- 3.06	0.46	30.96 36.63	7.12 8.42	1.78 1.62	12.65 13.68
5	3.06- 3.17	0.11	36.63 36.90	2.01 2.03	1.43 1.40	2.89 2.83
6	3.17- 4.17	1.00	36.90 39.41	18.45 19.71	1.03 0.69	18.94 13.66
7	4.17- 4.44	0.27	39.41 40.09	5.32 5.41	0.27 0.18	1.44 0.97
8	4.44- 4.53	0.09	40.09 37.46	1.80 1.69	0.06 0.03	0.11 0.05
$\Sigma P = 117.34$		$\Sigma M = 195.24$				

P_0 : active earth pressure + residual water pressure - passive earth pressure
P: load $P_s \times h/2 \times B$
B: unit width = 1.000 m
Y: height of acting position from imaginary riverbed
M: moment by load $P \times Y$

Arbitrary load lateral load $P_i = 0.0 \text{ kN/m}$
depth to acting position $H_i = 0.0 \text{ m}$
moment $M_{i0} = 0.0 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_{i0} = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 4.44 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below

$$M_i = P_i (H + L_k - H_i) + M_{i0} = 0.00 \text{ kN} \cdot \text{m}$$

h_0 : Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} \\ &= \frac{195.24}{117.34} = 1.66 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 117.34}{4.53} = 51.81 \text{ kN/m}$$

5.3 Seismic Condition

Assuming $K_h = 12468 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.348 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.88 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.53 m) and 2.88 m depth (GL -7.41 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.53	0.14	9.0	9.0	1.26
2	4.67	1.00	9.0	11.0	10.00
3	5.67	1.00	11.0	8.0	9.50
4	6.67	0.74	8.0	8.0	5.88
L = $\Sigma h = 2.88$			$\Sigma A =$		26.64

A: (upper N-value + lower N-value) $\times$ h/2

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{26.64}{2.88} \\ &= 9.27 \end{aligned}$$

K_h is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800 N' = 2800 \times 9.27 = 25945 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 25945 = 172965 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2) \\ K_b &= K_{10} (B_u/0.3)^{-3/4} = 172965 (10.00/0.3)^{-3/4} = 12468 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 12468 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1.2 Seismic Condition

No	Depth, Z m	Thickness h m	Lateral Forth P ₀ kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.17	1.17	1.95 16.75	1.14 9.80	4.14 3.75	4.72 36.74
2	1.17- 2.17	1.00	16.75 29.40	8.37 14.70	3.03 2.69	25.35 39.59
3	2.17- 2.58	0.41	29.40 34.58	6.03 7.09	2.22 2.09	13.40 14.79
4	2.58- 2.60	0.02	34.58 34.64	0.35 0.35	1.94 1.94	0.67 0.67
5	2.60- 3.17	0.57	34.36 36.49	9.79 10.40	1.74 1.55	17.04 16.12
6	3.17- 4.17	1.00	36.49 40.22	18.24 20.11	1.03 0.69	18.73 13.94
7	4.17- 4.44	0.27	40.22 41.23	5.43 5.57	0.27 0.18	1.47 1.00
8	4.44- 4.53	0.09	41.23 39.97	1.86 1.80	0.06 0.03	0.11 0.05
			Σ P = 121.01	Σ M = 204.39		

P_0 : active earth pressure + residual water pressure - passive earth pressure
P: load $P_s \times h/2 \times B$
B: unit width = 1.000 m
Y: height of acting position from imaginary riverbed
M: moment by load $P \times Y$

Arbitrary load lateral load $P_i = 0.0 \text{ kN/m}$
depth to acting position $H_i = 0.00 \text{ m}$
moment $M_{i0} = 0.0 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_{i0} = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 4.44 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.09 \text{ m}$

Moment M_i by arbitrary load is as below

$$M_i = P_i (H + L_k - H_i) + M_{i0} = 0.00 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth, Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} × m
1	2.58- 3.58	1.00	0.0 2.3	0.00 1.17	1.62 1.28	0.00 1.50
2	3.58- 4.44	0.86	2.3 3.2	1.01 1.37	0.66 0.38	0.67 0.52
Σ P _{dw} = 3.55				Σ M _{dw} = 2.68		

h_0 : Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{dw}}{\Sigma P + P_i + \Sigma P_{dw}} \\ &= \frac{207.08}{124.56} = 1.66 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_1)} = \frac{2 \times 124.56}{4.53} = 54.99 \text{ kN/m}$$

6.2 Sectional Force

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

Material name	10 H _ H 450 -200 -9 -19 -13
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 = 0.83
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 128300 cm ⁴ (original condition) I = 106489 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 106489 × 10 ⁻⁸	= 2.130 × 10 ⁵

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

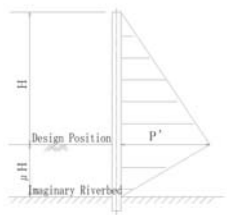
$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 6067 kN/m ³
calculated value	β = 0.29050 m ⁻¹
resultant earth force (lateral)	P ₀ = 117.34 kN/m
height of acting position of load	h ₀ = 1.66 m
moment	M ₀ = 195.24 kN·m/m

in consideration of ψ _m = 1.426, maximum moment	M _{max} = 278.39 kN·m/m
depth of generated position of M _{max}	l _m = 1.619 m
depth of l st fixed point	l _i = 4.323 m



$$\mu = \frac{L_k}{H} = \frac{0.09}{4.44} = 0.020$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4) = \frac{51.81 \times 4.44^4}{120 \times 2.00 \times 10^8 \times 106489 \times 10^{-8}} (4+20 \times 0.020+40 \times 0.020^2+35 \times 0.020^3+11 \times 0.020^4) = 0.00348 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01667 + 0.02908 + 0.00348 = 0.04923 \text{ m}$$

$$\text{Size} = 49.23 \leq \delta a = 50.00 \text{ mm}$$

Where,

δ₁ : Displacement at imaginary ground

δ₂ : Displacement by angle of inclination slope at imaginary ground

δ₃ : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6.2.2 Seismic Condition

Displacement Calculation

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b = 12468 kN/m ³
calculated value	β = 0.34782 m ⁻¹
resultant earth force (lateral)	P ₀ = 124.56 kN/m
height of acting position of load	h ₀ = 1.66 m
moment	M ₀ = 207.08 kN·m/m

in consideration of ψ _m = 1.331, maximum moment	M _{max} = 275.72 kN·m/m
depth of generated position of M _{max}	l _m = 1.248 m
depth of l st fixed point	l _i = 3.506 m

6.3 Stress Intensity

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

Material Name	10 H _ H 450 -200 -9 -19 -13
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 = 3280 cm ³ (original condition) Z = 2788 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{278.39 \times 10^6}{2788 \times 10^3} = 100 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

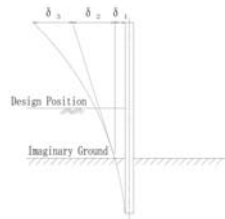
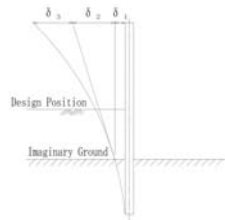
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{275.72 \times 10^6}{2788 \times 10^3} = 99 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

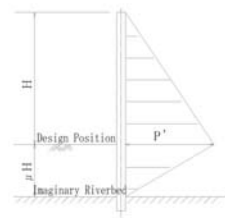
6.4.1 Normal Condition

Displacement Calculation



$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1+0.3478 \times 1.66) \times 124.56}{2 \times 2.00 \times 10^8 \times 106489 \times 10^{-8} \times 0.3478^3} = 0.01097 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_1) = \frac{(1+2 \times 0.3478 \times 1.66) \times 124.56}{2 \times 2.00 \times 10^8 \times 106489 \times 10^{-8} \times 0.3478^2} \times (4.44+0.09) = 0.02361 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.09}{4.44} = 0.020$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4) = \frac{54.99 \times 4.44^4}{120 \times 2.00 \times 10^8 \times 106489 \times 10^{-8}} (4+20 \times 0.020+40 \times 0.020^2+35 \times 0.020^3+11 \times 0.020^4) = 0.00370 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01097 + 0.02361 + 0.00370 = 0.03828 \text{ m}$$

$$\text{Size} = 38.28 \leq \delta a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name 10 H H 450 -200 -9 -19 -13
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 = 128300 cm⁴ (original condition)
 I = 128300 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 128300 × 10⁻⁸ = 2.566 × 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:

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

$$L = H - H_{it} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction K_b = 6067 kN/m³
Calculated value β = 0.27727 m⁻¹
Penetration length of SSP $D = 0.09 + \frac{3}{0.277} = 10.91$ m
Whole length of SSP $L = 4.44 - 0.40 + 10.91 = 14.95$ m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction K_b = 12468 kN/m³
Calculated value β = 0.33199 m⁻¹
Penetration length of SSP $D = 0.09 + \frac{3}{0.332} = 9.13$ m
Whole length of SSP $L = 4.44 - 0.40 + 9.13 = 13.17$ m

Therefore, the total length of the sheet pile is 15.00 m from the rounded length value of 0.50 m.

8 Calculation Result

front sheet pile 10 H H 450 -200 -9 -19 -13

			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	128300		
Sectional Modulus	Z (cm ³)	3280		
Maximum bending moment	Mmax (kN × m × m)		278.39	275.72
Stress intensity	σ (N/mm ²)		100 (180)	99 (270)
Lateral displacement	δ (mm)		49.23 (50.0)	38.28 (75.0)
Penetration depths	D (m)		10.91	9.13
Whole length of SSP	L (m)	15.00		

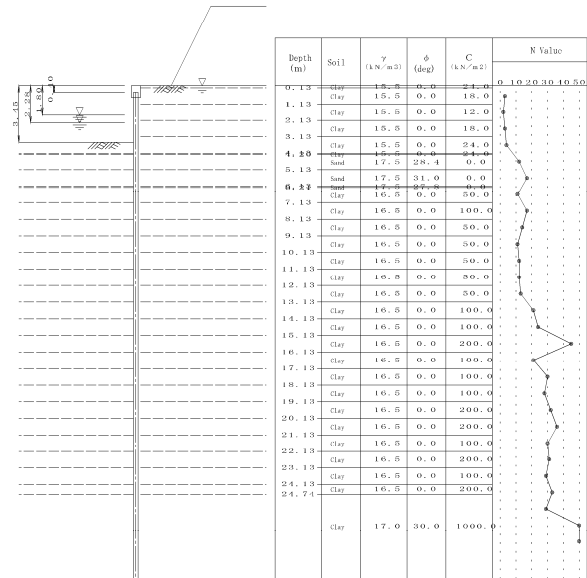
Block No. : R-18
Sta. : 9+200~9+380

Design Cross Section : Sta 9+280
Boring Name : BR13

Specification : SSP SP-25H
(Combined) : H 1000-300-16-32-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed H = 3.45 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} = 2.28 m (Normal Condition)
 L_{wp} = 1.80 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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
	$P_t = 44.8 \text{ kN/m}$ (Normal Condition)
	$P_t' = 105.5 \text{ kN/m}$ (Seismic Condition)
	Depth of acting point
	$H_t = 0.0 \text{ m}$ (Normal Condition)
	$H_t' = 0.0 \text{ m}$ (Seismic Condition)
	Moment
	$M_{tm} = 11.9 \text{ kN}\cdot\text{m/m}$ (Normal Condition)
	$M_{tm}' = 122.9 \text{ kN}\cdot\text{m/m}$ (Seismic Condition)
	Depth of acting point
	$H_{tm}' = 0.00 \text{ m}$ (Seismic Condition)
	$H_{tm} = 0.00 \text{ m}$ (Normal Condition)
	(‘Depth’ means distance from top of coping)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_{s0} = K_{s0} \left(\frac{B_H}{0.3} \right)^{-3/4}$ $K_{s0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$ $B_H = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
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	0.63	3	11	10.63	12	21	20.63	36
2	1.63	2	12	11.63	12	22	21.63	30
3	2.63	3	13	12.63	13	23	22.63	31
4	3.63	4	14	13.63	21	24	23.63	29
5	4.63	12	15	14.63	24	25	24.63	33
6	5.63	17	16	15.63	45	26	25.63	29
7	6.63	11	17	16.63	21	27	26.63	50
8	7.63	17	18	17.63	30	28	27.63	50
9	8.63	14	19	18.63	28	29	28.63	50
10	9.63	11	20	19.63	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 (Include Projection Length)	Thickness m (excluding projected length)
1	0.13	0.13
2	1.13	1.00
3	2.13	1.00
4	3.13	1.00
5	4.13	1.00
6	4.20	0.07
7	5.13	0.93
8	6.13	1.00
9	6.21	0.08
10	7.13	0.92
11	8.13	1.00
12	9.13	1.00
13	10.13	1.00
14	11.13	1.00
15	12.13	1.00
16	13.13	1.00
17	14.13	1.00
18	15.13	1.00
19	16.13	1.00
20	17.13	1.00
21	18.13	1.00
22	19.13	1.00
23	20.13	1.00
24	21.13	1.00
25	22.13	1.00
26	23.13	1.00
27	24.13	1.00
28	24.74	0.61
29	28.63	3.89

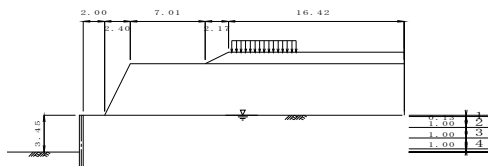
No	Depth m	earth Soil	N Value kN/m ²	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	Kh (kN/m ³)		
										Normal Condition	Seismic Condition	Normal Condition	Seismic Condition
1	0.13	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto		
2	1.13	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200	Auto	Auto		
3	2.13	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto		
4	3.13	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200	Auto	Auto		
5	4.13	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto		
6	4.20	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto		
7	5.13	S	12.0	17.50	7.70	28.4	0.0	0.0	0.200	Auto	Auto		
8	6.13	S	17.0	17.50	7.70	31.0	0.0	0.0	0.200	Auto	Auto		
9	6.21	S	11.0	17.50	7.70	27.8	0.0	0.0	0.200	Auto	Auto		
10	7.13	C	11.0	16.50	6.70	0.0	50.0	0.0	0.200	Auto	Auto		
11	8.13	C	17.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
12	9.13	C	14.0	16.50	6.70	0.0	50.0	0.0	0.200	Auto	Auto		
13	10.13	C	11.0	16.50	6.70	0.0	50.0	0.0	0.200	Auto	Auto		
14	11.13	C	12.0	16.50	6.70	0.0	50.0	0.0	0.200	Auto	Auto		
15	12.13	C	12.0	16.50	6.70	0.0	50.0	0.0	0.200	Auto	Auto		
16	13.13	C	13.0	16.50	6.70	0.0	50.0	0.0	0.200	Auto	Auto		
17	14.13	C	21.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
18	15.13	C	24.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
19	16.13	C	45.0	16.50	6.70	0.0	200.0	0.0	0.200	Auto	Auto		
20	17.13	C	21.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
21	18.13	C	30.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
22	19.13	C	28.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
23	20.13	C	32.0	16.50	6.70	0.0	200.0	0.0	0.200	Auto	Auto		
24	21.13	C	36.0	16.50	6.70	0.0	200.0	0.0	0.200	Auto	Auto		
25	22.13	C	30.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
26	23.13	C	31.0	16.50	6.70	0.0	200.0	0.0	0.200	Auto	Auto		
27	24.13	C	29.0	16.50	6.70	0.0	100.0	0.0	0.200	Auto	Auto		
28	24.74	C	33.0	16.50	6.70	0.0	200.0	0.0	0.200	Auto	Auto		
29	28.63	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto		

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

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate			Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ		
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	2.00	4.40	30.00	30.00	4.80	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	11.41	13.58	30.00	30.00	1.08	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	13.88	19.88	10.0	5.0

Angle of rapture in embankment	calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	25 H H 1000 -300 -16 -32 -18
Young's modulus	$E = 200000 \text{ N/mm}^2$
Inertia sectional moment	$I_0 = 1129800 \text{ cm}^4$
Sectional factor	$Z_0 = 16330 \text{ cm}^3$

Corrosion margin	$t_1 = 1.00 \text{ mm}$ (riverside)	$t_2 = 1.00 \text{ mm}$ (landside)

Corrosion rate (to I_0)	$\eta = 0.89$
Corrosion rate (to Z_0)	$\eta = 0.90$
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	$\sigma_a = 180 \text{ N/mm}^2$ (Normal)
	$\sigma_a' = 270 \text{ N/mm}^2$ (Seismic)

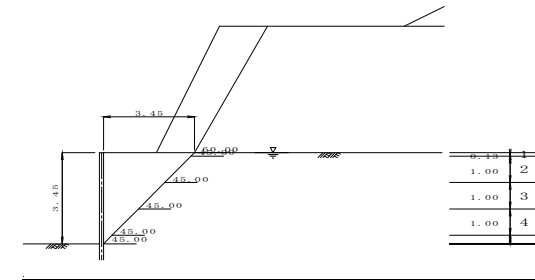
Allowable displacement	$\delta_a = 50.0 \text{ mm}$ (Normal)
	$\delta_a' = 75.0 \text{ mm}$ (Seismic)

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	$\gamma \times h$ kNm ²	Angle of Rupture ζ degree
1	3.45~3.13	Clay	0.0	15.0	24.0	19.66	43.24	33.81	45.00
2	3.13~2.13	Clay	0.0	15.0	18.0	17.84	43.24	30.67	45.00
3	2.13~1.13	Clay	0.0	15.0	12.0	12.14	43.24	20.87	45.00
4	1.13~0.13	Clay	0.0	15.0	18.0	6.44	43.24	11.07	45.00
5	0.13~0.00	Clay	0.0	15.0	24.0	0.74	43.24	1.27	45.00
6		embankment t	30.0	—	0.0	111.72	10.00	0.00	60.00

• Angle of active rupture of sandy soil

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

• 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 $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.32	0.00	0.00	0.32	0.32
2	45.00	1.00	0.32	0.32	1.32	1.32
3	45.00	1.00	1.32	1.32	2.32	2.32
4	45.00	1.00	2.32	2.32	3.32	3.32
5	45.00	0.13	3.32	3.32	3.45	3.45
6	60.00	4.80	3.45	3.45	6.22	8.25

From the above table, the loading width (L) on the ground surface is 3.45 m.

2.1.3 Acting Load by Embankment

No	γ kNm ³	A m ²	$\gamma \times A$ kNm
1	19.0	7.85	149.17
Σ			149.17

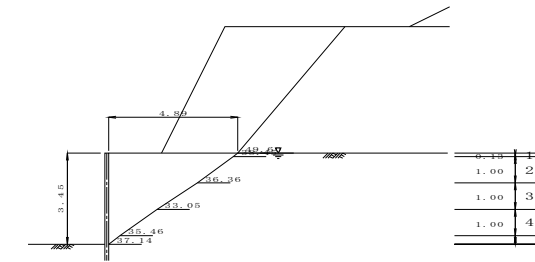
γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{149.17 + 0.00 + 0.00}{3.45}$$
$$= 43.24 \text{ kN/m}^2$$

2.2 Seismic 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	$\gamma \times h$ kNm ²	k (%)	θ degree	Angle of Rupture ζ degree
1	3.45~3.13	Clay	0.0	15.0	24.0	19.66	69.59	33.81	0.200	11.31	37.14
2	3.13~2.13	Clay	0.0	15.0	18.0	17.84	69.59	30.67	0.200	11.31	35.46
3	2.13~1.13	Clay	0.0	15.0	12.0	12.14	69.59	20.87	0.200	11.31	33.05
4	1.13~0.13	Clay	0.0	15.0	18.0	6.44	69.59	11.07	0.200	11.31	36.36
5	0.13~0.00	Clay	0.0	15.0	24.0	0.74	69.59	1.27	0.200	11.31	38.45
6		embankment t	30.0	—	0.0	111.72	5.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	37.14	0.32	0.00	0.00	0.42	0.32
2	35.46	1.00	0.42	0.32	1.83	1.32
3	33.05	1.00	1.83	1.32	3.36	2.32
4	36.36	1.00	3.36	2.32	4.72	3.32
5	38.45	0.13	4.72	3.32	4.89	3.45
6	49.60	4.80	4.89	3.45	8.97	8.25

From the above table, the loading width (L) on the ground surface is 4.89 m.

2.2.3 Acting Load by Embankment

No	γ kNm ³	A m ²	$\gamma \times A$ kNm
1	19.0	17.89	339.97
Σ			339.97

γ : unit weight of embankment soil

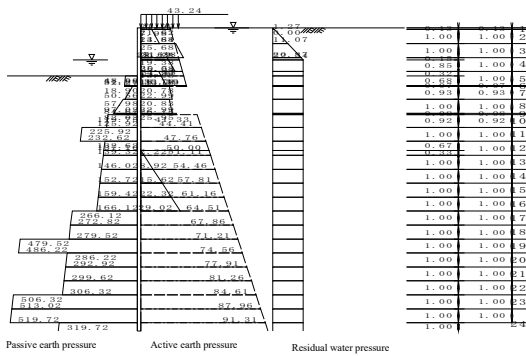
A : sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{339.97 + 0.00 + 0.00}{4.89}$$
$$= 69.59 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	Ka	$K_a \times \cos \delta$
1	0.00- 0.13	Clay	5.7	—	24.0 24.0	43.238 43.979	—	—
2	0.13- 1.13	Clay	5.7	—	18.0 18.0	43.979 49.679	—	—
3	1.13- 2.13	Clay	5.7	—	12.0 12.0	49.679 55.379	—	—
4	2.13- 2.28	Clay	5.7	—	18.0 18.0	55.379 56.234	—	—
5	2.28- 3.13	Clay	5.7	—	18.0 18.0	56.234 61.079	—	—
6	3.13- 3.45	Clay	5.7	—	24.0 24.0	61.079 62.903	—	—
7	3.45- 4.13	Clay	5.7	—	24.0 24.0	62.903 66.779	—	—
8	4.13- 4.20	Clay	5.7	—	24.0 24.0	66.779 67.178	—	—
9	4.20- 5.13	Sand	7.7	28.4	—	67.178 74.339	0.32022 0.32022	0.30931 0.30931
10	5.13- 6.13	Sand	7.7	31.0	—	74.339 82.039	0.29008 0.29008	0.28020 0.28020
11	6.13- 6.21	Sand	7.7	27.8	—	82.039 82.655	0.32749 0.32749	0.31633 0.31633
12	6.21- 7.13	Clay	6.7	—	50.0 50.0	82.655 88.819	—	—

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_0$ kN/m ²	Kp	$K_p \times \cos \delta$
7	3.45- 4.13	Clay	5.7	0.0	24.0 24.0	0.000 3.876	—	—
8	4.13- 4.20	Clay	5.7	0.0	24.0 24.0	3.876 4.275	—	—
9	4.20- 5.13	Sand	7.7	28.4	—	4.275 11.436	4.57728 4.57728	4.42131 4.42131
10	5.13- 6.13	Sand	7.7	31.0	—	11.436 19.136	5.24888 5.24888	5.07003 5.07003
11	6.13- 6.21	Sand	7.7	27.8	—	19.136 19.752	4.43813 4.43813	4.28690 4.28690
12	6.21- 7.13	Clay	6.7	0.0	50.0 50.0	19.752 25.916	—	—
13	7.13- 8.13	Clay	6.7	0.0	100.0 100.0	25.916 32.616	—	—
14	8.13- 8.80	Clay	6.7	0.0	50.0 50.0	32.616 37.097	—	—
15	8.80- 9.13	Clay	6.7	0.0	50.0 50.0	37.097 39.316	—	—
16	9.13- 10.13	Clay	6.7	0.0	50.0 50.0	39.316 46.016	—	—
17	10.13- 11.13	Clay	6.7	0.0	50.0 50.0	46.016 52.716	—	—
18	11.13- 12.13	Clay	6.7	0.0	50.0 50.0	52.716 59.416	—	—
19	12.13- 13.13	Clay	6.7	0.0	50.0 50.0	59.416 66.116	—	—
20	13.13- 14.13	Clay	6.7	0.0	100.0 100.0	66.116 72.816	—	—
21	14.13- 15.13	Clay	6.7	0.0	100.0 100.0	72.816 79.516	—	—
22	15.13- 16.13	Clay	6.7	0.0	200.0 200.0	79.516 86.216	—	—
23	16.13- 17.13	Clay	6.7	0.0	100.0 100.0	86.216 92.916	—	—
24	17.13- 18.13	Clay	6.7	0.0	100.0 100.0	92.916 99.616	—	—
25	18.13- 19.13	Clay	6.7	0.0	100.0 100.0	99.616 106.316	—	—
26	19.13- 20.13	Clay	6.7	0.0	200.0 200.0	106.316 113.016	—	—
27	20.13- 21.13	Clay	6.7	0.0	200.0 200.0	113.016 119.716	—	—
28	21.13- 22.13	Clay	6.7	0.0	100.0 100.0	119.716 126.416	—	—
29	22.13- 23.13	Clay	6.7	0.0	200.0 200.0	126.416 133.116	—	—
30	23.13- 23.72	Clay	6.7	0.0	100.0 100.0	133.116 137.097	—	—
31	23.72- 24.13	Clay	6.7	0.0	100.0 100.0	137.097 139.816	—	—

13	7.13- 8.13	Clay	6.7	—	100.0 100.0	88.819 95.519	—	—
14	8.13- 8.80	Clay	6.7	—	50.0 50.0	95.519 100.000	—	—
15	8.80- 9.13	Clay	6.7	—	50.0 50.0	100.000 102.219	—	—
16	9.13- 10.13	Clay	6.7	—	50.0 50.0	102.219 108.919	—	—
17	10.13- 11.13	Clay	6.7	—	50.0 50.0	108.919 115.619	—	—
18	11.13- 12.13	Clay	6.7	—	50.0 50.0	115.619 122.319	—	—
19	12.13- 13.13	Clay	6.7	—	50.0 50.0	122.319 129.019	—	—
20	13.13- 14.13	Clay	6.7	—	100.0 100.0	129.019 135.719	—	—
21	14.13- 15.13	Clay	6.7	—	100.0 100.0	135.719 142.419	—	—
22	15.13- 16.13	Clay	6.7	—	200.0 200.0	142.419 149.119	—	—
23	16.13- 17.13	Clay	6.7	—	100.0 100.0	149.119 155.819	—	—
24	17.13- 18.13	Clay	6.7	—	100.0 100.0	155.819 162.519	—	—
25	18.13- 19.13	Clay	6.7	—	100.0 100.0	162.519 169.219	—	—
26	19.13- 20.13	Clay	6.7	—	200.0 200.0	169.219 175.919	—	—
27	20.13- 21.13	Clay	6.7	—	200.0 200.0	175.919 182.619	—	—
28	21.13- 22.13	Clay	6.7	—	100.0 100.0	182.619 189.319	—	—
29	22.13- 23.13	Clay	6.7	—	200.0 200.0	189.319 196.019	—	—
30	23.13- 23.72	Clay	6.7	—	100.0 100.0	196.019 200.000	—	—
31	23.72- 24.13	Clay	6.7	—	200.0 100.0	200.000 202.719	—	—
32	24.13- 24.74	Clay	6.7	—	200.0 200.0	202.719 206.806	—	—
33	24.74- 28.63	Clay	7.2	—	1000.0 1000.0	206.806 234.814	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

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

32	24.13- 24.74	Clay	6.7	0.0	200.0 200.0	139.816 143.903	—	—
33	24.74- 28.63	Clay	7.2	30.0	1000.0 1000.0	143.903 171.911	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 0.13	—	-4.76 -4.02	21.62 21.99	21.62 21.99	0.00 1.27
2	0.13- 1.13	—	7.38 13.68	21.99 24.84	21.99 24.84	1.27 11.07
3	1.13- 2.13	—	25.68 31.38	24.84 27.69	25.68 31.38	11.07 20.87
4	2.13- 2.28	—	19.38 20.23	27.69 28.12	27.69 28.12	20.87 22.34
5	2.28- 3.13	—	20.23 25.08	28.12 30.54	28.12 30.54	22.34 22.34
6	3.13- 3.45	—	13.08 14.90	30.54 31.45	30.54 31.45	22.34 22.34
7	3.45- 4.13	—	14.90 18.78	31.45 33.39	31.45 33.39	22.34 22.34
8	4.13- 4.20	—	18.78 19.18	33.39 33.59	33.39 33.59	22.34 22.34
9	4.20- 5.13	—	20.78 22.99	20.78 22.99	22.34 22.34	18.90 50.56
10	5.13- 6.13	—	20.83 22.99	20.83 22.99	22.34 22.34	57.98 97.82
11	6.13- 6.21	—	25.95 26.15	25.95 26.15	22.34 22.34	82.03 84.67
12	6.21- 7.13	—	-17.35 -11.18	41.33 44.41	41.33 44.41	22.34 22.34
13	7.13- 8.13	—	-111.18 -104.48	44.41 47.76	44.41 47.76	22.34 22.34
14	8.13- 8.80	—	-4.48 0.00	47.76 50.00	47.76 50.00	22.34 22.34
15	8.80- 9.13	—	0.00 2.22	50.00 51.11	50.00 51.11	22.34 22.34
16	9.13- 10.13	—	2.22 8.92	51.11 54.46	51.11 54.46	22.34 22.34
17	10.13- 11.13	—	8.92 15.62	54.46 57.81	54.46 57.81	22.34 22.34
18	11.13- 12.13	—	15.62 22.32	57.81 61.16	57.81 61.16	22.34 22.34

19	12.13- 13.13	22.32 29.02	61.16 64.51	61.16 64.51	22.34 22.34	159.42 166.12
20	13.13- 14.13	-70.98 -64.28	64.51 67.86	64.51 67.86	22.34 22.34	266.12 272.82
21	14.13- 15.13	-64.28 -57.58	67.86 71.21	67.86 71.21	22.34 22.34	272.82 279.52
22	15.13- 16.13	-257.58 -250.88	71.21 74.56	71.21 74.56	22.34 22.34	479.52 486.22
23	16.13- 17.13	-50.88 -44.18	74.56 77.91	74.56 77.91	22.34 22.34	286.22 292.92
24	17.13- 18.13	-44.18 -37.48	77.91 81.26	77.91 81.26	22.34 22.34	292.92 299.62
25	18.13- 19.13	-37.48 -30.78	81.26 84.61	81.26 84.61	22.34 22.34	299.62 306.32
26	19.13- 20.13	-230.78 -224.08	84.61 87.96	84.61 87.96	22.34 22.34	506.32 513.02
27	20.13- 21.13	-224.08 -217.38	87.96 91.31	87.96 91.31	22.34 22.34	513.02 519.72
28	21.13- 22.13	-17.28 -10.68	91.31 94.66	91.31 94.66	22.34 22.34	319.72 326.42
29	22.13- 23.13	-210.68 -203.98	94.66 98.01	94.66 98.01	22.34 22.34	526.42 533.12
30	23.13- 23.72	-3.98 0.00	98.01 100.00	98.01 100.00	22.34 22.34	333.12 337.10
31	23.72- 24.13	0.00 2.72	100.00 101.36	100.00 101.36	22.34 22.34	337.10 339.82
32	24.13- 24.74	-197.28 -193.19	101.36 103.40	101.36 103.40	22.34 22.34	539.82 543.90
33	24.74- 28.63	-1793.19 -1765.19	103.40 117.41	103.40 117.41	22.34 22.34	2143.90 2171.91

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

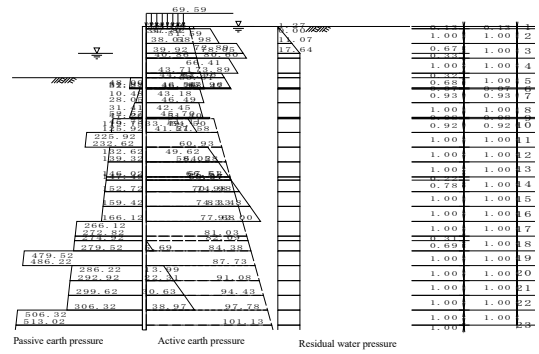
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{sub} kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-0.13	Clay	5.7	—	24.0	69.59	0.00	0.300	11.31	—	—	38.51
					24.0	70.33	1.27	0.300	11.31	—	—	38.45
2	0.13-1.13	Clay	5.7	—	18.0	70.33	1.27	0.300	11.31	—	—	36.84
					18.0	76.03	11.07	0.300	11.31	—	—	36.36
3	1.13-1.80	Clay	5.7	—	12.0	76.03	11.07	0.300	11.31	—	—	33.59
					12.0	79.85	17.64	0.300	11.31	—	—	33.23
4	1.80-2.13	Clay	5.7	—	12.0	81.73	20.87	0.300	11.31	—	—	33.23
					12.0	81.73	20.87	0.300	11.31	—	—	33.05
5	2.13-3.13	Clay	5.7	—	18.0	81.73	20.87	0.300	11.31	—	—	35.90
					18.0	87.43	30.67	0.300	11.31	—	—	35.46
6	3.13-3.45	Clay	5.7	—	24.0	87.43	30.67	0.300	11.31	—	—	37.26
					24.0	89.25	33.81	0.300	11.31	—	—	37.14
7	3.45-4.13	Clay	5.7	—	24.0	89.25	33.81	0.300	11.31	—	—	37.14
					24.0	93.13	40.47	0.300	11.31	—	—	36.88
8	4.13-4.20	Clay	5.7	—	24.0	93.13	40.47	0.300	11.31	—	—	36.86
					24.0	93.53	41.16	0.300	11.31	—	—	36.86
9	4.20-5.13	Sand	7.7	28.4	—	93.53	41.16	0.300	11.31	0.47900	0.46172	—
					—	100.69	50.27	0.300	11.31	0.47900	0.46172	—
10	5.13-6.13	Sand	7.7	31.0	—	100.69	50.27	0.300	11.31	0.43652	0.42164	—
					—	108.39	60.07	0.300	11.31	0.43652	0.42164	—
11	6.13-6.21	Sand	7.7	27.8	—	108.39	60.07	0.300	11.31	0.48814	0.47151	—
					—	109.01	60.86	0.300	11.31	0.48814	0.47151	—
12	6.21-7.13	Clay	6.7	—	50.0	109.01	60.86	0.200	11.31	—	—	39.84
					50.0	115.17	69.87	0.200	11.31	—	—	39.60
13	7.13-8.13	Clay	6.7	—	100.0	115.17	69.87	0.200	11.31	—	—	42.04
					100.0	121.87	79.67	0.200	11.31	—	—	41.88

14	8.13-9.13	Clay	6.7	—	50.0	121.87	79.67	0.200	11.31	—	—	39.35
					50.0	128.57	89.47	0.200	11.31	—	—	39.10
15	9.13-10.13	Clay	6.7	—	50.0	128.57	89.47	0.200	11.31	—	—	39.10
					50.0	135.27	99.27	0.200	11.31	—	—	38.85
16	10.13-10.35	Clay	6.7	—	50.0	135.27	99.27	0.200	11.31	—	—	38.85
					50.0	136.74	109.07	0.200	11.31	—	—	38.61
17	10.35-11.13	Clay	6.7	—	50.0	136.74	109.07	0.200	11.31	—	—	38.61
					50.0	141.97	118.87	0.200	11.31	—	—	38.38
18	11.13-12.13	Clay	6.7	—	50.0	141.97	118.87	0.200	11.31	—	—	38.38
					50.0	148.67	128.67	0.200	11.31	—	—	38.14
19	12.13-13.13	Clay	6.7	—	50.0	148.67	128.67	0.200	11.31	—	—	38.14
					50.0	155.37	138.47	0.200	11.31	—	—	41.14
20	13.13-14.13	Clay	6.7	—	100.0	155.37	138.47	0.200	11.31	—	—	40.99
					100.0	162.07	148.27	0.200	11.31	—	—	40.99
21	14.13-14.44	Clay	6.7	—	100.0	162.07	148.27	0.200	11.31	—	—	40.99
					100.0	164.17	158.07	0.200	11.31	—	—	40.85
22	14.44-15.13	Clay	6.7	—	100.0	164.17	158.07	0.200	11.31	—	—	40.85
					100.0	167.77	167.87	0.200	11.31	—	—	42.77
23	15.13-16.13	Clay	6.7	—	200.0	167.77	167.87	0.200	11.31	—	—	42.69
					200.0	175.47	177.67	0.200	11.31	—	—	40.71
24	16.13-17.13	Clay	6.7	—	100.0	175.47	177.67	0.200	11.31	—	—	40.71
					100.0	182.17	187.47	0.200	11.31	—	—	40.57
25	17.13-18.13	Clay	6.7	—	100.0	182.17	187.47	0.200	11.31	—	—	40.57
					100.0	188.87	197.27	0.200	11.31	—	—	40.43
26	18.13-19.13	Clay	6.7	—	100.0	188.87	197.27	0.200	11.31	—	—	40.43
					100.0	195.57	207.07	0.200	11.31	—	—	40.29
27	19.13-20.13	Clay	6.7	—	200.0	195.57	207.07	0.200	11.31	—	—	42.44
					200.0	202.27	212.07	0.200	11.31	—	—	42.37
28	20.13-21.13	Clay	6.7	—	200.0	202.27	212.07	0.200	11.31	—	—	42.37
					200.0	208.97	218.77	0.200	11.31	—	—	42.29
29	21.13-22.13	Clay	6.7	—	100.0	208.97	218.77	0.200	11.31	—	—	40.02
					100.0	215.67	226.67	0.200	11.31	—	—	39.89
30	22.13-23.13	Clay	6.7	—	200.0	215.67	226.67	0.200	11.31	—	—	42.21
					200.0	222.37	232.17	0.200	11.31	—	—	42.13
31	23.13-24.13	Clay	6.7	—	100.0	222.37	232.17	0.200	11.31	—	—	39.76
					100.0	229.07	238.87	0.200	11.31	—	—	39.63
32	24.13-24.74	Clay	6.7	—	200.0	229.07	238.87	0.200	11.31	—	—	42.65
					200.0	235.16	244.96	0.200	11.31	—	—	42.00
33	24.74-28.63	Clay	7.2	—	1000.0	235.16	244.96	0.200	11.31	—	—	44.35
					1000.0	261.16	280.57	0.200	11.31	—	—	44.27

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{sub} kN/m ²	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
7	3.45-4.13	Clay	5.70	0.0	24.0	0.000	0.00	0.200	11.31	—	—
					24.0	3.876	6.66	0.200	11.31	—	—
8	4.13-4.20	Clay	5.70	0.0	24.0	3.876	6.66	0.200	11.31	—	—
					24.0	4.275	7.35	0.200	11.31	—	—
9	4.20-5.13	Sand	7.70	28.4	—	4.275	7.35	0.200	11.31	2.45342	2.45342
					—	11.436	16.46	0.200	11.31	2.45342	2.45342
10	5.13-6.13	Sand	7.70	31.0	—	11.436	16.46	0.200	11.31	2.74701	2.74701
					—	19.136	26.26	0.200	11.31	2.74701	2.74701
11	6.13-6.21	Sand	7.70	27.8	—	19.136	26.26	0.200	11.31	2.38966	2.38966
					—	19.752	27.05	0.200	11.31	2.38966	2.38966
12	6.21-7.13	Clay	6.70	0.0	50.0	19.752	27.05	0.200	11.31	—	—
					50.0	25.916	36.06	0.200	11.31	—	—
13	7.13-8.13	Clay	6.70	0.0	100.0	25.916	36.06	0.200	11.31	—	—
					100.0	32.616	45.86	0.200	11.31	—	—
14	8.13-9.13	Clay	6.70	0.0	50.0	32.616	45.86	0.200	11.31	—	—
					50.0	39.316	55.66	0.200	11.31	—	—
15	9.13-10.13	Clay	6.70	0.0	50.0	39.316	55.66	0.200	11.31	—	—
					50.0	46.016	65.46	0.200	11.31	—	—
16	10.13-10.35	Clay	6.70	0.0	50.0	46.016	65.46	0.200	11.31	—	—
					50.0	47.490	—	0.200	11.31	—	—
17	10.35-11.13	Clay	6.70	0.0	50.0	47.490	—	0.200	11.31	—	—
					50.0	52.716	75.26	0.200	11.31	—	—
18	11.13-12.13	Clay	6.70	0.0	50.0	52.716	75.26	0.200	11.31	—	—
					50.0	59.416	85.06	0.200	11.31	—	—
19	12.13-13.13	Clay	6.70	0.0	50.0	59.416	85.06	0.200	11.31	—	—
					50.0	66.116	94.86	0.200	11.31	—	—
20	13.13-14.13	Clay	6.70	0.0	100.0	66.116	94.86	0.200	11.31	—	—
					100.0	72.816	104.66	0.200	11.31	—	—
21	14.13-14.44	Clay	6.70	0.0	100.0	72.816	104.66	0.200	11.31	—	—
					100.0	74.921	—	0.200	11.31	—	—
22	14.44-15.13	Clay	6.70	0.0	100.0	74.921	—	0.200	11.31	—	—
					100.0	79.516	114.46	0.200	11.31	—	—
23	15.13-16.13	Clay	6.70	0.0	200.0	79.516	114.46	0.200	11.31	—	—
					200.0	86.216	124.26	0.200	11.31	—	—
24	16.13-17.13	Clay	6.70	0.0	100.0	86.216	124.26	0.200	11.31	—	—
					100.0	92.916	134.06	0.200	11.31	—	—
25	17.13-18.13	Clay	6.70	0.0	100.0	92.916	134.06	0.200	11.31	—	—
					100.0	99.616	143.86	0.200	11.31	—	—
26	18.13-19.13	Clay	6.70	0.0	100.0	99.616	143.86	0.200	11.31	—	—
					100.0	106.316	153.66	0.200	11.31	—	—
27	19.13-20.13	Clay	6.70	0.0	200.0	106.316	153.66	0.200	11.31	—	—
					200.0	113.016	163.46	0.200	11.31	—	—
28	20.13-21.13	Clay	6.70	0.0	200.0	113.016	163.46	0.200	11.31	—	—
					200.0	119.716	173.26	0.200	11.31	—	—
29	21.13-22.13	Clay	6.70	0.0	100.0	119.716	173.26	0.200	11.31	—	—
					100.0	126.416	183.06	0.200	11.31	—	—
30	22.13-23.13	Clay	6.70	0.0	200.0	126.416	183.06	0.200	11.31	—	—
					200.0	133.116	192.86	0.200	11.31	—	—
31	23.13-24.13	Clay	6.70	0.0	100.0	133.116	192.86	0.200	11.31	—	—
					100.0	139.816	202.66	0.200	11.31	—	—

32	24.13- 24.74	Clay	6.70	0.0	200.0 200.0	139.816 143.903	202.66 208.64	0.200 0.200	11.31 11.31	=====	=====
33	24.74- 28.63	Clay	7.20	30.0	1000.0 1000.0	143.903 171.911	208.64 246.76	0.200 0.200	11.31 11.31	=====	=====

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	
1	0.00- 0.13	37.82 38.76	34.79 35.16	37.82 38.76	0.00 1.27	=====
2	0.13- 1.13	51.59 58.98	35.16 38.01	51.59 58.98	1.27 11.07	=====
3	1.13- 1.80	72.89 78.05	38.01 39.92	72.89 78.05	11.07 17.64	=====
4	1.80- 2.13	78.05 80.60	39.92 40.86	78.05 80.60	17.64 17.64	=====
5	2.13- 3.13	66.41 73.89	40.86 43.71	66.41 73.89	17.64 17.64	=====
6	3.13- 3.45	60.61 62.96	43.71 44.63	60.61 62.96	17.64 17.64	=====
7	3.45- 4.13	62.96 67.96	44.63 46.56	62.96 67.96	17.64 17.64	48.00 51.88
8	4.13- 4.20	67.96 68.47	46.56 46.76	67.96 68.47	17.64 17.64	51.88 52.27
9	4.20- 5.13	43.18 46.49	=====	43.18 46.49	17.64 17.64	10.48 28.05
10	5.13- 6.13	42.45 45.70	=====	42.45 45.70	17.64 17.64	31.41 52.57
11	6.13- 6.21	51.11 51.40	=====	51.11 51.40	17.64 17.64	45.73 47.20
12	6.21- 7.13	33.49 41.21	54.50 57.58	54.50 57.58	17.64 17.64	119.75 125.92
13	7.13- 8.13	40.36 52.14	57.58 60.93	57.58 60.93	17.64 17.64	225.92 232.62
14	8.13- 9.13	49.62 58.05	60.93 64.28	60.93 64.28	17.64 17.64	132.62 139.32
15	9.13- 10.13	58.05 66.51	64.28 67.63	64.28 67.63	17.64 17.64	139.32 146.02
16	10.13- 10.35	66.51 68.37	67.63 68.37	67.63 68.37	17.64 17.64	146.02 147.49
17	10.35- 11.13	68.37 74.98	68.37 70.98	68.37 74.98	17.64 17.64	147.49 152.72

18	11.13- 12.13	74.98 83.48	70.98 74.33	74.98 83.48	17.64 17.64	152.72 159.42
19	12.13- 13.13	83.48 92.00	74.33 77.68	83.48 92.00	17.64 17.64	159.42 166.12
20	13.13- 14.13	-10.89 -2.61	77.68 81.03	77.68 81.03	17.64 17.64	266.12 272.82
21	14.13- 14.44	-2.61 0.00	81.03 82.09	81.03 82.09	17.64 17.64	272.82 274.92
22	14.44- 15.13	0.00 5.69	82.09 84.38	82.09 84.38	17.64 17.64	274.92 279.52
23	15.13- 16.13	-195.96 -187.79	84.38 87.73	84.38 87.73	17.64 17.64	479.52 486.22
24	16.13- 17.13	13.99 22.31	87.73 91.08	87.73 91.08	17.64 17.64	286.22 292.92
25	17.13- 18.13	22.31 30.63	91.08 94.43	91.08 94.43	17.64 17.64	292.92 299.62
26	18.13- 19.13	30.63 38.97	94.43 97.78	94.43 97.78	17.64 17.64	299.62 306.32
27	19.13- 20.13	-103.26 -155.07	97.78 101.13	97.78 101.13	17.64 17.64	306.32 313.02
28	20.13- 21.13	-155.07 -146.88	101.13 104.48	101.13 104.48	17.64 17.64	513.02 519.72
29	21.13- 22.13	55.68 64.05	104.48 107.83	104.48 107.83	17.64 17.64	319.72 326.42
30	22.13- 23.13	-138.68 -130.48	107.83 111.18	107.83 111.18	17.64 17.64	526.42 533.12
31	23.13- 24.13	72.43 80.82	111.18 114.53	111.18 114.53	17.64 17.64	333.12 339.82
32	24.13- 24.74	-122.27 -117.26	114.53 116.58	114.53 116.58	17.64 17.64	539.82 543.90
33	24.74- 28.63	-1719.66 -1685.90	116.58 130.58	116.58 130.58	17.64 17.64	2143.90 2171.91

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5
 Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

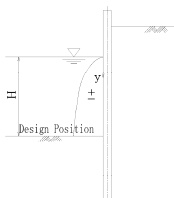
3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m2
1	1.80	0.00	0.00
2	2.80	1.00	2.30
3	3.45	1.65	2.83

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

Where,

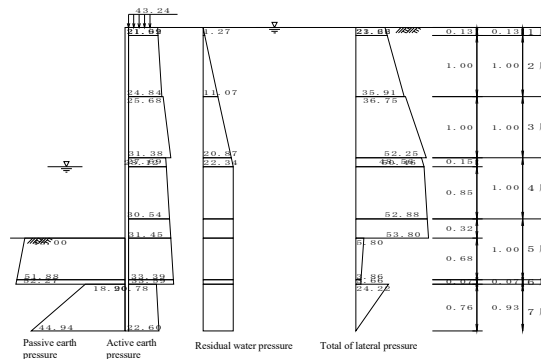
k_{dw} : design seismic coefficient
 γ_w : unit weight of water
 H : water depth of riverside
 y : depth from water surface to the point where active water pressure is calculated



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

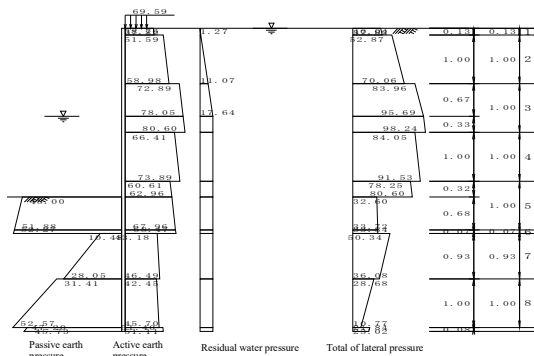


No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.13	21.62 21.99	0.00 1.27	=====	21.62 23.26
2	0.13- 1.13	21.99 24.84	1.27 11.07	=====	23.26 35.91
3	1.13- 2.13	25.68 31.38	11.07 20.87	=====	36.75 52.25
4	2.13- 2.28	27.69 28.12	20.87 22.34	=====	48.56 50.46
5	2.28- 3.13	28.12 30.54	22.34 22.34	=====	50.46 52.88
6	3.13- 3.45	30.54 31.45	22.34 22.34	=====	52.88 53.80
7	3.45- 4.13	31.45 33.39	22.34 22.34	48.00 51.88	5.80 3.86
8	4.13- 4.20	33.39 33.59	22.34 22.34	51.88 52.27	3.86 3.66
9	4.20- 4.97	20.78 22.60	22.34 22.34	18.90 44.94	24.22 -0.00
10	4.97- 5.13	22.60 22.99	22.34 22.34	44.94 50.56	0.00 -5.22

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 Lk: 1.52 m (GL -4.97 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00-	37.82	0.00	—	37.82
	0.13	38.76	1.27	—	40.04
2	0.13-	51.59	1.27	—	52.87
	1.13	58.98	11.07	—	70.06
3	1.13-	72.89	11.07	—	83.96
	1.80	78.05	17.64	—	95.69
4	1.80-	78.05	17.64	—	95.69
	2.13	80.60	17.64	—	98.24
5	2.13-	66.41	17.64	—	84.05
	3.13	73.89	17.64	—	91.53
6	3.13-	60.61	17.64	—	78.25
	3.45	62.96	17.64	—	80.60
7	3.45-	62.96	17.64	48.00	32.60
	4.13	67.96	17.64	51.88	33.72
8	4.13-	67.96	17.64	51.88	33.72
	4.20	68.47	17.64	52.27	33.84
9	4.20-	41.18	17.64	10.48	50.34
	5.13	46.49	17.64	28.05	36.08
10	5.13-	42.45	17.64	31.41	28.68
	6.13	45.70	17.64	52.57	10.77
11	6.13-	51.11	17.64	45.73	23.02
	6.21	51.40	17.64	47.20	21.84
12	6.21-	54.50	17.64	119.75	-47.61
	7.13	57.58	17.64	125.92	-50.69

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure

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

Imaginary riverbed L_A : 2.76 m (GL -6.21 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of U/β from the virtual ground surface. Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{b0} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H = 10.00m)$$

$$K_{b0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	25 H	H 1000 -300 -16 -32 -18
Unit width	B	= 1.0000 m
Corrosion margin	t ₁	= 1.00 mm (active side)
Corrosion rate	t ₂	= 1.00 mm (passive side)
Section efficiency	η	= 0.89
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 1129800 cm ⁴ (original condition)
	I	= 1005522 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	= 200000 × 10 ³ × 1005522 × 10 ⁻⁸ = 2.011 × 10 ⁶

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	0.63	3	11	10.63	12	21	20.63	36
2	1.63	2	12	11.63	12	22	21.63	30
3	2.63	3	13	12.63	13	23	22.63	31
4	3.63	4	14	13.63	21	24	23.63	29
5	4.63	12	15	14.63	24	25	24.63	33
6	5.63	17	16	15.63	45	26	25.63	29
7	6.63	11	17	16.63	21	27	26.63	50
8	7.63	17	18	17.63	30	28	27.63	50
9	8.63	14	19	18.63	28	29	28.63	50
10	9.63	11	20	19.63	32			

5.2 Normal Condition

Assuming $K_h = 9282 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.184 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 5.43 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.97 m) to

5.43 m depth (GL -10.39 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.96	0.67	13.7	17.0	10.20
2	5.63	1.00	17.0	11.0	14.00
3	6.63	1.00	11.0	17.0	14.00
4	7.63	1.00	17.0	14.0	15.50
5	8.63	1.00	14.0	11.0	12.50
6	9.63	0.76	11.0	11.8	8.66

$L = \Sigma h = 5.43$

$\Sigma A = 74.86$

$A : (\text{upper N-value} + \text{lower N-value}) \times h/2$

Average N-value $N' = \frac{\Sigma A}{L}$
$$= \frac{74.86}{5.43}$$

$$= 13.80$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 13.80 = 38631 \text{ kN/m}^2$$

$$K_{b0} = \frac{1}{0.3} \times \alpha \times 38631 = 128770 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_b = K_{b0} (B_H/0.3)^{-3/4} = 128770 (10.00/0.3)^{-3/4} = 9282 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 9282 kN/m³.

5.3 Seismic Condition

Assuming $K_h = 17784 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.217 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.61 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.21 m) and 4.61 m depth (GL -10.82 m).

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 13.22 = 37006 \text{ kN/m}^2$$

$$K_{b0} = \frac{1}{0.3} \times \alpha \times 37006 = 246704 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_b = K_{b0} (B_H/0.3)^{-3/4} = 246704 (10.00/0.3)^{-3/4} = 17784 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 17784 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m2	Loath P kN	Arm length Y m	Moment M kN · m
1	0.00-	0.13	21.62	1.41	4.92	6.92
	0.13		23.26	1.51	4.88	7.38
2	0.13-	1.00	23.26	11.63	4.50	52.36
	1.13		35.91	17.96	4.17	74.85
3	1.13-	1.00	36.75	18.38	3.50	64.35
	2.13		52.25	26.13	3.17	82.78
4	2.13-	0.15	48.56	3.64	2.79	10.14
	2.28		50.46	3.78	2.74	10.35
5	2.28-	0.85	50.46	21.45	2.40	51.51
	3.13		52.88	22.48	2.12	47.61

6	3.13- 3.45	0.32	52.88 53.80	8.46 8.61	1.73 1.62	14.62 13.96
7	3.45- 4.13	0.68	5.80 3.86	1.97 1.31	1.29 1.06	2.54 1.39
8	4.13- 4.20	0.07	3.86 3.66	0.14 0.13	0.81 0.79	0.11 0.10
9	4.20- 4.97	0.77	24.22 0.00	9.26 0.00	0.51 0.26	4.73 0.00
$\Sigma P = 158.24 \quad \Sigma M = 445.69$						

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

Arbitrary load lateral load $P_i = 44.8 \text{ kN/m}$
 depth to acting position $H_i = 0.0 \text{ m}$
 moment $M_{in} = 11.9 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_{in} = 0.00 \text{ m}$
 Height from riverbed to top of coping $H = 3.45 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 1.52 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 234.33 \text{ kN}\cdot\text{m}$
 h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{680.02}{203.04} = 3.35 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 203.04}{4.97} = 81.79 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.13	0.13	37.82 40.04	2.46 2.60	6.17 6.12	15.16 15.93
2	0.13- 1.13	1.00	52.87 70.06	26.43 35.03	5.75 5.41	151.90 189.62
3	1.13- 1.80	0.67	83.96 95.69	28.13 32.06	4.86 4.63	136.60 148.52
4	1.80- 2.13	0.33	95.69 98.24	15.79 16.21	4.30 4.19	67.89 67.92
5	2.13- 3.13	1.00	84.05 91.53	42.03 45.76	3.75 3.41	157.46 156.21
6	3.13- 3.45	0.32	78.25 80.60	12.52 12.90	2.97 2.87	37.23 36.97
7	3.45- 4.13	0.68	32.60 33.72	11.08 11.47	2.53 2.31	28.08 26.45

Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 1129800 \text{ cm}^4$ (original condition)
 $I = 1005522 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 1005522 \times 10^{-8}$
 $= 2.011 \times 10^6$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_b = 9282 \text{ kN/m}^3$
 calculated value $\beta = 0.18431 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 203.04 \text{ kN/m}$
 height of acting position of load $h_0 = 3.35 \text{ m}$
 moment $M_0 = 680.02 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{in} = 1.302$,
 maximum moment $M_{max} = 885.30 \text{ kN}\cdot\text{m/m}$
 depth of generated position of M_{max} $l_m = 2.283 \text{ m}$
 depth of l^{st} fixed point $l_l = 6.544 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_b = 17784 \text{ kN/m}^3$
 calculated value $\beta = 0.21684 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 466.77 \text{ kN/m}$
 height of acting position of load $h_0 = 4.51 \text{ m}$
 moment $M_0 = 2104.09 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{in} = 1.151$,
 maximum moment $M_{max} = 2422.74 \text{ kN}\cdot\text{m/m}$
 depth of generated position of M_{max} $l_m = 1.505 \text{ m}$
 depth of l^{st} fixed point $l_l = 5.127 \text{ m}$

6.3 Stress Intensity

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

Material Name 25 H₁₀₀₀₋₃₀₀₋₁₆₋₃₂₋₁₈
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.90$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 16330 \text{ cm}^3$ (original condition)
 $Z = 16330 \text{ cm}^3$ (after reduction by corrosion and section)

8	4.13- 4.20	0.07	33.72 33.84	1.18 1.18	2.06 2.05	2.43 2.41
9	4.20- 5.13	0.93	50.34 36.08	23.41 16.78	1.70 1.39	39.79 23.32
10	5.13- 6.13	1.00	28.68 10.77	14.34 5.39	0.75 0.41	10.71 2.23
11	6.13- 6.21	0.08	23.02 21.84	0.92 0.87	0.05 0.05	0.05 0.02
$\Sigma P = 358.53 \quad \Sigma M = 1316.89$						

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

Arbitrary load lateral load $P_i = 105.5 \text{ kN/m}$
 depth to acting position $H_i = 0.00 \text{ m}$
 moment $M_{in} = 122.9 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_{in} = 0.00 \text{ m}$
 Height from riverbed to top of coping $H = 3.45 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 778.05 \text{ kN}\cdot\text{m}$

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	1.80- 2.80	1.00	0.0 2.2	0.00 1.10	4.08 3.74	0.00 4.12
2	2.80- 3.45	0.65	2.2 2.8	0.72 0.92	3.19 2.98	2.29 2.74
$\Sigma P_{dw} = 2.74 \quad \Sigma M_{dw} = 9.15$						

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{dw}}{\Sigma P + P_i + \Sigma P_{dw}} = \frac{2104.09}{466.77} = 4.51 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 466.77}{6.21} = 150.33 \text{ kN/m}$$

6.2 Sectional Force

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

Material name 25 H₁₀₀₀₋₃₀₀₋₁₆₋₃₂₋₁₈
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.89$
 Section efficiency $\mu = 1.00$

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{885.30 \times 10^6}{14697 \times 10^3} = 60 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

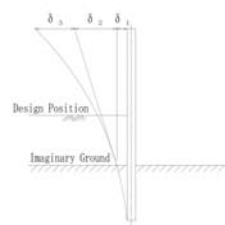
6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{2422.74 \times 10^6}{14697 \times 10^3} = 165 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

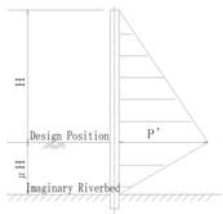


$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.1843 \times 3.35) \times 203.04}{2 \times 2.00 \times 10^6 \times 1005522 \times 10^{-8} \times 0.1843^3} = 0.01304 \text{ m}$$

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

$$= \frac{(1+2 \times 0.1843 \times 3.35) \times 203.04}{2 \times 2.00 \times 10^6 \times 1005522 \times 10^{-8} \times 0.1843^2} \times (3.45+1.52) = 0.01649 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{1.52}{3.45} = 0.439$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{81.79 \times 3.45^4}{120 \times 2.00 \times 10^8 \times 1005522 \times 10^{-8}} (4 + 20 \times 0.439 + 40 \times 0.439^2 + 35 \times 0.439^3 + 11 \times 0.439^4)$$

$$= 0.00115 \text{ m}$$

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

$$= 0.01304 + 0.01649 + 0.00115$$

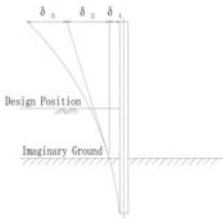
$$= 0.03067 \text{ m}$$

$$\text{Size} = 30.67 \leq \delta_a = 50.00 \text{ mm}$$

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

Displacement Calculation



$$\text{Inertia sectional moment } I_0 = 1129800 \text{ cm}^4 (\text{original condition})$$

$$I = 1129800 \text{ cm}^4 (\text{after reduction by corrosion and section})$$

$$EI = 200000 \times 10^3 \times 1129800 \times 10^{-8} = 2.260 \times 10^6$$

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 follows:

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

$$L = H - H_{11} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

$$\text{Modules of lateral subgrade reaction } K_b = 9282 \text{ kN/m}^3$$

$$\text{Calculated value } \beta = 0.17902 \text{ m}^{-1}$$

$$\text{Penetration length of SSP } D = 1.52 + \frac{3}{0.179} = 18.27 \text{ m}$$

$$\text{Whole length of SSP } L = 3.45 - 0.40 + 18.27 = 21.32 \text{ m}$$

7.1.2 Seismic Condition

$$\text{Modules of lateral subgrade reaction } K_b = 17784 \text{ kN/m}^3$$

$$\text{Calculated value } \beta = 0.21061 \text{ m}^{-1}$$

$$\text{Penetration length of SSP } D = 2.76 + \frac{3}{0.211} = 17.00 \text{ m}$$

$$\text{Whole length of SSP } L = 3.45 - 0.40 + 17.00 = 20.05 \text{ m}$$

Therefore, the total length of the sheet pile is 21.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 25 H_H 1000-300-16-32-18

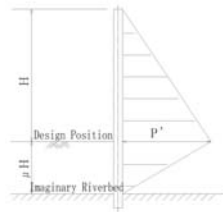
		Normal Condition		Seismic Condition
Inertia sectional moment	I (cm ⁴)	1129800		
Sectional Modulus	Z (cm ³)	16330		
Maximum bending moment	Mmax (kN · m)	885.30	2422.74	
Stress intensity	σ (N/mm ²)	60 (180)	165 (270)	
Lateral displacement	δ (mm)	30.67 (50.0)	73.80 (75.0)	
Penetration depth	D (m)	18.27	17.00	
Whole length of SSP	L (m)	21.50		

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

$$= \frac{(1 + 0.2168 \times 4.51) \times 466.77}{2 \times 2.00 \times 10^8 \times 1005522 \times 10^{-8} \times 0.2168^3} = 0.02251 \text{ m}$$

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

$$= \frac{(1 + 2 \times 0.2168 \times 4.51) \times 466.77}{2 \times 2.00 \times 10^8 \times 1005522 \times 10^{-8} \times 0.2168^2} \times (3.45 + 2.76) = 0.04529 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{2.76}{3.45} = 0.800$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{150.33 \times 3.45^4}{120 \times 2.00 \times 10^8 \times 1005522 \times 10^{-8}} (4 + 20 \times 0.800 + 40 \times 0.800^2 + 35 \times 0.800^3 + 11 \times 0.800^4)$$

$$= 0.00600 \text{ m}$$

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

$$= 0.02251 + 0.04529 + 0.00600$$

$$= 0.07380 \text{ m}$$

$$\text{Size} = 73.80 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	25 H_H 1000-300-16-32-18
Unit width	B = 1.0000 m
Corrosion rate	η = 1.00
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²

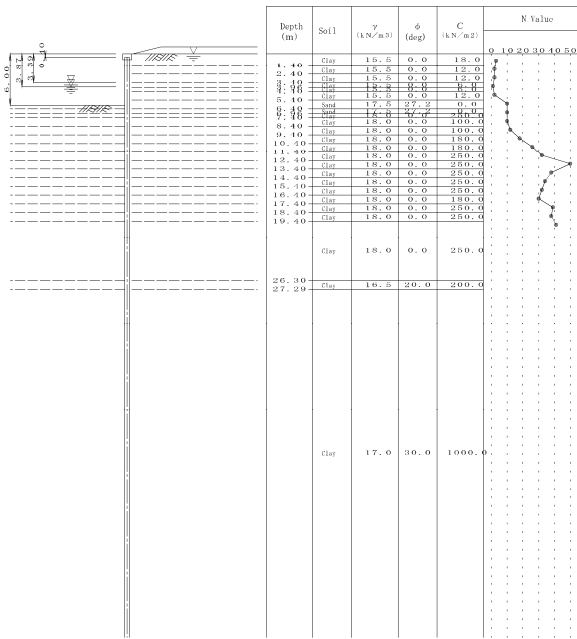
Block No. : R-19
Sta. : 9+380~9+700

Design Cross Section : Sta 9+500
Boring Name : BMRL-27

Specification : SSP SP-25H
(Combined) : H 1000-300-16-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	=	6.00 m
Depth from coping top to rear side ground	H ₀	=	0.00 m
Depth from coping top to SSP top	H _h	=	0.40 m
Landside WL	L _{wa}	=	0.00 m (Normal Condition)
	L _{wa}	=	0.00 m (Seismic Condition)
Riverside WL	L _{wp}	=	3.87 m (Normal Condition)
	L _{wp}	=	3.39 m (Seismic Condition)

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	0.80	3	11	10.80	26
2	1.80	2	12	11.80	32
3	2.80	2	13	12.80	50
4	3.80	1	14	13.80	38
5	4.80	2	15	14.80	34
6	5.80	10	16	15.80	32
7	6.80	10	17	16.80	30
8	7.80	10	18	17.80	39
9	8.80	12	19	18.80	38
10	9.80	18	20	19.80	41

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 (Include Projection Length)	Thickness m (excluding projected length)
1	1.40	1.40
2	2.40	1.00
3	3.40	1.00
4	3.96	0.56
5	4.40	0.44
6	5.40	1.00
7	6.40	1.00
8	6.96	0.56
9	7.40	0.44
10	8.40	1.00
11	9.40	1.00
12	10.40	1.00
13	11.40	1.00
14	12.40	1.00
15	13.40	1.00
16	14.40	1.00
17	15.40	1.00
18	16.40	1.00
19	17.40	1.00
20	18.40	1.00
21	19.40	1.00
22	26.30	6.90
23	27.29	0.99
24	65.20	37.91

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.40	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200	Auto	Auto
2	2.40	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto
3	3.40	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto
4	3.96	C	1.0	15.50	5.70	0.0	6.0	0.0	0.200	Auto	Auto
5	4.40	C	1.0	15.50	5.70	0.0	6.0	0.0	0.200	Auto	Auto
6	5.40	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_p = 10 \text{ degrees}$

Rear side angle of slope not considered

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$$

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

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{b0} \left(\frac{B_b}{0.3} \right)^{-3/4}$
	$K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
	$B_b = 10.00 \text{ m}$
	$E_0 = 2800 \text{ N}$

Average N-value calculated from average N-value between imaginary riverbed and depth as 1/3

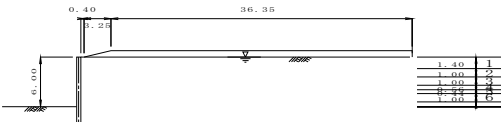
No	Depth m	earth Soil	N Value	γ	γ'	ϕ	C	a	k'	ζ (degree)	
				kN/m ³	kN/m ³					degree	Normal Condition
7	6.40	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
8	6.96	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
9	7.40	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
10	8.40	C	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
11	9.40	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
12	10.40	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	11.40	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	12.40	C	32.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	13.40	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	14.40	C	38.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	15.40	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	16.40	C	32.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	17.40	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
20	18.40	C	39.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
21	19.40	C	38.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
22	26.30	C	41.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
23	27.29	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
24	65.20	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

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

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kNm3	Seismic Condition kNm3	ϕ degree	C kNm2	Normal Condition degree	Seismic Condition degree
1	Sand	0.40	3.65	40.00	40.00	0.80	19.0	19.0	30.0	0.0	Auto	Auto

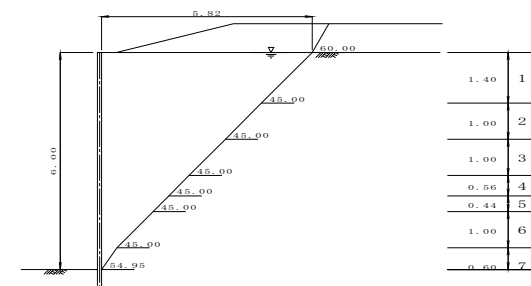
Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	25 H	H 1000 -300 -16 -22 -18
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 962300 cm ⁴
Sectional factor	Z ₀	= 13420 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	= 0.88
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	= 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	Σ γ h kN/m ²	Q kN/m ²	γ silty kN/m ²	Angle of Rupture ζ degree
1	6.00~5.40	Sand	27.2	15.0	0.0	35.40	10.52	58.80	54.95

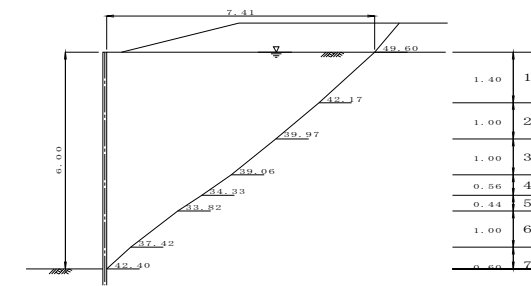
1	19.0	3.22	61.21
Σ			61.21

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

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{61.21 + 0.00 + 0.00}{5.82}$$
$$= 10.52 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C' kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ silty kN/m ²	k (t ⁻¹)	θ degree	Angle of Rupture ζ degree
1	6.00~5.40	Sand	27.2	15.0	0.0	35.40	11.75	58.80	0.200	11.31	42.40
2	5.40~4.40	Clay	0.0	15.0	12.0	30.78	11.75	52.92	0.200	11.31	37.42
3	4.40~3.96	Clay	0.0	15.0	6.0	25.08	11.75	43.12	0.200	11.31	33.82
4	3.96~3.40	Clay	0.0	15.0	6.0	22.57	11.75	38.81	0.200	11.31	34.33
5	3.40~2.40	Clay	0.0	15.0	12.0	19.38	11.75	33.32	0.200	11.31	39.06
6	2.40~1.40	Clay	0.0	15.0	12.0	13.68	11.75	23.52	0.200	11.31	39.97
7	1.40~0.00	Clay	0.0	15.0	18.0	7.98	11.75	13.72	0.200	11.31	42.17
8		embankment	30.0	—	0.0	15.20	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

2	5.40~4.40	Clay	0.0	15.0	12.0	30.78	10.52	52.92	45.00
3	4.40~3.96	Clay	0.0	15.0	6.0	25.08	10.52	43.12	45.00
4	3.96~3.40	Clay	0.0	15.0	6.0	22.57	10.52	38.81	45.00
5	3.40~2.40	Clay	0.0	15.0	12.0	19.38	10.52	33.32	45.00
6	2.40~1.40	Clay	0.0	15.0	12.0	13.68	10.52	23.52	45.00
7	1.40~0.00	Clay	0.0	15.0	18.0	7.98	10.52	13.72	45.00
8		embankment	30.0	—	0.0	15.20	0.00	0.00	60.00

• Angle of active rupture of sandy soil

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

• Angle of active rupture of clayey soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.95	0.60	0.00	0.00	0.42	0.60
2	45.00	1.00	0.42	0.60	1.42	1.60
3	45.00	0.44	1.42	1.60	1.86	2.04
4	45.00	0.56	1.86	2.04	2.42	2.60
5	45.00	1.00	2.42	2.60	3.42	3.60
6	45.00	1.00	3.42	3.60	4.42	4.60
7	45.00	1.40	4.42	4.60	5.82	6.00
8	60.00	0.80	5.82	6.00	6.28	6.80

From the above table, the loading width (L) on the ground surface is 5.82 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.40	0.60	0.00	0.00	0.66	0.60
2	37.42	1.00	0.66	0.60	1.96	1.60
3	33.82	0.44	1.96	1.60	2.62	2.04
4	34.33	0.56	2.62	2.04	3.44	2.60
5	39.06	1.00	3.44	2.60	4.67	3.60
6	39.97	1.00	4.67	3.60	5.87	4.60
7	42.17	1.40	5.87	4.60	7.41	6.00
8	49.60	0.80	7.41	6.00	8.09	6.80

From the above table, the loading width (L) on the ground surface is 7.41 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	4.58	87.06
Σ			87.06

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

2.2.4 Calculated Load

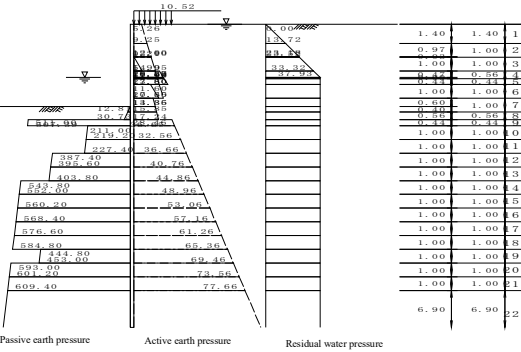
Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (87.06 + 0.00 + 0.00) / 7.41

= 11.75 kN/m²

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

	Depth, m	Soil	γ, kN/m³	φ, degree	C, kN/m²	Σ γ · h + Qa, kN/m²	Ka	Ka × cos δ
1	0.00-1.40	Clay	5.7	—	18.0	10.515	—	—
2	1.40-2.37	Clay	5.7	—	12.0	18.495	—	—
3	2.37-2.40	Clay	5.7	—	12.0	24.000	—	—
4	2.40-3.40	Clay	5.7	—	12.0	24.195	—	—
5	3.40-3.87	Clay	5.7	—	6.0	29.895	—	—
6	3.87-3.96	Clay	5.7	—	6.0	32.974	—	—
7	3.96-4.40	Clay	5.7	—	6.0	33.087	—	—

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ, kN/m³	φ, degree	C, kN/m²	Σ γ · h + Qp, kN/m²	Kp	Kp × cos δ
10	6.00-6.40	Sand	7.7	27.2	—	0.000	4.30428	4.15761
11	6.40-6.96	Sand	7.7	27.2	—	3.080	4.30428	4.15761
12	6.96-7.40	Clay	8.2	0.0	250.0	7.392	—	—
13	7.40-8.40	Clay	8.2	0.0	100.0	11.000	—	—
14	8.40-9.40	Clay	8.2	0.0	100.0	19.200	—	—
15	9.40-10.40	Clay	8.2	0.0	180.0	27.400	—	—
16	10.40-11.40	Clay	8.2	0.0	180.0	35.600	—	—
17	11.40-12.40	Clay	8.2	0.0	250.0	43.800	—	—
18	12.40-13.40	Clay	8.2	0.0	250.0	52.000	—	—
19	13.40-14.40	Clay	8.2	0.0	250.0	60.200	—	—
20	14.40-15.40	Clay	8.2	0.0	250.0	68.400	—	—
21	15.40-16.40	Clay	8.2	0.0	250.0	76.600	—	—
22	16.40-17.40	Clay	8.2	0.0	180.0	84.800	—	—
23	17.40-18.40	Clay	8.2	0.0	250.0	93.000	—	—
24	18.40-19.40	Clay	8.2	0.0	250.0	101.200	—	—
25	19.40-20.40	Clay	8.2	0.0	250.0	109.400	—	—
26	20.40-21.40	Clay	8.2	0.0	250.0	117.600	—	—
27	21.40-22.40	Clay	8.2	0.0	250.0	125.800	—	—

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

δ = -15.00, β = 0.00, θ = 0.00

Kp = (cos²(φ - θ) / (cos θ · cos(δ - θ) · [1 - √(sin(φ - δ) · sin(φ + β - θ)) / (cos(δ - θ) · cos(-β))])²

8	4.40-5.40	Clay	5.7	—	12.0	35.995	—	—
9	5.40-6.00	Sand	7.7	27.2	—	41.295	0.33489	0.32348
10	6.00-6.40	Sand	7.7	27.2	—	45.915	0.33489	0.32348
11	6.40-6.96	Sand	7.7	27.2	—	48.995	0.33489	0.32348
12	6.96-7.40	Clay	8.2	—	250.0	53.307	—	—
13	7.40-8.40	Clay	8.2	—	100.0	56.915	—	—
14	8.40-9.40	Clay	8.2	—	100.0	65.115	—	—
15	9.40-10.40	Clay	8.2	—	180.0	73.315	—	—
16	10.40-11.40	Clay	8.2	—	180.0	81.515	—	—
17	11.40-12.40	Clay	8.2	—	250.0	89.715	—	—
18	12.40-13.40	Clay	8.2	—	250.0	97.915	—	—
19	13.40-14.40	Clay	8.2	—	250.0	106.115	—	—
20	14.40-15.40	Clay	8.2	—	250.0	114.315	—	—
21	15.40-16.40	Clay	8.2	—	250.0	122.515	—	—
22	16.40-17.40	Clay	8.2	—	180.0	130.715	—	—
23	17.40-18.40	Clay	8.2	—	250.0	138.915	—	—
24	18.40-19.40	Clay	8.2	—	250.0	147.115	—	—
25	19.40-20.40	Clay	8.2	—	250.0	155.315	—	—
26	20.40-21.40	Clay	8.2	—	250.0	163.515	—	—
27	21.40-22.40	Clay	8.2	—	250.0	171.715	—	—

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

δ = 15.00, β = 0.00, θ = 0.00

Ka = (cos²(φ - θ) / (cos θ · cos(δ + θ) · [1 + √(sin(φ + δ) · sin(φ - β - θ)) / (cos(δ + θ) · cos(-β))])²

3.1.3 Lateral Forth

No	Depth, m	Active	Residual water pressure	Passive
		Pa1, kN/m²	Pa2, kN/m²	Pw, kN/m²
1	0.00-1.40	-25.48	5.26	0.00
2	1.40-2.37	-5.50	9.25	13.72
3	2.37-2.40	0.00	12.00	23.18
4	2.40-3.40	0.20	12.10	23.52
5	3.40-3.87	17.90	14.95	23.52
6	3.87-3.96	20.57	16.29	23.52
7	3.96-4.40	21.09	16.54	23.52
8	4.40-5.40	11.60	17.80	23.52
9	5.40-6.00	13.36	18.85	23.52
10	6.00-6.40	14.85	19.85	23.52
11	6.40-6.96	15.85	20.85	23.52
12	6.96-7.40	-446.69	26.65	26.65
13	7.40-8.40	-443.08	28.46	28.46
14	8.40-9.40	-434.88	32.56	32.56
15	9.40-10.40	-286.68	36.66	36.66
16	10.40-11.40	-278.48	40.76	40.76
17	11.40-12.40	-410.28	44.86	44.86
18	12.40-13.40	-402.08	48.96	48.96
19	13.40-14.40	-393.88	53.06	53.06
20	14.40-15.40	-385.68	57.16	57.16
21	15.40-16.40	-377.48	61.26	61.26
22	16.40-17.40	-229.28	65.36	65.36
23	17.40-18.40	-361.08	69.46	69.46
24	18.40-19.40	-352.88	73.56	73.56

25	19.40- 26.30	-344.68 -288.10	77.66 105.95	77.66 105.95	37.93 37.93	609.40 665.98
26	26.30- 27.29	-188.10 -181.47	105.95 109.26	105.95 109.26	37.93 37.93	565.98 572.61
27	27.29- 65.20	-1781.47 -1508.52	109.26 245.74	109.26 245.74	37.93 37.93	2172.61 2445.56

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma h + Q - 2 C$$

$$P_{a2} = K_a \cdot (\sum \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5

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

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

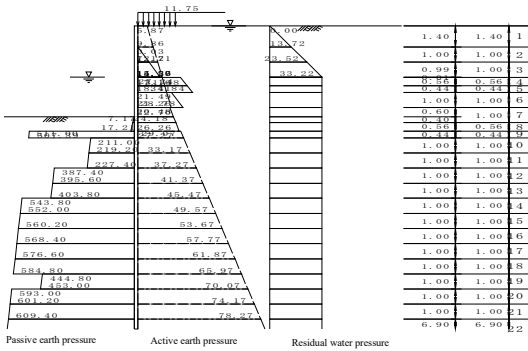
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma h + Q + 2 C$$

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

3.2 Seismic Condition



26	27.29- 65.20	Clay	7.2	—	1000.0	219.76	267.44	0.200	11.31	—	—	44.38
					1000.0	492.71	638.96	0.200	11.31	—	—	43.65

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$\delta = 15.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

$$\zeta = 45^\circ - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\sum \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q_p$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K_p	$K_p \times \cos \delta$
9	6.00- 6.40	Sand	7.70	27.2	—	0.000 3.080	0.00 3.92	0.200 0.200	11.31 11.31	2.32868 2.32868	2.32868 2.32868
10	6.40- 6.96	Sand	7.70	27.2	—	3.080 7.392	3.92 9.41	0.200 0.200	11.31 11.31	2.32868 2.32868	2.32868 2.32868
11	6.96- 7.40	Clay	8.20	0.0	250.0 250.0	7.392 11.000	9.41 13.72	0.200 0.200	11.31 11.31	—	—
12	7.40- 8.40	Clay	8.20	0.0	100.0 100.0	11.000 19.200	13.72 23.52	0.200 0.200	11.31 11.31	—	—
13	8.40- 9.40	Clay	8.20	0.0	100.0 100.0	19.200 27.400	23.52 33.32	0.200 0.200	11.31 11.31	—	—
14	9.40- 10.40	Clay	8.20	0.0	180.0 180.0	27.400 35.600	33.32 43.12	0.200 0.200	11.31 11.31	—	—
15	10.40- 11.40	Clay	8.20	0.0	180.0 180.0	35.600 43.800	43.12 52.92	0.200 0.200	11.31 11.31	—	—
16	11.40- 12.40	Clay	8.20	0.0	250.0 250.0	43.800 52.000	52.92 62.72	0.200 0.200	11.31 11.31	—	—
17	12.40- 13.40	Clay	8.20	0.0	250.0 250.0	52.000 60.200	62.72 72.52	0.200 0.200	11.31 11.31	—	—
18	13.40- 14.40	Clay	8.20	0.0	250.0 250.0	60.200 68.400	72.52 82.32	0.200 0.200	11.31 11.31	—	—
19	14.40- 15.40	Clay	8.20	0.0	250.0 250.0	68.400 76.600	82.32 92.12	0.200 0.200	11.31 11.31	—	—
20	15.40- 16.40	Clay	8.20	0.0	250.0 250.0	76.600 84.800	92.12 101.92	0.200 0.200	11.31 11.31	—	—
21	16.40- 17.40	Clay	8.20	0.0	180.0 180.0	84.800 93.000	101.92 111.72	0.200 0.200	11.31 11.31	—	—
22	17.40- 18.40	Clay	8.20	0.0	250.0 250.0	93.000 101.200	111.72 121.52	0.200 0.200	11.31 11.31	—	—
23	18.40- 19.40	Clay	8.20	0.0	250.0 250.0	101.200 109.400	121.52 131.32	0.200 0.200	11.31 11.31	—	—

3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.40	Clay	5.7	—	18.0 18.0	11.75 13.72	0.00 0.200	0.200 0.200	11.31 11.31	—	—	43.24 42.17
2	1.40- 2.40	Clay	5.7	—	12.0 12.0	19.73 25.43	13.72 23.52	0.200 0.200	11.31 11.31	—	—	40.94 39.97
3	2.40- 3.39	Clay	5.7	—	12.0 12.0	25.43 31.07	23.52 33.22	0.200 0.200	11.31 11.31	—	—	39.97 39.07
4	3.39- 3.40	Clay	5.7	—	12.0 12.0	31.07 31.13	33.22 33.32	0.200 0.200	11.31 11.31	—	—	39.07 39.06
5	3.40- 3.96	Clay	5.7	—	6.0 6.0	31.13 34.32	33.32 38.81	0.200 0.200	11.31 11.31	—	—	35.01 34.33
6	3.96- 4.40	Clay	5.7	—	6.0 6.0	34.32 36.83	38.81 43.12	0.200 0.200	11.31 11.31	—	—	34.33 33.82
7	4.40- 5.40	Clay	5.7	—	12.0 12.0	36.83 42.53	43.12 52.92	0.200 0.200	11.31 11.31	—	—	38.21 37.42
8	5.40- 6.00	Sand	7.7	27.2	—	42.53 47.15	52.92 58.80	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
9	6.00- 6.40	Sand	7.7	27.2	—	47.15 50.23	58.80 62.72	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
10	6.40- 6.96	Sand	7.7	27.2	—	50.23 54.54	62.72 68.21	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
11	6.96- 7.40	Clay	8.2	—	250.0 250.0	54.54 58.15	68.21 72.52	0.200 0.200	11.31 11.31	—	—	44.39 44.35
12	7.40- 8.40	Clay	8.2	—	100.0 100.0	58.15 66.35	72.52 82.32	0.200 0.200	11.31 11.31	—	—	43.42 43.22
13	8.40- 9.40	Clay	8.2	—	100.0 100.0	66.35 74.55	82.32 92.12	0.200 0.200	11.31 11.31	—	—	43.22 43.01
14	9.40- 10.40	Clay	8.2	—	180.0 180.0	74.55 82.75	92.12 101.92	0.200 0.200	11.31 11.31	—	—	43.86 43.74
15	10.40- 11.40	Clay	8.2	—	180.0 180.0	82.75 90.95	101.92 111.72	0.200 0.200	11.31 11.31	—	—	43.74 43.62
16	11.40- 12.40	Clay	8.2	—	250.0 250.0	90.95 99.15	111.72 121.52	0.200 0.200	11.31 11.31	—	—	43.99 43.91
17	12.40- 13.40	Clay	8.2	—	250.0 250.0	99.15 107.35	121.52 131.32	0.200 0.200	11.31 11.31	—	—	43.91 43.82
18	13.40- 14.40	Clay	8.2	—	250.0 250.0	107.35 115.55	131.32 141.12	0.200 0.200	11.31 11.31	—	—	43.82 43.73
19	14.40- 15.40	Clay	8.2	—	250.0 250.0	115.55 123.75	141.12 150.92	0.200 0.200	11.31 11.31	—	—	43.73 43.65
20	15.40- 16.40	Clay	8.2	—	250.0 250.0	123.75 131.95	150.92 160.72	0.200 0.200	11.31 11.31	—	—	43.65 43.56
21	16.40- 17.40	Clay	8.2	—	180.0 180.0	131.95 140.15	160.72 170.52	0.200 0.200	11.31 11.31	—	—	43.04 42.93
22	17.40- 18.40	Clay	8.2	—	250.0 250.0	140.15 148.35	170.52 180.32	0.200 0.200	11.31 11.31	—	—	43.48 43.39
23	18.40- 19.40	Clay	8.2	—	250.0 250.0	148.35 156.55	180.32 190.12	0.200 0.200	11.31 11.31	—	—	43.39 43.31
24	19.40- 26.30	Clay	8.2	—	250.0 250.0	156.55 213.13	190.12 257.74	0.200 0.200	11.31 11.31	—	—	43.31 42.75
25	26.30- 27.29	Clay	6.7	—	200.0 200.0	213.13 219.76	257.74 267.44	0.200 0.200	11.31 11.31	—	—	42.24 42.16

24	19.40- 26.30	Clay	8.20	0.0	250.0 250.0	109.400 165.980	131.32 198.94	0.200 0.200	11.31 11.31	—	—
25	26.30- 27.29	Clay	6.70	20.0	200.0 200.0	165.980 172.613	198.94 208.64	0.200 0.200	11.31 11.31	—	—
26	27.29- 65.20	Clay	7.20	30.0	1000.0 1000.0	172.613 445.565	208.64 580.16	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth, m	Active				Residual water pressure		Passive	
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pw kN/m ²	Pp kN/m ²	Pp kN/m ²	
1	0.00- 1.40	-21.82 -12.10	5.87 9.86	9.86 13.72	0.00 0.200	—	—	—	—
2	1.40- 2.40	0.03 7.12	9.86 12.71	9.86 12.71	13.72 23.52	—	—	—	—
3	2.40- 3.39	7.12 14.20	12.71 15.53	12.71 15.53	23.52 33.22	—	—	—	—
4	3.39- 3.40	14.20 14.27	15.53 15.56	15.53 15.56	33.22 33.22	—	—	—	—
5	3.40- 3.96	27.24 31.48	15.56 17.16	27.24 31.48	33.22 33.22	—	—	—	—
6	3.96- 4.40	31.48 34.84	17.16 18.41	31.48 34.84	33.22 33.22	—	—	—	—
7	4.40- 5.40	21.49 28.78	18.41 21.26	21.49 28.78	33.22 33.22	—	—	—	—
8	5.40- 6.00	—	—	20.48 22.70	33.22 33.22	—	—	—	—
9	6.00- 6.40	—	—	22.70 24.18	33.22 33.22	0.00 7.17	—	—	—
10	6.40- 6.96	—	—	24.18 26.26	33.22 33.22	7.17 17.21	—	—	—
11	6.96- 7.40	-434.43 -430.09	27.27 29.07	27.27 29.07	33.22 33.22	507.39 511.00	—	—	—
12	7.40- 8.40	-129.87 -119.92	29.07 33.17	29.07 33.17	33.22 33.22	211.00 219.20	—	—	—
13	8.40- 9.40	-119.92 -109.96	33.17 37.27	33.17 37.27	33.22 33.22	219.20 227.40	—	—	—
14	9.40- 10.40	-270.23 -260.31	37.27 41.37	37.27 41.37	33.22 33.22	387.40 395.60	—	—	—
15	10.40- 11.40	-260.31 -250.39	41.37 45.47	41.37 45.47	33.22 33.22	395.60 403.80	—	—	—
16	11.40- 12.40	-390.52 -380.62	45.47 49.57	45.47 49.57	33.22 33.22	543.80 552.00	—	—	—

17	12.40- 13.40	-380.62 -370.71	49.57 53.67	49.57 53.67	33.22 33.22	552.00 560.20
18	13.40- 14.40	-370.71 -360.79	53.67 57.77	53.67 57.77	33.22 33.22	560.20 568.40
19	14.40- 15.40	-360.79 -350.87	57.77 61.87	57.77 61.87	33.22 33.22	568.40 576.60
20	15.40- 16.40	-350.87 -340.94	61.87 65.97	61.87 65.97	33.22 33.22	576.60 584.80
21	16.40- 17.40	-340.94 -331.00	65.97 70.07	65.97 70.07	33.22 33.22	584.80 593.00
22	17.40- 18.40	-331.00 -321.06	70.07 74.17	70.07 74.17	33.22 33.22	593.00 601.20
23	18.40- 19.40	-321.06 -311.11	74.17 78.27	74.17 78.27	33.22 33.22	601.20 609.40
24	19.40- 20.40	-311.11 -301.17	78.27 82.37	78.27 82.37	33.22 33.22	609.40 617.60
25	20.40- 21.40	-301.17 -291.23	82.37 86.47	82.37 86.47	33.22 33.22	617.60 625.80
26	21.40- 22.40	-291.23 -281.29	86.47 90.57	86.47 90.57	33.22 33.22	625.80 634.00

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma h + Q - 2 C$$

$$P_{a2} = K_a \cdot (\sum \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma h + Q + 2 C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	3.39	0.00	0.00
2	4.39	1.00	2.77
3	5.39	2.00	3.92
4	6.00	2.61	4.48

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

Where,

k_{sa} : design seismic coefficient

3	2.37- 2.40	12.00 12.10	23.18 23.52	—	35.18 35.62
4	2.40- 3.40	12.10 14.95	23.52 33.32	—	35.62 48.27
5	3.40- 3.87	17.90 20.57	33.32 37.93	—	51.22 58.50
6	3.87- 3.96	20.57 21.09	37.93 37.93	—	58.50 59.01
7	3.96- 4.40	21.09 23.60	37.93 37.93	—	59.01 61.52
8	4.40- 5.40	17.80 20.65	37.93 37.93	—	55.72 58.57
9	5.40- 6.00	13.36 14.85	37.93 37.93	—	51.28 52.78
10	6.00- 6.40	14.85 15.85	37.93 37.93	0.00 12.81	52.78 40.97
11	6.40- 6.96	15.85 17.24	37.93 37.93	12.81 30.73	40.97 24.44

No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
12	6.96- 7.40	26.65 28.46	37.93 37.93	507.39 511.00	442.81 444.62

P_a : Active earth pressure

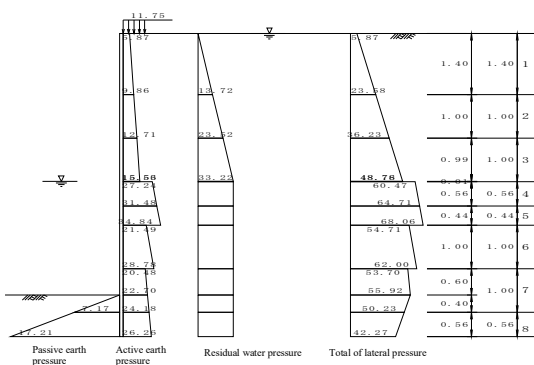
P_w : Residual water pressure

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 -6.96 m)

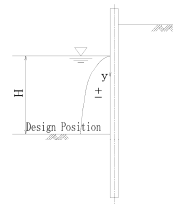
4.2 Seismic Condition



γ_w : unit weight of water

H : water depth of riverside

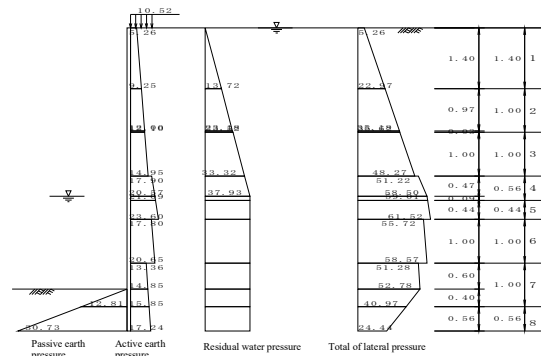
y : depth from water surface to the point where active water pressure is calculated



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



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 1.40	5.26 9.25	0.00 13.72	— —	5.26 22.97
2	1.40- 2.37	9.25 12.00	13.72 23.18	— —	22.97 35.18

No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 1.40	5.87 9.86	0.00 13.72	— —	5.87 23.58
2	1.40- 2.40	9.86 12.71	13.72 23.52	— —	23.58 36.23
3	2.40- 3.39	12.71 15.53	23.52 33.22	— —	36.23 48.76
4	3.39- 3.40	15.53 15.56	33.22 33.22	— —	48.76 48.78
5	3.40- 3.96	27.24 31.48	33.22 33.22	— —	60.47 64.71
6	3.96- 4.40	31.48 34.84	33.22 33.22	— —	64.71 68.06
7	4.40- 5.40	21.49 28.78	33.22 33.22	— —	54.71 62.00
8	5.40- 6.00	20.48 22.70	33.22 33.22	— —	53.70 55.92
9	6.00- 6.40	22.70 24.18	33.22 33.22	0.00 7.17	55.92 50.23
10	6.40- 6.96	24.18 26.26	33.22 33.22	7.17 17.21	50.23 42.27
11	6.96- 7.40	27.27 29.07	33.22 33.22	507.39 511.00	446.90 448.71

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 -6.96 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

Average N -value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{b0} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B=10, 00m)$$

$$K_{b0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$E_b = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	25 H _ H 1000 -300 -16 -22 -18		
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 = 962300 cm ⁴ (original condition)		
	I = 837201 cm ⁴ (after reduction by corrosion and section)		
Inertia sectional moment	EI = 200000 × 10 ³ × 837201 × 10 ⁻⁸ = 1.674 × 10 ⁶		

No	Depth m	N Value	No	Depth m	N Value
1	0.80	3	11	10.80	26
2	1.80	2	12	11.80	32
3	2.80	2	13	12.80	50
4	3.80	1	14	13.80	38
5	4.80	2	15	14.80	34
6	5.80	10	16	15.80	32
7	6.80	10	17	16.80	30
8	7.80	10	18	17.80	39
9	8.80	12	19	18.80	38
10	9.80	18	20	19.80	41

5.2 Normal Condition

Assuming Kh = 11927 kN/m3,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.205 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.87 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.96 m) to 4.87 m depth (GL -11.83 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.96	0.84	10.0	10.0	8.40
2	7.80	1.00	10.0	12.0	11.00
3	8.80	1.00	12.0	18.0	15.00
4	9.80	1.00	18.0	26.0	22.00
5	10.80	1.00	26.0	32.0	29.00
6	11.80	0.03	32.0	32.5	0.90
L = Σh=4.87			ΣA = 86.30		

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

$$\begin{aligned} \text{Average N-value} \quad N' &= \frac{\Sigma A}{L} \\ &= \frac{86.30}{4.87} \\ &= 17.73 \end{aligned}$$

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 1.40	1.40	5.26 22.97	3.68 16.08	6.49 6.03	23.90 96.89
2	1.40~ 2.37	0.97	22.97 35.18	11.09 16.99	5.24 4.92	58.09 83.52
3	2.37~ 2.40	0.03	35.18 35.62	0.40 0.61	4.58 4.57	2.76 2.79
4	2.40~ 3.40	1.00	35.62 48.27	17.81 24.13	4.23 3.89	75.27 93.96
5	3.40~ 3.87	0.47	51.22 58.50	12.04 13.75	3.40 3.25	40.96 44.63
6	3.87~ 3.96	0.09	58.50 59.01	2.63 2.66	3.06 3.03	8.06 8.05
7	3.96~ 4.40	0.44	59.01 61.52	12.98 13.53	2.85 2.71	37.04 36.63
8	4.40~ 5.40	1.00	55.72 58.37	27.86 29.29	2.23 1.89	62.04 55.45
9	5.40~ 6.00	0.60	51.28 52.78	15.39 15.83	1.36 1.16	20.92 18.37
10	6.00~ 6.40	0.40	52.78 40.97	10.56 8.19	0.83 0.69	8.73 5.68
11	6.40~ 6.96	0.56	40.97 24.44	11.47 6.84	0.37 0.19	4.28 1.28
ΣP = 274.01			ΣM = 789.31			

P₀ : active earth pressure + residual water pressure - passive earth pressure
P : load P₀ 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_l = 0.0 kN/m
depth to acting position H_l = 0.0 m
moment M_{l0} = 0.00 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 6.00 m
Depth of Imaginary riverbed from riverbed L_k = 0.96 m

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_l) + M_{l0} = 0.00 \text{ kN} \cdot \text{m}$$

h₀ Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_l}{\Sigma P + P_l} \\ &= \frac{789.31}{274.01} = 2.88 \text{ m} \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 17.73 = 49639 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 49639 = 165464 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10} (B_0/0.3)^{-3/4} = 165464 (10.00/0.3)^{-3/4} = 11927 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.

The lateral subgrade reaction coefficient Kh (Normal Condition) is 11927 kN/m3.

5.3 Seismic Condition

Assuming Kh = 21247 kN/m3,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.237 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.21 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.96 m) and 4.21 m depth (GL -11.17 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.96	0.84	10.0	10.0	8.40
2	7.80	1.00	10.0	12.0	11.00
3	8.80	1.00	12.0	18.0	15.00
4	9.80	1.00	18.0	26.0	22.00
5	10.80	0.37	26.0	28.2	10.13
L = Σh=4.21			ΣA = 66.53		

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

$$\begin{aligned} \text{Average N-value} \quad N' &= \frac{\Sigma A}{L} \\ &= \frac{66.53}{4.21} \\ &= 15.79 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 15.79 = 44212 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 44212 = 294745 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10} (B_0/0.3)^{-3/4} = 294745 (10.00/0.3)^{-3/4} = 21247 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.

The lateral subgrade reaction coefficient Kh (Seismic Condition) is 21247 kN/m3.

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 1.40	1.40	5.87 23.58	4.11 16.51	6.49 6.03	26.09 99.49
2	1.40~ 2.40	1.00	23.58 36.23	11.79 18.12	5.23 4.89	61.63 88.65
3	2.40~ 3.39	0.99	36.23 48.76	17.94 24.13	4.23 3.90	75.87 94.12
4	3.39~ 3.40	0.01	48.76 48.78	0.24 0.24	3.57 3.56	0.87 0.87
5	3.40~ 3.96	0.56	60.47 64.71	16.93 18.12	3.37 3.19	57.11 57.74
6	3.96~ 4.40	0.44	64.71 68.06	14.24 14.97	2.85 2.71	40.62 40.53
7	4.40~ 5.40	1.00	54.71 62.00	27.36 31.00	2.23 1.89	60.91 58.69
8	5.40~ 6.00	0.60	53.70 55.92	16.11 16.78	1.36 1.16	21.91 19.46
9	6.00~ 6.40	0.40	55.92 50.23	11.18 10.05	0.83 0.69	9.25 6.97
10	6.40~ 6.96	0.56	50.23 42.27	14.07 11.84	0.37 0.19	5.25 2.21
ΣP = 295.72			ΣM = 828.83			

P₀ : active earth pressure + residual water pressure - passive earth pressure

P : load P₀ 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_l = 0.0 kN/m
depth to acting position H_l = 0.00 m
moment M_{l0} = 0.0 kN·m/m
depth to acting position H_m = 0.00 m
Height from riverbed to top of coping H = 6.00 m
Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_l) + M_{l0} = 0.00 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	3.39~ 4.39	1.00	0.0 2.8	0.00 1.39	3.24 2.90	0.00 4.02
2	4.39~ 5.39	1.00	2.8 3.9	1.39 1.96	2.24 1.90	3.10 3.73
3	5.39~ 6.00	0.61	3.9 4.5	1.20 1.37	1.37 1.16	1.63 1.59
ΣP _{hw} = 7.29			Σ M _{hw} = 14.07			

h₀ Height of acting position of P₀ from imaginary riverbed

$$h_o = \frac{M_o}{P_o} = \frac{\Sigma M + M_i + \Sigma M_{io}}{\Sigma P + P_i + \Sigma P_{io}}$$

$$= \frac{842.90}{303.01} = 2.78 \text{ m}$$

6.2 Sectional Force

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

Material name	25 H _ H 1000 -300 -16 -22 -18
Unit width	B = 1.0000 m
Corrosion margin	t _i = 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 _o = 962300 cm ⁴ (original condition)
	I = 837201 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 837201 × 10 ⁻⁸	= 1.674 × 10 ⁶

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1+2\beta h_o)^2 + 1}}{2\beta h_o} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_o})$$

$$M_{max} = M_o \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_o}$$

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

$$M_{(x)} = \frac{P_o}{\beta} \times \exp^{-\beta x} (\beta h_o \cdot \cos \beta x + (1+\beta h_o) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 11927 kN/m ³
calculated value	β = 0.20543 m ⁻¹
resultant earth force (lateral)	P _o = 274.01 kN/m
height of acting position of load	h _o = 2.88 m
moment	M _o = 789.31 kN·m/m

in consideration of ψ _m = 1.321,	M _{max} = 1042.47 kN·m/m
maximum moment	l _m = 2.091 m
depth of generated position of M _{max}	l _i = 5.914 m
depth of 1 st fixed point	

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b = 21247 kN/m ³
calculated value	β = 0.23732 m ⁻¹
resultant earth force (lateral)	P _o = 303.01 kN/m
height of acting position of load	h _o = 2.78 m
moment	M _o = 842.90 kN·m/m

in consideration of ψ _m = 1.274	M _{max} = 1073.77 kN·m/m
maximum moment	l _m = 1.715 m
depth of generated position of M _{max}	l _i = 5.024 m
depth of 1 st fixed point	

6.3 Stress Intensity

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

Material Name	25 H _ H 1000 -300 -16 -22 -18
Corrosion margin	t _i = 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 _o = 13420 cm ³ (original condition)
	Z = 11810 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{1042.47 \times 10^6}{11810 \times 10^3} = 88 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{1073.77 \times 10^6}{11810 \times 10^3} = 91 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.40	6.49 6.03	0.933 0.866	0.300 0.267	3.68 16.08	1.104 4.288
2	1.40- 2.37	5.24 4.92	0.753 0.706	0.212 0.191	11.09 16.99	2.353 3.240
3	2.37- 2.40	4.58 4.57	0.658 0.657	0.169 0.168	0.60 0.61	0.102 0.103
4	2.40- 3.40	4.23 3.89	0.607 0.559	0.147 0.127	17.81 24.13	2.619 3.072
5	3.40- 3.87	3.40 3.25	0.489 0.466	0.100 0.092	12.04 13.75	1.204 1.263
6	3.87- 3.96	3.06 3.03	0.440 0.435	0.082 0.081	2.63 2.66	0.217 0.215
7	3.96- 4.40	2.85 2.71	0.410 0.389	0.073 0.066	12.98 13.53	0.942 0.891
8	4.40- 5.40	2.23 1.89	0.320 0.272	0.046 0.034	27.86 29.29	1.274 0.985
9	5.40- 6.00	1.36 1.16	0.195 0.167	0.018 0.013	15.39 15.83	0.275 0.208
10	6.00- 6.40	0.83 0.69	0.119 0.100	0.007 0.005	10.56 8.19	0.072 0.039

6.4.2 Seismic Condition

Modulus of deformation

No	Depth m	Y m	α	ζ	P kN	Q kN
1	0.00- 1.40	6.49 6.03	0.933 0.866	0.300 0.267	4.11 16.51	1.233 4.402
2	1.40- 2.40	5.23 4.89	0.751 0.703	0.211 0.189	11.79 18.12	2.493 3.428
3	2.40- 3.39	4.23 3.90	0.608 0.560	0.147 0.128	17.94 24.13	2.641 3.081
4	3.39- 3.40	3.57 3.56	0.512 0.512	0.109 0.109	0.24 0.24	0.027 0.027
5	3.40- 3.96	3.37 3.19	0.485 0.458	0.098 0.089	16.93 18.12	1.667 1.609
6	3.96- 4.40	2.85 2.71	0.410 0.389	0.073 0.066	14.24 14.97	1.033 0.986
7	4.40- 5.40	2.23 1.89	0.320 0.272	0.046 0.034	27.36 31.00	1.251 1.043
8	5.40- 6.00	1.36 1.16	0.195 0.167	0.018 0.013	16.11 16.78	0.288 0.220
9	6.00- 6.40	0.83 0.69	0.119 0.100	0.007 0.005	11.18 10.05	0.076 0.048
10	6.40- 6.96	0.37 0.19	0.054 0.027	0.001 0.000	14.07 11.84	0.020 0.004
Σ Q = 25.575						

Y : Height from imaginary riverbed to acting position
α : α = $\frac{Y}{H+L_k}$
ζ : ζ = $\frac{(3-\alpha) \times \alpha^2}{6}$
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 _{de} kN	Q _{de} kN
1	3.39- 4.39	2.24 2.90	0.465 0.417	0.091 0.075	0.00 1.39	0.000 0.104
2	4.39- 5.39	2.24 1.90	0.321 0.273	0.046 0.034	1.39 1.96	0.064 0.067
3	5.39- 6.00	1.37 1.16	0.196 0.167	0.018 0.013	1.20 1.37	0.022 0.018
Σ Q _{de} = 0.274						

Therefore, the deformation coefficient Q is expressed by
Q = 25.575 + 0.274 = 25.849

Displacement Calculation

11	6.40- 6.96	0.37 0.19	0.054 0.027	0.001 0.000	11.47 6.84	0.016 0.002
Σ Q = 24.484						

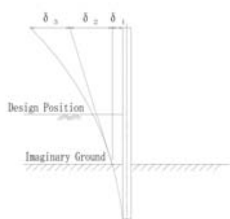
Y : Height from imaginary riverbed to acting position

$$\alpha : \alpha = \frac{Y}{H+L_k}$$

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

Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground

Displacement Calculation



$$\delta_1 = \frac{(1+\beta h_o) \times P_o}{2 E I \beta^3}$$

$$= \frac{(1+0.2054 \times 2.88) \times 274.01}{2 \times 2.00 \times 10^8 \times 837201 \times 10^{-8} \times 0.2054^3} = 0.01502 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_o) \times P_o}{2 E I \beta^3} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.2054 \times 2.88) \times 274.01}{2 \times 2.00 \times 10^8 \times 837201 \times 10^{-8} \times 0.2054^3} \times (6.00+0.96) = 0.02947 \text{ m}$$

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

$$= \frac{24.48 \times (6.00+0.96)^3}{2.00 \times 10^8 \times 837201 \times 10^{-8}} = 0.00493 \text{ m}$$

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

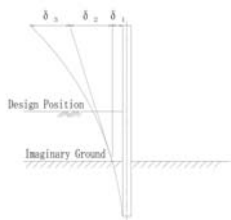
$$= 0.01502 + 0.02947 + 0.00493$$

$$= 0.04942 \text{ m}$$

$$\text{Size} = 49.42 \leq \delta_a = 50.00 \text{ mm}$$

Where,

δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement



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

$$= \frac{(1 + 0.2373 \times 2.78) \times 303.01}{2 \times 2.00 \times 10^8 \times 837201 \times 10^{-8} \times 0.2373^3} = 0.01124 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_u)$$

$$= \frac{(1 + 2 \times 0.2373 \times 2.78) \times 303.01}{2 \times 2.00 \times 10^8 \times 837201 \times 10^{-8} \times 0.2373^3} \times (6.00 + 0.96) = 0.02594 \text{ m}$$

$$\delta_3 = \frac{Q \times (H + L_u)^2}{E I}$$

$$= \frac{25.85 \times (6.00 + 0.96)^2}{2.00 \times 10^8 \times 837201 \times 10^{-8}} = 0.00520 \text{ m}$$

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

$$= 0.01124 + 0.02594 + 0.00520$$

$$= 0.04239 \text{ m}$$

$$\text{Size} = 42.39 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	25 H H 1000-300-16-22-18
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 = 962300 cm ⁴ (original condition)
	I = 962300 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 962300 × 10 ⁻⁸	= 1.2925 × 10 ⁵

7.1 Penetration Depth and Whole Length of SSP (Chang)

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

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

$$L = H - H_{u1} + D$$

$$\beta = \sqrt[4]{\frac{K_h \times B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _h = 11927 kN/m ³
Calculated value	β = 0.19840 m ⁻¹

Penetration length of SSP	D = 0.96 + $\frac{3}{0.198}$ = 16.08 m
Whole length of SSP	L = 6.00 - 0.40 + 16.08 = 21.68 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K _h = 21247 kN/m ³
Calculated value	β = 0.22920 m ⁻¹

Penetration length of SSP	D = 0.96 + $\frac{3}{0.229}$ = 14.05 m
Whole length of SSP	L = 6.00 - 0.40 + 14.05 = 19.65 m

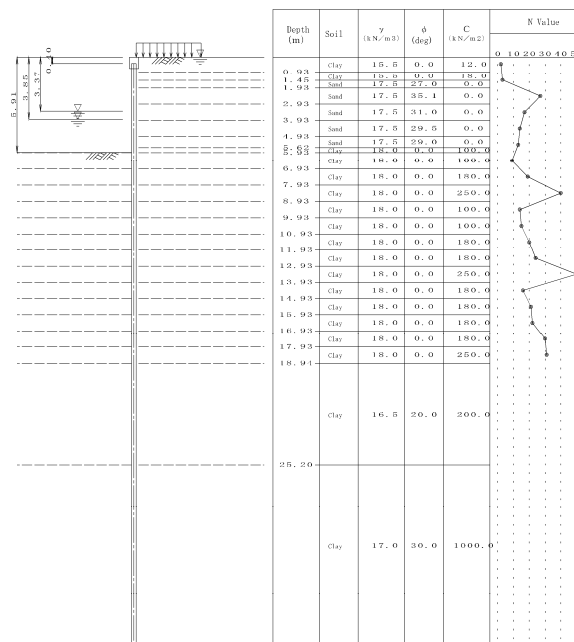
Therefore, the total length of the sheet pile is 22.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP		25 H H 1000-300-16-22-18		Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	962300			
Sectional Modulus	Z (cm ³)	13420			
Maximum bending moment	Mmax (kN × m × m)			1042.47	1073.77
Stress intensity	σ (N/mm ²)			88 (180)	91 (270)
Lateral displacement	δ (mm)			49.42 (50.0)	42.39 (75.0)
Penetration depths	D (m)			16.08	14.05
Whole length of SSP	L (m)	22.00			

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 5.91 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} = 3.85 m (Normal Condition)
	L _{wp} = 3.37 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered
Wind load, Impact load	not considered
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope	not considered
Angle of rupture (clayey soil)	$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$ $a = \sin \theta$ $b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{b0} \left(\frac{B_B}{0.3} \right)^{-3/4}$ $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2) $B_B = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
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	0.43	2	11	10.43	15
2	1.43	3	12	11.43	20
3	2.43	27	13	12.43	24
4	3.43	17	14	13.43	50
5	4.43	14	15	14.43	16
6	5.43	13	16	15.43	21
7	6.43	9	17	16.43	22
8	7.43	19	18	17.43	30
9	8.43	40	19	18.43	31
10	9.43	14			

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 (Include Projection Length)	Thickness m (excluding projected length)
1	0.93	0.93
2	1.45	0.52
3	1.93	0.48
4	2.93	1.00
5	3.93	1.00
6	4.93	1.00
7	5.62	0.69
8	5.93	0.31
9	6.93	1.00
10	7.93	1.00
11	8.93	1.00
12	9.93	1.00
13	10.93	1.00
14	11.93	1.00
15	12.93	1.00
16	13.93	1.00
17	14.93	1.00
18	15.93	1.00
19	16.93	1.00
20	17.93	1.00
21	18.94	1.01
22	25.20	6.26
23	35.20	10.00

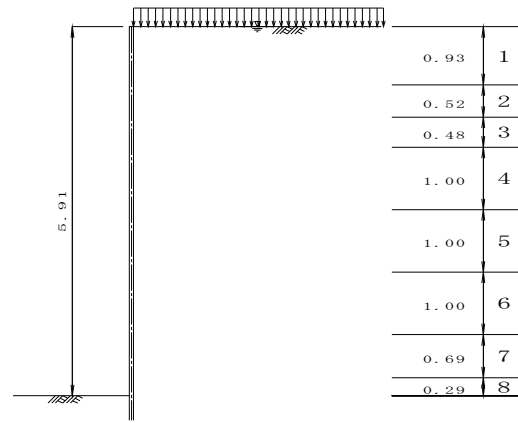
No	Depth m	earth Soil	N Value	γ kN/m ³	γ^* kN/m ³	ϕ degree	C kN/m ²	a	k [*]	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.93	C	2.0	15.50	5.70	0.0	12.0	0.0	0.200	Auto	Auto
2	1.45	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200	Auto	Auto
3	1.93	S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
4	2.93	S	27.0	17.50	7.70	35.1	0.0	0.0	0.200	Auto	Auto
5	3.93	S	17.0	17.50	7.70	31.0	0.0	0.0	0.200	Auto	Auto
6	4.93	S	14.0	17.50	7.70	29.5	0.0	0.0	0.200	Auto	Auto
7	5.62	S	13.0	17.50	7.70	29.0	0.0	0.0	0.200	Auto	Auto
8	5.93	C	13.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	6.93	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
10	7.93	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
11	8.93	C	40.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
12	9.93	C	14.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
13	10.93	C	15.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
14	11.93	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	12.93	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	13.93	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	14.93	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
18	15.93	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
19	16.93	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
20	17.93	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
21	18.94	C	31.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
22	25.20	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
23	35.20	C	121.5	17.00	7.20	30.0	1000.0	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 (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	4.00	5.0	0.0

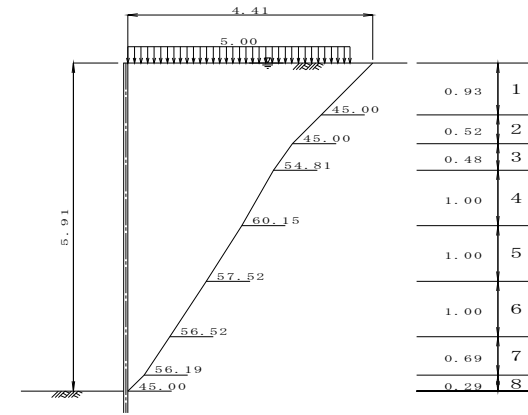
Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 700 -200 - 12-19-18
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 299700 cm ⁴
Sectional factor	Z ₀	= 5540 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	= 0.86
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



8	45.00	0.93	3.48	4.98	4.41	5.91

From the above table, the loading width (L) on the ground surface is 4.41 m.

2.1.3 Acting Load by Surcharge Load

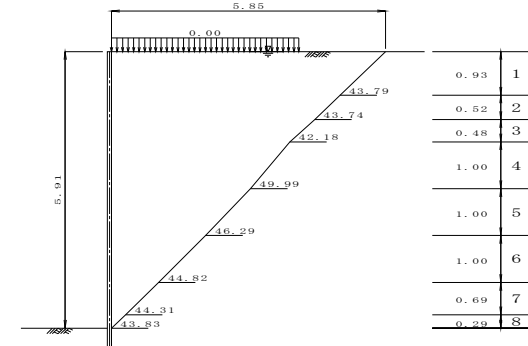
No	Q kN/m ²	l m	Q _{el} kN/m
1	5.0	4.00	20.00
Σ			20.00

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{0.00 + 20.00 + 0.00}{4.41}$$
$$= 4.53 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Angle of Rupture ζ degree
1	5.91 ~ 5.62	Clay	0.0	15.0	100.0	42.75	0.00	57.92	0.200	11.31	43.83
2	5.62 ~ 4.93	Sand	29.0	15.0	0.0	40.37	0.00	55.08	0.200	11.31	44.31
3	4.93 ~ 3.93	Sand	29.5	15.0	0.0	35.06	0.00	48.31	0.200	11.31	44.82

2.1.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	Angle of Rupture ζ degree
1	5.91 ~ 5.62	Clay	0.0	15.0	100.0	42.75	4.53	57.92	45.00
2	5.62 ~ 4.93	Sand	29.0	15.0	0.0	40.37	4.53	55.08	56.19
3	4.93 ~ 3.93	Sand	29.5	15.0	0.0	35.06	4.53	48.31	56.52
4	3.93 ~ 2.93	Sand	31.0	15.0	0.0	27.36	4.53	38.51	57.52
5	2.93 ~ 1.93	Sand	35.1	15.0	0.0	19.66	4.53	28.71	60.15
6	1.93 ~ 1.45	Sand	27.0	15.0	0.0	11.96	4.53	18.91	54.81
7	1.45 ~ 0.93	Clay	0.0	15.0	18.0	8.26	4.53	14.21	45.00
8	0.93 ~ 0.00	Clay	0.0	15.0	12.0	5.30	4.53	9.11	45.00

• 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

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.29	0.00	0.00	0.29	0.29
2	56.19	0.69	0.29	0.29	0.75	0.98
3	56.52	1.00	0.75	0.98	1.41	1.98
4	57.52	1.00	1.41	1.98	2.05	2.98
5	60.15	1.00	2.05	2.98	2.62	3.98
6	54.81	0.48	2.62	3.98	2.96	4.46
7	45.00	0.52	2.96	4.46	3.48	4.98

4	3.93 ~ 2.93	Sand	31.0	15.0	0.0	27.36	0.00	38.51	0.200	11.31	46.29
5	2.93 ~ 1.93	Sand	35.1	15.0	0.0	19.66	0.00	28.71	0.200	11.31	49.99
6	1.93 ~ 1.45	Sand	27.0	15.0	0.0	11.96	0.00	18.91	0.200	11.31	42.18
7	1.45 ~ 0.93	Clay	0.0	15.0	18.0	8.26	0.00	14.21	0.200	11.31	43.74
8	0.93 ~ 0.00	Clay	0.0	15.0	12.0	5.30	0.00	9.11	0.200	11.31	43.79

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.83	0.29	0.00	0.00	0.30	0.29
2	44.31	0.69	0.30	0.29	1.01	0.98
3	44.82	1.00	1.01	0.98	2.02	1.98
4	46.29	1.00	2.02	1.98	2.97	2.98
5	49.99	1.00	2.97	2.98	3.81	3.98
6	42.18	0.48	3.81	3.98	4.34	4.46
7	43.74	0.52	4.34	4.46	4.88	4.98
8	43.79	0.93	4.88	4.98	5.85	5.91

From the above table, the loading width (L) on the ground surface is 5.85 m.

2.2.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Q _{el} kN/m

1	0.0	4.00	0.00
Σ			0.00

Q = width of surcharge load set by line of active rupture
 l: Loading width of uniform load surrounded by main collapse line

2.2.2 Calculated Load

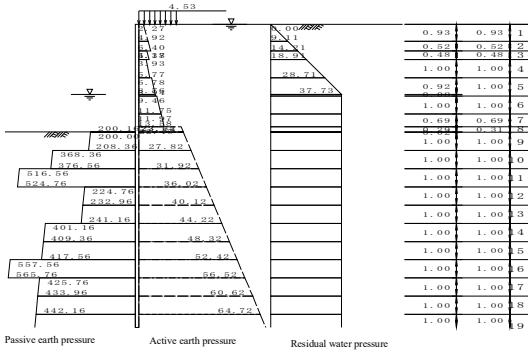
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

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

$$= 0.00 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

Depth, m	Soil	γ kN/m³	φ degree	C kN/m²	Σ γ·h + Q _a kN/m²	K _a	K _a × cos δ
1 0.00-0.93	Clay	5.7	—	12.0 12.0	4.533 9.834	—	—
2 0.93-1.45	Clay	5.7	—	18.0 18.0	9.834 12.798	—	—
3 1.45-1.93	Sand	7.7	27.0	—	12.798 16.494	0.33738 0.33738	0.32289 0.32289
4 1.93-2.93	Sand	7.7	35.1	—	16.494 24.194	0.24677 0.24677	0.23836 0.23836

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m³	φ degree	C kN/m²	Σ γ·h + Q _p kN/m²	K _p	K _p × cos δ
10	5.91-5.93	Clay	8.2	0.0	100.0 100.0	0.000 0.164	—	—
11	5.93-6.93	Clay	8.2	0.0	100.0 100.0	0.164 8.364	—	—
12	6.93-7.93	Clay	8.2	0.0	180.0 180.0	8.364 16.564	—	—
13	7.93-8.93	Clay	8.2	0.0	250.0 250.0	16.564 24.764	—	—
14	8.93-9.93	Clay	8.2	0.0	100.0 100.0	24.764 32.964	—	—
15	9.93-10.93	Clay	8.2	0.0	100.0 100.0	32.964 41.164	—	—
16	10.93-11.93	Clay	8.2	0.0	180.0 180.0	41.164 49.364	—	—
17	11.93-12.93	Clay	8.2	0.0	180.0 180.0	49.364 57.564	—	—
18	12.93-13.93	Clay	8.2	0.0	250.0 250.0	57.564 65.764	—	—
19	13.93-14.93	Clay	8.2	0.0	180.0 180.0	65.764 73.964	—	—
20	14.93-15.93	Clay	8.2	0.0	180.0 180.0	73.964 82.164	—	—
21	15.93-16.93	Clay	8.2	0.0	180.0 180.0	82.164 90.364	—	—
22	16.93-17.93	Clay	8.2	0.0	180.0 180.0	90.364 98.564	—	—
23	17.93-18.94	Clay	8.2	0.0	250.0 250.0	98.564 106.846	—	—
24	18.94-25.20	Clay	6.7	20.0	200.0 200.0	106.846 148.788	—	—
25	25.20-35.20	Clay	7.2	30.0	1000.0 1000.0	148.788 220.788	—	—

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 δ = -15.00, 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 Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²	Pw kN/m²	Pp kN/m²
1	0.00-0.93	-19.47 -14.17	2.27 4.92	2.27 4.92	0.00 9.11	—
2	0.93-1.45	-26.17 -23.20	4.92 6.40	4.92 6.40	9.11 14.21	—

5	2.93-3.85	Sand	7.7	31.0	—	24.194 31.278	0.29008 0.29008	0.28020 0.28020
6	3.85-3.93	Sand	7.7	31.0	—	31.278 31.894	0.29008 0.29008	0.28020 0.28020
7	3.93-4.93	Sand	7.7	29.5	—	31.894 39.594	0.30720 0.30720	0.29674 0.29674
8	4.93-5.62	Sand	7.7	29.0	—	39.594 44.907	0.31307 0.31307	0.30240 0.30240
9	5.62-5.91	Clay	8.2	—	100.0 100.0	44.907 47.285	—	—
10	5.91-5.93	Clay	8.2	—	100.0 100.0	47.285 47.449	—	—
11	5.93-6.93	Clay	8.2	—	100.0 100.0	47.449 55.649	—	—
12	6.93-7.93	Clay	8.2	—	180.0 180.0	55.649 63.849	—	—
13	7.93-8.93	Clay	8.2	—	250.0 250.0	63.849 72.049	—	—
14	8.93-9.93	Clay	8.2	—	100.0 100.0	72.049 80.249	—	—
15	9.93-10.93	Clay	8.2	—	100.0 100.0	80.249 88.449	—	—
16	10.93-11.93	Clay	8.2	—	180.0 180.0	88.449 96.649	—	—
17	11.93-12.93	Clay	8.2	—	180.0 180.0	96.649 104.849	—	—
18	12.93-13.93	Clay	8.2	—	250.0 250.0	104.849 113.049	—	—
19	13.93-14.93	Clay	8.2	—	180.0 180.0	113.049 121.249	—	—
20	14.93-15.93	Clay	8.2	—	180.0 180.0	121.249 129.449	—	—
21	15.93-16.93	Clay	8.2	—	180.0 180.0	129.449 137.649	—	—
22	16.93-17.93	Clay	8.2	—	180.0 180.0	137.649 145.849	—	—
23	17.93-18.94	Clay	8.2	—	250.0 250.0	145.849 154.131	—	—
24	18.94-25.20	Clay	6.7	—	200.0 200.0	154.131 196.073	—	—
25	25.20-35.20	Clay	7.2	—	1000.0 1000.0	196.073 268.073	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 δ = 15.00, 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	1.45-1.93	4.17 5.38	—	4.17 5.38	14.21 18.91	—
4	1.93-2.93	3.93 5.77	—	3.93 5.77	18.91 28.71	—
5	2.93-3.85	6.78 8.76	—	6.78 8.76	28.71 37.73	—
6	3.85-3.93	8.76 8.94	—	8.76 8.94	37.73 37.73	—
7	3.93-4.93	9.46 11.75	—	9.46 11.75	37.73 37.73	—
8	4.93-5.62	11.97 13.58	—	11.97 13.58	37.73 37.73	—
9	5.62-5.91	135.09 152.72	22.45 23.64	22.45 23.64	37.73 37.73	—
10	5.91-5.93	152.72 152.55	23.64 23.72	23.64 23.72	37.73 37.73	200.00 200.16
11	5.93-6.93	152.55 144.35	23.72 27.82	23.72 27.82	37.73 37.73	200.16 208.36
12	6.93-7.93	304.35 296.15	27.82 31.92	27.82 31.92	37.73 37.73	368.36 376.56
13	7.93-8.93	436.15 427.95	31.92 36.02	31.92 36.02	37.73 37.73	516.56 524.76
14	8.93-9.93	427.95 419.75	36.02 40.12	36.02 40.12	37.73 37.73	524.76 532.96
15	9.93-10.93	419.75 411.55	40.12 44.22	40.12 44.22	37.73 37.73	532.96 541.16
16	10.93-11.93	271.55 263.35	44.22 48.32	44.22 48.32	37.73 37.73	401.16 409.36
17	11.93-12.93	263.35 255.15	48.32 52.42	48.32 52.42	37.73 37.73	409.36 417.56
18	12.93-13.93	395.15 386.95	52.42 56.52	52.42 56.52	37.73 37.73	557.56 565.76
19	13.93-14.93	246.95 238.75	56.52 60.62	56.52 60.62	37.73 37.73	425.76 433.96
20	14.93-15.93	238.75 230.55	60.62 64.72	60.62 64.72	37.73 37.73	433.96 442.16
21	15.93-16.93	230.55 222.35	64.72 68.82	64.72 68.82	37.73 37.73	442.16 450.36
22	16.93-17.93	222.35 214.15	68.82 72.92	68.82 72.92	37.73 37.73	450.36 458.56
23	17.93-18.94	354.15 345.87	72.92 77.07	72.92 77.07	37.73 37.73	598.56 606.85
24	18.94-25.20	245.87 203.93	77.07 98.04	77.07 98.04	37.73 37.73	596.85 548.79
25	25.20-35.20	1803.93 1731.93	98.04 134.04	98.04 134.04	37.73 37.73	2148.79 2220.79

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2 C$$

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

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

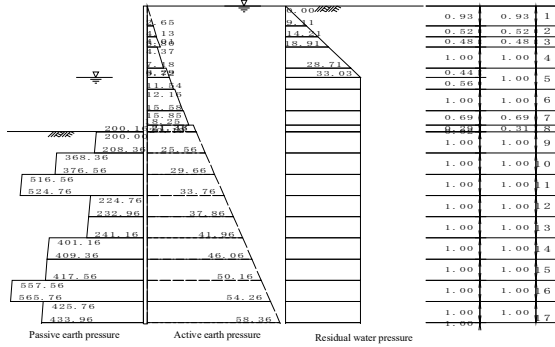
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2 C$$

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

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{water} kN/m ³	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-0.93	Clay	5.7	—	12.0	0.00	0.00	0.200	11.31	—	—	45.00
					12.0	5.30	9.11	0.200	11.31	—	—	43.79
2	0.93-1.45	Clay	5.7	—	18.0	5.30	9.11	0.200	11.31	—	—	44.18
					18.0	8.27	14.21	0.200	11.31	—	—	43.74
3	1.45-1.93	Sand	7.7	27.0	—	8.27	14.21	0.200	11.31	0.50201	0.48490	—
					—	11.96	18.91	0.200	11.31	0.50201	0.48490	—
4	1.93-2.93	Sand	7.7	35.1	—	11.96	18.91	0.200	11.31	0.37794	0.36506	—
					—	19.66	28.71	0.200	11.31	0.37794	0.36506	—
5	2.93-3.37	Sand	7.7	31.0	—	19.66	28.71	0.200	11.31	0.43652	0.42164	—
					—	23.05	33.03	0.200	11.31	0.43652	0.42164	—

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{water} kN/m ³	k (k')	θ degree	K_p	$K_p \times \cos \delta$
10	5.91-5.93	Clay	8.20	0.0	100.0	0.000	0.00	0.200	11.31	—	—
					100.0	0.164	0.20	0.200	11.31	—	—
11	5.93-6.93	Clay	8.20	0.0	100.0	0.164	0.20	0.200	11.31	—	—
					100.0	8.364	10.00	0.200	11.31	—	—
12	6.93-7.93	Clay	8.20	0.0	180.0	8.364	10.00	0.200	11.31	—	—
					180.0	16.564	19.80	0.200	11.31	—	—
13	7.93-8.93	Clay	8.20	0.0	250.0	16.564	19.80	0.200	11.31	—	—
					250.0	24.764	29.60	0.200	11.31	—	—
14	8.93-9.93	Clay	8.20	0.0	100.0	24.764	29.60	0.200	11.31	—	—
					100.0	32.964	39.40	0.200	11.31	—	—
15	9.93-10.93	Clay	8.20	0.0	100.0	32.964	39.40	0.200	11.31	—	—
					100.0	41.164	49.20	0.200	11.31	—	—
16	10.93-11.93	Clay	8.20	0.0	180.0	41.164	49.20	0.200	11.31	—	—
					180.0	49.364	59.00	0.200	11.31	—	—
17	11.93-12.93	Clay	8.20	0.0	180.0	49.364	59.00	0.200	11.31	—	—
					180.0	57.564	68.80	0.200	11.31	—	—
18	12.93-13.93	Clay	8.20	0.0	250.0	57.564	68.80	0.200	11.31	—	—
					250.0	65.764	78.60	0.200	11.31	—	—
19	13.93-14.93	Clay	8.20	0.0	180.0	65.764	78.60	0.200	11.31	—	—
					180.0	73.964	88.40	0.200	11.31	—	—
20	14.93-15.93	Clay	8.20	0.0	180.0	73.964	88.40	0.200	11.31	—	—
					180.0	82.164	98.20	0.200	11.31	—	—
21	15.93-16.93	Clay	8.20	0.0	180.0	82.164	98.20	0.200	11.31	—	—
					180.0	90.364	108.00	0.200	11.31	—	—
22	16.93-17.93	Clay	8.20	0.0	180.0	90.364	108.00	0.200	11.31	—	—
					180.0	98.564	117.80	0.200	11.31	—	—
23	17.93-18.94	Clay	8.20	0.0	250.0	98.564	117.80	0.200	11.31	—	—
					250.0	106.846	127.69	0.200	11.31	—	—
24	18.94-25.20	Clay	6.70	20.0	200.0	106.846	127.69	0.200	11.31	—	—
					200.0	148.788	189.04	0.200	11.31	—	—
25	25.20-35.20	Clay	7.20	30.0	1000.0	148.788	189.04	0.200	11.31	—	—
					1000.0	220.788	287.04	0.200	11.31	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$$\delta = 0.00 \text{ degrees}, \beta = 0.00 \text{ degrees}$$

$$\text{Seismic composite angle } \theta = \tan^{-1} k$$

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

6	3.37-3.93	Sand	7.7	31.0	—	23.05	33.03	0.200	11.31	0.43652	0.42164	—
					—	27.36	38.51	0.200	11.31	0.43652	0.42164	—
7	3.93-4.93	Sand	7.7	29.5	—	27.36	38.51	0.200	11.31	0.45999	0.44432	—
					—	35.06	48.31	0.200	11.31	0.45999	0.44432	—
8	4.93-5.62	Sand	7.7	29.0	—	35.06	48.31	0.200	11.31	0.46809	0.45214	—
					—	40.37	55.08	0.200	11.31	0.46809	0.45214	—
9	5.62-5.91	Clay	8.2	—	100.0	40.37	55.08	0.200	11.31	—	—	43.89
					100.0	42.75	57.92	0.200	11.31	—	—	43.83
10	5.91-5.93	Clay	8.2	—	100.0	42.75	57.92	0.200	11.31	—	—	43.83
					100.0	42.92	58.11	0.200	11.31	—	—	43.82
11	5.93-6.93	Clay	8.2	—	100.0	42.92	58.11	0.200	11.31	—	—	43.82
					100.0	51.12	67.91	0.200	11.31	—	—	43.61
12	6.93-7.93	Clay	8.2	—	180.0	51.12	67.91	0.200	11.31	—	—	44.21
					180.0	59.32	77.71	0.200	11.31	—	—	44.09
13	7.93-8.93	Clay	8.2	—	250.0	59.32	77.71	0.200	11.31	—	—	44.34
					250.0	67.52	87.51	0.200	11.31	—	—	44.25
14	8.93-9.93	Clay	8.2	—	100.0	67.52	87.51	0.200	11.31	—	—	43.19
					100.0	75.72	97.31	0.200	11.31	—	—	42.98
15	9.93-10.93	Clay	8.2	—	100.0	75.72	97.31	0.200	11.31	—	—	42.98
					100.0	83.92	107.11	0.200	11.31	—	—	42.78
16	10.93-11.93	Clay	8.2	—	180.0	83.92	107.11	0.200	11.31	—	—	43.72
					180.0	92.12	116.91	0.200	11.31	—	—	43.60
17	11.93-12.93	Clay	8.2	—	180.0	92.12	116.91	0.200	11.31	—	—	43.60
					180.0	100.32	126.71	0.200	11.31	—	—	43.49
18	12.93-13.93	Clay	8.2	—	250.0	100.32	126.71	0.200	11.31	—	—	43.89
					250.0	108.52	136.51	0.200	11.31	—	—	43.81
19	13.93-14.93	Clay	8.2	—	180.0	108.52	136.51	0.200	11.31	—	—	43.37
					180.0	116.72	146.31	0.200	11.31	—	—	43.25
20	14.93-15.93	Clay	8.2	—	180.0	116.72	146.31	0.200	11.31	—	—	43.25
					180.0	124.92	156.11	0.200	11.31	—	—	43.14
21	15.93-16.93	Clay	8.2	—	180.0	124.92	156.11	0.200	11.31	—	—	43.14
					180.0	133.12	165.91	0.200	11.31	—	—	43.03
22	16.93-17.93	Clay	8.2	—	180.0	133.12	165.91	0.200	11.31	—	—	43.03
					180.0	141.32	175.71	0.200	11.31	—	—	42.91
23	17.93-18.94	Clay	8.2	—	250.0	141.32	175.71	0.200	11.31	—	—	43.47
					250.0	149.60	185.61	0.200	11.31	—	—	43.38
24	18.94-25.20	Clay	6.7	—	200.0	149.60	185.61	0.200	11.31	—	—	43.00
					200.0	191.54	246.96	0.200	11.31	—	—	42.49
25	25.20-35.20	Clay	7.2	—	1000.0	191.54	246.96	0.200	11.31	—	—	44.26
					1000.0	263.54	344.96	0.200	11.31	—	—	44.26

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$$\delta = 15.00 \text{ degrees}, \beta = 0.00 \text{ degrees}$$

$$\text{Seismic composite angle } \theta = \tan^{-1} k$$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

3.2.3 Lateral Forth

No	Depth, m	Active		Residual water pressure	Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00-0.93	-24.00 -17.61	0.00 2.65	0.00 2.65	9.09 4.13	— —
2	0.93-1.45	-29.62 -26.04	2.65 4.13	2.65 4.13	9.11 14.21	— —
3	1.45-1.93	4.01 5.80	— —	4.01 5.80	14.21 18.91	— —
4	1.93-2.93	4.37 7.18	— —	4.37 7.18	18.91 28.71	— —
5	2.93-3.37	8.29 9.72	— —	8.29 9.72	28.71 33.03	— —
6	3.37-3.93	9.72 11.54	— —	9.72 11.54	33.03 33.03	— —
7	3.93-4.93	12.16 15.58	— —	12.16 15.58	33.03 33.03	— —
8	4.93-5.62	15.85 18.25	— —	15.85 18.25	33.03 33.03	— —
9	5.62-5.91	-151.38 -148.51	20.19 21.38	20.19 21.38	33.03 33.03	— —
10	5.91-5.93	-148.51 -148.31	21.38 21.46	21.38 21.46	33.03 33.03	200.00 200.16
11	5.93-6.93	-148.31 -138.39	21.46 25.56	21.46 25.56	33.03 33.03	200.16 208.36
12	6.93-7.93	-298.51 -288.62	25.56 29.66	25.56 29.66	33.03 33.03	368.36 376.56
13	7.93-8.93	-428.68 -418.79	29.66 33.76	29.66 33.76	33.03 33.03	516.56 524.76
14	8.93-9.93	-118.50 -108.53	33.76 37.86	33.76 37.86	33.03 33.03	224.76 232.96
15	9.93-10.93	-108.53 -98.55	37.86 41.96	37.86 41.96	33.03 33.03	232.96 241.16
16	10.93-11.93	-258.89 -248.97	41.96 46.06	41.96 46.06	33.03 33.03	401.16 409.36
17	11.93-12.93	-248.97 -239.03	46.06 50.16	46.06 50.16	33.03 33.03	409.36 417.56
18	12.93-13.93	-379.20 -369.29	50.16 54.26	50.16 54.26	33.03 33.03	557.56 565.76
19	13.93-14.93	-229.09 -219.14	54.26 58.36	54.26 58.36	33.03 33.03	425.76 433.96
20	14.93-15.93	-209.18 -209.18	58.36 62.46	58.36 62.46	33.03 33.03	433.96 442.16
21	15.93-16.93	-209.18 -199.22	62.46 66.56	62.46 66.56	33.03 33.03	442.16 450.36
22	16.93-17.93	-199.22 -189.24	66.56 70.66	66.56 70.66	33.03 33.03	450.36 458.56
23	17.93-18.94	-329.58 -319.54	70.66 74.80	70.66 74.80	33.03 33.03	598.56 606.83
24	18.94-25.20	-219.29 -168.18	74.80 95.77	74.80 95.77	33.03 33.03	506.83 548.79

25	25.20-35.20	-1769.78 -1683.04	95.77 131.77	95.77 131.77	33.03 33.03	2148.79 2220.79

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	3.37	0.00	0.00
2	4.37	1.00	2.73
3	5.37	2.00	3.87
4	5.91	2.54	4.36

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

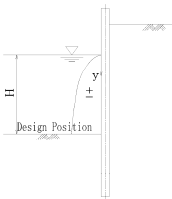
Where,

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

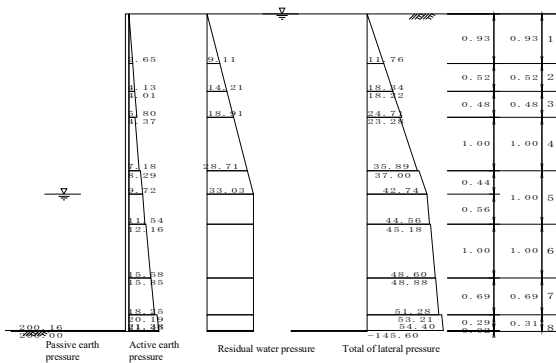


P_p : Passive earth pressure

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

Imaginary riverbed L_k : 0.00 m (GL -5.91 m)

4.2 Seismic Condition



No	Depth m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00-0.93	0.00 2.65	0.00 9.11	— —	0.00 11.76
2	0.93-1.45	2.65 4.13	9.11 14.21	— —	11.76 18.34
3	1.45-1.93	4.01 5.80	14.21 18.91	— —	18.22 24.71
4	1.93-2.93	4.37 7.18	18.91 28.71	— —	23.28 35.89
5	2.93-3.37	8.29 9.72	28.71 33.03	— —	37.00 42.74
6	3.37-3.93	9.72 11.54	33.03 33.03	— —	42.74 44.56
7	3.93-4.93	12.16 15.98	33.03 33.03	— —	45.18 48.60
8	4.93-5.62	15.85 18.25	33.03 33.03	— —	48.88 51.28
9	5.62-5.91	20.19 21.38	33.03 33.03	— —	53.21 54.40
10	5.91-5.93	21.38 21.46	33.03 33.03	200.00 200.16	-145.60 -145.68

P_a : Active earth pressure

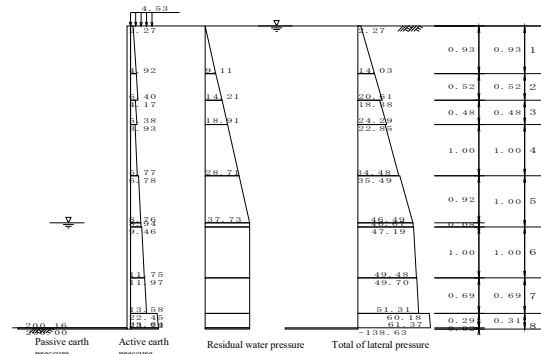
P_w : Residual water pressure

P_p : Passive earth 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



No	Depth m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00-0.93	2.27 4.92	0.00 9.11	— —	2.27 14.03
2	0.93-1.45	4.92 6.40	9.11 14.21	— —	14.03 20.61
3	1.45-1.93	4.17 5.38	14.21 18.91	— —	18.38 24.29
4	1.93-2.93	3.93 5.77	18.91 28.71	— —	22.85 34.48
5	2.93-3.85	6.78 8.76	28.71 37.73	— —	35.49 46.49
6	3.85-3.93	8.76 8.94	37.73 37.73	— —	46.49 46.67
7	3.93-4.93	9.46 11.75	37.73 37.73	— —	47.19 49.48
8	4.93-5.62	11.97 13.58	37.73 37.73	— —	49.70 51.31
9	5.62-5.91	22.45 23.64	37.73 37.73	— —	60.18 61.37
10	5.91-5.93	23.64 23.72	37.73 37.73	200.00 200.16	-138.63 -138.71

P_a : Active earth pressure

P_w : Residual water pressure

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

Imaginary riverbed L_k : 0.00 m (GL -5.91 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of U/β from the virtual ground surface.

Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_h = K_{h0} \left(\frac{B_H}{0.3} \right)^{-0.4} \quad (B_H = 10, 00m)$$

$$K_{h0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_h = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}}$$

Material Name

Unit width

Corrosion margin

Corrosion rate

Section efficiency

Young's modulus

Inertia sectional moment

Inertia sectional moment

10 H₂ H 700-200 - 12-19-18

B = 1.0000 m

t_1 = 1.00 mm (active side) t_2 = 1.00 mm (passive side)

η = 0.84

μ = 1.00

E = 200000 N/mm²

I_0 = 299700 cm⁴(original condition)

I = 251748 cm⁴(after reduction by corrosion and section)

EI = 200000 × 10³ × 251748 × 10⁻⁸ = 5.035 × 10⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.43	2	11	10.43	15
2	1.43	3	12	11.43	20
3	2.43	27	13	12.43	24
4	3.43	17	14	13.43	80
5	4.43	14	15	14.43	16
6	5.43	13	16	15.43	21
7	6.43	9	17	16.43	22
8	7.43	19	18	17.43	30
9	8.43	40	19	18.43	31
10	9.43	14			

5.2 Normal Condition

Assuming $K_h = 14587 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}} = 0.292 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.43 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.91 m) to

3.43 m depth (GL -9.34 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.91	0.52	11.1	9.0	5.22
2	6.43	1.00	9.0	19.0	14.00
3	7.43	1.00	19.0	40.0	29.50
4	8.43	0.91	40.0	16.4	25.60
L = Σ h = 3.43			Σ A = 74.32		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\begin{aligned} \text{Average N-value} \quad N' &= \frac{\Sigma A}{L} \\ &= \frac{74.32}{3.43} \\ &= 21.68 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800 N' = 2800 \times 21.68 = 60708 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 60708 = 202361 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10} (B_u/0.3)^{-3/4} = 202361 (10.00/0.3)^{-3/4} = 14587 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 14587 kN/m³.

5.3 Seismic Condition

Assuming Kh = 28758 kN/m³,

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E_0 I}} = 0.346 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.89 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.91 m) and 2.89 m depth (GL -8.80 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.91	0.52	11.1	9.0	5.22
2	6.43	1.00	9.0	19.0	14.00
3	7.43	1.00	19.0	40.0	29.50
4	8.43	0.37	40.0	30.3	13.11
L = Σ h = 2.89			Σ A = 61.83		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\begin{aligned} \text{Arbitrary load lateral load} \quad P_i &= 0.0 \text{ kN/m} \\ \text{depth to acting position} \quad H_i &= 0.0 \text{ m} \\ \text{moment} \quad M_m &= 0.00 \text{ kN}\cdot\text{m/m} \\ \text{depth to acting position} \quad H_m &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping} \quad H &= 5.91 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed} \quad L_k &= 0.00 \text{ m} \end{aligned}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_m = 0.00 \text{ kN}\cdot\text{m}$$

h_0 , Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} \\ &= \frac{422.41}{197.74} = 2.14 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 197.74}{5.91} = 66.92 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.93	0.93	0.00 11.76	0.00 5.47	5.60 5.29	0.00 28.94
2	0.93- 1.45	0.52	11.76 18.34	3.06 4.77	4.81 4.63	14.70 22.10
3	1.45- 1.93	0.48	18.22 24.71	4.37 5.93	4.30 4.14	18.80 24.56
4	1.93- 2.93	1.00	22.28 35.89	11.64 17.95	3.65 3.31	42.45 59.46
5	2.93- 3.37	0.44	37.00 42.74	8.14 9.40	2.83 2.69	23.07 25.26
6	3.37- 3.93	0.56	42.74 44.56	11.97 12.48	2.35 2.17	28.17 27.03
7	3.93- 4.93	1.00	45.18 48.60	22.59 24.30	1.65 1.31	37.20 31.92
8	4.93- 5.62	0.69	48.88 51.28	16.86 17.69	0.75 0.52	12.85 9.20
9	5.62- 5.91	0.29	53.21 54.40	7.72 7.89	0.19 0.10	1.49 0.76
Σ P = 192.23			Σ M = 407.75			

P_0 : active earth pressure + residual water pressure - passive earth pressure

P : load $P_0 \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

$$\begin{aligned} \text{Arbitrary load lateral load} \quad P_i &= 0.0 \text{ kN/m} \\ \text{depth to acting position} \quad H_i &= 0.00 \text{ m} \\ \text{moment} \quad M_m &= 0.0 \text{ kN}\cdot\text{m/m} \\ \text{depth to acting position} \quad H_m &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping} \quad H &= 5.91 \text{ m} \end{aligned}$$

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

$$\begin{aligned} &= \frac{61.83}{2.89} \\ &= 21.37 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 21.37 = 59842 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 59842 = 398950 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{10} (B_u/0.3)^{-3/4} = 398950 (10.00/0.3)^{-3/4} = 28758 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 28758 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.93	0.93	2.27 14.03	1.05 6.52	5.60 5.29	5.90 34.51
2	0.93- 1.45	0.52	14.03 20.61	3.65 5.36	4.81 4.63	17.53 24.83
3	1.45- 1.93	0.48	18.38 24.29	4.41 5.83	4.30 4.14	18.97 24.13
4	1.93- 2.93	1.00	22.85 34.46	11.42 17.24	3.65 3.31	41.65 57.12
5	2.93- 3.85	0.92	35.49 46.49	16.33 21.39	2.67 2.37	43.65 50.62
6	3.85- 3.93	0.08	46.49 46.67	1.86 1.87	2.03 2.01	3.78 3.75
7	3.93- 4.93	1.00	47.19 49.48	23.60 24.74	1.65 1.31	38.86 32.49
8	4.93- 5.62	0.69	49.70 51.31	17.15 17.70	0.75 0.52	12.86 9.21
9	5.62- 5.91	0.29	60.18 61.37	8.73 8.90	0.19 0.10	1.69 0.86
Σ P = 197.74			Σ M = 422.41			

P_0 : active earth pressure + residual water pressure - passive earth pressure

P : load $P_0 \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

$$\text{Depth of Imaginary riverbed from riverbed} \quad L_k = 0.00 \text{ m}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_m = 0.00 \text{ kN}\cdot\text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure P_{dw} kN/m ²	Loads P_{dw} kN	Arm length Y m	Moment M_{dw} kN · m
1	3.37- 4.37	1.00	0.0 2.7	0.00 1.37	2.21 1.87	0.00 2.56
2	4.37- 5.37	1.00	2.7 3.9	1.37 1.93	1.21 0.87	1.65 1.69
3	5.37- 5.91	0.54	3.9 4.4	1.04 1.18	0.36 0.18	0.38 0.21
Σ P_{dw} = 6.89			Σ M_{dw} = 6.48			

h_0 , Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{dw}}{\Sigma P + P_i + \Sigma P_{dw}} \\ &= \frac{414.24}{199.12} = 2.08 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 199.12}{5.91} = 67.38 \text{ kN/m}$$

6.2 Sectional Force

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

$$\begin{aligned} \text{Material name} \quad B &= 10 \text{ H } 700 - 200 - 12 - 19 - 18 \\ \text{Unit width} \quad u &= 1.0000 \text{ m} \\ \text{Corrosion margin} \quad t_1 &= 1.00 \text{ mm (active side)} \quad t_2 = 1.00 \text{ mm (passive side)} \\ \text{Corrosion rate} \quad \eta &= 0.84 \\ \text{Section efficiency} \quad \mu &= 1.00 \\ \text{Young's modulus} \quad E &= 200000 \text{ N/mm}^2 \\ \text{Inertia sectional moment} \quad I_0 &= 299700 \text{ cm}^4 \text{ (original condition)} \\ &= 251748 \text{ cm}^4 \text{ (after reduction by corrosion and section)} \\ EI &= 200000 \times 10^3 \times 251748 \times 10^{-8} \\ &= 5.035 \times 10^5 \end{aligned}$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_b	=	14587	kN/m ³
calculated value	β	=	0.29173	m ⁻¹
resultant earth force (lateral)	P_0	=	197.74	kN/m
height of acting position of load	h_0	=	2.14	m
moment	M_0	=	422.41	kN·m/m
in consideration of $\psi_{lm} = 1.298$, maximum moment	$M_{\max}$	=	548.20	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	1.436	m
depth of 1 st fixed point	l_i	=	4.128	m

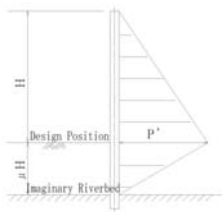
6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_b	=	28758	kN/m ³
calculated value	β	=	0.34568	m ⁻¹
resultant earth force (lateral)	P_0	=	199.12	kN/m
height of acting position of load	h_0	=	2.08	m
moment	M_0	=	414.24	kN·m/m
in consideration of $\psi_{lm} = 1.242$, maximum moment	$M_{\max}$	=	51430	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	1.126	m
depth of 1 st fixed point	l_i	=	3.398	m

6.3 Stress Intensity

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

Material Name	10 H ₂ H 700-200-12-19-18
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 0.86$
Section efficiency	$\mu = 1.00$
Module of section	$Z_0 = 5540$ cm ³ (original condition)
	$Z = 4764$ cm ³ (after reduction by corrosion and section)



$$\mu = \frac{L_k}{H} = \frac{0.00}{5.91} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4)$$

$$= \frac{66.92 \times 5.91^4}{120 \times 2.00 \times 10^8 \times 251748 \times 10^{-8}} (4+20 \times 0.000+40 \times 0.000^2+35 \times 0.000^3+11 \times 0.000^4)$$

$$= 0.00540 \text{ m}$$

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

$$= 0.01284 + 0.03063 + 0.00540$$

$$= 0.04888 \text{ m}$$

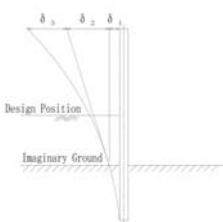
$$\text{Size} = 48.88 \leq \delta_a = 50.00 \text{ mm}$$

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

Displacement Calculation



6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{548.20 \times 10^6}{4764 \times 10^3} = 115 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

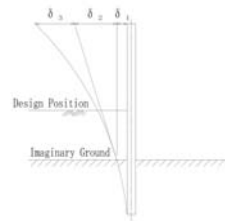
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{514.30 \times 10^6}{4764 \times 10^3} = 108 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



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

$$= \frac{(1+0.2917 \times 2.14) \times 197.74}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.2917^3} = 0.01284 \text{ m}$$

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

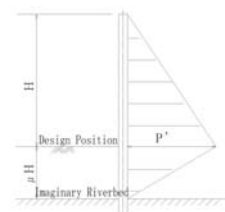
$$= \frac{(1+2 \times 0.2917 \times 2.14) \times 197.74}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.2917^2} \times (5.91+0.00) = 0.03063 \text{ m}$$

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

$$= \frac{(1+0.3457 \times 2.08) \times 199.12}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.3457^3} = 0.00823 \text{ m}$$

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

$$= \frac{(1+2 \times 0.3457 \times 2.08) \times 199.12}{2 \times 2.00 \times 10^8 \times 251748 \times 10^{-8} \times 0.3457^2} \times (5.91+0.00) = 0.02385 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.00}{5.91} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4)$$

$$= \frac{67.38 \times 5.91^4}{120 \times 2.00 \times 10^8 \times 251748 \times 10^{-8}} (4+20 \times 0.000+40 \times 0.000^2+35 \times 0.000^3+11 \times 0.000^4)$$

$$= 0.00544 \text{ m}$$

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

$$= 0.00823 + 0.02385 + 0.00544$$

$$= 0.03752 \text{ m}$$

$$\text{Size} = 37.52 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	10 H ₂ H 700-200-12-19-18
Unit width	$B = 1.0000$ m
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Young's modulus	$E = 200000$ N/mm ²

Inertia sectional moment $I_0 = 299700 \text{ cm}^4$ (original condition)
 $I = 299700 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 299700 \times 10^{-8} = 5.994 \times 10^8$

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 follows:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{11} + D$$
$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_b = 14587 \text{ kN/m}^3$
Calculated value $\beta = 0.27928 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.279} = 10.74 \text{ m}$
Whole length of SSP $L = 5.91 - 0.40 + 10.74 = 16.25 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 28758 \text{ kN/m}^3$
Calculated value $\beta = 0.33094 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.331} = 9.07 \text{ m}$
Whole length of SSP $L = 5.91 - 0.40 + 9.07 = 14.58 \text{ m}$

Therefore, the total length of the sheet pile is 16.50 m from the rounded length value of 0.50 m.

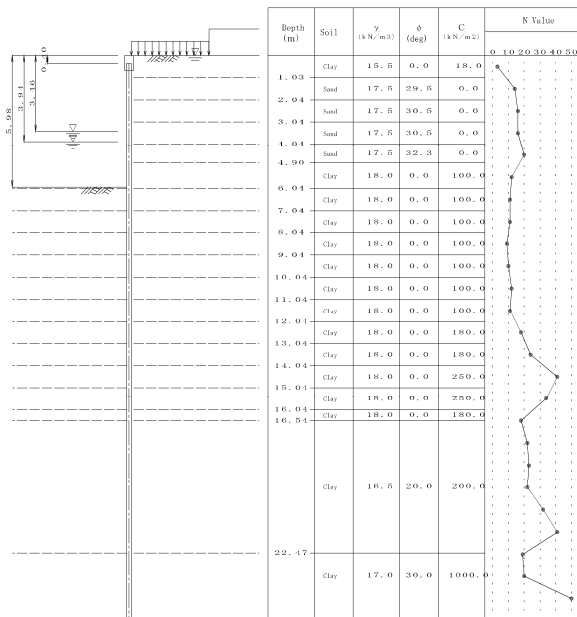
8 Calculation Result

SSP 10 H_H 700-200-12-19-18

			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	299700		
Sectional Modulus	Z (cm ³)	5540		
Maximum bending moment	Mmax (kN · m · m)		548.20	514.30
Stress intensity	σ (N/mm ²)		115 (180)	108 (170)
Lateral displacement	δ (mm)		48.88 (50.0)	37.52 (35.0)
Penetration depths	D (m)		10.74	9.07
Whole length of SSP	L (m)	16.50		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 5.98 \text{ m}$
Depth from coping top to rear side ground $H_0 = 0.00 \text{ m}$
Depth from coping top to SSP top $H_k = 0.40 \text{ m}$
Landside WL $L_{na} = 0.00 \text{ m}$ (Normal Condition)
 $L_{na'} = 0.00 \text{ m}$ (Seismic Condition)
Riverside WL $L_{wp} = 3.94 \text{ m}$ (Normal Condition)
 $L_{wp'} = 3.46 \text{ m}$ (Seismic Condition)

Block No. : R-21
Sta. : 9+900~10+380

Design Cross Section : Sta 9+960
Boring Name : DD-BH-R11

Specification : SSP SP-10H
(Combined) : H 900-250-14-25-18

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$
 $a = \sin \theta$
 $b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{b0} \left(\frac{B_B}{0.3} \right)^{-3/4}$
 $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_B = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	0.54	3	11	10.54	12	21	20.54	32
2	1.54	14	12	11.54	11	22	21.54	41
3	2.54	16	13	12.54	18	23	22.54	19
4	3.54	16	14	13.54	24	24	23.54	20
5	4.54	20	15	14.54	41	25	24.54	50
6	5.54	12	16	15.54	34			
7	6.54	11	17	16.54	18			
8	7.54	11	18	17.54	22			
9	8.54	9	19	18.54	23			
10	9.54	10	20	19.54	22			

Vertical load on riverside not considered

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.03	1.03
2	2.04	1.01
3	3.04	1.00
4	4.03	1.00
5	4.90	0.86
6	6.00	1.14
7	7.04	1.00
8	8.04	1.00
9	9.04	1.00
10	10.04	1.00
11	11.04	1.00
12	12.04	1.00
13	13.04	1.00
14	14.04	1.00
15	15.04	1.00
16	16.04	1.00
17	16.54	0.50
18	22.47	5.93
19	24.54	2.07

No	Depth m	earth Soil	N Value	γ	γ'	ϕ	C	a	k'	ζ (degree)	
				kN/m ³	kN/m ³					degree	kN/m ²
1	1.03	C	3.0	15.50	5.70	0.0	18.0	0.0	0.200	Auto	Auto
2	2.04	S	14.0	17.50	7.70	29.5	0.0	0.0	0.200	Auto	Auto
3	3.04	S	16.0	17.50	7.70	30.5	0.0	0.0	0.200	Auto	Auto
4	4.04	S	16.0	17.50	7.70	30.5	0.0	0.0	0.200	Auto	Auto
5	4.90	S	20.0	17.50	7.70	32.3	0.0	0.0	0.200	Auto	Auto
6	5.80	S	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
7	7.04	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
8	8.04	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	9.04	S	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
10	10.04	S	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
11	11.04	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto

No	Depth m	north S	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
12	12.04	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
13	13.04	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	14.04	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	15.04	C	41.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	16.04	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	16.54	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
18	22.47	C	63.5	16.50	7.20	20.0	200.0	0.0	0.200	Auto	Auto
19	24.54	C	121.5	17.00	6.70	30.0	1000.0	0.0	0.200	Auto	Auto

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

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.03	1
1.03	2
1.03	3
1.03	4
0.03	5
1.03	6

No	Soil	X Coordinate				Thickness		soil single weight γ	internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	3.51	3.51	30.00	30.00	1.18	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	3.50	5.0	0.0

Angle of rapture in embankment calculated in consideration of embankment conditions

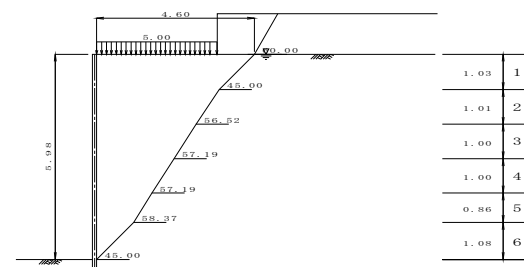
Material name	10 H H 900 -250 -14 -25 -18	
Young's modulus	$E = 200000 \text{ N/mm}^2$	
Inertia sectional moment	$I_0 = 631400 \text{ cm}^4$	
Sectional factor	$Z_0 = 1012 \text{ cm}^3$	
Corrosion margin	$t_1 = 1.00 \text{ mm (riverside)}$	$t_2 = 1.00 \text{ mm (landside)}$
Corrosion rate (to I_0)	$\eta = 0.87$	
Corrosion rate (to Z_0)	$\eta = 0.88$	
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	$\sigma_a = 180 \text{ N/mm}$ (Normal) $\sigma_a' = 270 \text{ N/mm}$ (Seismic)
Allowable displacement	$\delta_a = 50.0 \text{ mm}$ (Normal) $\delta_a' = 75.0 \text{ mm}$ (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

2.1 Normal Condition



No	Depth, m	Soil	δ degree	δ degree	C kN/m ²	$\Sigma \gamma$ kN/m ²	Q ₂	γ value	Angle of rupture C, degree
1	5.98 - 4.90	Clay	0.0	15.0	100.0	44.53	10.77	58.60	45.00
2	4.90 - 4.04	Sand	32.3	15.0	0.0	35.67	10.77	48.02	58.37
3	4.04 - 3.04	Sand	30.5	15.0	0.0	29.02	10.77	39.59	57.19
4	3.04 - 2.04	Sand	30.5	15.0	0.0	21.35	10.77	29.79	57.19
5	2.04 - 1.03	Sand	29.5	15.0	0.0	13.65	10.77	19.99	56.52
6	1.03 - 0.00	Clay	0.0	15.0	18.0	5.87	10.77	10.09	45.00
7	embankment	embankment	30.0	—	0.0	22.42	0.00	0.00	60.00

• Angle of active rupture of sandy soil

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

- Angle of active rupture of clayey soil

$$\begin{aligned} \zeta &= 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}} \\ a &= \sin \theta \\ b &= \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q} \end{aligned}$$

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

No	Angle of Rotation ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	1.08	0.00	0.00	1.08	1.08
2	58.37	0.86	1.08	1.08	1.61	1.94
3	57.19	1.00	1.61	1.94	2.25	2.94
4	57.19	1.00	2.25	2.94	2.90	3.94
5	56.52	1.01	2.90	3.94	3.57	4.95
6	45.00	1.03	3.57	4.95	4.60	5.98
7	60.00	1.18	4.60	5.98	5.28	7.16

From the above table, the loading width (L) on the ground surface is 4.60 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	1.68	32.00
Σ			32.00

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

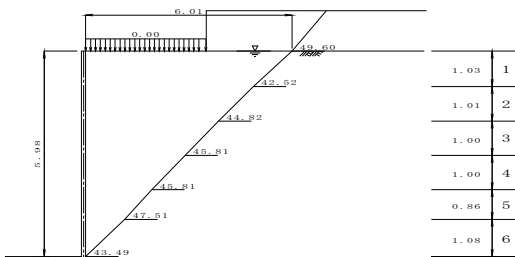
No	Q kN/m ²	l m	Qxl kN/m
1	5.0	3.50	17.50
Σ			17.50

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{32.00 + 17.50 + 0.00}{4.60}$$
$$= 10.77 \text{ kN/m}^2$$

2.2 Seismic 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	γ_{wh} kN/m ²	k (%)	θ degree	Angle of Rupture ζ degree
1	5.98-4.90	Clay	0.0	15.0	100.0	44.53	11.20	58.60	0.200	11.31	43.49
2	4.90-4.04	Sand	32.3	15.0	0.0	35.67	11.20	48.02	0.200	11.31	47.51
3	4.04-3.04	Sand	30.5	15.0	0.0	29.05	11.20	39.59	0.200	11.31	45.81
4	3.04-2.04	Sand	30.5	15.0	0.0	21.35	11.20	29.79	0.200	11.31	44.82
5	2.04-1.03	Sand	29.5	15.0	0.0	13.65	11.20	19.99	0.200	11.31	42.52
6	1.03-0.00	Clay	0.0	15.0	18.0	5.87	11.20	10.09	0.200	11.31	49.60
7		embankment	30.0	—	0.0	22.42	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

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

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.49	1.08	0.00	0.00	1.14	1.08
2	47.51	0.88	1.14	1.08	1.93	1.94
3	45.81	1.00	1.93	1.94	2.90	2.94
4	45.81	1.00	2.90	2.94	3.87	3.94
5	44.82	1.01	3.87	3.94	4.89	4.95
6	42.52	1.03	4.89	4.95	6.01	5.98
7	49.60	1.18	6.01	5.98	7.01	7.16

From the above table, the loading width (L) on the ground surface is 6.01 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	3.54	67.32
Σ			67.32

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/m ²	l m	Qxl kN/m
1	0.0	3.50	0.00
Σ			0.00

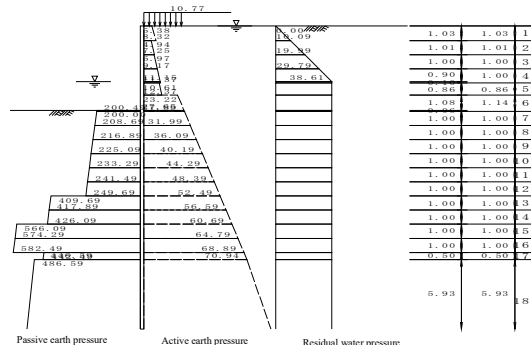
Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{67.32 + 0.00 + 0.00}{6.01}$$
$$= 11.20 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Qa$ kN/m ²	Ka	$Ka \times \cos \delta$
1	0.00-1.03	Clay	5.7	—	18.0 18.0	10.769 16.640	—
2	1.03-2.04	Sand	7.7	29.5	—	16.640 24.417	0.30720 0.30720
3	2.04-3.04	Sand	7.7	30.5	—	24.417 32.117	0.29571 0.29571
4	3.04-3.94	Sand	7.7	30.5	—	32.117 39.047	0.29571 0.29571
5	3.94-4.04	Sand	7.7	30.5	—	39.047 39.817	0.29571 0.29571
6	4.04-4.90	Sand	7.7	32.3	—	39.817 46.439	0.27581 0.27581
7	4.90-5.98	Clay	8.2	—	100.0 100.0	46.439 55.295	—
8	5.98-6.04	Clay	8.2	—	100.0 100.0	55.295 55.787	—
9	6.04-7.04	Clay	8.2	—	100.0 100.0	55.787 63.987	—
10	7.04-8.04	Clay	8.2	—	100.0 100.0	63.987 72.187	—
11	8.04-9.04	Clay	8.2	—	100.0 100.0	72.187 80.387	—
12	9.04-10.04	Clay	8.2	—	100.0 100.0	80.387 88.587	—
13	10.04-11.04	Clay	8.2	—	100.0 100.0	88.587 96.787	—
14	11.04-12.04	Clay	8.2	—	100.0 100.0	96.787 104.987	—
15	12.04-13.04	Clay	8.2	—	180.0 180.0	104.987 113.187	—
16	13.04-14.04	Clay	8.2	—	180.0 180.0	113.187 121.387	—
17	14.04-15.04	Clay	8.2	—	250.0 250.0	121.387 129.587	—
18	15.04-16.04	Clay	8.2	—	250.0 250.0	129.587 137.787	—
19	16.04-16.54	Clay	8.2	—	180.0 180.0	137.787 141.887	—
20	16.54-22.47	Clay	6.7	—	200.0 200.0	141.887 181.618	—
21	22.47-24.54	Clay	7.2	—	1000.0 1000.0	181.618 196.522	—

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

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

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	K _p	$K_p \times \cos \delta$
8	5.98-6.04	Clay	8.2	0.0	100.0 100.0	0.000 0.492	—	—
9	6.04-7.04	Clay	8.2	0.0	100.0 100.0	0.492 8.692	—	—
10	7.04-8.04	Clay	8.2	0.0	100.0 100.0	8.692 16.892	—	—
11	8.04-9.04	Clay	8.2	0.0	100.0 100.0	16.892 25.092	—	—
12	9.04-10.04	Clay	8.2	0.0	100.0 100.0	25.092 33.292	—	—
13	10.04-11.04	Clay	8.2	0.0	100.0 100.0	33.292 41.492	—	—
14	11.04-12.04	Clay	8.2	0.0	100.0 100.0	41.492 49.692	—	—
15	12.04-13.04	Clay	8.2	0.0	180.0 180.0	49.692 57.892	—	—
16	13.04-14.04	Clay	8.2	0.0	180.0 180.0	57.892 66.092	—	—
17	14.04-15.04	Clay	8.2	0.0	250.0 250.0	66.092 74.292	—	—
18	15.04-16.04	Clay	8.2	0.0	250.0 250.0	74.292 82.492	—	—
19	16.04-16.54	Clay	8.2	0.0	180.0 180.0	82.492 86.592	—	—
20	16.54-22.47	Clay	6.7	20.0	200.0 200.0	86.592 126.323	—	—
21	22.47-24.54	Clay	7.2	30.0	1000.0 1000.0	126.323 141.227	—	—

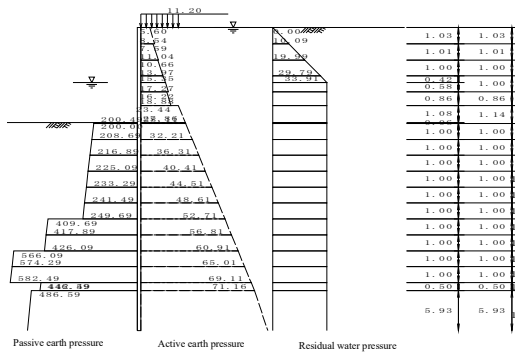
Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

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

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pe kN/m ²	Pp kN/m ²
1	0.00-1.03	-25.23 -19.36	5.38 8.32	5.38 8.32	0.00 10.09	—
2	1.03-2.04	4.94 7.25	—	4.94 7.25	10.09 19.99	—
3	2.04-3.04	6.97 9.17	—	6.97 9.17	19.99 29.79	—
4	3.04-3.94	9.17 11.15	—	9.17 11.15	29.79 38.61	—

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-1.03	Clay	5.7	—	18.0 18.0	11.20 17.07	0.00 10.09	0.200 0.200	11.31 11.31	—	—	43.32 42.52
2	1.03-2.04	Sand	7.7	29.5	—	17.07 24.85	10.09 19.99	0.200 0.200	11.31 11.31	0.45999 0.45999	0.44432 0.44432	—
3	2.04-3.04	Sand	7.7	30.5	—	24.85 32.55	19.99 29.79	0.200 0.200	11.31 11.31	0.44421 0.44421	0.42907 0.42907	—
4	3.04-3.46	Sand	7.7	30.5	—	32.55 35.78	29.79 33.91	0.200 0.200	11.31 11.31	0.44421 0.44421	0.42907 0.42907	—
5	3.46-4.04	Sand	7.7	30.5	—	35.78 40.25	33.91 39.59	0.200 0.200	11.31 11.31	0.44421 0.44421	0.42907 0.42907	—
6	4.04-4.90	Sand	7.7	32.3	—	40.25 46.87	39.59 48.02	0.200 0.200	11.31 11.31	0.41711 0.41711	0.40290 0.40290	—
7	4.90-5.98	Clay	8.2	—	100.0 100.0	46.87 55.73	48.02 58.60	0.200 0.200	11.31 11.31	—	—	43.72 43.49
8	5.98-6.04	Clay	8.2	—	100.0 100.0	55.73 56.22	58.60 59.19	0.200 0.200	11.31 11.31	—	—	43.49 43.47
9	6.04-7.04	Clay	8.2	—	100.0 100.0	56.22 64.42	59.19 68.99	0.200 0.200	11.31 11.31	—	—	43.47 43.27
10	7.04-8.04	Clay	8.2	—	100.0 100.0	64.42 72.62	68.99 78.79	0.200 0.200	11.31 11.31	—	—	43.27 43.06
11	8.04-9.04	Clay	8.2	—	100.0 100.0	72.62 80.82	78.79 88.59	0.200 0.200	11.31 11.31	—	—	43.06 42.86
12	9.04-10.04	Clay	8.2	—	100.0 100.0	80.82 89.02	88.59 98.39	0.200 0.200	11.31 11.31	—	—	42.86 42.66
13	10.04-11.04	Clay	8.2	—	100.0 100.0	89.02 97.22	98.39 108.19	0.200 0.200	11.31 11.31	—	—	42.66 42.46
14	11.04-12.04	Clay	8.2	—	100.0 100.0	97.22 105.42	108.19 117.99	0.200 0.200	11.31 11.31	—	—	42.46 42.26

5	3.94-4.04	—	11.15 11.37	—	11.15 11.37	38.61 38.61	—	—
6	4.04-4.90	—	10.61 12.37	—	10.61 12.37	38.61 38.61	—	—
7	4.90-5.98	—	-153.56 -144.70	23.22 27.65	23.22 27.65	38.61 38.61	—	—
8	5.98-6.04	—	-144.70 -144.21	27.65 27.89	27.65 27.89	38.61 38.61	200.00 200.49	—
9	6.04-7.04	—	-144.21 -136.01	27.89 31.99	27.89 31.99	38.61 38.61	200.49 208.69	—
10	7.04-8.04	—	-136.01 -127.81	31.99 36.09	31.99 36.09	38.61 38.61	208.69 216.89	—
11	8.04-9.04	—	-127.81 -119.61	36.09 40.19	36.09 40.19	38.61 38.61	216.89 225.09	—
12	9.04-10.04	—	-119.61 -111.41	40.19 44.29	40.19 44.29	38.61 38.61	225.09 233.29	—
13	10.04-11.04	—	-111.41 -103.21	44.29 48.39	44.29 48.39	38.61 38.61	233.29 241.49	—
14	11.04-12.04	—	-103.21 -95.01	48.39 52.49	48.39 52.49	38.61 38.61	241.49 249.69	—
15	12.04-13.04	—	-255.01 -246.81	52.49 56.59	52.49 56.59	38.61 38.61	409.69 417.89	—
16	13.04-14.04	—	-246.81 -238.61	56.59 60.69	56.59 60.69	38.61 38.61	417.89 426.09	—
17	14.04-15.04	—	-238.61 -370.41	60.69 64.79	60.69 64.79	38.61 38.61	426.09 574.29	—
18	15.04-16.04	—	-370.41 -302.21	64.79 68.89	64.79 68.89	38.61 38.61	574.29 582.49	—
19	16.04-16.54	—	-222.21 -218.11	68.89 70.94	68.89 70.94	38.61 38.61	442.49 446.59	—
20	16.54-22.47	—	-258.11 -218.38	70.94 90.81	70.94 90.81	38.61 38.61	446.59 526.32	—
21	22.47-24.54	—	-1818.38 -1803.48	90.81 98.26	90.81 98.26	38.61 38.61	526.32 2141.23	—

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

15	12.04-13.04	Clay	8.2	—	180.0 180.0	105.42 113.62	117.99 127.79	0.200 0.200	11.31 11.31	—	—	43.41 43.30
16	13.04-14.04	Clay	8.2	—	180.0 180.0	113.62 121.82	127.79 137.59	0.200 0.200	11.31 11.31	—	—	43.30 43.18
17	14.04-15.04	Clay	8.2	—	250.0 250.0	121.82 130.02	137.59 147.39	0.200 0.200	11.31 11.31	—	—	43.07 43.58
18	15.04-16.04	Clay	8.2	—	250.0 250.0	130.02 138.22	147.39 157.19	0.200 0.200	11.31 11.31	—	—	43.58 43.50
19	16.04-16.54	Clay	8.2	—	180.0 180.0	138.22 142.32	157.19 162.09	0.200 0.200	11.31 11.31	—	—	42.96 42.90
20	16.54-22.47	Clay	6.7	—	200.0 200.0	142.32 182.05	162.09 220.21	0.200 0.200	11.31 11.31	—	—	43.10 42.61
21	22.47-24.54	Clay	7.2	—	1000.0 1000.0	182.05 196.95	220.21 246.49	0.200 0.200	11.31 11.31	—	—	44.49 44.45

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$\delta = -15.00^\circ$ degrees, $\beta = 0.00^\circ$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

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

• Angle (ζ) between the collapse surface and the horizontal in cohesive soil

$$\zeta = 45^\circ - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K _p	$K_p \times \cos \delta$
8	5.98-6.04	Clay	8.20	0.0	100.0 100.0	0.000 0.492	0.00 0.59	0.200 0.200	11.31 11.31	—	—
9	6.04-7.04	Clay	8.20	0.0	100.0 100.0	0.492 8.692	0.59 10.39	0.200 0.200	11.31 11.31	—	—
10	7.04-8.04	Clay	8.20	0.0	100.0 100.0	8.692 16.892	10.39 20.19	0.200 0.200	11.31 11.31	—	—
11	8.04-9.04	Clay	8.20	0.0	100.0 100.0	16.892 25.092	20.19 29.99	0.200 0.200	11.31 11.31	—	—
12	9.04-10.04	Clay	8.20	0.0	100.0 100.0	25.092 33.292	29.99 39.79	0.200 0.200	11.31 11.31	—	—
13	10.04-11.04	Clay	8.20	0.0	100.0 100.0	33.292 41.492	39.79 49.59	0.200 0.200	11.31 11.31	—	—
14	11.04-12.04	Clay	8.20	0.0	100.0 100.0	41.492 49.692	49.59 59.39	0.200 0.200	11.31 11.31	—	—
15	12.04-13.04	Clay	8.20	0.0	180.0 180.0	49.692 57.892	59.39 69.19	0.200 0.200	11.31 11.31	—	—
16	13.04-14.04	Clay	8.20	0.0	180.0 180.0	57.892 66.092	69.19 78.99	0.200 0.200	11.31 11.31	—	—

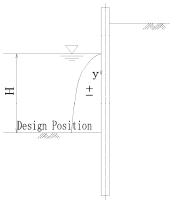
17	14.04- 15.04	Clay	8.20	0.0	250.0 250.0	66.092 74.292	78.99 88.79	0.200 0.200	11.31 11.31	=====	=====
18	15.04- 16.04	Clay	8.20	0.0	250.0 250.0	74.292 82.492	88.79 98.59	0.200 0.200	11.31 11.31	=====	=====
19	16.04- 16.54	Clay	8.20	0.0	180.0 180.0	82.492 86.392	98.59 103.49	0.200 0.200	11.31 11.31	=====	=====
20	16.54- 22.47	Clay	6.70	20.0	200.0 200.0	86.392 126.323	103.49 161.60	0.200 0.200	11.31 11.31	=====	=====
21	22.47- 24.54	Clay	7.20	30.0	1000.0 1000.0	126.323 141.227	161.60 181.89	0.200 0.200	11.31 11.31	=====	=====

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

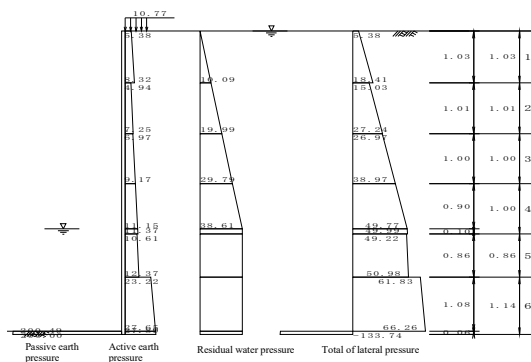
No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	
1	0.00- 1.03	-22.49 -15.34	5.60 8.54	5.60 8.54	0.00 10.09	=====
2	1.03- 2.04	7.59 11.04	=====	7.59 11.04	10.09 19.99	=====
3	2.04- 3.04	10.66 13.97	=====	10.66 13.97	19.99 29.79	=====
4	3.04- 3.46	13.97 15.35	=====	13.97 15.35	29.79 33.91	=====
5	3.46- 4.04	15.35 17.27	=====	15.35 17.27	33.91 =====	=====
6	4.04- 4.90	16.22 18.88	=====	16.22 18.88	33.91 33.91	=====
7	4.90- 5.98	-143.53 -132.80	23.44 27.86	23.44 27.86	33.91 33.91	=====
8	5.98- 6.04	-132.80 -132.21	27.86 28.11	27.86 28.11	33.91 33.91	200.00 200.49
9	6.04- 7.04	-132.21 -122.26	28.11 32.21	28.11 32.21	33.91 33.91	200.49 208.69
10	7.04- 8.04	-122.26 -112.30	32.21 36.31	32.21 36.31	33.91 33.91	208.69 216.89
11	8.04- 9.04	-112.30 -102.32	36.31 40.41	36.31 40.41	33.91 33.91	216.89 225.09
12	9.04- 10.04	-102.32 -92.33	40.41 44.51	40.41 44.51	33.91 33.91	225.09 233.29
13	10.04- 11.04	-92.33 -82.32	44.51 48.61	44.51 48.61	33.91 33.91	233.29 241.49
14	11.04- 12.04	-82.32 -72.30	48.61 52.71	48.61 52.71	33.91 33.91	241.49 249.69
15	12.04- 13.04	-232.85 -222.90	52.71 56.81	52.71 56.81	33.91 33.91	409.69 417.89



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



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 1.03	5.38 8.32	0.00 10.09	=====	5.38 18.41
2	1.03- 2.04	4.94 7.25	10.09 19.99	=====	15.03 27.24
3	2.04- 3.04	6.97 9.17	19.99 29.79	=====	26.97 38.97
4	3.04- 3.94	9.17 11.15	29.79 38.61	=====	38.97 49.77
5	3.94- 4.04	11.15 11.37	38.61 38.61	=====	49.77 49.99

16	13.04- 14.04	-222.90 -212.95	56.81 60.91	56.81 60.91	33.91 33.91	417.89 426.09
17	14.04- 15.04	-353.20 -343.27	60.91 65.01	60.91 65.01	33.91 33.91	566.09 574.29
18	15.04- 16.04	-343.27 -333.34	65.01 69.11	65.01 69.11	33.91 33.91	574.29 582.49
19	16.04- 16.54	-193.01 -188.02	69.11 71.16	69.11 71.16	33.91 33.91	442.49 446.59
20	16.54- 22.47	-228.15 -179.76	71.16 91.02	71.16 91.02	33.91 33.91	486.59 526.32
21	22.47- 24.54	-1791.20 -1763.26	91.02 98.48	91.02 98.48	33.91 33.91	2126.32 2141.23

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5

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

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

- Formula for passive earth pressure

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

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m2
1	3.46	0.00	0.00
2	4.46	1.00	2.72
3	5.46	2.00	3.85
4	5.98	2.52	4.32

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

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

6	4.04- 4.90	10.61 12.37	38.61 38.61	=====	49.22 50.98
7	4.90- 5.98	23.22 27.65	38.61 38.61	=====	61.83 66.26
8	5.98- 6.04	27.65 27.89	38.61 38.61	200.00 200.49	-133.74 -133.99

P_a : Active earth pressure

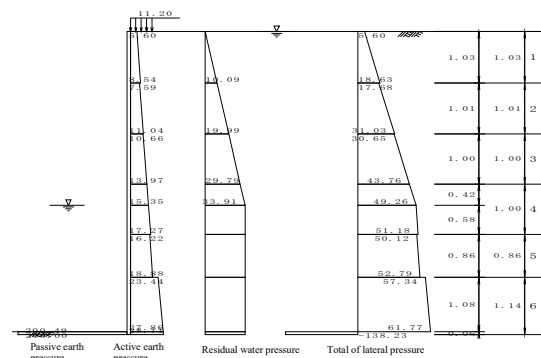
P_w : Residual water pressure

P_p : Passive earth pressure

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

Imaginary riverbed Lk: 0.00 m (GL -5.98 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 1.03	5.60 8.54	0.00 10.09	=====	5.60 18.63
2	1.03- 2.04	7.59 11.04	10.09 19.99	=====	17.68 31.03
3	2.04- 3.04	10.66 13.97	19.99 29.79	=====	30.65 43.76
4	3.04- 3.46	13.97 15.35	29.79 33.91	=====	43.76 49.26
5	3.46- 4.04	15.35 17.27	33.91 33.91	=====	49.26 51.18
6	4.04- 4.90	16.22 18.88	33.91 33.91	=====	50.12 52.79
7	4.90- 5.98	23.44 27.86	33.91 33.91	=====	57.34 61.77

8	5.98- 6.04	27.86 28.11	33.91 33.91	200.00 200.49	-138.23 -138.47

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

Imaginary riverbed L_k: 0.00 m (GL -5.98 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of 1/ β from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{50} = K_{50} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H=10.00m)$$

$$K_{50} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

Material Name 10 H_H 900 -250 -14 -25 -18
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 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 I₀ = 631400 cm⁴(original condition)
Inertia sectional moment I = 549318 cm⁴(after reduction by corrosion and section)
EI = 200000 × 10³ × 549318 × 10⁻⁸ = 1.099 × 10⁶

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	0.54	3	11	10.54	12	21	20.54	32
2	1.54	14	12	11.54	11	22	21.54	41
3	2.54	16	13	12.54	18	23	22.54	49
4	3.54	16	14	13.54	24	24	23.54	20
5	4.54	20	15	14.54	41	25	24.54	50
6	5.54	12	16	15.54	34			
7	6.54	11	17	16.54	18			
8	7.54	11	18	17.54	22			
9	8.54	9	19	18.54	23			
10	9.54	10	20	19.54	22			

5.2 Normal Condition

Assuming Kh = 7129 kN/m3,

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.98	0.56	11.6	11.0	6.32
2	6.54	1.00	11.0	11.0	11.00
3	7.54	1.00	11.0	9.0	10.00
4	8.54	1.00	9.0	10.0	9.50
5	9.54	0.65	10.0	11.3	6.93
L = Σh=4.21 ΣA= 43.75					

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

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

$$= \frac{43.75}{4.21}$$

$$= 10.39$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 10.39 = 29091 \text{ kN/m}^2$$

$$K_{50} = \frac{1}{0.3} \times \alpha \times 29091 = 193938 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{50} (B_H/0.3)^{-3/4} = 193938 (10.00/0.3)^{-3/4} = 13980 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 13980 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _l kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.03	1.03	5.38 18.41	2.77 9.48	5.64 5.29	15.63 50.20
2	1.03- 2.04	1.01	15.03 27.24	7.59 13.75	4.61 4.28	35.02 58.83
3	2.04- 3.04	1.00	26.97 38.97	13.48 19.48	3.61 3.27	48.63 63.77
4	3.04- 3.94	0.90	38.97 49.77	17.53 22.39	2.64 2.34	46.29 52.40
5	3.94- 4.04	0.10	49.77 49.99	2.49 2.50	2.01 1.97	4.99 4.93
6	4.04- 4.90	0.86	49.22 50.98	21.16 21.92	1.65 1.37	34.99 29.96
7	4.90- 5.98	1.08	61.83 66.26	33.39 35.78	0.72 0.36	24.04 12.88
ΣP = 223.74 ΣM = 482.57						

$$\beta = 4 \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.201 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.98 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.98 m) to 4.98 m depth (GL -10.96 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.98	0.56	11.6	11.0	6.32
2	6.54	1.00	11.0	11.0	11.00
3	7.54	1.00	11.0	9.0	10.00
4	8.54	1.00	9.0	10.0	9.50
5	9.54	1.00	10.0	12.0	11.00
6	10.54	0.42	12.0	11.6	4.98
L = 2.6~4.98 ΣA= 52.80					

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

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

$$= \frac{52.80}{4.98}$$

$$= 10.60$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 10.60 = 29670 \text{ kN/m}^2$$

$$K_{50} = \frac{1}{0.3} \times \alpha \times 29670 = 98901 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_b = K_{50} (B_H/0.3)^{-3/4} = 98901 (10.00/0.3)^{-3/4} = 7129 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 7129 kN/m3.

5.3 Seismic Condition

Assuming Kh = 13980 kN/m3,

$$\beta = 4 \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.237 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.21 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.98 m) and 4.21 m depth (GL -10.19 m).

P_a : active earth pressure + residual water pressure - passive earth pressure
P : load P_a 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_l = 0.0 kN/m
depth to acting position H_l = 0.0 m
moment M_{l0} = 0.00 kN·m/m
depth to acting position H_{l0} = 0.00 m
Height from riverbed to top of coping H = 5.98 m
Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_l by arbitrary load is as below

M_l = P_l·(H + L_k - H_l) + M_{l0} = 0.00 kN·m
h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_l}{\Sigma P + P_l}$$

$$= \frac{482.57}{223.74} = 2.16 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 223.74}{5.98} = 74.83 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _l kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.03	1.03	5.60 18.63	2.88 9.59	5.64 5.29	16.26 50.79
2	1.03- 2.04	1.01	17.68 31.03	8.93 15.67	4.61 4.28	41.19 67.02
3	2.04- 3.04	1.00	30.65 43.76	15.33 21.88	3.61 3.27	58.28 71.62
4	3.04- 3.46	0.42	43.76 49.26	9.19 10.34	2.80 2.66	25.73 27.52
5	3.46- 4.04	0.58	49.26 51.18	14.29 14.84	2.33 2.13	33.24 31.66
6	4.04- 4.90	0.86	50.12 52.79	21.55 22.70	1.65 1.37	35.63 31.02
7	4.90- 5.98	1.08	57.34 61.77	30.97 33.36	0.72 0.36	22.30 12.01
ΣP = 231.52 ΣM = 521.26						

P_l : active earth pressure + residual water pressure - passive earth pressure
P : load P_a 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_l = 0.0 kN/m
depth to acting position H_l = 0.00 m
moment M_{l0} = 0.0 kN·m/m
depth to acting position H_{l0} = 0.00 m

Height from riverbed to top of coping H = 5.98 m
 Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_i by arbitrary load is as below
 M_i = P_i · (H + L_k - H₀) + M_m = 0.00 kN·m

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	3.46- 4.46	1.00	0.0 2.7	0.00 1.36	2.19 1.85	0.00 2.52
2	4.46- 5.46	1.00	2.7 3.9	1.36 1.93	1.19 0.85	1.62 1.64
3	5.46- 5.98	0.52	3.9 4.3	1.00 1.12	0.35 0.17	0.35 0.19
Σ P ₀ =				6.77	Σ M ₀ =	6.32

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0i}}{\Sigma P + P_i + \Sigma P_{0i}} = \frac{527.58}{238.29} = 2.21 \text{ m}$$

When the resultant force of the Lateral Earth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 238.29}{5.98} = 79.70 \text{ kN/m}$$

6.2 Sectional Force

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

Material name	10 H _ H 900 -250 -14 -25 -18
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 = 631400 cm ⁴ (original condition) I = 549318 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 549318 × 10 ⁻⁸	= 1.099 × 10 ⁶

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{721.42 \times 10^6}{8906 \times 10^3} = 81 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

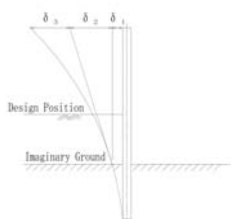
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{727.52 \times 10^6}{8906 \times 10^3} = 82 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2007 \times 2.16) \times 223.74}{2 \times 2.00 \times 10^8 \times 549318 \times 10^{-8} \times 0.2007^3} = 0.01805 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.2007 \times 2.16) \times 223.74}{2 \times 2.00 \times 10^8 \times 549318 \times 10^{-8} \times 0.2007^3} \times (5.98 + 0.00) = 0.02821 \text{ m} \end{aligned}$$

$$\beta = \sqrt{\frac{K_b \cdot B}{4 E I}}$$

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

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

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

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

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

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 7129 kN/m ³
calculated value	β = 0.20069 m ⁻¹
resultant earth force (lateral)	P ₀ = 223.74 kN/m
height of acting position of load	h ₀ = 2.16 m
moment	M ₀ = 482.57 kN·m/m

in consideration of ν ₀ = 1.495,	
maximum moment	M _{max} = 721.42 kN·m/m
depth of generated position of M _{max}	l _m = 2.452 m
depth of 1 st fixed point	l _i = 6.365 m

6.2.2 Seismic Condition

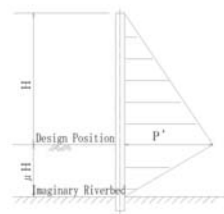
modulus of lateral subgrade reaction	K _b = 13980 kN/m ³
calculated value	β = 0.23749 m ⁻¹
resultant earth force (lateral)	P ₀ = 238.29 kN/m
height of acting position of load	h ₀ = 2.21 m
moment	M ₀ = 527.58 kN·m/m

in consideration of ν ₀ = 1.379	
maximum moment	M _{max} = 727.52 kN·m/m
depth of generated position of M _{max}	l _m = 1.910 m
depth of 1 st fixed point	l _i = 5.217 m

6.3 Stress Intensity

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

Material Name	10 H _ H 900 -250 -14 -25 -18
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 = 10120 cm ³ (original condition) Z = 8906 cm ³ (after reduction by corrosion and section)



$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{0.00}{5.98} = 0.000 \\ \delta_3 &= \frac{P' \cdot H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{74.83 \times 5.98^4}{120 \times 2.00 \times 10^8 \times 549318 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4) \\ &= 0.00290 \text{ m} \end{aligned}$$

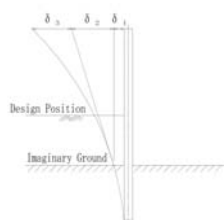
$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01805 + 0.02821 + 0.00290 \\ &= 0.04916 \text{ m} \\ \text{Size} &= 49.16 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

Where,

- δ₁ : Displacement at imaginary ground
- δ₂ : Displacement by angle of inclination slope at imaginary ground
- δ₃ : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

6.4.2 Seismic Condition

Displacement Calculation

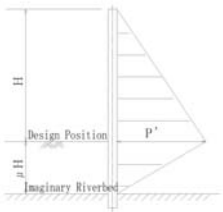


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.2375 \times 2.21) \times 238.29}{2 \times 2.00 \times 10^9 \times 549318 \times 10^{-8} \times 0.2375^3} = 0.01235 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u)$$

$$= \frac{(1 + 2 \times 0.2375 \times 2.21) \times 238.29}{2 \times 2.00 \times 10^9 \times 549318 \times 10^{-8} \times 0.2375^2} \times (5.98 + 0.00) = 0.02359 \text{ m}$$



$$\mu = \frac{L_u}{H} = \frac{0.00}{5.98} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4)$$

$$= \frac{79.70 \times 5.98^4}{120 \times 2.00 \times 10^9 \times 549318 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4)$$

$$= 0.00309 \text{ m}$$

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

$$= 0.01235 + 0.02359 + 0.00309$$

$$= 0.03904 \text{ m}$$

$$\text{Size} = 39.04 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

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

Material Name	10 H _ H 900 -250 -14 -25 -18
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 = 631400 cm ⁴ (original condition)
EI = 200000 × 10 ³ × 631400 × 10 ⁻⁸	I = 631400 cm ⁴ (after reduction by corrosion and section)
	= 1.263 × 10 ⁸

7.1 Penetration Depth and Whole Length of SSP (Chang)

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

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

$$L = H - H_{it} + D$$

$$\beta = \sqrt[4]{\frac{K_u \times B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_u = 7129 kN/m ³
Calculated value	β = 0.19383 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.194}$ = 15.48 m
Whole length of SSP	L = 5.98 - 0.40 + 15.48 = 21.06 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_u = 13980 kN/m ³
Calculated value	β = 0.22936 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.229}$ = 13.08 m
Whole length of SSP	L = 5.98 - 0.40 + 13.08 = 18.66 m

Therefore, the total length of the sheet pile is 21.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP	10 H _ H 900 -250 -14 -25 -18			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm4)		631400		
Sectional Modulus	Z (cm3)		10120		
Maximum bending moment	Mmax (kN × m × m)			721.42	727.52
Stress intensity	σ (N/mm2)			81 (180)	82 (270)
Lateral displacement	δ (mm)			49.16 (50.0)	39.04 (75.0)
Penetration depth	D (m)			15.48	13.08
Whole length of SSP	L (m)	21.50			

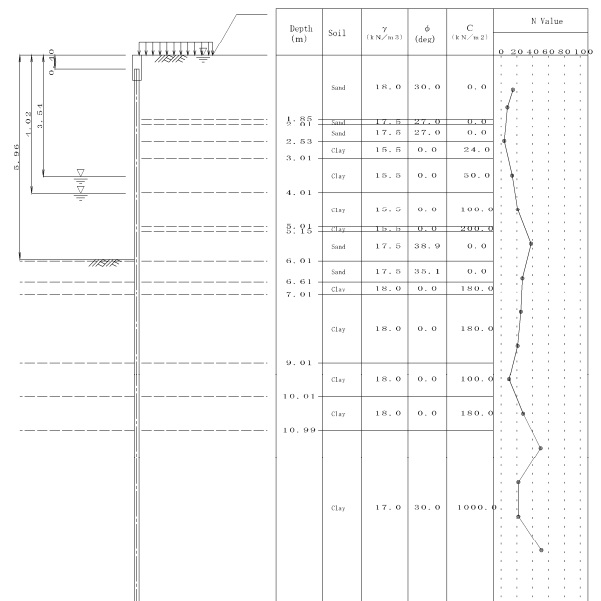
Block No. : R-22
Sta. : 10+380~10+520

Design Cross Section : Sta 10+440
Boring Name : BMRL-30

Specification : SSP SP-10H
(Combined) : H 950-250-16-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 5.96 m
Depth from coping top to rear side ground	H ₀ = 0.00 m
Depth from coping top to SSP top	H _b = 0.40 m
Landside WL	L _{wa} = 0.00 m (Normal Condition)
	L _{wa} = 0.00 m (Seismic Condition)
Riverside WL	L _{wp} = 4.02 m (Normal Condition)
	L _{wp} = 3.54 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$
Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered
Wind load, Impact load	not considered
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope	not considered

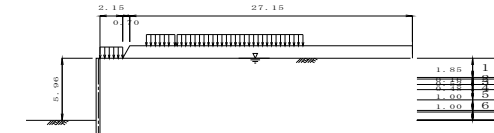
Angle of rupture (clayey soil)	$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$ $a = \sin \theta$ $b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4}$ $K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$ $B_H = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
Average N-value	calculated from average N-value between imaginary riverbed and depth as 1/β

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle φ degree	stickiness C kN/m2	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m3	Seismic Condition kN/m3			Normal Condition degree	Seismic Condition degree
1	Sand	2.15	2.85	30.00	30.00	1.20	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	0.00	2.15	5.0	0.0
2	4.44	7.19	5.0	0.0
3	7.38	19.48	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	1.00	15	11	10.51	28
2	1.51	8	12	11.51	50
3	2.51	4	13	12.51	22
4	3.51	14	14	13.51	22
5	4.51	21	15	14.51	51
6	5.51	38	16	15.51	50
7	6.51	27			
8	7.51	25			
9	8.51	21			
10	9.51	10			

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	earth Soil	N Value	Depth m (including Projection Length)		Thickness m (excluding projected length)		γ kN/m3	γ' kN/m3	φ degree	C kN/m2	a	k'	ζ (degree)	
														Normal Condition	Seismic Condition
1	1.85	S	15.0	18.00	8.20	30.0	0.0	0.0	0.200	Auto	Auto			Auto	Auto
2	2.01	S	8.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto			Auto	Auto
3	2.53	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto			Auto	Auto
4	3.01	C	4.0	15.50	5.70	0.0	24.0	0.0	0.200	Auto	Auto			Auto	Auto
5	4.01	C	14.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto			Auto	Auto
6	5.01	C	21.0	15.50	5.70	0.0	100.0	0.0	0.200	Auto	Auto			Auto	Auto
7	5.15	C	38.0	15.50	5.70	0.0	200.0	0.0	0.200	Auto	Auto			Auto	Auto
8	6.01	S	38.0	17.50	7.70	38.9	0.0	0.0	0.200	Auto	Auto			Auto	Auto
9	6.61	S	27.0	17.50	7.70	35.1	0.0	0.0	0.200	Auto	Auto			Auto	Auto
10	7.01	C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto			Auto	Auto
11	9.01	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto			Auto	Auto
12	10.01	C	10.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto			Auto	Auto
13	10.99	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto			Auto	Auto
14	15.51	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto			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_a : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
ζ : angle of active rupture
kh : modulus of subgrade reaction

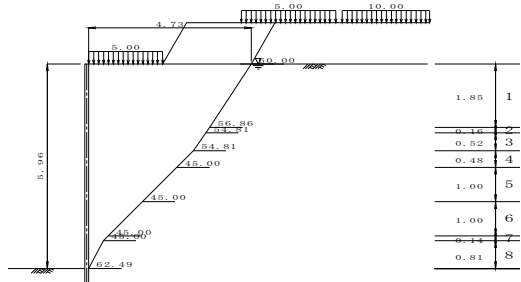
1.9 Steel Sheet Pile (SSP)

Material name	10 H H 950 -250 -16 -22 -18
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 688700 cm ⁴
Sectional factor	Z ₀ = 10570 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 = 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

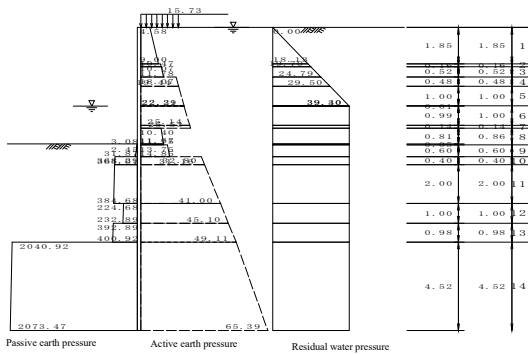


2.1.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ when kN/m2	Angle of Rupture ζ degree
1	5.96~5.15	Sand	38.9	15.0	0.0	41.58	15.73	58.41	62.49

3 Lateral Forth

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	$\Sigma \gamma h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00~ 1.85	Sand	8.2	30.0	—	15.729 30.899	0.30142 0.30142	0.29115 0.29115
2	1.85~ 2.01	Sand	7.7	27.0	—	30.899 32.131	0.33738 0.33738	0.32589 0.32589
3	2.01~ 2.53	Sand	7.7	27.0	—	32.131 36.135	0.33738 0.33738	0.32589 0.32589
4	2.53~ 3.01	Clay	5.7	—	24.0	36.135 24.0	— —	— —
5	3.01~ 4.01	Clay	5.7	—	50.0	38.871 50.0	— —	— —
6	4.01~ 4.02	Clay	5.7	—	100.0	44.571 100.0	— —	— —
7	4.02~ 5.01	Clay	5.7	—	100.0	44.628 50.271	— —	— —
8	5.01~ 5.15	Clay	5.7	—	200.0	50.271 51.069	— —	— —
9	5.15~ 5.96	Sand	7.7	38.9	—	51.069 57.306	0.21078 0.21078	0.20360 0.20360
10	5.96~ 6.01	Sand	7.7	38.9	—	57.306 57.691	0.21078 0.21078	0.20360 0.20360
11	6.01~ 6.61	Sand	7.7	35.1	—	57.691 62.311	0.24677 0.24677	0.23836 0.23836
12	6.61~ 7.01	Clay	8.2	—	180.0	62.311 180.0	— —	— —

13	7.01~ 9.01	Clay	8.2	—	180.0	65.591 81.991	— —	— —
14	9.01~ 10.01	Clay	8.2	—	100.0	81.991 90.191	— —	— —
15	10.01~ 10.99	Clay	8.2	—	180.0	90.191 98.227	— —	— —
16	10.99~ 15.51	Clay	7.2	—	1000.0	98.227 130.771	— —	— —

• The principal earth pressure coefficient (K_a) of Sand is calculated by the following equation.

$\delta = 15.00$ degrees, $\beta = 0.00$ degrees, $\theta = 0.00$ degrees

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

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	K_p	$K_p \times \cos \delta$
10	5.96~ 6.01	Sand	7.7	38.9	—	0.000 0.385	8.27722 8.27722	7.99518 7.99518
11	6.01~ 6.61	Sand	7.7	35.1	—	0.385 5.005	6.59258 6.59258	6.36794 6.36794
12	6.61~ 7.01	Clay	8.2	0.0	180.0	5.005 8.285	— —	— —
13	7.01~ 9.01	Clay	8.2	0.0	180.0	8.285 24.685	— —	— —
14	9.01~ 10.01	Clay	8.2	0.0	100.0	24.685 32.885	— —	— —
15	10.01~ 10.99	Clay	8.2	0.0	180.0	32.885 40.921	— —	— —
16	10.99~ 15.51	Clay	7.2	30.0	1000.0	40.921 73.465	— —	— —

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

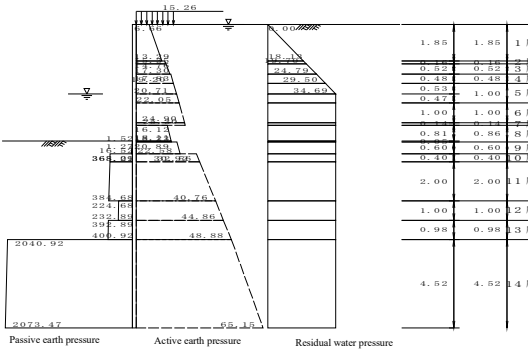
$\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		P_{a1} kN/m ²	P_{a2} kN/m ²	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²
1	0.00~ 1.85	4.58 9.00	— —	4.58 9.00	0.00 18.13	— —
2	1.85~ 2.01	— —	— —	— —	10.07 19.70	— —

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{shw} kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00~ 1.85	Sand	8.2	30.0	—	15.26 30.43	0.00 18.13	0.200 0.200	11.31	0.45203	0.43663	—
2	1.85~ 2.01	Sand	7.7	27.0	—	30.43 31.66	18.13 19.70	0.200 0.200	11.31	0.50201	0.48490	—
3	2.01~ 2.53	Sand	7.7	27.0	—	31.66 35.67	19.70 24.79	0.200 0.200	11.31	0.50201	0.48490	—
4	2.53~ 3.01	Clay	5.7	—	24.0	35.67 24.0	24.79 29.50	0.200 0.200	11.31	— —	— —	41.28 41.04
5	3.01~ 3.54	Clay	5.7	—	50.0	38.40 50.0	29.50 34.69	0.200 0.200	11.31	— —	— —	42.95 42.81
6	3.54~ 4.01	Clay	5.7	—	50.0	41.42 50.0	34.69 39.30	0.200 0.200	11.31	— —	— —	42.81 42.68
7	4.01~ 5.01	Clay	5.7	—	100.0	44.10 49.80	39.30 49.10	0.200 0.200	11.31	— —	— —	43.79 43.64
8	5.01~ 5.15	Clay	5.7	—	200.0	49.80 50.60	49.10 50.47	0.200 0.200	11.31	— —	— —	44.30 44.29
9	5.15~ 5.96	Sand	7.7	38.9	—	50.60 56.84	50.47 58.41	0.200 0.200	11.31	0.32979	0.31855	—
10	5.96~ 6.01	Sand	7.7	38.9	—	56.84 57.22	58.41 58.90	0.200 0.200	11.31	0.32979	0.31855	—
11	6.01~ 6.61	Sand	7.7	35.1	—	57.22 61.84	58.90 64.78	0.200 0.200	11.31	0.37794	0.36506	—
12	6.61~ 7.01	Clay	8.2	—	180.0	61.84 65.12	64.78 68.70	0.200 0.200	11.31	— —	— —	44.05 44.00
13	7.01~ 9.01	Clay	8.2	—	180.0	65.12 81.52	68.70 88.30	0.200 0.200	11.31	— —	— —	44.00 43.76

- Formula for active earth pressure

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

Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of P_{a1} or P_{a2} is applied as active earth pressure (P_a)

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

- Formula for passive earth pressure

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

Clay $P_p = \Sigma \gamma h + Q + 2C$

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

14	9.01- 10.01	Clay	8.2	—	100.0 100.0	81.52 89.72	88.30 98.10	0.200 0.200	11.31 11.31	—	—	42.84 42.64
15	10.01- 10.99	Clay	8.2	—	180.0 180.0	89.72 97.76	98.10 107.70	0.200 0.200	11.31 11.31	—	—	43.64 43.52
16	10.99- 15.51	Clay	7.2	—	1000.0 1000.0	97.76 130.30	107.70 152.00	0.200 0.200	11.31 11.31	—	—	44.72 44.63

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

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

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

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{sub} kN/m ²	k (ϕ°)	θ degree	Kp	Kp $\times \cos \delta$
10	5.96- 6.01	Sand	7.70	38.9	—	0.000 0.385	0.00 0.40	0.200 0.200	11.31 11.31	3.93917 3.93917	3.93917 3.93917
11	6.01- 6.61	Sand	7.70	35.1	—	0.385 5.005	0.49 6.37	0.200 0.200	11.31 11.31	3.30051 3.30051	3.30051 3.30051
12	6.61- 7.01	Clay	8.20	0.0	180.0 180.0	5.005 8.285	6.37 10.29	0.200 0.200	11.31 11.31	—	—
13	7.01- 9.01	Clay	8.20	0.0	180.0 180.0	8.285 24.685	10.29 29.89	0.200 0.200	11.31 11.31	—	—
14	9.01- 10.01	Clay	8.20	0.0	100.0 100.0	24.685 32.885	29.89 39.69	0.200 0.200	11.31 11.31	—	—
15	10.01- 10.99	Clay	8.20	0.0	180.0 180.0	32.885 40.921	39.69 49.29	0.200 0.200	11.31 11.31	—	—
16	10.99- 15.51	Clay	7.20	30.0	1000.0 1000.0	40.921 73.465	49.29 93.59	0.200 0.200	11.31 11.31	—	—

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

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

3.2.3 Lateral Forth

No	Depth m	Active		Residual water pressure	Passive	
		Pa1 kN/m ²	Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²	
1	0.00- 1.85	6.66 13.29	—	6.66 13.29	0.00 18.13	—
2	1.85- 2.01	14.76 15.35	—	14.76 15.35	18.13 19.70	—
3	2.01- 2.53	15.35 17.30	—	15.35 17.30	19.70 24.79	—
4	2.53- 3.01	-4.62 -1.24	17.83 19.20	17.83 19.20	24.79 29.50	—
5	3.01- 3.54	-53.60 -49.92	19.20 20.71	19.20 20.71	29.50 34.69	—
6	3.54- 4.01	-49.92 -46.66	20.71 22.05	20.71 22.05	34.69 34.69	—
7	4.01- 5.01	-146.87 -139.98	22.05 24.90	22.05 24.90	34.69 34.69	—
8	5.01- 5.15	-340.11 -339.15	24.90 25.30	24.90 25.30	34.69 34.69	—
9	5.15- 5.96	16.12 18.11	—	16.12 18.11	34.69 34.69	—
10	5.96- 6.01	18.11 18.23	—	18.11 18.23	34.69 34.69	0.00 1.52
11	6.01- 6.61	20.89 22.58	—	20.89 22.58	34.69 34.69	1.27 16.52
12	6.61- 7.01	-285.57 -281.61	30.92 32.56	30.92 32.56	34.69 34.69	365.01 368.29
13	7.01- 9.01	-281.61 -261.79	32.56 40.76	32.56 40.76	34.69 34.69	368.29 384.68
14	9.01- 10.01	-101.46 -91.47	40.76 44.86	40.76 44.86	34.69 34.69	224.68 232.89
15	10.01- 10.99	-251.87 -242.13	44.86 48.88	44.86 48.88	34.69 34.69	392.89 400.92
16	10.99- 15.51	-1882.29 -1843.46	48.88 65.15	48.88 65.15	34.69 34.69	2040.92 2073.47

- Formula for active earth pressure

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

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

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

K_a : Equilibrium coefficient of compression: 0.5
 Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

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

- Formula for passive earth pressure

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

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	3.54	0.00	0.00
2	4.54	1.00	2.67
3	5.54	2.00	3.77
4	5.96	2.42	4.15

$$p_{dw} = \pm \frac{7}{8} k_{dw} \cdot \gamma_w \cdot \sqrt{H} \cdot y$$

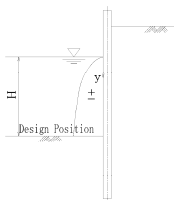
Where,

k_{dw} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

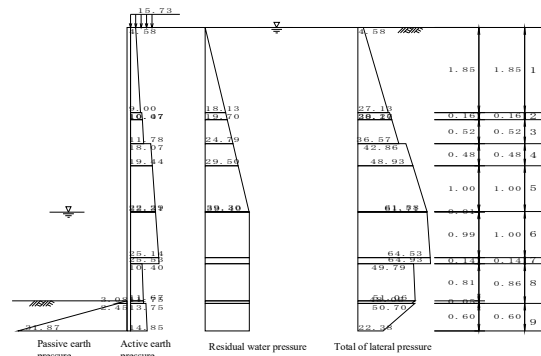
y : depth from water surface to the point where active water pressure is calculated



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



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 1.85	4.58 9.00	0.00 18.13	— —	4.58 27.13
2	1.85- 2.01	10.07 10.47	18.13 19.70	— —	28.20 30.17
3	2.01- 2.53	10.47 11.78	19.70 24.79	— —	30.17 36.57
4	2.53- 3.01	18.07 19.44	24.79 29.50	— —	42.86 48.93
5	3.01- 4.01	19.44 22.29	29.50 39.30	— —	48.93 61.58
6	4.01- 4.02	22.29 22.31	39.30 39.40	— —	61.58 61.71
7	4.02- 5.01	22.31 25.14	39.40 39.40	— —	61.71 64.53
8	5.01- 5.15	25.14 25.53	39.40 39.40	— —	64.53 64.93
9	5.15- 5.96	10.40 11.67	39.40 39.40	— —	49.79 51.06
10	5.96- 6.01	11.67 11.75	39.40 39.40	0.00 3.08	51.06 48.06
11	6.01- 6.61	13.75 14.85	39.40 39.40	2.45 31.87	50.70 22.38
12	6.61- 7.01	31.16 32.80	39.40 39.40	365.01 368.29	-294.45 -296.09

P_a : Active earth pressure

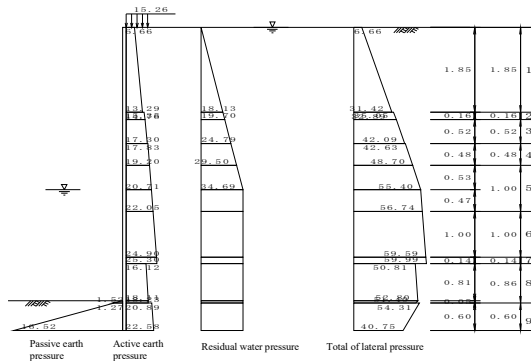
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_A: 0.65 m (GL -6.61 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00~ 1.85	6.66 13.29	0.00 18.13	— —	6.66 31.42
2	1.85~ 2.01	14.76 15.35	18.13 19.70	— —	32.89 35.05
3	2.01~ 2.53	15.35 17.30	19.70 24.79	— —	35.05 42.09
4	2.53~ 3.01	17.83 19.20	24.79 29.50	— —	42.63 48.70
5	3.01~ 3.54	19.20 20.71	29.50 34.69	— —	48.70 55.40
6	3.54~ 4.01	20.71 22.05	34.69 34.69	— —	55.40 56.74
7	4.01~ 5.01	22.05 24.90	34.69 34.69	— —	56.74 59.59
8	5.01~ 5.15	24.90 25.30	34.69 34.69	— —	59.59 59.99
9	5.15~ 5.96	16.12 18.11	34.69 34.69	— —	50.81 52.80
10	5.96~ 6.01	18.11 18.23	34.69 34.69	0.00 1.52	52.80 51.40
11	6.01~ 6.61	20.89 22.58	34.69 34.69	1.27 16.52	54.31 40.75
12	6.61~ 7.01	30.92 32.56	34.69 34.69	365.01 368.29	-299.39 -301.03

Pa: Active earth pressure strength

$$L = \frac{1}{\beta} = 4.25 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.61 m) to 4.25 m depth (GL -10.86 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.61	0.90	26.8	25.0	23.31
2	7.51	1.00	25.0	21.0	23.00
3	8.51	1.00	21.0	10.0	15.50
4	9.51	1.00	10.0	28.0	19.00
5	10.51	0.35	28.0	35.7	11.07
L = Σh = 4.25			ΣA =		91.88

A: (upper N-value + lower N-value) × h/2

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{91.88}{4.25} \\ &= 21.63 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800 N' = 2800 \times 21.63 = 60564 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 60564 = 201881 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10} (B/0.3)^{-3/4} = 201881 (10.00/0.3)^{-3/4} = 14552 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 14552 kN/m³.

5.3 Seismic Condition

Assuming Kh = 27392 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.276 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.63 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.61 m) and 3.36 m depth (GL -10.24 m).

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_A: 0.65 m (GL -6.61 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B = 10.00 \text{ m})$$

$$\begin{aligned} K_{10} &= \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ E_0 &= 2800 N' \end{aligned}$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name H 950-250-16-22-18
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.86
Section efficiency η = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 688700 cm⁴ (original condition)
I = 592282 cm⁴ (after reduction by corrosion and section)
Inertia sectional moment EI = 200000 × 10³ × 592282 × 10⁻⁸ = 1.185 × 10⁶

No	Depth m	N Value	No	Depth m	N Value
1	1.00	15	11	10.51	28
2	1.51	9	12	11.51	50
3	2.51	4	13	12.51	22
4	3.51	14	14	13.51	22
5	4.51	21	15	14.51	51
6	5.51	38	16	15.51	50
7	6.51	27			
8	7.51	25			
9	8.51	21			
10	9.51	10			

5.2 Normal Condition

Assuming Kh = 14552 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.235 \text{ m}^{-1}$$

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.61	0.90	26.8	25.0	23.31
2	7.51	1.00	25.0	21.0	23.00
3	8.51	1.00	21.0	10.0	15.50
4	9.51	0.73	10.0	23.1	12.02
L = Σh = 3.63			ΣA =		73.83

A: (upper N-value + lower N-value) × h/2

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{73.83}{3.63} \\ &= 20.36 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800 N' = 2800 \times 20.36 = 57000 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 57000 = 380001 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10} (B/0.3)^{-3/4} = 380001 (10.00/0.3)^{-3/4} = 27392 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 27392 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 1.85	1.85	4.58 27.13	4.24 25.09	5.99 5.38	25.39 134.91
2	1.85~ 2.01	0.16	28.20 30.17	2.26 2.41	4.71 4.65	10.62 11.23
3	2.01~ 2.53	0.52	30.17 36.57	7.84 9.51	4.43 4.28	34.72 40.44
4	2.53~ 3.01	0.48	42.86 48.93	10.29 11.74	3.92 3.76	40.32 44.16
5	3.01~ 4.01	1.00	48.93 61.58	24.47 30.79	3.27 2.95	79.92 90.32
6	4.01~ 4.02	0.01	61.58 61.71	0.31 0.31	2.60 2.59	0.80 0.80

7	4.02- 5.01	0.99	61.71 64.53	30.55 31.94	2.26 1.93	69.03 61.65
8	5.01- 5.15	0.14	64.53 64.93	4.52 4.55	1.55 1.51	7.02 6.85
9	5.15- 5.96	0.81	49.79 51.06	20.17 20.68	1.19 0.92	24.00 19.03
10	5.96- 6.01	0.05	51.06 48.06	1.28 1.20	0.63 0.62	0.81 0.74
11	6.01- 6.61	0.60	50.70 22.38	15.21 6.71	0.40 0.20	6.08 1.34
			$\Sigma P =$	266.05	$\Sigma M =$	710.19

P_a : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_a \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_l = 0.0 \text{ kN/m}$
 depth to acting position $H_l = 0.0 \text{ m}$
 moment $M_m = 0.0 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_m = 0.00 \text{ m}$
 Height from riverbed to top of coping $H = 5.96 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_l \cdot (H + L_k - H_l) + M_m = 0.00 \text{ kN}\cdot\text{m}$
 h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_l} = \frac{710.19}{266.05} = 2.67 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 266.05}{6.61} = 80.50 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P_0 kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.85	1.85	6.66 31.42	6.16 29.06	5.99 5.38	36.94 156.25
2	1.85- 2.01	0.16	32.89 35.05	2.63 2.80	4.71 4.65	12.38 13.05
3	2.01- 2.53	0.52	35.05 42.09	9.11 10.94	4.43 4.25	40.34 46.55
4	2.53- 3.01	0.48	42.63 48.70	10.23 11.69	3.92 3.76	40.10 43.95
5	3.01- 3.54	0.53	48.70 55.40	12.91 14.68	3.42 3.25	44.18 47.67
6	3.54- 4.01	0.47	55.40 56.74	13.02 13.33	2.91 2.76	37.93 36.76

Material name 10 H _ H 950 -250 -16 -22 -18
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.86$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 688700 \text{ cm}^4$ (original condition)
 $I = 592282 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 592282 \times 10^{-8} = 1.185 \times 10^6$

$$\beta = 4 \sqrt{\frac{K_0 \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$l_1 = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_0 = 14552 \text{ kN/m}^3$
 calculated value $\beta = 0.23541 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 266.05 \text{ kN/m}$
 height of acting position of load $h_0 = 2.67 \text{ m}$
 moment $M_0 = 710.19 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_m = 1.294$,
 maximum moment $M_{\max} = 919.14 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 1.772 \text{ m}$
 depth of 1st fixed point $l_1 = 5.108 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_0 = 27392 \text{ kN/m}^3$
 calculated value $\beta = 0.27574 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 282.42 \text{ kN/m}$
 height of acting position of load $h_0 = 2.67 \text{ m}$
 moment $M_0 = 755.17 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_m = 1.233$,
 maximum moment $M_{\max} = 930.96 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 1.393 \text{ m}$
 depth of 1st fixed point $l_1 = 4.241 \text{ m}$

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name 10 H _ H 950 -250 -16 -22 -18

7	4.01- 5.01	1.00	56.74 59.59	28.37 29.80	2.27 1.93	64.31 57.61
8	5.01- 5.15	0.14	59.59 59.99	4.17 4.20	1.55 1.51	6.48 6.33
9	5.15- 5.96	0.81	50.81 52.80	20.58 21.38	1.19 0.92	24.49 19.67
10	5.96- 6.01	0.05	52.80 51.40	1.32 1.29	0.63 0.62	0.84 0.79
11	6.01- 6.61	0.60	54.31 40.75	16.29 12.22	0.40 0.20	6.52 2.44
			$\Sigma P =$	276.20	$\Sigma M =$	745.57

P_a : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_a \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_l = 0.00 \text{ kN/m}$
 depth to acting position $H_l = 0.00 \text{ m}$
 moment $M_m = 0.0 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_m = 0.0 \text{ m}$
 Height from riverbed to top of coping $H = 5.96 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 0.65 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_l \cdot (H + L_k - H_l) + M_m = 0.00 \text{ kN}\cdot\text{m}$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	3.54- 4.54	1.00	0.0 2.7	0.00 1.33	2.74 2.40	0.00 3.21
2	4.54- 5.54	1.00	2.7 3.8	1.33 1.89	1.74 1.40	2.32 2.65
3	5.54- 5.96	0.42	3.8 4.2	0.79 0.87	0.93 0.79	0.74 0.69
			$\Sigma P_{dw} =$	6.22	$\Sigma M_{dw} =$	9.60

h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{dw}}{\Sigma P + P_l + \Sigma P_{dw}} = \frac{755.17}{282.42} = 2.67 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 282.42}{6.61} = 85.45 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.88$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 10570 \text{ cm}^3$ (original condition)
 $Z = 9302 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{919.14 \times 10^6}{9302 \times 10^3} = 99 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

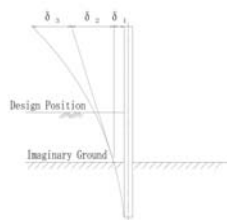
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{930.96 \times 10^6}{9302 \times 10^3} = 100 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

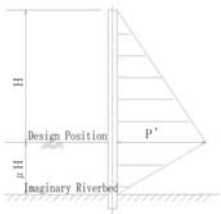


$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.2354 \times 2.67) \times 266.05}{2 \times 2.00 \times 10^8 \times 592282 \times 10^{-8} \times 0.2354^3} = 0.01402 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_k)$$

$$= \frac{(1+2 \times 0.2354 \times 2.67) \times 266.05}{2 \times 2.00 \times 10^8 \times 592282 \times 10^{-8} \times 0.2354^3} \times (5.96+0.65) = 0.03023 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.65}{5.96} = 0.109$$

$$\begin{aligned}\delta_3 &= \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4) \\ &= \frac{80.50 \times 5.96^4}{120 \times 2.00 \times 10^8 \times 592282 \times 10^{-8}} (4+20 \times 0.109+40 \times 0.109^2+35 \times 0.109^3+11 \times 0.109^4) \\ &= 0.00479 \text{ m}\end{aligned}$$

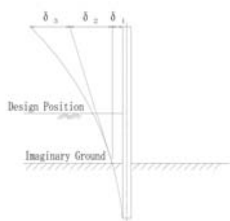
$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01402 + 0.03023 + 0.00479 \\ &= 0.04904 \text{ m} \\ \text{Size} &= 49.04 \leq \delta_a = 50.00 \text{ mm}\end{aligned}$$

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

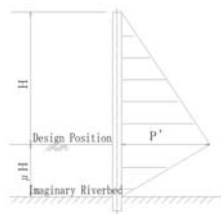
6.4.2 Seismic Condition

Displacement Calculation



$$\begin{aligned}\delta_1 &= \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1+0.2757 \times 2.67) \times 282.42}{2 \times 2.00 \times 10^8 \times 592282 \times 10^{-8} \times 0.2757^3} = 0.00988 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta_2 &= \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k) \\ &= \frac{(1+2 \times 0.2757 \times 2.67) \times 282.42}{2 \times 2.00 \times 10^8 \times 592282 \times 10^{-8} \times 0.2757^2} \times (5.96+0.65) = 0.02565 \text{ m}\end{aligned}$$



$$\mu = \frac{L_k}{H} = \frac{0.65}{5.96} = 0.109$$

$$\begin{aligned}\delta_3 &= \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4) \\ &= \frac{85.45 \times 5.96^4}{120 \times 2.00 \times 10^8 \times 592282 \times 10^{-8}} (4+20 \times 0.109+40 \times 0.109^2+35 \times 0.109^3+11 \times 0.109^4) \\ &= 0.00509 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00988 + 0.02565 + 0.00509 \\ &= 0.04061 \text{ m} \\ \text{Size} &= 40.61 \leq \delta_a = 75.00 \text{ mm}\end{aligned}$$

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:

Material Name	10 H 950-250-16-22-18
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 = 688700 cm ⁴ (original condition)
	I = 688700 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 688700 × 10 ⁻⁸	= 1.377 × 10 ⁶

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:

$$\begin{aligned}D &= L_k + \frac{3}{\beta} \\ L &= H - H_{11} + D \\ \beta &= \sqrt[4]{\frac{K_h \cdot B}{4 E I}}\end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	$K_h = 14552 \text{ kN/m}^3$
Calculated value	$\beta = 0.22670 \text{ m}^{-1}$

Penetration length of SSP	$D = 0.65 + \frac{3}{0.227} = 13.88 \text{ m}$
Whole length of SSP	$L = 5.96 - 0.40 + 13.88 = 19.44 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	$K_h = 27392 \text{ kN/m}^3$
Calculated value	$\beta = 0.26554 \text{ m}^{-1}$

Penetration length of SSP	$D = 0.65 + \frac{3}{0.266} = 11.95 \text{ m}$
Whole length of SSP	$L = 5.96 - 0.40 + 11.95 = 17.51 \text{ m}$

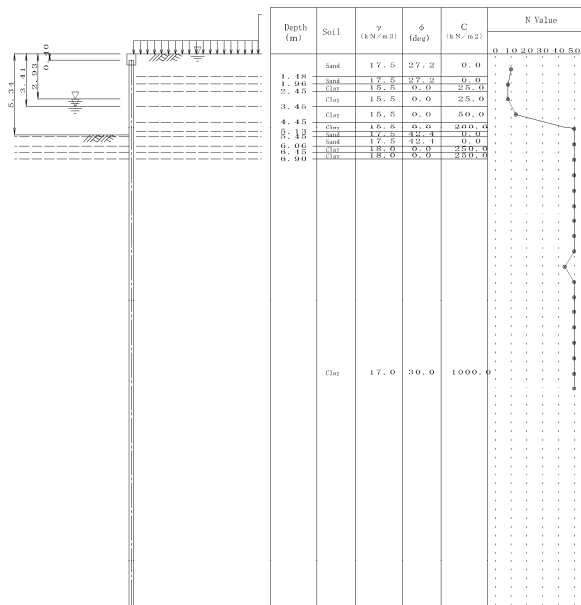
Therefore, the total length of the sheet pile is 19.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP		10 H 950-250-16-22-18			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	688700				
Sectional Modulus	Z (cm ³)	10570				
Maximum bending moment	Mmax (kN · m · m)				919.14	930.96
Stress intensity	σ (N/mm ²)				99 (180)	100 (270)
Lateral displacement	δ (mm)				49.04 (50.0)	40.61 (75.0)
Penetration depth	D (m)				13.88	11.95
Whole length of SSP	L (m)	19.50				

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 5.34 m
Depth from coping top to rear side ground	H ₀ = 0.00 m
Depth from coping top to SSP top	H _b = 0.40 m
Landside WL	L _{wa} = 0.00 m (Normal Condition)
	L _{wa} = 0.00 m (Seismic Condition)
Riverside WL	L _{wp} = 3.41 m (Normal Condition)
	L _{wp} = 2.93 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered
Wind load, Impact load	not considered
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope	not considered
Angle of rupture (clayey soil)	$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$ $a = \sin \theta$ $b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$
Equilibrium factor of compression	$K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{b0} \left(\frac{B_H}{0.3} \right)^{-3/4}$ $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2) $B_H = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
Average N-value	calculated from average N-value between imaginary riverbed and depth as 1/3

N-value distribution

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	1.00	10	11	10.95	50	21	20.95	50
2	2.00	8	12	11.95	50	22	21.95	50
3	2.95	8	13	12.95	50			
4	3.95	13	14	13.95	44			
5	4.95	50	15	14.95	50			
6	5.95	50	16	15.95	50			
7	6.95	50	17	16.95	50			
8	7.95	50	18	17.95	50			
9	8.95	50	19	18.95	50			
10	9.95	50	20	19.95	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

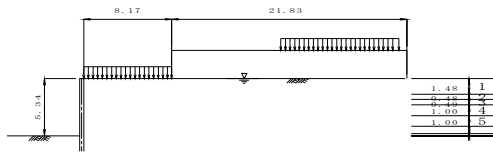
Soil Modulus										
No	Depth m (Include Projection Length)	Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)
										Normal Condition
										Seismic Condition
1	1.48	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto
2	1.96	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto
3	2.45	C	7.8	15.50	5.70	0.0	25.0	0.0	0.200	Auto
4	3.45	C	7.8	15.50	5.70	0.0	25.0	0.0	0.200	Auto
5	4.45	C	13.0	15.50	5.70	0.0	50.0	0.0	0.200	Auto
6	5.13	C	50.0	15.50	5.70	0.0	200.0	0.0	0.200	Auto
7	5.45	S	50.0	17.50	7.70	42.4	0.0	0.0	0.200	Auto
8	6.06	S	50.0	17.50	7.70	42.4	0.0	0.0	0.200	Auto
9	6.45	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto
10	6.90	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto
11	34.80	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto

Note	depth	: from top of coping to bottom of the layer	C ₀	: soil adhesion
	soil	: sandy(S), clayey(C), mixed (M)	a	: slope of soil adhesion
	N-value	: average N-value in the layer	k'	: design seismic coefficient (underwater)
	γ	: wet unit weight of soil	ζ	: angle of active rupture
	γ'	: saturated unit weight of soil	kh	: modulus of subgrade reaction
	ϕ	: internal friction angle of soil		

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants												
No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	8.17	8.17	30.00	30.00	2.61	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment					
No	load area		load strength		
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²	
1	0.00	8.16	5.0	0.0	
2	18.30	29.27	10.0	5.0	

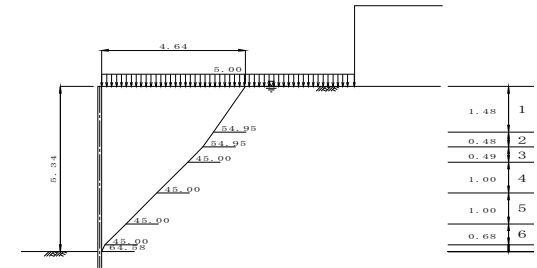
Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H 600 -200 - 12-16-13		
Young's modulus	E	=	200000 N/mm ²
Inertia sectional moment	I ₀	=	208200 cm ⁴
Sectional factor	Z ₀	=	4270 cm ³
Corrosion margin	t ₁	=	1.00 mm (riverside)
	t ₂	=	1.00 mm (landside)
Corrosion rate (to I ₀)	η	=	0.83
Corrosion rate (to Z ₀)	η	=	0.85
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/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ value kN/m ³	Angle of Rupture ζ degree
1	5.34 ~ 5.13	Sand	42.4	15.0	0.0	34.78	5.00	52.33	64.58

2.1.3 Acting Load by Surcharge Load

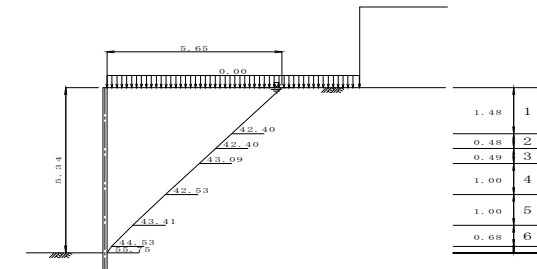
No	Q kN/m ²	l m	Qxl kN/m
1	5.0	4.64	23.22
Σ			23.22

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{0.00 + 23.22 + 0.00}{4.64}$$
$$= 5.00 \text{ kN/m}^2$$

2.2 Seismic 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	γ value kN/m ³	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	5.34 ~ 5.13	Sand	42.4	15.0	0.0	34.78	0.00	52.33	0.200	11.31	55.75
2	5.13 ~ 4.45	Clay	0.0	15.0	200.0	33.16	0.00	50.27	0.200	11.31	44.53
3	4.45 ~ 3.45	Clay	0.0	15.0	80.0	29.28	0.00	43.61	0.200	11.31	43.41
4	3.45 ~ 2.45	Clay	0.0	15.0	25.0	23.58	0.00	33.81	0.200	11.31	42.53
5	2.45 ~ 1.96	Clay	0.0	15.0	25.0	17.89	0.00	24.01	0.200	11.31	43.09
6	1.96 ~ 1.48	Sand	27.2	15.0	0.0	15.09	0.00	19.21	0.200	11.31	42.40

2.1.2 Coordinates of Collapse Line

Using the design plane as the XY origin, the coordinates where the main collapse line of each layer crosses the boundary of the soil layer, water level, etc., are calculated.

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X(m)	Y(m)	X(m)	Y(m)
1	64.58	0.21	0.00	0.00	0.10	0.21
2	45.00	0.68	0.10	0.21	0.78	0.89
3	45.00	1.00	0.78	0.89	1.78	1.89
4	45.00	1.00	1.78	1.89	2.78	2.89
5	45.00	0.49	2.78	2.89	3.27	3.38
6	54.95	0.48	3.27	3.38	3.61	3.86
7	54.95	1.48	3.61	3.86	4.64	5.34

From the above table, the loading width (L) on the ground surface is 4.64 m.

7	1.48~0.00	Sand	27.2	15.0	0.0	11.40	0.00	14.50	0.200	11.31	42.40

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \theta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	55.75	0.21	0.00	0.00	0.14	0.21
2	44.53	0.68	0.14	0.21	0.83	0.89
3	43.41	1.00	0.83	0.89	1.89	1.89
4	42.53	1.00	1.89	1.89	2.98	2.89
5	43.09	0.49	2.98	2.89	3.51	3.38
6	42.40	0.48	3.51	3.38	4.03	3.86
7	42.40	1.48	4.03	3.86	5.65	5.34

From the above table, the loading width (L) on the ground surface is 5.65 m.

2.2.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qel kN/m
1	0.0	5.65	0.00
Σ			0.00

Q : width of surcharge load set by line of active rupture

l : Loading width of uniform load surrounded by main collapse line

2.2.4 Calculated Load

9	5.34- 5.45	Sand	7.7	42.4	—	39.778 40.625	0.18084 0.18084	0.17468 0.17468
10	5.45- 6.06	Sand	7.7	42.4	—	40.625 45.322	0.18084 0.18084	0.17468 0.17468
11	6.06- 6.45	Clay	8.2	—	230.0 230.0	45.322 48.520	—	—
12	6.45- 6.90	Clay	8.2	—	230.0 230.0	48.520 52.210	—	—
13	6.90- 34.80	Clay	7.2	—	1000.0 1000.0	52.210 253.090	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth. m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	Kp	$K_p \times \cos \delta$
9	5.34- 5.45	Sand	7.7	42.4	—	0.000 0.847	10.38845 10.38845	10.03447 10.03447
10	5.45- 6.06	Sand	7.7	42.4	—	0.847 5.544	10.38845 10.38845	10.03447 10.03447
11	6.06- 6.45	Clay	8.2	0.0	230.0 230.0	5.544 8.742	—	—
12	6.45- 6.90	Clay	8.2	0.0	230.0 230.0	8.742 12.432	—	—
13	6.90- 34.80	Clay	7.2	30.0	1000.0 1000.0	12.432 213.312	—	—

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth. m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 1.48	1.62 5.30	—	1.62 5.30	0.00 14.50	—
2	1.48- 1.96	5.30 6.50	—	5.30 6.50	14.50 19.21	—
3	1.96- 2.45	-29.91 -27.12	10.05 11.44	10.05 11.44	19.21 24.01	—

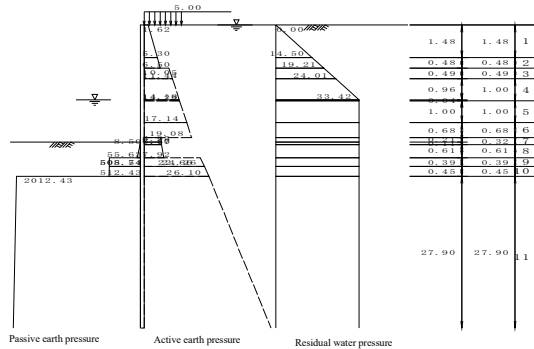
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{0.00 + 0.00 + 0.00}{5.65}$$

$$= 0.00 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Q_a$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00- 1.48	Sand	7.7	27.2	—	5.000 16.396	0.33489 0.33489	0.32348 0.32348
2	1.48- 1.96	Sand	7.7	27.2	—	16.396 20.092	0.33489 0.33489	0.32348 0.32348
3	1.96- 2.45	Clay	5.7	—	25.0 25.0	20.092 22.885	—	—
4	2.45- 3.41	Clay	5.7	—	25.0 25.0	22.885 28.357	—	—
5	3.41- 3.45	Clay	5.7	—	25.0 25.0	28.357 28.585	—	—
6	3.45- 4.45	Clay	5.7	—	50.0 50.0	28.585 34.285	—	—
7	4.45- 5.13	Clay	5.7	—	200.0 200.0	34.285 38.161	—	—
8	5.13- 5.34	Sand	7.7	42.4	—	38.161 39.778	0.18084 0.18084	0.17468 0.17468

4	2.45- 3.41	—	-27.12 -21.64	11.44 14.18	11.44 14.18	24.01 33.42	—
5	3.41- 3.45	—	-21.64 -21.42	14.18 14.29	14.18 14.29	33.42 33.42	—
6	3.45- 4.45	—	-71.42 -65.72	14.29 17.14	14.29 17.14	33.42 33.42	—
7	4.45- 5.13	—	-365.71 -361.84	17.14 19.08	17.14 19.08	33.42 33.42	—
8	5.13- 5.34	—	6.67 6.95	—	6.67 6.95	33.42 33.42	—
9	5.34- 5.45	—	6.95 7.10	—	6.95 7.10	33.42 33.42	0.00 8.50
10	5.45- 6.06	—	7.10 7.92	—	7.10 7.92	33.42 33.42	8.50 55.63
11	6.06- 6.45	—	-454.68 -451.48	22.66 24.26	22.66 24.26	33.42 33.42	505.54 508.74
12	6.45- 6.90	—	-451.48 -447.79	24.26 26.10	24.26 26.10	33.42 33.42	508.74 512.43
13	6.90- 34.80	—	-1947.79 -1746.91	26.10 126.54	26.10 126.54	33.42 33.42	2012.43 2213.31

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2 C$$

$$P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$$

K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2 C \sqrt{K_a}] \cdot \cos \delta$$

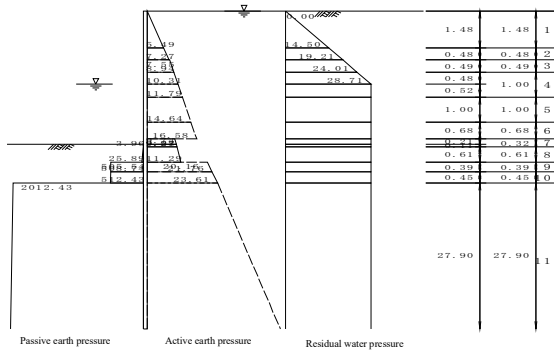
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2 C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2 C \sqrt{K_p}] \cdot \cos \delta$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K _a	K _a × cos δ	ζ degree
1	0.00-1.48	Sand	7.7	27.2	—	0.00 14.50	0.00 14.50	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
2	1.48-1.96	Sand	7.7	27.2	—	11.40 15.09	14.50 19.21	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
3	1.96-2.45	Clay	5.7	—	25.0 17.89	15.09 24.01	19.21 24.01	0.200 0.200	11.31 11.31	—	—	43.37 43.09
4	2.45-2.93	Clay	5.7	—	25.0 25.0	17.89 20.62	24.01 28.71	0.200 0.200	11.31 11.31	—	—	43.09 42.81
5	2.93-3.45	Clay	5.7	—	25.0 25.0	20.62 23.59	28.71 33.81	0.200 0.200	11.31 11.31	—	—	42.81 42.53
6	3.45-4.45	Clay	5.7	—	50.0 50.0	23.59 29.29	33.81 43.61	0.200 0.200	11.31 11.31	—	—	43.71 43.41
7	4.45-5.13	Clay	5.7	—	200.0 200.0	29.29 33.16	43.61 50.27	0.200 0.200	11.31 11.31	—	—	44.59 44.53
8	5.13-5.34	Sand	7.7	42.4	—	33.16 34.78	50.27 52.33	0.200 0.200	11.31 11.31	0.28983 0.28983	0.27995 0.27995	—
9	5.34-5.45	Sand	7.7	42.4	—	34.78 35.63	52.33 53.41	0.200 0.200	11.31 11.31	0.28983 0.28983	0.27995 0.27995	—
10	5.45-6.06	Sand	7.7	42.4	—	35.63 40.32	53.41 59.39	0.200 0.200	11.31 11.31	0.28983 0.28983	0.27995 0.27995	—
11	6.06-6.45	Clay	8.2	—	250.0 250.0	40.32 43.52	59.39 63.21	0.200 0.200	11.31 11.31	—	—	44.55 44.51
12	6.45-6.90	Clay	8.2	—	250.0 250.0	43.52 47.21	63.21 67.62	0.200 0.200	11.31 11.31	—	—	44.51 44.47
13	6.90-34.80	Clay	7.2	—	1000.0 1000.0	47.21 248.09	67.62 341.04	0.200 0.200	11.31 11.31	—	—	44.87 44.31

7	4.45-5.13	-364.81 -360.15	14.64 16.58	14.64 16.58	28.71 28.71	—
8	5.13-5.34	9.28 9.74	—	9.28 9.74	28.71 28.71	—
9	5.34-5.45	9.74 9.97	—	9.74 9.97	28.71 28.71	0.00 3.96
10	5.45-6.06	9.97 11.29	—	9.97 11.29	28.71 28.71	3.96 25.89
11	6.06-6.45	-451.55 -447.70	20.16 21.76	20.16 21.76	28.71 28.71	505.54 508.74
12	6.45-6.90	-447.70 -443.26	21.76 23.61	21.76 23.61	28.71 28.71	508.74 512.43
13	6.90-34.80	-1943.33 -1701.66	23.61 124.04	23.61 124.04	28.71 28.71	2012.43 2213.31

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_p = \Sigma \gamma h + Q + 2C$

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, m	water level, y, m	pdw, kN/m ²
1	2.93	0.00	0.00
2	3.93	1.00	2.66
3	4.93	2.00	3.77
4	5.34	2.41	4.13

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

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

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;

$\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	K _p	K _p × cos δ
9	5.34-5.45	Sand	7.70	42.4	—	0.000 0.847	0.000 1.08	0.200 0.200	11.31 11.31	4.67049 4.67049	4.67049 4.67049
10	5.45-6.06	Sand	7.70	42.4	—	0.847 5.544	1.08 7.06	0.200 0.200	11.31 11.31	4.67049 4.67049	4.67049 4.67049
11	6.06-6.45	Clay	8.20	0.0	250.0	5.544 8.742	7.06 10.88	0.200 0.200	11.31 11.31	—	—
12	6.45-6.90	Clay	8.20	0.0	250.0	8.742 12.432	10.88 15.29	0.200 0.200	11.31 11.31	—	—
13	6.90-34.80	Clay	7.20	30.0	1000.0 1000.0	12.432 213.312	15.29 288.71	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

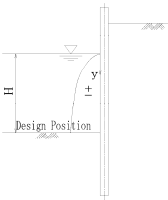
$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

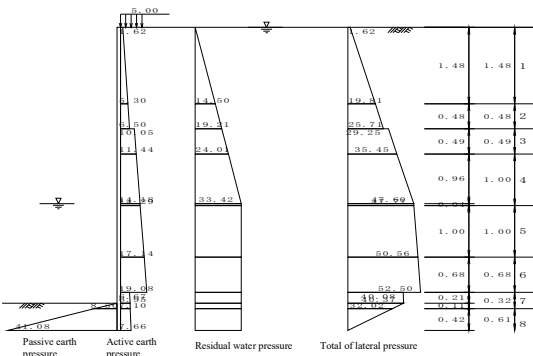
No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-1.48	0.00 5.49	—	0.00 5.49	0.00 14.50	—
2	1.48-1.96	5.49 7.27	—	5.49 7.27	14.50 19.21	—
3	1.96-2.45	-31.79 -28.40	7.55 8.94	7.55 8.94	19.21 24.01	—
4	2.45-2.93	-28.40 -25.07	8.94 10.31	8.94 10.31	24.01 28.71	—
5	2.93-3.45	-25.07 -21.46	10.31 11.79	10.31 11.79	28.71 28.71	—
6	3.45-4.45	-71.58 -64.68	11.79 14.64	11.79 14.64	28.71 28.71	—



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



No	Depth, m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00-1.48	1.62 5.30	0.00 14.50	—	1.62 19.81
2	1.48-1.96	5.30 6.50	14.50 19.21	—	19.81 25.71
3	1.96-2.45	10.05 11.44	19.21 24.01	—	29.25 35.45
4	2.45-3.41	11.44 14.18	24.01 33.42	—	35.45 47.60
5	3.41-3.45	14.18 14.29	33.42 33.42	—	47.60 47.71

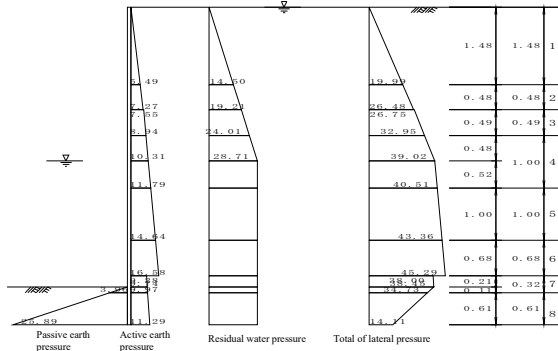
6	3.45- 4.45	14.29 17.14	33.42 33.42	———— ————	47.71 50.56
7	4.45- 5.13	17.14 19.08	33.42 33.42	———— ————	50.56 52.50
8	5.13- 5.34	6.67 6.95	33.42 33.42	———— ————	40.08 40.37
9	5.34- 5.45	6.95 7.10	33.42 33.42	0.00 8.50	40.37 32.02
10	5.45- 5.87	7.10 7.66	33.42 33.42	8.50 41.08	32.02 0.00
11	5.87- 6.06	7.66 7.92	33.42 33.42	41.08 55.63	0.00 -14.30

P_a : Active earth pressure
 P_w : Residual water pressure
 P_p : Passive earth pressure
 P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 0.53 m (GL -5.87 m)

Let the virtual ground surface $L_k = 0.53$ m (GL -5.87 m).

4.2 Seismic Condition



No	Depth, m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00- 1.48	0.00 5.49	0.00 14.50	———— ————	0.00 19.99
2	1.48- 1.96	5.49 7.27	14.50 19.21	———— ————	19.99 26.48
3	1.96- 2.45	7.55 8.94	19.21 24.01	———— ————	26.76 32.95

No	Depth, m	N Value	No	Depth, m	N Value	No	Depth, m	N Value
1	1.00	10	11	10.95	50	21	20.95	50
2	2.00	8	12	11.95	50	22	21.95	50
3	2.95	8	13	12.95	50			
4	3.95	13	14	13.95	44			
5	4.95	50	15	14.95	50			
6	5.95	50	16	15.95	50			
7	6.95	50	17	16.95	50			
8	7.95	50	18	17.95	50			
9	8.95	50	19	18.95	50			
10	9.95	50	20	19.95	50			

5.2 Normal Condition

Assuming $K_h = 33639$ kN/m³,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.395 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.53 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.87 m) to 2.53 m depth (GL -8.40 m).

No	Depth, Z, m	Thickness, h, m	N Value, upper	N Value, lower	Area, A
1	5.87	0.08	50.0	50.0	3.92
2	5.95	1.00	50.0	50.0	50.00
3	6.95	1.00	50.0	50.0	50.00
4	7.95	0.45	50.0	50.0	22.68
L = $\Sigma h = 2.53$		$\Sigma A = 126.60$			

A: (upper N-value + lower N-value) $\times$ h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{126.60}{2.53} = 50.00$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 50.00 = 140000 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 140000 = 466667 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{10} (B/0.3)^{-3/4} = 466667 (10.00/0.3)^{-3/4} = 33639 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 33639 kN/m³.

4	2.45- 2.93	8.94 10.31	24.01 28.71	———— ————	32.95 39.02
5	2.93- 3.45	10.31 11.79	28.71 28.71	———— ————	39.02 40.51
6	3.45- 4.45	11.79 14.64	28.71 28.71	———— ————	40.51 43.36
7	4.45- 5.13	14.64 16.58	28.71 28.71	———— ————	43.36 45.29
8	5.13- 5.34	9.28 9.74	28.71 28.71	———— ————	38.00 38.45
9	5.34- 5.45	9.74 9.97	28.71 28.71	0.00 3.96	38.45 34.73
10	5.45- 6.06	9.97 11.29	28.71 28.71	3.96 25.89	34.73 14.11

No	Depth, m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
11	6.06- 6.45	20.16 21.76	28.71 28.71	505.54 508.74	-456.67 -498.27

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 : 0.72 m (GL -6.06 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B = 10.00 \text{ m})$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H - H 600 -200 - 12-16-13
Unit width	B = 1.0000 m
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 0.83$
Section efficiency	$\mu = 1.00$
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	$I_0 = 208200 \text{ cm}^4$ (original condition)
	I = 172806 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 $\times 10^3 \times 172806 \times 10^{-8} = 3.456 \times 10^5$

5.3 Seismic Condition

Assuming $K_h = 67279$ kN/m³,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.470 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.06 m) and 2.13 m depth (GL -8.19 m).

No	Depth, Z, m	Thickness, h, m	N Value, upper	N Value, lower	Area, A
1	6.06	0.89	50.0	50.0	44.50
2	6.95	1.00	50.0	50.0	50.00
3	7.95	0.24	50.0	50.0	11.95
L = $\Sigma h = 2.13$		$\Sigma A = 106.45$			

A: (upper N-value + lower N-value) $\times$ h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{106.45}{2.13} = 50.00$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 50.00 = 140000 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 140000 = 933333 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{10} (B/0.3)^{-3/4} = 933333 (10.00/0.3)^{-3/4} = 67279 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 67279 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Force P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth, Z, m	Thickness, h, m	Lateral Force, P_s kN/m ²	Loads, P, kN	Arm length, Y, m	Moment, M, kN $\cdot$ m

1	0.00- 1.48	1.48	1.62 19.81	1.20 14.66	5.38 4.89	6.44 71.60
2	1.48- 1.96	0.48	19.81 25.71	4.75 6.17	4.23 4.07	20.12 25.12
3	1.96- 2.45	0.49	29.25 35.45	7.17 8.69	3.75 3.59	26.87 31.14
4	2.45- 3.41	0.96	35.45 47.60	17.02 22.85	3.10 2.78	52.78 63.55
5	3.41- 3.45	0.04	47.60 47.71	0.95 0.95	2.45 2.44	2.33 2.32
6	3.45- 4.45	1.00	47.71 50.56	23.86 25.28	2.09 1.76	49.82 44.37
7	4.45- 5.13	0.68	50.56 52.50	17.19 17.85	1.20 0.97	20.54 17.28
8	5.13- 5.34	0.21	40.08 40.37	4.21 4.24	0.67 0.60	2.83 2.55
9	5.34- 5.45	0.11	40.37 32.02	2.22 1.76	0.50 0.46	1.10 0.81
10	5.45- 5.87	0.42	32.02 0.00	6.75 0.00	0.28 0.14	1.90 0.00
			$\Sigma P = 187.76$		$\Sigma M = 443.47$	

P_r : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_r \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_r = 0.0 \text{ kN/m}$
 depth to acting position $H_r = 0.0 \text{ m}$
 moment $M_{rn} = 0.00 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_m = 0.00 \text{ m}$
 Height from riverbed to top of coping $H = 5.34 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_r \cdot (H + L_k - H_r) + M_{rn} = 0.00 \text{ kN}\cdot\text{m}$
 h_0 Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_r} = \frac{443.47}{187.76} = 2.36 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 187.76}{5.87} = 63.95 \text{ kN/m}$$

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0s}}{\Sigma P + P_r + \Sigma P_{0s}} = \frac{447.85}{183.71} = 2.44 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 183.71}{6.06} = 60.63 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name 10 H _ H 600 -200 - 12-16-13
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm (active side)}$ $t_2 = 1.00 \text{ mm (passive side)}$
 Corrosion rate $\eta = 0.83$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 208200 \text{ cm}^4$ (original condition)
 $I = 172806 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 172806 \times 10^{-8} = 3.456 \times 10^6$

$$\beta = 4 \sqrt{\frac{K_a \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$1_s = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

$$1_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_a = 33639 \text{ kN/m}^3$
 calculated value $\beta = 0.39496 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 187.76 \text{ kN/m}$
 height of acting position of load $h_0 = 2.36 \text{ m}$
 moment $M_0 = 443.47 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{tm} = 1.163$,
 maximum moment $M_{\max} = 515.69 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 0.850 \text{ m}$
 depth of 1st fixed point $l_i = 2.839 \text{ m}$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _r kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.48	1.48	0.00 19.99	0.00 14.79	5.57 5.07	0.00 75.05
2	1.48- 1.96	0.48	19.99 26.48	4.80 6.35	4.42 4.26	21.21 27.07
3	1.96- 2.45	0.49	26.75 32.95	6.55 8.07	3.94 3.77	25.80 30.46
4	2.45- 2.93	0.48	32.95 39.02	7.91 9.37	3.45 3.29	27.28 30.81
5	2.93- 3.45	0.52	39.02 40.51	10.15 10.53	2.96 2.78	30.00 29.31
6	3.45- 4.45	1.00	40.51 43.36	20.25 21.68	2.28 1.94	46.11 42.13
7	4.45- 5.13	0.68	43.36 45.29	14.74 15.40	1.38 1.16	20.39 17.81
8	5.13- 5.34	0.21	38.00 38.45	3.90 4.04	0.86 0.79	3.43 3.19
9	5.34- 5.45	0.11	38.45 34.73	2.11 1.91	0.68 0.65	1.45 1.24
10	5.45- 6.06	0.61	34.73 14.11	10.59 4.30	0.41 0.20	4.31 0.88
			$\Sigma P = 177.55$		$\Sigma M = 437.93$	

P_r : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_r \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_r = 0.00 \text{ kN/m}$
 depth to acting position $H_r = 0.00 \text{ m}$
 moment $M_{rn} = 0.0 \text{ kN}\cdot\text{m/m}$
 depth to acting position $H_m = 0.0 \text{ m}$
 Height from riverbed to top of coping $H = 5.34 \text{ m}$
 Depth of Imaginary riverbed from riverbed $L_k = 0.72 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_r \cdot (H + L_k - H_r) + M_{rn} = 0.00 \text{ kN}\cdot\text{m}$

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	2.93- 3.93	1.00	0.0 2.7	0.00 1.33	2.80 2.46	0.00 3.28
2	3.93- 4.93	1.00	2.7 3.8	1.33 1.88	1.80 1.46	2.39 2.75
3	4.93- 5.34	0.41	3.8 4.1	0.77 0.85	0.99 0.86	0.77 0.73
			$\Sigma P_{dw} = 6.16$		$\Sigma M_{dw} = 9.92$	

h_0 Height of acting position of P_0 from imaginary riverbed

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_a = 67279 \text{ kN/m}^3$
 calculated value $\beta = 0.46969 \text{ m}^{-1}$
 resultant earth force (lateral) $P_0 = 183.71 \text{ kN/m}$
 height of acting position of load $h_0 = 2.44 \text{ m}$
 moment $M_0 = 447.85 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{tm} = 1.118$,
 maximum moment $M_{\max} = 500.65 \text{ kN}\cdot\text{m/m}$
 depth of generated position of $M_{\max}$ $l_m = 0.628 \text{ m}$
 depth of 1st fixed point $l_i = 2.300 \text{ m}$

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as follows:

Material Name 10 H _ H 600 -200 - 12-16-13
 Corrosion margin $t_1 = 1.00 \text{ mm (active side)}$ $t_2 = 1.00 \text{ mm (passive side)}$
 Corrosion rate $\eta = 0.85$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 4270 \text{ cm}^3$ (original condition)
 $Z = 3630 \text{ cm}^3$ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{515.69 \times 10^6}{3630 \times 10^3} = 142 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

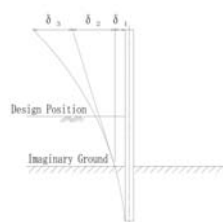
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{500.65 \times 10^6}{3630 \times 10^3} = 138 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

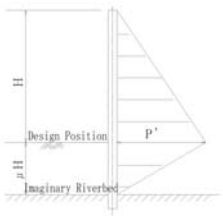


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.3950 \times 2.36) \times 187.76}{2 \times 2.00 \times 10^9 \times 172806 \times 10^{-8} \times 0.3950^3} = 0.00852 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u)$$

$$= \frac{(1 + 2 \times 0.3950 \times 2.36) \times 187.76}{2 \times 2.00 \times 10^9 \times 172806 \times 10^{-8} \times 0.3950^2} \times (5.34 + 0.53) = 0.02930 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.53}{5.34} = 0.100$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{63.95 \times 5.34^4}{120 \times 2.00 \times 10^9 \times 172806 \times 10^{-8}} (4 + 20 \times 0.100 + 40 \times 0.100^2 + 35 \times 0.100^3 + 11 \times 0.100^4)$$

$$= 0.00805 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00852 + 0.02930 + 0.00805$$

$$= 0.04588 \text{ m}$$

$$\text{Size} = 45.88 \leq \delta_a = 50.00 \text{ mm}$$

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

$$\mu = \frac{L_k}{H} = \frac{0.72}{5.34} = 0.135$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{60.63 \times 5.34^4}{120 \times 2.00 \times 10^9 \times 172806 \times 10^{-8}} (4 + 20 \times 0.135 + 40 \times 0.135^2 + 35 \times 0.135^3 + 11 \times 0.135^4)$$

$$= 0.00893 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00550 + 0.02402 + 0.00893$$

$$= 0.03845 \text{ m}$$

$$\text{Size} = 38.45 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H ₂ H 600 -200 - 12-16-13
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 = 208200 cm ⁴ (original condition)
	I = 208200 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 208200 × 10 ⁻⁸	= 4.164 × 10 ⁶

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:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{11} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

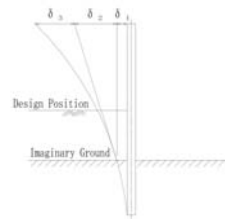
7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 33639 kN/m ³
Calculated value	β = 0.37698 m ⁻¹

Penetration length of SSP	D = 0.53 + $\frac{3}{0.377}$ = 8.49 m
Whole length of SSP	L = 5.34 - 0.40 + 8.49 = 13.43 m

6.4.2 Seismic Condition

Displacement Calculation

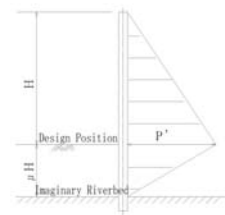


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.4697 \times 2.44) \times 183.71}{2 \times 2.00 \times 10^9 \times 172806 \times 10^{-8} \times 0.4697^3} = 0.00550 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u)$$

$$= \frac{(1 + 2 \times 0.4697 \times 2.44) \times 183.71}{2 \times 2.00 \times 10^9 \times 172806 \times 10^{-8} \times 0.4697^2} \times (5.34 + 0.72) = 0.02402 \text{ m}$$



7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_b = 67279 kN/m ³
Calculated value	β = 0.44831 m ⁻¹
Penetration length of SSP	D = 0.72 + $\frac{3}{0.448}$ = 7.41 m
Whole length of SSP	L = 5.34 - 0.40 + 7.41 = 12.35 m

Therefore, the total length of the sheet pile is 13.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H ₂ H 600 -200 - 12-16-13				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	208200		
Sectional Modulus	Z (cm ³)	4270		
Maximum bending moment	Mmax (kN × m × m)		515.69	500.65
Stress intensity	σ (N/mm ²)		142 (180)	128 (170)
Lateral displacement	δ (mm)		45.88 (50.0)	38.45 (75.0)
Penetration depths	D (m)		8.49	7.41
Whole length of SSP	L (m)	13.50		

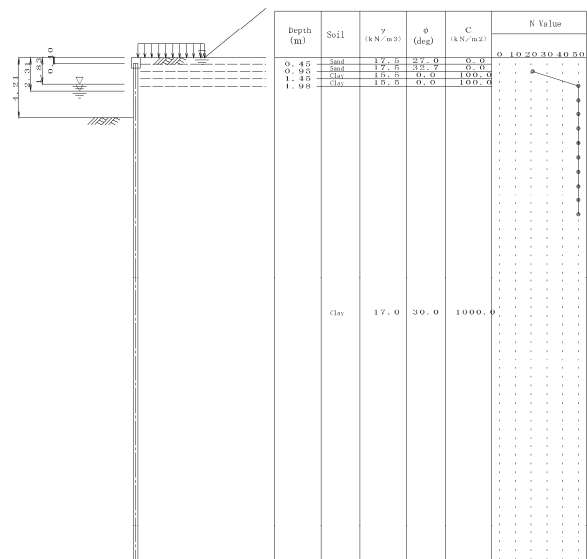
1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log

Block No. : R-24
Sta. : 10+540~10+660

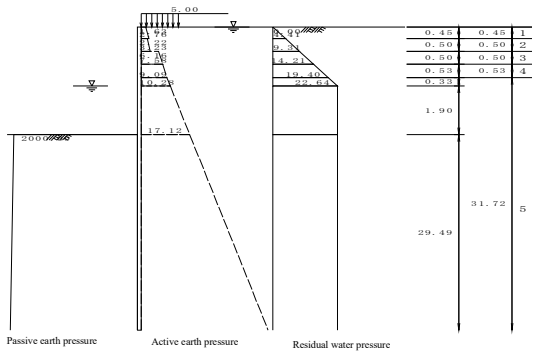
Design Cross Section : Sta 10+640
Boring Name : BMRL-31

Specification : SSP SP-10H
(Combined) : H 550-200-12-16-13



3 Lateral Forth

3.1 Normal Condition



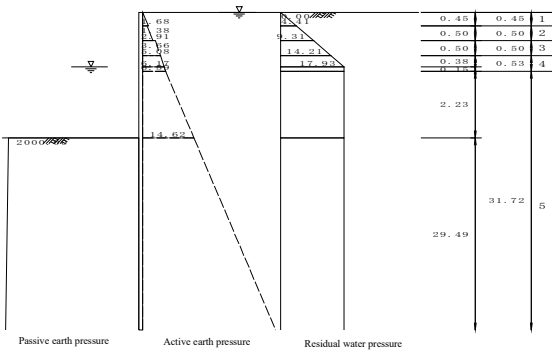
3.1.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_u$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00-0.45	Sand	7.7	27.0	—	5.000 8.465	0.33738 0.33738	0.32589 0.32589
2	0.45-0.95	Sand	7.7	32.7	—	8.465 12.315	0.27152 0.27152	0.26227 0.26227
3	0.95-1.45	Clay	5.7	—	100.0 15.165	12.315 15.165	—	—
4	1.45-1.98	Clay	5.7	—	100.0 18.186	15.165 18.186	—	—
5	1.98-2.31	Clay	7.2	—	1000.0 20.562	18.186 20.562	—	—
6	2.31-4.21	Clay	7.2	—	1000.0 34.242	20.562 34.242	—	—
7	4.21-33.70	Clay	7.2	—	1000.0 246.570	34.242 246.570	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_u$ kN/m ²	γ_{shw} kN/m ³	k (k ⁻¹)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-0.45	Sand	7.7	27.0	—	0.00 3.47	0.00 4.41	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
2	0.45-0.95	Sand	7.7	32.7	—	3.47 7.32	4.41 9.31	0.200 0.200	11.31 11.31	0.41130 0.41130	0.39729 0.39729	—
3	0.95-1.45	Clay	5.7	—	100.0 10.17	7.32 10.17	9.31 14.21	0.200 0.200	11.31 11.31	—	—	44.79 44.71
4	1.45-1.83	Clay	5.7	—	100.0 12.33	10.17 12.33	14.21 17.93	0.200 0.200	11.31 11.31	—	—	44.71 44.65
5	1.83-1.98	Clay	5.7	—	100.0 13.19	12.33 13.19	17.93 19.40	0.200 0.200	11.31 11.31	—	—	44.65 44.65
6	1.98-4.21	Clay	7.2	—	1000.0 41.26	13.19 41.26	19.40 41.26	0.200 0.200	11.31 11.31	—	—	44.96 44.92
7	4.21-33.70	Clay	7.2	—	1000.0 241.57	41.26 241.57	41.26 330.26	0.200 0.200	11.31 11.31	—	—	44.92 44.32

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	44.92	2.23	0.00	0.00	2.24	2.23
2	44.63	0.53	2.24	2.23	2.77	2.76
3	44.71	0.50	2.77	2.76	3.28	3.26
4	47.87	0.50	3.28	3.26	3.73	3.76
5	42.18	0.45	3.73	3.76	4.23	4.21

From the above table, the loading width (L) on the ground surface is 4.23 m.

2.2.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qxl kN/m
1	0.0	4.23	0.00
Σ			0.00

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{0.00 + 0.00 + 0.00}{4.23}$$
$$= 0.00 \text{ kN/m}^2$$

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	K_p	$K_p \times \cos \delta$
7	4.21-33.70	Clay	7.2	30.0	1000.0 212.328	0.000 212.328	—	—

Coefficient of passive earth pressure of sandy soil K_p is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Dpth. m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00- 0.45	1.63 2.76	—	1.63 4.41	0.00 4.41	—
	0.45- 0.95	2.22 3.23	—	2.22 3.23	4.41 9.31	—
3	0.95- 1.45	-187.68 -184.83	6.16 7.58	6.16 7.58	9.31 14.21	—
4	1.45- 1.98	-184.83 -181.81	7.58 9.09	7.58 9.09	14.21 19.40	—
5	1.98- 2.31	-1981.81 -1979.44	9.09 10.28	9.09 10.28	19.40 22.64	—
6	2.31- 4.21	-1979.44 -1965.76	10.28 17.12	10.28 17.12	22.64 22.64	—
7	4.21- 33.70	-1965.76 -1753.43	17.12 123.29	17.12 123.29	22.64 22.64	2000.00 2212.33

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Kp	$K_p \times \cos \delta$
7	4.21- 33.70	Clay	7.20	30.0	1000.0	0.000	0.00	0.200	11.31	————	————
					1000.0	212.328	289.00	0.200	11.31	————	————

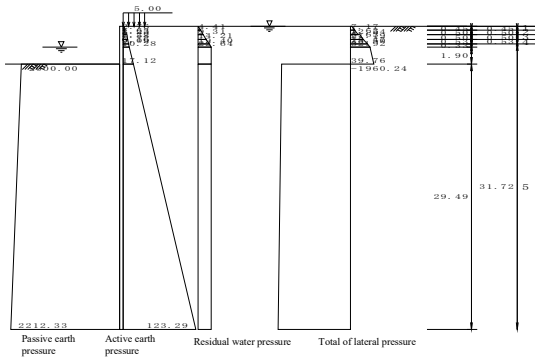
• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta)} \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2$$

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 0.45	0.00 1.68	———— ————	0.00 1.68	0.00 4.41	———— ————
2	0.45- 0.95	1.38 2.91	———— ————	1.38 2.91	4.41 9.31	———— ————
3	0.95- 1.45	-191.22 -187.79	3.66 5.08	3.66 5.08	9.31 14.21	———— ————
4	1.45- 1.83	-187.79 -185.19	5.08 6.17	5.08 6.17	14.21 17.93	———— ————
5	1.83- 1.98	-185.19 -184.16	6.17 6.59	6.17 6.59	17.93 17.93	———— ————
6	1.98- 4.21	-1984.18 -1964.90	6.59 14.62	6.59 14.62	17.93 17.93	———— ————
7	4.21- 33.70	-1964.90 -1709.52	14.62 120.79	14.62 120.79	17.93 17.93	2000.00 2212.33

- Formula for active earth pressure
Sand $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2 C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)
Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2 C \sqrt{K_a}] \cdot \cos \delta$
- Formula for passive earth pressure
Sand $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2 C$
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2 C \sqrt{K_p}] \cdot \cos \delta$



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.45	1.63 2.76	0.00 4.41	———— ————	1.63 7.17
2	0.45- 0.95	2.22 3.23	4.41 9.31	———— ————	6.63 12.54
3	0.95- 1.45	6.16 7.88	9.31 14.21	———— ————	15.47 21.79
4	1.45- 1.98	7.88 9.09	14.21 19.40	———— ————	21.79 28.50
5	1.98- 2.31	9.09 10.28	19.40 22.64	———— ————	28.50 32.92
6	2.31- 4.21	10.28 17.12	22.64 22.64	———— ————	32.92 39.76
7	4.21- 33.70	17.12 121.29	22.64 22.64	2000.00 2212.33	-1960.24 -2066.41

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure $P_s = P_a + P_w - P_p$

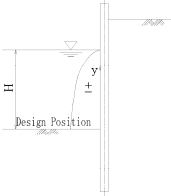
Imaginary riverbed Lk: 0.00 m (GL -4.21 m)
Let the virtual ground surface Lk = 0.00 m (GL -4.21 m).

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m ²
1	1.83	0.00	0.00
2	2.83	1.00	2.65
3	3.83	2.00	3.74
4	4.21	2.38	4.08

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma \cdot \sqrt{H \cdot y}$$

Where,
 k_{hs} : design seismic coefficient
 γ : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated

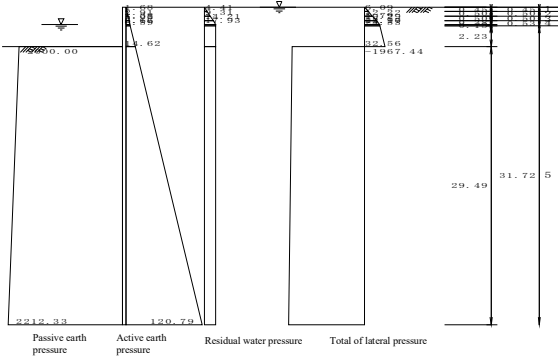


4 Imaginary Riverbed

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

4.2 Seismic Condition



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.45	1.68	0.00	————	0.00 6.09
2	0.45- 0.95	1.38 2.91	4.41 9.31	———— ————	5.79 12.22
3	0.95- 1.45	3.66 5.08	9.31 14.21	———— ————	12.97 19.29
4	1.45- 1.83	5.08 6.17	14.21 17.93	———— ————	19.29 24.10
5	1.83- 1.98	6.17 6.59	17.93 17.93	———— ————	24.10 24.53
6	1.98- 4.21	6.59 14.62	17.93 17.93	———— ————	24.53 32.56
7	4.21- 33.70	14.62 120.79	17.93 17.93	2000.00 2212.33	-1967.44 -2073.61

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed Lk: 0.00 m (GL -4.21 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{\lambda} = K_{\lambda 0} \left(\frac{B_{\lambda}}{0.3} \right)^{-3/4} \quad (B_{\lambda}=10.00\text{m})$$
$$K_{\lambda 0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha:\text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$E_0 = 2800\text{N}'$$

where:

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}}$$

Material Name	10 H _H 550 -200 - 12-16-13		
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	=	0.83
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm ²
Inertia sectional moment	I ₀	=	177600 cm ⁴ (original condition)
	I	=	147408 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 × 10 ³ × 147408 × 10 ⁻⁸ = 2.948 × 10 ⁷

No	Depth m	N Value	No	Depth m	N Value
1	0.95	21	11	10.95	50
2	1.95	50			
3	2.95	50			
4	3.95	50			
5	4.95	50			
6	5.95	50			
7	6.95	50			
8	7.95	50			
9	8.95	50			
10	9.95	50			

5.2 Normal Condition

Assuming Kh = 33639 kN/m3,

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}} = 0.411 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.43 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.21 m) to 2.43 m depth (GL -6.64 m).

Average N-value $N' = \frac{\Sigma A}{L}$
$$= \frac{102.31}{2.05}$$

$$= 50.00$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 50.00 = 140000 \text{ kN/m}^2$$
$$K_{\lambda 0} = \frac{1}{0.3} \times \alpha \times 140000 = 933333 \text{ kN/m}^3 \quad (\alpha:\text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$K_{\lambda} = K_{\lambda 0} (B_{\lambda}/0.3)^{-3/4} = 933333 (10.00/0.3)^{-3/4} = 67279 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 67279 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.45	0.45	1.63 7.17	0.37 1.61	4.06 3.91	1.49 6.31
2	0.45- 0.95	0.50	6.63 12.54	1.66 3.43	3.39 3.43	5.96 10.74
3	0.95- 1.45	0.50	15.47 21.79	3.87 5.45	3.09 2.93	11.96 15.94
4	1.45- 1.98	0.53	21.79 28.50	5.78 7.55	2.58 2.41	14.92 18.17
5	1.98- 2.31	0.33	28.50 32.92	4.70 5.43	2.12 2.01	9.97 10.92
6	2.31- 4.21	1.90	32.92 39.76	31.27 37.77	1.27 0.63	39.61 23.92
			Σ P =	108.59	Σ M =	169.91

P₀ : active earth pressure + residual water pressure - passive earth pressure
P : load P₀ 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 P₀ = 50.3 kN/m
depth to acting position H₀ = 0.0 m
moment M₀ = 0.0 kN·m/m
depth to acting position H₀ = 0.00 m
Height from riverbed to top of coping H = 4.21 m

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.21	0.74	50.0	50.0	37.00
2	4.95	1.00	50.0	50.0	50.00
3	5.95	0.69	50.0	50.0	34.66
L = Σ h = 2.43			Σ A = 121.66		

A: (upper N-value + lower N-value) × h/2

Average N-value $N' = \frac{\Sigma A}{L}$
$$= \frac{121.66}{2.43}$$

$$= 50.00$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 50.00 = 140000 \text{ kN/m}^2$$
$$K_{\lambda 0} = \frac{1}{0.3} \times \alpha \times 140000 = 466667 \text{ kN/m}^3 \quad (\alpha:\text{Normal Condition}=1, \text{Seismi Condition}=2)$$
$$K_{\lambda} = K_{\lambda 0} (B_{\lambda}/0.3)^{-3/4} = 466667 (10.00/0.3)^{-3/4} = 33639 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 33639 kN/m3.

5.3 Seismic Condition

Assuming Kh = 67279 kN/m3,

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}} = 0.489 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.05 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.21 m) and 2.05 m depth (GL -6.26 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.21	0.74	50.0	50.0	37.00
2	4.95	1.00	50.0	50.0	50.00
3	5.95	0.31	50.0	50.0	15.31
L = Σ h = 2.05			Σ A = 102.31		

A: (upper N-value + lower N-value) × h/2

Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M₀ by arbitrary load is as below
M₀ = P₀·(H + L_k - H₀) + M₀ = 211.76 kN·m

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_0}{\Sigma P + P_0}$$
$$= \frac{381.68}{158.89} = 2.40 \text{ m}$$

When the resultant force of the Latent Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 158.89}{4.21} = 75.48 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.45	0.45	0.00 6.09	0.00 1.37	4.06 3.91	0.00 5.36
2	0.45- 0.95	0.50	5.79 12.22	1.45 3.05	3.59 3.43	5.20 10.47
3	0.95- 1.45	0.50	12.97 19.29	3.24 4.82	3.09 2.93	10.03 14.12
4	1.45- 1.83	0.38	19.29 24.10	3.67 4.58	2.63 2.51	9.65 11.48
5	1.83- 1.98	0.15	24.10 24.53	1.81 1.84	2.33 2.28	4.21 4.19
6	1.98- 4.21	2.23	24.53 32.56	27.35 36.30	1.49 0.74	40.66 26.98
			Σ P =	89.47	Σ M =	142.34

P₀ : active earth pressure + residual water pressure - passive earth pressure
P : load P₀ 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 P₀ = 140.0 kN/m
depth to acting position H₀ = 0.00 m
moment M₀ = 43.4 kN·m/m

Height from riverbed to top of coping H = 4.21 m
Depth of Imaginary riverbed from riverbed L_k = 0.65 m

Moment M₀ by arbitrary load is as below
M₀ = P₀·(H + L_k - H₀) + M₀ = 632.80 kN·m

Hydrodynamic Pressure

No	Depth, Z m	Thickness, h m	Hydrodynamic Pressure, p ₀ kN/m ²	Loads, P ₀ kN	Arm length, Y m	Moment, M ₀ kN·m
1	1.83-2.83	1.00	0.0 2.6	0.00 1.32	2.05 1.71	0.00 2.27
2	2.83-3.83	1.00	2.6 3.7	1.32 1.87	1.05 0.71	1.38 1.33
3	3.83-4.21	0.38	3.7 4.1	0.71 0.78	0.25 0.13	0.18 0.10
Σ P ₀ =				6.00	Σ M ₀ =	5.26

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_1 + \Sigma M_{av}}{\Sigma P + P_1 + \Sigma P_{av}} = \frac{780.40}{235.48} = 3.31 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 235.48}{4.21} = 111.87 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name	10 H _ H 550 -200 - 12-16-13
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 = 0.83
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 177600 cm ⁴ (original condition) I = 147408 cm ⁴ (after reduction by corrosion and section)
EI	= 200000 × 10 ³ × 147408 × 10 ⁻⁸ = 2.948 × 10 ⁵

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4 E I}}$$

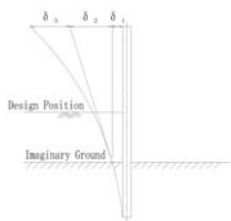
$$\phi_a = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

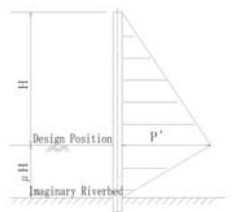
$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$



$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^2} = \frac{(1+0.4110 \times 2.40) \times 158.89}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4110^2} = 0.00771 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_u) = \frac{(1+2 \times 0.4110 \times 2.40) \times 158.89}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4110^2} \times (4.21+0.00) = 0.01998 \text{ m}$$



$$\mu = \frac{L_u}{H} = \frac{0.00}{4.21} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4) = \frac{75.48 \times 4.21^4}{120 \times 2.00 \times 10^8 \times 147408 \times 10^{-8}} (4+20 \times 0.000+40 \times 0.000^2+35 \times 0.000^3+11 \times 0.000^4) = 0.00268 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.00771 + 0.01998 + 0.00268 = 0.03038 \text{ m}$$

$$\text{Size} = 30.38 \leq \delta_a = 50.00 \text{ mm}$$

Where,

δ₁ : Displacement at imaginary ground

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 33639 kN/m ³
calculated value	β = 0.41097 m ⁻¹
resultant earth force (lateral)	P ₀ = 158.89 kN/m
height of acting position of load	h ₀ = 2.40 m
moment	M ₀ = 381.68 kN·m/m

in consideration of ψ ₀ = 1.149,	
maximum moment	M _{max} = 438.59 kN·m/m
depth of generated position of M _{max}	l _m = 0.789 m
depth of 1 st fixed point	l _i = 2.700 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b = 67279 kN/m ³
calculated value	β = 0.48873 m ⁻¹
resultant earth force (lateral)	P ₀ = 235.48 kN/m
height of acting position of load	h ₀ = 3.31 m
moment	M ₀ = 780.40 kN·m/m

in consideration of ψ ₀ = 1.067,	
maximum moment	M _{max} = 832.36 kN·m/m
depth of generated position of M _{max}	l _m = 0.474 m
depth of 1 st fixed point	l _i = 2.081 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as follows:

Material Name	10 H _ H 550 -200 - 12-16-13
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 = 3900 cm ³ (original condition) Z = 3315 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{438.59 \times 10^6}{3315 \times 10^3} = 132 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{832.36 \times 10^6}{3315 \times 10^3} = 251 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

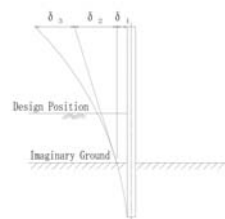
6.4.1 Normal Condition

Displacement Calculation

δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

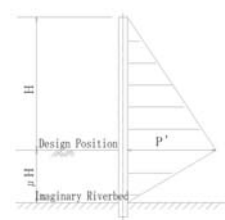
6.4.2 Seismic Condition

Displacement Calculation



$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^2} = \frac{(1+0.4887 \times 3.31) \times 235.48}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4887^2} = 0.00896 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_u) = \frac{(1+2 \times 0.4887 \times 3.31) \times 235.48}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4887^2} \times (4.21+0.00) = 0.02984 \text{ m}$$



$$\begin{aligned} \delta &= \delta 1 + \delta 2 + \delta 3 \\ &= 0.00896 + 0.02984 + 0.00397 \\ &= 0.04278 \text{ m} \\ \text{Size} &= 42.78 \leq \delta a = 75.00 \text{ mm} \end{aligned}$$

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

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H 1550 -200 - 12-16-13
Unit width	B = 1.0000 m
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	$I_0 = 177600 \text{ cm}^4$ (original condition) $I = 177600 \text{ cm}^4$ (after reduction by corrosion and section)
El = 200000 × 10 ³ × 177600 × 10 ⁻⁸	= 3.552 × 10 ⁶

Based on the depth of imaginary riverbed as L_k , penetration depth of SSP (D) and whole length of SSP (L) are calculated as follows:

$$\begin{aligned} D &= L_k + \frac{3}{\beta} \\ L &= H - H_{1k} + D \\ \beta &= 4 \sqrt{\frac{K_h \cdot B}{4 E I}} \end{aligned}$$

Modules of lateral subgrade reaction	$K_b = 33639 \text{ kN/m}^3$
Calculated value	$\beta = 0.39226 \text{ m}^{-1}$

$$\begin{aligned} \text{Penetration length of SSP} \quad D &= 0.00 + \frac{3}{0.392} = 7.65 \text{ m} \\ \text{Whole length of SSP} \quad L &= 4.21 - 0.40 + 7.65 = 11.46 \text{ m} \end{aligned}$$

Modules of lateral subgrade reaction	$K_h = 67279 \text{ kN/m}^2$
Calculated value	$\beta = 0.46648 \text{ m}^{-1}$

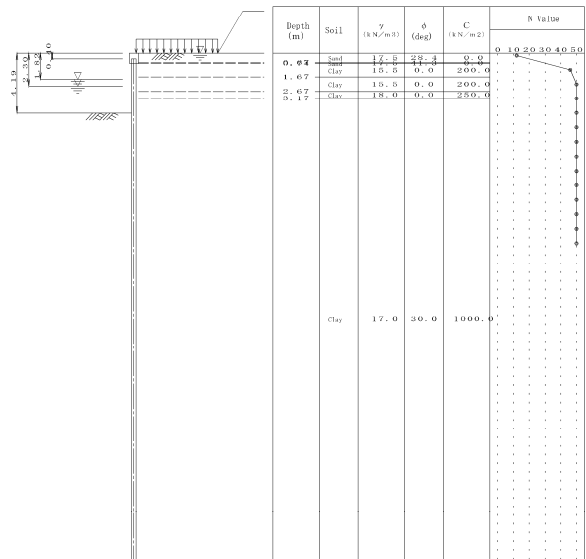
$$\begin{aligned} \text{Penetration length of SSP} \quad D &= 0.00 + \frac{3}{0.466} = 6.43 \text{ m} \\ \text{Whole length of SSP} \quad L &= 4.21 - 0.40 + 6.43 = 10.24 \text{ m} \end{aligned}$$

Therefore, the total length of the sheet pile is 11.50 m from the rounded length value of 0.50 m.

SSP 10 H _ H 550 -200 - 12-16-13

			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	177600		
Sectional Modulus	Z (cm ³)	3900		
Maximum bending moment	Maxm (kN · m = t · m)		438.59	832.36
Stress intensity	σ (N/mm ²)		132 / 150	251 / 270
Lateral displacement	δ (mm)		30.38 (180)	42.78 (75.0)
Penetration depth	D (m)		7.65	6.43
Whole length of SSP	L (m)	11.50		

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth from coping top to riverbed	H	=	4.19 m
Depth from coping top to rear side ground	H ₀	=	0.00 m
Depth from coping top to SSP top	H _a	=	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} '	=	1.82 m (Seismic Condition)

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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

Arbitrary load	Horizontal load	P _t	= 50.3 kN/m	(Normal Condition)
		P _t '	= 140.0 kN/m	(Seismic Condition)
Depth of acting point		H _t	= 0.0 m	(Normal Condition)
		H _t '	= 0.0 m	(Seismic Condition)
Moment		M _a	= 0.0 kN·m/m	(Normal Condition)
		M _a '	= 43.4 kN·m/m	(Seismic Condition)
Depth of acting point		H _a '	= 0.00 m	(Seismic Condition)
		H _a	= 0.00 m	(Normal Condition)

('Depth' means distance from top of coping)

Rear side angle of slope	not considered

Angle of rupture (clayey soil)

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\gamma H}$$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

Applied formula

$$K_b = K_{10} \left(\frac{B_0}{0.3} \right)^{-3/4}$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$B_0 = 10.00 \text{ m}$$

$$E_0 = 2800 \text{ N}$$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

8.84	4
1.00	4
4.02	6

No	Soil	X. Coordinate				Thickness		soil angle weight γ		internal friction angle	stickness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ²	Seismic Condition kN/m ²	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree	
1	Sand	5.67	7.40	30.00	30.00	2.94	19.0	19.0	30.0	0.0	Auto	Auto	
2	Sand	9.47	9.47	30.00	30.00	2.92	19.0	19.0	30.0	0.0	Auto	Auto	

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	5.66	5.0	0.0

Angle of rapture in embankment calculated in consideration of embankment conditions

No	Depth m	N Value
1	0.17	12
2	1.17	46
3	2.17	50
4	3.17	50
5	4.17	50
6	5.17	50
7	6.17	50
8	7.17	50
9	8.17	50
10	9.17	50

Vertical load on landside	calculated in consideration of embankment shape on landside
Vertical load on riverside	not considered

No	Depth m (Include Projection Length)	Thickness m (excluding projection length)
1	0.67	0.67
2	0.74	0.07
3	1.67	0.93
4	2.67	1.00
5	3.17	0.50
6	33.70	30.53

No	Depth m	earth Soil	N Value	γ	γ'	ϕ	C	a	k'	ζ (degree)	
				kN/m ³	kN/m ³	degree	kN/m ²			Normal Condition	Seismic Condition
1	0.67	S	12.0	17.50	7.70	28.4	0.0	0.0	0.200	Auto	Auto
2	0.74	S	46.0	17.50	7.70	41.3	0.0	0.0	0.200	Auto	Auto
3	1.67	C	46.0	15.50	5.70	0.0	200.0	0.0	0.200	Auto	Auto
4	2.67	C	50.0	15.50	5.70	0.0	200.0	0.0	0.200	Auto	Auto
5	3.17	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
6	33.70	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

Note)	depth :	from top of coping to bottom of the layer	C_a :	soil adhesion
	soil :	sandy(S), clayey(C), mixed (M)	a :	slope of soil adhesion
	N-value :	average N-value in the layer	k' :	design seismic coefficient (underwater)
	γ :	wet unit weight of soil	ζ :	angle of active rupture
	γ' :	saturated unit weight of soil	kh :	modulus of subgrade reaction
	ϕ :	internal friction angle of soil		

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

Material name	10 H, H 550 - 200 - 12-16-13	
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 177600 cm ⁴
Sectional factor	Z ₀	= 3900 cm ³
Corrosion margin	t ₁	= 1.00 mm (riverside) t ₂ = 1.00 mm (landside)
Corrosion rate (to I ₀)	η	= 0.83
Corrosion rate (to Z ₀)	η	= 0.85
Section efficiency (to I ₀)	μ	= 1.00
Section efficiency (to Z ₀)	μ	= 1.00

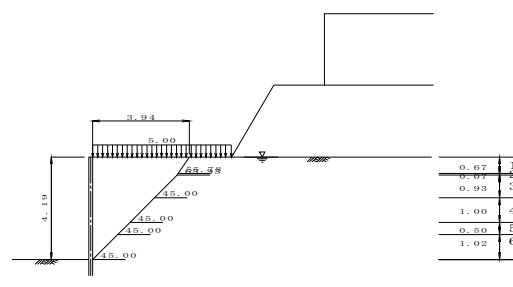
Round unit of SSP length	0.50 m		
Allowable stress	σ_a	=	180 N/mm (Normal)
	σ_a'	=	270 N/mm (Seismic)

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

2.1 Normal Condition



No	Depth, m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ_{whw} kN/m ²	Angle of Rupture ζ degree
1	4.19 ~ 3.17	Clay	30.0	15.0	1000.0	28.14	5.00	41.06	45.00

2	3.17~2.67	Clay	0.0	15.0	250.0	20.80	5.00	31.07	45.00
3	2.67~1.67	Clay	0.0	15.0	200.0	16.70	5.00	26.17	45.00
4	1.67~0.74	Clay	0.0	15.0	200.0	11.00	5.00	16.37	45.00
5	0.74~0.67	Sand	41.3	15.0	0.0	5.70	5.00	7.25	63.93
6	0.67~0.00	Sand	28.4	15.0	0.0	5.16	5.00	6.57	55.78

• 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

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	1.02	0.00	0.00	1.02	1.02
2	45.00	0.50	1.02	1.02	1.52	1.52
3	45.00	1.00	1.52	1.52	2.52	2.52
4	45.00	0.93	2.52	2.52	3.45	3.45
5	63.93	0.07	3.45	3.45	3.48	3.52
6	55.78	0.67	3.48	3.52	3.94	4.19

From the above table, the loading width (L) on the ground surface is 3.94 m.

2.1.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qul kN/m
1	5.0	3.94	19.70
Σ			19.70

Q : width of surcharge load set by line of active rupture

l : Loading width of uniform load surrounded by main collapse line

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	44.92	1.02	0.00	0.00	1.02	1.02
2	44.76	0.50	1.02	1.02	1.53	1.52
3	44.76	1.00	1.53	1.52	2.54	2.52
4	44.84	0.93	2.54	2.52	3.47	3.45
5	54.93	0.07	3.47	3.45	3.52	3.52
6	43.69	0.67	3.52	3.52	4.22	4.19

From the above table, the loading width (L) on the ground surface is 4.22 m.

2.2.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qul kN/m
1	0.0	4.22	0.00
Σ			0.00

Q : width of surcharge load set by line of active rupture

l : Loading width of uniform load surrounded by main collapse line

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{0.00 + 0.00 + 0.00}{4.22}$$

$$= 0.00 \text{ kN/m}^2$$

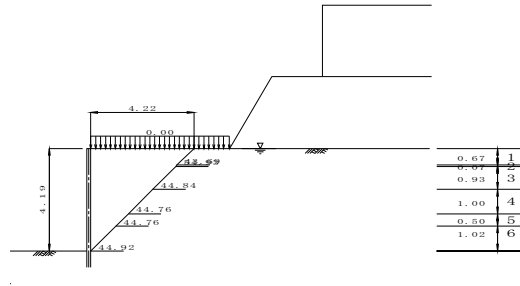
2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{0.00 + 19.70 + 0.00}{3.94}$$

$$= 5.00 \text{ kN/m}^2$$

2.2 Seismic 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	γ when kN/m ³	k (k')	θ degree	Angle of Rupture ζ degree
1	4.19~3.17	Clay	30.0	15.0	1000.0	28.14	0.00	41.06	0.200	11.31	44.92
2	3.17~2.67	Clay	0.0	15.0	250.0	20.80	0.00	31.07	0.200	11.31	44.76
3	2.67~1.67	Clay	0.0	15.0	200.0	16.70	0.00	26.17	0.200	11.31	44.76
4	1.67~0.74	Clay	0.0	15.0	200.0	11.00	0.00	16.37	0.200	11.31	44.84
5	0.74~0.67	Sand	41.3	15.0	0.0	5.70	0.00	7.25	0.200	11.31	54.93
6	0.67~0.00	Sand	28.4	15.0	0.0	5.16	0.00	6.57	0.200	11.31	43.69

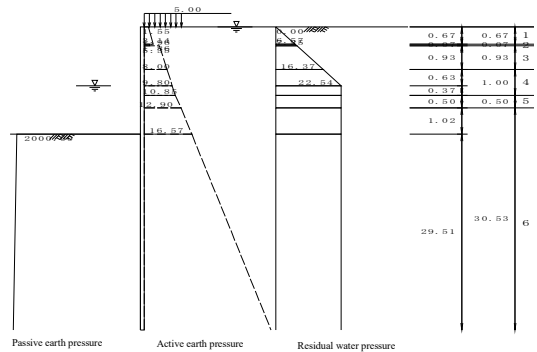
• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive soil

3 Lateral Forth

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	$\Sigma \gamma h + Q_u$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00~0.67	Sand	7.7	28.4	—	5.000 10.159	0.32022 0.32022	0.30931 0.30931
2	0.67~0.74	Sand	7.7	41.3	—	10.159 10.698	0.18993 0.18993	0.18346 0.18346
3	0.74~1.67	Clay	5.7	—	200.0 200.0	10.698 15.999	—	—
4	1.67~2.30	Clay	5.7	—	200.0 200.0	15.999 19.590	—	—
5	2.30~2.67	Clay	5.7	—	200.0 200.0	19.590 21.699	—	—
6	2.67~3.17	Clay	8.2	—	250.0 250.0	21.699 25.799	—	—
7	3.17~4.19	Clay	7.2	—	1000.0	25.799 33.143	—	—
8	4.19~33.70	Clay	7.2	—	1000.0	33.143 245.615	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Qp$ kN/m ²	Kp	$Kp \times \cos \delta$
8	4.19- 33.70	Clay	7.2	30.0	1000.0 1000.0	0.000 212.472	—	—

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 0.67	1.55 3.14	—	1.55 3.14	0.00 6.57	—
2	0.67- 0.74	1.86 1.96	—	1.86 1.96	6.57 7.25	—
3	0.74- 1.67	-389.30 -384.00	5.35 8.00	5.35 8.00	7.25 16.37	—
4	1.67- 2.30	-384.00 -380.41	8.00 9.80	8.00 9.80	16.37 22.54	—
5	2.30- 2.67	-380.41 -378.30	9.80 10.85	9.80 10.85	22.54 22.54	—
6	2.67- 3.17	-478.30 -474.20	10.85 12.90	10.85 12.90	22.54 22.54	—
7	3.17- 4.19	-1974.20 -1966.86	12.90 16.57	12.90 16.57	22.54 22.54	—
8	4.19- 33.70	-1966.86 -1754.39	16.57 122.81	16.57 122.81	22.54 22.54	2000.00 2212.47

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_p = \Sigma \gamma h + Q + 2C$

Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$

$$\zeta = 45^\circ - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Qp$ kN/m ²	γ when kN/m ²	k (k ²)	θ degree	Kp	$Kp \times \cos \delta$
8	4.19- 33.70	Clay	7.20	30.0	1000.0 1000.0	0.000 212.472	0.00 289.20	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00^\circ$ degree, $\beta = 0.00^\circ$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

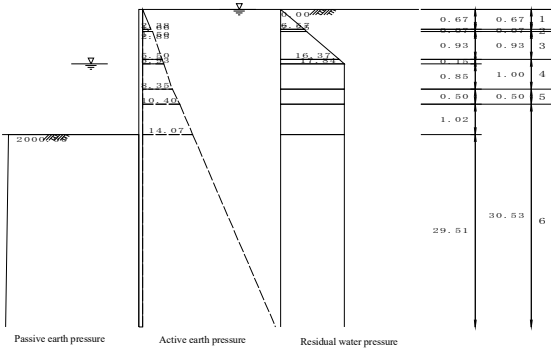
$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 0.67	0.00 2.38	—	0.00 2.38	0.00 6.57	—
2	0.67- 0.74	1.50 1.66	—	1.50 1.66	6.57 7.25	—
3	0.74- 1.67	-393.16 -386.80	2.85 5.50	2.85 5.50	7.25 16.37	—
4	1.67- 1.82	-386.80 -385.77	5.50 5.93	5.50 5.93	16.37 17.84	—
5	1.82- 2.67	-385.77 -379.95	5.93 8.35	5.93 8.35	17.84 17.84	—
6	2.67- 3.17	-479.95 -475.02	8.35 10.40	8.35 10.40	17.84 17.84	—
7	3.17- 4.19	-1975.04 -1966.22	10.40 14.07	10.40 14.07	17.84 17.84	—
8	4.19- 33.70	-1966.22 -1710.67	14.07 120.31	14.07 120.31	17.84 17.84	2000.00 2212.47

- Formula for active earth pressure

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ when kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 0.67	Sand	7.7	28.4	—	0.00 5.16	0.00 6.57	0.200 0.200	11.31 11.31	0.47800 0.47800	0.46172 0.46172	—
2	0.67- 0.74	Sand	7.7	41.3	—	5.16 5.70	6.57 7.25	0.200 0.200	11.31 11.31	0.30197 0.30197	0.29168 0.29168	—
3	0.74- 1.67	Clay	5.7	—	200.0 200.0	5.70 11.00	7.25 16.37	0.200 0.200	11.31 11.31	—	—	44.92 44.84
4	1.67- 2.30	Clay	5.7	—	200.0 200.0	11.00 11.85	16.37 17.84	0.200 0.200	11.31 11.31	—	—	44.84 44.83
5	1.82- 2.67	Clay	5.7	—	200.0 200.0	11.85 16.70	17.84 26.17	0.200 0.200	11.31 11.31	—	—	44.83 44.76
6	2.67- 3.17	Clay	8.2	—	250.0 250.0	16.70 20.80	26.17 31.07	0.200 0.200	11.31 11.31	—	—	44.81 44.76
7	3.17- 4.19	Clay	7.2	—	1000.0 1000.0	20.80 28.14	31.07 41.06	0.200 0.200	11.31 11.31	—	—	44.94 44.92
8	4.19- 33.70	Clay	7.2	—	1000.0 1000.0	28.14 240.62	41.06 336.26	0.200 0.200	11.31 11.31	—	—	44.92 44.33

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$

Clay $P_p = \Sigma \gamma h + Q + 2C$

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	water level y m	p _{dw} kN/m ²
1	1.82	0.00	0.00
2	2.82	1.00	2.64
3	3.82	2.00	3.73
4	4.19	2.37	4.06

$$p_{dw} = \pm \frac{7}{8} k_{dw} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

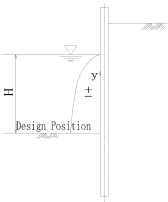
Where,

k_{dw} : dynamic seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

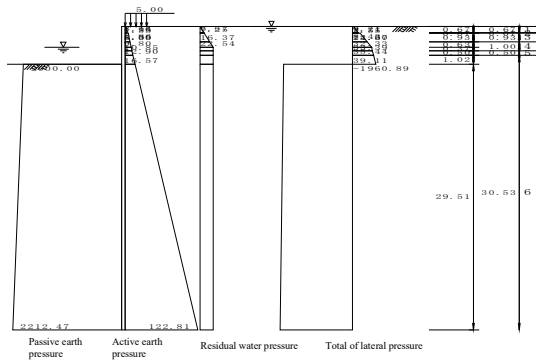
y : depth from water surface to the point where active water pressure is calculated



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

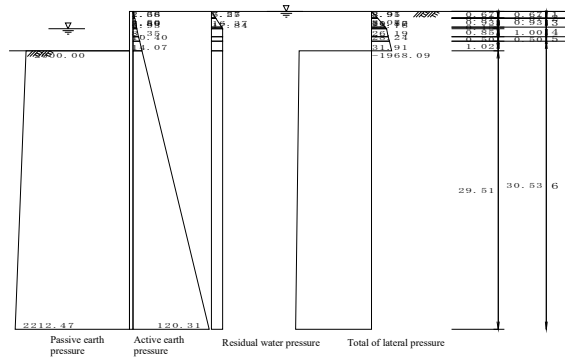


No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Pt kN/m2
1	0.00~ 0.67	1.35 3.14	0.00 6.57	———— ————	1.35 9.71
2	0.67~ 0.74	1.86 1.96	6.57 7.25	———— ————	8.43 9.21
3	0.74~ 1.67	5.35 8.00	7.25 16.37	———— ————	12.60 24.37
4	1.67~ 2.30	8.00 9.80	16.37 22.54	———— ————	24.37 32.33
5	2.30~ 2.67	9.80 10.85	22.54 22.54	———— ————	32.33 33.39
6	2.67~ 3.17	10.85 12.90	22.54 22.54	———— ————	33.39 35.44
7	3.17~ 4.19	12.90 16.57	22.54 22.54	———— ————	35.44 39.11
8	4.19~ 33.70	16.57 122.81	22.54 22.54	2000.00 2212.47	-1969.89 -2067.12

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Pt : Lateral pressure Pt = Pa + Pw - Pp

Imaginary riverbed L4: 0.00 m (GL -4.19 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Pt kN/m2
1	0.00~ 0.67	0.00 2.38	0.00 6.57	———— ————	0.00 8.95
2	0.67~ 0.74	1.50 1.66	6.57 7.25	———— ————	8.07 8.91
3	0.74~ 1.67	2.85 5.50	7.25 16.37	———— ————	10.10 21.87
4	1.67~ 1.82	5.50 5.93	16.37 17.84	———— ————	21.87 23.76
5	1.82~ 2.67	5.93 8.35	17.84 17.84	———— ————	23.76 26.19
6	2.67~ 3.17	8.35 10.40	17.84 17.84	———— ————	26.19 28.24
7	3.17~ 4.19	10.40 14.07	17.84 17.84	———— ————	28.24 31.91
8	4.19~ 33.70	14.07 120.31	17.84 17.84	2000.00 2212.47	-1968.09 -2074.33

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Pt : Lateral pressure Pt = Pa + Pw - Pp

Imaginary riverbed L4: 0.00 m (GL -4.19 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_h = K_{h0} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H = 10.00 \text{ m})$$
$$K_{h0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$
$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}}$$

Material Name	10 H_H 550 -200 -12-16-13
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 = 0.83
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 177600 cm ⁴ (original condition) I = 147408 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 147408 × 10 ⁻⁸ = 2.948 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.17	12	11	10.17	50
2	1.17	46	12	11.17	50
3	2.17	50	13	12.17	50
4	3.17	50	14	13.17	50
5	4.17	50			
6	5.17	50			
7	6.17	50			
8	7.17	50			
9	8.17	50			
10	9.17	50			

5.2 Normal Condition

Assuming Kh = 33639 kN/m³,

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}} = 0.411 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.43 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.19 m) to 3.43 m depth (GL -6.62 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.19	0.98	50.0	50.0	49.00
2	5.17	1.00	50.0	50.0	50.00
3	6.17	0.45	50.0	50.0	22.66
L = Σh = 2.43			ΣA = 121.66		

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$
$$= \frac{121.66}{2.43}$$
$$= 50.00$$

Kh is recalculated from the calculated average N-value.

$$E_0 = 2800 N' = 2800 \times 50.00 = 140000 \text{ kN/m}^2$$
$$K_{h0} = \frac{1}{0.3} \times \alpha \times 140000 = 466667 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$
$$K_h = K_{h0} (B_H / 0.3)^{-3/4} = 466667 (10.00 / 0.3)^{-3/4} = 33639 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 33639 kN/m³.

5.3 Seismic Condition

Assuming Kh = 67279 kN/m³,

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}} = 0.489 \text{ m}^{-1}$$
$$L = \frac{1}{\beta} = 2.05 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.19 m) and 2.05 m depth (GL -6.24 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.19	0.98	50.0	50.0	49.00
2	5.17	1.00	50.0	50.0	50.00
3	6.17	0.07	50.0	50.0	3.31
L = Σh = 2.05			ΣA = 102.31		

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$
$$= \frac{102.31}{2.05}$$
$$= 50.00$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 50,00 = 140000 \text{ kN/m}^2$$
$$K_{10} = \frac{1}{0,3} \times \alpha \times 140000 = 933333 \text{ kN/m}^2 \quad (\alpha: \text{Normal Condition}=1, \text{ Seismi Condition}=2)$$
$$K_b = K_{10} (B_0/0,3)^{-3/4} = 933333 (10,00/0,3)^{-3/4} = 67279 \text{ kN/m}^2$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 67279 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.67	0.67	1.55 9.71	0.52 3.25	3.97 3.74	2.06 12.17
2	0.67- 0.74	0.07	8.43 9.21	0.30 0.32	3.50 3.47	1.03 1.12
3	0.74- 1.67	0.93	12.60 24.37	5.86 11.33	3.14 2.83	18.40 32.06
4	1.67- 2.30	0.63	24.37 32.34	7.68 10.19	2.31 2.10	17.73 21.39
5	2.30- 2.67	0.37	32.34 33.39	5.98 6.18	1.77 1.64	10.57 10.15
6	2.67- 3.17	0.50	33.39 35.44	8.35 8.86	1.35 1.19	11.30 10.51
7	3.17- 4.19	1.02	35.44 39.11	18.07 19.95	0.68 0.34	12.29 6.78
			ΣP=	106.83	ΣM=	167.56

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_i = 0.0 kN/m
depth to acting position H_i = 0.0 m
moment M_{in} = 0.0 kN·m/m
depth to acting position H_{in} = 0.00 m
Height from riverbed to top of coping H = 4.19 m
Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 0.00 \text{ kN} \cdot \text{m}$$

h₀ Height of acting position of P₀ from imaginary riverbed

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	1.82- 2.82	1.00	0.0 2.6	0.00 1.32	2.04 1.70	0.00 2.25
2	2.82- 3.82	1.00	2.6 3.7	1.32 1.87	1.04 0.70	1.37 1.31
3	3.82- 4.19	0.37	3.7 4.1	0.69 0.75	0.25 0.12	0.17 0.09
			ΣP ₀ =	5.95	Σ M ₀ =	5.19

h₀ Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0i}}{\Sigma P + P_i + \Sigma P_{0i}}$$
$$= \frac{774.08}{233.33} = 3.32 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 233.33}{4.19} = 111.38 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name	10 H _ H 550 -200 - 12-16-13
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 = 0.83
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 177600 cm ⁴ (original condition) I = 147408 cm ⁴ (after reduction by corrosion and section)
El = 200000 × 10 ³ × 147408 × 10 ⁻⁸	= 2.948 × 10 ⁵

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_s = \frac{\sqrt{(1+2\beta h_0)^2 + 1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_s$$

$$1_s = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$1_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i}$$
$$= \frac{378.32}{157.13} = 2.41 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 157.13}{4.19} = 75.00 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.67	0.67	0.00 8.95	0.00 3.00	3.97 3.74	0.00 11.22
2	0.67- 0.74	0.07	8.07 8.91	0.28 0.31	3.50 3.47	0.99 1.08
3	0.74- 1.67	0.93	10.10 21.87	4.70 10.17	3.14 2.83	14.75 28.77
4	1.67- 1.82	0.15	21.87 23.76	1.64 1.78	2.47 2.42	4.05 4.31
5	1.82- 2.67	0.85	23.76 26.19	10.10 11.13	2.09 1.80	21.07 20.07
6	2.67- 3.17	0.50	26.19 28.24	6.55 7.06	1.35 1.19	8.86 8.38
7	3.17- 4.19	1.02	28.24 31.91	14.40 16.27	0.68 0.34	9.79 5.53
			ΣP=	87.38	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_i = 140.0 kN/m
depth to acting position H_i = 0.00 m
moment M_{in} = 43.4 kN·m/m
depth to acting position H_{in} = 0.00 m
Height from riverbed to top of coping H = 4.19 m
Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{in} = 630.0 \text{ kN} \cdot \text{m}$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction K_b = 33639 kN/m³
calculated value β = 0.41097 m⁻¹
resultant earth force (lateral) P₀ = 157.13 kN/m
height of acting position of load h₀ = 2.41 m
moment M₀ = 378.32 kN·m/m

in consideration of ψ_{in} = 1.149,

maximum moment

depth of generated position of M_{max}

depth of 1st fixed point

M_{max} = 434.53 kN·m/m
l_m = 0.788 m
l_i = 2.699 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction K_b = 67279 kN/m³
calculated value β = 0.48873 m⁻¹
resultant earth force (lateral) P₀ = 233.33 kN/m
height of acting position of load h₀ = 3.32 m
moment M₀ = 774.08 kN·m/m

in consideration of ψ_{in} = 1.066,

maximum moment

depth of generated position of M_{max}

depth of 1st fixed point

M_{max} = 825.53 kN·m/m
l_m = 0.474 m
l_i = 2.081 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name	10 H _ H 550 -200 - 12-16-13
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 = 3990 cm ³ (original condition) Z = 3315 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{434.53 \times 10^6}{3315 \times 10^3} = 131 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

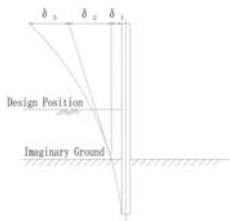
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{825.53 \times 10^6}{3315 \times 10^3} = 249 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

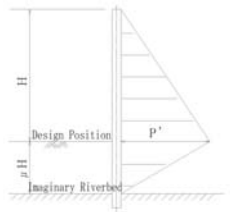


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.4110 \times 2.41) \times 157.13}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4110^3} = 0.00764 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_k)$$

$$= \frac{(1 + 2 \times 0.4110 \times 2.41) \times 157.13}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4110^3} \times (4.19 + 0.00) = 0.01969 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.00}{4.19} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{75.00 \times 4.19^4}{120 \times 2.00 \times 10^8 \times 147408 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4)$$

$$= 0.00261 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00764 + 0.01969 + 0.00261$$

$$= 0.02995 \text{ m}$$

$$\text{Size} = 29.95 \leq \delta_a = 50.00 \text{ mm}$$

$$\mu = \frac{L_k}{H} = \frac{0.00}{4.19} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{111.38 \times 4.19^4}{120 \times 2.00 \times 10^8 \times 147408 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4)$$

$$= 0.00388 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00889 + 0.02945 + 0.00388$$

$$= 0.04222 \text{ m}$$

$$\text{Size} = 42.22 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H ₁ H 550 -200 - 12-16-13
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 = 177600 cm ⁴ (original condition)
	I = 177600 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 177600 × 10 ⁻⁸	= 3.552 × 10 ⁶

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:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{11} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _b = 33639 kN/m ³
Calculated value	β = 0.39226 m ⁻¹

$$\text{Penetration length of SSP} \quad D = 0.00 + \frac{3}{0.392} = 7.65 \text{ m}$$

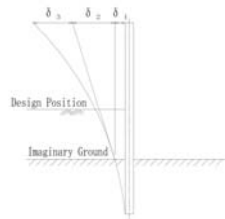
$$\text{Whole length of SSP} \quad L = 4.19 - 0.40 + 7.65 = 11.44 \text{ m}$$

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

Displacement Calculation

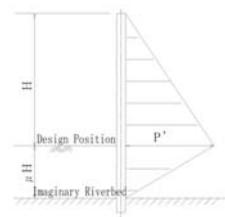


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.4887 \times 3.32) \times 233.33}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4887^3} = 0.00889 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_k)$$

$$= \frac{(1 + 2 \times 0.4887 \times 3.32) \times 233.33}{2 \times 2.00 \times 10^8 \times 147408 \times 10^{-8} \times 0.4887^3} \times (4.19 + 0.00) = 0.02945 \text{ m}$$



7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K _b = 67279 kN/m ³
Calculated value	β = 0.46648 m ⁻¹

$$\text{Penetration length of SSP} \quad D = 0.00 + \frac{3}{0.466} = 6.43 \text{ m}$$

$$\text{Whole length of SSP} \quad L = 4.19 - 0.40 + 6.43 = 10.22 \text{ m}$$

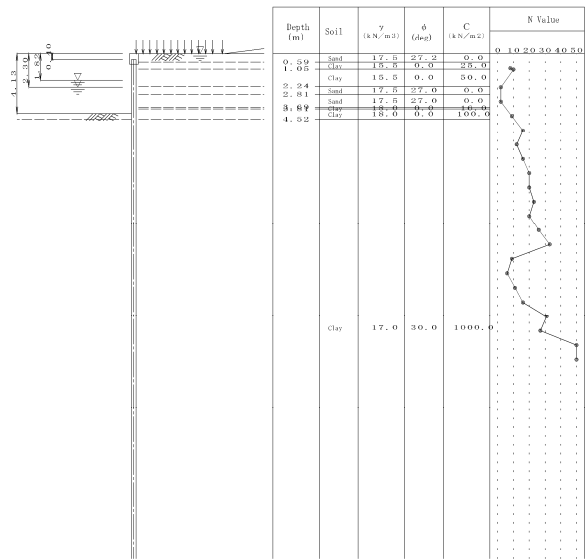
Therefore, the total length of the sheet pile is 11.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H ₁ H 550 -200 - 12-16-13				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	177600		
Sectional Modulus	Z (cm ³)	3900		
Maximum bending moment	M _{max} (kN · m · m)		434.53	825.53
Stress intensity	σ (N/mm ²)		131.4 (180)	269.4 (270)
Lateral displacement	δ (mm)		29.95 (50.0)	42.22 (75.0)
Penetration depths	D (m)		7.65	6.43
Whole length of SSP	L (m)	11.50		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	=	4.13 m
Depth from coping top to rear side ground	H ₀	=	0.00 m
Depth from coping top to SSP top	H _a	=	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}	=	1.82 m (Seismic Condition)

Block No. : R-26
Sta. : 10+760~10+820

Design Cross Section : Sta 10+780
Boring Name : DD-BH-R13

Specification : SSP SP-10H
(Combined) : H 400-200-9-12-13

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered

Wind load, Impact load not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope not considered

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

Angle of rupture (clayey soil)

$$\begin{aligned} a &= \sin \theta \\ b &= \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q} \end{aligned}$$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_{50} = K_{50} \left(\frac{B_H}{0.3} \right)^{-3/4}$
	$K_{50} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$
	$B_H = 10.00 \text{ m}$
	$E_0 = 2800 \text{ N}$
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	1.00	8	11	10.31	23	21	20.31	50
2	1.09	10	12	11.31	20	22	21.31	50
3	2.31	2	13	12.31	26			
4	3.31	2	14	13.31	33			
5	4.31	9	15	14.31	9			
6	5.31	16	16	15.31	6			
7	6.31	12	17	16.31	11			
8	7.31	16	18	17.31	16			
9	8.31	20	19	18.31	31			
10	9.31	20	20	19.31	27			

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 (Include Projection Length)	Thickness m (excluding projected length)
1	0.59	0.59
2	1.05	0.46
3	2.24	1.19
4	2.81	0.57
5	3.69	0.88
6	3.81	0.12
7	4.52	0.71
8	33.70	29.18

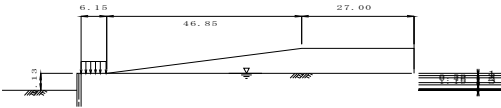
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.59	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
2	1.05	C	7.8	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
3	2.24	C	9.9	15.50	5.70	0.0	50.0	0.0	0.200	Auto	Auto
4	2.81	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	3.69	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	3.81	C	2.0	18.00	8.20	0.0	16.0	0.0	0.200	Auto	Auto
7	4.52	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
8	33.70	C	121.5	17.00	7.20	30.0	1000.0	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 (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



No		X Coordinate				Thickness		soil single weight γ		internal friction angle		stickiness		decay angle ζ	
		Bottom Left	Top Left	Top Right	Bottom Right	h	m	Normal Condition	Seismic Condition	ϕ	degree	C	kN/m ²	Normal Condition	Seismic Condition
1	Sand	6.15	53.00	80.00	80.00	6.01	19.0	19.0	19.0	30.0	0.0	Auto	Auto	Auto	Auto

No		load area		load strength	
		From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1		0.00	6.00	5.0	0.0

Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 400 -200 -9 -12 -13
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 87800 cm ⁴
Sectional factor	Z ₀	= 2320 cm ³
Corrosion margin	t ₁	= 1.00 mm (riverside)
	t ₂	= 1.00 mm (landside)
Corrosion rate (to I ₀)	η	= 0.80
Corrosion rate (to Z ₀)	η	= 0.81
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

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.32	0.00	0.00	0.32	0.32
2	45.00	0.12	0.32	0.32	0.44	0.44
3	54.81	0.88	0.44	0.44	1.06	1.32
4	54.81	0.57	1.06	1.32	1.46	1.89
5	45.00	1.19	1.46	1.89	2.65	3.08
6	45.00	0.46	2.65	3.08	3.11	3.54
7	54.95	0.59	3.11	3.54	3.53	4.13

From the above table, the loading width (L) on the ground surface is 3.53 m.

2.1.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qel kN/m
1	5.0	3.53	17.63
Σ			17.63

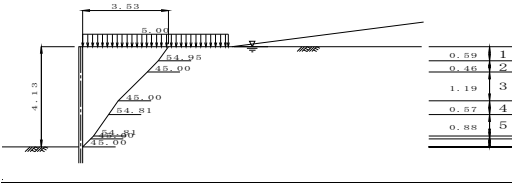
Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{0.00 + 17.63 + 0.00}{3.53}$$
$$= 5.00 \text{ kN/m}^2$$

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	γ whw kN/m ²	Angle of Rupture ζ degree
1	4.13 ~ 3.81	Clay	0.0	15.0	100.0	28.72	5.00	40.47	45.00
2	3.81 ~ 3.69	Clay	0.0	15.0	16.0	26.10	5.00	37.34	45.00
3	3.69 ~ 2.81	Sand	27.0	15.0	0.0	25.11	5.00	36.16	54.81
4	2.81 ~ 2.24	Sand	27.0	15.0	0.0	18.34	5.00	27.54	54.81
5	2.24 ~ 1.05	Clay	0.0	15.0	50.0	13.95	5.00	21.95	45.00
6	1.05 ~ 0.59	Clay	0.0	15.0	25.0	7.16	5.00	10.29	45.00
7	0.59 ~ 0.00	Sand	27.2	15.0	0.0	4.54	5.00	5.78	54.95

• 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

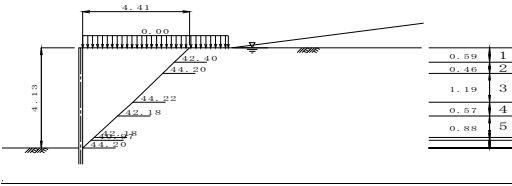
$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0^\circ$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)
- ϕ : internal friction angle (degree)
- δ : wall friction angle (degree)

2.2 Seismic 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	γ whw kN/m ²	k (k')	θ degree	Angle of Rupture ζ degree
1	4.13 ~ 3.81	Clay	0.0	15.0	100.0	28.72	0.00	40.47	0.200	11.31	44.20
2	3.81 ~ 3.69	Clay	0.0	15.0	16.0	26.10	0.00	37.34	0.200	11.31	40.97
3	3.69 ~ 2.81	Sand	27.0	15.0	0.0	25.11	0.00	36.16	0.200	11.31	42.18
4	2.81 ~ 2.24	Sand	27.0	15.0	0.0	18.34	0.00	27.54	0.200	11.31	42.18
5	2.24 ~ 1.05	Clay	0.0	15.0	50.0	13.95	0.00	21.95	0.200	11.31	44.22
6	1.05 ~ 0.59	Clay	0.0	15.0	25.0	7.16	0.00	10.29	0.200	11.31	44.20
7	0.59 ~ 0.00	Sand	27.2	15.0	0.0	4.54	0.00	5.78	0.200	11.31	42.40

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	44.20	0.32	0.00	0.00	0.33	0.32
2	40.97	0.12	0.33	0.32	0.47	0.44
3	42.18	0.88	0.47	0.44	1.44	1.32
4	42.18	0.57	1.44	1.32	2.07	1.89
5	44.22	1.19	2.07	1.89	3.29	3.08
6	44.20	0.46	3.29	3.08	3.76	3.54
7	42.40	0.59	3.76	3.54	4.41	4.13

From the above table, the loading width (L) on the ground surface is 4.41 m.

2.2.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qxl kN/m
1	0.0	4.41	0.00
Σ			0.00

Q : width of surcharge load set by line of active rupture

l: Loading width of uniform load surrounded by main collapse line

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{0.00 + 0.00 + 0.00}{4.41}$$

$$= 0.00 \text{ kN/m}^2$$

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Qp$ kN/m ²	Kp	$Kp \times \cos \delta$
9	4.13- 4.52	Clay	8.2	0.0	100.0 100.0	0.000 3.198	_____	_____
10	4.52- 33.70	Clay	7.2	30.0	1000.0 1000.0	3.198 213.294	_____	_____

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

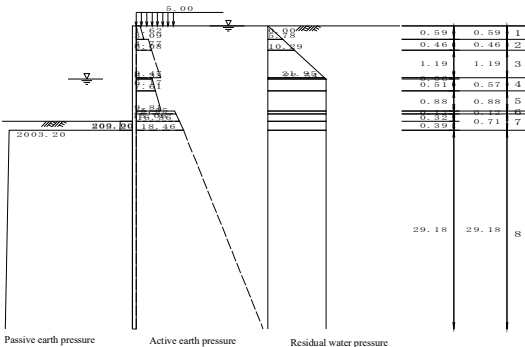
3.1.3 Lateral Forth

No	Depth m	Active				Residual water pressure		Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Pp kN/m ²	
1	0.00- 0.59	1.62 3.09	_____	1.62 3.09	0.00 5.78	_____	_____	_____
2	0.59- 1.05	-40.46 -37.83	4.77 6.08	4.77 6.08	5.78 10.29	_____	_____	_____
3	1.05- 2.24	-87.83 -81.05	6.08 9.47	6.08 9.47	10.29 21.95	_____	_____	_____
4	2.24- 2.30	6.17 6.33	_____	6.17 6.33	21.95 22.54	_____	_____	_____
5	2.30- 2.81	6.33 7.61	_____	6.33 7.61	22.54 22.54	_____	_____	_____
6	2.81- 3.69	7.61 9.81	_____	7.61 9.81	22.54 22.54	_____	_____	_____
7	3.69- 3.81	-1.89 -0.90	15.06 15.55	15.06 15.55	22.54 22.54	_____	_____	_____
8	3.81- 4.13	-168.90 -166.28	15.55 16.86	15.55 16.86	22.54 22.54	_____	_____	_____
9	4.13- 4.52	-166.28 -163.08	16.86 18.46	16.86 18.46	22.54 22.54	200.20 203.20	_____	_____
10	4.52- 33.70	-1963.08 -1752.98	18.46 123.51	18.46 123.51	22.54 22.54	2003.20 2213.29	_____	_____

- Formula for active earth pressure

3 Lateral Forth

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	$\Sigma \gamma \cdot h + Qa$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00- 0.59	Sand	7.7	27.2	_____	5.000 9.543	0.33489 0.32348
2	0.59- 1.05	Clay	5.7	_____	25.0 25.0	9.543 12.165	_____
3	1.05- 2.24	Clay	5.7	_____	50.0 50.0	12.165 18.948	_____
4	2.24- 2.30	Sand	7.7	27.0	_____	18.948 19.410	0.32378 0.32378
5	2.30- 2.81	Sand	7.7	27.0	_____	19.410 23.337	0.32378 0.32378
6	2.81- 3.69	Sand	7.7	27.0	_____	23.337 30.113	0.32378 0.32378
7	3.69- 3.81	Clay	8.2	_____	16.0 16.0	30.113 31.097	_____
8	3.81- 4.13	Clay	8.2	_____	100.0 100.0	31.097 33.721	_____
9	4.13- 4.52	Clay	8.2	_____	100.0 100.0	33.721 36.919	_____
10	4.52- 33.70	Clay	7.2	_____	1000.0 1000.0	36.919 247.015	_____

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma \cdot h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma \cdot h + Q)$$

K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma \cdot h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

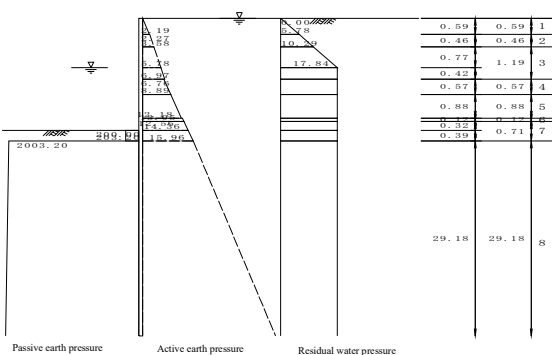
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma \cdot h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma \cdot h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q$ kN/m ²	$\gamma \cdot \sin \theta$ kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 0.59	Sand	7.7	27.2	_____	0.00 4.54	0.00 5.78	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	_____
2	0.59- 1.05	Clay	5.7	_____	25.0 25.0	4.54 7.17	5.78 10.29	0.200 0.200	11.31 11.31	_____	_____	44.49 44.20
3	1.05- 1.82	Clay	5.7	_____	50.0 50.0	7.17 11.55	10.29 17.84	0.200 0.200	11.31 11.31	_____	_____	44.60 44.35
4	1.82- 2.24	Clay	5.7	_____	50.0 50.0	11.55 13.95	17.84 21.95	0.200 0.200	11.31 11.31	_____	_____	44.35 44.22
5	2.24- 2.81	Sand	7.7	27.0	_____	13.95 18.34	21.95 27.54	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	_____

6	2.81- 3.69	Sand	7.7	27.0	—	18.34 25.11	27.54 36.16	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
7	3.69- 3.81	Clay	8.2	—	16.0 16.0	25.11 26.10	36.16 37.34	0.200 0.200	11.31 11.31	—	—	41.10 40.97
8	3.81- 4.13	Clay	8.2	—	100.0 100.0	26.10 28.72	37.34 40.47	0.200 0.200	11.31 11.31	—	—	44.27 44.20
9	4.13- 4.52	Clay	8.2	—	100.0 100.0	28.72 31.92	40.47 44.30	0.200 0.200	11.31 11.31	—	—	44.20 44.11
10	4.52- 33.70	Clay	7.2	—	1000.0 1000.0	31.92 242.02	44.30 330.26	0.200 0.200	11.31 11.31	—	—	44.91 44.32

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

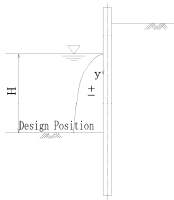
No	Depth m	Soil	γ kN/m ³	δ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{side} kN/m ³	k (ϕ)	θ degree	Kp	Kp $\times \cos \delta$
9	4.13- 4.52	Clay	8.20	0.0	100.0 100.0	0.000 3.198	0.00 3.82	0.200 0.200	11.31 11.31	—	—
10	4.52- 33.70	Clay	7.20	30.0	1000.0 1000.0	3.198 213.294	3.82 289.79	0.200 0.200	11.31 11.31	—	—

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

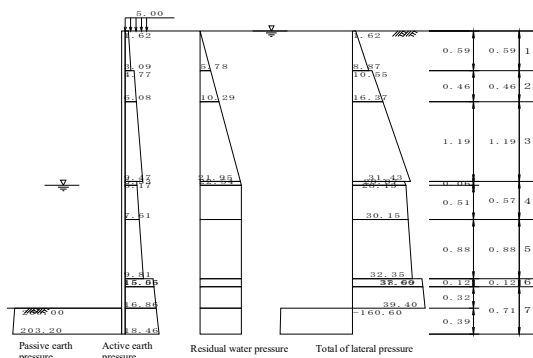
No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²		Pp kN/m ²	
1	0.00- 0.59	0.00 2.19	—	—	0.00 5.78	—	—	—
2	0.59- 1.05	-44.54 -41.38	2.27 3.58	2.27 3.58	5.78 10.29	—	—	—
3	1.05- 1.82	-91.39 -86.11	3.58 5.78	3.58 5.78	10.29 17.84	—	—	—



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



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.59	1.62 3.09	0.00 5.78	—	1.62 8.87
2	0.59- 1.05	4.77 6.08	5.78 10.29	—	10.55 16.37
3	1.05- 2.24	6.08 9.47	10.29 21.95	—	16.37 31.43
4	2.24- 2.30	6.17 6.33	21.95 22.54	—	28.13 28.87
5	2.30- 2.81	6.33 7.61	22.54 22.54	—	28.87 30.15

4	1.82- 2.24	-86.11 -83.22	5.78 6.97	5.78 6.97	17.84 17.84	—
5	2.24- 2.81	6.76 8.89	—	6.76 8.89	17.84 17.84	—
6	2.81- 3.69	8.89 12.18	—	8.89 12.18	17.84 17.84	—
7	3.69- 3.81	-1.43 -0.21	12.56 13.05	12.56 13.05	17.84 17.84	—
8	3.81- 4.13	-168.61 -165.45	13.05 14.36	13.05 14.36	17.84 17.84	—
9	4.13- 4.52	-165.45 -161.59	14.36 15.96	14.36 15.96	17.84 17.84	200.00 203.20
10	4.52- 33.70	-1961.69 -1708.98	15.96 121.01	15.96 121.01	17.84 17.84	2032.20 2213.29

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_c : Equilibrium coefficient of compression: 0.5
 Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m ²
1	1.82	0.00	0.00
2	2.82	1.00	2.61
3	3.82	2.00	3.69
4	4.13	2.31	3.96

$$p_{dw} = \pm \frac{7}{8} k_{hw} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

k_{hw} : 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

6	2.81- 3.69	7.61 9.81	22.54 22.54	—	30.15 32.35
7	3.69- 3.81	15.06 15.55	22.54 22.54	—	37.60 38.09
8	3.81- 4.13	15.55 16.86	22.54 22.54	—	38.09 39.40
9	4.13- 4.52	16.86 18.46	22.54 22.54	200.00 203.20	-160.60 -162.20

P_a : Active earth pressure

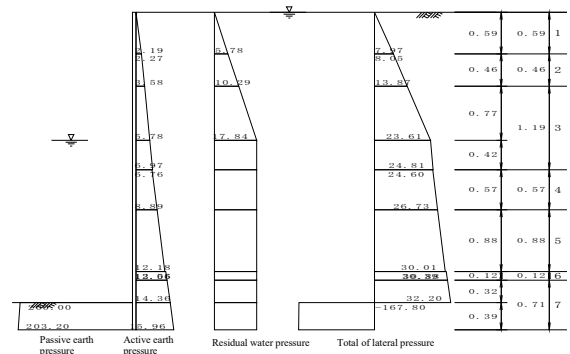
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 0.00 m (GL -4.13 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.59	0.00 2.19	0.00 5.78	—	0.00 7.97
2	0.59- 1.05	2.27 3.58	5.78 10.29	—	8.05 13.87
3	1.05- 1.82	3.58 5.78	10.29 17.84	—	13.87 23.61
4	1.82- 2.24	5.78 6.97	17.84 17.84	—	23.61 24.81
5	2.24- 2.81	6.76 8.89	17.84 17.84	—	24.60 28.73
6	2.81- 3.69	8.89 12.18	17.84 17.84	—	26.73 30.01

7	3.69- 3.81	12.56 13.05	17.84 17.84	———— ————	30.39 30.88
8	3.81- 4.13	11.05 14.36	17.84 17.84	———— ————	30.88 32.20
9	4.13- 4.52	14.36 15.96	17.84 17.84	200.00 203.20	-167.80 -169.40

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_A : 0.00 m (GL -4.13 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{\Delta} = K_{\Delta 0} \left(\frac{B_{\Delta}}{0.3} \right)^{-3/4} \quad (B_{\Delta} = 10.00\text{m})$$

$$K_{\Delta 0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = \sqrt[4]{\frac{K_{\Delta} \cdot B}{4 E I}}$$

Material Name 10 H_H 400 -200 -9 -12 -13
Unit width $B = 1.0000\text{ m}$
Corrosion margin $t_1 = 1.00\text{ mm (active side)}$ $t_2 = 1.00\text{ mm (passive side)}$
Corrosion rate $\eta_1 = 0.80$
Section efficiency $\eta = 1.00$
Young's modulus $E = 200000\text{ N/mm}^2$
Inertia sectional moment $I_0 = 87800\text{ cm}^4$ (original condition)
 $I = 70240\text{ cm}^4$ (after reduction by corrosion and section)
Inertia sectional moment $EI = 200000 \times 10^3 \times 70240 \times 10^{-8} = 1.405 \times 10^5$

No	Depth Z m	N Value	No	Depth Z m	N Value	No	Depth Z m	N Value
1	1.00	8	11	10.31	23	21	20.31	50
2	1.09	10	12	11.31	20	22	21.31	50
3	2.31	2	13	12.31	26			
4	3.31	2	14	13.31	33			
5	4.31	9	15	14.31	9			
6	5.31	16	16	15.31	6			
7	6.31	12	17	16.31	11			
8	7.31	16	18	17.31	16			
9	8.31	20	19	18.31	31			
10	9.31	20	20	19.31	27			

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.13	0.18	7.7	9.0	1.51
2	4.31	1.00	9.0	16.0	12.50
3	5.31	1.00	16.0	12.0	14.00
4	6.31	0.21	12.0	12.8	2.60
L = $\Sigma h = 2.39$			$\Sigma A = 30.61$		

A: (upper N-value + lower N-value) $\times$ h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$

$$= \frac{30.61}{2.39}$$

$$= 12.81$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 12.81 = 35867\text{ kN/m}^2$$

$$K_{\Delta 0} = \frac{1}{0.3} \times \alpha \times 35867 = 239111\text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_{\Delta} = K_{\Delta 0} (B_{\Delta}/0.3)^{-3/4} = 239111 (10.00/0.3)^{-3/4} = 17236\text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 17236 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.59	0.59	1.62 8.87	0.48 2.62	3.93 3.74	1.88 9.78
2	0.59- 1.05	0.46	10.55 16.37	2.43 3.77	3.39 3.23	8.22 12.18
3	1.05- 2.24	1.19	16.37 31.43	9.74 18.70	2.68 2.29	26.14 42.76
4	2.24- 2.30	0.06	28.13 28.87	0.84 0.87	1.87 1.85	1.58 1.60
5	2.30- 2.81	0.51	28.87 30.15	7.36 7.69	1.66 1.49	12.22 11.45
6	2.81- 3.69	0.88	30.15 32.35	13.26 14.24	1.03 0.73	13.62 10.44
7	3.69- 3.81	0.12	37.60 38.09	2.26 2.29	0.40 0.36	0.90 0.82

5.2 Normal Condition

Assuming Kh = 8715 kN/m³,

$$\beta = \sqrt[4]{\frac{K_{\Delta} \cdot B}{4 E I}} = 0.353\text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.83\text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.13 m) to 2.83 m depth (GL -6.96 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.13	0.18	7.7	9.0	1.51
2	4.31	1.00	9.0	16.0	12.50
3	5.31	1.00	16.0	12.0	14.00
4	6.31	0.65	12.0	14.6	8.70
L = $\Sigma h = 2.83$			$\Sigma A = 36.71$		

A: (upper N-value + lower N-value) $\times$ h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$

$$= \frac{36.71}{2.83}$$

$$= 12.95$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 12.95 = 36269\text{ kN/m}^2$$

$$K_{\Delta 0} = \frac{1}{0.3} \times \alpha \times 36269 = 120896\text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$K_{\Delta} = K_{\Delta 0} (B_{\Delta}/0.3)^{-3/4} = 120896 (10.00/0.3)^{-3/4} = 8715\text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 8715 kN/m³.

5.3 Seismic Condition

Assuming Kh = 17236 kN/m³,

$$\beta = \sqrt[4]{\frac{K_{\Delta} \cdot B}{4 E I}} = 0.419\text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.39\text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.13 m) and 2.39 m depth (GL -6.52 m).

8	3.81~ 4.13	0.32	38.09 39.40	6.09 6.30	0.21 0.11	1.30 0.67
$\Sigma P = 98.92 \quad \Sigma M = 155.55$						

P_s : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_s \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_t = 0.0\text{ kN/m}$
depth to acting position $H_t = 0.0\text{ m}$
moment $M_m = 0.0\text{ kN} \cdot \text{m/m}$
depth to acting position $H_m = 0.00\text{ m}$
Height from riverbed to top of coping $H = 4.13\text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 1.08\text{ m}$

Moment M_0 by arbitrary load is as below
 $M_0 = P_t \cdot (H + L_k - H_t) + M_m = 0.00\text{ kN} \cdot \text{m}$
 h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t}$$

$$= \frac{155.55}{98.92} = 1.57\text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 98.92}{4.13} = 47.90\text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.59	0.59	0.00 7.97	0.00 2.35	3.93 3.74	0.00 8.78
2	0.59- 1.05	0.46	8.05 13.87	1.85 3.19	3.39 3.23	6.27 10.32
3	1.05- 1.82	0.77	13.87 23.61	5.34 9.09	2.82 2.57	15.08 23.33
4	1.82- 2.24	0.42	23.61 24.81	4.96 5.21	2.17 2.03	10.76 10.58
5	2.24- 2.81	0.57	24.60 26.73	7.01 7.62	1.70 1.51	11.92 11.50
6	2.81- 3.69	0.88	26.73 30.01	11.76 13.21	1.03 0.73	12.07 9.68
7	3.69- 3.81	0.12	30.39 30.88	1.82 1.85	0.40 0.36	0.73 0.67
8	3.81- 4.13	0.32	30.88 32.20	4.94 5.15	0.21 0.11	1.05 0.55
			Σ P = 85.36	Σ M = 133.30		

P_s : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_s \times h/2 \times B$
 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 $P_l = 0.0 \text{ kN/m}$
depth to acting position $H_l = 0.00 \text{ m}$
moment $M_m = 0.0 \text{ kN}\cdot\text{m/m}$
depth to acting position $H_m = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 4.13 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.00 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_l \cdot (H + L_k - H_l) + M_m = 0.00 \text{ kN}\cdot\text{m}$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads p _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	1.82~ 2.82	1.00	0.0 2.6	0.00 1.30	1.98 1.64	0.00 2.14
	2.82~ 3.82		2.6 3.7	1.30 1.84	0.98 0.64	1.27 1.19
3	3.82~ 4.13	0.31	3.7 4.0	0.57 0.61	0.21 0.10	0.12 0.06
	Σ P _{hw} = 5.64		Σ M _{hw} = 4.78			

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{hw}}{\Sigma P + P_l + \Sigma P_{hw}} = \frac{138.09}{90.99} = 1.52 \text{ m}$$

When the resultant force of the Lateral Earth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 90.99}{4.13} = 44.06 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name 10 H _H 400 -200 -9 -12 -13
Unit width $B = 1.0000 \text{ m}$
Corrosion margin $t_1 = 1.00 \text{ mm (active side)}$ $t_2 = 1.00 \text{ mm (passive side)}$
Corrosion rate $\eta = 0.80$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 87800 \text{ cm}^4$ (original condition)
 $I = 70240 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 70240 \times 10^{-8} = 1.405 \times 10^5$

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{210.21 \times 10^6}{1879 \times 10^3} = 112 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

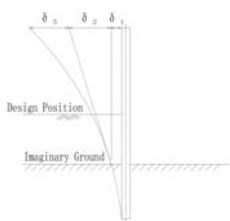
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{178.10 \times 10^6}{1879 \times 10^3} = 95 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3529 \times 1.57) \times 98.92}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3529^3} = 0.01246 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^3} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3529 \times 1.57) \times 98.92}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3529^3} \times (4.13 + 0.00) = 0.02464 \text{ m} \end{aligned}$$

$$\beta = \sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_b = 8715 \text{ kN/m}^3$
calculated value $\beta = 0.35289 \text{ m}^{-1}$
resultant earth force (lateral) $P_0 = 98.92 \text{ kN/m}$
height of acting position of load $h_0 = 1.57 \text{ m}$
moment $M_0 = 155.55 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{tm} = 1.351$,
maximum moment $M_{\max} = 210.21 \text{ kN}\cdot\text{m/m}$
depth of generated position of $M_{\max}$ $l_m = 1.254 \text{ m}$
depth of 1st fixed point $l_i = 3.480 \text{ m}$

6.2.2 Seismic Condition

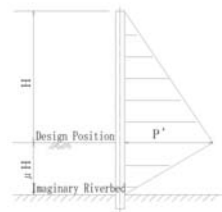
modulus of lateral subgrade reaction $K_b = 17236 \text{ kN/m}^3$
calculated value $\beta = 0.41850 \text{ m}^{-1}$
resultant earth force (lateral) $P_0 = 90.99 \text{ kN/m}$
height of acting position of load $h_0 = 1.52 \text{ m}$
moment $M_0 = 138.09 \text{ kN}\cdot\text{m/m}$

in consideration of $\psi_{tm} = 1.290$,
maximum moment $M_{\max} = 178.10 \text{ kN}\cdot\text{m/m}$
depth of generated position of $M_{\max}$ $l_m = 0.991 \text{ m}$
depth of 1st fixed point $l_i = 2.868 \text{ m}$

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as follows:

Material Name 10 H _H 400 -200 -9 -12 -13
Corrosion margin $t_1 = 1.00 \text{ mm (active side)}$ $t_2 = 1.00 \text{ mm (passive side)}$
Corrosion rate $\eta = 0.81$
Section efficiency $\mu = 1.00$
Module of section $Z_0 = 2320 \text{ cm}^3$ (original condition)
 $Z = 1879 \text{ cm}^3$ (after reduction by corrosion and section)



$$\mu = \frac{L_k}{H} = \frac{0.00}{4.13} = 0.000$$

$$\begin{aligned} \delta_3 &= \frac{P' \cdot H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{47.90 \times 4.13^4}{120 \times 2.00 \times 10^8 \times 70240 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4) \\ &= 0.00331 \text{ m} \end{aligned}$$

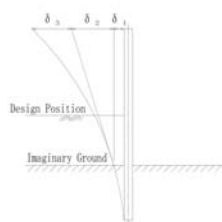
$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01246 + 0.02464 + 0.00331 \\ &= 0.04040 \text{ m} \\ \text{Size} &= 40.40 \text{ mm} \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

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

Displacement Calculation

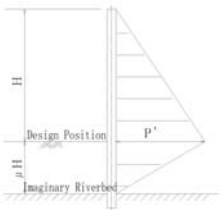


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.4185 \times 1.52) \times 90.99}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4185^3} = 0.00722 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u)$$

$$= \frac{(1 + 2 \times 0.4185 \times 1.52) \times 90.99}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4185^2} \times (4.13 + 0.00) = 0.01734 \text{ m}$$



$$\mu = \frac{L_u}{H} = \frac{0.00}{4.13} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4)$$

$$= \frac{44.06 \times 4.13^4}{120 \times 2.00 \times 10^8 \times 70240 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4)$$

$$= 0.00304 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00722 + 0.01734 + 0.00304$$

$$= 0.02760 \text{ m}$$

$$\text{Size} = 27.60 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H _H 400 -200 -9 -12 -13
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 = 87800 cm ⁴ (original condition)
	I = 87800 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 87800 × 10 ⁻⁸	= 1.756 × 10 ⁷

7.1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_u , penetration depth of SSP (D) and whole length of SSP (L) are calculated as follows:

$$D = L_u + \frac{3}{\beta}$$

$$L = H - H_{u1} + D$$

$$\beta = 4 \sqrt{\frac{K_u \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_u = 8715 kN/m ³
Calculated value	β = 0.33375 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.334}$ = 8.99 m
Whole length of SSP	L = 4.13 − 0.40 + 8.99 = 12.72 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_u = 17236 kN/m ³
Calculated value	β = 0.39579 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.396}$ = 7.58 m
Whole length of SSP	L = 4.13 − 0.40 + 7.58 = 11.31 m

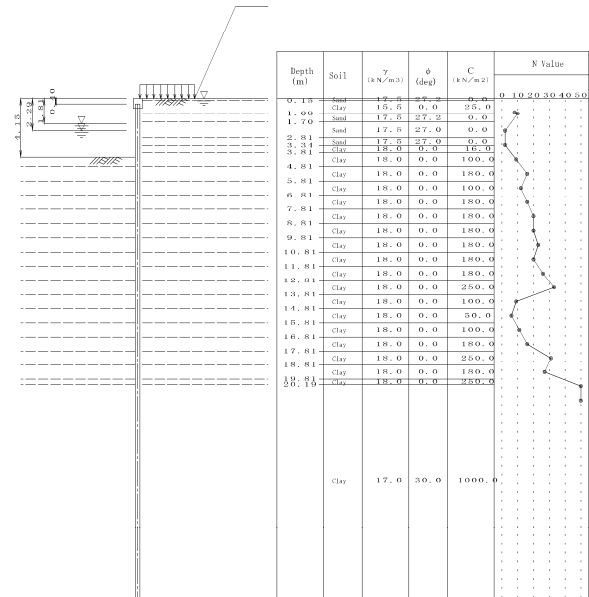
Therefore, the total length of the sheet pile is 13.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP		10 H _H 400 -200 -9 -12 -13		Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	87800			
Sectional Modulus	Z (cm ³)	2320			
Maximum bending moment	Mmax (N·m / m)		210.21	178.10	
Stress intensity	σ (N/mm ²)		112 (180)	95 (270)	
Lateral displacement	δ (mm)		40.40 (50.0)	27.60 (75.0)	
Penetration depth	D (m)		8.99	7.58	
Whole length of SSP	L (m)	13.00			

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 4.15 m
Depth from coping top to rear side ground	H ₀ = 0.00 m
Depth from coping top to SSP top	H _a = 0.40 m
Landside WL	L _{wa} = 0.00 m (Normal Condition)
	L _{wa} = 0.00 m (Seismic Condition)
Riverside WL	L _{wp} = 2.29 m (Normal Condition)
	L _{wp} = 1.81 m (Seismic Condition)

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

Note	depth :	from top of coping to bottom of the layer	C _o :	soil adhesion
	soil :	sandy(S), clayey(C), mixed (M)	a :	slope of soil adhesion
N-value	average N-value in the layer		k'	design seismic coefficient (underwater)
γ	wet unit weight of soil		ζ	angle of active rupture
γ'	saturated unit weight of soil		kh	modulus of subgrade reaction
ϕ	internal friction angle of soil			

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

3.85 2.87 23.28

4.15 0.15

0.15 0.15 0.15 1.15 0.15 0.15

No	Soil	X Coordinate				Thickness h m	soil single weight γ Normal Condition kN/m ³	Seismic Condition kN/m ³	internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m						Normal Condition degree	Seismic Condition degree
1	Sand	3.85	6.72	30.00	30.00	6.50	19.0	19.0	30.0	0.0	Auto	Auto

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	1.00	8	11	10.31	23	21	20.31	50
2	1.09	10	12	11.31	20	22	21.31	50
3	2.31	2	13	12.31	26			
4	3.31	2	14	13.31	33			
5	4.31	9	15	14.31	9			
6	5.31	16	16	15.31	6			
7	6.31	12	17	16.31	11			
8	7.31	16	18	17.31	16			
9	8.31	20	19	18.31	31			
10	9.31	20	20	19.31	27			

Vertical load on riverside not considered

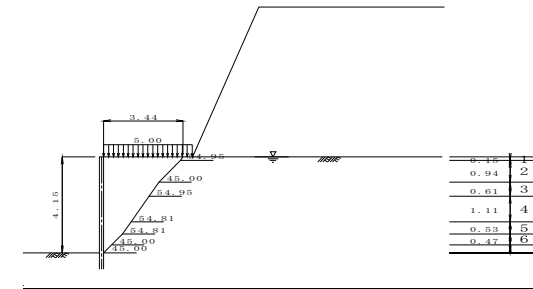
Soil Modulus		
No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	0.15	0.15
2	1.09	0.94
3	1.70	0.61
4	2.81	1.11
5	3.34	0.53
6	3.81	0.47
7	4.81	1.00
8	5.81	1.00
9	6.81	1.00
10	7.81	1.00
11	8.81	1.00
12	9.81	1.00
13	10.81	1.00
14	11.81	1.00
15	12.81	1.00
16	13.81	1.00
17	14.81	1.00
18	15.81	1.00
19	16.81	1.00
20	17.81	1.00
21	18.81	1.00
22	19.81	1.00
23	20.19	0.38
24	33.70	13.51

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	3.84	5.0	0.0

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	γ whw kN/m ²	Angle of Rupture ζ degree
1	4.15~3.81	Clay	0.0	15.0	100.0	30.48	5.00	40.67	45.00
2	3.81~3.34	Clay	0.0	15.0	16.0	27.69	5.00	37.34	45.00
3	3.34~2.81	Sand	27.0	15.0	0.0	23.84	5.00	32.73	54.81
4	2.81~1.70	Sand	27.0	15.0	0.0	19.76	5.00	27.54	54.81
5	1.70~1.09	Sand	27.2	15.0	0.0	11.21	5.00	16.66	54.95
6	1.09~0.15	Clay	0.0	15.0	25.0	6.51	5.00	10.68	45.00
7	0.15~0.00	Sand	27.2	15.0	0.0	1.15	5.00	1.47	54.95

• 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

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.34	0.00	0.00	0.34	0.34
2	45.00	0.47	0.34	0.34	0.81	0.81
3	54.81	0.53	0.81	0.81	1.18	1.34
4	54.81	1.11	1.18	1.34	1.97	2.45
5	54.95	0.61	1.97	2.45	2.39	3.06
6	45.00	0.94	2.39	3.06	3.33	4.00
7	54.95	0.15	3.33	4.00	3.44	4.15

From the above table, the loading width (L) on the ground surface is 3.44 m.

2.1.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qd kN/m
1	5.0	3.44	17.20
Σ			17.20

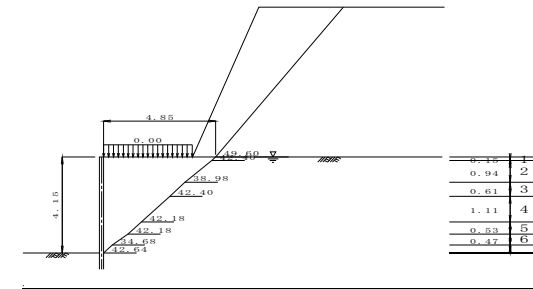
Q: width of surcharge load set by line of active rupture

l: Loading width of uniform load surrounded by main collapse line

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{0.00 + 17.20 + 0.00}{3.44}$$
$$= 5.00 \text{ kN/m}^2$$

2.2 Seismic 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	γ whw kN/m ²	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	4.15~3.81	Clay	0.0	15.0	100.0	30.48	59.38	40.67	0.200	11.31	42.64
2	3.81~3.34	Clay	0.0	15.0	16.0	27.69	59.38	37.34	0.200	11.31	34.68
3	3.34~2.81	Sand	27.0	15.0	0.0	23.84	59.38	32.73	0.200	11.31	42.18
4	2.81~1.70	Sand	27.0	15.0	0.0	19.76	59.38	27.54	0.200	11.31	42.18
5	1.70~1.09	Sand	27.2	15.0	0.0	11.21	59.38	16.66	0.200	11.31	42.40
6	1.09~0.15	Clay	0.0	15.0	25.0	6.51	59.38	10.68	0.200	11.31	38.98
7	0.15~0.00	Sand	27.2	15.0	0.0	1.15	59.38	1.47	0.200	11.31	42.40
8		embankment t	30.0	—	0.0	123.50	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.64	0.34	0.00	0.00	0.37	0.34
2	34.68	0.47	0.37	0.34	1.05	0.81
3	42.18	0.53	1.05	0.81	1.63	1.34
4	42.18	1.11	1.63	1.34	2.86	2.45
5	42.40	0.61	2.86	2.45	3.53	3.06
6	38.98	0.94	3.53	3.06	4.69	4.00
7	42.40	0.15	4.69	4.00	4.85	4.15
8	49.60	6.50	4.85	4.15	10.38	10.65

From the above table, the loading width (L) on the ground surface is 4.85 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	15.16	288.11
Σ			288.11

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	Qd kN/m
1	0.0	3.84	0.00
Σ			0.00

Q: width of surcharge load set by line of active rupture

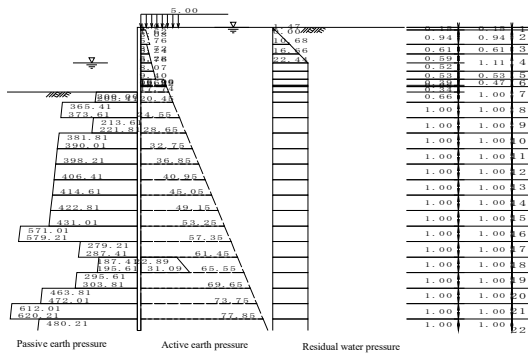
l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{288.11 + 0.00 + 0.00}{4.85}$$
$$= 59.38 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Q_a$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00~ 0.15	Sand	7.7	27.2	—	5.000 6.155	0.32489 0.32489	0.32348 0.32348
2	0.15~ 1.09	Clay	5.7	—	25.0 25.0	6.155 11.513	—	—
3	1.09~ 1.70	Sand	7.7	27.2	—	11.513 16.210	0.32489 0.32489	0.32348 0.32348
4	1.70~ 2.29	Sand	7.7	27.0	—	16.210 20.753	0.32378 0.32378	0.32589 0.32589
5	2.29~ 2.81	Sand	7.7	27.0	—	20.753 24.757	0.32378 0.32378	0.32589 0.32589
6	2.81~ 3.34	Sand	7.7	27.0	—	24.757 28.838	0.32378 0.32378	0.32589 0.32589
7	3.34~ 3.73	Clay	8.2	—	16.0 16.0	28.838 32.000	—	—
8	3.73~ 3.81	Clay	8.2	—	16.0 16.0	32.000 32.092	—	—
9	3.81~ 4.15	Clay	8.2	—	100.0 100.0	32.092 35.480	—	—
10	4.15~ 4.81	Clay	8.2	—	100.0 100.0	35.480 40.892	—	—
11	4.81~ 5.81	Clay	8.2	—	180.0 180.0	40.892 49.092	—	—
12	5.81~ 6.81	Clay	8.2	—	100.0 100.0	49.092 57.292	—	—

13	6.81~ 7.81	Clay	8.2	—	180.0 180.0	57.292 65.492	—	—
14	7.81~ 8.81	Clay	8.2	—	180.0 180.0	65.492 73.692	—	—
15	8.81~ 9.81	Clay	8.2	—	180.0 180.0	73.692 81.892	—	—
16	9.81~ 10.81	Clay	8.2	—	180.0 180.0	81.892 90.092	—	—
17	10.81~ 11.81	Clay	8.2	—	180.0 180.0	90.092 98.292	—	—
18	11.81~ 12.81	Clay	8.2	—	180.0 180.0	98.292 106.492	—	—
19	12.81~ 13.81	Clay	8.2	—	250.0 250.0	106.492 114.692	—	—
20	13.81~ 14.81	Clay	8.2	—	100.0 100.0	114.692 122.892	—	—
21	14.81~ 15.81	Clay	8.2	—	50.0 50.0	122.892 131.092	—	—
22	15.81~ 16.81	Clay	8.2	—	100.0 100.0	131.092 139.292	—	—
23	16.81~ 17.81	Clay	8.2	—	180.0 180.0	139.292 147.492	—	—
24	17.81~ 18.81	Clay	8.2	—	250.0 250.0	147.492 155.692	—	—
25	18.81~ 19.81	Clay	8.2	—	180.0 180.0	155.692 163.892	—	—
26	19.81~ 20.19	Clay	8.2	—	250.0 250.0	163.892 167.808	—	—
27	20.19~ 33.70	Clay	7.2	—	1000.0 1000.0	167.808 264.280	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	K_p	$K_p \times \cos \delta$
10	4.15~ 4.81	Clay	8.2	0.0	100.0 100.0	0.000 5.412	—	—
11	4.81~ 5.81	Clay	8.2	0.0	180.0 180.0	5.412 13.612	—	—
12	5.81~ 6.81	Clay	8.2	0.0	100.0 100.0	13.612 21.812	—	—
13	6.81~ 7.81	Clay	8.2	0.0	180.0 180.0	21.812 30.012	—	—
14	7.81~ 8.81	Clay	8.2	0.0	180.0 180.0	30.012 38.212	—	—
15	8.81~ 9.81	Clay	8.2	0.0	180.0 180.0	38.212 46.412	—	—

16	9.81~ 10.81	Clay	8.2	0.0	180.0 180.0	46.412 54.612	—	—
17	10.81~ 11.81	Clay	8.2	0.0	180.0 180.0	54.612 62.812	—	—
18	11.81~ 12.81	Clay	8.2	0.0	180.0 180.0	62.812 71.012	—	—
19	12.81~ 13.81	Clay	8.2	0.0	250.0 250.0	71.012 79.212	—	—
20	13.81~ 14.81	Clay	8.2	0.0	100.0 100.0	79.212 87.412	—	—
21	14.81~ 15.81	Clay	8.2	0.0	50.0 50.0	87.412 95.612	—	—
22	15.81~ 16.81	Clay	8.2	0.0	100.0 100.0	95.612 103.812	—	—
23	16.81~ 17.81	Clay	8.2	0.0	180.0 180.0	103.812 112.012	—	—
24	17.81~ 18.81	Clay	8.2	0.0	250.0 250.0	112.012 120.212	—	—
25	18.81~ 19.81	Clay	8.2	0.0	180.0 180.0	120.212 128.412	—	—
26	19.81~ 20.19	Clay	8.2	0.0	250.0 250.0	128.412 131.528	—	—
27	20.19~ 33.70	Clay	7.2	30.0	1000.0 1000.0	131.528 228.800	—	—

Coefficient of passive earth pressure of sandy soil K_p is calculated by the formula below;
 $\delta = -15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure P_w kN/m ²	Passive P_p kN/m ²
		$Pa1$ kN/m ²	$Pa2$ kN/m ²	Pa kN/m ²		
1	0.00~ 0.15	1.62 1.99	—	1.62 1.99	0.00 1.47	—
2	0.15~ 1.09	-43.85 -38.49	3.08 5.76	3.08 5.76	1.47 10.68	—
3	1.09~ 1.70	3.72 5.24	—	3.72 5.24	10.68 16.66	—
4	1.70~ 2.29	5.28 6.76	—	5.28 6.76	16.66 22.44	—
5	2.29~ 2.81	6.76 8.07	—	6.76 8.07	22.44 24.44	—
6	2.81~ 3.34	8.07 9.40	—	8.07 9.40	24.44 24.44	—
7	3.34~ 3.73	-3.16 0.00	14.42 16.00	14.42 16.00	22.44 22.44	—
8	3.73~ 3.81	0.00 0.69	16.00 16.35	16.00 16.35	22.44 22.44	—

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of $Pa1$ or $Pa2$ is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

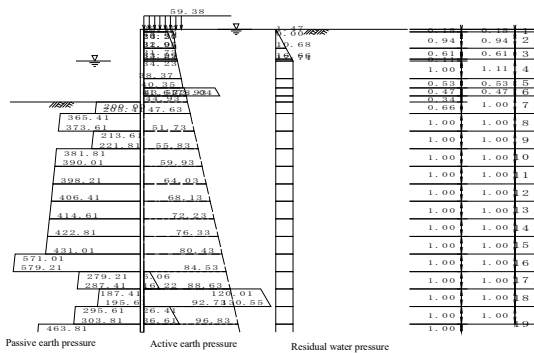
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Ka	$Ka \times \cos \delta$	ζ degree
1	0.00~0.15	Sand	7.7	27.2	—	59.38	0.00	0.200	11.31	0.49850	0.48152	—
2	0.15~1.09	Clay	5.7	—	25.0	60.53	1.47	0.200	11.31	—	—	39.38
3	1.09~1.70	Sand	7.7	27.2	—	65.89	10.68	0.200	11.31	0.49850	0.48152	—
4	1.70~1.81	Sand	7.7	27.0	—	70.59	16.66	0.200	11.31	0.49850	0.48152	—
5	1.81~2.81	Sand	7.7	27.0	—	71.43	17.74	0.200	11.31	0.50201	0.48490	—
6	2.81~3.34	Sand	7.7	27.0	—	79.13	27.54	0.200	11.31	0.50201	0.48490	—
7	3.34~3.81	Clay	8.2	—	16.0	83.21	32.73	0.200	11.31	—	—	35.00
8	3.81~4.15	Clay	8.2	—	100.0	87.07	37.34	0.200	11.31	—	—	42.70
9	4.15~4.81	Clay	8.2	—	100.0	89.86	40.67	0.200	11.31	—	—	42.64
10	4.81~5.81	Clay	8.2	—	100.0	95.27	47.14	0.200	11.31	—	—	43.56
11	5.81~6.81	Clay	8.2	—	100.0	103.47	56.94	0.200	11.31	—	—	42.31

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Ka	$Ka \times \cos \delta$	ζ degree
12	6.81~7.81	Clay	8.2	—	180.0	111.67	66.74	0.200	11.31	—	—	43.33
13	7.81~8.81	Clay	8.2	—	180.0	119.87	76.54	0.200	11.31	—	—	43.10
14	8.81~9.81	Clay	8.2	—	180.0	128.07	86.34	0.200	11.31	—	—	43.10
15	9.81~10.81	Clay	8.2	—	180.0	136.27	96.14	0.200	11.31	—	—	42.98
16	10.81~11.81	Clay	8.2	—	180.0	144.47	105.94	0.200	11.31	—	—	42.87
17	11.81~12.81	Clay	8.2	—	180.0	152.67	115.74	0.200	11.31	—	—	42.76
18	12.81~13.81	Clay	8.2	—	250.0	160.87	125.54	0.200	11.31	—	—	42.76
19	13.81~14.81	Clay	8.2	—	250.0	169.07	135.34	0.200	11.31	—	—	42.65
20	14.81~15.81	Clay	8.2	—	100.0	177.27	145.14	0.200	11.31	—	—	42.31
21	15.81~16.81	Clay	8.2	—	100.0	185.47	154.94	0.200	11.31	—	—	42.31
22	16.81~17.81	Clay	8.2	—	100.0	193.67	164.74	0.200	11.31	—	—	42.11
23	17.81~18.81	Clay	8.2	—	180.0	201.87	174.54	0.200	11.31	—	—	42.11
24	18.81~19.81	Clay	8.2	—	250.0	210.07	184.34	0.200	11.31	—	—	42.86
25	19.81~20.19	Clay	8.2	—	250.0	218.27	194.14	0.200	11.31	—	—	42.78
26	20.19~33.70	Clay	7.2	—	1000.0	226.47	203.94	0.200	11.31	—	—	42.00

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)} \right]}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = 45^\circ - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{whw} kN/m ²	k (k ²)	θ degree	Kp	$Kp \times \cos \delta$
9	4.15~4.81	Clay	8.20	0.0	100.0	0.000	0.00	0.200	11.31	—	—
10	4.81~5.81	Clay	8.20	0.0	180.0	5.412	6.47	0.200	11.31	—	—

11	5.81~6.81	Clay	8.20	0.0	100.0	13.612	16.27	0.200	11.31	—	—
12	6.81~7.81	Clay	8.20	0.0	180.0	21.812	26.07	0.200	11.31	—	—
13	7.81~8.81	Clay	8.20	0.0	180.0	30.012	35.87	0.200	11.31	—	—
14	8.81~9.81	Clay	8.20	0.0	180.0	38.212	45.67	0.200	11.31	—	—
15	9.81~10.81	Clay	8.20	0.0	180.0	46.412	55.47	0.200	11.31	—	—
16	10.81~11.81	Clay	8.20	0.0	180.0	54.612	65.27	0.200	11.31	—	—
17	11.81~12.81	Clay	8.20	0.0	180.0	62.812	75.07	0.200	11.31	—	—
18	12.81~13.81	Clay	8.20	0.0	250.0	71.012	84.87	0.200	11.31	—	—
19	13.81~14.81	Clay	8.20	0.0	250.0	79.212	94.67	0.200	11.31	—	—
20	14.81~15.81	Clay	8.20	0.0	100.0	87.412	104.47	0.200	11.31	—	—
21	15.81~16.81	Clay	8.20	0.0	50.0	95.612	114.27	0.200	11.31	—	—
22	16.81~17.81	Clay	8.20	0.0	100.0	103.812	124.07	0.200	11.31	—	—
23	17.81~18.81	Clay	8.20	0.0	180.0	112.012	133.87	0.200	11.31	—	—
24	18.81~19.81	Clay	8.20	0.0	250.0	120.212	143.67	0.200	11.31	—	—
25	19.81~20.19	Clay	8.20	0.0	180.0	128.412	153.47	0.200	11.31	—	—
26	20.19~33.70	Clay	7.20	30.0	1000.0	136.612	163.27	0.200	11.31	—	—

* The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.
 $\delta = 0.00^\circ$ degrees, $\beta = 0.00^\circ$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)} \right]}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		P_{a1} kN/m ²	P_{a2} kN/m ²	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²
1	0.00~0.15	28.59	—	28.59	0.00	—
2	0.15~1.09	24.30	30.27	32.94	1.47	—
3	1.09~1.70	31.73	—	31.73	10.68	—

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

$$K_a : \text{Equilibrium coefficient of compression: } 0.5$$

$$\text{Larger of } Pa1 \text{ or } Pa2 \text{ is applied as active earth pressure (Pa)}$$

$$\text{Mixed soil } P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m2
1	1.81	0.00	0.00
2	2.81	1.00	2.62
3	3.81	2.00	3.71
4	4.15	2.34	4.01

$$p_{dw} = \pm \frac{7}{8} k_{dw} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

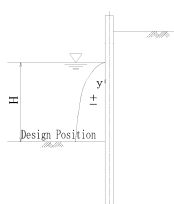
Where,

k_{dw} : design seismic coefficient

γ_w : unit weight of water

H: water depth of riverside

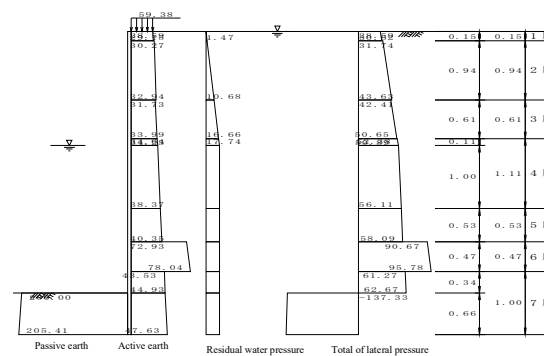
y: depth from water surface to the point where active water pressure is calculated



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.

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.15	28.59 29.15	0.00 1.47	— —	28.59 30.62
2	0.15- 1.09	30.27 32.94	1.47 10.68	— —	31.74 43.63
3	1.09- 1.70	31.73 33.99	10.68 16.66	— —	42.41 50.65
4	1.70- 1.81	34.23 34.64	16.66 17.74	— —	50.89 52.38
5	1.81- 2.81	34.64 38.37	17.74 17.74	— —	52.38 56.11
6	2.81- 3.34	38.37 40.35	17.74 17.74	— —	56.11 58.09
7	3.34- 3.81	72.93 78.04	17.74 17.74	— —	90.67 95.78
8	3.81- 4.15	43.53 44.93	17.74 17.74	— —	61.27 62.67
9	4.15- 4.81	44.93 47.63	17.74 17.74	200.00 205.41	-137.33 -140.04

Pa: Active earth pressure

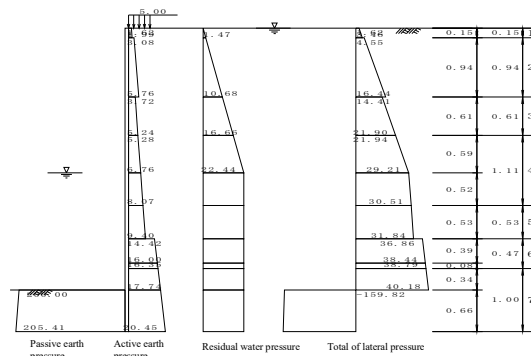
Pw: Residual water pressure

Pp: Passive earth pressure

Ps: Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed Lk: 0.00 m (GL -4.15 m)

4.1 Normal Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 0.15	1.62 1.99	0.00 1.47	— —	1.62 3.46
2	0.15- 1.09	3.08 5.76	1.47 10.68	— —	4.55 16.44
3	1.09- 1.70	3.72 5.24	10.68 16.66	— —	14.41 21.90
4	1.70- 2.29	5.28 6.76	16.66 22.44	— —	21.94 29.21
5	2.29- 2.81	6.76 8.07	22.44 22.44	— —	29.21 30.51
6	2.81- 3.34	8.07 9.40	22.44 22.44	— —	30.51 31.84
7	3.34- 3.73	14.42 16.00	22.44 22.44	— —	36.86 38.44
8	3.73- 3.81	16.00 16.35	22.44 22.44	— —	38.44 38.79
9	3.81- 4.15	16.35 17.74	22.44 22.44	— —	38.79 40.18
10	4.15- 4.81	17.74 20.45	22.44 22.44	200.00 205.41	-159.82 -162.52

Pa: Active earth pressure

Pw: Residual water pressure

Pp: Passive earth pressure

Ps: Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed Lk: 0.00 m (GL -4.15 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_h = K_{h0} \left(\frac{B_H}{0.3} \right)^{-3/4} \quad (B_H = 10, 00m)$$

$$K_{h0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4 E I}}$$

Material Name

Unit width B = 1.0000 m

Corrosion margin $t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)

Corrosion rate $\eta = 0.87$

Section efficiency $\mu = 1.00$

Young's modulus E = 200000 N/mm²

Inertia sectional moment $I_0 = 892400$ cm⁴(original condition)

I = 776388 cm⁴(after reduction by corrosion and section)

Inertia sectional moment EI = 200000 × 10³ × 776388 × 10⁻⁸ = 1.553 × 10⁶

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	1.00	8	11	10.31	23	21	20.31	50
2	1.09	10	12	11.31	20	22	21.31	50
3	2.31	2	13	12.31	26			
4	3.31	2	14	13.31	33			
5	4.31	9	15	14.31	9			
6	5.31	16	16	15.31	6			
7	6.31	12	17	16.31	11			
8	7.31	16	18	17.31	16			
9	8.31	20	19	18.31	31			
10	9.31	20	20	19.31	27			

5.2 Normal Condition

Assuming $K_h = 10287$ kN/m³,

$$\beta = \sqrt[4]{\frac{K_h \cdot B}{4 E I}} = 0.202 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.96 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.15 m) to 4.96 m depth (GL -9.11 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.15	0.16	7.9	9.0	1.35
2	4.31	1.00	9.0	16.0	12.50
3	5.31	1.00	16.0	12.0	14.00
4	6.31	1.00	12.0	16.0	14.00
5	7.31	1.00	16.0	20.0	18.00
6	8.31	0.80	20.0	20.0	15.94
Σ h = 4.96			Σ A = 75.79		

A: (upper N-value + lower N-value) × h/2

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{75.79}{4.96} \\ &= 15.29 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 15.29 = 42811 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 42811 = 142704 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 142704(10.00/0.3)^{-3/4} = 10287 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 10287 kN/m³.

5.3 Seismic Condition

Assuming Kh = 19477 kN/m³,

$$\begin{aligned} \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.237 \text{ m}^{-1} \\ L &= \frac{1}{\beta} = 4.23 \text{ m} \end{aligned}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.15 m) and 4.23 m depth (GL -8.38 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.15	0.16	7.9	9.0	1.35
2	4.31	1.00	9.0	16.0	12.50
3	5.31	1.00	16.0	12.0	14.00
4	6.31	1.00	12.0	16.0	14.00
5	7.31	1.00	16.0	20.0	18.00
6	8.31	0.07	20.0	20.0	1.32
Σ h = 4.23			Σ A = 61.17		

A: (upper N-value + lower N-value) × h/2

$$\begin{aligned} \text{Arbitrary load lateral load } P_l &= 69.7 \text{ kN/m} \\ \text{depth to acting position } H_l &= 0.0 \text{ m} \\ \text{moment } M_m &= 0.0 \text{ kN}\cdot\text{m/m} \\ \text{depth to acting position } H_m &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 4.15 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.00 \text{ m} \end{aligned}$$

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_l) + M_m = 345.65 \text{ kN}\cdot\text{m}$$

h_0 , Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_l}{\Sigma P + P_l} \\ &= \frac{498.73}{169.36} = 2.94 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 169.36}{4.15} = 81.62 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _l kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.15	0.15	28.59 30.62	2.14 2.30	4.10 4.05	8.79 9.30
2	0.15- 1.09	0.94	31.74 43.63	14.92 20.50	3.69 3.37	54.99 69.17
3	1.09- 1.70	0.61	42.41 50.65	12.93 15.45	2.86 2.65	36.95 40.99
4	1.70- 1.81	0.11	50.89 52.38	2.80 2.88	2.41 2.38	6.75 6.85
5	1.81- 2.81	1.00	52.38 56.11	26.19 28.06	2.01 1.67	52.55 46.95
6	2.81- 3.34	0.53	56.11 58.09	14.87 15.39	1.16 0.99	17.30 15.19
7	3.34- 3.81	0.47	90.87 95.78	21.31 22.51	0.65 0.50	13.92 11.38
8	3.81- 4.15	0.34	61.27 62.67	10.42 10.65	0.23 0.11	2.36 1.21
Σ P = 223.31			Σ M = 394.44			

P_l : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_s \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

$$\begin{aligned} \text{Arbitrary load lateral load } P_l &= 168.3 \text{ kN/m} \\ \text{depth to acting position } H_l &= 0.00 \text{ m} \\ \text{moment } M_m &= 298.9 \text{ kN}\cdot\text{m/m} \\ \text{depth to acting position } H_m &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 4.15 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.00 \text{ m} \end{aligned}$$

Moment M_l by arbitrary load is as below

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{61.17}{4.23} \\ &= 14.47 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 14.47 = 40530 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 40530 = 270197 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 270197(10.00/0.3)^{-3/4} = 19477 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 19477 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _l kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.15	0.15	1.62 3.46	0.12 0.26	4.10 4.05	0.50 1.05
2	0.15- 1.09	0.94	4.55 16.44	2.14 7.73	3.69 3.37	7.88 26.06
3	1.09- 1.70	0.61	14.41 21.90	4.39 6.68	2.86 2.65	12.55 17.73
4	1.70- 2.29	0.59	21.94 29.21	6.47 8.62	2.25 2.06	14.59 17.72
5	2.29- 2.81	0.52	29.21 30.51	7.59 7.93	1.69 1.51	12.81 12.00
6	2.81- 3.34	0.53	30.51 31.84	8.09 8.44	1.16 0.99	9.41 8.33
7	3.34- 3.73	0.39	36.86 38.44	7.11 7.41	0.68 0.55	4.84 4.10
8	3.73- 3.81	0.08	38.44 38.79	1.62 1.64	0.40 0.37	0.64 0.60
9	3.81- 4.15	0.34	38.79 40.18	6.59 6.83	0.21 0.11	1.49 0.77
Σ P = 99.66			Σ M = 153.07			

P_l : active earth pressure + residual water pressure - passive earth pressure

P : load $P_s \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

$$M_l = P_l \cdot (H + L_k - H_l) + M_m = 997.35 \text{ kN}\cdot\text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	1.81- 2.81	1.00	0.0 2.6	0.00 1.31	2.01 1.67	0.00 2.19
2	2.81- 3.81	1.00	2.6 3.7	1.31 1.86	1.01 0.67	1.32 1.25
3	3.81- 4.15	0.34	3.7 4.0	0.63 0.68	0.25 0.11	0.14 0.08
Σ P _{dw} = 5.79			Σ M _{dw} = 4.98			

h_0 , Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_l + \Sigma M_{dw}}{\Sigma P + P_l + \Sigma P_{dw}} \\ &= \frac{1396.77}{397.40} = 3.51 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 397.40}{4.15} = 191.52 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name	25 H ₁₀₀₀ -250-16-22-18
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 = 892400 cm ⁴ (original condition)
	I = 776388 cm ⁴ (after reduction by corrosion and section)
	EI = 200000 × 10 ³ × 776388 × 10 ⁻⁸ = 1.553 × 10 ⁷

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_s = \frac{\sqrt{(1+2\beta h_0)^2 + 1}}{2\beta h_0} \times \exp\left(-\tan^{-1} \frac{1}{1+2\beta h_0}\right)$$

$$M_{\max} = M_0 \cdot \phi_s$$

$$l_s = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_b	=	10287	kN/m ³
calculated value	β	=	0.20173	m ⁻¹
resultant earth force (lateral)	P_0	=	169.36	kN/m
height of acting position of load	h_0	=	2.94	m
moment	M_0	=	498.73	kN·m/m
in consideration of $\psi_{lm} = 1.319$, maximum moment	$M_{\max}$	=	657.80	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	2.125	m
depth of 1 st fixed point	l_i	=	6.018	m

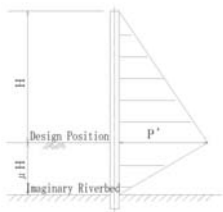
6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_b	=	19477	kN/m ³
calculated value	β	=	0.23664	m ⁻¹
resultant earth force (lateral)	P_0	=	397.40	kN/m
height of acting position of load	h_0	=	3.51	m
moment	M_0	=	1396.77	kN·m/m
in consideration of $\psi_{lm} = 1.194$, maximum moment	$M_{\max}$	=	1668.06	kN·m/m
depth of generated position of $M_{\max}$	l_m	=	1.518	m
depth of 1 st fixed point	l_i	=	4.837	m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name	25 H ₂ H 1000-250-16-22-18
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 0.88$
Section efficiency	$\mu = 1.00$
Module of section	$Z_0 = 12240$ cm ³ (original condition)
	$Z = 10771$ cm ³ (after reduction by corrosion and section)



$$\mu = \frac{L_k}{H} = \frac{0.00}{4.15} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4)$$

$$= \frac{81.62 \times 4.15^4}{120 \times 2.00 \times 10^8 \times 776388 \times 10^{-8}} (4+20 \times 0.000+40 \times 0.000^2+35 \times 0.000^3+11 \times 0.000^4)$$

$$= 0.00052 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.01059 + 0.01217 + 0.00052$$

$$= 0.02328 \text{ m}$$

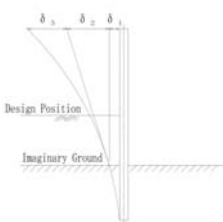
$$Size = 23.28 \leq \delta_a = 50.00 \text{ mm}$$

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

Displacement Calculation



6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{657.80 \times 10^6}{10771 \times 10^3} = 61 \text{ N/mm}^2 \leq \sigma_a = 180 \text{ N/mm}^2$$

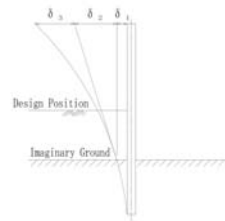
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{1668.06 \times 10^6}{10771 \times 10^3} = 155 \text{ N/mm}^2 \leq \sigma_a = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.2017 \times 2.94) \times 169.36}{2 \times 2.00 \times 10^8 \times 776388 \times 10^{-8} \times 0.2017^3} = 0.01059 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$$

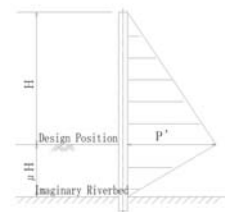
$$= \frac{(1+2 \times 0.2017 \times 2.94) \times 169.36}{2 \times 2.00 \times 10^8 \times 776388 \times 10^{-8} \times 0.2017^2} \times (4.15+0.00) = 0.01217 \text{ m}$$

$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.2366 \times 3.51) \times 397.40}{2 \times 2.00 \times 10^8 \times 776388 \times 10^{-8} \times 0.2366^3} = 0.01769 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.2366 \times 3.51) \times 397.40}{2 \times 2.00 \times 10^8 \times 776388 \times 10^{-8} \times 0.2366^2} \times (4.15+0.00) = 0.02526 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.00}{4.15} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4)$$

$$= \frac{191.52 \times 4.15^4}{120 \times 2.00 \times 10^8 \times 776388 \times 10^{-8}} (4+20 \times 0.000+40 \times 0.000^2+35 \times 0.000^3+11 \times 0.000^4)$$

$$= 0.00122 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.01769 + 0.02526 + 0.00122$$

$$= 0.04417 \text{ m}$$

$$Size = 44.17 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	25 H ₂ H 1000-250-16-22-18
Unit width	$B = 1.0000$ m
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Young's modulus	$E = 200000$ N/mm ²

Inertia sectional moment $I_0 = 892400 \text{ cm}^4$ (original condition)
 $I = 892400 \text{ cm}^4$ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 892400 \times 10^{-8} = 1.785 \times 10^6$

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 follows:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{Lk} + D$$
$$\beta = 4\sqrt{\frac{K_b \cdot B}{4EI}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction $K_b = 10287 \text{ kN/m}^3$
Calculated value $\beta = 0.19483 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.195} = 15.40 \text{ m}$
Whole length of SSP $L = 4.15 - 0.40 + 15.40 = 19.15 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 19477 \text{ kN/m}^3$
Calculated value $\beta = 0.22854 \text{ m}^{-1}$

Penetration length of SSP $D = 0.00 + \frac{3}{0.229} = 13.13 \text{ m}$
Whole length of SSP $L = 4.15 - 0.40 + 13.13 = 16.88 \text{ m}$

Therefore, the total length of the sheet pile is 19.50 m from the rounded length value of 0.50 m.

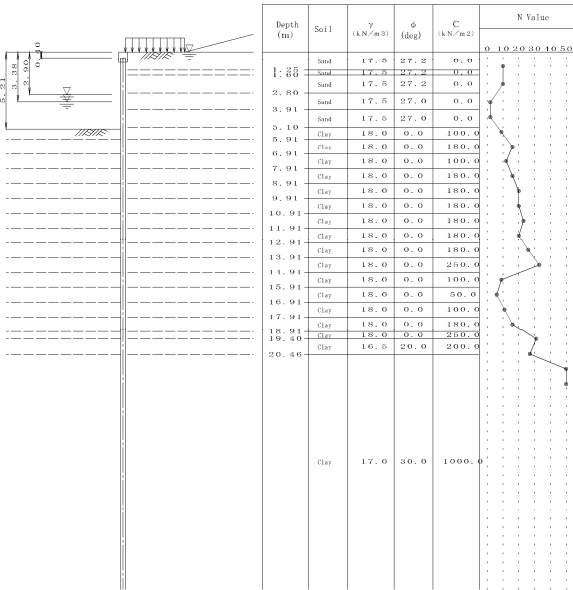
8 Calculation Result

SSP 25 H_H 1000-250-16-22-18

			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	892400		
Sectional Modulus	Z (cm ³)	12240		
Maximum bending moment	$M_{\max}$ (kN·m)		657.80	1668.06
Stress intensity	σ (N/mm ²)		61 (180)	155 (270)
Lateral displacement	δ (mm)		23.28 (50.0)	44.17 (75.0)
Penetration depth	D (m)		15.40	13.13
Whole length of SSP	L (m)	19.50		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 5.21 \text{ m}$
Depth from coping top to rear side ground $H_0 = 0.00 \text{ m}$
Depth from coping top to SSP top $H_b = 0.40 \text{ m}$
Landside WL $L_{wa} = 0.00 \text{ m}$ (Normal Condition)
 $L_{wa} = 0.00 \text{ m}$ (Seismic Condition)
 $L_{wp} = 3.38 \text{ m}$ (Normal Condition)
 $L_{wp} = 2.90 \text{ m}$ (Seismic Condition)
Riverside WL

Block No. : R-28
Sta. : 10+980~11+200

Design Cross Section : Sta 11+060
Boring Name : DD-BH-R13

Specification : SSP SP-10H
(Combined) : H 900-250-14-22-18

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 $P_t = 67.3 \text{ kN/m}$ (Normal Condition)
 $P_t' = 159.7 \text{ kN/m}$ (Seismic Condition)
Depth of acting point $H_t = 0.0 \text{ m}$ (Normal Condition)
 $H_t' = 0.0 \text{ m}$ (Seismic Condition)
Moment $M_m = 75.1 \text{ kN·m/m}$ (Normal Condition)
 $M_m' = 275.4 \text{ kN·m/m}$ (Seismic Condition)
Depth of acting point $H_m' = 0.00 \text{ m}$ (Seismic Condition)
 $H_m = 0.00 \text{ m}$ (Normal Condition)
(*'Depth' means distance from top of coping)

Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$
 $a = \sin \theta$
 $b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_H = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
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	1.00	10	11	11.41	23	21	21.41	50
2	2.19	10	12	12.41	20	22	22.41	50
3	3.41	2	13	13.41	26			
4	4.41	2	14	14.41	33			
5	5.41	9	15	15.41	9			
6	6.41	16	16	16.41	6			
7	7.41	12	17	17.41	11			
8	8.41	16	18	18.41	16			
9	9.41	20	19	19.41	31			
10	10.41	20	20	20.41	27			

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 (Include Projection Length)	Thickness m (excluding projected length)
1	1.25	1.25
2	1.60	0.35
3	2.80	1.20
4	3.91	1.11
5	5.10	1.19
6	5.91	0.81
7	6.91	1.00
8	7.91	1.00
9	8.91	1.00
10	9.91	1.00
11	10.91	1.00
12	11.91	1.00
13	12.91	1.00
14	13.91	1.00
15	14.91	1.00
16	15.91	1.00
17	16.91	1.00
18	17.91	1.00
19	18.91	1.00
20	19.40	0.49
21	20.46	1.06
22	34.80	14.34

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree) Normal Condition	Seismic Condition
1	1.25	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
2	1.60	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
3	2.80	S	9.9	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
4	3.91	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	5.10	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	5.91	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
7	6.91	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
8	7.91	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	8.91	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
10	9.91	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
11	10.91	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	11.91	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	12.91	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	13.91	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	14.91	C	33.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	15.91	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
17	16.91	C	6.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto
18	17.91	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
19	18.91	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
20	19.40	C	11.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
21	20.46	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
22	34.80	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 900 -250 -14 -22 -18
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 597600 cm⁴
Sectional factor Z₀ = 9470 cm³

Corrosion margin t₁ = 1.00 mm (riverside) t₂ = 1.00 mm (landside)

Corrosion rate (to I₀) η = 0.86
Corrosion rate (to Z₀) η = 0.88
Section efficiency (to I₀) μ = 1.00
Section efficiency (to Z₀) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_s = 180 N/mm (Normal)
 σ_s' = 270 N/mm (Seismic)

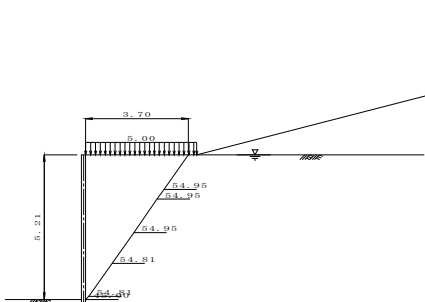
Allowable displacement δ_s = 50.0 mm (Normal)
 δ_s' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
 Not reduced: I₀ applied to calculation of penetration depth
 Reduced: I₀ applied to calculation of section forces and displacement
 Reduced: Z₀ applied to calculation of stresses

2 Calculation of Acting Load

2.1 Normal Condition

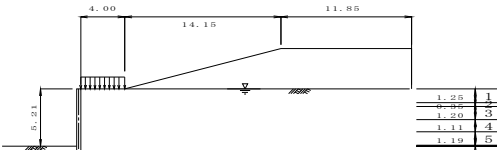


Note) depth : from top of coping to bottom of the layer
soil : sandy(S), clayey(C), mixed (M)
N-value : average N-value in the layer
 γ : wet unit weight of soil
 γ' : saturated unit weight of soil
 ϕ : internal friction angle of soil
C₀ : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		h m	Normal Condition kN/m3			Seismic Condition kN/m3	ϕ degree
1	Sand	4.00	18.15	30.00	30.00	3.64	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	0.00	4.00	5.0	0.0

Angle of rapture in embankment calculated in consideration of embankment conditions

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	γ value kN/m ³	Angle of Rapture ζ degree
1	5.21 ~ 5.10	Clay	0.0	15.0	100.0	40.17	5.00	51.06	45.00
2	5.10 ~ 3.91	Sand	27.0	15.0	0.0	39.27	5.00	40.98	54.81
3	3.91 ~ 2.80	Sand	27.0	15.0	0.0	30.11	5.00	38.32	54.81
4	2.80 ~ 1.60	Sand	27.2	15.0	0.0	21.56	5.00	27.44	54.95
5	1.60 ~ 1.25	Sand	27.2	15.0	0.0	12.32	5.00	15.68	54.95
6	1.25 ~ 0.00	Sand	27.2	15.0	0.0	9.63	5.00	12.25	54.95

• Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \theta) + \sqrt{\frac{\cos(\phi + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Angle of active rupture of clayey soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.11	0.00	0.00	0.11	0.11
2	54.81	1.19	0.11	0.11	0.95	1.30
3	54.81	1.11	0.95	1.30	1.73	2.41
4	54.95	1.20	1.73	2.41	2.57	3.61
5	54.95	0.35	2.57	3.61	2.82	3.96
6	54.95	1.25	2.82	3.96	3.70	5.21

From the above table, the loading width (L) on the ground surface is 3.70 m.

2.1.3 Acting Load by Surcharge Load

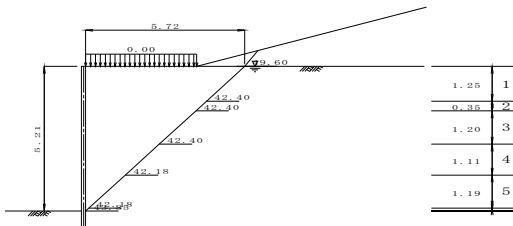
No	Q kN/m ²	l m	Qxl kN/m
1	5.0	3.70	18.48
Σ			18.48

Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{0.00 + 18.48 + 0.00}{3.70}$$
$$= 5.00 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth. m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	k (δ°)	θ degree	Angle of Rupture ζ degree
1	5.21~5.10	Clay	0.0	15.0	100.0	40.17	1.62	51.06	0.200	11.31	43.85
2	5.10~3.91	Sand	27.0	15.0	0.0	39.27	1.62	49.98	0.200	11.31	42.18
3	3.91~2.80	Sand	27.0	15.0	0.0	30.11	1.62	38.32	0.200	11.31	42.18
4	2.80~1.60	Sand	27.2	15.0	0.0	21.56	1.62	27.44	0.200	11.31	42.40
5	1.60~1.25	Sand	27.2	15.0	0.0	12.32	1.62	15.68	0.200	11.31	42.40
6	1.25~0.00	Sand	27.2	15.0	0.0	9.63	1.62	12.25	0.200	11.31	42.40
7		embankment t	30.0	—	0.0	69.16	0.00	0.00	0.200	11.31	49.60

Major collapse angle of Sand, intermediate soil, and split rock

Σ			0.00

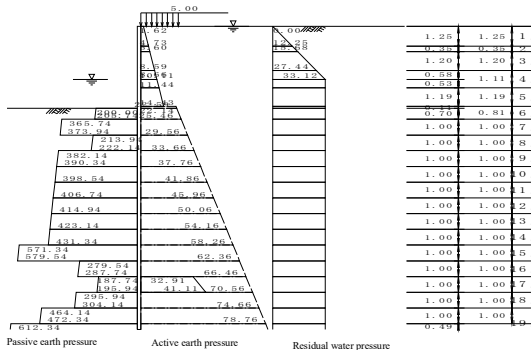
Q : width of surcharge load set by line of active rupture
l : Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{9.25 + 0.00 + 0.00}{5.72}$$
$$= 1.62 \text{ kN/m}^2$$

3 Lateral Forth

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	Σ γ h + Q _u kN/m ²	K _a	K _a × cos δ
1	0.00~1.25	Sand	7.7	27.2	—	5.000 14.625	0.33489 0.33489	0.32348 0.32348
2	1.25~1.60	Sand	7.7	27.2	—	14.625 17.320	0.33489 0.33489	0.32348 0.32348
3	1.60~2.80	Sand	7.7	27.2	—	17.320 26.560	0.33489 0.33489	0.32348 0.32348
4	2.80~3.38	Sand	7.7	27.0	—	26.560 31.026	0.33738 0.33738	0.32589 0.32589

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

Where,

- ζ : angle of active rupture (degree, ζ ≥ 10.0°)
- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.85	0.11	0.00	0.00	0.11	0.11
2	42.18	1.19	0.11	0.11	1.43	1.30
3	42.18	1.11	1.43	1.30	2.65	2.41
4	42.40	1.20	2.65	2.41	3.97	3.61
5	42.40	0.35	3.97	3.61	4.35	3.96
6	42.40	1.25	4.35	3.96	5.72	5.21
7	49.60	0.57	5.72	5.21	6.20	5.78

From the above table, the loading width (L) on the ground surface is 5.72 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.49	9.25
Σ			9.25

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	Qxl kN/m
1	0.0	4.00	0.00

5	3.38~3.91	Sand	7.7	27.0	—	31.026 35.107	0.33738 0.33738	0.32589 0.32589
6	3.91~5.10	Sand	7.7	27.0	—	35.107 44.270	0.33738 0.33738	0.32589 0.32589
7	5.10~100.0	Clay	8.2	—	100.0 100.0	44.270 45.172	—	—
8	5.21~5.91	Clay	8.2	—	100.0 100.0	45.172 50.912	—	—
9	5.91~6.91	Clay	8.2	—	180.0 180.0	50.912 59.112	—	—
10	6.91~7.91	Clay	8.2	—	100.0 100.0	59.112 67.312	—	—
11	7.91~8.91	Clay	8.2	—	180.0 180.0	67.312 75.512	—	—
12	8.91~9.91	Clay	8.2	—	180.0 180.0	75.512 83.712	—	—
13	9.91~10.91	Clay	8.2	—	180.0 180.0	83.712 91.912	—	—
14	10.91~11.91	Clay	8.2	—	180.0 180.0	91.912 100.112	—	—
15	11.91~12.91	Clay	8.2	—	180.0 180.0	100.112 108.312	—	—
16	12.91~13.91	Clay	8.2	—	180.0 180.0	108.312 116.512	—	—
17	13.91~14.91	Clay	8.2	—	250.0 250.0	116.512 124.712	—	—
18	14.91~15.91	Clay	8.2	—	100.0 100.0	124.712 132.912	—	—
19	15.91~16.91	Clay	8.2	—	50.0 50.0	132.912 141.112	—	—
20	16.91~17.91	Clay	8.2	—	100.0 100.0	141.112 149.312	—	—
21	17.91~18.91	Clay	8.2	—	180.0 180.0	149.312 157.512	—	—
22	18.91~19.40	Clay	8.2	—	250.0 250.0	157.512 161.530	—	—
23	19.40~20.46	Clay	6.7	—	200.0 200.0	161.530 168.632	—	—
24	20.46~34.80	Clay	7.2	—	1000.0 1000.0	168.632 271.880	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
δ = 15.00, 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

No	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qp kN/m2	Kp	Kp × cos δ
8	5.21- 5.91	Clay	8.2	0.0	100.0 100.0	0.000 5.740	=====	=====
9	5.91- 6.91	Clay	8.2	0.0	180.0 180.0	5.740 13.940	=====	=====
10	6.91- 7.91	Clay	8.2	0.0	100.0 100.0	13.940 22.140	=====	=====
11	7.91- 8.91	Clay	8.2	0.0	180.0 180.0	22.140 30.340	=====	=====
12	8.91- 9.91	Clay	8.2	0.0	180.0 180.0	30.340 38.540	=====	=====
13	9.91- 10.91	Clay	8.2	0.0	180.0 180.0	38.540 46.740	=====	=====
14	10.91- 11.91	Clay	8.2	0.0	180.0 180.0	46.740 54.940	=====	=====
15	11.91- 12.91	Clay	8.2	0.0	180.0 180.0	54.940 63.140	=====	=====
16	12.91- 13.91	Clay	8.2	0.0	180.0 180.0	63.140 71.340	=====	=====
17	13.91- 14.91	Clay	8.2	0.0	230.0 230.0	71.340 79.540	=====	=====
18	14.91- 15.91	Clay	8.2	0.0	100.0 100.0	79.540 87.740	=====	=====
19	15.91- 16.91	Clay	8.2	0.0	50.0 50.0	87.740 95.940	=====	=====
20	16.91- 17.91	Clay	8.2	0.0	100.0 100.0	95.940 104.140	=====	=====
21	17.91- 18.91	Clay	8.2	0.0	180.0 180.0	104.140 112.340	=====	=====
22	18.91- 19.40	Clay	8.2	0.0	230.0 230.0	112.340 116.358	=====	=====
23	19.40- 20.46	Clay	6.7	20.0	200.0 200.0	116.358 123.460	=====	=====
24	20.46- 34.80	Clay	7.2	30.0	1000.0 1000.0	123.460 226.708	=====	=====

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
δ= -15.00, β= 0.00, θ= 0.00

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta)} \cdot \left[1 + \frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)} \right]^2$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00- 1.25	1.62 4.73	=====	1.62 4.73	0.00 12.25	=====

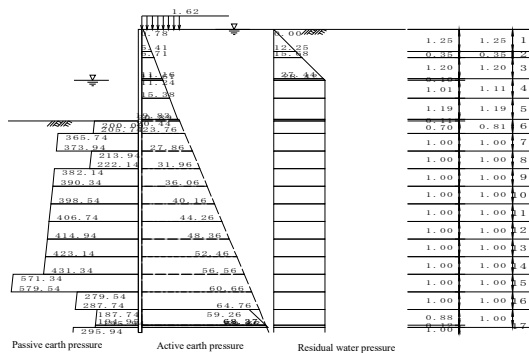
Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2 C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a (\Sigma \gamma h + Q) - 2 C \sqrt{K_a}] \cdot \cos \delta$

- Formula for passive earth pressure

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2 C$
Mixed soil $P_p = [K_p (\Sigma \gamma h + Q) + 2 C \sqrt{K_p}] \cdot \cos \delta$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Q kN/m2	γ sub kN/m2	k (k ²)	θ degree	Ka	Ka × cos δ	ζ degree
1	0.00- 1.25	Sand	7.7	27.2	=====	1.62 11.24	0.00 12.25	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	=====
2	1.25- 1.60	Sand	7.7	27.2	=====	11.24 13.94	12.25 15.68	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	=====
3	1.60- 2.80	Sand	7.7	27.2	=====	13.94 23.18	15.68 27.44	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	=====
4	2.80- 2.90	Sand	7.7	27.0	=====	23.18 23.95	27.44 28.42	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
5	2.90- 3.91	Sand	7.7	27.0	=====	23.95 31.72	28.42 38.32	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====

No	Depth m	Active			Residual water pressure		Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2	
2	1.25-	4.73	_____	4.73	12.25	15.68	
	1.60	5.60	_____	5.60	_____		
3	1.60-	5.60	_____	5.60	15.68	27.44	
	2.80	8.59	_____	8.59	_____		
4	2.80-	8.66	_____	8.66	27.44	33.12	
	3.38	10.11	_____	10.11	_____		
5	3.38-	10.11	_____	10.11	33.12	33.12	
	3.91	11.44	_____	11.44	_____		
6	3.91-	11.44	_____	11.44	33.12	33.12	
	5.10	14.43	_____	14.43	_____		
7	5.10-	-155.73	22.14	22.14	33.12	33.12	
	5.21	-154.83	22.59	22.59	_____		
8	5.21-	-154.83	22.59	22.59	33.12	200.00	
	5.91	-149.09	25.46	25.46	33.12		
9	5.91-	-309.09	25.46	25.46	33.12	365.74	
	6.91	-300.89	29.56	29.56	33.12		
10	6.91-	-140.89	29.56	29.56	33.12	213.94	
	7.91	-132.69	33.66	33.66	33.12		
11	7.91-	-292.69	33.66	33.66	33.12	382.14	
	8.91	-284.49	37.76	37.76	33.12		
12	8.91-	-284.49	37.76	37.76	33.12	390.34	
	9.91	-276.29	41.86	41.86	33.12		
13	9.91-	-276.29	41.86	41.86	33.12	398.54	
	10.91	-268.09	45.96	45.96	33.12		
14	10.91-	-268.09	45.96	45.96	33.12	406.74	
	11.91	-259.89	50.06	50.06	33.12		
15	11.91-	-259.89	50.06	50.06	33.12	414.94	
	12.91	-251.69	54.16	54.16	33.12		
16	12.91-	-251.69	54.16	54.16	33.12	423.14	
	13.91	-243.49	58.26	58.26	33.12		
17	13.91-	-383.49	58.26	58.26	33.12	571.34	
	14.91	-375.29	62.36	62.36	33.12		
18	14.91-	-75.29	62.36	62.36	33.12	279.54	
	15.91	-67.09	66.46	66.46	33.12		
19	15.91-	32.91	66.46	66.46	33.12	187.74	
	16.91	41.11	70.56	70.56	33.12		
20	16.91-	-58.89	70.56	70.56	33.12	295.94	
	17.91	-50.69	74.66	74.66	33.12		
21	17.91-	-210.69	74.66	74.66	33.12	464.14	
	18.91	-202.49	78.76	78.76	33.12		
22	18.91-	-342.49	78.76	78.76	33.12	612.34	
	19.40	-338.47	80.76	80.76	33.12		
23	19.40-	-238.47	80.76	80.76	33.12	516.36	
	20.46	-231.37	84.32	84.32	33.12		
24	20.46-	-1831.37	84.32	84.32	33.12	2123.46	
	34.80	-1728.12	135.94	135.94	33.12		

- Formula for active earth pressure

6	3.91- 5.10	Sand	7.7	27.0	=====	31.72 40.89	38.32 49.98	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
7	5.10- 5.21	Clay	8.2	=====	100.0 100.0	40.89 41.79	49.98 51.06	0.200 0.200	11.31 11.31	=====	=====	43.87 43.85
8	5.21- 5.91	Clay	8.2	=====	100.0 100.0	41.79 47.53	51.06 57.92	0.200 0.200	11.31 11.31	=====	=====	43.85 43.70
9	5.91- 6.91	Clay	8.2	=====	180.0 180.0	47.53 55.73	57.92 67.72	0.200 0.200	11.31 11.31	=====	=====	44.26 44.14
10	6.91- 7.91	Clay	8.2	=====	100.0 100.0	55.73 63.93	67.72 77.52	0.200 0.200	11.31 11.31	=====	=====	43.49 43.28
11	7.91- 8.91	Clay	8.2	=====	180.0 180.0	63.93 72.13	77.52 87.32	0.200 0.200	11.31 11.31	=====	=====	44.02 43.90
12	8.91- 9.91	Clay	8.2	=====	180.0 180.0	72.13 80.33	87.32 97.12	0.200 0.200	11.31 11.31	=====	=====	43.90 43.78
13	9.91- 10.91	Clay	8.2	=====	180.0 180.0	80.33 88.53	97.12 106.92	0.200 0.200	11.31 11.31	=====	=====	43.78 43.66
14	10.91- 11.91	Clay	8.2	=====	180.0 180.0	88.53 96.73	106.92 116.72	0.200 0.200	11.31 11.31	=====	=====	43.66 43.54
15	11.91- 12.91	Clay	8.2	=====	180.0 180.0	96.73 104.93	116.72 126.52	0.200 0.200	11.31 11.31	=====	=====	43.54 43.42
16	12.91- 13.91	Clay	8.2	=====	180.0 180.0	104.93 113.13	126.52 136.32	0.200 0.200	11.31 11.31	=====	=====	43.42 43.30
17	13.91- 14.91	Clay	8.2	=====	250.0 250.0	113.13 121.33	136.32 146.12	0.200 0.200	11.31 11.31	=====	=====	43.76 43.67
18	14.91- 15.91	Clay	8.2	=====	100.0 100.0	121.33 129.53	146.12 155.92	0.200 0.200	11.31 11.31	=====	=====	41.89 41.71
19	15.91- 16.79	Clay	8.2	=====	50.0 50.0	129.53 136.74	155.92 =====	0.200 0.200	11.31 =====	=====	=====	39.06
20	16.79- 16.91	Clay	8.2	=====	50.0 50.0	136.74 137.73	=====	0.200 0.200	11.31 =====	=====	=====	38.76
21	16.91- 17.91	Clay	8.2	=====	100.0 100.0	137.73 145.93	165.72 175.52	0.200 0.200	11.31 11.31	=====	=====	41.52 41.34
22	17.91- 18.91	Clay	8.2	=====	180.0 180.0	145.93 154.13	175.52 185.32	0.200 0.200	11.31 11.31	=====	=====	42.85 42.74
23	18.91- 19.40	Clay	8.2	=====	250.0 250.0	154.13 158.15	185.32 190.12	0.200 0.200	11.31 11.31	=====	=====	42.34 42.29
24	19.40- 20.46	Clay	6.7	=====	200.0 200.0	158.15 165.25	190.12 200.51	0.200 0.200	11.31 11.31	=====	=====	42.90 42.81
25	20.46- 34.80	Clay	7.2	=====	1000.0 1000.0	165.25 268.50	200.51 341.04	0.200 0.200	11.31 11.31	=====	=====	44.53 44.25

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ= 15.00, β= 0.00, θ= 0.00

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta)} \cdot \left[1 + \frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)} \right]^2$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{B}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_p$ kN/m ²	$\gamma \cdot \sin \alpha$ kN/m ²	k (k ²)	θ degree	Kp	$K_p \times \cos \delta$
8	5.21~ 5.91	Clay	8.20	0.0	100.0 100.0	0.000 5.740	0.00 6.86	0.200 0.200	11.31 11.31	=====	=====
9	5.91~ 6.91	Clay	8.20	0.0	180.0 180.0	5.740 13.940	6.86 16.66	0.200 0.200	11.31 11.31	=====	=====
10	6.91~ 7.91	Clay	8.20	0.0	100.0 100.0	13.940 22.140	16.66 26.46	0.200 0.200	11.31 11.31	=====	=====
11	7.91~ 8.91	Clay	8.20	0.0	180.0 180.0	22.140 30.340	26.46 36.26	0.200 0.200	11.31 11.31	=====	=====
12	8.91~ 9.91	Clay	8.20	0.0	180.0 180.0	30.340 38.540	36.26 46.06	0.200 0.200	11.31 11.31	=====	=====
13	9.91~ 10.91	Clay	8.20	0.0	180.0 180.0	38.540 46.740	46.06 55.86	0.200 0.200	11.31 11.31	=====	=====
14	10.91~ 11.91	Clay	8.20	0.0	180.0 180.0	46.740 54.940	55.86 65.66	0.200 0.200	11.31 11.31	=====	=====
15	11.91~ 12.91	Clay	8.20	0.0	180.0 180.0	54.940 63.140	65.66 75.46	0.200 0.200	11.31 11.31	=====	=====
16	12.91~ 13.91	Clay	8.20	0.0	180.0 180.0	63.140 71.340	75.46 85.26	0.200 0.200	11.31 11.31	=====	=====
17	13.91~ 14.91	Clay	8.20	0.0	250.0 250.0	71.340 79.540	85.26 95.06	0.200 0.200	11.31 11.31	=====	=====
18	14.91~ 15.91	Clay	8.20	0.0	100.0 100.0	79.540 87.740	95.06 104.86	0.200 0.200	11.31 11.31	=====	=====
19	15.91~ 16.79	Clay	8.20	0.0	50.0 50.0	87.740 94.954	104.86 =====	0.200 =====	11.31 =====	=====	=====
20	16.79~ 16.91	Clay	8.20	0.0	50.0 50.0	94.954 95.940	===== 114.66	===== 0.200	===== 11.31	=====	=====
21	16.91~ 17.91	Clay	8.20	0.0	100.0 100.0	95.940 104.140	114.66 124.46	0.200 0.200	11.31 11.31	=====	=====
22	17.91~ 18.91	Clay	8.20	0.0	180.0 180.0	104.140 112.340	124.46 134.26	0.200 0.200	11.31 11.31	=====	=====
23	18.91~ 19.40	Clay	8.20	0.0	250.0 250.0	112.340 116.358	134.26 139.06	0.200 0.200	11.31 11.31	=====	=====
24	19.40~ 20.46	Clay	6.70	20.0	200.0 200.0	116.358 123.460	139.06 149.45	0.200 0.200	11.31 11.31	=====	=====
25	20.46~ 34.80	Clay	7.20	30.0	1000.0 1000.0	123.460 226.708	149.45 289.98	0.200 0.200	11.31 11.31	=====	=====

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth m	Active		Residual water pressure		Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pw kN/m ²	Pp kN/m ²	
1	0.00~ 1.25	0.78 5.41	=====	0.78 5.41	0.00 12.25	=====
2	1.25~ 1.60	5.41 6.71	=====	5.41 6.71	12.25 15.68	=====
3	1.60~ 2.80	6.71 11.16	=====	6.71 11.16	15.68 27.44	=====
4	2.80~ 2.90	11.24 11.61	=====	11.24 11.61	27.44 28.42	=====
5	2.90~ 3.91	11.61 15.38	=====	11.61 15.38	28.42 28.42	=====
6	3.91~ 5.10	15.38 19.83	=====	15.38 19.83	28.42 28.42	=====
7	5.10~ 5.21	-150.76 -149.67	20.44 20.89	20.44 20.89	28.42 28.42	=====
8	5.21~ 5.91	-149.67 -142.73	20.89 23.76	20.89 23.76	28.42 28.42	200.00 205.74
9	5.91~ 6.91	-302.84 -292.95	23.76 27.86	23.76 27.86	28.42 28.42	365.74 373.94
10	6.91~ 7.91	-132.80 -122.85	27.86 31.96	27.86 31.96	28.42 28.42	213.94 222.14
11	7.91~ 8.91	-283.05 -273.15	31.96 36.06	31.96 36.06	28.42 28.42	382.14 390.34
12	8.91~ 9.91	-273.15 -263.23	36.06 40.16	36.06 40.16	28.42 28.42	390.34 398.54
13	9.91~ 10.91	-263.23 -253.31	40.16 44.26	40.16 44.26	28.42 28.42	398.54 406.74
14	10.91~ 11.91	-253.31 -243.38	44.26 48.36	44.26 48.36	28.42 28.42	406.74 414.94
15	11.91~ 12.91	-243.38 -233.44	48.36 52.46	48.36 52.46	28.42 28.42	414.94 423.14
16	12.91~ 13.91	-233.44 -223.50	52.46 56.56	52.46 56.56	28.42 28.42	423.14 431.34
17	13.91~ 14.91	-363.71 -353.79	56.56 60.66	56.56 60.66	28.42 28.42	571.34 579.54
18	14.91~ 15.91	-52.80 -42.73	60.66 64.76	60.66 64.76	28.42 28.42	279.54 287.74
19	15.91~ 16.79	59.26 68.37	64.76 68.37	64.76 68.37	28.42 28.42	187.74 194.95
20	16.79~ 16.91	68.37 69.62	68.37 68.86	68.37 69.62	28.42 28.42	194.95 195.94
21	16.91~ 17.91	-32.64 -22.54	68.86 72.96	68.86 72.96	28.42 28.42	295.94 304.14
22	17.91~ 18.91	-183.62 -173.64	72.96 77.06	72.96 77.06	28.42 28.42	464.14 472.34
23	18.91~ 19.40	-314.05 -309.17	77.06 79.07	77.06 79.07	28.42 28.42	612.34 616.36
24	19.40~ 20.46	-208.89 -200.25	79.07 82.62	79.07 82.62	28.42 28.42	516.36 523.46

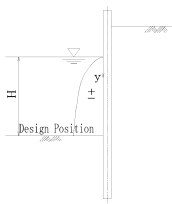
25	20.46~ 34.80	-1801.42 -1677.06	82.62 134.25	82.62 134.25	28.42 28.42	2123.46 2226.71

- Formula for active earth pressure
- Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
- Clay $P_{a1} = \Sigma \gamma \cdot h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma \cdot h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)
- Mixed soil $P_{a1} = [K_a(\Sigma \gamma \cdot h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$
- Formula for passive earth pressure
- Sand $P_p = K_p \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
- Clay $P_p = \Sigma \gamma \cdot h + Q + 2C$
- Mixed soil $P_p = [K_p(\Sigma \gamma \cdot h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$

3.2.4 Dynamic Water Pressure due to Earthquake

$$p_{dw} = \pm \frac{7}{8} k_{wa} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

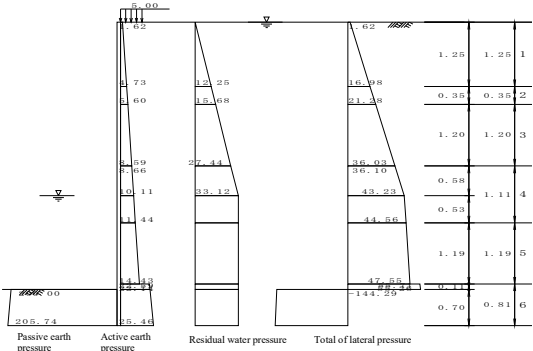
Where,
 k_{wa} : design seismic coefficient
 γ_w : unit weight of water
H : water depth of riverside
y : depth from water surface to the point where active water pressure is calculated



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

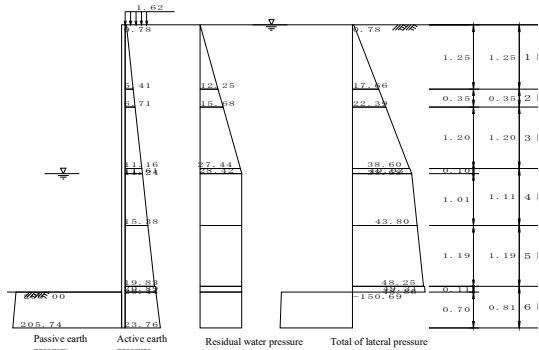


No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00~ 1.25	1.62 4.73	0.00 12.25	=====	1.62 16.98
2	1.25~ 1.60	4.73 5.60	12.25 15.68	=====	16.98 21.28
3	1.60~ 2.80	5.60 8.59	15.68 27.44	=====	21.28 36.03
4	2.80~ 3.38	8.66 10.11	27.44 33.12	=====	36.10 43.23
5	3.38~ 3.91	10.11 11.44	33.12 33.12	=====	43.23 44.56
6	3.91~ 5.10	11.44 14.43	33.12 33.12	=====	44.56 47.55
7	5.10~ 5.21	22.14 22.59	33.12 33.12	=====	55.26 55.71
8	5.21~ 5.91	22.59 25.46	33.12 33.12	200.00 205.74	-144.29 -147.16

Pa : Active earth pressure
Pw : Residual water pressure
Pp : Passive earth pressure
Ps : Lateral pressure Ps = Pa + Pw - Pp

Imaginary riverbed Lk: 0.00 m (GL -5.21 m)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.25	0.78 5.41	0.00 12.25	————	0.78 17.66
2	1.25- 1.60	5.41 6.71	12.25 15.68	————	17.66 22.39
3	1.60- 2.80	6.71 11.16	15.68 27.44	————	22.39 38.60
4	2.80- 2.90	11.24 11.61	27.44 28.42	————	38.68 40.03
5	2.90- 3.91	11.61 15.38	28.42 28.42	————	40.03 43.80
6	3.91- 5.10	15.38 19.63	28.42 28.42	————	43.80 48.25
7	5.10- 5.21	20.44 20.89	28.42 28.42	————	48.86 49.31
8	5.21- 5.91	20.89 23.76	28.42 28.42	200.00 205.74	-150.69 -153.56

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 L₄: 0.00 m (GL -5.21 m)

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.21	0.20	7.6	9.0	1.66
2	5.41	1.00	9.0	16.0	12.50
3	6.41	1.00	16.0	12.0	14.00
4	7.41	1.00	12.0	16.0	14.00
5	8.41	1.00	16.0	20.0	18.00
6	9.41	0.31	20.0	20.0	6.28

A: (Top N + Bottom N) x h/2

Average N-value N' = $\frac{\sum A}{L}$
= $\frac{66.44}{4.51}$
= 14.72

Kh is recalculated from the calculated average N value.

$E_0 = 2800N' = 2800 \times 14.72 = 41213 \text{ kN/m}^2$
 $K_{10} = \frac{1}{0.3} \times \alpha \times 41213 = 137376 \text{ kN/m}^3$ (α :Normal Condition =1, Seismi Condition =2)
 $K_h = K_{10}(B_u/0.3)^{-3/4} = 137376(10.00/0.3)^{-3/4} = 9903 \text{ kN/m}^3$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 9903 kN/m³.

5.3 Seismic Condition

Assuming Kh = 18669 kN/m³,

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0,260 \text{ m}^{-1}$
 $L = \frac{1}{\beta} = 3,85 \text{ m}$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.21 m) and 3.85 m depth (GL -9.06 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.21	0.20	7.6	9.0	1.66
2	5.41	1.00	9.0	16.0	12.50
3	6.41	1.00	16.0	12.0	14.00
4	7.41	1.00	12.0	16.0	14.00
5	8.41	0.65	16.0	18.6	11.29

A: (upper N-value + lower N-value) × h/2

Average N-value N' = $\frac{\sum A}{L}$

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of 1/β from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$K_h = K_{10} \left(\frac{B_u}{0.3} \right)^{-3/4}$ (B_u=10.00m)
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α :Normal Condition =1, Seismi Condition =2)
E₀ = 2800N'

where:

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}}$

Material Name	10 H ₂ H 900 -250 -14 -22 -18
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 = 597600 cm ⁴ (original condition)
	I = 513936 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 513936 × 10 ⁻⁸ = 1.028 × 10 ⁶

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	1.00	10	11	11.41	23	21	21.41	50
2	2.19	10	12	12.41	20	22	22.41	50
3	3.41	2	13	13.41	26			
4	4.41	2	14	14.41	33			
5	5.41	9	15	15.41	9			
6	6.41	16	16	16.41	6			
7	7.41	12	17	17.41	11			
8	8.41	16	18	18.41	16			
9	9.41	20	19	19.41	31			
10	10.41	20	20	20.41	27			

5.2 Normal Condition

Assuming Kh = 9903 kN/m³,

$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0,222 \text{ m}^{-1}$

$L = \frac{1}{\beta} = 4.51 \text{ m}$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.21 m) to 4.51 m depth (GL -9.72 m).

= $\frac{53.45}{3.85}$

= 13.87

Kh is recalculated from the calculated average N value.

$E_0 = 2800N' = 2800 \times 13.87 = 38848 \text{ kN/m}^2$
 $K_{10} = \frac{1}{0.3} \times \alpha \times 38848 = 258989 \text{ kN/m}^3$ (α :Normal Condition =1, Seismi Condition =2)
 $K_h = K_{10}(B_u/0.3)^{-3/4} = 258989(10.00/0.3)^{-3/4} = 18669 \text{ kN/m}^3$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 18669 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.25	1.25	1.62 16.98	1.01 10.61	4.79 4.38	4.85 46.45
2	1.25- 1.60	0.35	16.98 21.28	2.97 3.72	3.84 3.73	11.42 13.88
3	1.60- 2.80	1.20	21.28 36.03	12.77 21.62	3.21 2.81	40.99 60.75
4	2.80- 3.38	0.58	36.10 43.23	10.47 12.54	2.22 2.02	23.20 25.37
5	3.38- 3.91	0.53	43.23 44.56	11.46 11.81	1.65 1.48	18.94 17.44
6	3.91- 5.10	1.19	44.56 47.55	26.52 28.29	0.90 0.51	23.95 14.34
7	5.10- 5.21	0.11	52.36 55.71	3.04 3.06	0.07 0.04	0.22 0.11
			Σ P = 159.89		Σ M = 301.91	

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 _s	= 67.3 kN/m
depth to acting position	H _s	= 0.0 m
moment	M _{so}	= 75.1 kN·m/m
depth to acting position	H _m	= 0.00 m

Height from riverbed to top of coping H = 5.21 m
 Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_i by arbitrary load is as below
 M_i = P_i·(H + L_k – H_i) + M_m = 425.73 kN·m
 h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{727.65}{227.19} = 3.20 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 227.19}{5.21} = 87.21 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 1.25	1.25	0.78 17.66	0.49 11.04	4.79 4.38	2.33 48.32
2	1.25~ 1.60	0.35	17.66 22.39	3.09 3.92	3.84 3.73	11.88 14.60
3	1.60~ 2.80	1.20	22.39 38.60	13.43 23.16	3.21 2.81	43.12 65.08
4	2.80~ 2.90	0.10	38.68 40.03	1.93 2.00	2.38 2.34	4.60 4.69
5	2.90~ 3.91	1.01	40.03 43.80	20.22 22.12	1.97 1.64	39.89 36.20
6	3.91~ 5.10	1.19	43.80 48.25	26.06 28.71	0.90 0.51	23.54 14.54
7	5.10~ 5.21	0.11	48.86 49.31	2.69 2.71	0.07 0.04	0.20 0.10
			ΣP=	161.57	ΣM=	309.10

P_i : 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_i = 159.7 kN/m
 depth to acting position H_i = 0.00 m
 moment M_m = 275.4 kN·m/m
 depth to acting position H_m = 0.00 m
 Height from riverbed to top of coping H = 5.21 m
 Depth of Imaginary riverbed from riverbed L_k = 0.00 m

Moment M_i by arbitrary load is as below
 M_i = P_i·(H + L_k – H_i) + M_m = 1107.44 kN·m

6.2.1 Normal Condition

modulus of lateral subgrade reaction K₀ = 9903 kN/m³
 calculated value β = 0.22153 m⁻¹
 resultant earth force (lateral) P₀ = 227.19 kN/m
 height of acting position of load h₀ = 3.20 m
 moment M₀ = 27.65 kN·m/m

in consideration of ψ_m = 1.246,
 maximum moment M_{max} = 906.96 kN·m/m
 depth of generated position of M_{max} l_m = 1.769 m
 depth of 1st fixed point l_i = 5.315 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction K₀ = 18669 kN/m³
 calculated value β = 0.25959 m⁻¹
 resultant earth force (lateral) P₀ = 326.91 kN/m
 height of acting position of load h₀ = 4.35 m
 moment M₀ = 1421.32 kN·m/m

in consideration of ψ_m = 1.121,
 maximum moment M_{max} = 1592.79 kN·m/m
 depth of generated position of M_{max} l_m = 1.147 m
 depth of 1st fixed point l_i = 4.173 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name 10 H _H 900 -250 -14 -22 -18
 Corrosion margin t₁ = 1.00 mm (active side) t₂= 1.00 mm (passive side)
 Corrosion rate η = 0.88
 Section efficiency μ = 1.00
 Module of section Z₀ = 9470 cm³ (original condition)
 Z = 8334 cm³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{906.96 \times 10^6}{8334 \times 10^3} = 109 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{1592.79 \times 10^6}{8334 \times 10^3} = 191 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	2.90~ 3.90	1.00	0.0 2.6	0.00 1.30	1.98 1.64	0.00 2.14
2	3.90~ 4.90	1.00	2.6 3.7	1.30 1.84	0.98 0.64	1.27 1.19
3	4.90~ 5.21	0.31	3.7 4.0	0.57 0.61	0.21 0.10	0.12 0.06
			ΣP ₀ =	5.64	ΣM ₀ =	4.78

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0i}}{\Sigma P + P_i + \Sigma P_{0i}} = \frac{1421.32}{326.91} = 4.35 \text{ m}$$

When the resultant force of the Latelr Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 326.91}{5.21} = 125.49 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Material name 10 H _H 900 -250 -14 -22 -18
 Unit width B = 1.0000 m
 Corrosion margin t₁ = 1.00 mm (active side) t₂= 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 I₀ = 597600 cm⁴ (original condition)
 I = 513936 cm⁴ (after reduction by corrosion and section)
 EI = 200000 × 10³ × 513936 × 10⁻⁸
 = 1.028 × 10⁶

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_s = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

$$M_{max} = M_0 \cdot \phi_s$$

$$l_s = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

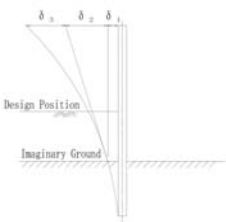
$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M(x) = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

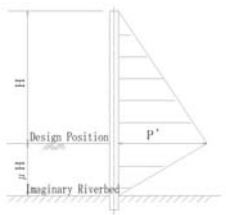


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.2215 \times 3.20) \times 227.19}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2215^3} = 0.01738 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k)$$

$$= \frac{(1 + 2 \times 0.2215 \times 3.20) \times 227.19}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2215^2} \times (5.21 + 0.00) = 0.02838 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.00}{5.21} = 0.000$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4)$$

$$= \frac{87.21 \times 5.21^4}{120 \times 2.00 \times 10^8 \times 513936 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4)$$

$$= 0.00208 \text{ m}$$

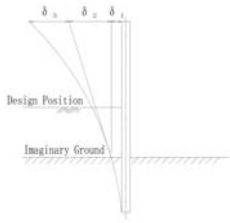
$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01738 + 0.02838 + 0.00208 \\ &= 0.04784 \text{ m} \\ \text{Size} &= 47.84 \leq \delta a = 50.00 \text{ mm}\end{aligned}$$

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

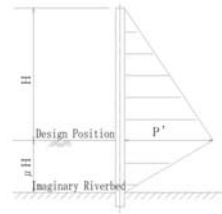
6.4.2 Seismic Condition

Displacement Calculation



$$\begin{aligned}\delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2596 \times 4.35) \times 326.91}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2596^3} = 0.01935 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_1) \\ &= \frac{(1 + 2 \times 0.2596 \times 4.35) \times 326.91}{2 \times 2.00 \times 10^8 \times 513936 \times 10^{-8} \times 0.2596^2} \times (5.21 + 0.00) = 0.04005 \text{ m}\end{aligned}$$



$$\mu = \frac{L_k}{H} = \frac{0.00}{5.21} = 0.000$$

$$\begin{aligned}\delta_3 &= \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{125.49 \times 5.21^4}{120 \times 2.00 \times 10^8 \times 513936 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4) \\ &= 0.00300 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01935 + 0.04005 + 0.00300 \\ &= 0.06240 \text{ m} \\ \text{Size} &= 62.40 \leq \delta a = 75.00 \text{ mm}\end{aligned}$$

where:

- δ_1 : amount of displacement at the virtual ground surface
- δ_2 : the amount of displacement due to the deflection angle of the virtual ground plane
- δ_3 : amount of displacement as a cantilever above the virtual ground plane
- δ : amount of displacement of sheet pile head
- δa : allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H _ H 900 -250 -14 -22 -18
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 = 597600 cm ⁴ (original condition)
	I = 597600 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 597600 × 10 ⁻⁸	= 1.195 × 10 ⁸

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:

$$\begin{aligned}D &= L_k + \frac{3}{\beta} \\ L &= H - H_{(1)} + D \\ \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}}\end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 9903 kN/m ³
Calculated value	β = 0.21334 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.213}$ = 14.06 m
Whole length of SSP	L = 5.21 - 0.40 + 14.06 = 18.87 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_b = 18669 kN/m ³
Calculated value	β = 0.24998 m ⁻¹

Penetration length of SSP	D = 0.00 + $\frac{3}{0.250}$ = 12.00 m
Whole length of SSP	L = 5.21 - 0.40 + 12.00 = 16.81 m

Therefore, the total length of the sheet pile is 19.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H _ H 900 -250 -14 -22 -18				
		Normal Condition	Seismic Condition	
Inertia sectional moment	I (cm ⁴)	597600		
Sectional Modulus	Z (cm ³)	9470		
Maximum bending moment	Mmax (kN · m · m)		906.96	1592.79
Stress intensity	σ (N/mm ²)		109 (180)	191 (270)
Lateral displacement	δ (mm)		47.84 (50.0)	62.40 (75.0)
Penetration depths	D (m)		14.06	12.00
Whole length of SSP	L (m)	19.00		

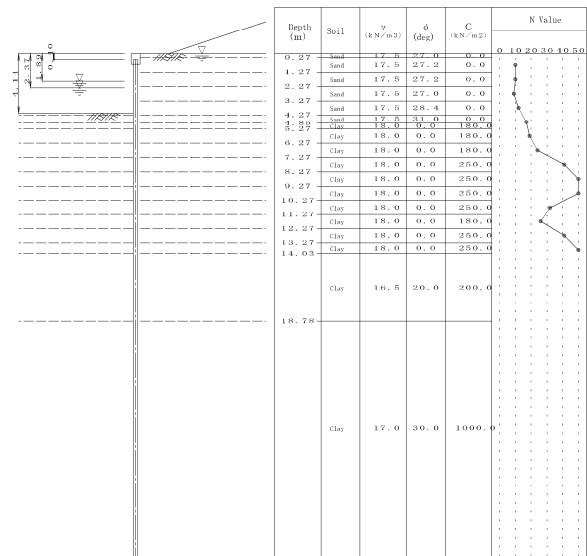
Block No. : R-29
Sta. : 11+200~11+360

Design Cross Section : Sta 11+340
Boring Name : BMRL-33

Specification : SSP SP-10H
(Combined) : H 400-200-9-12-13

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed
Depth from coping top to rear side ground
Depth from coping top to SSP top
Landside WL
Riverside WL

H = 4.14 m
H₀ = 0.00 m
H_a = 0.40 m
L_{wa} = 0.00 m (Normal Condition)
L_{wa} = 0.00 m (Seismic Condition)
L_{wp} = 2.37 m (Normal Condition)
L_{wp} = 1.89 m (Seismic Condition)

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	0.77	10	11	10.77	32
2	1.77	10	12	11.77	26
3	2.77	9	13	12.77	41
4	3.77	12	14	13.77	50
5	4.77	17			
6	5.77	19			
7	6.77	24			
8	7.77	41			
9	8.77	50			
10	9.77	50			

1.6 Vertical Load

Vertical load on landside
Vertical load on riverside

calculated in consideration of embankment shape on landside
not considered

1.7 Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	0.27	0.27
2	1.27	1.00
3	2.27	1.00
4	3.27	1.00
5	4.27	1.00
6	4.85	0.58
7	5.27	0.42
8	6.27	1.00
9	7.27	1.00
10	8.27	1.00
11	9.27	1.00
12	10.27	1.00
13	11.27	1.00
14	12.27	1.00
15	13.27	1.00
16	14.03	0.76
17	18.78	4.75
18	33.80	15.02

No	Depth m	earth Soil	N Value kN/m ²	γ kN/m ³	γ' kN/m ³	φ degree	C kN/m ²	a	k'	ζ (degree)		Kh (kN/m ³)	
										Normal Condition	Seismic Condition	Normal Condition	Seismic Condition
1	0.27	S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	Auto	Auto
2	1.27	S	10.0	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto	Auto	Auto
3	2.27	S	10.0	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto	Auto	Auto
4	3.27	S	9.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	Auto	Auto
5	4.27	S	12.0	17.50	7.70	28.4	0.0	0.0	0.200	Auto	Auto	Auto	Auto
6	4.85	S	17.0	17.50	7.70	31.0	0.0	0.0	0.200	Auto	Auto	Auto	Auto
7	5.27	C	17.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto
8	6.27	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto
9	7.27	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto
10	8.27	C	41.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	Auto	Auto
11	9.27	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	Auto	Auto
12	10.27	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	Auto	Auto

1.3 Applied Formula

Formula for generated stress
Penetration depths

Chang's formula
 $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water
Type of water pressure
Lateral pressure
Study case

$\gamma_w = 9.8 \text{ kN/m}^3$
trapezoidal water pressure
calculated in consideration of site conditions
- Normal Condition
- Seismic Condition

Design earthquake intensity
 $k = 0.200$

Dynamic water pressure due to earthquake
considered as distributed load

Arbitrary load
not considered

Wind load, Impact load
not considered

Minimum angle of rupture
 $\zeta_0 = 10 \text{ degrees}$

Rear side angle of slope
not considered

Angle of rupture (clayey soil)
Equilibrium factor of compression

$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
 $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula
 $K_b = K_{b0} \left(\frac{B_b}{0.3} \right)^{-3/4}$
 $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_b = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$

Average N-value
calculated from average N-value between imaginary riverbed and depth as 1/β

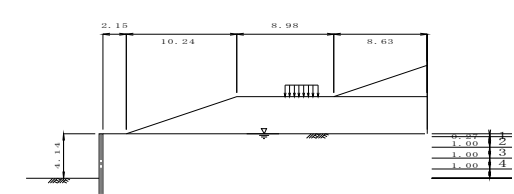
No	Depth m	earth Soil	N Value kN/m ²	γ kN/m ³	γ' kN/m ³	φ degree	C kN/m ²	a	k'	ζ (degree)		Kh (kN/m ³)	
										Normal Condition	Seismic Condition	Normal Condition	Seismic Condition
13	11.27	C	32.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	Auto	Auto
14	12.27	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto
15	13.27	C	41.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	Auto	Auto
16	14.03	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	Auto	Auto
17	18.78	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto	Auto	Auto
18	33.80	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto	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_s : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		h m	Normal Condition kN/m ³			Seismic Condition kN/m ³	Normal Condition degree
1	Sand	2.15	12.39	30.00	30.00	3.41	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	21.37	30.00	30.00	30.00	2.90	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	16.84	19.90	10.0	5.0

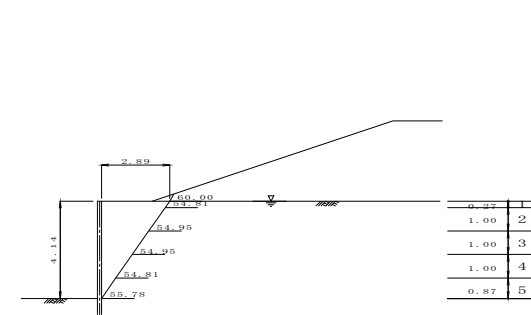
Angle of rupture in embankment
calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 400 -200 -9 -12 -13
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 87800 cm ⁴
Sectional factor	Z ₀	= 2320 cm ³
Corrosion margin	t ₁	= 1.00 mm (riverside) t ₂ = 1.00 mm (landside)
Corrosion rate (to I ₀)	η	= 0.80
Corrosion rate (to Z ₀)	η	= 0.81
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

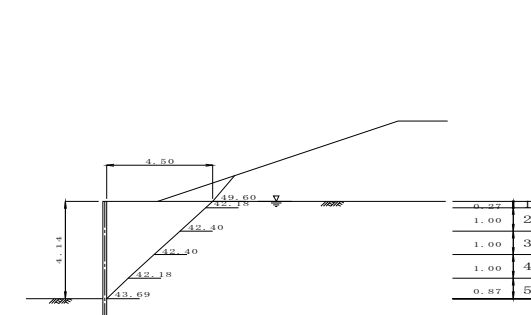


A: sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{2.15 + 0.00 + 0.00}{2.89}$$
$$= 0.74 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	4.14~3.27	Sand	28.4	15.0	0.0	31.88	5.43	40.57	0.200	11.31	43.69
2	3.27~2.27	Sand	27.0	15.0	0.0	25.18	5.43	32.05	0.200	11.31	42.18
3	2.27~1.27	Sand	27.2	15.0	0.0	17.48	5.43	22.25	0.200	11.31	42.40
4	1.27~0.27	Sand	27.2	15.0	0.0	9.78	5.43	12.45	0.200	11.31	42.40
5	0.27~0.00	Sand	27.0	15.0	0.0	2.08	5.43	2.65	0.200	11.31	42.18
6		embankment t	30.0	—	0.0	119.89	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive soil

2.1.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	Angle of Rupture ζ degree
1	4.14~3.27	Sand	28.4	15.0	0.0	31.88	0.74	40.57	55.78
2	3.27~2.27	Sand	27.0	15.0	0.0	25.18	0.74	32.05	54.81
3	2.27~1.27	Sand	27.2	15.0	0.0	17.48	0.74	22.25	54.95
4	1.27~0.27	Sand	27.2	15.0	0.0	9.78	0.74	12.45	54.95
5	0.27~0.00	Sand	27.0	15.0	0.0	2.08	0.74	2.65	54.81
6		embankment t	30.0	—	0.0	119.89	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 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)
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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	55.78	0.87	0.00	0.00	0.59	0.87
2	54.81	1.00	0.59	0.87	1.30	1.87
3	54.95	1.00	1.30	1.87	2.00	2.87
4	54.95	1.00	2.00	2.87	2.70	3.87
5	54.81	0.27	2.70	3.87	2.89	4.14
6	60.00	0.31	2.89	4.14	3.07	4.45

From the above table, the loading width (L) on the ground surface is 2.89 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.11	2.15
Σ			2.15

γ : unit weight of embankment 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.69	0.87	0.00	0.00	0.91	0.87
2	42.18	1.00	0.91	0.87	2.01	1.87
3	42.40	1.00	2.01	1.87	3.11	2.87
4	42.40	1.00	3.11	2.87	4.20	3.87
5	42.18	0.27	4.20	3.87	4.50	4.14
6	49.60	1.09	4.50	4.14	5.43	5.23

From the above table, the loading width (L) on the ground surface is 4.50 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	1.29	24.43
Σ			24.43

γ : unit weight of embankment soil

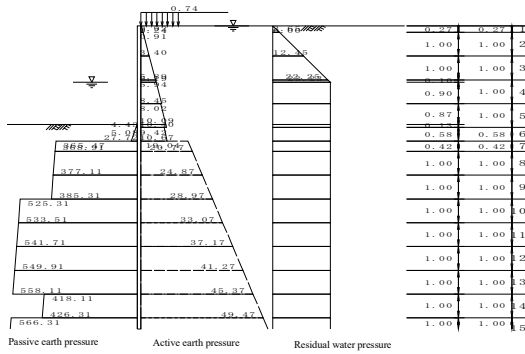
A: sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{24.43 + 0.00 + 0.00}{4.50}$$
$$= 5.43 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Q_0$ kN/m ²	K _a	K _a × cos δ
1	0.00-0.27	Sand	7.7	27.0	—	0.743 2.822	0.33738 0.33738	0.32589 0.32589
2	0.27-1.27	Sand	7.7	27.2	—	2.822 10.522	0.33489 0.33489	0.32348 0.32348
3	1.27-2.27	Sand	7.7	27.2	—	10.522 18.222	0.33489 0.33489	0.32348 0.32348
4	2.27-2.37	Sand	7.7	27.0	—	18.222 18.902	0.33738 0.33738	0.32589 0.32589
5	2.37-3.27	Sand	7.7	27.0	—	18.902 25.922	0.33738 0.33738	0.32589 0.32589
6	3.27-4.14	Sand	7.7	28.4	—	25.922 32.621	0.32022 0.32022	0.30931 0.30931
7	4.14-4.27	Sand	7.7	28.4	—	32.621 33.622	0.32022 0.32022	0.30931 0.30931
8	4.27-4.85	Sand	7.7	31.0	—	33.622 38.088	0.29008 0.29008	0.28020 0.28020
9	4.85-5.27	Clay	8.2	—	180.0	38.088 41.532	—	—
10	5.27-6.27	Clay	8.2	—	180.0	41.532 49.732	—	—
11	6.27-7.27	Clay	8.2	—	180.0	49.732 57.932	—	—
12	7.27-8.27	Clay	8.2	—	250.0 250.0	57.932 66.132	—	—

20	18.78-33.80	Clay	7.2	30.0	1000.0 1000.0	112.568 220.712	—	—

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-0.27	0.24 0.92	—	0.24 0.92	0.00 2.65	—
2	0.27-1.27	0.91 3.40	—	0.91 3.40	2.65 12.45	—
3	1.27-2.27	3.40 5.89	—	3.40 5.89	12.45 22.25	—
4	2.27-2.37	5.94 6.19	—	5.94 6.19	22.25 23.23	—
5	2.37-3.27	6.19 8.45	—	6.19 8.45	23.23 23.23	—
6	3.27-4.14	8.02 10.09	—	8.02 10.09	23.23 23.23	—
7	4.14-4.27	10.09 10.40	—	10.09 10.40	23.23 23.23	0.00 4.43
8	4.27-4.85	9.42 10.67	—	9.42 10.67	23.23 23.23	5.08 27.72
9	4.85-5.27	-321.91 -318.47	19.04 20.77	19.04 20.77	23.23 23.23	365.47 368.91
10	5.27-6.27	-318.47 -310.27	20.77 24.87	20.77 24.87	23.23 23.23	368.91 377.11
11	6.27-7.27	-310.27 -302.07	24.87 28.97	24.87 28.97	23.23 23.23	377.11 385.31
12	7.27-8.27	-442.07 -433.87	28.97 33.07	28.97 33.07	23.23 23.23	525.31 533.51
13	8.27-9.27	-433.87 -425.67	33.07 37.17	33.07 37.17	23.23 23.23	533.51 541.71
14	9.27-10.27	-425.67 -417.47	37.17 41.27	37.17 41.27	23.23 23.23	541.71 549.91
15	10.27-11.27	-417.47 -409.27	41.27 45.37	41.27 45.37	23.23 23.23	549.91 558.11
16	11.27-12.27	-269.27 -261.07	45.37 49.47	45.37 49.47	23.23 23.23	418.11 426.31
17	12.27-13.27	-401.07 -392.87	49.47 53.57	49.47 53.57	23.23 23.23	566.31 574.51
18	13.27-14.03	-392.87 -386.64	53.57 56.68	53.57 56.68	23.23 23.23	574.51 580.74
19	14.03-18.78	-286.64 -254.81	56.68 72.59	56.68 72.59	23.23 23.23	480.74 512.57

13	8.27-9.27	Clay	8.2	—	250.0 250.0	66.132 74.332	—	—
14	9.27-10.27	Clay	8.2	—	250.0 250.0	74.332 82.532	—	—
15	10.27-11.27	Clay	8.2	—	250.0 250.0	82.532 90.732	—	—
16	11.27-12.27	Clay	8.2	—	180.0 180.0	90.732 98.932	—	—
17	12.27-13.27	Clay	8.2	—	250.0 250.0	98.932 107.132	—	—
18	13.27-14.03	Clay	8.2	—	250.0 250.0	107.132 113.364	—	—
19	14.03-18.78	Clay	6.7	—	200.0 200.0	113.364 145.189	—	—
20	18.78-33.80	Clay	7.2	—	1000.0 1000.0	145.189 253.333	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	K _p	K _p × cos δ
7	4.14-4.27	Sand	7.7	28.4	—	0.000 1.001	4.57728 4.57728	4.42131 4.42131
8	4.27-4.85	Sand	7.7	31.0	—	1.001 5.467	5.24888 5.24888	5.07003 5.07003
9	4.85-5.27	Clay	8.2	0.0	180.0	5.467 8.911	—	—
10	5.27-6.27	Clay	8.2	0.0	180.0 180.0	8.911 17.111	—	—
11	6.27-7.27	Clay	8.2	0.0	180.0 180.0	17.111 25.311	—	—
12	7.27-8.27	Clay	8.2	0.0	250.0 250.0	25.311 33.511	—	—
13	8.27-9.27	Clay	8.2	0.0	250.0 250.0	33.511 41.711	—	—
14	9.27-10.27	Clay	8.2	0.0	250.0 250.0	41.711 49.911	—	—
15	10.27-11.27	Clay	8.2	0.0	250.0 250.0	49.911 58.111	—	—
16	11.27-12.27	Clay	8.2	0.0	180.0 180.0	58.111 66.311	—	—
17	12.27-13.27	Clay	8.2	0.0	250.0 250.0	66.311 74.511	—	—
18	13.27-14.03	Clay	8.2	0.0	250.0 250.0	74.511 80.743	—	—
19	14.03-18.78	Clay	6.7	20.0	200.0 200.0	80.743 112.568	—	—

20	18.78-33.80	-1854.81 -1746.67	72.59 126.67	23.23 23.23	2112.57 2220.71

- Formula for active earth pressure

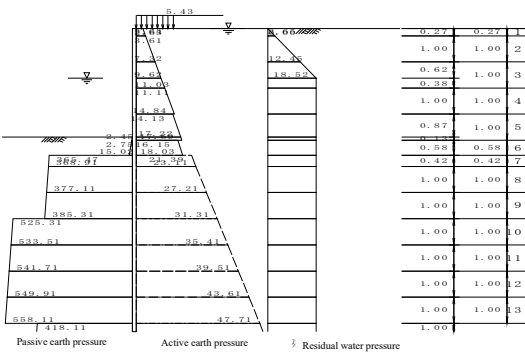
Sand $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$
K_c : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$

- Formula for passive earth pressure

Sand $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2C$
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/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	k (k)	θ degree	K _a	K _a × cos δ	ζ degree
1	0.00-0.27	Sand	7.7	27.0	—	5.43 7.51	0.00 2.65	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
2	0.27-1.27	Sand	7.7	27.2	—	7.51 15.21	2.65 12.45	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
3	1.27-1.89	Sand	7.7	27.2	—	15.21 19.98	12.45 18.52	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—

4	1.89- 2.27	Sand	7.7	27.2	————	19.98 22.91	18.52 22.25	0.200	11.31	0.49850 0.49850	0.48152 0.48152	————
5	2.27- 3.27	Sand	7.7	27.0	————	22.91 30.61	22.25 32.05	0.200	11.31	0.50201 0.50201	0.48499 0.48499	————
6	3.27- 4.14	Sand	7.7	28.4	————	30.61 37.30	32.05 40.57	0.200	11.31	0.47800 0.47800	0.46172 0.46172	————
7	4.14- 4.27	Sand	7.7	28.4	————	37.30 38.31	40.57 41.85	0.200	11.31	0.47800 0.47800	0.46172 0.46172	————
8	4.27- 4.85	Sand	7.7	31.0	————	38.31 42.77	41.85 47.53	0.200	11.31	0.43652 0.43652	0.42164 0.42164	————
9	4.85- 5.27	Clay	8.2	—	180.0 180.0	42.77 46.22	47.53 51.65	0.200	11.31	————	————	44.61 44.58
10	5.27- 6.27	Clay	8.2	—	180.0 180.0	46.22 54.42	51.65 61.45	0.200	11.31	————	————	44.58 44.52
11	6.27- 7.27	Clay	8.2	—	180.0 180.0	54.42 62.62	61.45 71.25	0.200	11.31	————	————	44.52 44.45
12	7.27- 8.27	Clay	8.2	—	250.0 250.0	62.62 70.82	71.25 81.05	0.200	11.31	————	————	44.60 44.56
13	8.27- 9.27	Clay	8.2	—	250.0 250.0	70.82 79.02	81.05 90.85	0.200	11.31	————	————	44.56 44.51
14	9.27- 10.27	Clay	8.2	—	250.0 250.0	79.02 87.22	90.85 100.65	0.200	11.31	————	————	44.51 44.46
15	10.27- 11.27	Clay	8.2	—	250.0 250.0	87.22 95.42	100.65 110.45	0.200	11.31	————	————	44.46 44.41
16	11.27- 12.27	Clay	8.2	—	180.0 180.0	95.42 103.62	110.45 120.25	0.200	11.31	————	————	44.17 44.11
17	12.27- 13.27	Clay	8.2	—	250.0 250.0	103.62 111.82	120.25 130.05	0.200	11.31	————	————	44.36 44.31
18	13.27- 14.03	Clay	8.2	—	250.0 250.0	111.82 118.05	130.05 137.49	0.200	11.31	————	————	44.31 44.27
19	14.03- 18.78	Clay	6.7	—	200.0 200.0	118.05 149.87	137.49 184.04	0.200	11.31	————	————	44.09 43.84
20	18.78- 33.80	Clay	7.2	—	1000.0 1000.0	149.87 258.02	184.04 331.24	0.200	11.31	————	————	44.78 44.62

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$$

4	1.89- 2.27	9.62 11.03	————	9.62 11.03	18.52 18.52	————
5	2.27- 3.27	11.11 14.84	————	11.11 14.84	18.52 18.52	————
6	3.27- 4.14	14.13 17.22	————	14.13 17.22	18.52 18.52	————
7	4.14- 4.27	17.22 17.69	————	17.22 17.69	18.52 18.52	0.00 2.45
8	4.27- 4.85	16.15 18.03	————	16.15 18.03	18.52 18.52	2.75 15.02
9	4.85- 5.27	-308.59 -304.44	21.39 23.11	21.39 23.11	18.52 18.52	365.47 368.91
10	5.27- 6.27	-304.44 -294.57	23.11 27.21	23.11 27.21	18.52 18.52	368.91 377.11
11	6.27- 7.27	-294.57 -284.68	27.21 31.31	27.21 31.31	18.52 18.52	377.11 385.31
12	7.27- 8.27	-424.74 -414.86	31.31 35.41	31.31 35.41	18.52 18.52	525.31 533.51
13	8.27- 9.27	-414.86 -404.98	35.41 39.51	35.41 39.51	18.52 18.52	533.51 541.71
14	9.27- 10.27	-404.98 -395.10	39.51 43.61	39.51 43.61	18.52 18.52	541.71 549.91
15	10.27- 11.27	-395.10 -385.21	43.61 47.71	43.61 47.71	18.52 18.52	549.91 558.11
16	11.27- 12.27	-245.09 -235.18	47.71 51.81	47.71 51.81	18.52 18.52	418.11 426.31
17	12.27- 13.27	-375.32 -365.42	51.81 55.91	51.81 55.91	18.52 18.52	566.31 574.51
18	13.27- 14.03	-365.42 -357.90	55.91 59.02	55.91 59.02	18.52 18.52	574.51 580.74
19	14.03- 18.78	-257.78 -219.24	59.02 74.94	59.02 74.94	18.52 18.52	480.74 512.57
20	18.78- 33.80	-1819.98 -1689.87	74.94 129.01	74.94 129.01	18.52 18.52	2112.57 2220.71

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\sum \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\sum \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\sum \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\sum \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Kp	$K_p \times \cos \delta$
7	4.14- 4.27	Sand	7.70	28.4	————	0.000 1.001	0.00 1.27	0.200 0.200	11.31	2.45242 2.45242	2.45242 2.45242
8	4.27- 4.85	Sand	7.70	31.0	————	1.001 5.467	1.27 6.96	0.200 0.200	11.31	2.74701 2.74701	2.74701 2.74701
9	4.85- 5.27	Clay	8.20	0.0	180.0 180.0	5.467 8.911	6.96 11.07	0.200 0.200	11.31	————	————
10	5.27- 6.27	Clay	8.20	0.0	180.0 180.0	8.911 17.111	11.07 20.87	0.200 0.200	11.31	————	————
11	6.27- 7.27	Clay	8.20	0.0	180.0 180.0	17.111 25.311	20.87 30.67	0.200 0.200	11.31	————	————
12	7.27- 8.27	Clay	8.20	0.0	250.0 250.0	25.311 33.511	30.67 40.47	0.200 0.200	11.31	————	————
13	8.27- 9.27	Clay	8.20	0.0	250.0 250.0	33.511 41.711	40.47 50.27	0.200 0.200	11.31	————	————
14	9.27- 10.27	Clay	8.20	0.0	250.0 250.0	41.711 49.911	50.27 60.07	0.200 0.200	11.31	————	————
15	10.27- 11.27	Clay	8.20	0.0	250.0 250.0	49.911 58.111	60.07 69.87	0.200 0.200	11.31	————	————
16	11.27- 12.27	Clay	8.20	0.0	180.0 180.0	58.111 66.311	69.87 79.67	0.200 0.200	11.31	————	————
17	12.27- 13.27	Clay	8.20	0.0	250.0 250.0	66.311 74.511	79.67 89.47	0.200 0.200	11.31	————	————
18	13.27- 14.03	Clay	8.20	0.0	250.0 250.0	74.511 80.743	89.47 96.92	0.200 0.200	11.31	————	————
19	14.03- 18.78	Clay	6.70	20.0	200.0 200.0	80.743 112.568	96.92 143.47	0.200 0.200	11.31	————	————
20	18.78- 33.80	Clay	7.20	30.0	1000.0 1000.0	112.568 220.712	143.47 280.67	0.200 0.200	11.31	————	————

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 0.27	2.63 3.64	————	2.63 3.64	0.00 2.65	————
2	0.27- 1.27	3.61 7.32	————	3.61 7.32	2.65 12.45	————
3	1.27- 1.89	————	————	7.32 9.62	12.45 18.52	————

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth, m	water level, y m	pdw kN/m ²
1	1.89	0.00	0.00
2	2.89	1.00	2.57
3	3.89	2.00	3.64
4	4.14	2.25	3.86

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

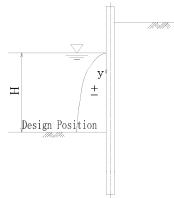
Where,

k_{hs} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

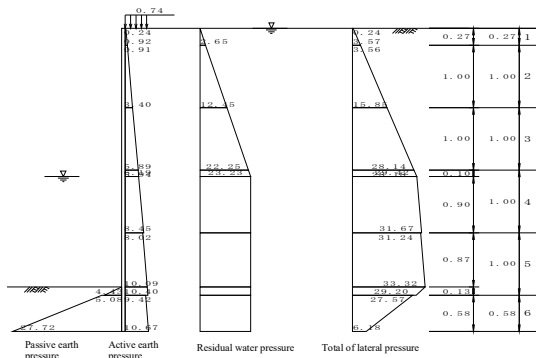
y : depth from water surface to the point where active water pressure is calculated



4 Imaginary Riverbed

Imaginary ground level 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

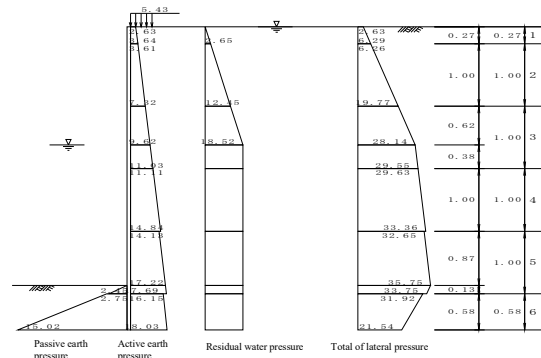


No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.27	0.24 0.92	0.00 2.65	— —	0.24 3.57
2	0.27- 1.27	0.91 5.89	2.65 12.45	— —	3.56 15.85
3	1.27- 2.27	3.40 5.89	12.45 22.25	— —	15.85 28.14
4	2.27- 2.37	5.94 6.19	22.25 23.23	— —	28.18 29.42
5	2.37- 3.27	6.19 8.45	23.23 23.23	— —	29.42 31.67
6	3.27- 4.14	8.02 10.09	23.23 23.23	— —	31.24 33.32
7	4.14- 4.27	10.09 10.40	23.23 23.23	0.00 4.43	33.32 29.20
8	4.27- 4.85	9.42 10.67	23.23 23.23	5.08 27.72	27.57 6.18
9	4.85- 5.27	19.04 20.77	23.23 23.23	365.47 368.91	-323.20 -324.92

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_4 : 0.71 m (GL -4.85 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.27	2.63 3.64	0.00 2.65	— —	2.63 6.29
2	0.27- 1.27	3.61 7.32	2.65 12.45	— —	6.26 19.77
3	1.27- 1.89	7.32 9.62	12.45 18.52	— —	19.77 28.14
4	1.89- 2.27	9.62 11.03	18.52 18.52	— —	28.14 29.55
5	2.27- 3.27	11.11 14.84	18.52 18.52	— —	29.63 33.36
6	3.27- 4.14	14.13 17.22	18.52 18.52	— —	32.65 35.75
7	4.14- 4.27	17.22 17.69	18.52 18.52	0.00 2.45	35.75 33.75
8	4.27- 4.85	16.15 18.03	18.52 18.52	2.75 15.02	31.92 21.54
9	4.85- 5.27	21.39 23.11	18.52 18.52	365.47 368.91	-325.56 -327.28

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_4 : 0.71 m (GL -4.85 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{b0} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B = 10.00 \text{ m})$$

$$K_{b0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H ₂ H 400 -200 -9 -12 -13
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 = 0.80
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 87800 cm ⁴ (original condition)
Inertia sectional moment	I = 70240 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 70240 × 10 ⁻⁸ = 1.405 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	0.77	10	11	10.77	32
2	1.77	10	12	11.77	26
3	2.77	9	13	12.77	41
4	3.77	12	14	13.77	50
5	4.77	17			
6	5.77	19			
7	6.77	24			
8	7.77	41			
9	8.77	50			
10	9.77	50			

5.2 Normal Condition

Assuming $K_h = 14731 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.402 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.49 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.85 m) to 2.49 m depth (GL -7.36 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.85	0.92	17.2	19.0	16.63
2	5.77	1.00	19.0	24.0	21.50
3	6.77	0.57	24.0	33.6	16.28
L = $\Sigma h = 2.49$			$\Sigma A = 54.41$		

A: (Top N + Bottom N) × h/2

$$\text{Average N-value } N' = \frac{\sum A}{L}$$

$$= \frac{54.41}{2.49}$$

$$= 21.89$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 21.89 = 61305 \text{ kN/m}^2$$

$$K_{b0} = \frac{1}{0.3} \times \alpha \times 61305 = 204351 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{b0} (B/0.3)^{-3/4} = 204351 (10.00/0.3)^{-3/4} = 14731 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 14731 kN/m³.

5.3 Seismic Condition

Assuming $K_h = 27494 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.470 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.85 m) and 2.13 m depth (GL -6.98 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.85	0.92	17.2	19.0	16.63
2	5.77	1.00	19.0	24.0	21.50
3	6.77	0.21	24.0	27.5	5.31
L = $\Sigma h = 2.13$			$\Sigma A =$		43.44

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\sum A}{L}$$

$$= \frac{43.44}{2.13}$$

$$= 20.43$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800N' = 2800 \times 20.43 = 57213 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 57213 = 381418 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_b = K_{10} (B_u/0.3)^{-3/4} = 381418 (10.00/0.3)^{-3/4} = 27494 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 27494 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.27	0.27	0.24 3.57	0.03 0.48	4.76 4.67	0.16 2.25
2	0.27~ 1.27	1.00	3.56 15.85	1.78 7.92	4.25 3.91	7.56 31.01
3	1.27~ 2.27	1.00	15.85 28.14	7.92 14.07	3.25 2.91	25.73 40.99
4	2.27~ 2.37	0.10	28.18 29.42	1.41 1.47	2.55 2.51	3.59 3.70
5	2.37~ 3.27	0.90	29.42 31.67	13.24 14.25	2.18 1.88	28.86 26.80
6	3.27~ 4.14	0.87	31.24 33.32	13.59 14.49	1.29 1.00	17.53 14.49
7	4.14~ 4.27	0.13	33.32 29.20	2.17 1.90	0.67 0.62	1.44 1.18
8	4.27~ 4.85	0.58	27.57 6.18	8.00 1.79	0.39 0.19	3.09 0.35
			ΣP =	104.52	ΣM =	208.72

Ps : active earth pressure + residual water pressure - passive earth pressure
P : load Ps 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 $P_l = 0.0 \text{ kN/m}$
depth to acting position $H_l = 0.0 \text{ m}$
moment $M_{ln} = 0.0 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_{ln} = 0.00 \text{ m}$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	1.89~ 2.89	1.00	0.0 2.6	0.00 1.29	2.63 2.29	0.00 2.95
2	2.89~ 3.89	1.00	2.6 3.6	1.29 1.82	1.63 1.29	2.09 2.35
3	3.89~ 4.14	0.25	3.6 3.9	0.45 0.48	0.88 0.79	0.40 0.38
			Σ P _{hw} =	5.33	Σ M _{hw} =	8.18

h₀ Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_l + \Sigma M_{hw}}{\Sigma P + P_l + \Sigma P_{hw}}$$

$$= \frac{251.22}{126.63} = 1.98 \text{ m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name 10 H H 400-200-9-12-13
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.80
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 87800 cm⁴ (original condition)
I = 70240 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 70240 × 10⁻⁸ = 1.405 × 10⁵

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_s = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_s$$

$$l_s = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$l_l = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M(x) = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_b = 14731 \text{ kN/m}^3$
calculated value $\beta = 0.40238 \text{ m}^{-1}$

Height from riverbed to top of coping H = 4.14 m
Depth of Imaginary riverbed from riverbed L_k = 0.71 m

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_0) + M_{ln} = 0.00 \text{ kN} \cdot \text{m}$$

h₀ Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_l}{\Sigma P + P_l}$$

$$= \frac{208.72}{104.52} = 2.00 \text{ m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth Ps kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.27	0.27	2.63 6.29	0.36 0.85	4.76 4.67	1.69 3.96
2	0.27~ 1.27	1.00	6.28 19.77	3.13 9.88	4.25 3.91	12.29 38.68
3	1.27~ 1.89	0.62	19.77 28.14	6.13 8.72	3.37 3.17	20.67 27.63
4	1.89~ 2.27	0.38	28.14 29.55	5.35 5.61	2.83 2.71	15.15 15.20
5	2.27~ 3.27	1.00	29.63 33.36	14.81 16.68	2.25 1.91	33.28 31.92
6	3.27~ 4.14	0.87	32.68 35.75	14.20 15.55	1.29 1.00	18.32 15.55
7	4.14~ 4.27	0.13	35.75 33.75	2.32 2.19	0.67 0.62	1.55 1.37
8	4.27~ 4.85	0.58	31.92 21.54	9.26 6.25	0.39 0.19	3.58 1.21
			ΣP =	121.30	ΣM =	243.05

Ps : active earth pressure + residual water pressure - passive earth pressure

P : load Ps 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 $P_l = 0.0 \text{ kN/m}$
depth to acting position $H_l = 0.00 \text{ m}$
moment $M_{ln} = 0.00 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_{ln} = 0.00 \text{ m}$

Height from riverbed to top of coping H = 4.14 m
Depth of Imaginary riverbed from riverbed L_k = 0.71 m

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_0) + M_{ln} = 0.00 \text{ kN} \cdot \text{m}$$

resultant earth force (lateral) $P_0 = 104.32 \text{ kN/m}$
height of acting position of load $h_0 = 2.00 \text{ m}$
moment $M_0 = 208.72 \text{ kN} \cdot \text{m/m}$

in consideration of ψ_{ln} = 1.205,
maximum moment $M_{\max} = 251.43 \text{ kN} \cdot \text{m/m}$
depth of generated position of M_{max} $l_m = 0.910 \text{ m}$
depth of 1st fixed point $l_l = 2.862 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_b = 27494 \text{ kN/m}^3$
calculated value $\beta = 0.47032 \text{ m}^{-1}$
resultant earth force (lateral) $P_0 = 126.63 \text{ kN/m}$
height of acting position of load $h_0 = 1.98 \text{ m}$
moment $M_0 = 251.22 \text{ kN} \cdot \text{m/m}$

in consideration of ψ_{ln} = 1.163,
maximum moment $M_{\max} = 292.12 \text{ kN} \cdot \text{m/m}$
depth of generated position of M_{max} $l_m = 0.714 \text{ m}$
depth of 1st fixed point $l_l = 2.384 \text{ m}$

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as follows:

Material Name 10 H H 400-200-9-12-13
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.81
Section efficiency μ = 1.00
Module of section Z₀ = 2320 cm³ (original condition)
Z = 1879 cm³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{251.43 \times 10^6}{1879 \times 10^3} = 134 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{292.12 \times 10^6}{1879 \times 10^3} = 155 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

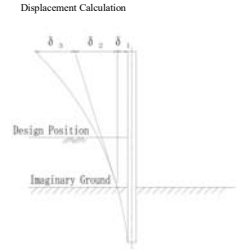
6.4 Displacement Calculation

6.4.1 Normal Condition

Modulus of deformation

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-0.27	4.76 4.67	0.981 0.963	0.324 0.315	0.03 0.48	0.011 0.152
2	0.27-1.27	4.25 3.91	0.876 0.807	0.271 0.238	1.78 7.92	0.483 1.886
3	1.27-2.27	3.25 2.91	0.669 0.601	0.174 0.144	7.92 14.07	1.379 2.030
4	2.27-2.37	2.55 2.51	0.525 0.518	0.114 0.111	1.41 1.47	0.160 0.163
5	2.37-3.27	2.18 1.88	0.449 0.388	0.086 0.065	13.24 14.25	1.137 0.932
6	3.27-4.14	1.29 1.00	0.266 0.206	0.032 0.020	13.59 14.49	0.438 0.287
7	4.14-4.27	0.67 0.62	0.137 0.129	0.009 0.008	2.17 1.90	0.020 0.015
8	4.27-4.85	0.39 0.19	0.080 0.040	0.003 0.001	8.00 1.79	0.025 0.001
Σ Q =					9.119	

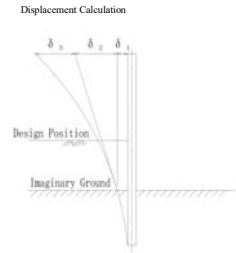
Y : Height from imaginary riverbed to acting position
α : $\alpha = \frac{Y}{H+L_k}$
ζ : $\zeta = \frac{(3-\alpha) \times \alpha^2}{6}$
Q : ζ × P
P : Lateral force
H : Depth to design position
L_k : Depth from design position to imaginary ground



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$
$$= \frac{(1 + 0.4024 \times 2.00) \times 104.52}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4024^3} = 0.01030 \text{ m}$$

No	Depth, m	Y, m	α	ζ	Pdw, kN	Qdw, kN
1	1.89-2.89	2.63 2.29	0.542 0.473	0.120 0.094	0.00 1.29	0.000 0.121
2	2.89-3.89	1.63 1.29	0.335 0.267	0.050 0.032	1.29 1.82	0.004 0.059
3	3.89-4.14	0.88 0.79	0.181 0.164	0.015 0.013	0.45 0.48	0.007 0.006
Σ Qdw =					0.257	

Therefore, the deformation coefficient Q is expressed by
Q = 10.933 + 0.257 = 11.190



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$
$$= \frac{(1 + 0.4703 \times 1.98) \times 126.63}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4703^3} = 0.00837 \text{ m}$$
$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k)$$
$$= \frac{(1 + 2 \times 0.4703 \times 1.98) \times 126.63}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4703^2} \times (4.14 + 0.71) = 0.02832 \text{ m}$$
$$\delta_3 = \frac{Q \times (H + L_k)^3}{E I}$$
$$= \frac{11.19 \times (4.14 + 0.71)^3}{2.00 \times 10^8 \times 70240 \times 10^{-8}} = 0.00909 \text{ m}$$

δ = δ₁ + δ₂ + δ₃
= 0.00837 + 0.02832 + 0.00909
= 0.04579 m
Size = 45.79 ≤ δ a = 75.00 mm

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : Displacement at higher part of imaginary ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k)$$
$$= \frac{(1 + 2 \times 0.4024 \times 2.00) \times 104.52}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4024^2} \times (4.14 + 0.71) = 0.02905 \text{ m}$$
$$\delta_3 = \frac{Q \times (H + L_k)^3}{E I}$$
$$= \frac{9.12 \times (4.14 + 0.71)^3}{2.00 \times 10^8 \times 70240 \times 10^{-8}} = 0.00741 \text{ m}$$

δ = δ₁ + δ₂ + δ₃
= 0.01030 + 0.02905 + 0.00741
= 0.04676 m
Size = 46.76 ≤ δ a = 50.00 mm

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : 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

No	Depth, m	Y, m	α	ζ	P, kN	Q, kN
1	0.00-0.27	4.76 4.67	0.981 0.963	0.324 0.315	0.36 0.85	0.115 0.267
2	0.27-1.27	4.25 3.91	0.876 0.807	0.271 0.238	3.13 9.88	0.850 2.352
3	1.27-1.89	3.37 3.17	0.696 0.653	0.186 0.167	6.13 8.72	1.139 1.455
4	1.89-2.27	2.83 2.71	0.584 0.558	0.137 0.127	5.35 5.61	0.735 0.712
5	2.27-3.27	2.25 1.91	0.463 0.395	0.091 0.068	14.81 16.68	1.344 1.127
6	3.27-4.14	1.29 1.00	0.266 0.206	0.032 0.020	14.20 15.55	0.458 0.308
7	4.14-4.27	0.67 0.62	0.137 0.129	0.009 0.008	2.32 2.19	0.021 0.017
8	4.27-4.85	0.39 0.19	0.080 0.040	0.003 0.001	9.26 6.25	0.029 0.005
Σ Q =					10.933	

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

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H ₂ H 400 -200 -9 -12 -13
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 = 87800 cm ⁴ (original condition) I = 87800 cm ⁴ (after reduction by corrosion and section)
EI	200000 × 10 ³ × 87800 × 10 ⁻⁸ = 1.756 × 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 follows:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{11} + D$$
$$\beta = 4 \sqrt{\frac{K_b \times B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _b = 14731 kN/m ³
Calculated value	β = 0.38055 m ⁻¹
Penetration length of SSP	D = 0.71 + $\frac{3}{0.381}$ = 8.59 m
Whole length of SSP	L = 4.14 - 0.40 + 8.59 = 12.33 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K _b = 27494 kN/m ³
Calculated value	β = 0.44480 m ⁻¹
Penetration length of SSP	D = 0.71 + $\frac{3}{0.445}$ = 7.45 m
Whole length of SSP	L = 4.14 - 0.40 + 7.45 = 11.19 m

Therefore, the total length of the sheet pile is 12.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP		10 H _H 400-200 -9-12-13				
			Normal Condition		Seismic Condition	
Inertia sectional moment	I (cm ⁴)	87800				
Sectional Modulus	Z (cm ³)	2320				
Maximum bending moment	Mmax (kN·m = α × m)			251.43	292.12	
Stress intensity	σ (N/mm ²)			134 (180)	155 (270)	
Lateral displacement	δ (mm)			46.76 (50.0)	45.79 (50.0)	
Penetration depth	D (m)			8.59	7.45	
Whole length of SSP	L (m)	12.50				

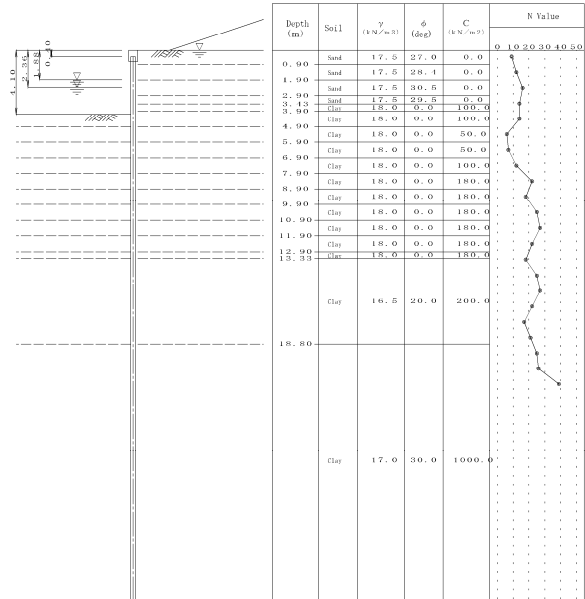
Block No. : R-30
Sta. : 11+360~11+700

Design Cross Section : Sta 11+500
Boring Name : DD-BH-R14

Specification : SSP SP-10H
(Combined) : H 400-200-9-12-13

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed H = 4.10 m
Depth from coping top to rear side ground H₀ = 0.00 m
Depth from coping top to SSP top H₁ = 0.40 m
Landside WL L_{wa} = 0.00 m (Normal Condition)
L_{wa}' = 0.00 m (Seismic Condition)
Riverside WL L_{wp} = 2.36 m (Normal Condition)
L_{wp}' = 1.88 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress Chang's formula

$$\text{Penetration depths } L = \frac{3}{\beta}$$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_s = K_{s0} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{s0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_H = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
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	0.40	9	11	10.40	25	21	20.40	26
2	1.40	12	12	11.40	27	22	21.40	39
3	2.40	16	13	12.40	22			
4	3.40	14	14	13.40	18			
5	4.40	14	15	14.40	25			
6	5.40	6	16	15.40	27			
7	6.40	7	17	16.40	22			
8	7.40	12	18	17.40	17			
9	8.40	22	19	18.40	21			
10	9.40	18	20	19.40	25			

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 (Include Projection Length)	Thickness m (excluding projected length)
1	0.90	0.90
2	1.90	1.00
3	2.90	1.00
4	3.43	0.53
5	3.90	0.47
6	4.90	1.00
7	5.90	1.00
8	6.90	1.00
9	7.90	1.00
10	8.90	1.00
11	9.90	1.00
12	10.90	1.00
13	11.90	1.00
14	12.90	1.00
15	13.33	0.43
16	18.80	5.47
17	33.80	15.00

No	Depth m	Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	K _h (kN/m ²)	Normal Condition	Seismic Condition	Normal Condition	Seismic Condition
1	0.90	S	9.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
2	1.90	S	12.0	17.50	7.70	28.4	0.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
3	2.90	S	16.0	17.50	7.70	30.5	0.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
4	3.43	S	14.0	17.50	7.70	29.5	0.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
5	3.90	C	14.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
6	4.90	C	14.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
7	5.90	C	6.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
8	6.90	C	7.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
9	7.90	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
10	8.90	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
11	9.90	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
12	10.90	C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto
13	11.90	C	27.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	Auto	Auto	Auto	Auto

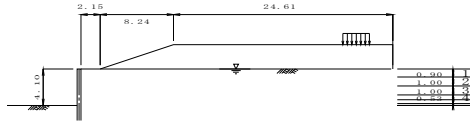
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	Kh (kN/m ³)
										Normal Condition	Seismic Condition
14	12.90	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	13.33	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	18.80	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
17	33.80	C	121.5	17.00	7.20	30.0	1000.0	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_u : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness h m	soil single weight Normal Condition kN/m ³	γ kN/m ³	internal friction angle ϕ degree	stickiness C kN/m ²	theory angle ζ degree
		Bottom Left m	Top Left m	Top Right m	Bottom Right m						
1	Sand	2.15	10.39	35.00	35.00	2.74	19.0	19.0	30.0	0.0	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	29.37	32.35	10.0	5.0

Angle of rupture in embankment calculated in consideration of embankment conditions

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	γ when kN/m ²	Angle of Rupture ζ degree
1	4.10~3.90	Clay	0.0	15.0	100.0	31.90	0.90	40.18	45.00
2	3.90~3.43	Clay	0.0	15.0	100.0	30.26	0.90	38.22	45.00
3	3.43~2.90	Sand	29.5	15.0	0.0	26.41	0.90	33.61	56.52
4	2.90~1.90	Sand	30.5	15.0	0.0	22.33	0.90	28.42	57.19
5	1.90~0.90	Sand	28.4	15.0	0.0	14.63	0.90	18.62	55.78
6	0.90~0.00	Sand	27.0	15.0	0.0	6.93	0.90	8.82	54.81
7		embankment	30.0	—	0.0	52.06	10.00	0.00	60.00

• Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) \sqrt{\frac{\cos(\phi + \delta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• 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 $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.00	0.20	0.00	0.00	0.20	0.20
2	45.00	0.47	0.20	0.20	0.67	0.67
3	56.52	0.53	0.67	0.67	1.02	1.20
4	57.19	1.00	1.02	1.20	1.67	2.20
5	55.78	1.00	1.67	2.20	2.35	3.20
6	54.81	0.90	2.35	3.20	2.98	4.10
7	60.00	0.34	2.98	4.10	3.18	4.44

From the above table, the loading width (L) on the ground surface is 2.98 m.

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 400 -200 -9 -12 -13
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 87800 cm⁴
Sectional factor Z₀ = 2320 cm³

Corrosion margin t₁ = 1.00 mm (riverside) t₂ = 1.00 mm (landside)

Corrosion rate (to I₀) η = 0.80
Corrosion rate (to Z₀) η = 0.81
Section efficiency (to I₀) μ = 1.00
Section efficiency (to Z₀) 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)

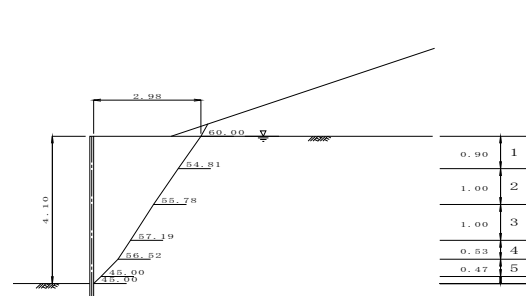
Allowable displacement δ_a = 50.0 mm (Normal)
 δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I₀ applied to calculation of penetration depth
Reduced: I₀ applied to calculation of section forces and displacement
Reduced: Z₀ applied to calculation of stresses

2 Calculation of Acting Load

2.1 Normal Condition



2.1.3 Acting Rupture by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.14	2.69
Σ			2.69

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

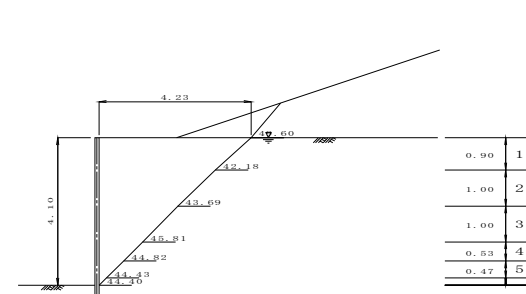
2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{2.69 + 0.00 + 0.00}{2.98}$$

$$= 0.90 \text{ kN/m}^2$$

2.2 Seismic 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	γ when kN/m ²	k (k')	θ degree	Angle of Rupture ζ degree
1	4.10~3.90	Clay	0.0	15.0	100.0	31.90	4.50	40.18	0.200	11.31	44.40
2	3.90~3.43	Clay	0.0	15.0	100.0	30.26	4.50	38.22	0.200	11.31	44.43
3	3.43~2.90	Sand	29.5	15.0	0.0	26.41	4.50	33.61	0.200	11.31	44.82
4	2.90~1.90	Sand	30.5	15.0	0.0	22.33	4.50	28.42	0.200	11.31	45.81
5	1.90~0.90	Sand	28.4	15.0	0.0	14.63	4.50	18.62	0.200	11.31	43.69
6	0.90~0.00	Sand	27.0	15.0	0.0	6.93	4.50	8.82	0.200	11.31	42.18

7		embankment	30.0	0.0	52.06	5.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive 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/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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	44.40	0.20	0.00	0.00	0.20	0.20
2	44.43	0.47	0.20	0.20	0.68	0.67
3	44.82	0.53	0.68	0.67	1.22	1.20
4	45.81	1.00	1.22	1.20	2.19	2.20
5	43.69	1.00	2.19	2.20	3.24	3.20
6	42.18	0.90	3.24	3.20	4.23	4.10
7	49.60	0.96	4.23	4.10	5.05	5.06

From the above table, the loading width (L) on the ground surface is 4.23 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	1.00	19.05
Σ			19.05

γ : unit weight of embankment soil

A: sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

10	5.90- 6.90	Clay	8.2	—	50.0	47.569	—	—
11	6.90- 7.90	Clay	8.2	—	100.0	55.769	—	—
12	7.90- 8.90	Clay	8.2	—	180.0	63.969	—	—
13	8.90- 9.90	Clay	8.2	—	180.0	72.169	—	—
14	9.90- 10.90	Clay	8.2	—	180.0	80.369	—	—
15	10.90- 11.90	Clay	8.2	—	180.0	88.569	—	—
16	11.90- 12.90	Clay	8.2	—	180.0	96.769	—	—
17	12.90- 13.33	Clay	8.2	—	180.0	104.969	—	—
18	13.33- 18.80	Clay	6.7	—	200.0	108.495	—	—
19	18.80- 33.80	Clay	7.2	—	1000.0	145.144	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$$\delta = 15.00, \beta = 0.00, \theta = 0.00$$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

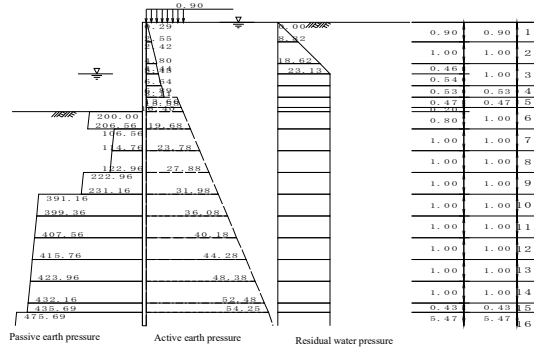
No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	Kp	$K_p \times \cos \delta$
8	4.10- 4.90	Clay	8.2	0.0	100.0	0.000	—	—
9	4.90- 5.90	Clay	8.2	0.0	50.0	6.560	—	—
10	5.90- 6.90	Clay	8.2	0.0	50.0	14.760	—	—
11	6.90- 7.90	Clay	8.2	0.0	100.0	22.960	—	—
12	7.90- 8.90	Clay	8.2	0.0	180.0	31.160	—	—
13	8.90- 9.90	Clay	8.2	0.0	180.0	39.360	—	—
14	9.90- 10.90	Clay	8.2	0.0	180.0	47.560	—	—
15	10.90- 11.90	Clay	8.2	0.0	180.0	55.760	—	—
16	11.90- 12.90	Clay	8.2	0.0	180.0	63.960	—	—
17	12.90- 13.33	Clay	8.2	0.0	180.0	72.160	—	—
18	13.33- 18.80	Clay	6.7	20.0	200.0	75.686	—	—

$$= \frac{19.05 + 0.00 + 0.00}{4.23}$$

$$= 4.50 \text{ kN/m}^2$$

3 Lateral Forth

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	$\Sigma \gamma h + Q_s$ kN/m ²	Ka	$K_a \times \cos \delta$
1	0.00- 0.90	Sand	7.7	27.0	—	0.904 7.834	0.33738 0.33738	0.32589 0.32589
2	0.90- 1.90	Sand	7.7	28.4	—	7.834 15.534	0.32022 0.32022	0.30951 0.30951
3	1.90- 2.36	Sand	7.7	30.5	—	15.534 19.076	0.29571 0.29571	0.28563 0.28563
4	2.36- 2.90	Sand	7.7	30.5	—	19.076 23.234	0.29571 0.29571	0.28563 0.28563
5	2.90- 3.43	Sand	7.7	29.5	—	23.234 27.315	0.30720 0.30720	0.29674 0.29674
6	3.43- 3.90	Clay	8.2	—	100.0	27.315 31.169	—	—
7	3.90- 4.10	Clay	8.2	—	100.0	31.169 32.809	—	—
8	4.10- 4.90	Clay	8.2	—	100.0	32.809 39.369	—	—
9	4.90- 5.90	Clay	8.2	—	50.0	39.369 47.569	—	—

19	18.80- 33.80	Clay	7.2	30.0	1000.0	112.335	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;

$$\delta = -15.00, \beta = 0.00, \theta = 0.00$$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active		Residual water pressure		Passive	
		P _{a1} kN/m ²	P _{a2} kN/m ²	P _w kN/m ²	P _w kN/m ²	P _p kN/m ²	P _p kN/m ²
1	0.00- 0.90	0.29 2.55	—	0.29 2.55	0.00 8.82	—	—
2	0.90- 1.90	2.42 4.80	—	2.42 4.80	8.82 18.62	—	—
3	1.90- 2.36	4.44 5.45	—	4.44 5.45	18.62 23.13	—	—
4	2.36- 2.90	5.45 6.64	—	5.45 6.64	23.13 23.13	—	—
5	2.90- 3.43	6.89 8.11	—	6.89 8.11	23.13 23.13	—	—
6	3.43- 3.90	-172.69 -168.83	13.66 15.58	13.66 15.58	23.13 23.13	—	—
7	3.90- 4.10	-168.83 -167.19	15.58 16.40	15.58 16.40	23.13 23.13	—	—
8	4.10- 4.90	-167.19 -160.63	16.40 19.68	16.40 19.68	23.13 23.13	200.00 206.56	—
9	4.90- 5.90	-60.63 -52.43	19.68 23.78	19.68 23.78	23.13 23.13	106.56 114.76	—
10	5.90- 6.90	-52.43 -44.23	23.78 27.88	23.78 27.88	23.13 23.13	114.76 122.96	—
11	6.90- 7.90	-144.23 -136.03	27.88 31.98	27.88 31.98	23.13 23.13	222.96 231.16	—
12	7.90- 8.90	-286.03 -287.83	31.98 36.08	31.98 36.08	23.13 23.13	391.16 399.36	—
13	8.90- 9.90	-287.83 -279.63	36.08 40.18	36.08 40.18	23.13 23.13	399.36 407.56	—
14	9.90- 10.90	-279.63 -271.43	40.18 44.28	40.18 44.28	23.13 23.13	407.56 415.76	—
15	10.90- 11.90	-271.43 -263.23	44.28 48.38	44.28 48.38	23.13 23.13	415.76 423.96	—
16	11.90- 12.90	-263.23 -255.03	48.38 52.48	48.38 52.48	23.13 23.13	423.96 432.16	—
17	12.90- 13.33	-255.03 -251.51	52.48 54.25	52.48 54.25	23.13 23.13	432.16 435.69	—
18	13.33- 18.80	-291.51 -254.86	54.25 72.57	54.25 72.57	23.13 23.13	475.69 512.33	—

19	18.80- 33.80	-1854.86 -1746.86	72.57 126.57	72.57 126.57	23.13 23.13	2112.33 2220.33

- Formula for active earth pressure

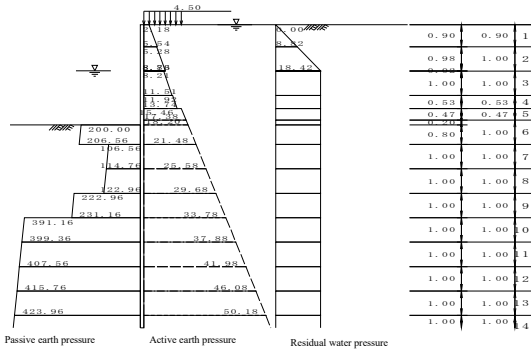
$$\begin{aligned} \text{Sand} \quad P_{a1} &= K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_{a1} &= \Sigma \gamma h + Q - 2C \\ P_{a2} &= K_a \cdot (\Sigma \gamma h + Q) \\ K_a &: \text{Equilibrium coefficient of compression: } 0.5 \\ \text{Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)} \end{aligned}$$

$$\text{Mixed soil} \quad P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\begin{aligned} \text{Sand} \quad P_p &= K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_p &= \Sigma \gamma h + Q + 2C \\ \text{Mixed soil} \quad P_p &= [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta \end{aligned}$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{ulw} kN/m ²	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-0.90	Sand	7.7	27.0	—	4.50 11.43	0.00 8.82	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
2	0.90-1.88	Sand	7.7	28.4	—	11.43 18.98	8.82 18.42	0.200 0.200	11.31 11.31	0.47800 0.47800	0.46172 0.46172	—
3	1.88-1.90	Sand	7.7	28.4	—	18.98 19.13	18.42 18.62	0.200 0.200	11.31 11.31	0.47800 0.47800	0.46172 0.46172	—

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{ulw} kN/m ²	k (k ²)	θ degree	Kp	$K_p \times \cos \delta$
8	4.10-4.90	Clay	8.20	0.0	100.0 100.0	0.000 6.560	0.00 7.84	0.200 0.200	11.31 11.31	—	—
9	4.90-5.90	Clay	8.20	0.0	50.0 14.760	6.560 17.64	7.84 16.40	0.200 0.200	11.31 11.31	—	—
10	5.90-6.90	Clay	8.20	0.0	50.0 22.960	14.760 27.44	17.64 37.24	0.200 0.200	11.31 11.31	—	—
11	6.90-7.90	Clay	8.20	0.0	100.0 31.160	22.960 37.24	27.44 50.00	0.200 0.200	11.31 11.31	—	—
12	7.90-8.90	Clay	8.20	0.0	180.0 39.360	31.160 47.04	37.24 60.40	0.200 0.200	11.31 11.31	—	—
13	8.90-9.90	Clay	8.20	0.0	180.0 47.560	39.360 56.84	47.04 70.40	0.200 0.200	11.31 11.31	—	—
14	9.90-10.90	Clay	8.20	0.0	180.0 55.760	47.560 66.64	56.84 80.00	0.200 0.200	11.31 11.31	—	—
15	10.90-11.90	Clay	8.20	0.0	180.0 63.960	55.760 76.44	66.64 99.20	0.200 0.200	11.31 11.31	—	—
16	11.90-12.90	Clay	8.20	0.0	180.0 72.160	63.960 86.24	76.44 108.80	0.200 0.200	11.31 11.31	—	—
17	12.90-13.33	Clay	8.20	0.0	180.0 75.686	72.160 90.45	86.24 110.40	0.200 0.200	11.31 11.31	—	—
18	13.33-18.80	Clay	6.70 20.0	20.0	200.0 200.0	75.686 112.335	90.45 144.06	0.200 0.200	11.31 11.31	—	—
19	18.80-33.80	Clay	7.20 30.0	30.0	1000.0 1000.0	112.335 220.335	144.06 291.06	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-0.90	2.18 5.54	—	2.18 5.54	0.00 8.82	—
2	0.90-1.88	5.28 8.76	—	5.28 8.76	8.82 18.42	—
3	1.88-1.90	8.76 8.83	—	8.76 8.83	18.42 18.42	—
4	1.90-2.90	8.21 11.51	—	8.21 11.51	18.42 18.42	—
5	2.90-3.43	11.80 13.74	—	11.80 13.74	18.42 18.42	—

4	1.90-2.90	Sand	7.7	30.5	—	19.13 26.83	18.62 28.42	0.200 0.200	11.31 11.31	0.44421 0.44421	0.42907 0.42907	—
5	2.90-3.43	Sand	7.7	29.5	—	26.83 30.92	28.42 33.61	0.200 0.200	11.31 11.31	0.45999 0.45999	0.44432 0.44432	—
6	3.43-4.10	Clay	8.2	—	100.0 100.0	30.92 34.77	33.61 38.22	0.200 0.200	11.31 11.31	—	—	44.48 44.43
7	3.90-4.10	Clay	8.2	—	100.0 100.0	34.77 36.41	38.22 40.18	0.200 0.200	11.31 11.31	—	—	44.43 44.40
8	4.10-4.90	Clay	8.2	—	100.0 100.0	36.41 42.97	40.18 48.02	0.200 0.200	11.31 11.31	—	—	44.40 44.30
9	4.90-5.90	Clay	8.2	—	50.0 50.0	42.97 51.17	48.02 57.82	0.200 0.200	11.31 11.31	—	—	43.57 43.31
10	5.90-6.90	Clay	8.2	—	50.0 50.0	51.17 59.37	57.82 67.62	0.200 0.200	11.31 11.31	—	—	43.31 43.04
11	6.90-7.90	Clay	8.2	—	100.0 100.0	59.37 67.57	67.62 77.42	0.200 0.200	11.31 11.31	—	—	44.05 43.93
12	7.90-8.90	Clay	8.2	—	180.0 180.0	67.57 75.77	77.42 87.22	0.200 0.200	11.31 11.31	—	—	44.41 44.35
13	8.90-9.90	Clay	8.2	—	180.0 180.0	75.77 83.97	87.22 97.02	0.200 0.200	11.31 11.31	—	—	44.35 44.28
14	9.90-10.90	Clay	8.2	—	180.0 180.0	83.97 92.17	97.02 106.82	0.200 0.200	11.31 11.31	—	—	44.28 44.21
15	10.90-11.90	Clay	8.2	—	180.0 180.0	92.17 100.37	106.82 116.62	0.200 0.200	11.31 11.31	—	—	44.21 44.14
16	11.90-12.90	Clay	8.2	—	180.0 180.0	100.37 108.57	116.62 126.42	0.200 0.200	11.31 11.31	—	—	44.14 44.07
17	12.90-13.33	Clay	8.2	—	180.0 180.0	108.57 112.10	126.42 136.63	0.200 0.200	11.31 11.31	—	—	44.07 44.04
18	13.33-18.80	Clay	6.7	—	200.0 200.0	112.10 148.74	136.63 184.24	0.200 0.200	11.31 11.31	—	—	44.14 43.86
19	18.80-33.80	Clay	7.2	—	1000.0 1000.0	148.74 256.74	184.24 331.24	0.200 0.200	11.31 11.31	—	—	44.78 44.62

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

6	3.43-3.90	-162.82 -158.18	15.46 17.38	15.46 17.38	18.42 18.42	—
7	3.90-4.10	-158.18 -156.20	17.38 18.20	17.38 18.20	18.42 18.42	—
8	4.10-4.90	-156.20 -148.28	18.20 21.48	18.20 21.48	18.42 18.42	200.00 206.56
9	4.90-5.90	-148.28 -38.15	21.48 25.58	21.48 25.58	18.42 18.42	106.56 114.76
10	5.90-6.90	-38.15 -28.15	25.58 29.68	25.58 29.68	18.42 18.42	114.76 122.96
11	6.90-7.90	-128.47 -118.54	29.68 33.78	29.68 33.78	18.42 18.42	222.96 231.16
12	7.90-8.90	-278.71 -268.82	33.78 37.88	33.78 37.88	18.42 18.42	391.16 399.36
13	8.90-9.90	-268.82 -258.92	37.88 41.98	37.88 41.98	18.42 18.42	399.36 407.56
14	9.90-10.90	-258.92 -249.02	41.98 46.08	41.98 46.08	18.42 18.42	407.56 415.76
15	10.90-11.90	-249.02 -239.11	46.08 50.18	46.08 50.18	18.42 18.42	415.76 423.96
16	11.90-12.90	-239.11 -229.19	50.18 54.28	50.18 54.28	18.42 18.42	423.96 432.16
17	12.90-13.33	-229.19 -224.92	54.28 56.05	54.28 56.05	18.42 18.42	432.16 435.69
18	13.33-18.80	-264.98 -220.62	56.05 74.37	56.05 74.37	18.42 18.42	475.69 512.33
19	18.80-33.80	-1821.34 -1691.40	74.37 128.37	74.37 128.37	18.42 18.42	2112.33 2220.33

- Formula for active earth pressure

$$\begin{aligned} \text{Sand} \quad P_{a1} &= K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_{a1} &= \Sigma \gamma h + Q - 2C \\ P_{a2} &= K_a \cdot (\Sigma \gamma h + Q) \\ K_a &: \text{Equilibrium coefficient of compression: } 0.5 \\ \text{Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)} \end{aligned}$$

$$\text{Mixed soil} \quad P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\begin{aligned} \text{Sand} \quad P_p &= K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_p &= \Sigma \gamma h + Q + 2C \\ \text{Mixed soil} \quad P_p &= [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta \end{aligned}$$

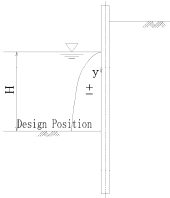
3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z, m	water level y m	p _{dw} kN/m ²
1	1.88	0.00	0.00
2	2.88	1.00	2.58
3	3.88	2.00	3.61
4	4.10	2.22	3.81

$$p_{dw} = \pm \frac{7}{8} k_{10} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

Where,

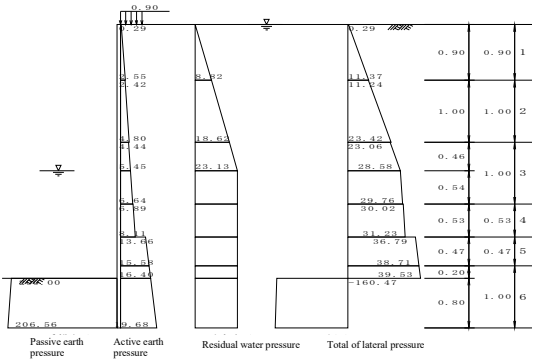
- k₁₀: design seismic coefficient
- γ_w: unit weight of water
- H: water depth of riverside
- y: depth from water surface to the point where active water pressure is calculated



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

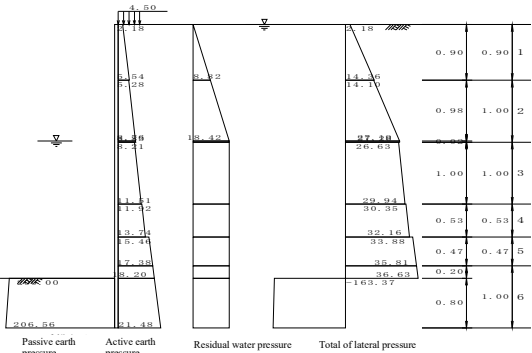


No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.90	0.29 2.55	0.00 8.82	——— ———	0.29 11.37
2	0.90- 1.90	2.42 4.80	8.82 18.62	——— ———	11.24 23.42
3	1.90- 2.36	4.44 5.45	18.62 23.13	——— ———	23.06 28.58
4	2.36- 2.90	5.45 6.64	23.13 23.13	——— ———	28.58 29.76
5	2.90- 3.43	6.89 8.11	23.13 23.13	——— ———	30.02 31.23
6	3.43- 3.90	13.66 15.58	23.13 23.13	——— ———	36.79 38.71
7	3.90- 4.10	15.58 16.40	23.13 23.13	——— ———	38.71 39.53
8	4.10- 4.90	16.40 19.68	23.13 23.13	200.00 206.56	-160.47 -163.75

- 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: 0.00 m (GL -4.10 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00- 0.90	2.18 5.54	0.00 8.82	——— ———	2.18 14.36
2	0.90- 1.88	5.28 8.76	8.82 18.42	——— ———	14.10 27.19
3	1.88- 1.90	8.76 8.83	18.42 18.42	——— ———	27.19 27.26
4	1.90- 2.90	8.21 11.51	18.42 18.42	——— ———	26.63 29.94
5	2.90- 3.43	11.92 13.74	18.42 18.42	——— ———	30.35 32.16
6	3.43- 3.90	15.46 17.38	18.42 18.42	——— ———	33.88 35.81
7	3.90- 4.10	17.38 18.20	18.42 18.42	——— ———	35.81 36.63
8	4.10- 4.90	18.20 21.48	18.42 18.42	200.00 206.56	-163.37 -166.65

- 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: 0.00 m (GL -4.10 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of 1/β from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_h = K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B=10, 00m)$$
$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$
$$E_0 = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}}$$

Material Name	10 H H 400 -200 -9 -12 -13
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 = 0.80
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 87800 cm ⁴ (original condition) I = 70240 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 70240 × 10 ⁻⁸ = 1.405 × 10 ⁷

No	Depth m	N Value	No	Depth m	N Value	No	Depth m	N Value
1	0.40	9	11	10.40	25	21	20.40	26
2	1.40	12	12	11.40	27	22	21.40	39
3	2.40	16	13	12.40	22			
4	3.40	14	14	13.40	18			
5	4.40	14	15	14.40	25			
6	5.40	16	16	15.40	27			
7	6.40	7	17	16.40	22			
8	7.40	12	18	17.40	17			
9	8.40	22	19	18.40	21			
10	9.40	18	20	19.40	25			

5.2 Normal Condition

Assuming Kh = 6056 kN/m³,

$$\beta = 4 \sqrt{\frac{K_h \cdot B}{4 E I}} = 0.322 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.10 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.10 m) to 3.10 m depth (GL -7.20 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.10	0.30	14.0	14.0	4.20
2	4.40	1.00	14.0	6.0	10.00
3	5.40	1.00	6.0	7.0	6.50
4	6.40	0.30	7.0	11.0	7.24
Σ h = 3.10			Σ A = 27.94		

A: (Top N + Bottom N) x h/2

$$\begin{aligned}\text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{27.94}{3.10} \\ &= 9.00\end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned}E_0 &= 2800N' = 2800 \times 9.00 = 25205 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 25205 = 84018 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B/0.3)^{-3/4} = 84018(10.00/0.3)^{-3/4} = 6056 \text{ kN/m}^3\end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 6056 kN/m³.

5.3 Seismic Condition

Assuming Kh = 11913 kN/m³,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.382 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.62 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.10 m) and 2.62 m depth (GL -6.72 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.10	0.30	14.0	14.0	4.20
2	4.40	1.00	14.0	6.0	10.00
3	5.40	1.00	6.0	7.0	6.50
4	6.40	0.32	7.0	8.6	2.50
Σ h = 2.62			Σ A = 23.20		

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$

$$\begin{aligned}\text{moment } M_n &= 0.0 \text{ kN}\cdot\text{m/m} \\ \text{depth to acting position } H_n &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 4.10 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.00 \text{ m}\end{aligned}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_n = 0.00 \text{ kN}\cdot\text{m}$$

h_0 , Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned}h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} \\ &= \frac{134.24}{92.01} = 1.46 \text{ m}\end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 92.01}{4.10} = 44.88 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.90	0.90	2.18 14.36	0.98 6.46	3.80 3.50	3.73 22.62
2	0.90- 1.88	0.98	14.10 27.19	6.91 13.32	2.87 2.55	19.85 33.93
3	1.88- 1.90	0.02	27.19 27.26	0.27 0.27	2.21 2.21	0.60 0.60
4	1.90- 2.90	1.00	26.63 29.94	13.32 14.97	1.87 1.53	24.86 22.95
5	2.90- 3.43	0.53	30.35 32.16	8.04 8.52	1.02 0.85	8.23 7.22
6	3.43- 3.90	0.47	33.88 35.81	7.96 8.42	0.51 0.36	4.09 3.00
7	3.90- 4.10	0.20	35.81 36.63	3.38 3.66	0.13 0.07	0.48 0.24
Σ P = 96.69			Σ M = 152.41			

P_i : active earth pressure + residual water pressure - passive earth pressure

P : load P_i 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

$$\begin{aligned}\text{Arbitrary load lateral load } P_i &= 0.0 \text{ kN/m} \\ \text{depth to acting position } H_i &= 0.00 \text{ m} \\ \text{moment } M_{in} &= 0.0 \text{ kN}\cdot\text{m/m} \\ \text{depth to acting position } H_n &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 4.10 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.00 \text{ m}\end{aligned}$$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_n = 0.00 \text{ kN}\cdot\text{m}$$

$$= \frac{23.20}{2.62}$$

$$= 8.85$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned}E_0 &= 2800N' = 2800 \times 8.85 = 24790 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 24790 = 165269 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B/0.3)^{-3/4} = 165269(10.00/0.3)^{-3/4} = 11913 \text{ kN/m}^3\end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 11913 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.90	0.90	0.29 11.37	0.13 5.12	3.80 3.50	0.50 17.91
2	0.90- 1.90	1.00	11.24 23.42	5.62 11.71	2.87 2.53	16.11 29.67
3	1.90- 2.36	0.46	23.06 28.58	5.30 6.57	2.05 1.89	10.85 12.44
4	2.36- 2.90	0.54	28.58 29.76	7.72 8.04	1.56 1.38	12.04 11.09
5	2.90- 3.43	0.53	30.02 31.23	7.96 8.28	1.02 0.85	8.14 7.01
6	3.43- 3.90	0.47	36.79 38.71	8.64 9.10	0.51 0.36	4.44 3.24
7	3.90- 4.10	0.20	38.71 39.53	3.87 3.95	0.13 0.07	0.52 0.26
Σ P = 92.01			Σ M = 134.24			

P_i : active earth pressure + residual water pressure - passive earth pressure

P : load P_i 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

$$\begin{aligned}\text{Arbitrary load lateral load } P_i &= 0.0 \text{ kN/m} \\ \text{depth to acting position } H_i &= 0.0 \text{ m}\end{aligned}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	1.88- 2.88	1.00	0.0 2.6	0.00 1.28	1.89 1.55	0.00 1.98
2	2.88- 3.88	1.00	2.6 3.6	1.28 1.81	0.89 0.55	1.13 1.00
3	3.88- 4.10	0.22	3.6 3.8	0.40 0.42	0.15 0.07	0.06 0.03
Σ P ₀ = 5.18			Σ M ₀ = 4.21			

h_0 , Height of acting position of P_0 from imaginary riverbed

$$\begin{aligned}h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i + \Sigma P_{0i}} \\ &= \frac{156.61}{101.87} = 1.54 \text{ m}\end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 101.87}{4.10} = 49.69 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name	10 H - H 400 -200 -9 -12 -13
Unit width	$B = 1.0000 \text{ m}$
Corrosion margin	$t_c = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate	$\eta = 0.80$
Section efficiency	$\mu = 1.00$
Young's modulus	$E = 200000 \text{ N/mm}^2$
Inertia sectional moment	$I_0 = 87800 \text{ cm}^4$ (original condition)
	$I = 70240 \text{ cm}^4$ (after reduction by corrosion and section)
	$EI = 200000 \times 10^3 \times 70240 \times 10^{-8} = 1.405 \times 10^5$

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_n = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

$$M_{in} = M_0 \cdot \phi_n$$

$$1_n = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

$$1_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{0i} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_a	=	6056	kN/m ³
calculated value	β	=	0.32224	m ³
resultant earth force (lateral)	P_0	=	92.01	kN/m
height of acting position of load	h_0	=	1.46	m
moment	M_0	=	134.24	kN·m/m
in consideration of $\psi_{tm} = 1.442$, maximum moment	M_{max}	=	193.64	kN·m/m
depth of generated position of M_{max}	l_m	=	1.477	m
depth of 1 st fixed point	l_i	=	3.915	m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_a	=	11913	kN/m ³
calculated value	β	=	0.38158	m ³
resultant earth force (lateral)	P_0	=	101.87	kN/m
height of acting position of load	h_0	=	1.54	m
moment	M_0	=	156.61	kN·m/m
in consideration of $\psi_{tm} = 1.325$, maximum moment	M_{max}	=	207.47	kN·m/m
depth of generated position of M_{max}	l_m	=	1.130	m
depth of 1 st fixed point	l_i	=	3.188	m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name	10 H ₂ H 400 -200 -9 -12 -13
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 0.81$
Section efficiency	$\mu = 1.00$
Module of section	$Z_0 = 2320$ cm ³ (original condition)
	$Z = 1879$ cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{193.64 \times 10^6}{1879 \times 10^3} = 103 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{207.47 \times 10^6}{1879 \times 10^3} = 110 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

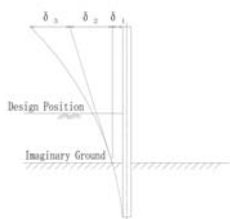
$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01439 + 0.02509 + 0.00301 \\ &= 0.04249 \text{ m} \\ \text{Size} &= 42.49 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

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

Displacement Calculation

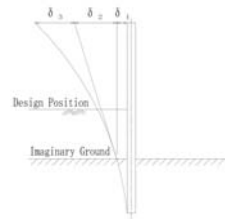


$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3816 \times 1.54) \times 101.87}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3816^3} = 0.01035 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3816 \times 1.54) \times 101.87}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3816^2} \times (4.10 + 0.00) = 0.02219 \text{ m} \end{aligned}$$

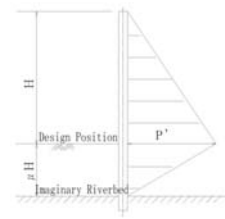
6.4 Displacement Calculation

6.4.1 Normal Condition

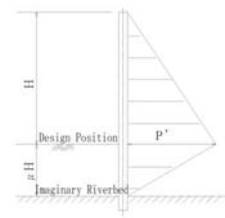
Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3222 \times 1.46) \times 92.01}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3222^3} = 0.01439 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3222 \times 1.46) \times 92.01}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3222^2} \times (4.10 + 0.00) = 0.02509 \text{ m} \end{aligned}$$



$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{0.00}{4.10} = 0.000 \\ \delta_3 &= \frac{P^* H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{44.88 \times 4.10^4}{120 \times 2.00 \times 10^8 \times 70240 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4) \\ &= 0.00301 \text{ m} \end{aligned}$$



$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{0.00}{4.10} = 0.000 \\ \delta_3 &= \frac{P^* H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{49.69 \times 4.10^4}{120 \times 2.00 \times 10^8 \times 70240 \times 10^{-8}} (4 + 20 \times 0.000 + 40 \times 0.000^2 + 35 \times 0.000^3 + 11 \times 0.000^4) \\ &= 0.00333 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01035 + 0.02219 + 0.00333 \\ &= 0.03587 \text{ m} \\ \text{Size} &= 35.87 \leq \delta_a = 75.00 \text{ mm} \end{aligned}$$

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:

Material Name	10 H ₂ H 400 -200 -9 -12 -13
Unit width	$B = 1.0000$ m
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Young's modulus	$E = 200000$ N/mm ²
Inertia sectional moment	$I_0 = 87800$ cm ⁴ (original condition)
	$I = 87800$ cm ⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 87800 \times 10^{-8}$	$= 1.756 \times 10^9$

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 follows:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{it} + D$$
$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _b = 6056 kN/m ³
Calculated value	β = 0.30472 m ⁻¹
Penetration length of SSP	D = 0.00 + $\frac{3}{0.305}$ = 9.84 m
Whole length of SSP	L = 4.10 - 0.40 + 9.84 = 13.54 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K _b = 11913 kN/m ³
Calculated value	β = 0.36088 m ⁻¹
Penetration length of SSP	D = 0.00 + $\frac{3}{0.361}$ = 8.31 m
Whole length of SSP	L = 4.10 - 0.40 + 8.31 = 12.01 m

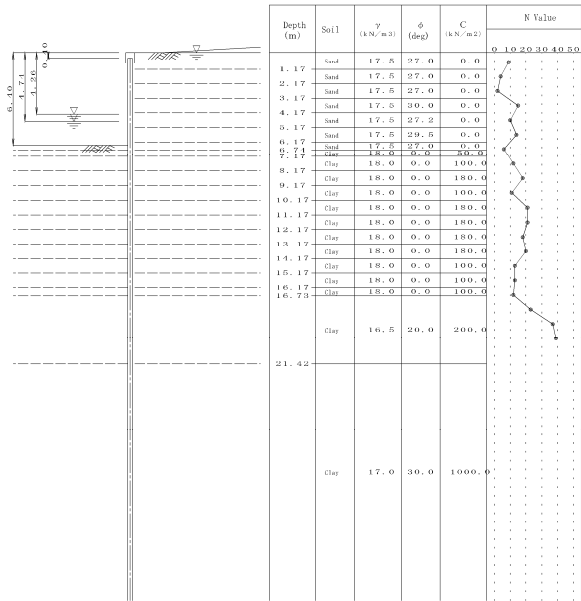
Therefore, the total length of the sheet pile is 14.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H _ H 400 -200 -9 -12 -13				
		Normal Condition	Seismic Condition	
Inertia sectional moment	I (cm ⁴)	87800		
Sectional Modulus	Z (cm ³)	2320		
Maximum bending moment	M _{max} (kN · m · m)	193.64		207.47
Stress intensity	σ (N/mm ²)	103 (180)		110 (270)
Lateral displacement	δ (mm)	42.49 (50.0)		35.87 (35.0)
Penetration depths	D (m)	9.84		8.31
Whole length of SSP	L (m)	14.00		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H = 6.40 m
Depth from coping top to rear side ground	H ₀ = 0.00 m
Depth from coping top to SSP top	H _B = 0.40 m
Landside WL	L _{wa} = 0.00 m (Normal Condition)
	L _{wa} = 0.00 m (Seismic Condition)
Riverside WL	L _{wp} = 4.74 m (Normal Condition)
	L _{wp} = 4.26 m (Seismic Condition)

Block No. : R-31
Sta. : 11+700~11+980

Design Cross Section : Sta 11+880
Boring Name : DD-BH-R15

Specification : SSP SP-10H
(Combined) : H 1000-250-16-25-18

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

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	not considered
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)	$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$
Equilibrium factor of compression	K _c = 0.50 (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_b = K_{10} \left(\frac{B_B}{0.3} \right)^{-3/4}$
	$K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2)
	B _B = 10.00 m
	E ₀ = 2800N
Average N-value	calculated from average N-value between imaginary riverbed and depth as 1/β

No	Depth	N Value	No	Depth	N Value
1	0.67	9	11	10.67	21
2	1.67	4	12	11.67	21
3	2.67	2	13	12.67	18
4	3.67	15	14	13.67	20
5	4.67	10	15	14.67	13
6	5.67	14	16	15.67	13
7	6.67	6	17	16.67	12
8	7.67	12	18	17.67	23
9	8.67	18	19	18.67	37
10	9.67	11	20	19.67	39

1.7 Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.17	1.17
2	2.17	1.00
3	3.17	1.00
4	4.17	1.00
5	5.17	1.00
6	6.17	1.00
7	6.74	0.57
8	7.17	0.43
9	8.17	1.00
10	9.17	1.00
11	10.17	1.00
12	11.17	1.00
13	12.17	1.00
14	13.17	1.00
15	14.17	1.00
16	15.17	1.00
17	16.17	1.00
18	16.73	0.56
19	21.42	4.69
20	36.20	14.78

No	Depth m	earth Soil	N Value kN/m ²	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	C (degree)		Kh (kN/m ³)	
										Normal Condition	Seismic Condition	Normal Condition	Seismic Condition
1	1.17	S	9.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	---	---
2	2.17	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	---	---
3	3.17	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	---	---
4	4.17	S	15.0	17.50	7.70	30.0	0.0	0.0	0.200	Auto	Auto	---	---
5	5.17	S	10.0	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto	---	---
6	6.17	S	14.0	17.50	7.70	29.5	0.0	0.0	0.200	Auto	Auto	---	---
7	6.94	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	---	---
8	7.17	C	6.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	---	---
9	8.17	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	---	---
10	9.17	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	---	---

No	Depth m	soil Soil	N Value kN/m ²	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)		Kh (kN/m)	
										Normal Condition	Seismic Condition	Normal Condition	Seismic Condition
11	10.17	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto		
12	11.17	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto		
13	12.17	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto		
14	13.17	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto		
15	14.17	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto		
16	15.17	C	13.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto		
17	16.17	C	13.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto		
18	16.73	C	12.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto		
19	21.42	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto		
20	26.20	C	121.5	17.00	7.20	30.0	100.0	0.0	0.200	Auto	Auto		

Note)	depth :	from top of coping to bottom of the layer	C_0 :	soil adhesion
	soil :	sandy(S), clayey(C), mixed (M)	α :	slope of soil adhesion
	N-value :	average N-value in the layer	k :	design seismic coefficient (underwater)
	γ :	wet unit weight of soil	ζ :	angle of active rupture
	γ' :	saturated unit weight of soil	kh :	modulus of subgrade reaction
	ϕ :	internal friction angle of soil		

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.17	1
1.00	2
1.00	3
1.00	4
1.00	5
1.00	6

No	Soil	X Coordinate				Thickness h m	soil single weight γ Normal Condition kN/m ³		internal friction angle ϕ degree	stickness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	2.15	18.31	30.00	30.00	0.92	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	18.31	20.79	30.00	30.00	2.01	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	9.54	12.59	10.0	0.0

Angle of rapture in embankment calculated in consideration of embankment conditions

Material name	10 H		H 1000 -250 -16 -25 -18	
Young's modulus	E	=	200000	N/mm ²
Inertia sectional moment	I ₀	=	876700	cm ⁴
Sectional factor	Z ₀	=	11980	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

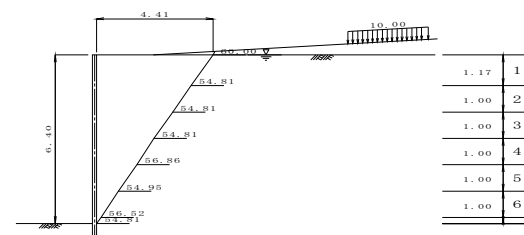
Allowable stress	σ_a	=	180 N/mm (Normal)
	σ_a'	=	270 N/mm (Seismic)

Allowable displacement	δ_a	=	50.0 mm
	δ_a'	=	75.0 mm

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

2.1 Normal Condition



No	Depth, m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ_{water} kN/m ³	Angle of Rupture ζ degrees
1	6.40 ~ 6.17	Sand	27.0	15.0	0.0	49.28	0.65	62.72	54.81

2	6.17 ~ 5.17	Sand	29.5	15.0	0.0	47.51	0.65	60.47	56.52
3	5.17 ~ 4.17	Sand	27.2	15.0	0.0	39.81	0.65	50.67	54.95
4	4.17 ~ 3.17	Sand	30.0	15.0	0.0	32.11	0.65	40.87	56.86
5	3.17 ~ 2.17	Sand	27.0	15.0	0.0	24.41	0.65	31.07	54.81
6	2.17 ~ 1.17	Sand	27.0	15.0	0.0	16.71	0.65	21.27	54.81
7	1.17 ~ 0.00	Sand	27.0	15.0	0.0	9.01	0.65	11.47	54.81
8		embankment L	30.0	—	0.0	55.67	0.00	0.00	60.00

• Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \theta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• 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 $\theta = 0^\circ$
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)

No	Angle of Rotation ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.81	0.23	0.00	0.00	0.16	0.23
2	86.52	1.06	0.16	0.23	0.82	1.23
3	54.95	1.00	0.82	1.23	1.52	2.23
4	86.86	1.00	1.52	2.23	2.18	3.23
5	54.81	1.00	2.18	3.23	2.88	4.23
6	54.81	1.00	2.88	4.23	3.59	5.23
7	54.81	1.17	3.59	5.23	4.41	6.40
8	60.00	0.13	4.41	6.40	4.49	6.53

From the above table, the loading width (L) on the ground surface is 4.41 m.

2.1.3 Acting Load by Embankment

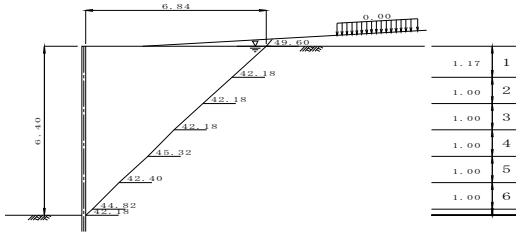
No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.15	2.86
Σ			2.86

γ: unit weight of embankment soil
A: sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{2.86 + 0.00 + 0.00}{4.41}$$
$$= 0.65 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

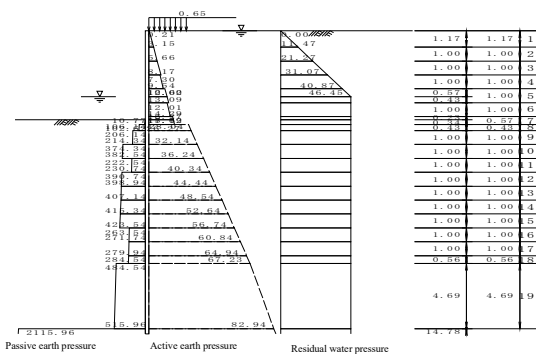
No	Depth m	Soil	φ degree	δ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ when kN/m2	k (k ²)	θ degree	Angle of Rupture ζ, degree
1	6.40~6.17	Sand	27.0	15.0	0.0	49.28	1.83	62.72	0.200	11.31	42.18
2	6.17~5.17	Sand	29.5	15.0	0.0	47.51	1.83	60.47	0.200	11.31	44.82
3	5.17~4.17	Sand	27.2	15.0	0.0	39.81	1.83	50.67	0.200	11.31	42.40
4	4.17~3.17	Sand	30.0	15.0	0.0	32.11	1.83	40.87	0.200	11.31	45.32
5	3.17~2.17	Sand	27.0	15.0	0.0	24.41	1.83	31.07	0.200	11.31	42.18
6	2.17~1.17	Sand	27.0	15.0	0.0	16.71	1.83	21.27	0.200	11.31	42.18
7	1.17~0.00	Sand	27.0	15.0	0.0	9.01	1.83	11.47	0.200	11.31	42.18

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{12.52 + 0.00 + 0.00}{6.84}$$
$$= 1.83 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Q _a kN/m2	K _a	K _a × cos δ
1	0.00~1.17	Sand	7.7	27.0	0.649 9.658	0.33738 0.33738	0.32589 0.32589
2	1.17~2.17	Sand	7.7	27.0	9.658 17.358	0.33738 0.33738	0.32589 0.32589
3	2.17~3.17	Sand	7.7	27.0	17.358 25.058	0.33738 0.33738	0.32589 0.32589
4	3.17~4.17	Sand	7.7	30.0	25.058 32.758	0.30142 0.30142	0.29115 0.29115
5	4.17~4.74	Sand	7.7	27.2	32.758 37.147	0.33489 0.33489	0.32348 0.32348
6	4.74~5.17	Sand	7.7	27.2	37.147 40.458	0.33489 0.33489	0.32348 0.32348
7	5.17~6.17	Sand	7.7	29.5	40.458 48.158	0.30720 0.30720	0.29674 0.29674

8		embankment	30.0	—	0.0	55.67	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	0.23	0.00	0.00	0.25	0.23
2	44.82	1.00	0.25	0.23	1.26	1.23
3	42.40	1.00	1.26	1.23	2.36	2.23
4	45.32	1.00	2.36	2.23	3.34	3.23
5	42.18	1.00	3.34	3.23	4.45	4.23
6	42.18	1.00	4.45	4.23	5.55	5.23
7	42.18	1.17	5.55	5.23	6.84	6.40
8	49.60	0.28	6.84	6.40	7.08	6.68

From the above table, the loading width (L) on the ground surface is 6.84 m.

2.2.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.66	12.52
Σ			12.52

γ: unit weight of embankment soil
A: sectional area of embankment enclosed by line of active rupture

8	6.17~6.40	Sand	7.7	27.0	—	48.158 49.929	0.33738 0.33738	0.32589 0.32589
9	6.40~6.74	Sand	7.7	27.0	—	49.929 52.547	0.33738 0.33738	0.32589 0.32589
10	6.74~7.17	Clay	8.2	—	50.0 56.073	52.547 56.073	—	—
11	7.17~8.17	Clay	8.2	—	100.0 100.0	56.073 64.273	—	—
12	8.17~9.17	Clay	8.2	—	180.0 180.0	64.273 72.473	—	—
13	9.17~10.17	Clay	8.2	—	100.0 100.0	72.473 80.673	—	—
14	10.17~11.17	Clay	8.2	—	180.0 180.0	80.673 88.873	—	—
15	11.17~12.17	Clay	8.2	—	180.0 180.0	88.873 97.073	—	—
16	12.17~13.17	Clay	8.2	—	180.0 180.0	97.073 105.273	—	—
17	13.17~14.17	Clay	8.2	—	180.0 180.0	105.273 113.473	—	—
18	14.17~15.17	Clay	8.2	—	100.0 100.0	113.473 121.673	—	—
19	15.17~16.17	Clay	8.2	—	100.0 100.0	121.673 129.873	—	—
20	16.17~16.73	Clay	8.2	—	100.0 100.0	129.873 134.465	—	—
21	16.73~21.42	Clay	6.7	—	200.0 200.0	134.465 165.888	—	—
22	21.42~36.20	Clay	7.2	—	1000.0 1000.0	165.888 272.304	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
δ = 15.00, 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

No	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Q _p kN/m2	K _p	K _p × cos δ
9	6.40~6.74	Sand	7.7	27.0	—	0.000 2.618	4.26080 4.26080	4.11561 4.11561
10	6.74~7.17	Clay	8.2	0.0	50.0 50.0	2.618 6.144	—	—
11	7.17~8.17	Clay	8.2	0.0	100.0 100.0	6.144 14.344	—	—
12	8.17~9.17	Clay	8.2	0.0	180.0 180.0	14.344 22.544	—	—
13	9.17~10.17	Clay	8.2	0.0	100.0 100.0	22.544 30.744	—	—
14	10.17~11.17	Clay	8.2	0.0	180.0 180.0	30.744 38.944	—	—

15	11.17- 12.17	Clay	8.2	0.0	180.0 180.0	38.944 47.144	=====	=====
16	12.17- 13.17	Clay	8.2	0.0	180.0 180.0	47.144 55.344	=====	=====
17	13.17- 14.17	Clay	8.2	0.0	180.0 180.0	55.344 63.544	=====	=====
18	14.17- 15.17	Clay	8.2	0.0	100.0 100.0	63.544 71.744	=====	=====
19	15.17- 16.17	Clay	8.2	0.0	100.0 100.0	71.744 79.944	=====	=====
20	16.17- 16.73	Clay	8.2	0.0	100.0 100.0	79.944 84.536	=====	=====
21	16.73- 21.42	Clay	6.7	20.0	200.0 200.0	84.536 115.959	=====	=====
22	21.42- 36.20	Clay	7.2	30.0	1000.0 1000.0	115.959 222.375	=====	=====

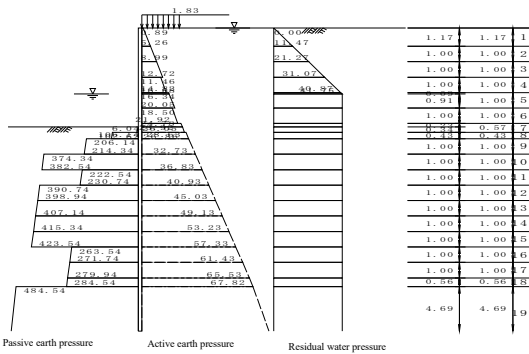
Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure Pw kN/m2	Passive Pp kN/m2
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2		
1	0.00- 1.17	0.21 3.15	=====	0.21 3.15	0.00 11.47	=====
2	1.17- 2.17	3.15 5.66	=====	3.15 5.66	11.47 21.27	=====
3	2.17- 3.17	5.66 8.17	=====	5.66 8.17	21.27 31.07	=====
4	3.17- 4.17	7.30 9.54	=====	7.30 9.54	31.07 40.87	=====
5	4.17- 4.74	10.60 12.02	=====	10.60 12.02	40.87 46.45	=====
6	4.74- 5.17	12.02 13.09	=====	12.02 13.09	46.45 46.45	=====
7	5.17- 6.17	12.01 14.29	=====	12.01 14.29	46.45 46.45	=====
8	6.17- 6.40	15.69 16.27	=====	15.69 16.27	46.45 46.45	=====
9	6.40- 6.74	16.27 17.12	=====	16.27 17.12	46.45 10.77	0.00
10	6.74- 7.17	-47.45 -43.93	26.27 28.04	26.27 28.04	46.45 46.45	102.62 106.14
11	7.17- 8.17	-143.93 -135.73	28.04 32.14	28.04 32.14	46.45 46.45	206.14 214.34
12	8.17- 9.17	-295.73 -287.53	32.14 36.24	32.14 36.24	46.45 46.45	374.34 382.54

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γwhw kN/m2	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.17	Sand	7.7	27.0	=====	1.83 10.84	0.00 11.47	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
2	1.17- 2.17	Sand	7.7	27.0	=====	10.84 18.54	11.47 21.27	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
3	2.17- 3.17	Sand	7.7	27.0	=====	18.54 26.24	21.27 31.07	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
4	3.17- 4.17	Sand	7.7	30.0	=====	26.24 33.94	31.07 40.87	0.200 0.200	11.31 11.31	0.45203 0.45203	0.43603 0.43603	=====
5	4.17- 4.26	Sand	7.7	27.2	=====	33.94 34.63	40.87 41.75	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	=====
6	4.26- 5.17	Sand	7.7	27.2	=====	34.63 41.64	41.75 50.67	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	=====
7	5.17- 6.17	Sand	7.7	28.5	=====	41.64 49.34	50.67 60.47	0.200 0.200	11.31 11.31	0.45999 0.45999	0.44432 0.44432	=====
8	6.17- 6.40	Sand	7.7	27.0	=====	49.34 51.11	60.47 62.72	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
9	6.40- 6.74	Sand	7.7	27.0	=====	51.11 53.73	62.72 66.05	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
10	6.74- 7.17	Clay	8.2	=====	50.0 50.0	53.73 57.25	66.05 70.27	0.200 0.200	11.31 11.31	=====	=====	43.31 43.20
11	7.17- 8.17	Clay	8.2	=====	100.0 100.0	57.25 65.45	70.27 80.07	0.200 0.200	11.31 11.31	=====	=====	44.13 44.00
12	8.17- 9.17	Clay	8.2	=====	180.0 180.0	65.45 73.65	80.07 89.87	0.200 0.200	11.31 11.31	=====	=====	44.45 44.39
13	9.17- 10.17	Clay	8.2	=====	100.0 100.0	73.65 81.85	89.87 99.67	0.200 0.200	11.31 11.31	=====	=====	43.88 43.75
14	10.17- 11.17	Clay	8.2	=====	180.0 180.0	81.85 90.05	99.67 109.47	0.200 0.200	11.31 11.31	=====	=====	44.32 44.25

13	9.17- 10.17	=====	-127.53 -119.33	36.24 40.34	36.24 40.34	46.45 46.45	222.54 230.74
14	10.17- 11.17	=====	-279.33 -271.13	40.34 44.44	40.34 44.44	46.45 46.45	390.74 398.94
15	11.17- 12.17	=====	-271.13 -262.93	44.44 48.54	44.44 48.54	46.45 46.45	398.94 407.14
16	12.17- 13.17	=====	-262.93 -254.73	48.54 52.64	48.54 52.64	46.45 46.45	407.14 415.34
17	13.17- 14.17	=====	-254.73 -246.53	52.64 56.74	52.64 56.74	46.45 46.45	415.34 423.54
18	14.17- 15.17	=====	-246.53 -238.33	56.74 60.84	56.74 60.84	46.45 46.45	423.54 431.74
19	15.17- 16.17	=====	-238.33 -230.13	60.84 64.94	60.84 64.94	46.45 46.45	431.74 439.94
20	16.17- 16.73	=====	-230.13 -221.93	64.94 69.04	64.94 69.04	46.45 46.45	439.94 448.14
21	16.73- 21.42	=====	-221.93 -213.73	69.04 73.14	69.04 73.14	46.45 46.45	448.14 456.34
22	21.42- 36.20	=====	-213.73 -205.53	73.14 77.24	73.14 77.24	46.45 46.45	456.34 464.54

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

15	11.17- 12.17	Clay	8.2	=====	180.0 180.0	90.05 98.25	109.47 119.27	0.200 0.200	11.31 11.31	=====	=====	44.25 44.18
16	12.17- 13.17	Clay	8.2	=====	180.0 180.0	98.25 106.45	119.27 129.07	0.200 0.200	11.31 11.31	=====	=====	44.18 44.11
17	13.17- 14.17	Clay	8.2	=====	180.0 180.0	106.45 114.65	129.07 138.87	0.200 0.200	11.31 11.31	=====	=====	44.11 44.04
18	14.17- 15.17	Clay	8.2	=====	100.0 100.0	114.65 122.85	138.87 148.67	0.200 0.200	11.31 11.31	=====	=====	44.04 43.97
19	15.17- 16.17	Clay	8.2	=====	100.0 100.0	122.85 131.05	148.67 158.47	0.200 0.200	11.31 11.31	=====	=====	43.97 42.96
20	16.17- 16.73	Clay	8.2	=====	100.0 100.0	131.05 135.65	158.47 163.95	0.200 0.200	11.31 11.31	=====	=====	42.96 42.88
21	16.73- 21.42	Clay	6.7	=====	200.0 200.0	135.65 167.07	163.95 209.92	0.200 0.200	11.31 11.31	=====	=====	42.88 43.76
22	21.42- 36.20	Clay	7.2	=====	1000.0 1000.0	167.07 273.48	209.92 354.76	0.200 0.200	11.31 11.31	=====	=====	43.76 44.60

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

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

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Qp$ kN/m2	γwhw kN/m2	k (k')	θ degree	Kp	$Kp \times \cos \delta$
9	6.40- 6.74	Sand	7.70	27.0	=====	0.000 2.618	0.00 3.33	0.200 0.200	11.31 11.31	2.30874 2.30874	2.30874 2.30874
10	6.74- 7.17	Clay	8.20	0.0	=====	2.618 6.144	3.33 7.55	0.200 0.200	11.31 11.31	=====	=====
11	7.17- 8.17	Clay	8.20	0.0	=====	6.144 14.344	7.55 17.35	0.200 0.200	11.31 11.31	=====	=====
12	8.17- 9.17	Clay	8.20	0.0	=====	14.344 22.544	17.35 27.15	0.200 0.200	11.31 11.31	=====	=====
13	9.17- 10.17	Clay	8.20	0.0	=====	22.544 30.744	27.15 36.95	0.200 0.200	11.31 11.31	=====	=====
14	10.17- 11.17	Clay	8.20	0.0	=====	30.744 38.944	36.95 46.75	0.200 0.200	11.31 11.31	=====	=====
15	11.17- 12.17	Clay	8.20	0.0	=====	38.944 47.144	46.75 56.55	0.200 0.200	11.31 11.31	=====	=====
16	12.17- 13.17	Clay	8.20	0.0	=====	47.144 55.344	56.55 66.35	0.200 0.200	11.31 11.31	=====	=====
17	13.17- 14.17	Clay	8.20	0.0	=====	55.344 63.544	66.35 76.15	0.200 0.200	11.31 11.31	=====	=====
18	14.17- 15.17	Clay	8.20	0.0	=====	63.544 71.744	76.15 85.95	0.200 0.200	11.31 11.31	=====	=====
19	15.17- 16.17	Clay	8.20	0.0	=====	71.744 79.944	85.95 95.75	0.200 0.200	11.31 11.31	=====	=====

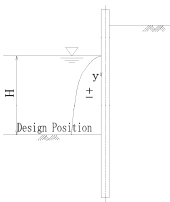
20	16.17- 16.73	Clay	8.20	0.0	100.0 100.0	79.944 84.536	95.75 101.23	0.200 0.200	11.31 11.31	=====	=====
21	16.73- 21.42	Clay	6.70	20.0	200.0 200.0	84.536 115.959	101.23 147.20	0.200 0.200	11.31 11.31	=====	=====
22	21.42- 36.20	Clay	7.20	30.0	1000.0 1000.0	115.959 222.375	147.20 292.04	0.200 0.200	11.31 11.31	=====	=====

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

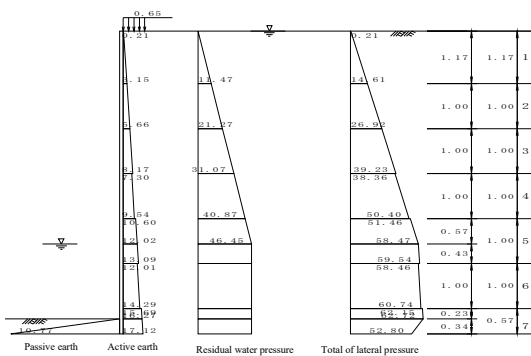
No	Depth m	Active			Residual water pressure Pw kN/m2	Passive Pp kN/m2
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2		
1	0.00- 1.17	0.89 5.26	=====	0.89 5.26	0.00 11.47	=====
2	1.17- 2.17	5.26 8.99	=====	5.26 8.99	11.47 21.27	=====
3	2.17- 3.17	8.99 12.72	=====	8.99 12.72	21.27 31.07	=====
4	3.17- 4.17	11.46 14.82	=====	11.46 14.82	31.07 40.87	=====
5	4.17- 4.26	16.34 16.68	=====	16.34 16.68	40.87 41.75	=====
6	4.26- 5.17	16.68 20.05	=====	16.68 20.05	41.75 41.75	=====
7	5.17- 6.17	=====	=====	18.50 21.92	41.75 41.75	=====
8	6.17- 6.40	=====	=====	23.92 24.78	41.75 41.75	=====
9	6.40- 6.74	24.78 26.05	=====	24.78 26.05	41.75 6.04	0.00
10	6.74- 7.17	-35.05 -30.75	26.86 28.63	26.86 28.63	41.75 41.75	102.62 106.14
11	7.17- 8.17	-131.03 -121.11	28.63 32.73	28.63 32.73	41.75 41.75	206.14 214.34
12	8.17- 9.17	-281.27 -271.38	32.73 36.83	32.73 36.83	41.75 41.75	374.34 382.54
13	9.17- 10.17	-111.18 -101.24	36.83 40.93	36.83 40.93	41.75 41.75	222.54 220.74
14	10.17- 11.17	-261.48 -251.58	40.93 45.03	40.93 45.03	41.75 41.75	390.74 398.94
15	11.17- 12.17	-251.58 -241.67	45.03 49.13	45.03 49.13	41.75 41.75	398.94 407.14
16	12.17- 13.17	-241.67 -231.76	49.13 53.23	49.13 53.23	41.75 41.75	407.14 415.34



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



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 1.17	0.21 3.15	0.00 11.47	=====	0.21 14.61
2	1.17- 2.17	3.15 5.66	11.47 21.27	=====	14.61 26.92
3	2.17- 3.17	5.66 8.17	21.27 31.07	=====	26.92 39.23
4	3.17- 4.17	7.30 9.54	31.07 40.87	=====	38.36 50.40

17	13.17- 14.17	-231.76 -221.84	53.23 57.33	53.23 57.33	41.75 41.75	415.34 423.54
18	14.17- 15.17	-61.33 -51.33	57.33 61.43	57.33 61.43	41.75 41.75	263.54 271.74
19	15.17- 16.17	-51.33 -41.31	61.43 65.53	61.43 65.53	41.75 41.75	271.74 279.94
20	16.17- 16.73	-41.31 -35.69	65.53 67.82	65.53 67.82	41.75 41.75	279.94 284.54
21	16.73- 21.42	-236.50 -198.40	67.82 83.53	67.82 83.53	41.75 41.75	484.54 515.96
22	21.42- 36.20	-1799.30 -1671.24	83.53 136.74	83.53 136.74	41.75 41.75	2115.96 2222.38

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
 Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m2
1	4.26	0.00	0.00
2	5.26	1.00	2.51
3	6.26	2.00	3.35
4	6.40	2.14	3.67

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma \cdot \sqrt{H \cdot y}$$

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

5	4.17- 4.74	10.60 12.02	40.87 46.45	=====	51.46 58.47
6	4.74- 5.17	12.02 13.09	46.45 46.45	=====	58.47 59.54
7	5.17- 6.17	12.01 14.29	46.45 46.45	=====	58.46 60.74
8	6.17- 6.40	15.69 16.27	46.45 46.45	=====	62.15 62.72
9	6.40- 6.74	16.27 17.12	46.45 46.45	0.00 10.77	62.72 52.80
10	6.74- 7.17	26.27 28.04	46.45 46.45	102.62 106.14	-29.89 -31.66

P_a : Active earth pressure

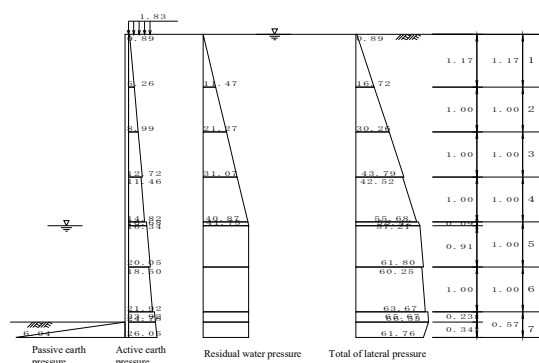
P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed Lk: 0.34 m (GL -6.74 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 1.17	0.89 5.26	0.00 11.47	=====	0.89 16.72
2	1.17- 2.17	5.26 8.99	11.47 21.27	=====	16.72 30.26
3	2.17- 3.17	8.99 12.72	21.27 31.07	=====	30.26 43.79
4	3.17- 4.17	11.46 14.82	31.07 40.87	=====	42.52 55.68

5	4.17- 4.26	16.34 16.68	40.87 41.75	———— ————	57.21 58.42
6	4.26- 5.17	16.68 20.05	41.75 41.75	———— ————	58.42 61.80
7	5.17- 6.17	18.50 21.92	41.75 41.75	———— ————	60.25 63.67
8	6.17- 6.40	23.92 24.78	41.75 41.75	———— ————	65.67 66.53
9	6.40- 6.74	24.78 26.05	41.75 41.75	0.00 6.04	66.53 61.76
10	6.74- 7.17	26.06 28.63	41.75 41.75	102.62 106.14	-34.01 -35.77

P_a : Active earth pressure
 P_w : Residual water pressure
 P_p : Passive earth pressure
 P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 0.34 m (GL -6.74 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{\lambda} = K_{\lambda 0} \left(\frac{B_{\lambda}}{0.3} \right)^{-3/4} \quad (B_{\lambda} = 10.00 \text{ m})$$

$$K_{\lambda 0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$E_{\lambda} = 2800 \text{ N}'$$

where:

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}}$$

Material Name 10 H _ H 1000 -250 -16 -25 -18
Unit width $B = 1.0000 \text{ m}$
Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
Corrosion rate $\eta = 0.87$
Section efficiency $\mu = 1.00$
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 806700 \text{ cm}^4$ (original condition)
Inertia sectional moment $I = 701829 \text{ cm}^4$ (after reduction by corrosion and section)
Inertia sectional moment $EI = 200000 \times 10^3 \times 701829 \times 10^{-8} = 1.404 \times 10^6$

No	Depth m	N Value	No	Depth m	N Value
1	0.67	9	11	10.67	21
2	1.67	4	12	11.67	21
3	2.67	2	13	12.67	18
4	3.67	15	14	13.67	20
5	4.67	10	15	14.67	13
6	5.67	14	16	15.67	13
7	6.67	6	17	16.67	12
8	7.67	12	18	17.67	23
9	8.67	18	19	18.67	37
10	9.67	11	20	19.67	39

5.2 Normal Condition

Assuming $K_h = 10177 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}} = 0.206 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.85 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.74 m) to 4.85 m depth (GL -11.59 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.74	0.93	6.4	12.0	8.57
2	7.67	1.00	12.0	18.0	15.00
3	8.67	1.00	18.0	11.0	14.50
4	9.67	1.00	11.0	21.0	16.00
5	10.67	0.92	21.0	21.0	19.25

$$L = \Sigma h = 4.85 \quad \Sigma A = 73.31$$

$$A : (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{73.31}{4.85} = 15.13$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 15.13 = 42355 \text{ kN/m}^2$$

$$K_{\lambda 0} = \frac{1}{0.3} \times \alpha \times 42355 = 141183 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_{\lambda} = K_{\lambda 0} (B_{\lambda}/0.3)^{-3/4} = 141183 (10.00/0.3)^{-3/4} = 10177 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 10177 kN/m³.

5.3 Seismic Condition

Assuming $K_h = 19017 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}} = 0.241 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.15 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.74 m) and 4.15 m depth (GL -10.89 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.74	0.93	6.4	12.0	8.57
2	7.67	1.00	12.0	18.0	15.00
3	8.67	1.00	18.0	11.0	14.50
4	9.67	1.00	11.0	21.0	16.00
5	10.67	0.22	21.0	21.0	4.52

$$L = \Sigma h = 4.15 \quad \Sigma A = 58.58$$

$$A : (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\text{Average N-value} \quad N' = \frac{\Sigma A}{L} = \frac{58.58}{4.15} = 14.13$$

K_h is recalculated from the calculated average N value.

$$E_0 = 2800 N' = 2800 \times 14.13 = 39572 \text{ kN/m}^2$$

$$K_{\lambda 0} = \frac{1}{0.3} \times \alpha \times 39572 = 263816 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_{\lambda} = K_{\lambda 0} (B_{\lambda}/0.3)^{-3/4} = 263816 (10.00/0.3)^{-3/4} = 19017 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 19017 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P_0 and Acting Elevation h_0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth Pa kN/m2	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.17	1.17	0.21 14.61	0.12 8.55	6.35 5.96	0.79 50.95
2	1.17- 2.17	1.00	14.61 26.92	7.31 13.46	5.24 4.90	38.26 66.01
3	2.17- 3.17	1.00	26.92 39.23	13.46 19.62	4.24 3.90	57.03 76.57
4	3.17- 4.17	1.00	39.23 50.40	19.18 25.20	3.24 2.90	62.08 73.17
5	4.17- 4.74	0.57	51.46 58.47	14.67 16.66	2.38 2.19	34.91 36.49
6	4.74- 5.17	0.43	58.47 59.54	12.57 12.80	1.86 1.71	23.34 21.93
7	5.17- 6.17	1.00	59.54 60.74	29.23 30.37	1.24 0.90	36.15 27.44
8	6.17- 6.40	0.23	60.74 62.15	7.15 7.21	0.49 0.42	3.23 3.01
9	6.40- 6.74	0.34	62.15 52.80	10.66 8.98	0.25 0.11	2.42 1.02
			$\Sigma P = 257.20$	$\Sigma M = 615.07$		

P_a : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_s \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_i = 0.0 \text{ kN/m}$
depth to acting position $H_i = 0.0 \text{ m}$
moment $M_{ai} = 0.0 \text{ kN} \cdot \text{m/m}$
depth to acting position $H_a = 0.00 \text{ m}$
Height from riverbed to top of coping $H = 6.40 \text{ m}$
Depth of Imaginary riverbed from riverbed $L_k = 0.34 \text{ m}$

Moment M_i by arbitrary load is as below
 $M_i = P_i \cdot (H + L_k - H_i) + M_{ai} = 0.00 \text{ kN} \cdot \text{m}$
 h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{615.07}{257.20} = 2.39 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 257.20}{6.74} = 76.32 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.17	1.17	0.89 16.72	0.52 9.78	6.35 5.56	3.29 58.30
2	1.17- 2.17	1.00	16.72 30.26	8.36 15.13	5.24 4.90	43.78 74.18
3	2.17- 3.17	1.00	30.26 43.79	15.13 21.89	4.24 3.90	64.09 85.46
4	3.17- 4.17	1.00	43.72 55.68	21.26 27.84	3.24 2.90	68.82 80.84
5	4.17- 4.26	0.09	57.21 58.42	2.57 2.63	2.54 2.51	6.54 6.60
6	4.26- 5.17	0.91	58.42 61.80	26.58 28.12	2.18 1.87	57.86 52.67
7	5.17- 6.17	1.00	60.25 63.67	30.12 31.83	1.24 0.90	37.25 28.76
8	6.17- 6.40	0.23	63.67 66.53	7.53 7.65	0.89 0.42	1.73 3.19
9	6.40- 6.74	0.34	66.53 61.76	11.31 10.50	0.23 0.11	2.56 1.19
			Σ P = 278.79	Σ M = 679.11		

P₀ : active earth pressure + residual water pressure - passive earth pressure
P : load P₀ 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_l = 0.0 kN/m
depth to acting position H_l = 0.00 m
moment M_l = 0.0 kN·m/m
depth to acting position H_l = 0.00 m
Height from riverbed to top of coping H = 6.40 m
Depth of Imaginary riverbed from riverbed L_k = 0.34 m

Moment M_l by arbitrary load is as below
M_l = P_l·(H + L_k - H_l) + M_l = 0.00 kN·m

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	4.26- 5.26	1.00	0.0 2.5	0.00 1.25	2.15 1.81	0.00 2.27
2	5.26- 6.26	1.00	2.5 3.5	1.25 1.77	1.15 0.81	1.44 1.44
3	6.26- 6.40	0.14	3.5 3.7	0.25 0.26	0.43 0.39	0.11 0.10
			Σ P _{dw} = 4.79	Σ M _{dw} = 5.36		

h₀, Height of acting position of P₀ from imaginary riverbed

6.2.2 Seismic Condition

modulus of lateral subgrade reaction K_s = 19017 kN/m³
calculated value β = 0.24124 m⁻¹
resultant earth force (lateral) P₀ = 283.58 kN/m
height of acting position of load h₀ = 2.41 m
moment M₀ = 684.47 kN·m/m

in consideration of ψ_{sa} = 1.328,
maximum moment M_{max} = 909.11 kN·m/m
depth of generated position of M_{max} l_m = 1.794 m
depth of lst fixed point l_i = 5.050 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name 10 H₂ H 1000-250-16-25-18
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.89
Section efficiency μ = 1.00
Module of section Z₀ = 11980 cm³ (original condition)
Z = 10662 cm³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{909.68 \times 10^6}{10662 \times 10^3} = 82 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

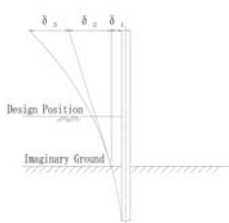
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{909.11 \times 10^6}{10662 \times 10^3} = 85 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_0 + \Sigma M_{dw}}{\Sigma P + P_0 + \Sigma P_{dw}} = \frac{684.47}{283.58} = 2.41 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 283.58}{6.74} = 84.15 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Material name 10 H₂ H 1000-250-16-25-18
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 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 I₀ = 806700 cm⁴ (original condition)
I = 701829 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 701829 × 10⁻⁸ = 1.405 × 10⁶

$$\beta = 4\sqrt{\frac{K_s \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

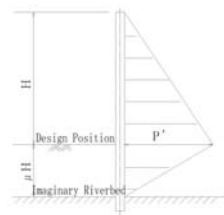
6.2.1 Normal Condition

modulus of lateral subgrade reaction K_s = 10177 kN/m³
calculated value β = 0.20634 m⁻¹
resultant earth force (lateral) P₀ = 257.20 kN/m
height of acting position of load h₀ = 2.39 m
moment M₀ = 615.07 kN·m/m

in consideration of ψ_{sa} = 1.414,
maximum moment M_{max} = 869.68 kN·m/m
depth of generated position of M_{max} l_m = 2.260 m
depth of lst fixed point l_i = 6.066 m

$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1 + 0.2063 \times 2.39) \times 257.20}{2 \times 2.00 \times 10^6 \times 701829 \times 10^{-8} \times 0.2063^3} = 0.01558 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k) = \frac{(1 + 2 \times 0.2063 \times 2.39) \times 257.20}{2 \times 2.00 \times 10^6 \times 701829 \times 10^{-8} \times 0.2063^2} \times (6.40 + 0.34) = 0.02882 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.34}{6.40} = 0.053$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) = \frac{76.32 \times 6.40^4}{120 \times 2.00 \times 10^6 \times 701829 \times 10^{-8}} (4 + 20 \times 0.053 + 40 \times 0.053^2 + 35 \times 0.053^3 + 11 \times 0.053^4) = 0.00394 \text{ m}$$

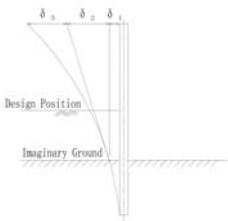
$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01558 + 0.02882 + 0.00394 = 0.04833 \text{ m}$$

$$\text{Size} = 48.33 \leq \delta_a = 50.00 \text{ mm}$$

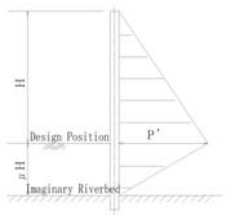
Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : Displacement at higher part of inclination ground as cantilever
δ : Displacement at top of SSP
δ_a : Allowable displacement

6.4.2 Seismic Condition

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta \cdot h_a) \times P_0}{2 E I \beta^3}$$
$$= \frac{(1 + 0.2412 \times 2.41) \times 283.58}{2 \times 2.00 \times 10^8 \times 701829 \times 10^{-8} \times 0.2412^3} = 0.01138 \text{ m}$$
$$\delta_2 = \frac{(1 + 2 \beta \cdot h_a) \times P_0}{2 E I \beta^2} \times (H + L_a)$$
$$= \frac{(1 + 2 \times 0.2412 \times 2.41) \times 283.58}{2 \times 2.00 \times 10^8 \times 701829 \times 10^{-8} \times 0.2412^2} \times (6.40 + 0.34) = 0.02532 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.34}{6.40} = 0.053$$
$$\delta_3 = \frac{P' \cdot H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$
$$= \frac{84.15 \times 6.40^4}{120 \times 2.00 \times 10^8 \times 701829 \times 10^{-8}} (4 + 20 \times 0.053 + 40 \times 0.053^2 + 35 \times 0.053^3 + 11 \times 0.053^4)$$
$$= 0.00434 \text{ m}$$

8 Calculation Result

SSP		10 H _H 1000 -250 -16 -25 -18		
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	806700		
Sectional Modulus	Z (cm ³)	11980		
Maximum bending moment	Mmax (kN · m · m)		809.68	909.11
Stress intensity	σ (N/mm ²)		82.1 (180)	85 (270)
Lateral displacement	δ (mm)		48.33 (50.0)	41.05 (75.0)
Penetration depth	D (m)		15.39	13.22
Whole length of SSP	L (m)	21.50		

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= 0.01138 + 0.02532 + 0.00434$$
$$= 0.04105 \text{ m}$$

Size = 41.05 ≤ δ a = 75.00 mm

Where,
δ₁ : Displacement at imaginary ground
δ₂ : Displacement by angle of inclination slope at imaginary ground
δ₃ : 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:

Material Name	10 H _H 1000 -250 -16 -25 -18
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 = 806700 cm ⁴ (original condition) I = 806700 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 806700 × 10 ⁻⁸	= 1.613 × 10 ⁸

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 follows:

$$D = L_k + \frac{3}{\beta}$$
$$L = H - H_{11} + D$$
$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K _b = 10177 kN/m ³
Calculated value	β = 0.19928 m ⁻¹

$$\text{Penetration length of SSP} \quad D = 0.34 + \frac{3}{0.199} = 15.39 \text{ m}$$
$$\text{Whole length of SSP} \quad L = 6.40 - 0.40 + 15.39 = 21.39 \text{ m}$$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K _b = 19017 kN/m ³
Calculated value	β = 0.23299 m ⁻¹

$$\text{Penetration length of SSP} \quad D = 0.34 + \frac{3}{0.233} = 13.22 \text{ m}$$
$$\text{Whole length of SSP} \quad L = 6.40 - 0.40 + 13.22 = 19.22 \text{ m}$$

Therefore, the total length of the sheet pile is 21.50 m from the rounded length value of 0.50 m.

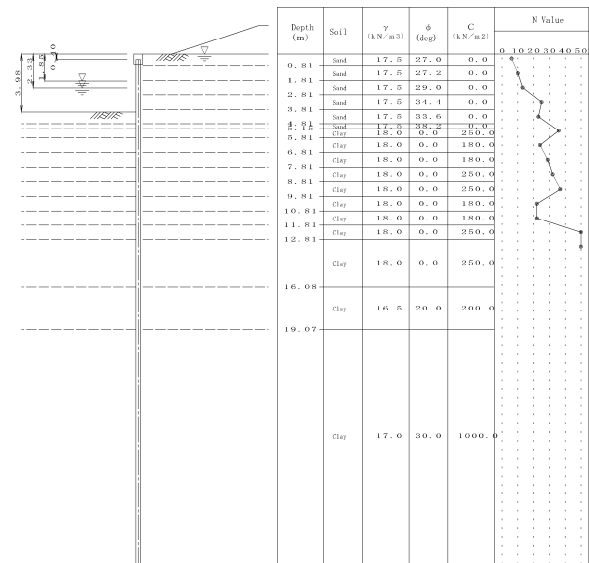
Block No. : R-32
Sta. : 11+980~12+000

Design Cross Section : Sta 11+960
Boring Name : BMRL-35

Specification : SSP SP-50H

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed
Depth from coping top to rear side ground
Depth from coping top to SSP top
Landside WL
Riverside WL

H = 3.98 m
H₀ = 0.00 m
H_u = 0.40 m
L_{wa} = 0.00 m (Normal Condition)
L_{wa} = 0.00 m (Seismic Condition)
L_{wp} = 2.33 m (Normal Condition)
L_{wp} = 1.85 m (Seismic Condition)

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	0.31	6	11	10.31	22
2	1.31	10	12	11.31	22
3	2.31	13	13	12.31	50
4	3.31	25	14	13.31	50
5	4.31	23			
6	5.31	36			
7	6.31	24			
8	7.31	29			
9	8.31	32			
10	9.31	37			

1.6 Vertical Load

Vertical load on landside
Vertical load on riverside

calculated in consideration of embankment shape on landside
not considered

1.7 Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	0.81	0.81
2	1.81	1.00
3	2.81	1.00
4	3.81	1.00
5	4.81	1.00
6	5.15	0.34
7	5.81	0.66
8	6.81	1.00
9	7.81	1.00
10	8.81	1.00
11	9.81	1.00
12	10.81	1.00
13	11.81	1.00
14	12.81	1.00
15	16.08	3.27
16	19.07	2.99
17	33.80	14.73

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	φ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.81	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	1.81	S	10.0	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
3	2.81	S	13.0	17.50	7.70	29.0	0.0	0.0	0.200	Auto	Auto
4	3.81	S	25.0	17.50	7.70	34.4	0.0	0.0	0.200	Auto	Auto
5	4.81	S	23.0	17.50	7.70	33.6	0.0	0.0	0.200	Auto	Auto
6	5.15	S	36.0	17.50	7.70	38.2	0.0	0.0	0.200	Auto	Auto
7	5.81	C	36.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
8	6.81	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
9	7.81	C	29.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
10	8.81	C	32.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
11	9.81	C	37.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
12	10.81	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	11.81	C	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	12.81	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	16.08	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	19.07	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
17	33.80	C	121.5	17.00	7.20	30.0	1000.0	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
C₀ : soil adhesion
a : slope of soil adhesion
k' : design seismic coefficient (underwater)
ζ : angle of active rupture

1.3 Applied Formula

Formula for generated stress
Penetration depths

Chang's formula
$$L = \frac{3}{\beta}$$

1.4 Design Constant

Unit weight of water
Type of water pressure
Lateral pressure
Study case
Design earthquake intensity
Dynamic water pressure due to earthquake
considered as distributed load
Arbitrary load
Wind load, Impact load
Minimum angle of rupture
Rear side angle of slope

$\gamma_w = 9.8 \text{ kN/m}^3$
trapezoidal water pressure
calculated in consideration of site conditions
- Normal Condition
- Seismic Condition
k = 0.200
considered as distributed load
not considered
not considered
 $\zeta_0 = 10 \text{ degrees}$
not considered

Angle of rupture (clayey soil)
Equilibrium factor of compression

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$$

K_c = 0.50 (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula
Average N-value

$$K_b = K_{b0} \left(\frac{B_H}{0.3} \right)^{-3/4}$$

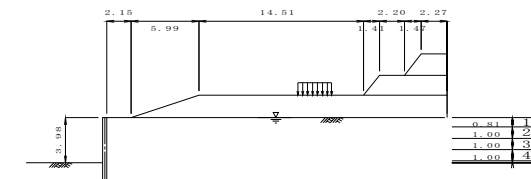
$$K_{b0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

B_H = 10.00 m
E₀ = 2800 N
calculated from average N-value between imaginary riverbed and depth as 1/β

γ' : saturated unit weight of soil
φ : internal friction angle of soil
kh : modulus of subgrade reaction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil angle weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	φ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	2.15	8.14	30.00	30.00	2.00	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	22.65	24.06	30.00	30.00	1.75	19.0	19.0	30.0	0.0	Auto	Auto
3	Sand	26.26	27.73	30.00	30.00	1.89	19.0	19.0	30.0	0.0	Auto	Auto

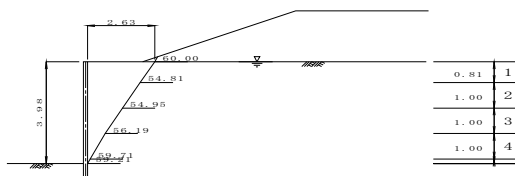
Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	16.85	19.83	10.0	5.0

Angle of rupture in embankment
calculated in consideration of embankment conditions

Material name	Hat steel sheet pile SP -50 H	
Young's modulus	$E = 200000 \text{ N/mm}^2$	
Inertia sectional moment	$I_0 = 51100 \text{ cm}^4$	
Sectional factor	$Z_0 = 2760 \text{ cm}^3$	
Corrosion margin	$t_1 = 1.00 \text{ mm (riverside)}$	$t_2 = 1.00 \text{ mm (landside)}$
Corrosion rate (to I_0)	$\eta = 0.87$	
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	$\sigma_a = 180 \text{ N/mm (Normal)}$	$\sigma_a' = 270 \text{ N/mm (Seismic)}$
Allowable displacement	$\delta_a = 50.0 \text{ mm (Normal)}$	$\delta_a' = 75.0 \text{ mm (Seismic)}$
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	

2.1 Normal Condition



No	Depth. m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ_{wet} kN/m ²	Angle of Rupture ζ degree
1	3.98 ~ 3.81	Sand	33.6	15.0	0.0	30.65	0.34	39.00	59.21

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$

$$= \frac{0.90 + 0.00 + 0.00}{2.63}$$

$$= 0.34 \text{ kN/m}^2$$
[illegible]

No	Depth. m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma$ h kN/m ²	Q kN/m ²	γ whm kN/m ³	k (t/m ²)	θ degree	Angle of Rupture χ degree
1	3.98 – 3.81	Sand	33.6	15.0	0.0	30.65	3.86	39.00	0.200	11.31	48.68
2	3.81 – 2.81	Sand	34.4	15.0	0.0	29.34	3.86	37.34	0.200	11.31	49.38
3	2.81 – 1.81	Sand	29.0	15.0	0.0	21.64	3.86	27.54	0.200	11.31	44.31
4	1.81 – 0.81	Sand	27.2	15.0	0.0	13.94	3.86	17.74	0.200	11.31	42.48
5	0.81 – 0.00	Sand	27.0	15.0	0.0	6.24	3.86	7.94	0.200	11.31	42.48
6	embankment	embankment	30.0	—	0.0	107.16	0.00	0.00	0.200	11.31	49.60

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

• Angle of active rupture of sandy soil

$$\zeta = 90^\circ - \tan^{-1} \frac{-\sin(\phi + \theta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$
$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

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)

No	Angle of Biaxial ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	59.21	0.17	0.00	0.00	0.10	0.17
2	59.71	1.00	0.10	0.17	0.69	1.17
3	56.19	1.00	0.69	1.17	1.36	2.17
4	54.95	1.00	1.36	2.17	2.06	3.17
5	54.81	0.81	2.06	3.17	2.63	3.98
6	60.00	0.20	2.63	3.98	2.74	4.18

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.05	0.90
Σ			0.90

γ : unit weight of embankment soil
 A : sectional area of embankment enclosed by line of active rupture

No	Angle of Repose γ degree	Thickness Z mm	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	48.68	0.17	0.00	0.00	0.15	0.17
2	49.38	1.00	0.15	0.17	1.01	1.17
3	44.31	1.00	1.01	1.17	2.03	2.17
4	42.40	1.00	2.03	2.17	3.13	3.17
5	42.18	0.81	3.13	3.17	4.02	3.98
6	49.60	0.87	4.02	3.98	4.76	4.85

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.82	15.50
Σ			15.50

γ : unit weight of embankment soil
 A : sectional area of embankment enclosed by line of active rupture

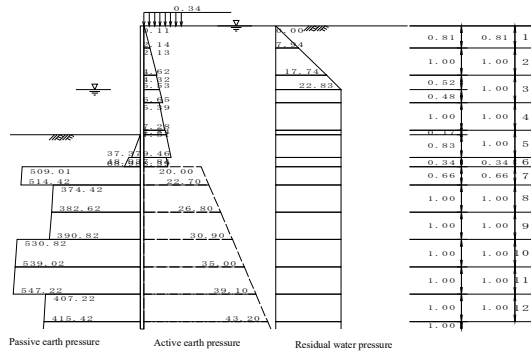
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{15.50 + 0.00 + 0.00}{4.02}$$

$$= 3.86 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	K_a	$K_a \times \cos \delta$
1	0.00-0.81	Sand	7.7	27.0	—	0.341 6.578	0.33738 0.33738	0.32589 0.32589
2	0.81-1.81	Sand	7.7	27.2	—	6.578 14.278	0.33489 0.33489	0.32348 0.32348
3	1.81-2.33	Sand	7.7	29.0	—	14.278 18.282	0.31307 0.31307	0.30240 0.30240
4	2.33-2.81	Sand	7.7	29.0	—	18.282 21.978	0.31307 0.31307	0.30240 0.30240
5	2.81-3.81	Sand	7.7	34.4	—	21.978 29.678	0.25382 0.25382	0.24517 0.24517
6	3.81-3.98	Sand	7.7	33.6	—	29.678 30.987	0.26205 0.26205	0.25312 0.25312
7	3.98-4.81	Sand	7.7	33.6	—	30.987 37.378	0.26205 0.26205	0.25312 0.25312
8	4.81-5.15	Sand	7.7	38.2	—	37.378 39.996	0.21713 0.21713	0.20973 0.20973
9	5.15-5.81	Clay	8.2	—	250.0 250.0	39.996 45.408	—	—
10	5.81-6.81	Clay	8.2	—	180.0 180.0	45.408 53.608	—	—
11	6.81-7.81	Clay	8.2	—	180.0 180.0	53.608 61.308	—	—
12	7.81-8.81	Clay	8.2	—	250.0 250.0	61.308 70.008	—	—

13	8.81-9.81	Clay	8.2	—	250.0 250.0	70.008 78.208	—	—
14	9.81-10.81	Clay	8.2	—	180.0 180.0	78.208 86.408	—	—
15	10.81-11.81	Clay	8.2	—	180.0 180.0	86.408 94.608	—	—
16	11.81-12.81	Clay	8.2	—	250.0 250.0	94.608 102.808	—	—
17	12.81-16.08	Clay	8.2	—	250.0 250.0	102.808 129.622	—	—
18	16.08-19.07	Clay	6.7	—	200.0 200.0	129.622 149.655	—	—
19	19.07-33.80	Clay	7.2	—	1000.0 1000.0	149.655 255.711	—	—

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	K_p	$K_p \times \cos \delta$
7	3.98-4.81	Sand	7.7	33.6	—	0.000 6.391	6.05364 6.05364	5.84737 5.84737
8	4.81-5.15	Sand	7.7	38.2	—	6.391 9.009	7.02661 7.02661	7.65652 7.65652
9	5.15-5.81	Clay	8.2	0.0	250.0 250.0	9.009 14.421	—	—
10	5.81-6.81	Clay	8.2	0.0	180.0 180.0	14.421 22.621	—	—
11	6.81-7.81	Clay	8.2	0.0	180.0 180.0	22.621 30.821	—	—
12	7.81-8.81	Clay	8.2	0.0	250.0 250.0	30.821 39.021	—	—
13	8.81-9.81	Clay	8.2	0.0	250.0 250.0	39.021 47.221	—	—
14	9.81-10.81	Clay	8.2	0.0	180.0 180.0	47.221 55.421	—	—
15	10.81-11.81	Clay	8.2	0.0	180.0 180.0	55.421 63.621	—	—
16	11.81-12.81	Clay	8.2	0.0	250.0 250.0	63.621 71.821	—	—
17	12.81-16.08	Clay	8.2	0.0	250.0 250.0	71.821 98.635	—	—
18	16.08-19.07	Clay	6.7	20.0	200.0 200.0	98.635 118.668	—	—
19	19.07-33.80	Clay	7.2	30.0	1000.0 1000.0	118.668 224.724	—	—

Coefficient of passive earth pressure of sandy soil K_p is calculated by the formula below;

$\delta = -15.00^\circ$, $\beta = 0.00^\circ$, $\theta = 0.00^\circ$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)} \right]^2}$$

Sand $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$

Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a2} = K_c \cdot (\Sigma \gamma h + Q)$
 K_c : Equilibrium coefficient of compression: 0.5
Larger of P_{a1} or P_{a2} 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

Sand $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$

Clay $P_p = \Sigma \gamma h + Q + 2C$

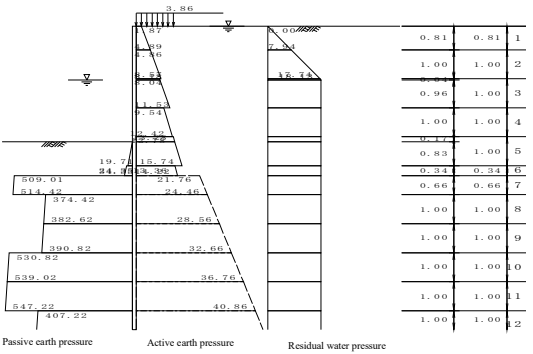
Mixed soil $P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure		Passive
		P_{a1} kN/m ²	P_{a2} kN/m ²	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	
1	0.00-0.81	0.11 2.14	—	0.11 2.14	0.00 7.94	—	—
2	0.81-1.81	—	2.13 4.62	2.13 4.62	7.94 17.74	—	—
3	1.81-2.33	—	4.32 5.53	4.32 5.53	17.74 22.83	—	—
4	2.33-2.81	—	5.53 6.65	5.53 6.65	22.83 22.83	—	—
5	2.81-3.81	—	5.39 7.28	5.39 7.28	22.83 22.83	—	—
6	3.81-3.98	—	7.51 7.84	7.51 7.84	22.83 22.83	—	—
7	3.98-4.81	—	7.84 9.46	7.84 9.46	22.83 37.37	0.00 37.37	—
8	4.81-5.15	—	7.84 8.39	7.84 8.39	22.83 22.83	48.93 68.98	—
9	5.15-5.81	-460.00 -454.59	20.00 22.70	20.00 22.70	22.83 22.83	509.01 514.42	—
10	5.81-6.81	-314.59 -306.39	22.70 26.80	22.70 26.80	22.83 22.83	374.42 382.62	—
11	6.81-7.81	-306.39 -298.19	26.80 30.90	26.80 30.90	22.83 22.83	382.62 390.82	—
12	7.81-8.81	-438.19 -429.99	30.90 35.00	30.90 35.00	22.83 22.83	530.82 539.02	—
13	8.81-9.81	-429.99 -421.79	35.00 39.10	35.00 39.10	22.83 22.83	539.02 547.22	—
14	9.81-10.81	-281.79 -273.59	39.10 43.20	39.10 43.20	22.83 22.83	407.22 415.42	—
15	10.81-11.81	-273.59 -265.39	43.20 47.30	43.20 47.30	22.83 22.83	415.42 423.62	—
16	11.81-12.81	-405.39 -397.19	47.30 51.40	47.30 51.40	22.83 22.83	563.62 571.82	—
17	12.81-16.08	-397.19 -370.38	51.40 64.81	51.40 64.81	22.83 22.83	571.82 598.64	—
18	16.08-19.07	-270.38 -250.34	64.81 74.83	64.81 74.83	22.83 22.83	498.64 518.67	—
19	19.07-33.80	-1850.34 -1744.29	74.83 127.86	74.83 127.86	22.83 22.83	2118.67 2224.72	—

- Formula for active earth pressure

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{whw} kN/m ²	ξ (k)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00-0.81	Sand	7.7	27.0	—	3.86 10.09	0.00 7.94	0.200 0.200	11.31 11.31	0.30201 0.30201	0.48490 0.48490	—
2	0.81-1.81	Sand	7.7	27.2	—	10.09 17.79	7.94 17.74	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
3	1.81-1.85	Sand	7.7	29.0	—	17.79 18.10	17.74 18.13	0.200 0.200	11.31 11.31	0.46809 0.46809	0.45214 0.45214	—
4	1.85-2.81	Sand	7.7	28.0	—	18.10 25.49	18.13 27.54	0.200 0.200	11.31 11.31	0.46809 0.46809	0.45214 0.45214	—
5	2.81-3.81	Sand	7.7	34.4	—	25.49 33.19	27.54 37.34	0.200 0.200	11.31 11.31	0.38741 0.38741	0.37421 0.37421	—

6	3.81~ 3.98	Sand	7.7	33.6	—	—	33.19 34.50	37.34 39.00	0.200 0.200	11.31 11.31	0.39850 0.39850	0.38492 0.38492	—
7	3.98~ 4.81	Sand	7.7	33.6	—	—	34.50 40.89	39.00 47.14	0.200 0.200	11.31 11.31	0.39850 0.39850	0.38492 0.38492	—
8	4.81~ 5.15	Sand	7.7	38.2	—	—	40.89 43.51	47.14 50.47	0.200 0.200	11.31 11.31	0.33826 0.33826	0.32674 0.32674	—
9	5.15~ 5.81	Clay	8.2	—	250.0 250.0	—	43.51 48.92	50.47 56.94	0.200 0.200	11.31 11.31	—	—	44.73 44.69
10	5.81~ 6.81	Clay	8.2	—	180.0 180.0	—	48.92 57.12	56.94 66.74	0.200 0.200	11.31 11.31	—	—	44.57 44.51
11	6.81~ 7.81	Clay	8.2	—	180.0 180.0	—	57.12 65.32	66.74 76.54	0.200 0.200	11.31 11.31	—	—	44.51 44.44
12	7.81~ 8.81	Clay	8.2	—	250.0 250.0	—	65.32 73.52	76.54 86.34	0.200 0.200	11.31 11.31	—	—	44.60 44.55
13	8.81~ 9.81	Clay	8.2	—	250.0 250.0	—	73.52 81.72	86.34 96.14	0.200 0.200	11.31 11.31	—	—	44.55 44.50
14	9.81~ 10.81	Clay	8.2	—	180.0 180.0	—	81.72 89.92	96.14 105.94	0.200 0.200	11.31 11.31	—	—	44.30 44.23
15	10.81~ 11.81	Clay	8.2	—	180.0 180.0	—	89.92 98.12	105.94 115.74	0.200 0.200	11.31 11.31	—	—	44.23 44.16
16	11.81~ 12.81	Clay	8.2	—	250.0 250.0	—	98.12 106.32	115.74 125.54	0.200 0.200	11.31 11.31	—	—	44.40 44.35
17	12.81~ 16.08	Clay	8.2	—	250.0 250.0	—	106.32 133.14	125.54 157.58	0.200 0.200	11.31 11.31	—	—	44.35 44.19
18	16.08~ 19.07	Clay	6.7	—	200.0 200.0	—	133.14 153.17	157.58 186.89	0.200 0.200	11.31 11.31	—	—	43.98 43.83
19	19.07~ 33.80	Clay	7.2	—	1000.0 1000.0	—	153.17 229.23	186.89 331.24	0.200 0.200	11.31 11.31	—	—	44.77 44.62

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$$

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γw_{sw} kN/m ²	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
7	3.98~ 4.81	Sand	7.70	33.6	—	0.000 6.391	0.00 8.13	0.200 0.200	11.31 11.31	3.08376 3.08376	3.08376 3.08376
8	4.81~ 5.15	Sand	7.70	38.2	—	6.391 9.009	8.13 11.47	0.200 0.200	11.31 11.31	3.81070 3.81070	3.81070 3.81070
9	5.15~ 5.81	Clay	8.20	0.0	250.0 250.0	9.009 14.421	11.47 17.93	0.200 0.200	11.31 11.31	—	—
10	5.81~ 6.81	Clay	8.20	0.0	180.0 180.0	14.421 22.621	17.93 27.73	0.200 0.200	11.31 11.31	—	—
11	6.81~ 7.81	Clay	8.20	0.0	180.0 180.0	22.621 30.821	27.73 37.53	0.200 0.200	11.31 11.31	—	—

12	7.81~ 8.81	-421.48 -411.60	32.66 36.76	32.66 36.76	18.13 18.13	530.82 539.02
13	8.81~ 9.81	-411.60 -401.72	36.76 40.86	36.76 40.86	18.13 18.13	539.02 547.22
14	9.81~ 10.81	-261.64 -251.73	40.86 44.96	40.86 44.96	18.13 18.13	407.22 415.42
15	10.81~ 11.81	-251.73 -241.83	44.96 49.06	44.96 49.06	18.13 18.13	415.42 423.62
16	11.81~ 12.81	-381.95 -372.06	49.06 53.16	49.06 53.16	18.13 18.13	563.62 571.82
17	12.81~ 16.08	-372.06 -339.67	53.16 66.57	53.16 66.57	18.13 18.13	571.82 598.64
18	16.08~ 19.07	-239.23 -215.25	66.57 76.58	66.57 76.58	18.13 18.13	498.64 518.67
19	19.07~ 33.80	-1816.02 -1688.41	76.58 129.61	76.58 129.61	18.13 18.13	2118.67 2228.72

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of P_{a1} or P_{a2} is applied as active earth pressure (P_a)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p _{dw} kN/m ²
1	1.85	0.00	0.00
2	2.85	1.00	2.50
3	3.85	2.00	3.54
4	3.98	2.13	3.65

$$p_{dw} = \pm \frac{7}{8} k_{iw} \cdot \gamma_w \cdot \sqrt{H} \cdot y$$

Where,

k_{iw} : 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

12	7.81~ 8.81	Clay	8.20	0.0	250.0 250.0	30.821 39.021	37.53 47.33	0.200 0.200	11.31 11.31	—	—	—
13	8.81~ 9.81	Clay	8.20	0.0	250.0 250.0	39.021 47.221	47.33 57.13	0.200 0.200	11.31 11.31	—	—	—
14	9.81~ 10.81	Clay	8.20	0.0	180.0 180.0	47.221 55.421	57.13 66.93	0.200 0.200	11.31 11.31	—	—	—
15	10.81~ 11.81	Clay	8.20	0.0	180.0 180.0	55.421 63.621	66.93 76.73	0.200 0.200	11.31 11.31	—	—	—
16	11.81~ 12.81	Clay	8.20	0.0	250.0 250.0	63.621 71.821	76.73 86.53	0.200 0.200	11.31 11.31	—	—	—
17	12.81~ 16.08	Clay	8.20	0.0	250.0 250.0	71.821 98.635	86.53 118.58	0.200 0.200	11.31 11.31	—	—	—
18	16.08~ 19.07	Clay	6.70	20.0	200.0 200.0	98.635 118.668	118.58 147.88	0.200 0.200	11.31 11.31	—	—	—
19	19.07~ 33.80	Clay	7.20	30.0	1000.0 1000.0	118.668 224.724	147.88 292.24	0.200 0.200	11.31 11.31	—	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

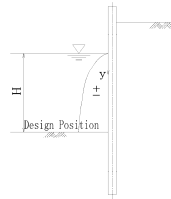
$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

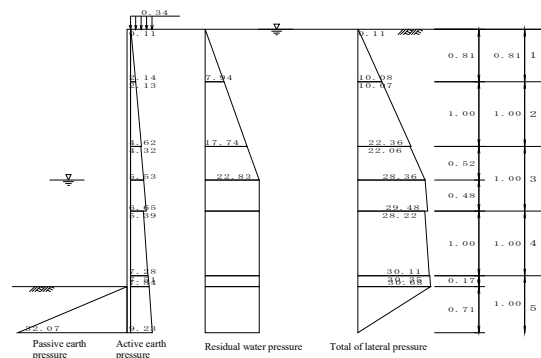
No	Depth. m	Active			Residual water pressure		Passive
		P _{a1} kN/m ²	P _{a2} kN/m ²	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	
1	0.00~ 0.81	1.87 4.89	—	1.87 4.89	0.00 7.94	—	—
2	0.81~ 1.81	—	4.86 8.57	4.86 8.57	7.94 17.74	—	—
3	1.81~ 1.85	—	8.04 8.18	8.04 8.18	17.74 18.13	—	—
4	1.85~ 2.81	—	8.18 11.53	8.18 11.53	18.13 18.13	—	—
5	2.81~ 3.81	—	9.54 12.42	9.54 12.42	18.13 18.13	—	—
6	3.81~ 3.98	12.78 13.28	—	12.78 13.28	18.13 18.13	—	—
7	3.98~ 4.81	13.28 15.74	—	13.28 15.74	18.13 18.13	0.00 19.71	—
8	4.81~ 5.15	13.36 14.22	—	13.36 14.22	18.13 18.13	24.35 34.33	—
9	5.15~ 5.81	—	21.76 24.46	21.76 24.46	18.13 18.13	509.01 514.42	—
10	5.81~ 6.81	—	24.46 28.56	24.46 28.56	18.13 18.13	374.42 382.62	—
11	6.81~ 7.81	—	28.56 32.66	28.56 32.66	18.13 18.13	382.62 390.82	—



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



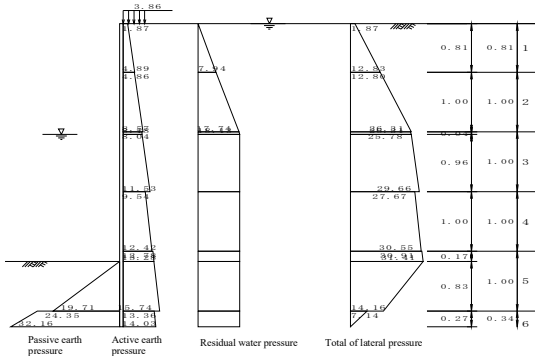
No	Depth. m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00~ 0.81	0.11 2.14	0.00 7.94	—	0.11 10.08
2	0.81~ 1.81	2.13 4.62	7.94 17.74	—	10.07 22.36
3	1.81~ 2.33	4.32 5.53	17.74 22.83	—	22.06 28.36
4	2.33~ 2.81	5.53 6.65	22.83 22.83	—	28.36 29.48

5	2.81~ 3.81	5.39 7.28	22.83 22.83	———— ————	28.22 30.11
6	3.81~ 3.98	7.51 7.84	22.83 22.83	———— ————	30.35 30.68
7	3.98~ 4.69	7.84 9.23	22.83 22.83	0.00 0.00	30.68 0.00
8	4.69~ 4.81	9.23 9.46	22.83 22.83	32.07 37.37	0.00 -5.08

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 : 0.71 m (GL -4.69 m)

4.2 Seismic Condition



No	Depth m	P_a kN/m ²	P_w kN/m ²	P_p kN/m ²	P_s kN/m ²
1	0.00~ 0.81	1.87 4.89	0.00 7.94	———— ————	1.87 12.83
2	0.81~ 1.81	4.86 8.57	7.94 17.74	———— ————	12.80 26.31
3	1.81~ 1.85	8.04 8.18	17.74 18.13	———— ————	25.78 26.31
4	1.85~ 2.81	8.18 11.53	18.13 18.13	———— ————	26.31 29.66
5	2.81~ 3.81	9.54 12.42	18.13 18.13	———— ————	27.67 30.55
6	3.81~ 3.98	12.78 13.28	18.13 18.13	———— ————	30.91 31.41

5.2 Normal Condition

Assuming $K_h = 19881 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.486 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.06 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.69 m) to 2.06 m depth (GL -6.75 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.69	0.62	28.0	36.0	19.76
2	5.31	1.00	36.0	24.0	30.00
3	6.31	0.44	24.0	26.5	11.01
L = $\Sigma h = 2.06$		$\Sigma A = 60.77$			

A: (upper N-value + lower N-value) $\times$ h/2

$$\begin{aligned}
 \text{Average N-value } N' &= \frac{\Sigma A}{L} \\
 &= \frac{60.77}{2.06} \\
 &= 29.55
 \end{aligned}$$

K_h is recalculated from the calculated average N-value.

$$\begin{aligned}
 E_0 &= 2800N' = 2800 \times 29.55 = 82740 \text{ kN/m}^2 \\
 K_{10} &= \frac{1}{0.3} \times \alpha \times 82740 = 275800 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\
 K_h &= K_{10}(B/0.3)^{-3/4} = 275800(10.00/0.3)^{-3/4} = 19881 \text{ kN/m}^3
 \end{aligned}$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 19881 kN/m³.

5.3 Seismic Condition

Assuming $K_h = 39337 \text{ kN/m}^3$,

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.577 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 1.73 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.08 m) and 1.73 m depth (GL -6.81 m).

7	3.98~ 4.81	13.28 15.74	18.13 18.13	0.00 19.71	31.41 14.16
8	4.81~ 5.08	13.36 14.03	18.13 18.13	24.35 32.16	7.14 0.00
9	5.08~ 5.15	14.03 14.22	18.13 18.13	32.16 34.33	0.00 -1.98

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 : 1.10 m (GL -5.08 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$\begin{aligned}
 K_h &= K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B=10.00\text{m}) \\
 K_{10} &= \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\
 E_0 &= 2800N'
 \end{aligned}$$

where:

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}}$$

Material Name Hat steel sheet pile SP -50 H
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.87$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 51100 \text{ cm}^4$ (original condition)
 $I = 44457 \text{ cm}^4$ (after reduction by corrosion and section)
 Inertia sectional moment $EI = 200000 \times 10^3 \times 44457 \times 10^{-8} = 8.891 \times 10^7$

No	Depth m	N Value	No	Depth m	N Value
1	0.31	6	11	10.31	22
2	1.31	10	12	11.31	22
3	2.31	13	13	12.31	50
4	3.31	25	14	13.31	50
5	4.31	23			
6	5.31	36			
7	6.31	24			
8	7.31	29			
9	8.31	32			
10	9.31	37			

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.08	0.23	33.0	36.0	8.07
2	5.31	1.00	36.0	24.0	30.00
3	6.31	0.50	24.0	26.5	12.63
L = $\Sigma h = 1.73$		$\Sigma A = 50.69$			

A: (upper N-value + lower N-value) $\times$ h/2

$$\begin{aligned}
 \text{Average N-value } N' &= \frac{\Sigma A}{L} \\
 &= \frac{50.69}{1.73} \\
 &= 29.23
 \end{aligned}$$

K_h is recalculated from the calculated average N-value.

$$\begin{aligned}
 E_0 &= 2800N' = 2800 \times 29.23 = 81857 \text{ kN/m}^2 \\
 K_{10} &= \frac{1}{0.3} \times \alpha \times 81857 = 545712 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition}=1, \text{Seismi Condition}=2) \\
 K_h &= K_{10}(B/0.3)^{-3/4} = 545712(10.00/0.3)^{-3/4} = 39337 \text{ kN/m}^3
 \end{aligned}$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Seismic Condition) is 39337 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P_s kN/m ²	Load P kN	Actm length Y m	Moment M kN · m
1	0.00~ 0.81	0.81	0.11 10.08	0.05 4.08	4.42 4.15	0.20 16.95
2	0.81~ 1.81	1.00	10.07 22.36	5.03 11.18	3.55 3.22	17.86 35.94
3	1.81~ 2.33	0.52	22.06 28.36	5.73 7.37	2.71 2.54	15.53 18.70
4	2.33~ 2.81	0.48	28.36 29.48	6.81 7.08	2.20 2.04	14.99 14.45
5	2.81~ 3.81	1.00	28.22 30.11	14.11 15.06	1.55 1.22	21.86 18.30
6	3.81~ 3.98	0.17	30.35 30.68	2.28 2.61	0.85 0.77	2.13 2.00
7	3.98~ 4.69	0.71	30.68 0.00	10.92 0.00	0.47 0.24	5.19 0.00

$\Sigma P =$	92.61	$\Sigma M =$	184.11

P_t : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_t \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_t = 0.0$ kN/m
 depth to acting position $H_t = 0.0$ m
 moment $M_{tn} = 0.0$ kN·m/m
 depth to acting position $H_m = 0.00$ m
 Height from riverbed to top of coping $H = 3.98$ m
 Depth of Imaginary riverbed from riverbed $L_k = 0.71$ m

Moment M_t by arbitrary load is as below
 $M_t = P_t \cdot (H + L_k - H_t) + M_{tn} = 0.00$ kN·m
 h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{184.11}{92.61} = 1.99 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 92.61}{4.69} = 39.47 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth, Z m	Thickness, h m	Lateral Forth, P _t kN/m ²	Loads, P kN	Arm length, Y m	Moment, M kN · m
1	0.00~ 0.81	0.81	1.87 12.83	0.76 5.20	4.81 4.54	3.64 23.57
2	0.81~ 1.81	1.00	12.80 26.31	6.40 13.15	3.93 3.60	25.17 47.34
3	1.81~ 1.85	0.04	25.78 26.31	0.52 0.53	3.25 3.24	1.68 1.70
4	1.85~ 2.81	0.96	26.31 29.66	12.63 14.24	2.91 2.59	36.71 36.81
5	2.81~ 3.81	1.00	27.67 30.55	13.83 15.28	1.93 1.60	26.74 24.43
6	3.81~ 3.98	0.17	30.91 31.41	2.63 2.67	1.21 1.15	3.18 3.08
7	3.98~ 4.81	0.83	31.41 14.16	13.04 5.88	0.82 0.54	10.68 3.19
8	4.81~ 5.08	0.27	7.14 0.00	0.95 0.00	0.18 0.09	0.17 0.00
			$\Sigma P =$	107.68	$\Sigma M =$	248.08

P_t : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_t \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

$$\beta = 4\sqrt{\frac{K_a \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$1_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$1_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_a = 19881$ kN/m³
 calculated value $\beta = 0.48624$ m⁻¹
 resultant earth force (lateral) $P_0 = 92.61$ kN/m
 height of acting position of load $h_0 = 1.99$ m
 moment $M_0 = 184.11$ kN·m/m

in consideration of $\psi_m = 1.154$,
 maximum moment $M_{\max} = 212.48$ kN·m/m
 depth of generated position of $M_{\max}$ $l_m = 0.676$ m
 depth of 1st fixed point $l_i = 2.291$ m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_a = 39337$ kN/m³
 calculated value $\beta = 0.57669$ m⁻¹
 resultant earth force (lateral) $P_0 = 112.42$ kN/m
 height of acting position of load $h_0 = 2.29$ m
 moment $M_0 = 256.96$ kN·m/m

in consideration of $\psi_m = 1.094$,
 maximum moment $M_{\max} = 281.07$ kN·m/m
 depth of generated position of $M_{\max}$ $l_m = 0.465$ m
 depth of 1st fixed point $l_i = 1.827$ m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name Hat steel sheet pile SP -50 H
 Corrosion margin $t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
 Corrosion rate $\eta = 0.87$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 2760$ cm³ (original condition)
 $Z = 2401$ cm³ (after reduction by corrosion and section)

Arbitrary load lateral load $P_t = 0.0$ kN/m
 depth to acting position $H_t = 0.00$ m
 moment $M_{tn} = 0.0$ kN·m/m
 depth to acting position $H_m = 0.00$ m
 Height from riverbed to top of coping $H = 3.98$ m
 Depth of Imaginary riverbed from riverbed $L_k = 1.10$ m

Moment M_t by arbitrary load is as below
 $M_t = P_t \cdot (H + L_k - H_t) + M_{tn} = 0.00$ kN·m

Hydrodynamic Pressure

No	Depth, Z m	Thickness, h m	Hydrodynamic Pressure, p _{dw} kN/m ²	Loads, P _{dw} kN	Arm length, Y m	Moment, M _{dw} kN · m
1	1.85~ 2.85	1.00	0.0 2.5	0.00 1.25	2.89 2.56	0.00 3.20
2	2.85~ 3.85	1.00	2.5 3.5	1.25 1.77	1.89 1.56	2.37 2.76
3	3.85~ 3.98	0.13	3.5 3.7	0.23 0.24	1.18 1.14	0.27 0.27
			$\Sigma P_{dw} =$	4.74	$\Sigma M_{dw} =$	8.87

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{256.96}{112.42} = 2.29 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 112.42}{5.08} = 44.30 \text{ kN/m}$$

6.2 Sectional Force

Material name Hat steel sheet pile SP -50 H
 Unit width $B = 1.0000$ m
 Corrosion margin $t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
 Corrosion rate $\eta = 0.87$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000$ N/mm²
 Inertia sectional moment $I_0 = 51100$ cm⁴ (original condition)
 $I = 44457$ cm⁴ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 44457 \times 10^{-8} = 8.891 \times 10^4$

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{212.48 \times 10^6}{2401 \times 10^3} = 88 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

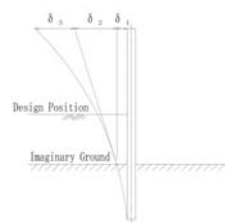
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{281.07 \times 10^6}{2401 \times 10^3} = 117 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

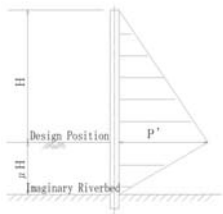


$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.4862 \times 1.99) \times 92.61}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.4862^3} = 0.00891 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.4862 \times 1.99) \times 92.61}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.4862^2} \times (3.98+0.71) = 0.03032 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.71}{3.98} = 0.179$$

$$\begin{aligned}\delta_3 &= \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4) \\ &= \frac{39.47 \times 3.98^4}{120 \times 2.00 \times 10^8 \times 44457 \times 10^{-8}} (4+20 \times 0.179+40 \times 0.179^2+35 \times 0.179^3+11 \times 0.179^4) \\ &= 0.00842 \text{ m}\end{aligned}$$

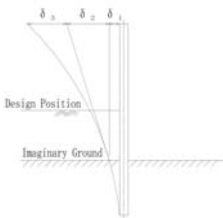
$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00891 + 0.03032 + 0.00842 \\ &= 0.04765 \text{ m} \\ \text{Size} &= 47.65 \leq \delta_a = 50.00 \text{ mm}\end{aligned}$$

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

Displacement Calculation



$$\begin{aligned}\text{Inertia sectional moment } I_0 &= 51100 \text{ cm}^4 (\text{original condition}) \\ I &= 51100 \text{ cm}^4 (\text{after reduction by corrosion and section}) \\ EI &= 200000 \times 10^3 \times 51100 \times 10^{-8} = 1.022 \times 10^9\end{aligned}$$

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 follows:

$$\begin{aligned}D &= L_k + \frac{3}{\beta} \\ L &= H - H_{(1)} + D \\ \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}}\end{aligned}$$

7.1.1 Normal Condition

$$\begin{aligned}\text{Modules of lateral subgrade reaction } K_b &= 19881 \text{ kN/m}^3 \\ \text{Calculated value } \beta &= 0.46960 \text{ m}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Penetration length of SSP } D &= 0.71 + \frac{3}{0.470} = 7.10 \text{ m} \\ \text{Whole length of SSP } L &= 3.98 - 0.40 + 7.10 = 10.68 \text{ m}\end{aligned}$$

7.1.2 Seismic Condition

$$\begin{aligned}\text{Modules of lateral subgrade reaction } K_b &= 39337 \text{ kN/m}^3 \\ \text{Calculated value } \beta &= 0.55696 \text{ m}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Penetration length of SSP } D &= 1.10 + \frac{3}{0.557} = 6.48 \text{ m} \\ \text{Whole length of SSP } L &= 3.98 - 0.40 + 6.48 = 10.06 \text{ m}\end{aligned}$$

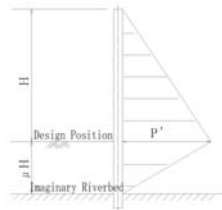
Therefore, the total length of the sheet pile is 11.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP Hat steel sheet pile SP -50 H

		Normal Condition		Seismic Condition
Inertia sectional moment	I (cm ⁴)	51100		
Sectional Modulus	Z (cm ³)	2760		
Maximum bending moment	Mmax (kN · m · m)		212.48	281.07
Stress intensity	σ (N/mm ²)		88 (180)	117 (270)
Lateral displacement	δ (mm)		47.65 (50.0)	56.62 (55.0)
Penetration depths	D (m)		7.10	6.48
Whole length of SSP	L (m)	11.00		

$$\begin{aligned}\delta_1 &= \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1+0.5767 \times 2.29) \times 112.42}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.5767^3} = 0.00764 \text{ m} \\ \delta_2 &= \frac{(1+2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k) \\ &= \frac{(1+2 \times 0.5767 \times 2.29) \times 112.42}{2 \times 2.00 \times 10^8 \times 44457 \times 10^{-8} \times 0.5767^2} \times (3.98+1.10) = 0.03509 \text{ m}\end{aligned}$$



$$\mu = \frac{L_k}{H} = \frac{1.10}{3.98} = 0.275$$

$$\begin{aligned}\delta_3 &= \frac{P' H^4}{120 E I} (4+20\mu+40\mu^2+35\mu^3+11\mu^4) \\ &= \frac{44.30 \times 3.98^4}{120 \times 2.00 \times 10^8 \times 44457 \times 10^{-8}} (4+20 \times 0.275+40 \times 0.275^2+35 \times 0.275^3+11 \times 0.275^4) \\ &= 0.01389 \text{ m}\end{aligned}$$

$$\begin{aligned}\delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00764 + 0.03509 + 0.01389 \\ &= 0.05662 \text{ m} \\ \text{Size} &= 56.62 \leq \delta_a = 75.00 \text{ mm}\end{aligned}$$

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:

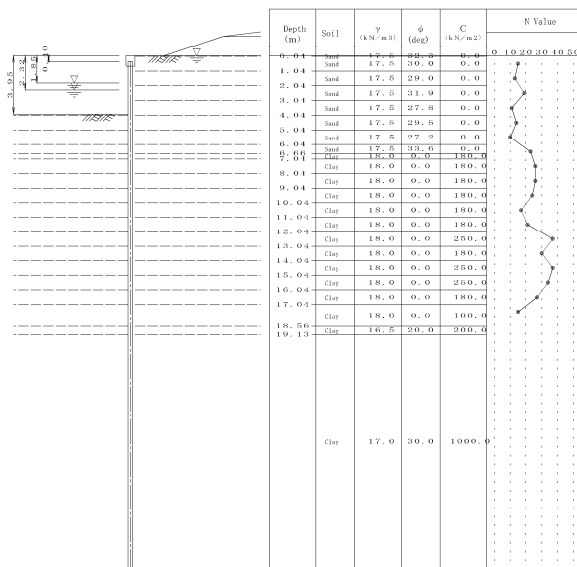
Material Name	Hat steel sheet pile SP -50 H
Unit width	B = 1.0000 m
Corrosion rate	η = 1.00
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²

Block No. : R-33
Sta. : 12+000~12+240

Design Cross Section : Sta 12+100
Boring Name : DD-BH-R16

Specification : SSP SP-10H
(Combined) : H 400-200-9-12-13

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



Depth from coping top to riverbed	H	=	3.95 m
Depth from coping top to rear side ground	H ₀	=	0.00 m
Depth from coping top to SSP	H _{lt}	=	0.40 m
Landside WL	L _{wa}	=	0.00 m (Normal Condition)
	L _{wa}	=	0.00 m (Seismic Condition)
Riverside WL	L _{wsp}	=	2.32 m (Normal Condition)
	L _{wsp}	=	1.85 m (Seismic Condition)

N-value distribution			N-value distribution		
No	Depth m	N Value	No	Depth m	N Value
1	0.54	15	11	10.54	17
2	1.54	13	12	11.54	21
3	2.54	19	13	12.54	37
4	3.54	11	14	13.54	30
5	4.54	14	15	14.54	37
6	5.54	10	16	15.54	34
7	6.54	23	17	16.54	27
8	7.54	26	18	17.54	15
9	8.54	26			
10	9.54	24			

Vertical load on landside	calculated in consideration of embankment shape on landside
Vertical load on riverside	not considered

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	0.04	0.04
2	1.04	1.00
3	2.04	1.00
4	3.04	1.00
5	4.04	1.00
6	5.04	1.00
7	6.04	1.00
8	6.66	0.62
9	7.04	0.38
10	8.04	1.00
11	9.04	1.00
12	10.04	1.00
13	11.04	1.00
14	12.04	1.00
15	13.04	1.00
16	14.04	1.00
17	15.04	1.00
18	16.04	1.00
19	17.04	1.00
20	18.56	1.52
21	19.13	0.57
22	33.80	14.67

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k ¹	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.04	S	20.0	17.50	7.70	32.3	0.0	0.0	0.0	0.200	Auto
2	1.04	S	15.0	17.50	7.70	30.0	0.0	0.0	0.0	0.200	Auto
3	2.04	S	13.0	17.50	7.70	29.0	0.0	0.0	0.0	0.200	Auto
4	3.04	S	19.0	17.50	7.70	31.9	0.0	0.0	0.0	0.200	Auto
5	4.04	S	11.0	17.50	7.70	27.8	0.0	0.0	0.0	0.200	Auto
6	5.04	S	14.0	17.50	7.70	28.5	0.0	0.0	0.0	0.200	Auto
7	6.04	S	10.0	17.50	7.70	27.2	0.0	0.0	0.0	0.200	Auto
8	6.66	S	23.0	17.50	7.70	33.6	0.0	0.0	0.0	0.200	Auto

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered

Wind load, Impact load	not considered

Minimum angle of rupture $\zeta_0 = 10$ degrees

Rear side angle of slope	not considered

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$$

Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

Applied formula

$$K_b = K_{10} \left(\frac{B_g}{0.3} \right)^{-3/4}$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$B_g = 10.00 \text{ m}$$

$$E_0 = 2800 \text{ N}$$

Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

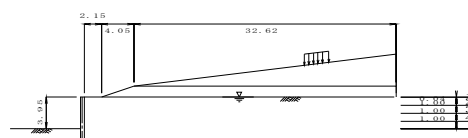
No	Depth m	earth core	N Value	γ kN/m ³	γ kN/m ³	ϕ degree	C kN/m ²	a	k ⁺	ζ (degree)	
										Normal Condition	Seismic Condition
9	7.04	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
10	8.04	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
11	9.04	C	26.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	10.04	C	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	11.04	C	17.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	12.04	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	13.04	C	37.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	14.04	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
17	15.04	C	37.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	16.04	C	34.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	17.04	C	27.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
20	18.50	C	15.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
21	19.13	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
22	33.80	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

Note)	depth :	from top of coping to bottom of the layer	C_0 :	soil adhesion
	soil :	sandy(S), clayey(C), mixed (M)	α :	slope of soil adhesion
	N-value :	average N-value in the layer	k' :	design seismic coefficient (underwater)
	γ :	wet unit weight of soil	ζ :	angle of active rupture
	γ' :	saturated unit weight of soil	kh :	modulus of subgrade reaction
	ϕ :	internal friction angle of soil		

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

Empirical data for soil parameters												
No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kNm ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kNm ³	Seismic Condition kNm ³			Normal Condition degree	Seismic Condition degree
1	Sand	2.15	6.20	38.82	38.82	1.35	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	6.20	38.82	38.82	3.99	19.0	19.0	30.0	0.0	Auto	Auto	

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	27.40	30.43	10.0	5.0

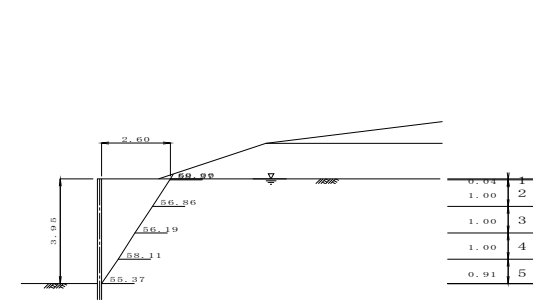
Angle of rapture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 400 -200 -9 -12 -13
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 87800 cm ⁴
Sectional factor	Z ₀	= 2320 cm ³
Corrosion margin	t ₁	= 1.00 mm (riverside)
	t ₂	= 1.00 mm (landside)
Corrosion rate (to I ₀)	η	= 0.80
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

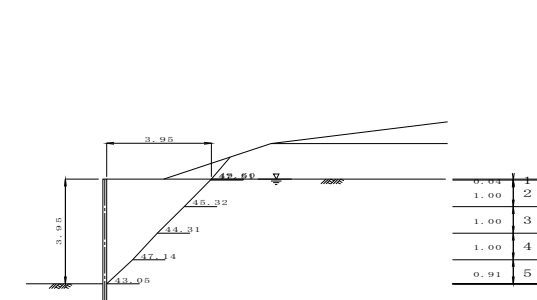


γ : unit weight of embankment soil
A: sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$Q = \frac{\sum (\gamma \times A) + \sum (Q \times 1) + \sum P}{L}$$
$$= \frac{0.79 + 0.00 + 0.00}{2.60}$$
$$= 0.30 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	3.95~3.04	Sand	27.8	15.0	0.0	30.41	3.63	38.71	0.200	11.31	43.05
2	3.04~2.04	Sand	31.9	15.0	0.0	23.41	3.63	29.79	0.200	11.31	47.14
3	2.04~1.04	Sand	29.0	15.0	0.0	15.71	3.63	19.99	0.200	11.31	44.31
4	1.04~0.04	Sand	30.0	15.0	0.0	8.01	3.63	10.19	0.200	11.31	45.32
5	0.04~0.00	Sand	32.3	15.0	0.0	0.31	3.63	0.39	0.200	11.31	47.51
6		embankment t	30.0	—	0.0	101.46	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive soil

2.1.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	Angle of Rupture ζ degree
1	3.95~3.04	Sand	27.8	15.0	0.0	30.41	0.30	38.71	55.37
2	3.04~2.04	Sand	31.9	15.0	0.0	23.41	0.30	29.79	58.11
3	2.04~1.04	Sand	29.0	15.0	0.0	15.71	0.30	19.99	56.19
4	1.04~0.04	Sand	30.0	15.0	0.0	8.01	0.30	10.19	56.86
5	0.04~0.00	Sand	32.3	15.0	0.0	0.31	0.30	0.39	58.37
6		embankment t	30.0	—	0.0	101.46	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

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$$

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)
- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	55.37	0.91	0.00	0.00	0.63	0.91
2	58.11	1.00	0.63	0.91	1.25	1.91
3	56.19	1.00	1.25	1.91	1.92	2.91
4	56.86	1.00	1.92	2.91	2.57	3.91
5	58.37	0.04	2.57	3.91	2.60	3.95
6	60.00	0.18	2.60	3.95	2.70	4.13

From the above table, the loading width (L) on the ground surface is 2.60 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.04	0.79
Σ			0.79

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	43.05	0.91	0.00	0.00	0.97	0.91
2	47.14	1.00	0.97	0.91	1.90	1.91
3	44.31	1.00	1.90	1.91	2.93	2.91
4	45.32	1.00	2.93	2.91	3.92	3.91
5	47.51	0.04	3.92	3.91	3.95	3.95
6	49.60	0.84	3.95	3.95	4.67	4.79

From the above table, the loading width (L) on the ground surface is 3.95 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.76	14.35
Σ			14.35

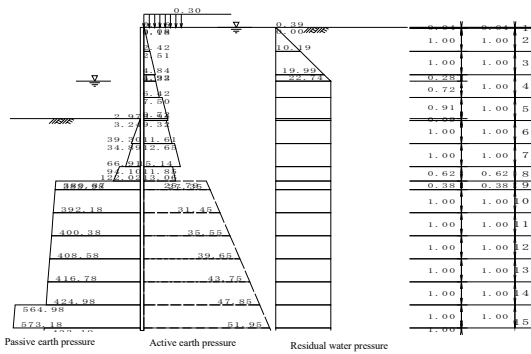
γ : unit weight of embankment soil
A: sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

$$Q = \frac{\sum (\gamma \times A) + \sum (Q \times 1) + \sum P}{L}$$
$$= \frac{14.35 + 0.00 + 0.00}{3.95}$$
$$= 3.63 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

	Depth m	Soil	γ kN/m³	φ degree	C kN/m²	Σ γ · h · Q _a kN/m²	K _a	K _a × cos δ
1	0.00- 0.04	Sand	7.7	32.3	—	0.303 0.611	0.27581 0.27581	0.26641 0.26641
2	0.04- 1.04	Sand	7.7	30.0	—	0.611 8.311	0.30142 0.30142	0.29115 0.29115
3	1.04- 2.04	Sand	7.7	28.0	—	8.311 16.011	0.31307 0.31307	0.30240 0.30240
4	2.04- 2.32	Sand	7.7	31.9	—	16.011 18.167	0.28015 0.28015	0.27060 0.27060
5	2.32- 3.04	Sand	7.7	31.9	—	18.167 23.711	0.28015 0.28015	0.27060 0.27060
6	3.04- 3.95	Sand	7.7	27.8	—	23.711 30.718	0.32749 0.32749	0.31633 0.31633
7	3.95- 4.04	Sand	7.7	27.8	—	30.718 31.411	0.32749 0.32749	0.31633 0.31633
8	4.04- 5.04	Sand	7.7	29.5	—	31.411 39.111	0.30720 0.30720	0.29674 0.29674
9	5.04- 6.04	Sand	7.7	27.2	—	39.111 46.811	0.33489 0.33489	0.32348 0.32348
10	6.04- 6.66	Sand	7.7	33.6	—	46.811 51.585	0.26205 0.26205	0.25312 0.25312
11	6.66- 7.04	Clay	8.2	—	180.0 180.0	51.585 54.701	—	—
12	7.04- 8.04	Clay	8.2	—	180.0 180.0	54.701 62.901	—	—

16	11.04- 12.04	Clay	8.2	0.0	180.0 180.0	56.783 64.983	—	—
17	12.04- 13.04	Clay	8.2	0.0	250.0 250.0	64.983 73.183	—	—
18	13.04- 14.04	Clay	8.2	0.0	180.0 180.0	73.183 81.383	—	—
19	14.04- 15.04	Clay	8.2	0.0	250.0 250.0	81.383 89.583	—	—
20	15.04- 16.04	Clay	8.2	0.0	250.0 250.0	89.583 97.783	—	—
21	16.04- 17.04	Clay	8.2	0.0	180.0 180.0	97.783 105.983	—	—
22	17.04- 18.56	Clay	8.2	0.0	100.0 100.0	105.983 118.447	—	—
23	18.56- 19.13	Clay	6.7	20.0	200.0 200.0	118.447 122.266	—	—
24	19.13- 33.80	Clay	7.2	30.0	1000.0 1000.0	122.266 227.890	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
δ = -15.00, 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 Forth

No	Depth m	Active			Residual water pressure Pw kN/m²	Passive Pp kN/m²
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²		
1	0.00- 0.04	0.08 0.16	—	0.08 0.16	0.00 0.39	—
2	0.04- 1.04	0.18 2.42	—	0.18 2.42	0.39 10.19	—
3	1.04- 2.04	2.51 4.84	—	2.51 4.84	10.19 19.99	—
4	2.04- 2.32	4.33 4.92	—	4.33 4.92	19.99 22.74	—
5	2.32- 3.04	4.92 6.42	—	4.92 6.42	22.74 22.74	—
6	3.04- 3.95	7.50 9.72	—	7.50 9.72	22.74 22.74	—
7	3.95- 4.04	9.72 9.94	—	9.72 9.94	22.74 2.97	0.00
8	4.04- 5.04	9.32 11.61	—	9.32 11.61	22.74 22.74	3.24 39.30
9	5.04- 6.04	12.65 15.14	—	12.65 15.14	22.74 22.74	34.89 66.91
10	6.04- 6.66	11.85 13.06	—	11.85 13.06	22.74 22.74	94.10 122.02
11	6.66- 7.04	200.42 305.30	25.79 27.35	25.79 27.35	22.74 22.74	280.87 383.98

13	8.04- 9.04	Clay	8.2	—	180.0 180.0	62.901 71.101	—	—
14	9.04- 10.04	Clay	8.2	—	180.0 180.0	71.101 79.301	—	—
15	10.04- 11.04	Clay	8.2	—	180.0 180.0	79.301 87.501	—	—
16	11.04- 12.04	Clay	8.2	—	180.0 180.0	87.501 95.701	—	—
17	12.04- 13.04	Clay	8.2	—	250.0 250.0	95.701 103.901	—	—
18	13.04- 14.04	Clay	8.2	—	180.0 180.0	103.901 112.101	—	—
19	14.04- 15.04	Clay	8.2	—	250.0 250.0	112.101 120.301	—	—
20	15.04- 16.04	Clay	8.2	—	250.0 250.0	120.301 128.501	—	—
21	16.04- 17.04	Clay	8.2	—	180.0 180.0	128.501 136.701	—	—
22	17.04- 18.56	Clay	8.2	—	100.0 100.0	136.701 149.165	—	—
23	18.56- 19.13	Clay	6.7	—	200.0 200.0	149.165 152.984	—	—
24	19.13- 33.80	Clay	7.2	—	1000.0 1000.0	152.984 258.608	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 15.00, 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

No	Depth m	Soil	γ kN/m³	φ degree	C kN/m²	Σ γ · h · Q _p kN/m²	K _p	K _p × cos δ
7	3.95- 4.04	Sand	7.7	27.8	—	0.000 0.693	4.43813 4.43813	4.26990 4.26990
8	4.04- 5.04	Sand	7.7	29.5	—	0.693 8.393	4.84712 4.84712	4.68196 4.68196
9	5.04- 6.04	Sand	7.7	27.2	—	8.393 16.093	4.30428 4.30428	4.15761 4.15761
10	6.04- 6.66	Sand	7.7	33.6	—	16.093 20.867	6.05364 6.05364	5.84737 5.84737
11	6.66- 7.04	Clay	8.2	0.0	180.0 180.0	20.867 23.983	—	—
12	7.04- 8.04	Clay	8.2	0.0	180.0 180.0	23.983 32.183	—	—
13	8.04- 9.04	Clay	8.2	0.0	180.0 180.0	32.183 40.383	—	—
14	9.04- 10.04	Clay	8.2	0.0	180.0 180.0	40.383 48.583	—	—
15	10.04- 11.04	Clay	8.2	0.0	180.0 180.0	48.583 56.783	—	—

12	7.04- 8.04	-305.30 -297.10	27.35 31.45	27.35 31.45	22.74 22.74	383.98 392.18
13	8.04- 9.04	-297.10 -288.90	31.45 35.55	31.45 35.55	22.74 22.74	392.18 400.38
14	9.04- 10.04	-288.90 -280.70	35.55 39.65	35.55 39.65	22.74 22.74	400.38 408.58
15	10.04- 11.04	-280.70 -272.50	39.65 43.75	39.65 43.75	22.74 22.74	408.58 416.78
16	11.04- 12.04	-272.50 -264.30	43.75 47.85	43.75 47.85	22.74 22.74	416.78 424.98
17	12.04- 13.04	-264.30 -256.10	47.85 51.95	47.85 51.95	22.74 22.74	424.98 433.18
18	13.04- 14.04	-256.10 -247.90	51.95 56.05	51.95 56.05	22.74 22.74	433.18 441.38
19	14.04- 15.04	-247.90 -239.70	56.05 60.15	56.05 60.15	22.74 22.74	441.38 449.58
20	15.04- 16.04	-239.70 -231.50	60.15 64.25	60.15 64.25	22.74 22.74	449.58 457.78
21	16.04- 17.04	-231.50 -223.30	64.25 68.35	64.25 68.35	22.74 22.74	457.78 465.98
22	17.04- 18.56	-223.30 -215.10	68.35 72.45	68.35 72.45	22.74 22.74	465.98 474.18
23	18.56- 19.13	-215.10 -206.90	72.45 76.55	72.45 76.55	22.74 22.74	474.18 482.38
24	19.13- 33.80	-206.90 -198.70	76.55 80.65	76.55 80.65	22.74 22.74	482.38 490.58

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$
$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

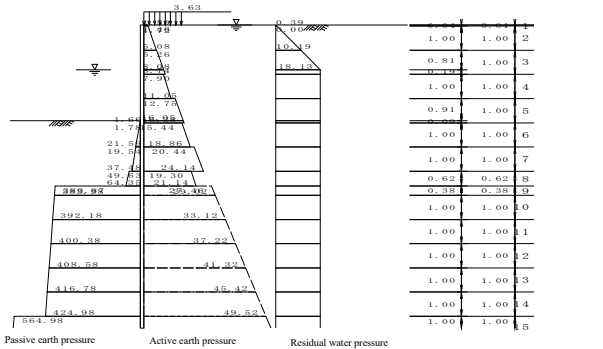
K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$
$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$
$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k')	θ degree	Ka	$K_a \times \cos \delta$	ζ degree
1	0.00-0.04	Sand	7.7	32.3	—	3.63 3.94	0.00 0.39	0.200 0.200	11.31 11.31	0.41711 0.41711	0.40290 0.40290	—
2	0.04-1.04	Sand	7.7	30.0	—	3.94 11.64	0.39 10.19	0.200 0.200	11.31 11.31	0.45203 0.45203	0.43663 0.43663	—
3	1.04-1.85	Sand	7.7	29.0	—	11.64 17.88	10.19 18.13	0.200 0.200	11.31 11.31	0.46809 0.46809	0.45214 0.45214	—
4	1.85-2.04	Sand	7.7	29.0	—	17.88 19.34	18.13 19.99	0.200 0.200	11.31 11.31	0.46809 0.46809	0.45214 0.45214	—
5	2.04-3.04	Sand	7.7	31.9	—	19.34 27.04	19.99 29.79	0.200 0.200	11.31 11.31	0.42299 0.42299	0.40858 0.40858	—
6	3.04-3.95	Sand	7.7	27.8	—	27.04 34.05	29.79 38.71	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	—
7	3.95-4.04	Sand	7.7	27.8	—	34.05 34.74	38.71 39.59	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	—
8	4.04-5.04	Sand	7.7	29.5	—	34.74 42.44	39.59 49.39	0.200 0.200	11.31 11.31	0.45999 0.45999	0.44432 0.44432	—
9	5.04-6.04	Sand	7.7	27.2	—	42.44 50.14	49.39 59.19	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
10	6.04-6.66	Sand	7.7	33.6	—	50.14 54.91	59.19 65.27	0.200 0.200	11.31 11.31	0.39850 0.39850	0.38492 0.38492	—
11	6.66-7.04	Clay	8.2	—	180.0 180.0	54.91 58.03	65.27 68.99	0.200 0.200	11.31 11.31	—	—	44.53 44.50
12	7.04-8.04	Clay	8.2	—	180.0 180.0	58.03 66.23	68.99 78.79	0.200 0.200	11.31 11.31	—	—	44.50 44.43
13	8.04-9.04	Clay	8.2	—	180.0 180.0	66.23 74.43	78.79 88.59	0.200 0.200	11.31 11.31	—	—	44.43 44.36
14	9.04-10.04	Clay	8.2	—	180.0 180.0	74.43 82.63	88.59 98.39	0.200 0.200	11.31 11.31	—	—	44.36 44.30

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(\beta - \theta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure Pw kN/m ²	Passive Pp kN/m ²
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²		
1	0.00-0.04	1.46 1.59	—	1.46 1.59	0.00 0.39	—
2	0.04-1.04	1.72 5.08	—	1.72 5.08	0.39 10.19	—
3	1.04-1.85	5.26 8.08	—	5.26 8.08	10.19 18.13	—
4	1.85-2.04	8.08 8.74	—	8.08 8.74	18.13 18.13	—
5	2.04-3.04	7.90 11.05	—	7.90 11.05	18.13 18.13	—
6	3.04-3.95	12.75 16.05	—	12.75 16.05	18.13 18.13	—
7	3.95-4.04	16.05 16.38	—	16.05 16.38	18.13 18.13	0.00 1.66
8	4.04-5.04	15.44 18.86	—	15.44 18.86	18.13 18.13	1.78 21.39
9	5.04-6.04	20.44 24.14	—	20.44 24.14	18.13 18.13	19.54 37.48
10	6.04-6.66	19.30 21.14	—	19.30 21.14	18.13 18.13	49.63 64.35

15	10.04-11.04	Clay	8.2	—	180.0 180.0	82.63 90.83	98.39 108.19	0.200 0.200	11.31 11.31	—	—	44.30 44.23
16	11.04-12.04	Clay	8.2	—	180.0 180.0	90.83 99.03	108.19 117.99	0.200 0.200	11.31 11.31	—	—	44.23 44.16
17	12.04-13.04	Clay	8.2	—	250.0 250.0	99.03 107.23	117.99 127.79	0.200 0.200	11.31 11.31	—	—	44.40 44.33
18	13.04-14.04	Clay	8.2	—	180.0 180.0	107.23 115.43	127.79 137.59	0.200 0.200	11.31 11.31	—	—	44.09 44.02
19	14.04-15.04	Clay	8.2	—	250.0 250.0	115.43 123.63	137.59 147.39	0.200 0.200	11.31 11.31	—	—	44.25 44.25
20	15.04-16.04	Clay	8.2	—	250.0 250.0	123.63 131.83	147.39 157.19	0.200 0.200	11.31 11.31	—	—	44.25 44.20
21	16.04-17.04	Clay	8.2	—	180.0 180.0	131.83 140.03	157.19 166.99	0.200 0.200	11.31 11.31	—	—	43.88 43.81
22	17.04-18.56	Clay	8.2	—	100.0 100.0	140.03 152.49	166.99 181.89	0.200 0.200	11.31 11.31	—	—	42.78 42.57
23	18.56-19.13	Clay	6.7	—	200.0 200.0	152.49 156.31	181.89 187.47	0.200 0.200	11.31 11.31	—	—	43.84 43.81
24	19.13-23.80	Clay	7.2	—	1000.0 1000.0	156.31 201.94	187.47 331.24	0.200 0.200	11.31 11.31	—	—	44.77 44.61

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(\beta - \theta)}} \right]^2}$$

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/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Qp$ kN/m ²	γ whw kN/m ²	k (k')	θ degree	Kp	$K_p \times \cos \delta$
7	3.95-4.04	Sand	7.7	27.8	—	0.000 0.693	0.00 0.88	0.200 0.200	11.31 11.31	2.38966 2.38966	2.38966 2.38966
8	4.04-5.04	Sand	7.7	29.5	—	0.693 8.393	0.88 10.68	0.200 0.200	11.31 11.31	2.57239 2.57239	2.57239 2.57239
9	5.04-6.04	Sand	7.7	27.2	—	8.393 16.093	10.68 20.48	0.200 0.200	11.31 11.31	2.32688 2.32688	2.32688 2.32688
10	6.04-6.66	Sand	7.7	33.6	—	16.093 20.867	20.48 26.56	0.200 0.200	11.31 11.31	3.08376 3.08376	3.08376 3.08376
11	6.66-7.04	Clay	8.2	0.0	180.0 180.0	20.867 23.983	26.56 30.28	0.200 0.200	11.31 11.31	—	—
12	7.04-8.04	Clay	8.2	0.0	180.0 180.0	23.983 32.183	30.28 40.08	0.200 0.200	11.31 11.31	—	—
13	8.04-9.04	Clay	8.2	0.0	180.0 180.0	32.183 40.383	40.08 49.88	0.200 0.200	11.31 11.31	—	—
14	9.04-10.04	Clay	8.2	0.0	180.0 180.0	40.383 48.583	49.88 59.68	0.200 0.200	11.31 11.31	—	—
15	10.04-11.04	Clay	8.2	0.0	180.0 180.0	48.583 56.783	59.68 69.48	0.200 0.200	11.31 11.31	—	—

11	6.66-7.04	-293.97 -290.21	27.46 29.02	27.46 29.02	18.13 18.13	380.87 383.98
12	7.04-8.04	-290.21 -280.33	29.02 33.12	29.02 33.12	18.13 18.13	383.98 392.18
13	8.04-9.04	-280.33 -270.44	33.12 37.22	33.12 37.22	18.13 18.13	392.18 400.38
14	9.04-10.04	-270.44 -260.54	37.22 41.32	37.22 41.32	18.13 18.13	400.38 408.58
15	10.04-11.04	-260.54 -250.64	41.32 45.42	41.32 45.42	18.13 18.13	408.58 416.78
16	11.04-12.04	-250.64 -240.73	45.42 49.52	45.42 49.52	18.13 18.13	416.78 424.98
17	12.04-13.04	-240.73 -230.85	49.52 53.62	49.52 53.62	18.13 18.13	424.98 433.18
18	13.04-14.04	-230.85 -220.89	53.62 57.72	53.62 57.72	18.13 18.13	433.18 441.38
19	14.04-15.04	-220.89 -210.96	57.72 61.82	57.72 61.82	18.13 18.13	441.38 449.58
20	15.04-16.04	-210.96 -201.03	61.82 65.92	61.82 65.92	18.13 18.13	449.58 457.78
21	16.04-17.04	-201.03 -191.09	65.92 70.02	65.92 70.02	18.13 18.13	457.78 465.98
22	17.04-18.56	-191.09 -181.16	70.02 76.25	70.02 76.25	18.13 18.13	465.98 474.18
23	18.56-19.13	-181.16 -171.24	76.25 78.16	76.25 78.16	18.13 18.13	474.18 482.38
24	19.13-23.80	-171.24 -168.15	78.16 130.97	78.16 130.97	18.13 18.13	482.38 2122.27

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(\beta - \theta)} \right] \cdot \cos \delta$$
$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(\beta - \theta)} \right] \cdot \cos \delta$$
$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$
$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.89	0.65	12.6	10.0	7.30
2	5.54	1.00	10.0	23.0	16.50
3	6.54	0.96	23.0	25.9	23.43
L= Σh=2.61			ΣA= 47.23		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{47.23}{2.61} \\ &= 18.13 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 18.13 = 50760 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 50760 = 169201 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 169201(10.00/0.3)^{-3/4} = 12197 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 12197 kN/m³.

5.3 Seismic Condition

Assuming Kh = 31946 kN/m³,

$$\begin{aligned} \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.488 \text{ m}^{-1} \\ L &= \frac{1}{\beta} = 2.05 \text{ m} \end{aligned}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.04 m) and 2.05 m depth (GL -8.09 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.04	0.50	16.5	23.0	9.88
2	6.54	1.00	23.0	26.0	24.50
3	7.54	0.55	26.0	26.0	14.25
L= Σh=2.05			ΣA= 48.62		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{48.62}{2.05} \\ &= 23.74 \end{aligned}$$

$$M_t = P_t \cdot (H + L_k - H_0) + M_m = 0.00 \text{ kN} \cdot \text{m}$$

h₀ Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} \\ &= \frac{203.84}{96.71} = 2.11 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 96.71}{4.89} = 39.53 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.04	0.04	1.46 1.98	0.03 0.04	6.03 6.01	0.18 0.24
2	0.04- 1.04	1.00	2.11 15.27	1.06 7.64	5.67 5.33	5.99 40.73
3	1.04- 1.85	0.81	15.46 26.21	6.26 10.62	4.73 4.46	20.61 47.55
4	1.85- 2.04	0.19	26.21 26.87	2.49 2.55	4.13 4.06	10.28 10.37
5	2.04- 3.04	1.00	26.03 29.18	13.02 14.59	3.67 3.33	47.73 48.63
6	3.04- 3.95	0.91	30.88 34.18	14.05 15.55	2.70 2.39	37.89 37.22
7	3.95- 4.04	0.09	34.18 32.85	1.54 1.48	2.06 2.03	3.17 3.00
8	4.04- 5.04	1.00	31.78 15.40	15.89 7.70	1.67 1.33	26.49 10.26
9	5.04- 6.04	1.00	19.02 4.80	9.51 2.40	0.67 0.33	6.34 0.80
ΣP= 126.41			ΣM= 366.27			

P_t : 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 = 3.95 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 · (H + L_k - H_t) + M_m = 0.00 kN·m

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 23.74 = 66476 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 66476 = 443174 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 443174(10.00/0.3)^{-3/4} = 31946 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 31946 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.04	0.04	0.08 0.55	0.00 0.01	4.88 4.87	0.01 0.05
2	0.04- 1.04	1.00	0.57 12.61	0.28 6.31	4.52 4.19	1.29 26.40
3	1.04- 2.04	1.00	12.71 24.83	6.35 12.42	3.52 3.19	22.36 39.57
4	2.04- 2.32	0.28	24.32 27.65	3.41 3.87	2.76 2.67	9.40 10.32
5	2.32- 3.04	0.72	27.65 29.15	9.95 10.49	2.35 2.09	23.23 31.97
6	3.04- 3.95	0.91	30.24 32.45	13.76 14.77	1.55 1.25	21.32 18.41
7	3.95- 4.04	0.09	32.45 29.70	1.46 1.34	0.91 0.88	1.33 1.18
8	4.04- 4.89	0.85	28.81 0.00	12.29 0.00	0.57 0.28	6.99 0.00
ΣP= 96.71			ΣM= 203.84			

P_t : 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 = 0.0 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 = 3.95 m
Depth of Imaginary riverbed from riverbed L_k = 0.94 m

Moment M_t by arbitrary load is as below

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	1.85- 2.85	1.00	0.0 2.5	0.00 1.24	3.86 3.52	0.00 4.38
2	2.85- 3.85	1.00	2.5 3.5	1.24 1.76	2.86 2.52	3.55 4.43
3	3.85- 3.95	0.10	3.5 3.6	0.18 0.18	2.16 2.12	0.38 0.38
Σ P ₀ = 4.60			Σ M ₀ = 13.12			

h₀ Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{0s}}{\Sigma P + P_t + \Sigma P_{0s}} \\ &= \frac{379.39}{131.00} = 2.90 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 131.00}{6.04} = 43.38 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name 10 H₄₀₀-200-9-12-13
Unit width B = 1.0000 m
Corrosion margin t_i = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.80
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 87800 cm⁴ (original condition)
I = 70240 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 70240 × 10⁻⁸ = 1.405 × 10⁹

$$\begin{aligned} \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} \\ \phi_a &= \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0}) \\ M_{\max} &= M_0 \cdot \phi_a \end{aligned}$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_0	=	12197 kN/m ³
calculated value	β	=	0.38383 m ⁻¹
resultant earth force (lateral)	P_0	=	96.71 kN/m
height of acting position of load	h_0	=	2.11 m
moment	M_0	=	203.84 kN·m/m
in consideration of $\psi_{in} = 1.203$,			
maximum moment	M_{max}	=	245.12 kN·m/m
depth of generated position of M_{max}	l_m	=	0.951 m
depth of 1 st fixed point	l_i	=	2.997 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_0	=	31946 kN/m ³
calculated value	β	=	0.48830 m ⁻¹
resultant earth force (lateral)	P_0	=	131.00 kN/m
height of acting position of load	h_0	=	2.90 m
moment	M_0	=	379.39 kN·m/m
in consideration of $\psi_{in} = 1.084$,			
maximum moment	M_{max}	=	411.09 kN·m/m
depth of generated position of M_{max}	l_m	=	0.523 m
depth of 1 st fixed point	l_i	=	2.132 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name	10 H ₂ H 400 -200 -9 -12 -13
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 0.82$
Section efficiency	$\mu = 1.00$
Module of section	$Z_0 = 2320$ cm ³ (original condition)
	$Z = 1879$ cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{245.12 \times 10^6}{1902 \times 10^3} = 129 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

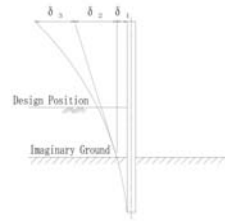
6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{411.09 \times 10^6}{1902 \times 10^3} = 216 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

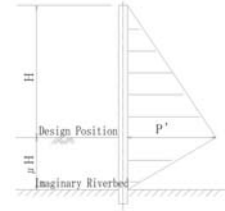
6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3838 \times 2.11) \times 96.71}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3838^3} = 0.01101 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_0) \\ &= \frac{(1 + 2 \times 0.3838 \times 2.11) \times 96.71}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3838^2} \times (3.95 + 0.94) = 0.02993 \text{ m} \end{aligned}$$



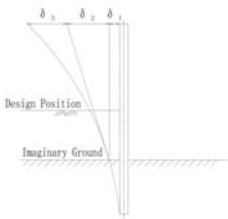
$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{0.94}{3.95} = 0.239 \\ \delta_3 &= \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4) \\ &= \frac{39.53 \times 3.95^4}{120 \times 2.00 \times 10^8 \times 70240 \times 10^{-8}} (4 + 20 \times 0.239 + 40 \times 0.239^2 + 35 \times 0.239^3 + 11 \times 0.239^4) \\ &= 0.00660 \text{ m} \\ \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01101 + 0.02993 + 0.00660 \\ &= 0.04755 \text{ m} \\ \text{Size} &= 47.55 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

Where,

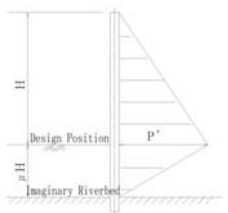
- δ_1 : Displacement at imaginary ground
- δ_2 : Displacement by angle of inclination slope at imaginary ground
- δ_3 : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

6.4.2 Seismic Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.4883 \times 2.90) \times 131.00}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4883^3} = 0.00967 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_0) \\ &= \frac{(1 + 2 \times 0.4883 \times 2.90) \times 131.00}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4883^2} \times (3.95 + 2.09) = 0.04522 \text{ m} \end{aligned}$$



7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H ₂ H 400 -200 -9 -12 -13
Unit width	$B = 1.0000$ m
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Young's modulus	$E = 200000$ N/mm ²
Inertia sectional moment	$I_0 = 87800$ cm ⁴ (original condition)
	$I = 87800$ cm ⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 87800 \times 10^{-8}$	$= 1.756 \times 10^5$

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:

$$\begin{aligned} D &= L_k + \frac{3}{\beta} \\ L &= H - H_{ik} + D \\ \beta &= \sqrt[4]{\frac{K_0 \times B}{4 E I}} \end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	$K_0 = 12197$ kN/m ³
Calculated value	$\beta = 0.36301$ m ⁻¹
Penetration length of SSP	$D = 0.94 + \frac{3}{0.363} = 9.21$ m
Whole length of SSP	$L = 3.95 - 0.40 + 9.21 = 12.76$ m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction K_{β} = 31946 kN/m³
Calculated value β = 0.46180 m⁻¹

Penetration length of SSP $D = 2.09 + \frac{3}{0.462} = 8.59$ m
Whole length of SSP $L = 3.95 - 0.40 + 8.59 = 12.14$ m

Therefore, the total length of the sheet pile is 13.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H _H 400 -200 -9 -12 -13				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	87800		
Sectional Modulus	Z (cm ³)	2320		
Maximum bending moment	Mmax (kN · m · m)		245.12	411.09
Stress intensity	σ (N/mm ²)		129 (180)	216 (270)
Lateral displacement	δ (mm)		47.51 (50.0)	74.82 (75.0)
Penetration depths	D (m)		9.21	8.59
Whole length of SSP	L (m)	13.00		

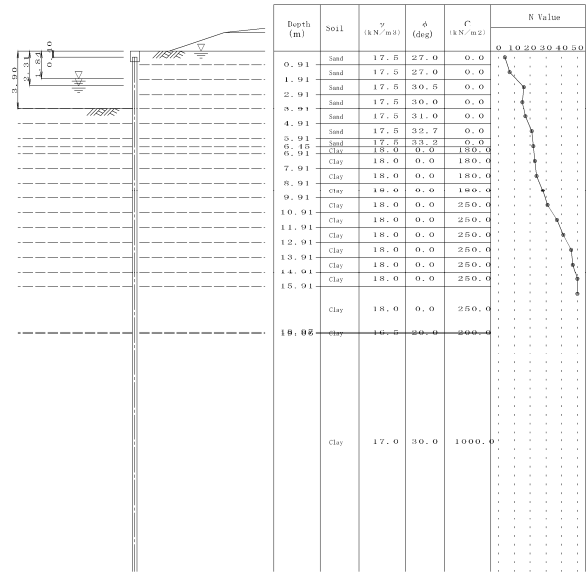
Block No. : R-34
Sta. : 12+240~12+520

Design Cross Section : Sta 12+300
Boring Name : BMRL-36

Specification : SSP SP-10H
(Combined) : H 400-200-9-12-13

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



No	Depth m	N Value	No	Depth m	N Value
1	0.41	4	11	10.41	31
2	1.41	7	12	11.41	37
3	2.41	16	13	12.41	41
4	3.41	15	14	13.41	46
5	4.41	17	15	14.41	47
6	5.41	21	16	15.41	50
7	6.41	22	17	16.41	50
8	7.41	23			
9	8.41	24			
10	9.41	28			

1.7 Soil Modulus

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	0.91	0.91
2	1	1
3	2.91	1.00
4	3.91	1.00
5	4.91	1.00
6	5.91	1.00
7	6.45	0.54
8	6.91	0.46
9	7.91	1.00
10	8.91	1.00
11	9.91	1.00
12	10.91	1.00
13	11.91	1.00
14	12.91	1.00
15	13.91	1.00
16	14.91	1.00
17	15.91	1.00
18	18.97	3.06
19	19.06	0.09
20	33.80	14.74

No	Depth, m	earth ball	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	C (degree)	
										Normal Condition	Seismic Condition
1	0.91	8	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	1.91	8	7.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	2.91	8	16.0	17.50	7.70	30.5	0.0	0.0	0.200	Auto	Auto
4	3.91	8	15.0	17.50	7.70	30.0	0.0	0.0	0.200	Auto	Auto
5	4.91	8	17.0	17.50	7.70	31.0	0.0	0.0	0.200	Auto	Auto
6	5.91	8	21.0	17.50	7.70	32.7	0.0	0.0	0.200	Auto	Auto
7	6.45	8	22.0	17.50	7.70	33.2	0.0	0.0	0.200	Auto	Auto
8	6.91	8	22.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
9	7.91	8	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
10	8.91	8	24.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto

No	Depth m	North S	N Value	γ kNm ³	γ' kNm ³	ϕ degree	C kNm ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
11	9.91	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	10.91	C	31.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
13	11.91	C	37.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
14	12.91	C	41.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
15	13.91	C	46.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
16	14.91	C	47.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	15.91	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
18	18.97	C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
19	19.06	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
20	33.80	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

Figure 1 shows a schematic diagram of a rectangular structure. The top edge is divided into four segments with dimensions 2.15, 3.79, 35.70, and 0.38. The left edge has a dimension of 2.50. A cross-section is shown on the right, consisting of three horizontal layers with dimensions 0.01, 1.01, and 0.04, and a total height of 1.06. A small rectangular feature is shown on the top surface.

No	Soil	X Coordinate				Thickness h	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	2.15	5.92	42.00	42.00	1.25	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	5.92	41.62	42.00	42.00	3.54	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	31.39	34.41	10.0	5.0

Angle of rapture in embankment calculated in consideration of embankment conditions

Material name	10 H H 400 -200 -9-12 -13	
Young's modulus	$E = 200000 \text{ N/mm}^2$	
Inertia sectional moment	$I_0 = 87800 \text{ cm}^4$	
Sectional factor	$Z_0 = 2320 \text{ cm}^3$	
Corrosion margin	$t_1 = 1.00 \text{ mm (riverside)}$	$t_2 = 1.00 \text{ mm (landside)}$
Corrosion rate (to I_0)	$\eta = 0.80$	
Corrosion rate (to Z_0)	$\eta = 0.81$	
Section efficiency (to I_0)	$\mu = 1.00$	
Section efficiency (to Z_0)	$\mu = 1.00$	

Round unit of SSP length 0.50 m

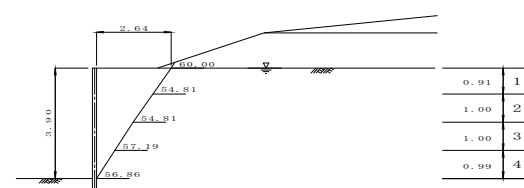
Allowable stress	σ_a	=	180 N/mm (Normal)
	σ_a'	=	270 N/mm (Seismic)

Allowable displacement	δ_a	=	50.0 mm (Normal)
	δ_a^s	=	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

2.1 Normal Condition



No	Depth, m	Soil	ϕ degree	ψ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ when kN/m ³	Angle of Repose ϕ degree
1	3.90 - 2.91	Sand	30.0	15.0	0.0	30.03	0.35	38.22	36.86
2	2.91 - 1.91	Sand	30.5	15.0	0.0	22.41	0.35	28.52	57.19
3	1.91 - 0.91	Sand	27.0	15.0	0.0	14.71	0.35	18.72	54.81
4	0.91 - 0.00	Sand	27.0	15.0	0.0	7.03	0.35	8.92	54.81
5		embankment	30.0	—	0.0	91.00	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 $\theta = 0^\circ$

Where,

ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)

ϕ : internal friction angle (deg)

 δ : wall friction angle (degree)

θ : earthquake combination angle (degree)

$$\theta = \tan^{-1}k \text{ or } \theta = \tan^{-1}k'$$

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)

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	56.86	0.99	0.00	0.00	0.65	0.99
2	57.19	1.00	0.65	0.99	1.29	1.99
3	54.81	1.00	1.29	1.99	2.00	2.99
4	54.81	0.91	2.00	2.99	2.64	3.90
5	60.00	0.20	2.64	3.90	2.75	4.10

From the above table, the loading width (L) on the ground surface is 2.64 m.

No	γ kN/m ³	Λ m ²	$\gamma \times \Lambda$ kN/m
1	19.0	0.05	0.93
Σ			0.93

 γ : unit weight of embankment soil

A: sectional area of embankment enclosed by line of active rupture

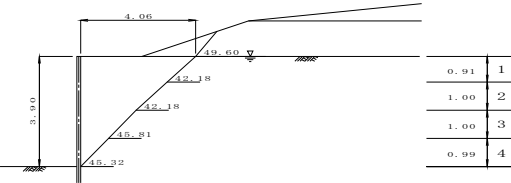
2.1.4 Calculated Load

Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (0.93 + 0.00 + 0.00) / 2.64

= 0.35 kN/m²

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth, m	Soil	φ degree	δ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ whw kN/m2	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	3.90~2.91	Sand	30.0	15.0	0.0	30.03	3.94	38.22	0.200	11.31	45.32
2	2.91~1.91	Sand	30.5	15.0	0.0	22.41	3.94	28.52	0.200	11.31	45.81
3	1.91~0.91	Sand	27.0	15.0	0.0	14.71	3.94	18.72	0.200	11.31	42.18
4	0.91~0.00	Sand	27.0	15.0	0.0	7.01	3.94	8.92	0.200	11.31	42.18
5	embankment	embankment	30.0	—	0.0	91.01	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

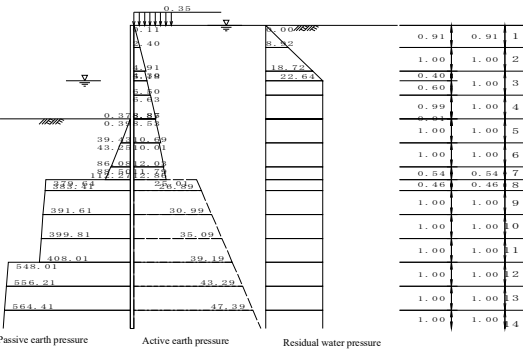
ζ = 90° - tan⁻¹ [sin(φ + δ) / cos(φ + δ)]

• Major collapse angle of cohesive soil

ζ = tan⁻¹ [1 - Σ γ h + 2Q / 2C] • tan θ

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

Depth, m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Q _p kN/m2	K _a	K _a × cos δ
1	0.00~0.91	Sand	7.7	27.0	0.352 7.359	0.33738 0.33738	0.32589 0.32589
2	0.91~1.91	Sand	7.7	27.0	7.320 15.059	0.33738 0.33738	0.32589 0.32589
3	1.91~2.31	Sand	7.7	30.5	15.059 18.139	0.29571 0.29571	0.28563 0.28563
4	2.31~2.91	Sand	7.7	30.5	18.139 22.759	0.29571 0.29571	0.28563 0.28563
5	2.91~3.90	Sand	7.7	30.0	22.759 30.382	0.30142 0.30142	0.29115 0.29115
6	3.90~3.91	Sand	7.7	30.0	30.382 30.459	0.30142 0.30142	0.29115 0.29115
7	3.91~4.91	Sand	7.7	31.0	30.459 38.159	0.29008 0.29008	0.28020 0.28020
8	4.91~5.91	Sand	7.7	32.7	38.159 45.859	0.27152 0.27152	0.26227 0.26227
9	5.91~6.45	Sand	7.7	33.2	45.859 50.017	0.26623 0.26623	0.25716 0.25716
10	6.45~6.91	Clay	8.2	—	180.0 53.789	—	—
11	6.91~7.91	Clay	8.2	—	180.0 61.989	—	—
12	7.91~8.91	Clay	8.2	—	180.0 70.189	—	—

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⁻¹ k or θ = 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	45.32	0.99	0.00	0.00	0.98	0.99
2	45.81	1.00	0.98	0.99	1.95	1.99
3	42.18	1.00	1.95	1.99	3.05	2.99
4	42.18	0.91	3.05	2.99	4.06	3.90
5	49.60	0.88	4.06	3.90	4.81	4.78

From the above table, the loading width (L) on the ground surface is 4.06 m.

2.2.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.84	15.99
Σ			15.99

γ : unit weight of embankment soil

A : sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (15.99 + 0.00 + 0.00) / 4.06

= 3.94 kN/m²

13	8.91~9.91	Clay	8.2	—	180.0 180.0	70.189 78.389		
14	9.91~10.91	Clay	8.2	—	250.0 250.0	78.389 86.589		
15	10.91~11.91	Clay	8.2	—	250.0 250.0	86.589 94.789		
16	11.91~12.91	Clay	8.2	—	250.0 250.0	94.789 102.989		
17	12.91~13.91	Clay	8.2	—	250.0 250.0	102.989 111.188		
18	13.91~14.91	Clay	8.2	—	250.0 250.0	111.188 119.388		
19	14.91~15.91	Clay	8.2	—	250.0 250.0	119.388 127.588		
20	15.91~16.91	Clay	8.2	—	250.0 250.0	127.588 135.788		
21	16.91~17.91	Clay	6.7	—	200.0 200.0	152.680 153.283		
22	19.06~19.80	Clay	7.2	—	1000.0 1000.0	153.283 259.411		

17	12.91~ 13.91	Clay	8.2	0.0	250.0 250.0	72.607 80.807	=====	=====
18	13.91~ 14.91	Clay	8.2	0.0	250.0 250.0	80.807 89.007	=====	=====
19	14.91~ 15.91	Clay	8.2	0.0	250.0 250.0	89.007 97.207	=====	=====
20	15.91~ 18.97	Clay	8.2	0.0	250.0 250.0	97.207 122.299	=====	=====
21	18.97~ 19.06	Clay	6.7	20.0	200.0 200.0	122.299 122.902	=====	=====
22	19.06~ 33.80	Clay	7.2	30.0	1000.0 1000.0	122.902 229.030	=====	=====

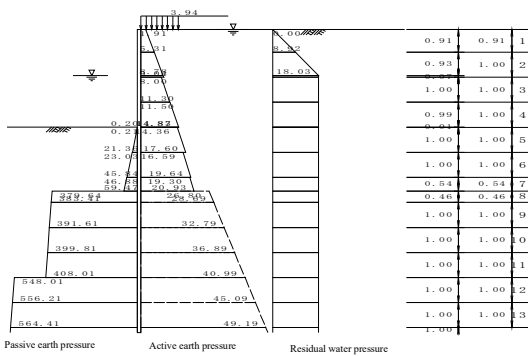
Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2		Pp kN/m2	
1	0.00~ 0.91	0.11 2.40	=====	0.11 2.40	0.00 8.92		=====	
2	0.91~ 1.91	2.40 4.91	=====	2.40 4.91	8.92 18.72		=====	
3	1.91~ 2.31	=====	=====	4.30 5.18	18.72 22.64		=====	
4	2.31~ 2.91	=====	=====	5.18 6.50	22.64 22.64		=====	
5	2.91~ 3.90	6.63 8.85	=====	6.63 8.85	22.64 22.64		=====	
6	3.90~ 3.91	8.85 8.87	=====	8.85 8.87	22.64 22.64	0.00 0.37	=====	
7	3.91~ 4.91	8.83 10.69	=====	8.83 10.69	22.64 22.64	0.39 39.43	=====	
8	4.91~ 5.91	10.01 12.03	=====	10.01 12.03	22.64 22.64	43.25 86.08	=====	
9	5.91~ 6.45	11.79 12.86	=====	11.79 12.86	22.64 22.64	88.50 112.27	=====	
10	6.45~ 6.91	-309.98 -306.21	25.01 26.89	25.01 26.89	22.64 22.64	379.64 383.41	=====	
11	6.91~ 7.91	-306.21 -298.01	26.89 30.99	26.89 30.99	22.64 22.64	383.41 391.61	=====	
12	7.91~ 8.91	-298.01 -289.81	30.99 35.09	30.99 35.09	22.64 22.64	391.61 399.81	=====	
13	8.91~ 9.91	-289.81 -281.61	35.09 39.19	35.09 39.19	22.64 22.64	399.81 408.01	=====	
14	9.91~ 10.91	-421.61 -413.41	39.19 43.29	39.19 43.29	22.64 22.64	548.01 556.21	=====	

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γ_{whw} kN/m2	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00~ 0.91	Sand	7.7	27.0	=====	3.94 10.95	0.00 8.92	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	=====
2	0.91~ 1.84	Sand	7.7	27.0	=====	10.95 18.11	8.92 18.03	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	=====
3	1.84~ 1.91	Sand	7.7	27.0	=====	18.11 18.65	18.03 18.72	0.200 0.200	11.31	0.50201 0.50201	0.48490 0.48490	=====
4	1.91~ 2.91	Sand	7.7	30.5	=====	18.65 26.35	18.72 28.52	0.200 0.200	11.31	0.44421 0.44421	0.42907 0.42907	=====
5	2.91~ 3.90	Sand	7.7	30.0	=====	26.35 33.97	28.52 38.22	0.200 0.200	11.31	0.45203 0.45203	0.43663 0.43663	=====
6	3.90~ 3.91	Sand	7.7	30.0	=====	33.97 34.05	38.22 38.32	0.200 0.200	11.31	0.45203 0.45203	0.43663 0.43663	=====
7	3.91~ 4.91	Sand	7.7	31.0	=====	34.05 41.75	38.32 48.12	0.200 0.200	11.31	0.43652 0.43652	0.42164 0.42164	=====
8	4.91~ 5.91	Sand	7.7	32.7	=====	41.75 49.45	48.12 57.92	0.200 0.200	11.31	0.41130 0.41130	0.39729 0.39729	=====
9	5.91~ 6.45	Sand	7.7	33.2	=====	49.45 53.61	57.92 62.21	0.200 0.200	11.31	0.40414 0.40414	0.39037 0.39037	=====
10	6.45~ 6.91	Clay	8.2	=====	180.0 180.0	53.61 57.38	62.21 67.72	0.200 0.200	11.31	=====	=====	44.53 44.50
11	6.91~ 7.91	Clay	8.2	=====	180.0 180.0	57.38 65.58	67.72 77.52	0.200 0.200	11.31	=====	=====	44.50 44.44
12	7.91~ 8.91	Clay	8.2	=====	180.0 180.0	65.58 73.78	77.52 87.32	0.200 0.200	11.31	=====	=====	44.44 44.37
13	8.91~ 9.91	Clay	8.2	=====	180.0 180.0	73.78 81.98	87.32 97.12	0.200 0.200	11.31	=====	=====	44.37 44.30

15	10.91~ 11.91				-413.41 -405.21	43.29 47.39	43.29 47.39	22.64 22.64	556.21 564.41
16	11.91~ 12.91				-405.21 -397.01	47.39 51.49	47.39 51.49	22.64 22.64	564.41 572.61
17	12.91~ 13.91				-397.01 -388.81	51.49 55.59	51.49 55.59	22.64 22.64	572.61 580.81
18	13.91~ 14.91				-388.81 -380.61	55.59 59.69	55.59 59.69	22.64 22.64	580.81 589.01
19	14.91~ 15.91				-380.61 -372.41	59.69 63.79	59.69 63.79	22.64 22.64	589.01 597.21
20	15.91~ 18.97				-372.41 -347.32	63.79 76.34	63.79 76.34	22.64 22.64	597.21 622.30
21	18.97~ 19.06				-247.32 -246.72	76.34 76.64	76.34 76.64	22.64 22.64	622.30 622.90
22	19.06~ 33.80				-1846.72 -1740.59	76.64 129.71	76.64 129.71	22.64 22.64	622.90 2122.90

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

14	9.91~ 10.91	Clay	8.2	=====	250.0 250.0	81.98 90.18	97.12 106.92	0.200 0.200	11.31 11.31	=====	=====	44.50 44.45
15	10.91~ 11.91	Clay	8.2	=====	250.0 250.0	90.18 98.38	106.92 116.72	0.200 0.200	11.31 11.31	=====	=====	44.45 44.40
16	11.91~ 12.91	Clay	8.2	=====	250.0 250.0	98.38 106.58	116.72 126.52	0.200 0.200	11.31 11.31	=====	=====	44.40 44.35
17	12.91~ 13.91	Clay	8.2	=====	250.0 250.0	106.58 114.78	126.52 136.32	0.200 0.200	11.31 11.31	=====	=====	44.35 44.30
18	13.91~ 14.91	Clay	8.2	=====	250.0 250.0	114.78 122.98	136.32 146.12	0.200 0.200	11.31 11.31	=====	=====	44.30 44.25
19	14.91~ 15.91	Clay	8.2	=====	250.0 250.0	122.98 131.18	146.12 155.92	0.200 0.200	11.31 11.31	=====	=====	44.25 44.20
20	15.91~ 18.97	Clay	8.2	=====	250.0 250.0	131.18 156.27	155.92 185.91	0.200 0.200	11.31 11.31	=====	=====	44.20 44.05
21	18.97~ 19.06	Clay	6.7	=====	200.0 200.0	156.27 156.87	185.91 186.79	0.200 0.200	11.31 11.31	=====	=====	43.80 43.80
22	19.06~ 33.80	Clay	7.2	=====	1000.0 1000.0	156.87 263.00	186.79 331.24	0.200 0.200	11.31 11.31	=====	=====	44.77 44.61

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

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

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q_p$ kN/m2	γ_{whw} kN/m2	k (k')	θ degree	Kp	$K_p \times \cos \delta$
6	3.90~ 3.91	Sand	7.7	30.0	=====	0.000 0.077	0.00 0.10	0.200 0.200	11.31	2.62913 2.62913	2.62913 2.62913
7	3.91~ 4.91	Sand	7.7	31.0	=====	0.077 0.777	0.10 0.90	0.200 0.200	11.31	2.74701 2.74701	2.74701 2.74701
8	4.91~ 5.91	Sand	7.7	32.7	=====	0.777 15.477	0.90 19.70	0.200 0.200	11.31	2.96192 2.96192	2.96192 2.96192
9	5.91~ 6.45	Sand	7.7	33.2	=====	15.477 19.635	19.70 24.99	0.200 0.200	11.31	3.02888 3.02888	3.02888 3.02888
10	6.45~ 6.91	Clay	8.2	0.0	180.0 180.0	19.635 23.407	24.99 29.50	0.200 0.200	11.31	=====	=====
11	6.91~ 7.91	Clay	8.2	0.0	180.0 180.0	23.407 31.607	29.50 39.30	0.200 0.200	11.31	=====	=====
12	7.91~ 8.91	Clay	8.2	0.0	180.0 180.0	31.607 39.807	39.30 49.10	0.200 0.200	11.31	=====	=====
13	8.91~ 9.91	Clay	8.2	0.0	180.0 180.0	39.807 48.007	49.10 58.50	0.200 0.200	11.31	=====	=====
14	9.91~ 10.91	Clay	8.2	0.0	250.0 250.0	48.007 56.207	58.50 68.70	0.200 0.200	11.31	=====	=====
15	10.91~ 11.91	Clay	8.2	0.0	250.0 250.0	56.207 64.407	68.70 78.50	0.200 0.200	11.31	=====	=====

16	11.91~ 12.91	Clay	8.20	0.0	250.0 250.0	64.007 72.007	78.50 88.30	0.200 0.200	11.31 11.31	=====	=====
17	12.91~ 13.91	Clay	8.20	0.0	250.0 250.0	72.007 80.807	88.30 98.10	0.200 0.200	11.31 11.31	=====	=====
18	13.91~ 14.91	Clay	8.20	0.0	250.0 250.0	80.807 89.007	98.10 107.90	0.200 0.200	11.31 11.31	=====	=====
19	14.91~ 15.91	Clay	8.20	0.0	250.0 250.0	89.007 97.207	107.90 117.70	0.200 0.200	11.31 11.31	=====	=====
20	15.91~ 18.97	Clay	8.20	0.0	250.0 250.0	97.207 122.299	117.70 147.69	0.200 0.200	11.31 11.31	=====	=====
21	18.97~ 19.06	Clay	6.70	20.0	200.0 200.0	122.299 122.902	147.69 148.57	0.200 0.200	11.31 11.31	=====	=====
22	19.06~ 33.80	Clay	7.20	30.0	1000.0 1000.0	122.902 229.030	148.57 293.02	0.200 0.200	11.31 11.31	=====	=====

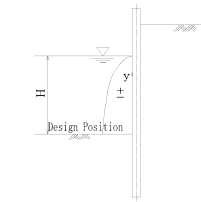
• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2		Pp kN/m2	
1	0.00~ 0.91	1.91 5.31	=====	1.91 5.31	0.00 8.92		=====	
2	0.91~ 1.84	5.31 8.78	=====	5.31 8.78	8.92 18.03		=====	
3	1.84~ 1.91	8.78 9.04	=====	8.78 9.04	18.03 18.03		=====	
4	1.91~ 2.91	8.00 11.30	=====	8.00 11.30	18.03 18.03		=====	
5	2.91~ 3.90	11.20 14.83	=====	11.20 14.83	18.03 18.03		=====	
6	3.90~ 3.91	14.83 14.87	=====	14.83 14.87	18.03 18.03	0.00 0.20	=====	
7	3.91~ 4.91	14.36 17.60	=====	14.36 17.60	18.03 18.03	0.21 21.36	=====	
8	4.91~ 5.91	16.59 19.64	=====	16.59 19.64	18.03 18.03	23.03 45.84	=====	
9	5.91~ 6.45	19.30 20.03	=====	19.30 20.03	18.03 18.03	46.88 59.47	=====	
10	6.45~ 6.91	-295.55 -291.00	26.80 28.69	26.80 28.69	18.03 18.03	379.64 383.41	=====	
11	6.91~ 7.91	-291.00 -281.12	28.69 32.79	28.69 32.79	18.03 18.03	383.41 391.61	=====	
12	7.91~ 8.91	-281.12 -271.23	32.79 36.89	32.79 36.89	18.03 18.03	391.61 399.81	=====	

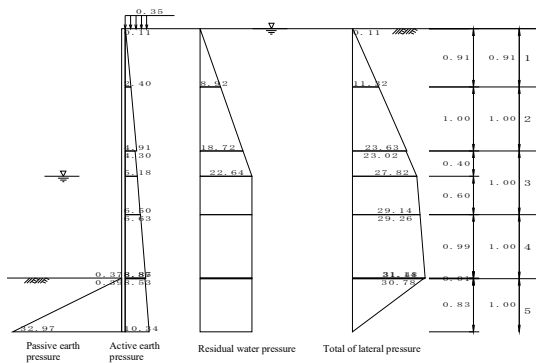
γ_w : unit weight of water
 H : water depth of riverside
 y : depth from water surface to the point where active water pressure is calculated



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



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00~ 0.91	0.11 2.40	0.00 8.92	=====	0.11 11.32
2	0.91~ 1.91	2.40 4.91	8.92 18.72	=====	11.32 23.63

13	8.91~ 9.91	-271.23 -261.33	36.89 40.99	36.89 40.99	18.03 18.03	399.81 408.01
14	9.91~ 10.91	-401.41 -391.53	40.99 45.09	40.99 45.09	18.03 18.03	548.01 556.21
15	10.91~ 11.91	-391.53 -381.64	45.09 49.19	45.09 49.19	18.03 18.03	556.21 564.41
16	11.91~ 12.91	-381.64 -371.75	49.19 53.29	49.19 53.29	18.03 18.03	564.41 572.61
17	12.91~ 13.91	-371.75 -361.85	53.29 57.39	53.29 57.39	18.03 18.03	572.61 580.81
18	13.91~ 14.91	-361.85 -351.95	57.39 61.49	57.39 61.49	18.03 18.03	580.81 589.01
19	14.91~ 15.91	-351.95 -342.04	61.49 65.59	61.49 65.59	18.03 18.03	589.01 597.21
20	15.91~ 18.97	-342.04 -311.70	65.59 78.13	65.59 78.13	18.03 18.03	597.21 622.30
21	18.97~ 19.06	-211.49 -210.76	78.13 78.44	78.13 78.44	18.03 18.03	522.30 522.90
22	19.06~ 33.80	-1811.26 -1883.47	78.44 131.50	78.44 131.50	18.03 18.03	2122.90 2229.03

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
 Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth m	water level y m	pdw kN/m2
1	1.84	0.00	0.00
2	2.84	1.00	2.46
3	3.84	2.00	3.48
4	3.90	2.06	3.53

$$p_{dw} = \pm \frac{7}{8} k_{hw} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

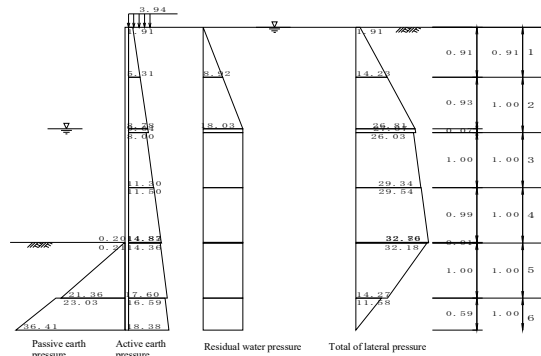
Where,
 k_{hw} : design seismic coefficient

3	1.91~ 2.31	4.30 5.18	18.72 22.64	=====	23.02 27.82
4	2.31~ 2.91	5.18 6.50	22.64 22.64	=====	27.82 29.14
5	2.91~ 3.90	6.63 8.85	22.64 22.64	=====	29.26 31.48
6	3.90~ 3.91	8.85 8.87	22.64 22.64	0.00 0.37	31.48 31.14
7	3.91~ 4.75	8.53 10.34	22.64 22.64	0.39 32.97	30.78 0.00
8	4.75~ 4.91	10.34 10.69	22.64 22.64	32.97 39.43	0.00 -6.10

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 : 0.85 m (GL -4.75 m)

4.2 Seismic Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00~ 0.91	1.91 5.31	0.00 8.92	=====	1.91 14.23
2	0.91~ 1.84	5.31 8.78	8.92 18.03	=====	14.23 26.81
3	1.84~ 1.91	8.78 9.04	18.03 18.03	=====	26.81 27.07
4	1.91~ 2.91	8.00 11.30	18.03 18.03	=====	26.03 29.34

5	2.91~ 3.90	11.50 14.83	18.03 18.03	———— ————	29.54 32.86
6	3.90~ 3.91	14.83 14.87	18.03 18.03	0.00 0.20	32.86 32.70
7	3.91~ 4.91	14.36 17.60	18.03 18.03	0.21 21.36	32.18 14.27
8	4.91~ 5.50	16.59 18.38	18.03 18.03	23.03 36.41	11.58 0.00
9	5.50~ 5.91	18.38 19.64	18.03 18.03	36.41 45.84	0.00 -8.16

P_a : Active earth pressure
 P_w : Residual water pressure
 P_p : Passive earth pressure
 P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 1.60 m (GL -5.50 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.
 Average N-value is calculated depending on the sectional area.
 The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{b0} \left(\frac{B_b}{0.3} \right)^{-3/4} \quad (B_b = 10.00\text{m})$$

$$K_{b0} = \frac{1}{0.3} \alpha E_o \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_b = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H _ H 400-200 -9 -12 -13		
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	=	0.80
Section efficiency	μ	=	1.00
Young's modulus	E	=	200000 N/mm ²
Inertia sectional moment	I ₀	=	87800 cm ⁴ (original condition)
	I	=	70240 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI	=	200000 × 10 ³ × 70240 × 10 ⁻⁸ = 1.405 × 10 ⁵

5.3 Seismic Condition

Assuming $K_h = 29776 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.480 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.08 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.50 m) and 2.08 m depth (GL -7.58 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.50	0.91	21.1	22.0	19.68
2	6.41	1.00	22.0	23.0	22.50
3	7.41	0.17	23.0	23.2	3.94
L = Σh = 2.08			ΣA =		46.12

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$

$$= \frac{46.12}{2.08}$$

$$= 22.13$$

K_h is recalculated from the calculated average N value.

$$E_o = 2800 N' = 2800 \times 22.13 = 61961 \text{ kN/m}^2$$

$$K_{b0} = \frac{1}{0.3} \times \alpha \times 61961 = 413074 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{b0} (B_u/0.3)^{-3/4} = 413074 (10.00/0.3)^{-3/4} = 29776 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
 The lateral subgrade reaction coefficient K_h (Seismic Condition) is 29776 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

No	Depth m	N Value	No	Depth m	N Value
1	0.41	4	11	10.41	31
2	1.41	7	12	11.41	37
3	2.41	16	13	12.41	41
4	3.41	15	14	13.41	46
5	4.41	17	15	14.41	47
6	5.41	21	16	15.41	50
7	6.41	22	17	16.41	50
8	7.41	23			
9	8.41	24			
10	9.41	28			

5.2 Normal Condition

Assuming $K_h = 14344 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.400 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.50 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.74 m) to 2.50 m depth (GL -7.25 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	4.74	0.67	18.3	21.0	13.09
2	5.41	1.00	21.0	22.0	21.50
3	6.41	0.84	22.0	22.8	18.75
L = Σh = 2.50			ΣA =		53.34

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$

$$= \frac{53.34}{2.50}$$

$$= 21.32$$

K_h is recalculated from the calculated average N value.

$$E_o = 2800 N' = 2800 \times 21.32 = 59696 \text{ kN/m}^2$$

$$K_{b0} = \frac{1}{0.3} \times \alpha \times 59696 = 198987 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{b0} (B_u/0.3)^{-3/4} = 198987 (10.00/0.3)^{-3/4} = 14344 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
 The lateral subgrade reaction coefficient K_h (Normal Condition) is 14344 kN/m³.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.91	0.91	0.11 11.32	0.05 5.15	4.44 4.14	0.23 21.31
2	0.91~ 1.91	1.00	11.32 23.63	5.66 11.81	3.50 3.17	19.81 37.42
3	1.91~ 2.31	0.40	23.02 27.82	4.60 5.56	2.70 2.57	12.44 14.29
4	2.31~ 2.91	0.60	27.82 29.14	8.35 8.74	2.23 2.03	18.65 17.79
5	2.91~ 3.90	0.99	29.26 31.46	14.49 15.58	1.50 1.17	21.80 18.31
6	3.90~ 3.91	0.01	31.48 31.14	0.16 0.16	0.84 0.84	0.13 0.13
7	3.91~ 4.74	0.83	30.78 0.00	12.85 0.00	0.56 0.28	7.15 0.00
ΣP =			93.16	ΣM =		189.44

P_s : active earth pressure + residual water pressure - passive earth pressure

P : load $P_s \times h/2 \times B$

B : unit width = 1.000 m

Y : height of acting position from imaginary riverbed

M : moment by load $P \times Y$

Arbitrary load lateral load	P_l	=	0.0 kN/m
depth to acting position	H_l	=	0.0 m
moment	M_{l0}	=	0.0 kN·m/m
depth to acting position	H_{l0}	=	0.00 m
Height from riverbed to top of coping	H	=	3.90 m
Depth of Imaginary riverbed from riverbed	L_k	=	0.84 m

Moment M_l by arbitrary load is as below

$$M_l = P_l \cdot (H + L_k - H_l) + M_{l0} = 0.00 \text{ kN} \cdot \text{m}$$

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_l}{\Sigma P + P_l}$$

$$= \frac{189.44}{93.16} = 2.03 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 93.16}{4.74} = 39.27 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00~ 0.91	0.91	1.91 14.23	0.87 6.47	5.19 4.89	4.51 31.65

2	0.91- 1.84	0.93	14.23 26.81	6.62 12.47	4.28 3.97	28.29 49.45
3	1.84- 1.91	0.07	26.81 27.07	0.94 0.95	3.63 3.61	3.41 3.42
4	1.91- 2.91	1.00	26.03 29.34	13.02 14.67	3.25 2.92	42.35 42.83
5	2.91- 3.90	0.99	29.54 32.86	14.62 16.27	2.26 1.93	32.99 31.34
6	3.90- 3.91	0.01	32.86 32.70	0.16 0.16	1.59 1.59	0.26 0.26
7	3.91- 4.91	1.00	32.18 14.27	16.09 7.14	1.25 0.92	20.16 6.56
8	4.91- 5.50	0.59	11.58 0.00	3.40 0.00	0.39 0.20	1.33 0.00
Σ P = 113.83 Σ M = 298.83						

P_a : active earth pressure + residual water pressure - passive earth pressure

P : load P_a 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_i = 0.0 kN/m
depth to acting position H_i = 0.00 m
moment M_{ia} = 0.0 kN·m/m
depth to acting position H_{ia} = 0.00 m
Height from riverbed to top of coping H = 3.90 m
Depth of Imaginary riverbed from riverbed L_k = 1.60 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{ia} = 0.00 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	1.84- 2.84	1.00	0.0 2.5	0.00 1.23	3.32 2.99	0.00 3.68
2	2.84- 3.84	1.00	2.5 3.5	1.23 1.74	2.32 1.99	2.86 3.46
3	3.84- 3.90	0.06	3.5 3.5	0.10 0.11	1.64 1.62	0.17 0.17
Σ P _{hw} = 4.41 Σ M _{hw} = 10.34						

h₀ Height of acting position of P_a from imaginary riverbed

$$h_0 = \frac{M_a}{P_a} = \frac{\Sigma M + M_i + \Sigma M_{aw}}{\Sigma P + P_i + \Sigma P_{av}} = \frac{309.17}{118.25} = 2.61 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_a}{(H + L_k)} = \frac{2 \times 118.25}{5.50} = 43.03 \text{ kN/m}$$

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name 10 H _ H 400 -200 -9 -12 -13
Corrosion margin t_i = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.81
Section efficiency μ = 1.00
Module of section Z₀ = 2320 cm³ (original condition)
Z = 1879 cm³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{227.54 \times 10^6}{1879 \times 10^3} = 121 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

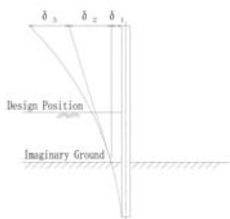
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{340.62 \times 10^6}{1879 \times 10^3} = 181 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_a}{2 E I \beta^3} \\ &= \frac{(1 + 0.3997 \times 2.03) \times 93.16}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3997^3} = 0.00941 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_a}{2 E I \beta^2} \times (H + L_k) \\ &= \frac{(1 + 2 \times 0.3997 \times 2.03) \times 93.16}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.3997^2} \times (3.90 + 0.84) = 0.02585 \text{ m} \end{aligned}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Material name 10 H _ H 400 -200 -9 -12 -13
Unit width B = 1.0000 m
Corrosion margin t_i = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
Corrosion rate η = 0.800
Section efficiency μ = 1.00
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 87800 cm⁴ (original condition)
I = 70240 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 70240 × 10⁻⁸ = 1.405 × 10⁵

$$\beta = \sqrt{\frac{K_a \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$1_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

$$1_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction K_b = 14344 kN/m³
calculated value β = 0.39971 m⁻¹
resultant earth force (lateral) P₀ = 93.16 kN/m
height of acting position of load h₀ = 2.03 m
moment M₀ = 189.44 kN·m/m

in consideration of ψ_{hm} = 1.201,

maximum moment

depth of generated position of M_{max}

depth of 1st fixed point

$$\begin{aligned} M_{\max} &= 277.54 \text{ kN} \cdot \text{m/m} \\ l_m &= 0.910 \text{ m} \\ l_i &= 2.875 \text{ m} \end{aligned}$$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction K_b = 29776 kN/m³
calculated value β = 0.47979 m⁻¹
resultant earth force (lateral) P₀ = 118.25 kN/m
height of acting position of load h₀ = 2.1 m
moment M₀ = 309.17 kN·m/m

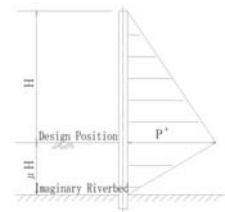
in consideration of ψ_{hm} = 1.102,

maximum moment

depth of generated position of M_{max}

depth of 1st fixed point

$$\begin{aligned} M_{\max} &= 340.62 \text{ kN} \cdot \text{m/m} \\ l_m &= 0.579 \text{ m} \\ l_i &= 2.216 \text{ m} \end{aligned}$$



$$\mu = \frac{L_k}{H} = \frac{0.84}{3.90} = 0.217$$

$$\begin{aligned} \delta_3 &= \frac{P' \cdot H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{39.27 \times 3.90^4}{120 \times 2.00 \times 10^8 \times 70240 \times 10^{-8}} (4 + 20 \times 0.217 + 40 \times 0.217^2 + 35 \times 0.217^3 + 11 \times 0.217^4) \\ &= 0.00571 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.00941 + 0.02585 + 0.00571 \\ &= 0.04097 \text{ m} \\ \text{Size} &= 40.97 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

Where,

δ₁ : Displacement at imaginary ground

δ₂ : Displacement by angle of inclination slope at imaginary ground

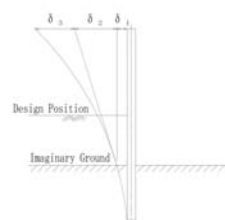
δ₃ : Displacement at higher part of imaginary ground as cantilever

δ : Displacement at top of SSP

δ_a : Allowable displacement

6.4.2 Seismic Condition

Displacement Calculation

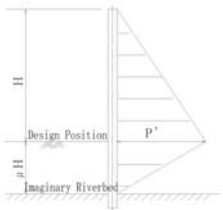


$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.4798 \times 2.61) \times 118.25}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4798^3} = 0.00859 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_0)$$

$$= \frac{(1 + 2 \times 0.4798 \times 2.61) \times 118.25}{2 \times 2.00 \times 10^8 \times 70240 \times 10^{-8} \times 0.4798^2} \times (3.90 + 1.60) = 0.03526 \text{ m}$$



$$\mu = \frac{L_0}{H} = \frac{1.60}{3.90} = 0.409$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4)$$

$$= \frac{43.03 \times 3.90^4}{120 \times 2.00 \times 10^8 \times 70240 \times 10^{-8}} (4 + 20 \times 0.409 + 40 \times 0.409^2 + 35 \times 0.409^3 + 11 \times 0.409^4)$$

$$= 0.01275 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00859 + 0.03526 + 0.01275$$

$$= 0.05661 \text{ m}$$

$$\text{Size} = 56.61 \text{ mm} \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	10 H ₂ H 400 -200 -9 -12 -13
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 = 87800 cm ⁴ (original condition)
	I = 87800 cm ⁴ (after reduction by corrosion and section)
EI	= 200000 × 10 ³ × 87800 × 10 ⁻⁸ = 1.756 × 10 ⁷

7.1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_0 , penetration depth of SSP (D) and whole length of SSP (L) are calculated as follows:

$$D = L_0 + \frac{3}{\beta}$$

$$L = H - H_{it} + D$$

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_b = 14344 kN/m ³
Calculated value	β = 0.37802 m ⁻¹

Penetration length of SSP	$D = 0.84 + \frac{3}{0.378} = 8.78 \text{ m}$
Whole length of SSP	$L = 3.90 - 0.40 + 8.78 = 12.28 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	K_b = 29776 kN/m ³
Calculated value	β = 0.45375 m ⁻¹

Penetration length of SSP	$D = 1.60 + \frac{3}{0.454} = 8.21 \text{ m}$
Whole length of SSP	$L = 3.90 - 0.40 + 8.21 = 11.71 \text{ m}$

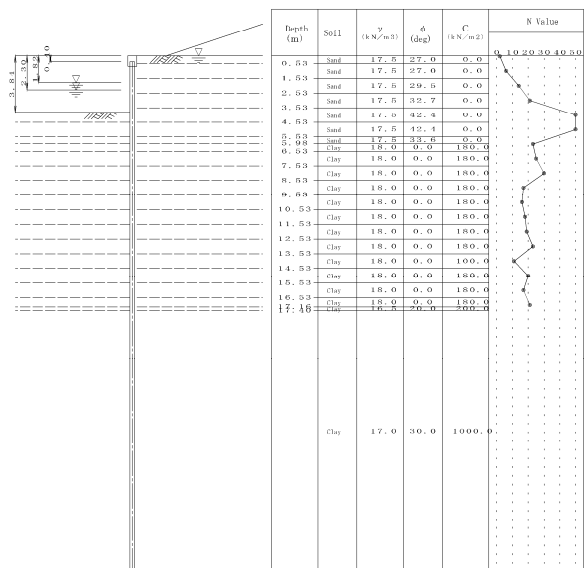
Therefore, the total length of the sheet pile is 12.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H ₂ H 400 -200 -9 -12 -13				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	87800		
Sectional Modulus	Z (cm ³)	2120		
Maximum bending moment	Mmax (kN · m · m)		227.54	340.62
Stress intensity	σ (N/mm ²)		121 (180)	181 (270)
Lateral displacement	δ (mm)		40.97 (50.0)	56.61 (75.0)
Penetration depth	D (m)		8.78	8.21
Whole length of SSP	L (m)	12.50		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered

Angle of rupture (clayey soil) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_{10} = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2)
 $B_H = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
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	0.03	2	11	10.03	16
2	1.03	6	12	11.03	18
3	2.03	14	13	12.03	19
4	3.03	21	14	13.03	23
5	4.03	50	15	14.03	11
6	5.03	50	16	15.03	20
7	6.03	23	17	16.03	17
8	7.03	25	18	17.03	21
9	8.03	30			
10	9.03	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 (Include Projection Length)	Thickness m (excluding projected length)
1	0.53	0.53
2	1.53	1.00
3	2.53	1.00
4	3.53	1.00
5	4.53	1.00
6	5.53	1.00
7	5.98	0.45
8	6.53	0.55
9	7.53	1.00
10	8.53	1.00
11	9.53	1.00
12	10.53	1.00
13	11.53	1.00
14	12.53	1.00
15	13.53	1.00
16	14.53	1.00
17	15.53	1.00
18	16.53	1.00
19	17.16	0.63
20	17.40	0.24
21	33.80	16.40

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	0.53	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
2	1.53	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	2.53	S	14.0	17.50	7.70	29.5	0.0	0.0	0.200	Auto	Auto
4	3.53	S	21.0	17.50	7.70	32.7	0.0	0.0	0.200	Auto	Auto
5	4.53	S	50.0	17.50	7.70	42.4	0.0	0.0	0.200	Auto	Auto
6	5.53	S	50.0	17.50	7.70	42.4	0.0	0.0	0.200	Auto	Auto
7	5.98	S	21.0	17.50	7.70	33.6	0.0	0.0	0.200	Auto	Auto
8	6.53	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
9	7.53	C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto

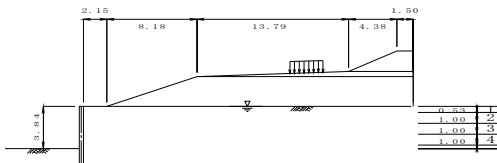
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
10	8.53	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
11	9.53	C	17.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
12	10.53	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
13	11.53	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	12.53	C	19.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	13.53	C	23.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	14.53	C	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
17	15.53	C	20.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
18	16.53	C	17.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
19	17.16	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
20	17.40	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
21	33.80	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	Auto	Auto

Note) depth : from top of coping to bottom of the layer C_u : soil adhesion
soil : sandy(S), clayey(C), mixed (M) a : slope of soil adhesion
N-value : average N-value in the layer k' : design seismic coefficient (underwater)
 γ : wet unit weight of soil ζ : angle of active rupture
 γ' : saturated unit weight of soil kh : modulus of subgrade reaction
 ϕ : internal friction angle of soil

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	Bottom Left m	Top Left m	Top Right m	Bottom Right m	Thickness h m	soil single weight γ Normal Condition kN/m ³	Seismic Condition kN/m ³	internal friction angle ϕ degree	stickiness C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	2.15	10.33	30.00	30.00	2.72	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	10.33	24.12	30.00	30.00	0.45	19.0	19.0	30.0	0.0	Auto	Auto
3	Sand	24.12	28.50	30.00	30.00	1.87	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m2	Seismic Condition kN/m2
1	18.77	21.79	10.0	0.0

Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name Hat steel sheet pile SP -25 H
Young's modulus $E = 200000 \text{ N/mm}^2$
Inertia sectional moment $I_0 = 24400 \text{ cm}^4$
Sectional factor $Z_0 = 1610 \text{ cm}^3$

Corrosion margin $t_1 = 1.00 \text{ mm}$ (riverside) $t_2 = 1.00 \text{ mm}$ (landside)
Corrosion rate (to I_0) $\eta = 0.82$
Corrosion rate (to Z_0) $\eta = 0.82$
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 $\sigma_a = 180 \text{ N/mm}$ (Normal)
 $\sigma_a' = 270 \text{ N/mm}$ (Seismic)

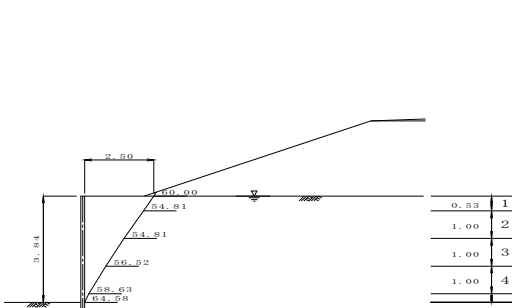
Allowable displacement $\delta_a = 50.0 \text{ mm}$ (Normal)
 $\delta_a' = 75.0 \text{ mm}$ (Seismic)

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	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	Angle of Rupture ζ degree
1	3.84~3.53	Sand	42.4	15.0	0.0	29.57	0.19	37.63	64.58
2	3.53~2.53	Sand	32.7	15.0	0.0	27.18	0.19	34.59	58.63
3	2.53~1.53	Sand	29.5	15.0	0.0	19.48	0.19	24.79	56.52
4	1.53~0.53	Sand	27.0	15.0	0.0	11.78	0.19	14.99	54.81
5	0.53~0.00	Sand	27.0	15.0	0.0	4.08	0.19	5.19	54.81
6		embankment t	30.0	—	0.0	95.76	0.00	0.00	60.00

• Angle of active rupture of sandy soil

$$\zeta = 90^\circ - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• 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 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)
- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	64.58	0.31	0.00	0.00	0.15	0.31
2	58.63	1.00	0.15	0.31	0.76	1.31
3	56.52	1.00	0.76	1.31	1.42	2.31
4	54.81	1.00	1.42	2.31	2.12	3.31
5	54.81	0.53	2.12	3.31	2.50	3.84
6	60.00	0.14	2.50	3.84	2.58	3.98

From the above table, the loading width (L) on the ground surface is 2.50 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.02	0.47
Σ			0.47

• Major collapse angle of cohesive 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	55.75	0.31	0.00	0.00	0.21	0.31
2	47.87	1.00	0.21	0.31	1.12	1.31
3	44.82	1.00	1.12	1.31	2.12	2.31
4	42.18	1.00	2.12	2.31	3.23	3.31
5	42.18	0.53	3.23	3.31	3.81	3.84
6	49.60	0.77	3.81	3.84	4.47	4.61

From the above table, the loading width (L) on the ground surface is 3.81 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.64	12.15
Σ			12.15

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

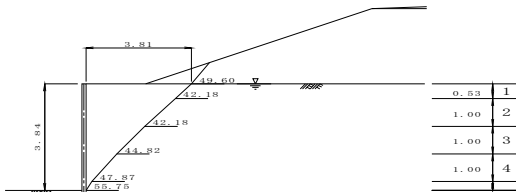
$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{12.15 + 0.00 + 0.00}{3.81}$$
$$= 3.19 \text{ kN/m}^2$$

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{0.47 + 0.00 + 0.00}{2.50}$$
$$= 0.19 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

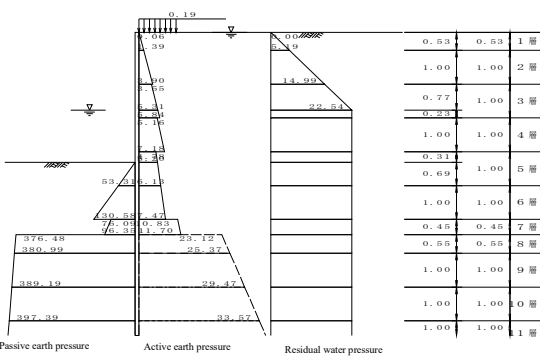
No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	k (%)	θ degree	Angle of Rupture ζ degree
1	3.84~3.53	Sand	42.4	15.0	0.0	29.57	3.19	37.63	0.200	11.31	55.75
2	3.53~2.53	Sand	32.7	15.0	0.0	27.18	3.19	34.59	0.200	11.31	47.87
3	2.53~1.53	Sand	29.5	15.0	0.0	19.48	3.19	24.79	0.200	11.31	44.82
4	1.53~0.53	Sand	27.0	15.0	0.0	11.78	3.19	14.99	0.200	11.31	42.18
5	0.53~0.00	Sand	27.0	15.0	0.0	4.08	3.19	5.19	0.200	11.31	42.18
6		embankment t	30.0	—	0.0	95.76	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90^\circ - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

3 Lateral Forth

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	Σ γ h + Q _a kN/m ²	K _a	K _a × cos δ
1	0.00~0.53	Sand	7.7	27.0	0.189 4.270	0.33738 0.33738	0.32589 0.32589
2	0.53~1.53	Sand	7.7	27.0	4.270 11.970	0.33738 0.33738	0.32589 0.32589
3	1.53~2.30	Sand	7.7	29.5	11.970 17.899	0.30720 0.30720	0.29674 0.29674
4	2.30~2.53	Sand	7.7	29.5	17.899 19.670	0.30720 0.30720	0.29674 0.29674
5	2.53~3.53	Sand	7.7	32.7	19.670 27.770	0.27152 0.27152	0.26227 0.26227
6	3.53~3.84	Sand	7.7	42.4	27.770 29.757	0.18084 0.18084	0.17468 0.17468
7	3.84~4.53	Sand	7.7	42.4	29.757 35.070	0.18084 0.18084	0.17468 0.17468
8	4.53~5.53	Sand	7.7	42.4	35.070 42.770	0.18084 0.18084	0.17468 0.17468
9	5.53~5.98	Sand	7.7	33.6	42.770 46.235	0.26205 0.26205	0.25312 0.25312
10	5.98~6.53	Clay	8.2	—	180.0 180.0	— —	— —
11	6.53~7.53	Clay	8.2	—	180.0 180.0	— —	— —
12	7.53~8.53	Clay	8.2	—	180.0 180.0	— —	— —

13	8.53- 9.53	Clay	8.2	—	180.0 180.0	67.145 75.345	—	—
14	9.53- 10.53	Clay	8.2	—	180.0 180.0	75.345 83.545	—	—
15	10.53- 11.53	Clay	8.2	—	180.0 180.0	83.545 91.745	—	—
16	11.53- 12.53	Clay	8.2	—	180.0 180.0	91.745 99.945	—	—
17	12.53- 13.53	Clay	8.2	—	180.0 180.0	99.945 108.145	—	—
18	13.53- 14.53	Clay	8.2	—	100.0 100.0	108.145 116.345	—	—
19	14.53- 15.53	Clay	8.2	—	180.0 180.0	116.345 124.545	—	—
20	15.53- 16.53	Clay	8.2	—	180.0 180.0	124.545 132.745	—	—
21	16.53- 17.16	Clay	8.2	—	180.0 180.0	132.745 137.911	—	—
22	17.16- 17.40	Clay	6.7	—	200.0 200.0	137.911 139.519	—	—
23	17.40- 33.80	Clay	7.2	—	1000.0 1000.0	139.519 257.399	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q_p$ kN/m ²	Kp	Kp $\times \cos \delta$
7	3.84- 4.53	Sand	7.7	42.4	—	0.000 5.313	10.38845 10.38845	10.03447 10.03447
8	4.53- 5.53	Sand	7.7	42.4	—	5.313 13.013	10.38845 10.38845	10.03447 10.03447
9	5.53- 5.98	Sand	7.7	33.6	—	13.013 16.478	6.05364 6.05364	5.84737 5.84737
10	5.98- 6.53	Clay	8.2	0.0	180.0 180.0	16.478 20.988	—	—
11	6.53- 7.53	Clay	8.2	0.0	180.0 180.0	20.988 29.188	—	—
12	7.53- 8.53	Clay	8.2	0.0	180.0 180.0	29.188 37.388	—	—
13	8.53- 9.53	Clay	8.2	0.0	180.0 180.0	37.388 45.588	—	—
14	9.53- 10.53	Clay	8.2	0.0	180.0 180.0	45.588 53.788	—	—
15	10.53- 11.53	Clay	8.2	0.0	180.0 180.0	53.788 61.988	—	—
16	11.53- 12.53	Clay	8.2	0.0	180.0 180.0	61.988 70.188	—	—

13	8.53- 9.53	-292.86 -284.66	33.57 37.67	33.57 37.67	22.54 22.54	397.39 405.59
14	9.53- 10.53	-284.66 -276.46	37.67 41.77	37.67 41.77	22.54 22.54	405.59 413.79
15	10.53- 11.53	-276.46 -268.26	41.77 45.87	41.77 45.87	22.54 22.54	413.79 421.99
16	11.53- 12.53	-268.26 -260.06	45.87 49.97	45.87 49.97	22.54 22.54	421.99 430.19
17	12.53- 13.53	-260.06 -251.86	49.97 54.07	49.97 54.07	22.54 22.54	430.19 438.39
18	13.53- 14.53	-251.86 -243.66	54.07 58.17	54.07 58.17	22.54 22.54	438.39 446.59
19	14.53- 15.53	-243.66 -235.46	58.17 62.27	58.17 62.27	22.54 22.54	446.59 454.79
20	15.53- 16.53	-235.46 -227.26	62.27 66.37	62.27 66.37	22.54 22.54	454.79 462.99
21	16.53- 17.16	-227.26 -222.09	66.37 68.96	66.37 68.96	22.54 22.54	462.99 468.15
22	17.16- 17.40	-222.09 -260.48	68.96 69.76	68.96 69.76	22.54 22.54	468.15 508.15
23	17.40- 33.80	-260.48 -1742.40	69.76 128.80	69.76 128.80	22.54 22.54	508.15 2109.76

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma \cdot h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma \cdot h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma \cdot h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma \cdot h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma \cdot h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma \cdot h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

17	12.53- 13.53	Clay	8.2	0.0	180.0 180.0	70.188 78.388	—	—
18	13.53- 14.53	Clay	8.2	0.0	100.0 100.0	78.388 86.588	—	—
19	14.53- 15.53	Clay	8.2	0.0	180.0 180.0	86.588 94.788	—	—
20	15.53- 16.53	Clay	8.2	0.0	180.0 180.0	94.788 102.988	—	—
21	16.53- 17.16	Clay	8.2	0.0	180.0 180.0	102.988 108.154	—	—
22	17.16- 17.40	Clay	6.7	20.0	200.0 200.0	108.154 109.762	—	—
23	17.40- 33.80	Clay	7.2	30.0	1000.0 1000.0	109.762 227.842	—	—

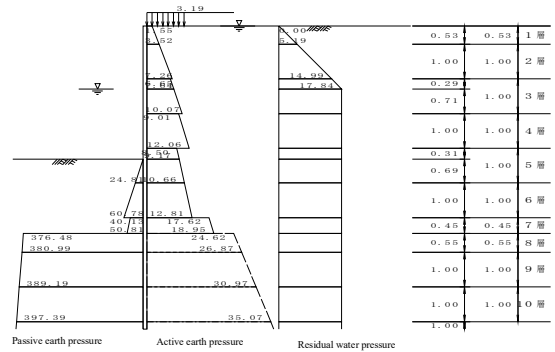
Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00- 0.53	0.06 1.39	—	0.06 1.39	0.00 5.19	—
2	0.53- 1.53	1.39 3.90	—	1.39 3.90	5.19 14.99	—
3	1.53- 2.30	3.55 5.31	—	3.55 5.31	14.99 22.54	—
4	2.30- 2.53	5.31 5.84	—	5.31 5.84	22.54 22.54	—
5	2.53- 3.53	5.84 7.18	—	5.84 7.18	22.54 22.54	—
6	3.53- 3.84	7.18 5.20	—	7.18 5.20	22.54 22.54	—
7	3.84- 4.53	5.20 6.13	—	5.20 6.13	22.54 22.54	0.00 53.31
8	4.53- 5.53	6.13 7.47	—	6.13 7.47	22.54 22.54	53.31 130.58
9	5.53- 5.98	7.47 11.70	—	7.47 11.70	22.54 22.54	76.09 96.35
10	5.98- 6.53	11.70 -313.77	23.12 25.37	11.70 25.37	22.54 22.54	376.48 380.99
11	6.53- 7.53	-313.77 -309.26	25.37 29.47	25.37 29.47	22.54 22.54	380.99 389.19
12	7.53- 8.53	-309.26 -292.86	29.47 33.57	29.47 33.57	22.54 22.54	389.19 397.39

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma \cdot h + Q$ kN/m ²	$\gamma \text{ value}$ kN/m ³	k (k)	θ degree	Ka	Ka $\times \cos \delta$	ζ degree
1	0.00- 0.53	Sand	7.7	27.0	—	3.19 7.27	0.00 5.19	0.300 0.300	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
2	0.53- 1.53	Sand	7.7	27.0	—	7.27 14.97	5.19 14.99	0.300 0.300	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
3	1.53- 1.82	Sand	7.7	29.5	—	14.97 17.20	14.99 17.84	0.300 0.300	11.31 11.31	0.45999 0.45999	0.44432 0.44432	—
4	1.82- 2.23	Sand	7.7	29.5	—	17.20 22.07	17.84 24.79	0.300 0.300	11.31 11.31	0.45999 0.45999	0.44432 0.44432	—
5	2.23- 3.53	Sand	7.7	32.7	—	22.07 30.37	24.79 34.59	0.300 0.300	11.31 11.31	0.41130 0.41130	0.39729 0.39729	—
6	3.53- 3.84	Sand	7.7	42.4	—	30.37 32.76	34.59 37.63	0.300 0.300	11.31 11.31	0.28983 0.28983	0.27995 0.27995	—
7	3.84- 4.53	Sand	7.7	42.4	—	32.76 38.07	37.63 44.39	0.300 0.300	11.31 11.31	0.28983 0.28983	0.27995 0.27995	—
8	4.53- 5.53	Sand	7.7	42.4	—	38.07 45.77	44.39 54.19	0.300 0.300	11.31 11.31	0.28983 0.28983	0.27995 0.27995	—
9	5.53- 5.98	Sand	7.7	33.6	—	45.77 49.23	54.19 58.60	0.300 0.300	11.31 11.31	0.39850 0.39850	0.38492 0.38492	—
10	5.98- 6.53	Clay	8.2	—	180.0 180.0	53.74 53.74	63.99 63.99	0.300 0.300	11.31 11.31	—	—	44.58 44.54
11	6.53- 7.53	Clay	8.2	—	180.0 180.0	61.94 61.94	63.99 73.79	0.300 0.300	11.31 11.31	—	—	44.54 44.47
12	7.53- 8.53	Clay	8.2	—	180.0 180.0	70.14 70.14	73.79 83.59	0.300 0.300	11.31 11.31	—	—	44.47 44.40
13	8.53- 9.53	Clay	8.2	—	180.0 180.0	78.34 78.34	83.59 93.39	0.300 0.300	11.31 11.31	—	—	44.40 44.34
14	9.53- 10.53	Clay	8.2	—	180.0 180.0	86.54 86.54	93.39 103.19	0.300 0.300	11.31 11.31	—	—	44.34 44.27

15	10.53- 11.53	Clay	8.2	—	180.0 180.0	86.54 94.74	103.19 112.99	0.200 0.200	11.31 11.31	—	—	44.27 44.20
16	11.53- 12.53	Clay	8.2	—	180.0 180.0	94.74 102.94	112.99 122.79	0.200 0.200	11.31 11.31	—	—	44.20 44.13
17	12.53- 13.53	Clay	8.2	—	180.0 180.0	102.94 111.14	122.79 132.59	0.200 0.200	11.31 11.31	—	—	44.13 44.06
18	13.53- 14.53	Clay	8.2	—	100.0 100.0	111.14 119.34	132.59 142.39	0.200 0.200	11.31 11.31	—	—	43.26 43.13
19	14.53- 15.53	Clay	8.2	—	180.0 180.0	119.34 127.54	142.39 152.19	0.200 0.200	11.31 11.31	—	—	43.99 43.92
20	15.53- 16.53	Clay	8.2	—	180.0 180.0	127.54 135.74	152.19 161.99	0.200 0.200	11.31 11.31	—	—	43.92 43.85
21	16.53- 17.16	Clay	8.2	—	180.0 180.0	135.74 140.91	161.99 168.17	0.200 0.200	11.31 11.31	—	—	43.85 43.81
22	17.16- 17.40	Clay	6.7	—	200.0 200.0	140.91 142.52	168.17 170.52	0.200 0.200	11.31 11.31	—	—	43.93 43.92
23	17.40- 33.80	Clay	7.2	—	1000.0 1000.0	142.52 260.60	170.52 331.24	0.200 0.200	11.31 11.31	—	—	44.79 44.62

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

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

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{ultw} kN/m ²	k (k ⁻¹)	θ degree	Kp	Kp $\times \cos \theta$
7	3.84- 4.53	Sand	7.70	42.4	—	0.000 5.313	0.00 6.76	0.200 0.200	11.31 11.31	4.67049 4.67049	4.67049 4.67049
8	4.53- 5.53	Sand	7.70	42.4	—	5.313 13.013	6.76 16.56	0.200 0.200	11.31 11.31	4.67049 4.67049	4.67049 4.67049
9	5.53- 5.98	Sand	7.70	33.6	—	13.013 16.478	16.56 20.97	0.200 0.200	11.31 11.31	3.08376 3.08376	3.08376 3.08376
10	5.98- 6.53	Clay	8.20	0.0	180.0 180.0	16.478 20.988	20.97 26.36	0.200 0.200	11.31 11.31	—	—
11	6.53- 7.53	Clay	8.20	0.0	180.0 180.0	20.988 29.188	26.36 36.16	0.200 0.200	11.31 11.31	—	—
12	7.53- 8.53	Clay	8.20	0.0	180.0 180.0	29.188 37.388	36.16 45.96	0.200 0.200	11.31 11.31	—	—
13	8.53- 9.53	Clay	8.20	0.0	180.0 180.0	37.388 45.588	45.96 55.76	0.200 0.200	11.31 11.31	—	—
14	9.53- 10.53	Clay	8.20	0.0	180.0 180.0	45.588 53.788	55.76 65.56	0.200 0.200	11.31 11.31	—	—
15	10.53- 11.53	Clay	8.20	0.0	180.0 180.0	53.788 61.988	65.56 75.36	0.200 0.200	11.31 11.31	—	—
16	11.53- 12.53	Clay	8.20	0.0	180.0 180.0	61.988 70.188	75.36 85.16	0.200 0.200	11.31 11.31	—	—

13	8.53- 9.53	-275.61 -265.72	35.07 39.17	35.07 39.17	17.84 17.84	397.39 405.59
14	9.53- 10.53	-265.72 -255.82	39.17 43.27	39.17 43.27	17.84 17.84	405.59 413.79
15	10.53- 11.53	-255.82 -245.91	43.27 47.37	43.27 47.37	17.84 17.84	413.79 421.99
16	11.53- 12.53	-245.91 -236.00	47.37 51.47	47.37 51.47	17.84 17.84	421.99 430.19
17	12.53- 13.53	-236.00 -226.08	51.47 55.57	51.47 55.57	17.84 17.84	430.19 438.39
18	13.53- 14.53	-226.08 -216.16	55.57 59.67	55.57 59.67	17.84 17.84	438.39 446.59
19	14.53- 15.53	-216.16 -206.22	59.67 63.77	59.67 63.77	17.84 17.84	446.59 454.79
20	15.53- 16.53	-206.22 -196.29	63.77 67.87	63.77 67.87	17.84 17.84	454.79 462.99
21	16.53- 17.16	-196.29 -190.02	67.87 70.45	67.87 70.45	17.84 17.84	462.99 468.15
22	17.16- 17.40	-190.02 -230.11	70.45 71.26	70.45 71.26	17.84 17.84	468.15 508.15
23	17.40- 33.80	-230.11 -1828.82	71.26 130.30	71.26 130.30	17.84 17.84	508.15 2109.76

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of P_{a1} or P_{a2} is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z, m	water level y, m	p _{dw} kN/m ²
1	1.82	0.00	0.00
2	2.82	1.00	2.44
3	3.82	2.00	3.45
4	3.84	2.02	3.46

$$p_{dw} = \pm \frac{\gamma}{8} k_{hw} \cdot \gamma_w \cdot \sqrt{H} \cdot y$$

17	12.53- 13.53	Clay	8.20	0.0	180.0 180.0	70.188 78.388	85.16 94.96	0.200 0.200	11.31 11.31	—	—
18	13.53- 14.53	Clay	8.20	0.0	100.0 100.0	78.388 86.588	94.96 104.76	0.200 0.200	11.31 11.31	—	—
19	14.53- 15.53	Clay	8.20	0.0	180.0 180.0	86.588 94.788	104.76 114.56	0.200 0.200	11.31 11.31	—	—
20	15.53- 16.53	Clay	8.20	0.0	180.0 180.0	94.788 102.988	114.56 124.36	0.200 0.200	11.31 11.31	—	—
21	16.53- 17.16	Clay	8.20	0.0	180.0 180.0	102.988 108.154	124.36 130.54	0.200 0.200	11.31 11.31	—	—
22	17.16- 17.40	Clay	6.70	20.0	200.0 200.0	108.154 109.762	130.54 132.89	0.200 0.200	11.31 11.31	—	—
23	17.40- 33.80	Clay	7.20	30.0	1000.0 1000.0	109.762 227.842	132.89 293.61	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure		Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	
1	0.00- 0.53	1.55 3.52	—	1.55 3.52	0.00 5.19	—	—
2	0.53- 1.53	3.52 7.26	—	3.52 7.26	5.19 14.99	—	—
3	1.53- 1.82	—	6.65 7.64	—	—	14.99 17.84	—
4	1.82- 2.53	—	7.64 10.07	—	—	17.84 17.84	—
5	2.53- 3.53	—	9.01 12.06	—	9.01 12.06	17.84 17.84	—
6	3.53- 3.84	—	8.50 9.17	—	8.50 9.17	17.84 17.84	—
7	3.84- 4.53	—	9.17 10.66	—	9.17 10.66	17.84 17.84	0.00 24.81
8	4.53- 5.53	—	10.66 12.81	—	10.66 12.81	17.84 17.84	24.81 60.78
9	5.53- 5.98	—	12.81 18.95	—	12.81 18.95	17.84 17.84	60.78 40.13
10	5.98- 6.53	—	-300.81 -295.38	24.62 26.87	24.62 26.87	17.84 17.84	376.48 380.99
11	6.53- 7.53	—	-295.38 -285.50	26.87 30.97	26.87 30.97	17.84 17.84	380.99 389.19
12	7.53- 8.53	—	-285.50 -275.61	30.97 35.07	30.97 35.07	17.84 17.84	389.19 397.39

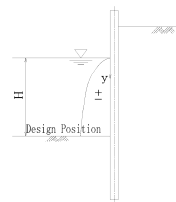
Where,

k_{hw} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

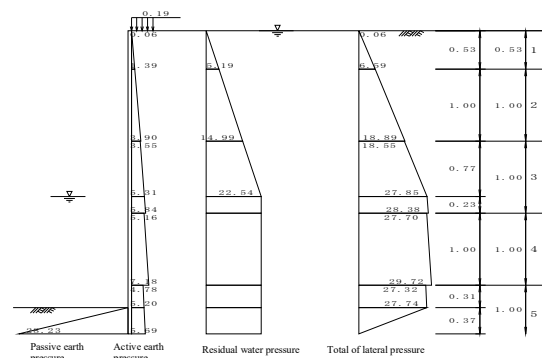
y : depth from water surface to the point where active water pressure is calculated



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

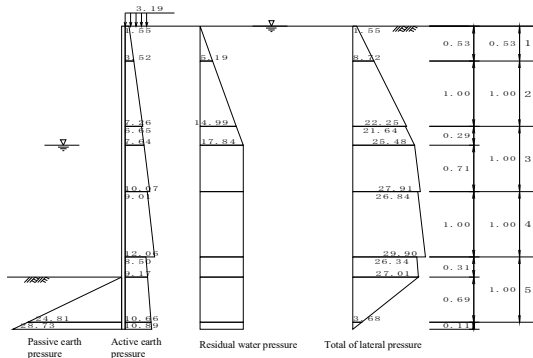


No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 0.53	0.06 1.39	0.00 5.19	----- -----	0.06 6.59
2	0.53- 1.53	1.39 3.90	5.19 14.99	----- -----	6.59 18.89
3	1.53- 2.30	3.55 5.31	14.99 22.54	----- -----	18.55 27.85
4	2.30- 2.53	5.31 5.84	22.54 22.54	----- -----	27.85 28.38
5	2.53- 3.53	5.16 7.18	22.54 22.54	----- -----	27.70 29.72
6	3.53- 3.84	4.78 5.20	22.54 22.54	----- -----	27.32 27.74
7	3.84- 4.21	5.20 5.69	22.54 22.54	0.00 28.23	27.74 0.00
8	4.21- 4.53	5.69 6.13	22.54 22.54	28.23 53.31	0.00 -24.65

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: 0.37 m (GL -4.21 m)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 0.53	1.55 3.52	0.00 5.19	----- -----	1.55 8.72

No	Depth m	N Value	No	Depth m	N Value
1	0.03	2	11	10.03	16
2	1.03	6	12	11.03	18
3	2.03	14	13	12.03	19
4	3.03	21	14	13.03	23
5	4.03	50	15	14.03	11
6	5.03	50	16	15.03	20
7	6.03	23	17	16.03	17
8	7.03	25	18	17.03	21
9	8.03	30			
10	9.03	17			

5.2 Normal Condition

Assuming Kh = 30816 kN/m³,

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.662 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 1.51 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.21 m) to 1.51 m depth (GL -5.72 m).

No	Depth Z m	Thickness h m	N' Value upper	N' Value lower	Area A
1	4.21	0.82	50.0	50.0	41.23
2	5.03	0.69	50.0	31.5	27.92
L = Σh = 1.51		ΣA = 69.15			

A: (upper N-value + lower N-value) × h/2

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{69.15}{1.51} \\ &= 45.80 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 45.80 = 128251 \text{ kN/m}^2 \\ K_{w0} &= \frac{1}{0.3} \times \alpha \times 128251 = 427502 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{ Seismic Condition} = 2) \\ K_h &= K_{w0}(B/0.3)^{-3/4} = 427502(10.00/0.3)^{-3/4} = 30816 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 30816 kN/m³.

5.3 Seismic Condition

Assuming Kh = 55705 kN/m³,

2	0.53- 1.53	3.52 7.26	5.19 14.99	----- -----	8.72 22.25
3	1.53- 1.82	6.65 7.64	14.99 17.84	----- -----	21.64 25.48
4	1.82- 2.53	7.64 10.07	17.84 17.84	----- -----	25.48 27.91
5	2.53- 3.53	9.01 12.06	17.84 17.84	----- -----	26.84 29.90
6	3.53- 3.84	8.50 9.17	17.84 17.84	----- -----	26.34 27.01
7	3.84- 4.53	9.17 10.66	17.84 17.84	0.00 24.81	27.01 3.68
8	4.53- 4.64	10.66 10.89	17.84 17.84	24.81 28.73	3.68 0.00
9	4.64- 5.53	10.89 12.81	17.84 17.84	28.73 60.78	0.00 -30.13

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: 0.80 m (GL -4.64 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of 1/β from the virtual ground surface.
Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$\begin{aligned} K_h &= K_{w0} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B=10.00\text{m}) \\ K_{w0} &= \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{ Seismic Condition} = 2) \\ E_0 &= 2800N' \end{aligned}$$

where:

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}}$$

Material Name	Hat steel sheet pile SP -25 H		
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 = 87800 cm ⁴ (original condition)		
	I = 20008 cm ⁴ (after reduction by corrosion and section)		
Inertia sectional moment	EI = 200000 × 10 ³ × 20008 × 10 ⁻⁸ = 4.002 × 10 ⁴		

$$\beta = 4\sqrt{\frac{K_h \cdot B}{4 E I}} = 0.768 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 1.30 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -4.64 m) and 1.30 m depth (GL -5.94 m).

No	Depth Z m	Thickness h m	N' Value		Area A
			upper	lower	
1	4.64	0.39	50.0	50.0	19.56
2	5.03	0.91	50.0	25.4	34.34
L = Σh = 1.30		ΣA = 53.90			

A: (upper N-value + lower N-value) × h/2

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{53.90}{1.30} \\ &= 41.40 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 41.40 = 115916 \text{ kN/m}^2 \\ K_{w0} &= \frac{1}{0.3} \times \alpha \times 115916 = 772771 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{ Seismic Condition} = 2) \\ K_h &= K_{w0}(B/0.3)^{-3/4} = 772771(10.00/0.3)^{-3/4} = 55705 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 55705 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.53	0.53	0.06 6.59	0.02 1.75	4.03 3.85	0.07 6.72
2	0.53- 1.53	1.00	6.59 18.89	3.29 9.45	3.34 3.01	11.00 28.42
3	1.53- 2.30	0.77	18.55 27.85	7.14 10.72	2.42 2.16	17.27 23.18

4	2.30- 2.53	0.23	27.85 28.38	3.20 3.26	1.83 1.75	5.86 5.72
5	2.53- 3.53	1.00	27.70 29.72	13.85 14.86	1.34 1.01	18.59 14.99
6	3.53- 3.84	0.31	27.32 27.34	4.23 4.30	0.57 0.47	2.42 2.02
7	3.84- 4.21	0.37	27.74 0.00	5.07 0.00	0.24 0.12	1.23 0.00
$\Sigma P = 81.14 \quad \Sigma M = 137.49$						

P_t : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_s \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

Arbitrary load lateral load $P_t = 0.0$ kN/m
 depth to acting position $H_t = 0.0$ 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 $H = 3.84$ m
 Depth of Imaginary riverbed from riverbed $L_k = 0.37$ 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

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t}{\Sigma P + P_t} = \frac{137.49}{81.14} = 1.69 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 81.14}{4.21} = 38.59 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _s kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 0.53	0.53	1.55 8.72	0.41 2.31	4.46 4.29	1.83 9.90
2	0.53- 1.53	1.00	8.72 22.25	4.36 11.13	3.78 3.44	16.46 38.30
3	1.53- 1.82	0.29	21.64 25.48	3.14 3.69	3.01 2.92	9.45 10.77
4	1.82- 2.53	0.71	25.48 27.91	9.05 9.91	2.58 2.35	23.36 23.24
5	2.53- 3.53	1.00	26.84 29.90	13.42 14.95	1.78 1.44	23.83 21.56
6	3.53- 3.84	0.31	26.34 27.01	4.08 4.19	1.01 0.90	4.10 3.78
7	3.84- 4.53	0.69	27.01 3.68	9.32 1.27	0.57 0.34	5.30 0.43

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1+2\beta h_0)^2 + 1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_b = 30816$ kN/m³
 calculated value $\beta = 0.66240$ m⁻¹
 resultant earth force (lateral) $P_0 = 81.14$ kN/m
 height of acting position of load $h_0 = 1.69$ m
 moment $M_0 = 137.49$ kN·m/m

in consideration of $\psi_m = 1.122$,
 maximum moment $M_{max} = 154.22$ kN·m/m
 depth of generated position of M_{max} $l_m = 0.451$ m
 depth of 1st fixed point $l_i = 1.637$ m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_b = 55705$ kN/m³
 calculated value $\beta = 0.76807$ m⁻¹
 resultant earth force (lateral) $P_0 = 95.65$ kN/m
 height of acting position of load $h_0 = 2.08$ m
 moment $M_0 = 198.79$ kN·m/m

in consideration of $\psi_m = 1.068$,
 maximum moment $M_{max} = 212.36$ kN·m/m
 depth of generated position of M_{max} $l_m = 0.305$ m
 depth of 1st fixed point $l_i = 1.327$ m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name Hat steel sheet pile SP -25 H
 Corrosion margin $t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
 Corrosion rate $\eta = 0.82$
 Section efficiency $\mu = 1.00$
 Module of section $Z_0 = 1610$ cm³ (original condition)
 $Z = 1520$ cm³ (after reduction by corrosion and section)

8	4.53- 4.64	0.11	3.68 0.00	0.20 0.00	0.07 0.04	0.01 0.00
$\Sigma P = 91.42 \quad \Sigma M = 192.32$						

P_s : active earth pressure + residual water pressure - passive earth pressure
 P : load $P_s \times h/2 \times B$
 B : unit width = 1.000 m
 Y : height of acting position from imaginary riverbed
 M : moment by load $P \times Y$

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 $H = 3.84$ m
 Depth of Imaginary riverbed from riverbed $L_k = 0.80$ 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

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	1.82- 2.82	1.00	0.0 2.4	0.00 1.22	2.49 2.15	0.00 2.62
2	2.82- 3.82	1.00	2.4 3.4	1.22 1.72	1.49 1.15	1.81 1.99
3	3.82- 3.84	0.02	3.4 3.5	0.03 0.03	0.81 0.81	0.03 0.03
$\Sigma P_{dw} = 4.21 \quad \Sigma M_{dw} = 6.48$						

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_t + \Sigma M_{dw}}{\Sigma P + P_t + \Sigma P_{dw}} = \frac{198.79}{95.65} = 2.08 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 95.65}{4.64} = 41.24 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Material name Hat steel sheet pile SP -25 H
 Unit width $B = 1.0000$ m
 Corrosion margin $t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
 Corrosion rate $\eta = 0.82$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000$ N/mm²
 Inertia sectional moment $I_0 = 24400$ cm⁴ (original condition)
 $I = 20008$ cm⁴ (after reduction by corrosion and section)
 $EI = 200000 \times 10^3 \times 20008 \times 10^{-8} = 4.002 \times 10^5$

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{154.22 \times 10^6}{1320 \times 10^3} = 117 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

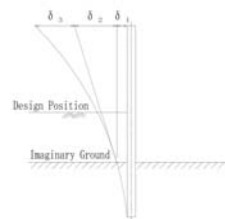
6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{212.36 \times 10^6}{1320 \times 10^3} = 161 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation

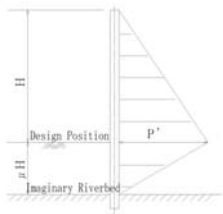


$$\delta_1 = \frac{(1+\beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1+0.6624 \times 1.69) \times 81.14}{2 \times 2.00 \times 10^8 \times 20008 \times 10^{-8} \times 0.6624^3} = 0.00740 \text{ m}$$

$$\delta_2 = \frac{(1+2\beta h_0) \times P_0}{2 E I \beta^2} \times (H+L_k)$$

$$= \frac{(1+2 \times 0.6624 \times 1.69) \times 81.14}{2 \times 2.00 \times 10^8 \times 20008 \times 10^{-8} \times 0.6624^2} \times (3.84+0.37) = 0.03153 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.37}{3.84} = 0.095$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{38.59 \times 3.84^4}{120 \times 2.00 \times 10^8 \times 20008 \times 10^{-8}} (4 + 20 \times 0.095 + 40 \times 0.095^2 + 35 \times 0.095^3 + 11 \times 0.095^4)$$

$$= 0.01100 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00740 + 0.03153 + 0.01100$$

$$= 0.04993 \text{ m}$$

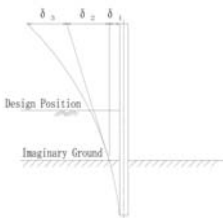
$$\text{Size} = 49.93 \leq \delta_a = 50.00 \text{ mm}$$

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

Displacement Calculation



$$\text{Inertia sectional moment } I_0 = 24400 \text{ cm}^4 \text{ (original condition)}$$

$$I = 24400 \text{ cm}^4 \text{ (after reduction by corrosion and section)}$$

$$EI = 200000 \times 10^3 \times 24400 \times 10^{-8} = 4.880 \times 10^6$$

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 follows:

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{10} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

$$\text{Modules of lateral subgrade reaction } K_b = 30816 \text{ kN/m}^3$$

$$\text{Calculated value } \beta = 0.63034 \text{ m}^{-1}$$

$$\text{Penetration length of SSP } D = 0.37 + \frac{3}{0.630} = 5.12 \text{ m}$$

$$\text{Whole length of SSP } L = 3.84 - 0.40 + 5.12 = 8.56 \text{ m}$$

7.1.2 Seismic Condition

$$\text{Modules of lateral subgrade reaction } K_b = 55705 \text{ kN/m}^3$$

$$\text{Calculated value } \beta = 0.73089 \text{ m}^{-1}$$

$$\text{Penetration length of SSP } D = 0.80 + \frac{3}{0.731} = 4.90 \text{ m}$$

$$\text{Whole length of SSP } L = 3.84 - 0.40 + 4.90 = 8.34 \text{ m}$$

Therefore, the total length of the sheet pile is 9.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP Hat steel sheet pile SP-25 H

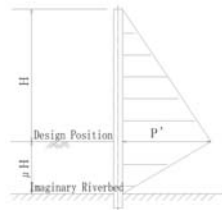
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	24400		
Sectional Modulus	Z (cm ³)	1610		
Maximum bending moment	Mmax (kN · m · m)		154.22	212.36
Stress intensity	σ (N/mm ²)		117 (180)	161 (270)
Lateral displacement	δ (mm)		49.59 (50.0)	65.35 (75.0)
Penetration depths	D (m)		5.12	4.90
Whole length of SSP	L (m)	9.00		

$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3}$$

$$= \frac{(1 + 0.7681 \times 2.08) \times 95.65}{2 \times 2.00 \times 10^8 \times 20008 \times 10^{-8} \times 0.7681^3} = 0.00685 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_k)$$

$$= \frac{(1 + 2 \times 0.7681 \times 2.08) \times 95.65}{2 \times 2.00 \times 10^8 \times 20008 \times 10^{-8} \times 0.7681^2} \times (3.84 + 0.80) = 0.03940 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{0.80}{3.84} = 0.208$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{41.24 \times 3.84^4}{120 \times 2.00 \times 10^8 \times 20008 \times 10^{-8}} (4 + 20 \times 0.208 + 40 \times 0.208^2 + 35 \times 0.208^3 + 11 \times 0.208^4)$$

$$= 0.01910 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.00685 + 0.03940 + 0.01910$$

$$= 0.06535 \text{ m}$$

$$\text{Size} = 65.35 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Material Name	Hat steel sheet pile SP-25 H
Unit width	B = 1.0000 m
Corrosion rate	η = 1.00
Section efficiency	μ = 1.00
Young's modulus	E = 200000 N/mm ²

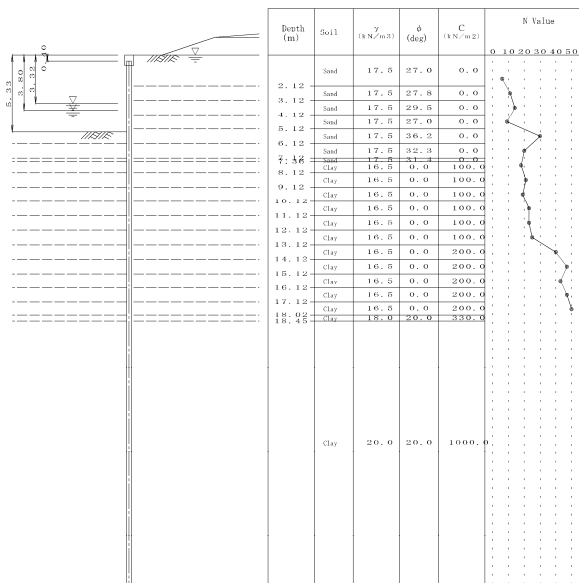
Block No. : R-36
Sta. : 12+540~12+660

Design Cross Section : Sta 12+560
Boring Name : BMRL-37

Specification : SSP SP-10H
(Combined) : H 800-250-14-22-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed H = 5.33 m
Depth from coping top to rear side ground H₀ = 0.00 m
Depth from coping top to SSP top H_B = 0.40 m
Landside WL L_{wa} = 0.00 m (Normal Condition)
L_{wa} = 0.00 m (Seismic Condition)
Riverside WL L_{wp} = 3.80 m (Normal Condition)
L_{wp} = 3.32 m (Seismic Condition)

N-value distribution

No	Depth m	N Value	No	Depth m	N Value
1	1.62	6	11	11.62	23
2	2.62	11	12	12.62	25
3	3.62	14	13	13.62	40
4	4.62	9	14	14.62	47
5	5.62	30	15	15.62	43
6	6.62	20	16	16.62	47
7	7.62	18	17	17.62	50
8	8.62	21			
9	9.62	19			
10	10.62	23			

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 (Include Projection Length)	Thickness m (excluding projected length)
1	2.12	2.12
2	3.12	1.00
3	4.12	1.00
4	5.12	1.00
5	6.12	1.00
6	7.12	1.00
7	7.36	0.24
8	8.12	0.76
9	9.12	1.00
10	10.12	1.00
11	11.12	1.00
12	12.12	1.00
13	13.12	1.00
14	14.12	1.00
15	15.12	1.00
16	16.12	1.00
17	17.12	1.00
18	18.02	0.90
19	18.45	0.43
20	35.30	16.85

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)
1	2.12	S	6.0	17.50	7.50	27.0	0.0	0.0	0.200	Auto
2	3.12	S	11.0	17.50	7.50	27.8	0.0	0.0	0.200	Auto
3	4.12	S	14.0	17.50	7.50	29.5	0.0	0.0	0.200	Auto
4	5.12	S	9.0	17.50	7.50	27.0	0.0	0.0	0.200	Auto
5	6.12	S	30.0	17.50	7.50	36.2	0.0	0.0	0.200	Auto
6	7.12	S	20.0	17.50	7.50	32.3	0.0	0.0	0.200	Auto
7	7.36	S	18.0	17.50	7.50	31.4	0.0	0.0	0.200	Auto
8	8.12	C	16.0	16.50	6.50	0.0	100.0	0.0	0.200	Auto
9	9.12	C	21.0	16.50	6.50	0.0	100.0	0.0	0.200	Auto
10	10.12	C	19.0	16.50	6.50	0.0	100.0	0.0	0.200	Auto

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered
Angle of rupture (clayey soil) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C}} \cdot \tan \theta$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{10} \left(\frac{B_B}{0.3} \right)^{-3/4}$
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_B = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

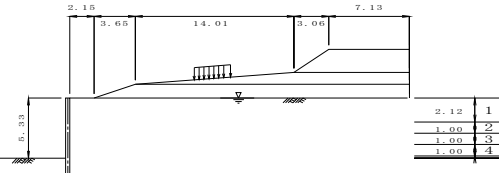
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)
11	11.12	C	23.0	16.50	6.50	0.0	100.0	0.0	0.200	Auto
12	12.12	C	23.0	16.50	6.50	0.0	100.0	0.0	0.200	Auto
13	13.12	C	25.0	16.50	6.50	0.0	100.0	0.0	0.200	Auto
14	14.12	C	40.0	16.50	6.50	0.0	200.0	0.0	0.200	Auto
15	15.12	C	47.0	16.50	6.50	0.0	200.0	0.0	0.200	Auto
16	16.12	C	43.0	16.50	6.50	0.0	200.0	0.0	0.200	Auto
17	17.12	C	47.0	16.50	6.50	0.0	200.0	0.0	0.200	Auto
18	18.02	C	50.0	16.50	6.50	0.0	200.0	0.0	0.200	Auto
19	18.45	C	38.2	18.00	8.00	20.0	330.0	0.0	0.200	Auto
20	35.30	C	44.4	20.00	10.00	20.0	1000.0	0.0	0.200	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 (underwater)
 ζ : angle of active rupture
kh : modulus of subgrade reaction

Angle of wall friction

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate	Thickness	soil single weight γ	internal friction angle	stickiness	decay angle ζ
		Bottom Left m	Top Left m	Bottom Right m	h m	Normal Condition kN/m ²	Seismic Condition degree
1	Sand	2.15	5.80	30.00	1.22	19.0	19.0
2	Sand	5.80	19.81	30.00	1.03	19.0	19.0
3	Sand	19.81	22.37	30.00	2.06	19.0	19.0

Surcharge load acting on embankment

No	load area	load strength
	From m	End point m
1	10.99	14.21

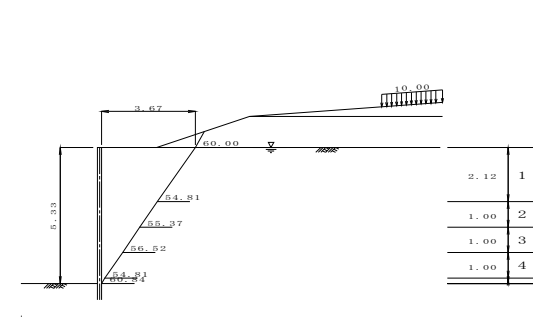
Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H	H 800 -250 -14 -22 -18
Young's modulus	E	= 200000 N/mm ²
Inertia sectional moment	I ₀	= 471700 cm ⁴
Sectional factor	Z ₀	= 8240 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	= 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



2.1.3 Acting Load by Embankment

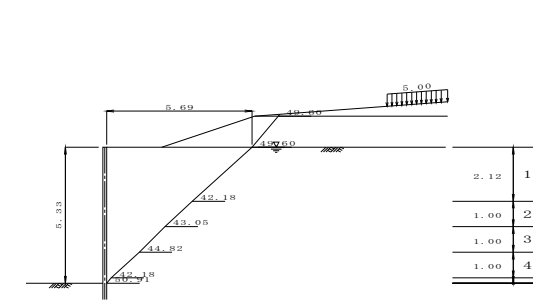
No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.48	9.08
Σ			9.08

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times 1) + \Sigma P}{L}$$
$$= \frac{9.08 + 0.00 + 0.00}{3.67}$$
$$= 2.48 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ wh kN/m ²	k (k ⁻¹)	θ degree	Angle of Rupture ζ degree
1	5.33 ~ 5.12	Sand	36.2	15.0	0.0	39.98	9.22	52.23	0.200	11.31	50.91
2	5.12 ~ 4.12	Sand	27.0	15.0	0.0	38.40	9.22	50.18	0.200	11.31	42.18
3	4.12 ~ 3.12	Sand	29.5	15.0	0.0	30.90	9.22	40.38	0.200	11.31	44.82
4	3.12 ~ 2.12	Sand	27.8	15.0	0.0	23.40	9.22	30.58	0.200	11.31	43.05
5	2.12 ~ 0.00	Sand	27.0	15.0	0.0	15.90	9.22	20.78	0.200	11.31	42.18
6		embankment t	30.0	—	0.0	81.89	0.00	0.00	0.200	11.31	49.60
7		embankment t	30.0	—	0.0	58.71	0.00	0.00	0.200	11.31	49.60

2.1.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ wh kN/m ²	Angle of Rupture ζ degree
1	5.33 ~ 5.12	Sand	36.2	15.0	0.0	39.98	2.48	52.23	60.84
2	5.12 ~ 4.12	Sand	27.0	15.0	0.0	38.40	2.48	50.18	54.81
3	4.12 ~ 3.12	Sand	29.5	15.0	0.0	30.90	2.48	40.38	56.52
4	3.12 ~ 2.12	Sand	27.8	15.0	0.0	23.40	2.48	30.58	55.37
5	2.12 ~ 0.00	Sand	27.0	15.0	0.0	15.90	2.48	20.78	54.81
6		embankment t	30.0	—	0.0	81.89	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 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)
- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	60.84	0.21	0.00	0.00	0.12	0.21
2	54.81	1.00	0.12	0.21	0.82	1.21
3	56.52	1.00	0.82	1.21	1.48	2.21
4	55.37	1.00	1.48	2.21	2.17	3.21
5	54.81	2.12	2.17	3.21	3.67	5.33
6	60.00	0.63	3.67	5.33	4.03	5.96

From the above table, the loading width (L) on the ground surface is 3.67 m.

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	50.91	0.21	0.00	0.00	0.17	0.21
2	42.18	1.00	0.17	0.21	1.27	1.21
3	44.82	1.00	1.27	1.21	2.28	2.21
4	43.05	1.00	2.28	2.21	3.35	3.21
5	42.18	2.12	3.35	3.21	5.69	5.33
6	49.60	1.22	5.69	5.33	6.73	6.55
7	49.60	0.07	6.73	6.55	6.79	6.62

From the above table, the loading width (L) on the ground surface is 5.69 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	2.73	51.80
2	19.0	0.03	0.64
Σ			52.44

γ : unit weight of embankment soil
A : sectional area of embankment enclosed by line of active rupture

2.2.4 Calculated Load

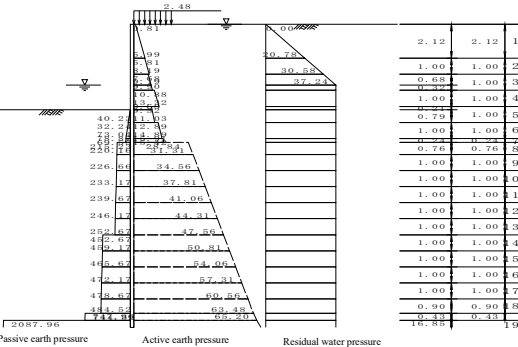
Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (52.44 + 0.00 + 0.00) / 5.69

= 9.22 kN/m²

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

	Depth, m	Soil	γ kN/m³	φ degree	C kN/m²	Σ γ h + Qe kN/m²	Ka	Ka × cos δ
1	0.00-2.12	Sand	7.5	27.0	—	2.475 18.375	0.32738 0.32738	0.32289 0.32289
2	2.12-3.12	Sand	7.5	27.8	—	18.375 25.875	0.32749 0.32749	0.31633 0.31633
3	3.12-3.80	Sand	7.5	28.5	—	25.875 30.975	0.30720 0.30720	0.29674 0.29674
4	3.80-4.12	Sand	7.5	28.5	—	30.975 33.375	0.30720 0.30720	0.29674 0.29674
5	4.12-5.12	Sand	7.5	27.0	—	33.375 40.875	0.32738 0.32738	0.32289 0.32289
6	5.12-5.33	Sand	7.5	36.2	—	40.875 42.450	0.22596 0.22596	0.22792 0.22792
7	5.33-6.12	Sand	7.5	36.2	—	42.450 48.375	0.22596 0.22596	0.22792 0.22792

13	10.12-11.12	Clay	6.5	0.0	100.0 100.0	33.165 39.665	—	—
14	11.12-12.12	Clay	6.5	0.0	100.0 100.0	39.665 46.165	—	—
15	12.12-13.12	Clay	6.5	0.0	100.0 100.0	46.165 52.665	—	—
16	13.12-14.12	Clay	6.5	0.0	200.0 200.0	52.665 59.165	—	—
17	14.12-15.12	Clay	6.5	0.0	200.0 200.0	59.165 65.665	—	—
18	15.12-16.12	Clay	6.5	0.0	200.0 200.0	65.665 72.165	—	—
19	16.12-17.12	Clay	6.5	0.0	200.0 200.0	72.165 78.665	—	—
20	17.12-18.02	Clay	6.5	0.0	200.0 200.0	78.665 84.515	—	—
21	18.02-18.45	Clay	8.0	20.0	330.0 330.0	84.515 87.955	—	—
22	18.45-35.30	Clay	10.0	20.0	1000.0 1000.0	87.955 256.455	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
δ = -15.00, β = 0.00, θ = 0.00

Kp = (cos²(φ - θ) / (cos θ · cos(δ - θ) · [1 - √(sin(φ - δ) · sin(φ + β - θ) / cos(δ - θ) · cos(-β))])²

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure Pw kN/m²	Passive Pp kN/m²
		Pa1 kN/m²	Pa2 kN/m²	Pa kN/m²		
1	0.00-2.12	0.81 5.99	—	0.81 5.99	0.00 20.78	—
2	2.12-3.12	5.81 8.19	—	5.81 8.19	20.78 30.58	—
3	3.12-3.80	7.68 9.19	—	7.68 9.19	30.58 37.24	—
4	3.80-4.12	9.19 9.90	—	9.19 9.90	37.24 37.24	—
5	4.12-5.12	10.88 13.32	—	10.88 13.32	37.24 37.24	—
6	5.12-5.33	9.32 9.68	—	9.32 9.68	37.24 37.24	—
7	5.33-6.12	9.68 11.03	—	9.68 11.03	37.24 37.24	0.00 40.23
8	6.12-7.12	12.89 14.89	—	12.89 14.89	37.24 37.24	32.24 73.04
9	7.12-7.36	15.42 15.91	—	15.42 15.91	37.24 37.24	69.55 78.87
10	7.36-8.12	-142.32 -137.38	28.84 31.31	28.84 31.31	37.24 37.24	215.23 220.16

8	6.12-7.12	Sand	7.5	32.3	—	48.375 55.875	0.27581 0.27581	0.26641 0.26641
9	7.12-7.36	Sand	7.5	31.4	—	55.875 57.675	0.28564 0.28564	0.27590 0.27590
10	7.36-8.12	Clay	6.5	—	100.0 100.0	57.675 62.615	—	—
11	8.12-9.12	Clay	6.5	—	100.0 100.0	62.615 69.115	—	—
12	9.12-10.12	Clay	6.5	—	100.0 100.0	69.115 75.615	—	—
13	10.12-11.12	Clay	6.5	—	100.0 100.0	75.615 82.115	—	—
14	11.12-12.12	Clay	6.5	—	100.0 100.0	82.115 88.615	—	—
15	12.12-13.12	Clay	6.5	—	100.0 100.0	88.615 95.115	—	—
16	13.12-14.12	Clay	6.5	—	200.0 200.0	95.115 101.615	—	—
17	14.12-15.12	Clay	6.5	—	200.0 200.0	101.615 108.115	—	—
18	15.12-16.12	Clay	6.5	—	200.0 200.0	108.115 114.615	—	—
19	16.12-17.12	Clay	6.5	—	200.0 200.0	114.615 121.115	—	—
20	17.12-18.02	Clay	6.5	—	200.0 200.0	121.115 126.965	—	—
21	18.02-18.45	Clay	8.0	—	330.0 330.0	126.965 130.405	—	—
22	18.45-35.30	Clay	10.0	—	1000.0 1000.0	130.405 298.905	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 15.00, β = 0.00, θ = 0.00

Ka = (cos²(φ - θ) / (cos θ · cos(δ + θ) · [1 + √(sin(φ + δ) · sin(φ - β - θ) / cos(δ + θ) · cos(-β))])²

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m³	φ degree	C kN/m²	Σ γ h + Op kN/m²	Kp	Kp × cos δ
7	5.33-6.12	Sand	7.5	36.2	—	0.000 5.925	7.02889 7.02889	4.78939 4.78939
8	6.12-7.12	Sand	7.5	32.3	—	5.925 13.425	5.63255 5.63255	5.44062 5.44062
9	7.12-7.36	Sand	7.5	31.4	—	13.425 15.225	5.36321 5.36321	5.18047 5.18047
10	7.36-8.12	Clay	6.5	0.0	100.0 100.0	15.225 20.165	—	—
11	8.12-9.12	Clay	6.5	0.0	100.0 100.0	20.165 26.665	—	—
12	9.12-10.12	Clay	6.5	0.0	100.0 100.0	26.665 33.165	—	—

11	8.12-9.12	-137.38 -130.88	31.31 34.56	31.31 34.56	37.24 37.24	220.16 226.66
12	9.12-10.12	-130.88 -124.38	34.56 37.81	34.56 37.81	37.24 37.24	226.66 233.17
13	10.12-11.12	-124.38 -117.88	37.81 41.06	37.81 41.06	37.24 37.24	233.17 239.67
14	11.12-12.12	-117.88 -111.38	41.06 44.31	41.06 44.31	37.24 37.24	239.67 246.17
15	12.12-13.12	-111.38 -104.88	44.31 47.56	44.31 47.56	37.24 37.24	246.17 252.67
16	13.12-14.12	-104.88 -98.38	47.56 50.81	47.56 50.81	37.24 37.24	252.67 259.17
17	14.12-15.12	-98.38 -91.88	50.81 54.06	50.81 54.06	37.24 37.24	259.17 265.67
18	15.12-16.12	-91.88 -85.38	54.06 57.31	54.06 57.31	37.24 37.24	265.67 272.17
19	16.12-17.12	-85.38 -78.88	57.31 60.56	57.31 60.56	37.24 37.24	272.17 278.67
20	17.12-18.02	-78.88 -72.03	60.56 63.48	60.56 63.48	37.24 37.24	278.67 285.17
21	18.02-18.45	-72.03 -65.20	63.48 65.20	63.48 65.20	37.24 37.24	285.17 291.67
22	18.45-35.30	-1869.59 -1701.09	65.20 149.45	65.20 149.45	37.24 37.24	291.67 2256.46

- Formula for active earth pressure

Sand Pa1 = Ka · [Σ γ h + Q / cos(-β)] · cos δ

Clay Pa1 = Σ γ h + Q - 2 C

Pa2 = Ka · (Σ γ h + Q)

Ka : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil Pa1 = [Ka · (Σ γ h + Q) - 2 C √Ka] · cos δ

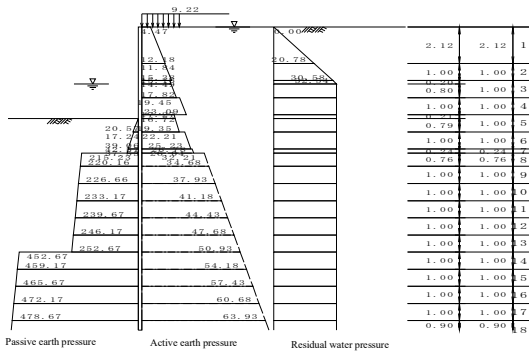
- Formula for passive earth pressure

Sand Pp = Kp · [Σ γ h + Q / cos(-β)] · cos δ

Clay Pp = Σ γ h + Q + 2 C

Mixed soil Pp = [Kp · (Σ γ h + Q) + 2 C √Kp] · cos δ

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Ka	Ka $\times \cos \delta$	ζ degree
1	0.00-2.12	Sand	7.5	27.0	—	9.22 25.12	0.00 20.78	0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
2	2.12-3.12	Sand	7.5	27.8	—	25.12 32.62	20.78 30.58	0.200	11.31	0.48814 0.48814	0.47151 0.47151	—
3	3.12-3.32	Sand	7.5	29.5	—	32.62 34.12	30.58 32.54	0.200	11.31	0.45999 0.45999	0.44432 0.44432	—
4	3.32-4.12	Sand	7.5	29.5	—	34.12 40.12	32.54 40.38	0.200	11.31	0.45999 0.45999	0.44432 0.44432	—
5	4.12-5.12	Sand	7.5	27.0	—	40.12 47.62	40.38 50.18	0.200	11.31	0.50201 0.50201	0.48490 0.48490	—
6	5.12-5.33	Sand	7.5	36.2	—	47.62 49.19	50.18 52.23	0.200	11.31	0.36344 0.36344	0.35106 0.35106	—
7	5.33-6.12	Sand	7.5	36.2	—	49.19 55.12	52.23 59.98	0.200	11.31	0.36344 0.36344	0.35106 0.35106	—
8	6.12-7.12	Sand	7.5	32.3	—	55.12 62.62	59.98 69.78	0.200	11.31	0.41711 0.41711	0.40290 0.40290	—
9	7.12-7.36	Sand	7.5	31.4	—	62.62 64.42	69.78 72.13	0.200	11.31	0.43046 0.43046	0.41579 0.41579	—
10	7.36-8.12	Clay	6.5	—	100.0 100.0	64.42 69.36	72.13 79.58	0.200	11.31	—	—	43.90 43.83
11	8.12-9.12	Clay	6.5	—	100.0 100.0	69.36 75.86	79.58 89.38	0.200	11.31	—	—	43.83 43.73
12	9.12-10.12	Clay	6.5	—	100.0 100.0	75.86 82.36	89.38 99.18	0.200	11.31	—	—	43.73 43.62
13	10.12-11.12	Clay	6.5	—	100.0 100.0	82.36 88.86	99.18 108.98	0.200	11.31	—	—	43.62 43.52
14	11.12-12.12	Clay	6.5	—	100.0 100.0	88.86 95.36	108.98 118.78	0.200	11.31	—	—	43.52 43.42

18	15.12-16.12	Clay	6.50	0.0	200.0 200.0	65.665 72.165	95.94 105.74	0.200	11.31	—	—	—
19	16.12-17.12	Clay	6.50	0.0	200.0 200.0	72.165 78.665	105.74 115.54	0.200	11.31	—	—	—
20	17.12-18.02	Clay	6.50	0.0	200.0 200.0	78.665 84.515	115.54 124.36	0.200	11.31	—	—	—
21	18.02-18.45	Clay	8.00	20.0	330.0 330.0	84.515 87.955	124.36 128.58	0.200	11.31	—	—	—
22	18.45-35.30	Clay	10.00	20.0	1000.0 1000.0	87.955 256.455	128.58 293.71	0.200	11.31	—	—	—

* The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-2.12	4.47 12.18	—	4.47 12.18	0.00 20.78	—
2	2.12-3.12	11.84 15.38	—	11.84 15.38	20.78 30.58	—
3	3.12-3.32	14.49 15.16	—	14.49 15.16	30.58 32.54	—
4	3.32-4.12	15.16 17.82	—	15.16 17.82	32.54 32.54	—
5	4.12-5.12	19.45 23.09	—	19.45 23.09	32.54 32.54	—
6	5.12-5.33	16.72 17.27	—	16.72 17.27	32.54 32.54	—
7	5.33-6.12	17.27 19.35	—	17.27 19.35	32.54 32.54	0.00 20.57
8	6.12-7.12	22.21 25.23	—	22.21 25.23	32.54 32.54	17.24 39.06
9	7.12-7.36	26.04 26.78	—	26.04 26.78	32.54 32.54	37.53 42.57
10	7.36-8.12	-122.35 -116.36	32.21 34.68	32.21 34.68	32.54 32.54	215.23 220.16
11	8.12-9.12	-116.36 -108.48	34.68 37.93	34.68 37.93	32.54 32.54	220.16 226.66
12	9.12-10.12	-108.48 -100.59	37.93 41.18	37.93 41.18	32.54 32.54	226.66 233.17
13	10.12-11.12	-100.59 -92.70	41.18 44.43	41.18 44.43	32.54 32.54	233.17 239.67
14	11.12-12.12	-92.70 -84.80	44.43 47.68	44.43 47.68	32.54 32.54	239.67 246.17

15	12.12-13.12	Clay	6.5	—	100.0 100.0	95.36 101.86	118.78 128.58	0.200 0.200	11.31 11.31	—	—	43.42 43.31
16	13.12-14.12	Clay	6.5	—	200.0 200.0	101.86 114.86	128.58 148.18	0.200 0.200	11.31 11.31	—	—	44.18 44.13
17	14.12-15.12	Clay	6.5	—	200.0 200.0	108.36 114.86	138.38 148.18	0.200 0.200	11.31 11.31	—	—	44.13 44.08
18	15.12-16.12	Clay	6.5	—	200.0 200.0	114.86 121.36	148.18 157.98	0.200 0.200	11.31 11.31	—	—	44.08 44.03
19	16.12-17.12	Clay	6.5	—	200.0 200.0	121.36 127.86	157.98 167.78	0.200 0.200	11.31 11.31	—	—	44.03 43.98
20	17.12-18.02	Clay	6.5	—	200.0 200.0	127.86 133.71	167.78 176.60	0.200 0.200	11.31 11.31	—	—	43.98 43.94
21	18.02-18.45	Clay	8.0	—	330.0 330.0	133.71 137.15	176.60 180.81	0.200 0.200	11.31 11.31	—	—	44.37 44.35
22	18.45-35.30	Clay	10.0	—	1000.0 1000.0	137.15 305.65	180.81 345.94	0.200 0.200	11.31 11.31	—	—	44.79 44.54

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

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

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ whw kN/m ²	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
7	5.33-6.12	Sand	7.50	36.2	—	0.000 5.925	0.00 7.74	0.200 0.200	11.31	3.47131 3.47131	3.47131 3.47131
8	6.12-7.12	Sand	7.50	32.3	—	5.925 13.425	7.74 17.54	0.200 0.200	11.31	2.90961 2.90961	2.90961 2.90961
9	7.12-7.36	Sand	7.50	31.4	—	13.425 15.225	17.54 19.49	0.200 0.200	11.31	2.79588 2.79588	2.79588 2.79588
10	7.36-8.12	Clay	6.50	0.0	100.0 100.0	15.225 20.165	19.49 27.34	0.200 0.200	11.31	—	—
11	8.12-9.12	Clay	6.50	0.0	100.0 100.0	20.165 26.665	27.34 37.14	0.200 0.200	11.31	—	—
12	9.12-10.12	Clay	6.50	0.0	100.0 100.0	26.665 33.165	37.14 46.94	0.200 0.200	11.31	—	—
13	10.12-11.12	Clay	6.50	0.0	100.0 100.0	33.165 39.665	46.94 56.74	0.200 0.200	11.31	—	—
14	11.12-12.12	Clay	6.50	0.0	100.0 100.0	39.665 46.165	56.74 66.54	0.200 0.200	11.31	—	—
15	12.12-13.12	Clay	6.50	0.0	100.0 100.0	46.165 52.665	66.54 76.34	0.200 0.200	11.31	—	—
16	13.12-14.12	Clay	6.50	0.0	200.0 200.0	52.665 59.165	76.34 86.14	0.200 0.200	11.31	—	—
17	14.12-15.12	Clay	6.50	0.0	200.0 200.0	59.165 65.665	86.14 95.94	0.200 0.200	11.31	—	—

15	12.12-13.12	-84.80 -76.88	47.68 50.93	47.68 50.93	32.54 32.54	246.17 252.67
16	13.12-14.12	-277.35 -269.49	50.93 54.18	50.93 54.18	32.54 32.54	452.67 459.17
17	14.12-15.12	-269.49 -261.63	54.18 57.43	54.18 57.43	32.54 32.54	459.17 465.67
18	15.12-16.12	-261.63 -253.77	57.43 60.68	57.43 60.68	32.54 32.54	465.67 472.17
19	16.12-17.12	-253.77 -245.90	60.68 63.93	60.68 63.93	32.54 32.54	472.17 478.67
20	17.12-18.02	-245.90 -238.82	63.93 66.85	63.93 66.85	32.54 32.54	478.67 484.52
21	18.02-18.45	-499.12 -494.97	66.85 68.57	66.85 68.57	32.54 32.54	744.52 747.96
22	18.45-35.30	-1835.28 -1632.50	68.57 152.82	68.57 152.82	32.54 32.54	2087.96 2256.46

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$
$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$
$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : 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

$$\text{Sand } P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$$
$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

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	water level, y, m	pdw, kN/m ²
1	3.32	0.00	0.00
2	4.32	1.00	2.43
3	5.32	2.00	3.44
4	5.33	2.01	3.45

$$p_{dw} = \pm \frac{\gamma}{8} k_{dw} \cdot \gamma \cdot \sqrt{H \cdot y}$$

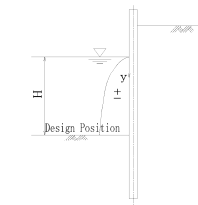
Where,

k_{dw} : design seismic coefficient

γ_w : unit weight of water

H: water depth of riverside

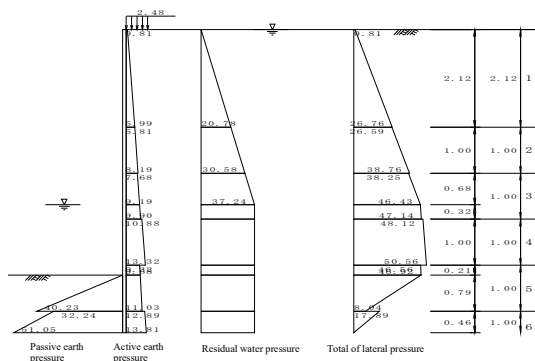
y: depth from water surface to the point where active water pressure is calculated



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



No	Depth, m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00-2.12	0.81 5.99	0.00 20.78	— —	0.81 26.76
2	2.12-3.12	5.81 8.19	20.78 30.58	— —	26.59 38.76
3	3.12-3.80	7.68 9.19	30.58 37.24	— —	38.25 46.43
4	3.80-4.12	9.19 9.90	37.24 37.24	— —	46.43 47.14

6	5.12-5.33	16.72 17.27	32.54 32.54	— —	49.25 49.80
7	5.33-6.12	17.27 19.35	32.54 32.54	0.00 20.57	49.80 31.32
8	6.12-7.12	22.21 25.23	32.54 32.54	17.24 39.06	37.00 18.70
9	7.12-7.36	26.04 26.78	32.54 32.54	37.53 42.57	21.04 16.75
10	7.36-8.12	32.21 34.68	32.54 32.54	215.23 220.16	-150.48 -152.95

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 : 2.03 m (GL -7.36 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{\Delta} = K_{10} \left(\frac{B_{\Delta}}{0.3} \right)^{-3/4} \quad (B_{\Delta} = 10.00 \text{ m})$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_{\Delta} = 2800 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_{\Delta} \cdot B}{4 E I}}$$

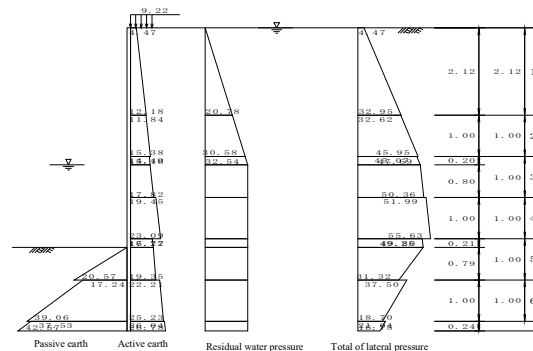
Material Name 10_H 800-250-14-22-18
 Unit width $B = 1.0000 \text{ m}$
 Corrosion margin $t_1 = 1.00 \text{ mm}$ (active side) $t_2 = 1.00 \text{ mm}$ (passive side)
 Corrosion rate $\eta = 0.86$
 Section efficiency $\mu = 1.00$
 Young's modulus $E = 200000 \text{ N/mm}^2$
 Inertia sectional moment $I_0 = 741700 \text{ cm}^4$ (original condition)
 $I = 405662 \text{ cm}^4$ (after reduction by corrosion and section)
 Inertia sectional moment $EI = 200000 \times 10^3 \times 405662 \times 10^{-8} = 8.113 \times 10^5$

5	4.12-5.12	10.88 13.32	37.24 37.24	— —	48.12 50.56
6	5.12-5.33	9.32 9.68	37.24 37.24	— —	46.56 46.92
7	5.33-6.12	9.68 11.03	37.24 37.24	0.00 40.23	46.92 8.04
8	6.12-6.58	12.89 13.81	37.24 37.24	32.24 51.05	17.89 0.00
9	6.58-7.12	13.81 14.89	37.24 37.24	51.05 73.04	0.00 -20.91

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 : 1.25 m (GL -6.58 m)

4.2 Seismic Condition



No	Depth, m	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²	Ps kN/m ²
1	0.00-2.12	4.47 12.18	0.00 20.78	— —	4.47 32.95
2	2.12-3.12	11.84 15.38	20.78 30.58	— —	32.62 45.95
3	3.12-3.32	14.49 15.16	30.58 32.54	— —	45.07 47.69
4	3.32-4.12	15.16 17.82	32.54 32.54	— —	47.69 50.36
5	4.12-5.12	19.45 23.09	32.54 32.54	— —	51.99 55.63

No	Depth, m	N Value	No	Depth, m	N Value
1	1.62	6	11	11.62	23
2	2.62	11	12	12.62	25
3	3.62	14	13	13.62	40
4	4.62	9	14	14.62	47
5	5.62	30	15	15.62	43
6	6.62	20	16	16.62	47
7	7.62	18	17	17.62	50
8	8.62	21			
9	9.62	19			
10	10.62	23			

5.2 Normal Condition

Assuming $K_h = 13329 \text{ kN/m}^3$,

$$\beta = 4 \sqrt{\frac{K_{\Delta} \cdot B}{4 E I}} = 0.253 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.95 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.58 m) to 3.95 m depth (GL -10.53 m).

No	Depth, m	Thickness, h, m	N Value, upper	N Value, lower	Area, A
1	6.58	0.04	20.4	20.0	0.79
2	6.62	1.00	20.0	18.0	19.00
3	7.62	1.00	18.0	21.0	19.50
4	8.62	1.00	21.0	19.0	20.00
5	9.62	0.91	19.0	22.6	18.97

$$L = \Sigma h = 3.95 \quad \Sigma A = 78.26$$

$$A : (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\text{Average N-value } N' = \frac{\Sigma A}{L} = \frac{78.26}{3.95} = 19.81$$

K_h is recalculated from the calculated average N-value.

$$E_0 = 2800 N' = 2800 \times 19.81 = 55473 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 55473 = 184909 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_{\Delta} = K_{10} (B_{\Delta}/0.3)^{-3/4} = 184909 (10.00/0.3)^{-3/4} = 13329 \text{ kN/m}^3$$

Thus, the assumed K_h is equal to the recalculated K_h .
The lateral subgrade reaction coefficient K_h (Normal Condition) is 13329 kN/m³.

5.3 Seismic Condition

Assuming Kh = 26993 kN/m3,

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0,302 \text{ m}^{-1}$$
$$L = \frac{1}{\beta} = 3,31 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -7.36 m) and 3.31 m depth (GL -10.67 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	7.36	0.26	18.5	18.0	4.75
2	7.62	1.00	18.0	21.0	19.50
3	8.62	1.00	21.0	19.0	20.00
4	9.62	1.00	19.0	23.0	21.00
5	10.62	0.05	23.0	23.0	1.18
L = Σh = 3.31			ΣA = 66.43		

A: (upper N-value + lower N-value) × h/2

Average N-value

$$N' = \frac{\Sigma A}{L} = \frac{66,43}{3,31} = 20,06$$

Kh is recalculated from the calculated average N value.

$$E_o = 2800N' = 2800 \times 20.06 = 56170 \text{ kN/m}^2$$
$$K_{10} = \frac{1}{0,3} \times \alpha \times 56170 = 374465 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$
$$K_b = K_{10} (B_o/0,3)^{-3/4} = 374465 (10,00/0,3)^{-3/4} = 26993 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 26993 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P _o kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 2.12	2.12	4.47 32.95	4.74 34.93	6.65 5.95	31.32 207.73
2	2.12- 3.12	1.00	32.62 45.95	16.31 22.98	4.91 4.57	80.02 105.08
3	3.12- 3.32	0.20	45.07 47.69	4.51 4.77	4.17 4.11	18.81 19.59
4	3.32- 4.12	0.80	47.69 50.36	19.08 20.14	3.77 3.51	71.99 70.64
5	4.12- 5.12	1.00	51.99 55.63	25.99 27.81	2.91 2.57	75.36 71.57
6	5.12- 5.33	0.21	49.25 49.80	5.17 5.23	2.17 2.10	11.22 10.98
7	5.33- 6.12	0.79	49.80 31.32	19.67 12.37	1.77 1.50	34.76 18.60
8	6.12- 7.12	1.00	37.50 18.70	18.75 9.35	0.91 0.57	17.00 5.36
9	7.12- 7.36	0.24	21.04 16.75	2.52 2.01	0.16 0.08	0.40 0.16
ΣP = 256.34			ΣM = 850.98			

P_o : active earth pressure + residual water pressure - passive earth pressure
P : load P_o 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

depth to acting position

moment

depth to acting position

Height from riverbed to top of coping

Depth of Imaginary riverbed from riverbed

P_o = 0.0 kN/m
H_o = 0.00 m
M_o = 0.0 kN·m/m
H_o = 0.00 m
H = 5.33 m
L_k = 2.03 m

Moment M_o by arbitrary load is as below

M_o = P_o·(H + L_k - H_o) + M_o = 0.00 kN·m

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dw} kN/m ²	Loads P _{dw} kN	Arm length Y m	Moment M _{dw} kN · m
1	3.32- 4.32	1.00	0.0 2.4	0.00 1.22	2.71 3.37	3.29 4.10
2	4.32- 5.32	1.00	2.4 3.4	1.22 1.72	2.71 2.37	3.29 4.08
3	5.32- 5.33	0.01	3.4 3.4	0.02 0.02	2.04 2.03	0.04 0.04
Σ P _{dw} = 4.19			Σ M _{dw} = 11.54			

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P _o kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 2.12	2.12	0.81 26.76	0.86 28.37	5.87 5.17	5.02 146.61
2	2.12- 3.12	1.00	26.59 38.76	13.29 19.38	4.13 3.79	54.88 73.54
3	3.12- 3.80	0.68	38.25 46.43	13.01 15.79	3.23 3.01	42.07 47.48
4	3.80- 4.12	0.32	46.43 47.14	7.43 7.54	2.67 2.57	19.87 18.37
5	4.12- 5.12	1.00	48.12 50.56	24.06 25.28	2.13 1.79	51.19 45.36
6	5.12- 5.33	0.21	46.56 46.92	4.89 4.93	1.39 1.32	6.80 6.51
7	5.33- 6.12	0.79	46.92 8.04	18.53 3.18	0.99 0.72	18.30 2.30
8	6.12- 6.58	0.46	17.89 0.00	4.12 0.00	0.31 0.15	1.27 0.00
Σ P = 190.65			Σ M = 540.56			

P_o : active earth pressure + residual water pressure - passive earth pressure
P : load P_o 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

depth to acting position

moment

depth to acting position

Height from riverbed to top of coping

Depth of Imaginary riverbed from riverbed

P_o = 0.0 kN/m
H_o = 0.0 m
M_o = 0.0 kN·m/m
H_o = 0.00 m
H = 5.33 m
L_k = 1.25 m

Moment M_o by arbitrary load is as below

M_o = P_o·(H + L_k - H_o) + M_o = 0.00 kN·m

h_o, Height of acting position of P_o from imaginary riverbed

$$h_o = \frac{M_o}{P_o} = \frac{\Sigma M + M_i}{\Sigma P + P_i} = \frac{540,56}{190,65} = 2.84 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_o}{(H + L_o)} = \frac{2 \times 190,65}{6,58} = 57,94 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name

Unit width

Corrosion margin

Corrosion rate

Section efficiency

Young's modulus

Inertia sectional moment

EI = 200000 × 10³ × 405662 × 10⁻⁸

10 H_o H 800 -250 -14 -22 -18
B = 1.0000 m
t_c = 1.00 mm (active side) t₂ = 1.00 mm (passive side)
η = 0.86
μ = 1.00
E = 200000 N/mm²
I_o = 471700 cm⁴ (original condition)
I = 405662 cm⁴ (after reduction by corrosion and section)
= 8.113 × 10⁵

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$
$$\phi_a = \frac{\sqrt{(1 + 2 \beta h_o)^2 + 1}}{2 \beta h_o} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_o})$$
$$M_{max} = M_o \cdot \phi_a$$
$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_o}$$
$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_o}{\beta h_o}$$
$$M_{(x)} = \frac{P_o}{\beta} \times \exp^{-\beta x} (\beta h_o \cdot \cos \beta x + (1 + \beta h_o) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction

calculated value

resultant earth force (lateral)

height of acting position of load

moment

K_b = 13229 kN/m³
β = 0.25315 m⁻¹
P_o = 190.65 kN/m
h_o = 2.84 m
M_o = 540.56 kN·m/m

in consideration of ψ_{ho} = 1.242,

maximum moment

depth of generated position of M_{max}

depth of 1st fixed point

M_{max} = 671.51 kN·m/m
l_m = 1.539 m
l_i = 4.641 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_b	=	26993 kN/m ³
calculated value	β	=	0.30199 m ³
resultant earth force (lateral)	P_0	=	260.53 kN/m
height of acting position of load	h_0	=	3.31 m
moment	M_0	=	862.52 kN·m/m
in consideration of $\psi_m = 1.146$, maximum moment	M_{max}	=	988.61 kN·m/m
depth of generated position of M_{max}	l_m	=	1.066 m
depth of 1° fixed point	l_i	=	3.666 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name	10 H H 800 -250 -14 -22 -18
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Module of section	$Z_0 = 8240$ cm ³ (original condition)
	$Z = 8240$ cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{671.51 \times 10^6}{8240 \times 10^3} = 81 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

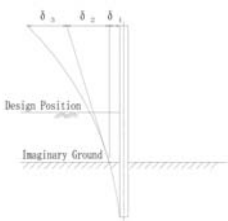
6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{988.61 \times 10^6}{8240 \times 10^3} = 120 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

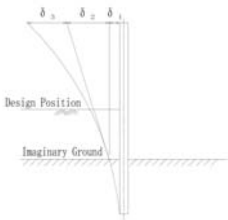
6.4.1 Normal Condition

Displacement Calculation

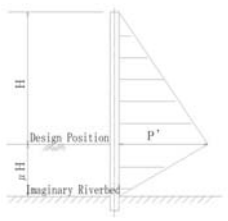


6.4.2 Seismic Condition

Displacement Calculation



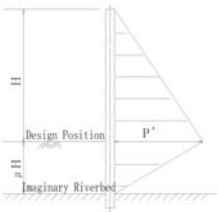
$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.3020 \times 3.31) \times 260.53}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.3020^3} = 0.01166 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_i) \\ &= \frac{(1 + 2 \times 0.3020 \times 3.31) \times 260.53}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.3020^2} \times (5.33 + 2.03) = 0.03887 \text{ m} \end{aligned}$$



$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{2.03}{5.33} = 0.381 \\ \delta_3 &= \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4) \\ &= \frac{70.80 \times 5.33^4}{120 \times 2.00 \times 10^8 \times 405662 \times 10^{-8}} (4 + 20 \times 0.381 + 40 \times 0.381^2 + 35 \times 0.381^3 + 11 \times 0.381^4) \\ &= 0.01149 \text{ m} \end{aligned}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2532 \times 2.84) \times 190.65}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.2532^3} = 0.01244 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_i) \\ &= \frac{(1 + 2 \times 0.2532 \times 2.84) \times 190.65}{2 \times 2.00 \times 10^8 \times 405662 \times 10^{-8} \times 0.2532^2} \times (5.33 + 1.25) = 0.02939 \text{ m} \end{aligned}$$



$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{1.25}{5.33} = 0.235 \\ \delta_3 &= \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4) \\ &= \frac{57.94 \times 5.33^4}{120 \times 2.00 \times 10^8 \times 405662 \times 10^{-8}} (4 + 20 \times 0.235 + 40 \times 0.235^2 + 35 \times 0.235^3 + 11 \times 0.235^4) \\ &= 0.00547 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01244 + 0.02939 + 0.00547 \\ &= 0.04729 \text{ m} \\ \text{Size} &= 47.29 \text{ mm} \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

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

$$\begin{aligned} &= 0.01166 + 0.03887 + 0.01149 \\ &= 0.06202 \text{ m} \\ \text{Size} &= 62.02 \text{ mm} \leq \delta_a = 75.00 \text{ mm} \end{aligned}$$

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:

Material Name	10 H H 800 -250 -14 -22 -18
Unit width	$B = 1.0000$ m
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Young's modulus	$E = 200000$ N/mm ²
Inertia sectional moment	$I_0 = 471700$ cm ⁴ (original condition)
	$I = 471700$ cm ⁴ (after reduction by corrosion and section)
	$EI = 200000 \times 10^3 \times 471700 \times 10^{-8} = 9.434 \times 10^8$

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:

$$\begin{aligned} D &= L_k + \frac{3}{\beta} \\ L &= H - H_{i1} + D \\ \beta &= 4 \sqrt{\frac{K_b \cdot B}{4 E I}} \end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	$K_b = 13329$ kN/m ³
Calculated value	$\beta = 0.24379$ m ⁻¹
Penetration length of SSP	$D = 1.25 + \frac{3}{0.244} = 13.56$ m
Whole length of SSP	$L = 5.33 - 0.40 + 13.56 = 18.49$ m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	$K_b = 26993$ kN/m ³
Calculated value	$\beta = 0.29082$ m ⁻¹
Penetration length of SSP	$D = 2.03 + \frac{3}{0.291} = 12.35$ m
Whole length of SSP	$L = 5.33 - 0.40 + 12.35 = 17.28$ m

Therefore, the total length of the sheet pile is 18.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H _ H 800 -250 -14 -22 -18				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm4)	471700		
Sectional Modulus	Z (cm3)	8240		
Maximum bending moment	Mmax (kN · m · m)		671.51	988.61
Stress intensity	σ (N/mm2)		811 (180)	120 (270)
Lateral displacement	δ (mm)		47.29 (50.0)	62.02 (75.0)
Penetration depths	D (m)		13.56	12.35
Whole length of SSP	L (m)	18.50		

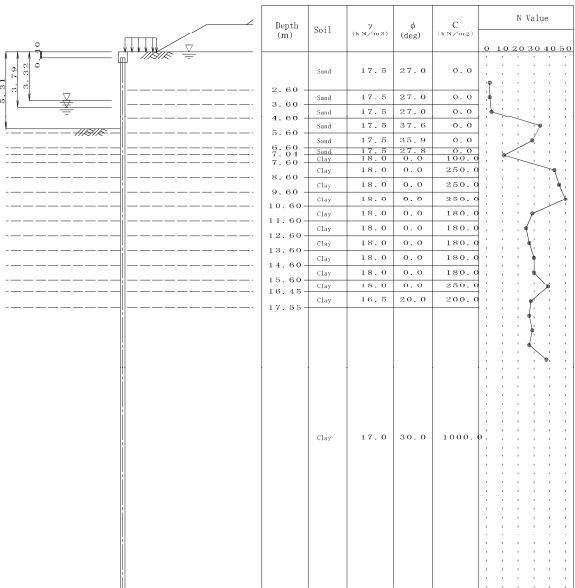
Block No. : R-37
Sta. : 12+660~12+740

Design Cross Section : Sta 12+660
Boring Name : BMRL-38

Specification : SSP SP-10H
(Combined) : H 700-250-12-16-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed H = 5.31 m
Depth from coping top to rear side ground H₀ = 0.00 m
Depth from coping top to SSP top H_h = 0.40 m
Landside WL L_{wa} = 0.00 m (Normal Condition)
L_{wa'} = 0.00 m (Seismic Condition)
Riverside WL L_{wsp} = 3.79 m (Normal Condition)
L_{wsp'} = 3.32 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered
Angle of rupture (clayey soil) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{10} \left(\frac{B_H}{0.3} \right)^{-3/4}$
 $K_{10} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismi Condition =2)
 $B_H = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

No	Depth m	N Value	No	Depth m	N Value
1	2.10	2	11	12.10	25
2	3.10	2	12	13.10	27
3	4.10	3	13	14.10	30
4	5.10	34	14	15.10	30
5	6.10	29	15	16.10	39
6	7.10	11	16	17.10	28
7	8.10	43	17	18.10	27
8	9.10	46	18	19.10	29
9	10.10	50	19	20.10	27
10	11.10	29	20	21.10	38

No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	2.60	2.60
2	3.60	1.00
3	4.60	1.00
4	5.60	1.00
5	6.60	1.00
6	7.04	0.44
7	7.60	0.56
8	8.60	1.00
9	9.60	1.00
10	10.60	1.00
11	11.60	1.00
12	12.60	1.00
13	13.60	1.00
14	14.60	1.00
15	15.60	1.00
16	16.45	0.85
17	17.55	1.10
18	35.30	17.75

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	2.60 S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	
2	4.60 S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	
3	4.60 S	3.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto	
4	5.60 S	3.40	17.50	7.70	27.6	0.0	0.0	0.200	Auto	Auto	
5	5.60 S	28.0	17.50	7.70	35.9	0.0	0.0	0.200	Auto	Auto	
6	7.60 S	11.0	17.50	7.70	27.6	0.0	0.0	0.200	Auto	Auto	
7	7.60 S	11.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto	
8	9.60 C	8.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	
9	9.60 C	46.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	
10	11.60 C	50.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto	
11	11.60 C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	
12	12.60 C	25.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto	

Material name	10 H		H 700 -250 - 12-16-18	
Young's modulus	E	=	200000 N/mm ²	
Inertia sectional moment	I ₀	=	308300 cm ⁴	
Sectional factor	Z ₀	=	5740 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 _s	=	180 N/mm (Normal)	
	σ _s '	=	270 N/mm (Seismic)	
Allowable displacement	δ _s	=	50.0 mm (Normal)	
	δ _s '	=	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 Not reduced: I ₀ applied to calculation of penetration depth Reduced: I ₀ applied to calculation of section forces and d Reduced: Z ₀ applied to calculation of stresses			

[illegible]

No	Depth m	Soil	N Value	γ	γ'	ϕ	C	a	k'	ζ (degree)	
				kN/m ³	kN/m ³	degree	kN/m ²			Normal Condition	Seismic Condition
13	13.66	C	27.6	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	30.00	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	15.69	C	30.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	16.45	C	39.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	17.55	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
18	35.30	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.300	Auto	Auto

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

2.60	1
1.00	2
1.00	3

No	Soil	X Coordinate				Thickness h	soil single weight γ Normal Condition kN/m ³	internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ Normal Condition degree	Scientific Condition degree	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m							
1	Sand	2.15	5.58	30.00	30.00	1.92	19.0	19.0	30.0	0.0	Auto	Auto
2	Sand	8.32	10.75	30.00	30.00	1.86	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	2.15	5.0	0.0

No	Depth, m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ when kN/m ³	Angle of Repose ϕ degree
1	5.31 - 4.60	Sand	37.6	15.0	0.0	40.89	7.69	52.04	61.70
2	4.60 - 3.60	Sand	27.0	15.0	0.0	35.42	7.69	45.08	54.81
3	3.60 - 2.60	Sand	27.0	15.0	0.0	27.72	7.69	35.28	54.81
4	2.60 - 0.00	Sand	27.0	15.0	0.0	20.02	7.69	25.48	54.81
5	embankment	embankment	30.0	—	0.0	71.82	0.00	0.00	60.00

• Angle of active rupture of sandy soil

$$\zeta = 90^\circ - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• 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 $\theta = 0^\circ$

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)

No	Angle of Rupture $\angle$ degree	Thickness Z (m)	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	61.70	0.71	0.00	0.00	0.38	0.71
2	54.81	1.00	0.38	0.71	1.09	1.71
3	54.81	1.00	1.09	1.71	1.79	2.71
4	54.81	2.60	1.79	2.71	3.63	5.31
5	60.00	1.22	3.63	5.31	4.33	6.53

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.90	17.12
Σ			17.12

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

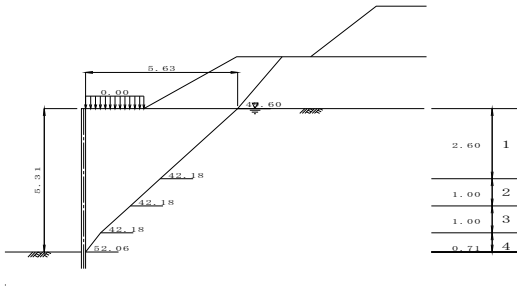
No	Q kN/m2	l m	Qxl kN/m
1	5.0	2.15	10.75
Σ			10.75

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{17.12 + 10.75 + 0.00}{3.63}$$
$$= 7.69 \text{ kN/m}^2$$

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ whw kN/m2	k (t)	θ degree	Angle of Rupture ζ degree
1	5.31~4.60	Sand	37.6	15.0	0.0	40.89	16.73	52.04	0.200	11.31	52.06
2	4.60~3.60	Sand	27.0	15.0	0.0	35.42	16.73	45.08	0.200	11.31	42.18
3	3.60~2.60	Sand	27.0	15.0	0.0	27.72	16.73	35.28	0.200	11.31	42.18
4	2.60~0.00	Sand	27.0	15.0	0.0	20.02	16.73	25.48	0.200	11.31	42.18
5		embankment t	30.0	—	0.0	71.82	0.00	0.00	0.200	11.31	49.60

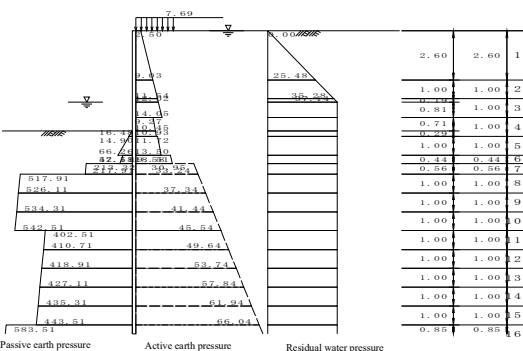
• Major collapse angle of Sand, intermediate soil, and split rock

2.2.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{94.20 + 0.00 + 0.00}{5.63}$$
$$= 16.73 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qe kN/m2	Ka	Ka × cos δ
1	0.00~ 2.60	Sand	7.7	27.0	—	7.686 27.706	0.33738 0.33738	0.32589 0.32589
2	2.60~ 3.60	Sand	7.7	27.0	—	27.706 35.406	0.33738 0.33738	0.32589 0.32589
3	3.60~ 3.79	Sand	7.7	27.0	—	35.406 36.869	0.33738 0.33738	0.32589 0.32589
4	3.79~ 4.60	Sand	7.7	27.0	—	36.869 43.106	0.33738 0.33738	0.32589 0.32589
5	4.60~ 5.31	Sand	7.7	37.6	—	43.106 48.573	0.22267 0.22267	0.21508 0.21508
6	5.31~ 5.60	Sand	7.7	37.6	—	48.573 50.806	0.22267 0.22267	0.21508 0.21508
7	5.60~ 6.60	Sand	7.7	35.9	—	50.806 58.506	0.23887 0.23887	0.23073 0.23073

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) \cdot \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

• Major collapse angle of cohesive 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⁻¹ k or θ = 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	52.06	0.71	0.00	0.00	0.55	0.71
2	42.18	1.00	0.55	0.71	1.66	1.71
3	42.18	1.00	1.66	1.71	2.76	2.71
4	42.18	2.60	2.76	2.71	5.63	5.31
5	49.60	1.92	5.63	5.31	7.26	7.23

From the above table, the loading width (L) on the ground surface is 5.63 m.

2.2.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	4.96	94.20
Σ			94.20

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	Qxl kN/m
1	0.0	2.15	0.00
Σ			0.00

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

8	6.60~ 7.04	Sand	7.7	27.8	—	58.506 61.894	0.32749 0.32749	0.31633 0.31633
9	7.04~ 7.60	Clay	8.2	—	100.0	61.894 66.486	—	—
10	7.60~ 8.60	Clay	8.2	—	250.0	66.486 74.686	—	—
11	8.60~ 9.60	Clay	8.2	—	250.0	74.686 82.886	—	—
12	9.60~ 10.60	Clay	8.2	—	250.0	82.886 91.086	—	—
13	10.60~ 11.60	Clay	8.2	—	180.0	91.086 99.286	—	—
14	11.60~ 12.60	Clay	8.2	—	180.0	99.286 107.486	—	—
15	12.60~ 13.60	Clay	8.2	—	180.0	107.486 115.686	—	—
16	13.60~ 14.60	Clay	8.2	—	180.0	115.686 123.886	—	—
17	14.60~ 15.60	Clay	8.2	—	180.0	123.886 132.086	—	—
18	15.60~ 16.45	Clay	8.2	—	250.0	132.086 139.056	—	—
19	16.45~ 17.55	Clay	6.7	—	200.0	139.056 146.426	—	—
20	17.55~ 35.30	Clay	7.2	—	1000.0	146.426 274.226	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 15.00, 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

No	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qp kN/m2	Kp	Kp × cos δ
6	5.31~ 5.60	Sand	7.7	37.6	—	0.000 2.233	7.64187 7.64187	7.38148 7.38148
7	5.60~ 6.60	Sand	7.7	35.9	—	2.233 9.933	6.90618 6.90618	6.67085 6.67085
8	6.60~ 7.04	Sand	7.7	27.8	—	9.933 13.321	4.43813 4.43813	4.28690 4.28690
9	7.04~ 7.60	Clay	8.2	0.0	100.0	13.321 17.913	—	—
10	7.60~ 8.60	Clay	8.2	0.0	250.0	17.913 26.113	—	—
11	8.60~ 9.60	Clay	8.2	0.0	250.0	26.113 34.313	—	—
12	9.60~ 10.60	Clay	8.2	0.0	250.0	34.313 42.513	—	—
13	10.60~ 11.60	Clay	8.2	0.0	180.0	42.513 50.713	—	—

14	11.60- 12.60	Clay	8.2	0.0	180.0 180.0	50.713 58.913	=====	=====
15	12.60- 13.60	Clay	8.2	0.0	180.0 180.0	58.913 67.113	=====	=====
16	13.60- 14.60	Clay	8.2	0.0	180.0 180.0	67.113 75.313	=====	=====
17	14.60- 15.60	Clay	8.2	0.0	180.0 180.0	75.313 83.513	=====	=====
18	15.60- 16.45	Clay	8.2	0.0	250.0 250.0	83.513 90.483	=====	=====
19	16.45- 17.55	Clay	6.7	20.0	200.0 200.0	90.483 97.853	=====	=====
20	17.55- 35.30	Clay	7.2	30.0	1000.0 1000.0	97.853 225.653	=====	=====

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2		Pp kN/m2	
1	0.00- 2.60	2.50 9.03	=====	2.50 9.03	0.00 25.48		=====	
2	2.60- 3.60	9.03 11.54	=====	9.03 11.54	25.48 35.28		=====	
3	3.60- 3.79	11.54 12.02	=====	11.54 12.02	35.28 37.14		=====	
4	3.79- 4.60	12.02 14.05	=====	12.02 14.05	37.14 37.14		=====	
5	4.60- 5.31	9.27 10.45	=====	9.27 10.45	37.14 37.14		=====	
6	5.31- 5.60	10.45 10.93	=====	10.45 10.93	37.14 37.14	0.00 16.48		
7	5.60- 6.60	11.72 13.50	=====	11.72 13.50	37.14 37.14	14.90 66.26		
8	6.60- 7.04	18.51 19.58	=====	18.51 19.58	37.14 37.14	42.58 57.11		
9	7.04- 7.60	-138.11 -133.51	30.95 33.24	30.95 33.24	37.14 37.14	213.32 217.91		
10	7.60- 8.60	-433.51 -423.31	33.24 37.34	33.24 37.34	37.14 37.14	517.91 526.11		
11	8.60- 9.60	-425.31 -417.11	37.34 41.44	37.34 41.44	37.14 37.14	526.11 534.31		
12	9.60- 10.60	-417.11 -408.91	41.44 45.54	41.44 45.54	37.14 37.14	534.31 542.51		
13	10.60- 11.60	-268.91 -260.71	45.54 49.64	45.54 49.64	37.14 37.14	402.51 410.71		

14	11.60- 12.60	-260.71 -252.51	49.64 53.74	49.64 53.74	37.14 37.14	410.71 418.91
15	12.60- 13.60	-252.51 -244.31	53.74 57.84	53.74 57.84	37.14 37.14	418.91 427.11
16	13.60- 14.60	-244.31 -236.11	57.84 61.94	57.84 61.94	37.14 37.14	427.11 435.31
17	14.60- 15.60	-236.11 -227.91	61.94 66.04	61.94 66.04	37.14 37.14	435.31 443.51
18	15.60- 16.45	-237.91 -260.94	66.04 69.53	66.04 69.53	37.14 37.14	443.51 490.48
19	16.45- 17.55	-260.94 -253.57	69.53 73.21	69.53 73.21	37.14 37.14	490.48 497.85
20	17.55- 35.30	-1853.57 -1725.77	73.21 137.11	73.21 137.11	37.14 37.14	2097.85 2226.65

- Formula for active earth pressure

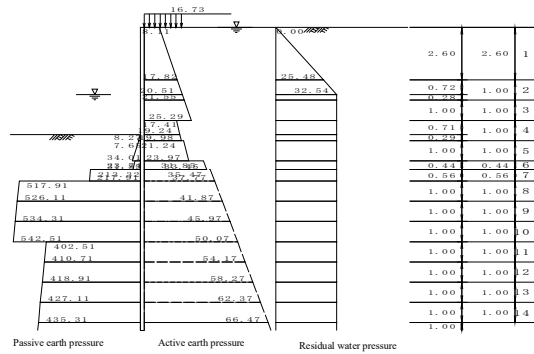
$$\begin{aligned} \text{Sand} \quad P_{a1} &= K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_{a1} &= \Sigma \gamma h + Q - 2 C \\ P_{a2} &= K_a \cdot (\Sigma \gamma h + Q) \\ K_a &: \text{Equilibrium coefficient of compression: } 0.5 \\ &\text{Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)} \end{aligned}$$

$$\text{Mixed soil} \quad P_{a1} = [K_a (\Sigma \gamma h + Q) - 2 C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\begin{aligned} \text{Sand} \quad P_p &= K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta \\ \text{Clay} \quad P_p &= \Sigma \gamma h + Q + 2 C \\ \text{Mixed soil} \quad P_p &= [K_p (\Sigma \gamma h + Q) + 2 C \sqrt{K_p}] \cdot \cos \delta \end{aligned}$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γ whw kN/m2	k (k')	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 2.60	Sand	7.7	27.0	=====	16.73 36.75	0.00 25.48	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
2	2.60- 3.32	Sand	7.7	27.0	=====	36.75 42.30	25.48 32.54	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
3	3.32- 3.60	Sand	7.7	27.0	=====	42.30 44.45	32.54 35.28	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
4	3.60- 4.60	Sand	7.7	27.0	=====	44.45 52.15	35.28 45.08	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	=====
5	4.60- 5.31	Sand	7.7	37.6	=====	52.15 57.62	45.08 52.04	0.200 0.200	11.31 11.31	0.34567 0.34567	0.33389 0.33389	=====
6	5.31- 5.60	Sand	7.7	37.6	=====	57.62 59.85	52.04 54.88	0.200 0.200	11.31 11.31	0.34567 0.34567	0.33389 0.33389	=====
7	5.60- 6.60	Sand	7.7	35.9	=====	59.85 67.55	54.88 64.68	0.200 0.200	11.31 11.31	0.36735 0.36735	0.35483 0.35483	=====
8	6.60- 7.04	Sand	7.7	27.8	=====	67.55 70.94	64.68 68.99	0.200 0.200	11.31 11.31	0.48814 0.48814	0.47151 0.47151	=====
9	7.04- 7.60	Clay	8.2	=====	100.0 100.0	70.94 75.53	68.99 74.48	0.200 0.200	11.31 11.31	=====	=====	43.69 43.61
10	7.60- 8.60	Clay	8.2	=====	250.0 250.0	75.53 83.73	74.48 84.28	0.200 0.200	11.31 11.31	=====	=====	44.46 44.41
11	8.60- 9.60	Clay	8.2	=====	250.0 250.0	83.73 91.93	84.28 94.08	0.200 0.200	11.31 11.31	=====	=====	44.41 44.36
12	9.60- 10.60	Clay	8.2	=====	250.0 250.0	91.93 100.13	94.08 103.88	0.200 0.200	11.31 11.31	=====	=====	44.36 44.31
13	10.60- 11.60	Clay	8.2	=====	180.0 180.0	100.13 108.33	103.88 113.68	0.200 0.200	11.31 11.31	=====	=====	44.04 43.97
14	11.60- 12.60	Clay	8.2	=====	180.0 180.0	108.33 116.53	113.68 123.48	0.200 0.200	11.31 11.31	=====	=====	43.97 43.90
15	12.60- 13.60	Clay	8.2	=====	180.0 180.0	116.53 124.73	123.48 133.28	0.200 0.200	11.31 11.31	=====	=====	43.90 43.83
16	13.60- 14.60	Clay	8.2	=====	180.0 180.0	124.73 132.93	133.28 143.08	0.200 0.200	11.31 11.31	=====	=====	43.83 43.76
17	14.60- 15.60	Clay	8.2	=====	180.0 180.0	132.93 141.13	143.08 152.88	0.200 0.200	11.31 11.31	=====	=====	43.76 43.69
18	15.60- 16.45	Clay	8.2	=====	250.0 250.0	141.13 148.10	152.88 161.21	0.200 0.200	11.31 11.31	=====	=====	44.07 44.02
19	16.45- 17.55	Clay	6.7	=====	200.0 200.0	148.10 155.47	161.21 171.99	0.200 0.200	11.31 11.31	=====	=====	43.77 43.71
20	17.55- 35.30	Clay	7.2	=====	1000.0 1000.0	155.47 283.27	171.99 345.94	0.200 0.200	11.31 11.31	=====	=====	44.75 44.56

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

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

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q_p$ kN/m2	γ whw kN/m2	k (k')	θ degree	Kp	$K_p \times \cos \delta$
6	5.31- 5.60	Sand	7.70	37.6	=====	0.000 2.233	0.00 2.84	0.200 0.200	11.31 11.31	3.70472 3.70472	3.70472 3.70472
7	5.60- 6.60	Sand	7.70	35.9	=====	2.233 9.933	2.84 12.64	0.200 0.200	11.31 11.31	3.42367 3.42367	3.42367 3.42367
8	6.60- 7.04	Sand	7.70	27.8	=====	9.933 13.321	12.64 16.95	0.200 0.200	11.31 11.31	2.38966 2.38966	2.38966 2.38966
9	7.04- 7.60	Clay	8.20	0.0	100.0 100.0	13.321 17.913	16.95 22.44	0.200 0.200	11.31 11.31	=====	=====
10	7.60- 8.60	Clay	8.20	0.0	250.0 250.0	17.913 26.113	22.44 32.24	0.200 0.200	11.31 11.31	=====	=====
11	8.60- 9.60	Clay	8.20	0.0	250.0 250.0	26.113 34.313	32.24 42.04	0.200 0.200	11.31 11.31	=====	=====
12	9.60- 10.60	Clay	8.20	0.0	250.0 250.0	34.313 42.513	42.04 51.84	0.200 0.200	11.31 11.31	=====	=====
13	10.60- 11.60	Clay	8.20	0.0	180.0 180.0	42.513 50.713	51.84 61.64	0.200 0.200	11.31 11.31	=====	=====
14	11.60- 12.60	Clay	8.20	0.0	180.0 180.0	50.713 58.913	61.64 71.44	0.200 0.200	11.31 11.31	=====	=====
15	12.60- 13.60	Clay	8.20	0.0	180.0 180.0	58.913 67.113	71.44 81.24	0.200 0.200	11.31 11.31	=====	=====
16	13.60- 14.60	Clay	8.20	0.0	180.0 180.0	67.113 75.313	81.24 91.04	0.200 0.200	11.31 11.31	=====	=====
17	14.60- 15.60	Clay	8.20	0.0	180.0 180.0	75.313 83.513	91.04 100.84	0.200 0.200	11.31 11.31	=====	=====
18	15.60- 16.45	Clay	8.20	0.0	250.0 250.0	83.513 90.483	100.84 109.17	0.200 0.200	11.31 11.31	=====	=====
19	16.45- 17.55	Clay	6.70	20.0	200.0 200.0	90.483 97.853	109.17 119.95	0.200 0.200	11.31 11.31	=====	=====
20	17.55- 35.30	Clay	7.20	30.0	1000.0 1000.0	97.853 225.653	119.95 293.90	0.200 0.200	11.31 11.31	=====	=====

- The coefficient of passive earth pressure (K_p) of Sand is obtained by the following equation.
 $\delta = 0.00$ degrees, $\beta = 0.00$ degrees
 Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2		Pp kN/m2	
1	0.00- 2.60	8.11 17.82	=====	8.11 17.82	0.00 25.48		=====	

2	2.60- 3.32	17.82 20.51	————	17.82 20.51	25.48 32.54	————
3	3.32- 3.60	20.51 21.55	————	20.51 21.55	32.54 32.54	————
4	3.60- 4.60	21.55 25.29	————	21.55 25.29	32.54 32.54	————
5	4.60- 5.31	17.41 19.24	————	17.41 19.24	32.54 32.54	————
6	5.31- 5.60	19.24 19.98	————	19.24 19.98	32.54 32.54	0.00 8.27
7	5.60- 6.60	21.24 23.97	————	21.24 23.97	32.54 32.54	7.65 34.01
8	6.60- 7.04	31.85 33.45	————	31.85 33.45	32.54 32.54	23.74 31.85
9	7.04- 7.60	-114.42 -108.85	35.47 37.77	35.47 37.77	32.54 32.54	213.32 217.91
10	7.60- 8.60	-409.16 -399.28	-37.77 41.87	-37.77 41.87	32.54 32.54	517.91 526.11
11	8.60- 9.60	-399.28 -389.39	41.87 45.97	41.87 45.97	32.54 32.54	526.11 534.31
12	9.60- 10.60	-389.39 -379.50	45.97 50.07	45.97 50.07	32.54 32.54	534.31 542.51
13	10.60- 11.60	-239.36 -229.44	50.07 54.17	50.07 54.17	32.54 32.54	402.51 410.71
14	11.60- 12.60	-229.44 -219.52	54.17 58.27	54.17 58.27	32.54 32.54	410.71 418.91
15	12.60- 13.60	-219.52 -209.58	58.27 62.37	58.27 62.37	32.54 32.54	418.91 427.11
16	13.60- 14.60	-209.58 -199.64	62.37 66.47	62.37 66.47	32.54 32.54	427.11 435.31
17	14.60- 15.60	-199.64 -189.70	66.47 70.57	66.47 70.57	32.54 32.54	435.31 443.51
18	15.60- 16.45	-329.97 -321.54	70.57 74.05	70.57 74.05	32.54 32.54	583.51 590.48
19	16.45- 17.55	-221.35 -212.41	74.05 77.74	74.05 77.74	32.54 32.54	490.48 497.85
20	17.55- 35.30	-1813.24 -1659.44	77.74 141.64	77.74 141.64	32.54 32.54	2097.85 2225.65

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \sum \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\sum \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\sum \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

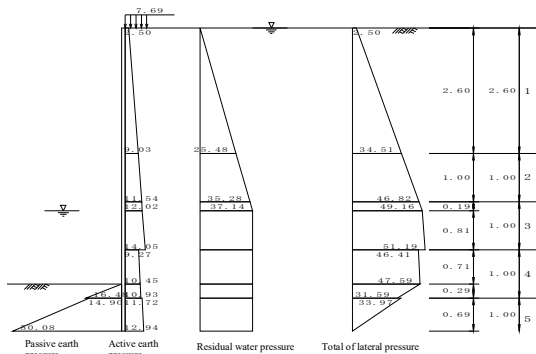
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \sum \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\sum \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

4.1 Normal Condition



No	Depth m	P_a kN/m²	P_w kN/m²	P_p kN/m²	P_s kN/m²
1	0.00- 2.60	2.50 9.03	0.00 0.08	———— ————	2.50 34.51
2	2.60- 3.60	9.03 11.54	25.48 35.28	———— ————	34.51 46.82
3	3.60- 3.79	11.54 12.02	35.28 37.14	———— ————	46.82 49.16
4	3.79- 4.60	12.02 14.05	37.14 37.14	———— ————	49.16 51.19
5	4.60- 5.31	9.27 10.45	37.14 37.14	———— ————	46.41 47.59
6	5.31- 5.60	10.45 10.93	37.14 37.14	0.00 16.48	47.59 31.59
7	5.60- 6.29	11.72 12.94	37.14 37.14	14.90 50.08	33.97 0.00
8	6.29- 6.60	12.94 13.50	37.14 37.14	50.08 66.26	0.00 -15.62

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 : 0.98 m (GL -6.29 m)

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	p_{dw} kN/m²
1	3.32	0.00	0.00
2	4.32	1.00	2.42
3	5.31	1.99	3.41

$$p_{dw} = \pm \frac{7}{8} k_{hs} \cdot \gamma \cdot \sqrt{H \cdot y}$$

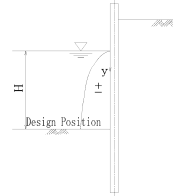
Where,

k_{hs} : design seismic coefficient

γ : unit weight of water

H : water depth of riverside

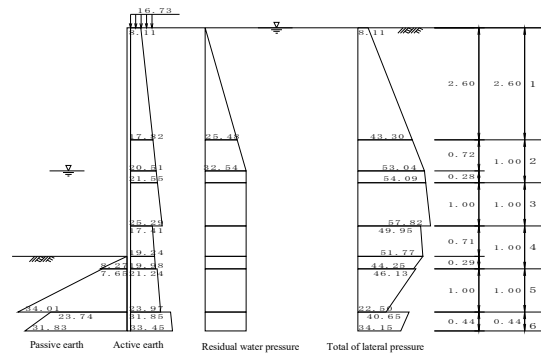
y : depth from water surface to the point where active water pressure is calculated



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.

4.2 Seismic Condition



No	Depth m	P_a kN/m²	P_w kN/m²	P_p kN/m²	P_s kN/m²
1	0.00- 2.60	8.11 17.82	0.00 0.08	———— ————	8.11 43.30
2	2.60- 3.32	17.82 20.51	25.48 32.54	———— ————	43.30 53.04
3	3.32- 3.60	20.51 21.55	32.54 32.54	———— ————	53.04 54.09
4	3.60- 4.60	21.55 25.29	32.54 32.54	———— ————	54.09 57.82
5	4.60- 5.31	17.41 19.24	32.54 32.54	———— ————	49.95 51.77
6	5.31- 5.60	19.24 19.98	32.54 32.54	0.00 8.27	51.77 44.25
7	5.60- 6.60	21.24 23.97	32.54 32.54	7.65 34.01	46.13 22.50
8	6.60- 7.04	31.85 33.45	32.54 32.54	23.74 31.83	40.65 34.15
9	7.04- 7.60	35.47 37.77	32.54 32.54	213.32 217.91	-145.32 -147.61

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 : 1.73 m (GL -7.04 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{\lambda} = K_{10} \left(\frac{B_{\lambda}}{0.3} \right)^{-3/4} \quad (B_{\lambda} = 10.00m)$$

$$K_{10} = \frac{1}{0.3} \alpha E_o \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$E_o = 2800 N'$$

where:

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}}$$

Material Name	10 H - H 700 -250 - 12-16-18
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 = 308300 cm ⁴ (original condition)
	I = 258972 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 258972 × 10 ⁻⁸ = 5.179 × 10 ⁵

No	Depth Z m	N Value	No	Depth Z m	N Value
1	2.10	2	11	12.30	25
2	3.10	2	12	13.30	27
3	4.10	3	13	14.30	30
4	5.10	34	14	15.30	30
5	6.10	29	15	16.30	39
6	7.10	11	16	17.30	28
7	8.10	43	17	18.30	27
8	9.10	46	18	19.30	29
9	10.10	50	19	20.30	27
10	11.10	29	20	21.30	38

5.2 Normal Condition

Assuming Kh = 21722 kN/m3,

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}} = 0.320 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.13 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.29 m) to 3.13 m depth (GL -9.41 m).

$$= \frac{94.50}{2.54}$$

$$= 37.28$$

Kh is recalculated from the calculated average N value.

$$E_o = 2800 N' = 2800 \times 37.28 = 104373 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 104373 = 695820 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_{\lambda} = K_{10} (B_{\lambda}/0.3)^{-3/4} = 695820 (10.00/0.3)^{-3/4} = 50158 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 50158 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 2.60	2.60	2.50 34.51	3.26 44.86	5.42 4.55	17.64 204.20
2	2.60- 3.60	1.00	34.51 46.82	17.25 23.41	3.35 3.02	57.83 70.66
3	3.60- 3.79	0.19	46.82 49.16	4.45 4.67	2.62 2.56	11.66 11.95
4	3.79- 4.60	0.81	49.16 51.19	19.91 20.73	2.23 1.96	44.30 40.53
5	4.60- 5.31	0.71	46.41 47.59	16.48 16.89	1.45 1.21	23.86 20.47
6	5.31- 5.60	0.29	47.59 31.59	6.90 4.58	0.88 0.78	6.06 3.58
7	5.60- 6.29	0.69	33.97 0.00	11.63 0.00	0.46 0.23	5.31 0.00
			ΣP =	195.02	ΣM =	518.05

P₀ : active earth pressure + residual water pressure - passive earth pressure
P : load P₀ 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 P₀ = 0.0 kN/m
depth to acting position H₀ = 0.0 m
moment M₀ = 0.0 kN·m/m
depth to acting position H₀ = 0.00 m

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	6.29	0.81	25.7	11.0	14.94
2	7.10	1.00	11.0	43.0	27.00
3	8.10	1.00	43.0	46.0	44.50
4	9.10	0.31	46.0	47.2	14.46
L = Σh = 3.13			ΣA =		100.90

A: (upper N-value + lower N-value) × h/2

Average N-value N' = $\frac{\Sigma A}{L}$
= $\frac{100.90}{3.13}$
= 32.29

Kh is recalculated from the calculated average N value.

$$E_o = 2800 N' = 2800 \times 32.29 = 90403 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0.3} \times \alpha \times 90403 = 301345 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismi Condition} = 2)$$

$$K_{\lambda} = K_{10} (B_{\lambda}/0.3)^{-3/4} = 301345 (10.00/0.3)^{-3/4} = 21722 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 21722 kN/m3.

5.3 Seismic Condition

Assuming Kh = 50158 kN/m3,

$$\beta = 4\sqrt{\frac{K_{\lambda} \cdot B}{4 E I}} = 0.394 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 2.54 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -7.04 m) and 2.54 m depth (GL -9.58 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	7.04	0.06	12.1	11.0	0.69
2	7.10	1.00	11.0	43.0	27.00
3	8.10	1.00	43.0	46.0	44.50
4	9.10	0.48	46.0	47.9	22.31
L = Σh = 2.54			ΣA =		94.50

A: (upper N-value + lower N-value) × h/2

Average N-value N' = $\frac{\Sigma A}{L}$

Height from riverbed to top of coping H = 5.31 m
Depth of Imaginary riverbed from riverbed L_k = 0.98 m

Moment M₀ by arbitrary load is as below
M₀ = P₀·(H + L_k - H₀) + M₀ = 0.00 kN·m
h₀: Height of acting position of P₀ from imaginary riverbed

$$h_o = \frac{M_0}{P_0} = \frac{\Sigma M + M_0}{\Sigma P + P_0}$$

$$= \frac{518.05}{195.02} = 2.66 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 195.02}{6.29} = 62.06 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 2.60	2.60	8.11 43.30	10.55 56.29	6.17 5.31	65.11 298.72
2	2.60- 3.32	0.72	43.30 53.04	15.59 19.10	4.20 3.96	65.47 75.62
3	3.32- 3.60	0.28	53.04 54.09	7.43 7.57	3.63 3.53	26.93 26.76
4	3.60- 4.60	1.00	54.09 57.82	27.05 28.91	3.11 2.77	84.02 80.18
5	4.60- 5.31	0.71	49.95 51.77	17.73 18.38	2.20 1.97	39.07 36.15
6	5.31- 5.60	0.29	51.77 44.25	7.51 6.42	1.63 1.54	12.26 9.86
7	5.60- 6.60	1.00	46.13 22.50	23.06 11.25	1.11 0.77	25.52 8.70
8	6.60- 7.04	0.44	40.65 34.15	8.94 7.51	0.29 0.15	2.62 1.10
			ΣP =	273.28	ΣM =	858.09

P₀ : active earth pressure + residual water pressure - passive earth pressure
P : load P₀ 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 P₀ = 0.0 kN/m
depth to acting position H₀ = 0.00 m
moment M₀ = 0.0 kN·m/m
depth to acting position H₀ = 0.00 m
Height from riverbed to top of coping H = 5.31 m
Depth of Imaginary riverbed from riverbed L_k = 1.73 m

Moment M₀ by arbitrary load is as below
M₀ = P₀·(H + L_k - H₀) + M₀ = 0.00 kN·m

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	3.32- 4.32	1.00	0.0 2.4	0.00 1.21	3.39 3.05	0.00 3.69
2	4.32- 5.31	0.99	2.4 3.4	1.20 1.69	2.39 2.06	2.86 3.48
Σ P ₀ =				4.10	Σ M ₀ =	10.04

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0i}}{\Sigma P + P_i + \Sigma P_{0i}} = \frac{868.13}{277.38} = 3.13 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 277.38}{7.04} = 78.80 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name	10 H ₂ H 700 -250 - 12-16-18
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 = 308300 cm ⁴ (original condition) I = 258972 cm ⁴ (after reduction by corrosion and section)
El = 200000 × 10 ³ × 258972 × 10 ⁻⁸	= 5.179 × 10 ⁵

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1+2\beta h_0)^2 + 1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M(x) = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 21722 kN/m ³
calculated value	β = 0.31999 m ⁻¹
resultant earth force (lateral)	P ₀ = 195.02 kN/m
height of acting position of load	h ₀ = 2.66 m
moment	M ₀ = 518.05 kN·m/m

in consideration of ψ₀ = 1.188,

maximum moment	M _{max} = 615.39 kN·m/m
depth of generated position of M _{max}	l _m = 1.108 m
depth of 1 st fixed point	l _i = 3.563 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b = 50158 kN/m ³
calculated value	β = 0.39446 m ⁻¹
resultant earth force (lateral)	P ₀ = 277.38 kN/m
height of acting position of load	h ₀ = 3.13 m
moment	M ₀ = 868.13 kN·m/m

in consideration of ψ₀ = 1.104,

maximum moment	M _{max} = 958.76 kN·m/m
depth of generated position of M _{max}	l _m = 0.711 m
depth of 1 st fixed point	l _i = 2.703 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as follows:

Material Name	10 H ₂ H 700 -250 - 12-16-18
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 = 5740 cm ³ (original condition) Z = 4879 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{615.39 \times 10^6}{4879 \times 10^3} = 126 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

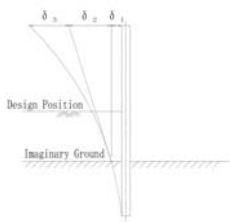
6.3.2 Seismic Condition

$$\sigma = \frac{M_{\max}}{Z} = \frac{958.76 \times 10^6}{4879 \times 10^3} = 197 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

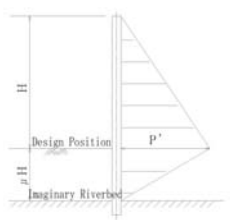
6.4.1 Normal Condition

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1 + 0.3200 \times 2.66) \times 195.02}{2 \times 2.00 \times 10^8 \times 258972 \times 10^{-8} \times 0.3200^3} = 0.01063 \text{ m}$$

$$\delta_2 = \frac{(1 + 2\beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) = \frac{(1 + 2 \times 0.3200 \times 2.66) \times 195.02}{2 \times 2.00 \times 10^8 \times 258972 \times 10^{-8} \times 0.3200^2} \times (5.31 + 0.98) = 0.03120 \text{ m}$$



$$\mu = \frac{L_u}{H} = \frac{0.98}{5.31} = 0.184$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4) = \frac{62.06 \times 5.31^4}{120 \times 2.00 \times 10^8 \times 258972 \times 10^{-8}} (4 + 20 \times 0.184 + 40 \times 0.184^2 + 35 \times 0.184^3 + 11 \times 0.184^4) = 0.00734 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01063 + 0.03120 + 0.00734 = 0.04917 \text{ m}$$

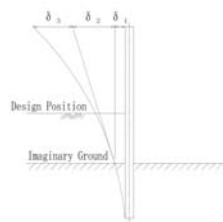
$$\text{Size} = 49.17 \leq \delta a = 50.00 \text{ mm}$$

Where,

- δ₁ : Displacement at imaginary ground
- δ₂ : Displacement by angle of inclination slope at imaginary ground
- δ₃ : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

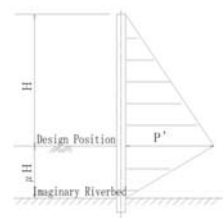
6.4.2 Seismic Condition

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} = \frac{(1 + 0.3945 \times 3.13) \times 277.38}{2 \times 2.00 \times 10^8 \times 258972 \times 10^{-8} \times 0.3945^3} = 0.00975 \text{ m}$$

$$\delta_2 = \frac{(1 + 2\beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) = \frac{(1 + 2 \times 0.3945 \times 3.13) \times 277.38}{2 \times 2.00 \times 10^8 \times 258972 \times 10^{-8} \times 0.3945^2} \times (5.31 + 1.73) = 0.04203 \text{ m}$$



$$= 0.01622 \text{ m}$$

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

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

7.1 Penetration Depth and Whole Length of SSP (Chang)

$$\begin{aligned} D &= L_k + \frac{3}{\beta} \\ L &= H - H_{1t} + D \\ \beta &= 4 \sqrt{\frac{K_h \cdot B}{4 E I}} \end{aligned}$$

Penetration length of SSP $D = 0.98 + \frac{3}{0.306} = 10.77 \text{ m}$

Whole length of SSP $L = 5.31 - 0.40 + 10.77 = 15.68 \text{ m}$

Penetration length of SSP	$D = 1.73 + \frac{3}{0.378} = 9.67 \text{ m}$
Whole length of SSP	$L = 5.31 - 0.40 + 9.67 = 14.58 \text{ m}$

8 Calculation Result

SSP		10 H ₂ O 700-250 - 12-16-18			
				Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)		308300		
Sectional Modulus	Z (cm ³)		5740		
Maximum bending moment	Mmax (N·m / m)			615.39	958.76
Stress intensity	σ (N/mm ²)			126 (180)	197 (270)
Lateral displacement	δ (mm)			49.17 (50.0)	68.00 (75.0)
Penetration depths	D (m)			10.77	9.67
Whole length of SSP	L (m)	16.00			

1.1 Longitudinal Section of SSP & Considered Geological Survey Log

[illegible]

Depth from coping top to riverbed	H	=	5.25 m
Depth from coping top to rear side ground	H ₀	=	0.00 m
Depth from coping top to SSP top	H _{ft}	=	0.40 m
Landside WL	L _{wa}	=	0.00 m (Normal Condition)
	L _{wa'}	=	0.00 m (Seismic Condition)
Riverside WL	L _{wp}	=	3.78 m (Normal Condition)
	L _{wp'}	=	3.30 m (Seismic Condition)

2.1.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	Angle of Rupture ζ degree
1	5.25 ~ 4.51	Sand	27.0	15.0	0.0	36.49	3.96	51.45	54.81
2	4.51 ~ 3.99	Sand	27.0	15.0	0.0	30.79	3.96	44.20	54.81
3	3.99 ~ 3.51	Clay	0.0	15.0	12.0	26.78	3.96	39.10	45.00
4	3.51 ~ 2.51	Clay	0.0	15.0	12.0	24.05	3.96	34.40	45.00
5	2.51 ~ 2.02	Clay	0.0	15.0	25.0	18.35	3.96	24.60	45.00
6	2.02 ~ 1.51	Sand	27.0	15.0	0.0	15.55	3.96	19.80	54.81
7	1.51 ~ 0.00	Sand	27.0	15.0	0.0	11.63	3.96	14.80	54.81
8		embankment	30.0	—	0.0	56.81	0.00	0.00	60.00

• Angle of active rupture of sandy soil

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}}{\sin(\phi - \theta)}$$

• Angle of active rupture of clayey soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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)
- 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.81	0.74	0.00	0.00	0.52	0.74
2	54.81	0.52	0.52	0.74	0.89	1.26
3	45.00	0.48	0.89	1.26	1.37	1.74
4	45.00	1.00	1.37	1.74	2.37	2.74
5	45.00	0.49	2.37	2.74	2.86	3.23
6	54.81	0.51	2.86	3.23	3.22	3.74
7	54.81	1.51	3.22	3.74	4.28	5.25
8	60.00	0.31	4.28	5.25	4.46	5.56

From the above table, the loading width (L) on the ground surface is 4.28 m.

2.2.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m ²	Σ γ h kN/m ²	Q kN/m ²	γ whw kN/m ²	k (k')	θ degree	Angle of Rupture ζ degree
1	5.25 ~ 4.51	Sand	27.0	15.0	0.0	36.49	3.44	51.45	0.200	11.31	42.18
2	4.51 ~ 3.99	Sand	27.0	15.0	0.0	30.79	3.44	44.20	0.200	11.31	42.18
3	3.99 ~ 3.51	Clay	0.0	15.0	12.0	26.78	3.44	39.10	0.200	11.31	39.20
4	3.51 ~ 2.51	Clay	0.0	15.0	12.0	24.05	3.44	34.40	0.200	11.31	39.63
5	2.51 ~ 2.02	Clay	0.0	15.0	25.0	18.35	3.44	24.60	0.200	11.31	42.70
6	2.02 ~ 1.51	Sand	27.0	15.0	0.0	15.55	3.44	19.80	0.200	11.31	42.18
7	1.51 ~ 0.00	Sand	27.0	15.0	0.0	11.63	3.44	14.80	0.200	11.31	42.18
8		embankment	30.0	—	0.0	56.81	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}}{\sin(\phi - \theta)}$$

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	0.74	0.00	0.00	0.82	0.74
2	42.18	0.52	0.82	0.74	1.39	1.26
3	39.20	0.48	1.39	1.26	1.98	1.74
4	39.63	1.00	1.98	1.74	3.19	2.74
5	42.70	0.49	3.19	2.74	3.72	3.23
6	42.18	0.51	3.72	3.23	4.28	3.74
7	42.18	1.51	4.28	3.74	5.95	5.25

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	0.33	6.21
Σ			6.21

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/m ²	l m	Ql kN/m
1	5.0	2.15	10.75
Σ			10.75

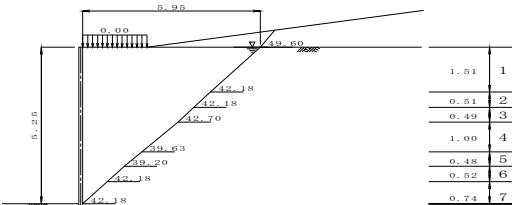
Q : width of surcharge load set by line of active rupture

l : Loading width of uniform load surrounded by main collapse line

2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{6.21 + 10.75 + 0.00}{4.28}$$
$$= 3.96 \text{ kN/m}^2$$

2.2 Seismic Condition



8	49.60	0.57	5.95	5.25	6.43	5.82

From the above table, the loading width (L) on the ground surface is 5.95 m.

2.2.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	γ × A kN/m
1	19.0	1.08	20.47
Σ			20.47

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/m ²	l m	Ql kN/m
1	0.0	2.15	0.00
Σ			0.00

Q : width of surcharge load set by line of active rupture

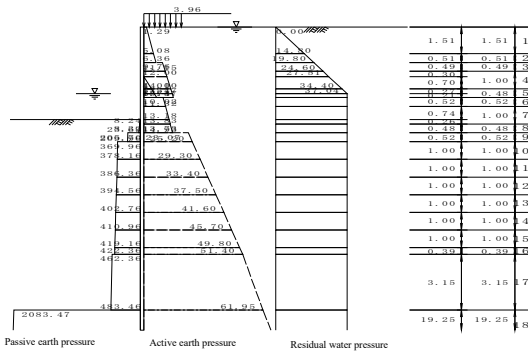
l : Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$
$$= \frac{20.47 + 0.00 + 0.00}{5.95}$$
$$= 3.44 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	Ka	Ka $\times \cos \delta$
1	0.00-1.51	Sand	7.7	27.0	—	3.959 15.586	0.33738 0.33738	0.32589 0.32589
2	1.51-2.02	Sand	7.7	27.0	—	15.586 19.513	0.33738 0.33738	0.32589 0.32589
3	2.02-2.51	Clay	5.7	—	25.0 22.306	19.513 22.306	— —	— —
4	2.51-2.81	Clay	5.7	—	12.0 24.000	22.306 24.000	— —	— —
5	2.81-3.51	Clay	5.7	—	12.0 12.0	24.000 28.006	— —	— —
6	3.51-3.78	Clay	5.7	—	12.0 12.0	28.006 29.545	— —	— —
7	3.78-3.99	Clay	5.7	—	12.0 12.0	29.545 30.742	— —	— —
8	3.99-4.51	Sand	7.7	27.0	—	30.742 34.746	0.33738 0.33738	0.32589 0.32589
9	4.51-5.25	Sand	7.7	27.0	—	34.746 40.444	0.33738 0.33738	0.32589 0.32589
10	5.25-5.51	Sand	7.7	27.0	—	40.444 42.446	0.33738 0.33738	0.32589 0.32589
11	5.51-5.99	Sand	7.7	27.2	—	42.446 46.142	0.33489 0.33489	0.32348 0.32348
12	5.99-6.51	Clay	8.2	—	100.0 100.0	46.142 50.406	— —	— —

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = -15.00, \beta = 0.00, \theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	Pp kN/m ²
1	0.00-1.51	1.29 5.08	—	1.29 5.08	0.00 14.80	—
2	1.51-2.02	5.08 6.36	—	5.08 6.36	14.80 19.80	—
3	2.02-2.51	-30.49 -27.69	9.76 11.15	9.76 11.15	19.80 24.60	—
4	2.51-2.81	-1.69 0.00	11.15 12.00	11.15 12.00	24.60 27.51	—
5	2.81-3.51	0.00 4.01	12.00 14.00	12.00 14.00	27.51 34.40	—
6	3.51-3.78	4.01 5.54	14.00 14.77	14.00 14.77	34.40 37.04	—
7	3.78-3.99	5.54 6.74	14.77 15.37	14.77 15.37	37.04 37.04	—
8	3.99-4.51	10.02 11.32	—	10.02 11.32	37.04 37.04	—
9	4.51-5.25	11.32 13.18	—	11.32 13.18	37.04 37.04	—
10	5.25-5.51	13.18 13.83	—	13.18 13.83	37.04 37.04	0.00 8.24
11	5.51-5.99	13.73 14.93	—	13.73 14.93	37.04 37.04	8.32 23.69
12	5.99-6.51	-153.86 -149.59	23.07 25.20	23.07 25.20	37.04 37.04	205.70 209.96
13	6.51-7.51	-209.59 -201.39	25.20 29.30	25.20 29.30	37.04 37.04	360.96 378.16
14	7.51-8.51	-201.39 -203.19	29.30 33.40	29.30 33.40	37.04 37.04	378.16 386.36
15	8.51-9.51	-293.19 -284.99	33.40 37.50	33.40 37.50	37.04 37.04	386.36 394.56
16	9.51-10.51	-284.99 -276.79	37.50 41.60	37.50 41.60	37.04 37.04	394.56 402.76
17	10.51-11.51	-276.79 -268.59	41.60 45.70	41.60 45.70	37.04 37.04	402.76 410.96
18	11.51-12.51	-268.59 -260.39	45.70 49.80	45.70 49.80	37.04 37.04	410.96 419.16
19	12.51-12.90	-260.39 -257.20	49.80 51.40	49.80 51.40	37.04 37.04	419.16 422.36
20	12.90-16.05	-297.20 -276.09	51.40 61.95	51.40 61.95	37.04 37.04	422.36 483.46

13	6.51-7.51	Clay	8.2	—	180.0 180.0	50.406 58.606	— —	— —
14	7.51-8.51	Clay	8.2	—	180.0 180.0	58.606 66.806	— —	— —
15	8.51-9.51	Clay	8.2	—	180.0 180.0	66.806 75.006	— —	— —
16	9.51-10.51	Clay	8.2	—	180.0 180.0	75.006 83.206	— —	— —
17	10.51-11.51	Clay	8.2	—	180.0 180.0	83.206 91.406	— —	— —
18	11.51-12.51	Clay	8.2	—	180.0 180.0	91.406 99.606	— —	— —
19	12.51-12.90	Clay	8.2	—	180.0 180.0	99.606 102.804	— —	— —
20	12.90-16.05	Clay	6.7	—	200.0 200.0	102.804 123.999	— —	— —
21	16.05-35.30	Clay	7.2	—	1000.0 1000.0	123.999 262.599	— —	— —

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_0$ kN/m ²	Kp	Kp $\times \cos \delta$
10	5.25-5.51	Sand	7.7	27.0	—	0.000 2.002	4.26080 4.26080	4.11561 4.11561
11	5.51-5.99	Sand	7.7	27.2	—	2.002 5.698	4.30428 4.30428	4.15761 4.15761
12	5.99-6.51	Clay	8.2	0.0	100.0 100.0	5.698 9.962	— —	— —
13	6.51-7.51	Clay	8.2	0.0	180.0 180.0	9.962 18.162	— —	— —
14	7.51-8.51	Clay	8.2	0.0	180.0 180.0	18.162 26.362	— —	— —
15	8.51-9.51	Clay	8.2	0.0	180.0 180.0	26.362 34.562	— —	— —
16	9.51-10.51	Clay	8.2	0.0	180.0 180.0	34.562 42.762	— —	— —
17	10.51-11.51	Clay	8.2	0.0	180.0 180.0	42.762 50.962	— —	— —
18	11.51-12.51	Clay	8.2	0.0	180.0 180.0	50.962 59.162	— —	— —
19	12.51-12.90	Clay	8.2	0.0	180.0 180.0	59.162 62.360	— —	— —
20	12.90-16.05	Clay	6.7	20.0	200.0 200.0	62.360 83.465	— —	— —
21	16.05-35.30	Clay	7.2	30.0	1000.0 1000.0	83.465 222.065	— —	— —

21	16.05-35.30	-1876.09 -1737.49	61.95 131.25	61.95 131.25	37.04 37.04	2083.47 2222.06

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a: Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = \left[K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a} \right] \cdot \cos \delta$$

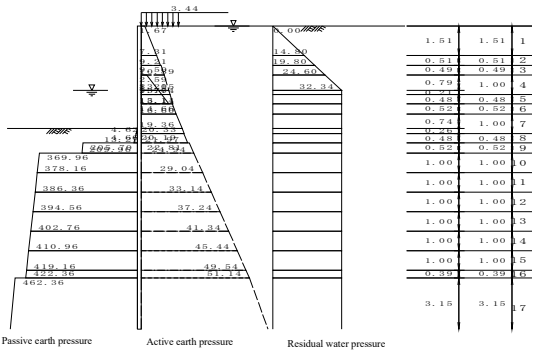
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = \left[K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p} \right] \cdot \cos \delta$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{shw} kN/m ²	γ (k°)	θ degree	Ka	Ka $\times \cos \delta$	C degree
1	0.00-1.51	Sand	7.7	27.0	—	15.07	0.00	0.200	11.31	0.50201	0.48490	—
2	1.51-2.02	Sand	7.7	27.0	—	15.07	14.80	0.200	11.31	0.50201	0.48490	—
3	2.02-2.51	Clay	5.7	—	25.0 25.0	19.80 21.79	19.80 24.60	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	— 42.98 42.70

4	2.51- 3.30	Clay	5.7	—	12.0 12.0	21.79 26.29	24.60 32.34	0.200 0.200	11.31 11.31	—	—	40.58 39.82
5	3.30- 3.51	Clay	5.7	—	12.0 12.0	26.29 27.49	32.34 34.40	0.200 0.200	11.31 11.31	—	—	39.82 39.63
6	3.51- 3.99	Clay	5.7	—	12.0 12.0	27.49 30.23	34.40 39.10	0.200 0.200	11.31 11.31	—	—	39.63 39.20
7	3.99- 4.51	Sand	7.7	27.0	—	30.23 34.23	39.10 44.20	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
8	4.51- 5.25	Sand	7.7	27.0	—	34.23 39.93	44.20 51.45	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
9	5.25- 5.51	Sand	7.7	27.0	—	39.93 41.93	51.45 54.00	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
10	5.51- 5.99	Sand	7.7	27.2	—	41.93 45.63	54.00 58.70	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	—
11	5.99- 6.51	Clay	8.2	—	100.0 100.0	45.63 49.89	58.70 63.80	0.200 0.200	11.31 11.31	—	—	43.75 43.64
12	6.51- 7.51	Clay	8.2	—	180.0 180.0	49.89 58.09	63.80 73.60	0.200 0.200	11.31 11.31	—	—	44.22 44.10
13	7.51- 8.51	Clay	8.2	—	180.0 180.0	58.09 66.29	73.60 83.40	0.200 0.200	11.31 11.31	—	—	44.10 43.98
14	8.51- 9.51	Clay	8.2	—	180.0 180.0	66.29 74.49	83.40 93.20	0.200 0.200	11.31 11.31	—	—	43.98 43.86
15	9.51- 10.51	Clay	8.2	—	180.0 180.0	74.49 82.69	93.20 103.00	0.200 0.200	11.31 11.31	—	—	43.86 43.74
16	10.51- 11.51	Clay	8.2	—	180.0 180.0	82.69 90.89	103.00 112.80	0.200 0.200	11.31 11.31	—	—	43.74 43.62
17	11.51- 12.51	Clay	8.2	—	180.0 180.0	90.89 99.09	112.80 122.60	0.200 0.200	11.31 11.31	—	—	43.62 43.50
18	12.51- 12.90	Clay	8.2	—	180.0 180.0	99.09 102.29	122.60 126.42	0.200 0.200	11.31 11.31	—	—	43.50 43.46
19	12.90- 16.05	Clay	6.7	—	200.0 200.0	102.29 123.39	126.42 157.29	0.200 0.200	11.31 11.31	—	—	43.61 43.33
20	16.05- 35.30	Clay	7.2	—	1000.0 1000.0	123.39 261.99	157.29 345.94	0.200 0.200	11.31 11.31	—	—	44.65 44.27

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{slw} kN/m ²	k (k γ)	θ degree	Kp	Kp $\times \cos \delta$
9	5.25- 5.51	Sand	7.70	27.0	—	0.000 2.002	0.00 2.55	0.200 0.200	11.31 11.31	2.30874 2.30874	2.30874 2.30874

9	5.25- 5.51	19.36 20.33	—	19.36 20.33	32.34 32.34	0.00 4.66
10	5.51- 5.99	20.19 21.97	—	20.19 21.97	32.34 32.34	4.66 13.27
11	5.99- 6.51	-145.00 -139.87	22.80 24.94	22.81 24.94	32.34 32.34	205.70 209.96
12	6.51- 7.51	-299.99 -290.10	24.94 29.04	24.94 29.04	32.34 32.34	369.96 378.16
13	7.51- 8.51	-290.10 -280.20	29.04 33.14	29.04 33.14	32.34 32.34	378.16 386.36
14	8.51- 9.51	-280.20 -270.29	33.14 37.24	33.14 37.24	32.34 32.34	386.36 394.56
15	9.51- 10.51	-270.29 -260.38	37.24 41.34	37.24 41.34	32.34 32.34	394.56 402.76
16	10.51- 11.51	-260.38 -250.45	41.34 45.44	41.34 45.44	32.34 32.34	402.76 410.96
17	11.51- 12.51	-250.45 -240.52	45.44 49.54	45.44 49.54	32.34 32.34	410.96 419.16
18	12.51- 12.90	-240.52 -236.65	49.54 51.14	49.54 51.14	32.34 32.34	419.16 422.36
19	12.90- 16.05	-276.71 -251.13	51.14 61.70	51.14 61.70	32.34 32.34	462.36 483.46
20	16.05- 35.30	-1851.78 -1684.91	61.70 131.00	61.70 131.00	32.34 32.34	2083.47 2222.66

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$$

- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$$

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth, Z, m	water level, y, m	p _{dw} kN/m ²
1	3.30	0.00	0.00
2	4.30	1.00	2.39
3	5.25	1.95	3.34

10	5.51- 5.99	Sand	7.70	27.2	—	2.002 5.698	2.55 7.25	0.200 0.200	11.31 11.31	2.32868 2.32868	2.32868 2.32868
11	5.99- 6.51	Clay	8.20	0.0	100.0 100.0	5.698 9.962	7.25 12.35	0.200 0.200	11.31 11.31	—	—
12	6.51- 7.51	Clay	8.20	0.0	180.0 180.0	9.962 18.162	12.35 22.15	0.200 0.200	11.31 11.31	—	—
13	7.51- 8.51	Clay	8.20	0.0	180.0 180.0	18.162 26.362	22.15 31.95	0.200 0.200	11.31 11.31	—	—
14	8.51- 9.51	Clay	8.20	0.0	180.0 180.0	26.362 34.562	31.95 41.75	0.200 0.200	11.31 11.31	—	—
15	9.51- 10.51	Clay	8.20	0.0	180.0 180.0	34.562 42.762	41.75 51.55	0.200 0.200	11.31 11.31	—	—
16	10.51- 11.51	Clay	8.20	0.0	180.0 180.0	42.762 50.962	51.55 61.35	0.200 0.200	11.31 11.31	—	—
17	11.51- 12.51	Clay	8.20	0.0	180.0 180.0	50.962 59.162	61.35 71.15	0.200 0.200	11.31 11.31	—	—
18	12.51- 12.90	Clay	8.20	0.0	180.0 180.0	59.162 62.360	71.15 74.97	0.200 0.200	11.31 11.31	—	—
19	12.90- 16.05	Clay	6.70	20.0	200.0 200.0	62.360 83.465	74.97 105.84	0.200 0.200	11.31 11.31	—	—
20	16.05- 35.30	Clay	7.20	30.0	1000.0 1000.0	83.465 222.865	105.84 294.49	0.200 0.200	11.31 11.31	—	—

• The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure		Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2	
1	0.00- 1.51	1.67 7.31	— —	1.67 7.31	0.00 14.80	— —	
2	1.51- 2.02	7.31 9.21	— —	7.31 9.21	14.80 19.80	— —	
3	2.02- 2.51	-27.05 -23.65	9.50 10.89	9.50 10.89	19.80 24.60	— —	
4	2.51- 3.30	2.59 8.20	10.89 13.15	10.89 13.15	24.60 32.34	— —	
5	3.30- 3.51	8.20 9.70	13.15 13.74	13.15 13.74	32.34 32.34	— —	
6	3.51- 3.99	9.70 13.14	13.74 15.11	13.74 15.11	32.34 32.34	— —	
7	3.99- 4.51	14.66 16.60	— —	14.66 16.60	32.34 32.34	— —	
8	4.51- 5.25	16.60 19.36	— —	16.60 19.36	32.34 32.34	— —	

$$p_{dw} = \pm \frac{7}{8} k_{bw} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

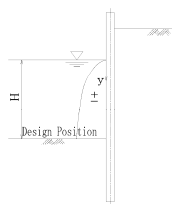
Where,

k_{bw} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

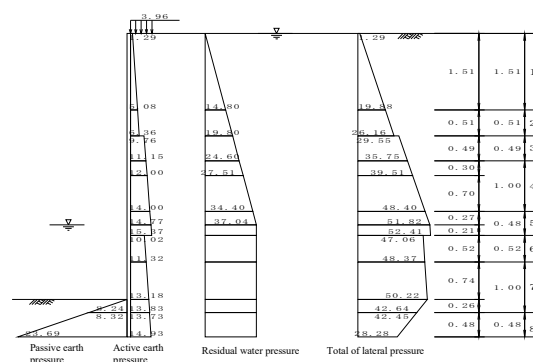
y : depth from water surface to the point where active water pressure is calculated



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

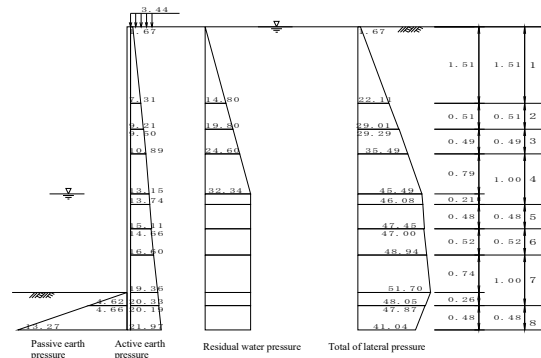


No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.51	1.29 5.08	0.00 14.80	----- -----	1.29 19.88
2	1.51- 2.02	5.08 6.36	14.80 19.80	----- -----	19.88 26.16
3	2.02- 2.51	9.76 11.15	19.80 24.60	----- -----	29.55 35.75
4	2.51- 2.81	11.15 12.00	24.60 27.51	----- -----	35.75 39.51
5	2.81- 3.51	12.00 14.00	27.51 34.40	----- -----	39.51 48.40
6	3.51- 3.78	14.00 14.77	34.40 37.04	----- -----	48.40 51.82
7	3.78- 3.99	14.77 15.37	37.04 37.04	----- -----	51.82 52.41
8	3.99- 4.51	10.02 11.32	37.04 37.04	----- -----	47.06 48.37
9	4.51- 5.25	11.32 13.18	37.04 37.04	----- -----	48.37 50.22
10	5.25- 5.51	13.18 13.83	37.04 37.04	0.00 8.24	50.22 42.64
11	5.51- 5.99	13.73 14.93	37.04 37.04	8.32 23.69	42.45 28.28
12	5.99- 6.51	23.07 25.20	37.04 37.04	205.70 209.96	-145.58 -147.72

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 L₄: 0.74 m (GL -5.99 m)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.51	1.67 7.31	0.00 14.80	----- -----	1.67 22.11
2	1.51- 2.02	7.31 9.21	14.80 19.80	----- -----	22.11 29.01
3	2.02- 2.51	9.50 10.89	19.80 24.60	----- -----	29.29 35.49
4	2.51- 3.30	10.89 13.15	24.60 32.34	----- -----	35.49 45.49
5	3.30- 3.51	13.15 13.74	32.34 32.34	----- -----	45.49 46.08
6	3.51- 3.99	13.74 15.11	32.34 32.34	----- -----	46.08 47.45
7	3.99- 4.51	14.66 16.60	32.34 32.34	----- -----	47.00 48.94
8	4.51- 5.25	16.60 19.36	32.34 32.34	----- -----	48.94 51.70
9	5.25- 5.51	19.36 20.33	32.34 32.34	0.00 4.62	51.70 46.05
10	5.51- 5.99	20.19 21.97	32.34 32.34	4.66 13.27	47.87 41.04
11	5.99- 6.51	22.81 24.94	32.34 32.34	205.70 209.96	-150.55 -152.68

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 L₄: 0.74 m (GL -5.99 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

Average N-value is calculated depending on the sectional area.
The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{b0} \left(\frac{B_b}{0.3} \right)^{-3/4} \quad (B_b = 10, 00\text{mm})$$

$$K_{b0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_0 = 2800 \text{ N}'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H ₂ H 700 -200 - 12-25-18
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 = 334800 cm ⁴ (original condition)
	I = 287928 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 287928 × 10 ⁻⁸ = 5.759 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	1.00	5	11	11.00	26
2	2.00	6	12	12.00	24
3	3.00	2	13	13.00	20
4	4.00	2	14	14.00	41
5	5.00	8	15	15.00	50
6	6.00	10	16	16.00	50
7	7.00	19	17	17.00	50
8	8.00	20			
9	9.00	28			
10	10.00	23			

5.2 Normal Condition

Assuming Kh = 13752 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.278 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.60 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.99 m) to 3.60 m depth (GL -9.59 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.99	0.02	10.0	10.0	0.20
2	6.01	1.00	10.0	19.0	14.50
3	7.01	1.00	19.0	20.0	19.50
4	8.01	1.00	20.0	28.0	24.00
5	9.01	0.58	28.0	25.1	15.34
L = Σh = 3.60			ΣA =		73.54

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$

$$= \frac{73.54}{3.60}$$

$$= 20.44$$

Kh is recalculated from the calculated average N value.

$$E_0 = 2800 \text{ N}' = 2800 \times 20.44 = 57233 \text{ kN/m}^2$$

$$K_{b0} = \frac{1}{0.3} \times \alpha \times 57233 = 190777 \text{ kN/m}^3 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$K_b = K_{b0} (B_b/0.3)^{-3/4} = 190777 (10.00/0.3)^{-3/4} = 13752 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 13752 kN/m³.

5.3 Seismic Condition

Assuming Kh = 26102 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.326 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 3.06 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.99 m) and 3.06 m depth (GL -9.05 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.99	0.02	10.0	10.0	0.20
2	6.01	1.00	10.0	19.0	14.50
3	7.01	1.00	19.0	20.0	19.50
4	8.01	1.00	20.0	28.0	24.00
5	9.01	0.04	28.0	27.8	1.25
L = Σh = 3.06			ΣA =		59.45

A: (upper N-value + lower N-value) × h/2

$$\text{Average N-value } N' = \frac{\Sigma A}{L}$$

$$= \frac{59,45}{3,06}$$

$$= 19,40$$

Kh is recalculated from the calculated average N value.

$$E_o = 2800N' = 2800 \times 19,40 = 54315 \text{ kN/m}^2$$

$$K_{10} = \frac{1}{0,3} \times \alpha \times 54315 = 362100 \text{ kN/m}^3 \quad (\alpha \text{ Normal Condition}=1, \text{ Seismi Condition}=2)$$

$$K_b = K_{10} (B_o/0,3)^{-3/4} = 362100 (10,00/0,3)^{-3/4} = 26102 \text{ kN/m}^3$$

Thus, the assumed Kh is equal to the recalculated Kh.

The lateral subgrade reaction coefficient Kh (Seismic Condition) is 26102 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.51	1.51	1.29 19.88	0.97 15.01	5.49 4.98	5.34 74.79
2	1.51- 2.02	0.51	19.88 26.16	5.07 6.67	4.31 4.14	21.85 27.61
3	2.02- 2.51	0.49	29.55 35.75	7.24 8.76	3.81 3.64	27.36 31.91
4	2.51- 2.81	0.30	35.75 39.51	5.31 5.87	3.38 3.28	17.96 19.27
5	2.81- 3.51	0.70	39.51 48.40	13.88 17.01	2.95 2.71	40.94 46.16
6	3.51- 3.78	0.27	48.40 51.82	6.53 7.00	2.39 2.30	15.62 16.09
7	3.78- 3.99	0.21	51.82 52.41	5.44 5.50	2.14 2.07	11.64 11.39
8	3.99- 4.51	0.52	47.06 48.37	12.24 12.58	1.83 1.65	22.35 20.79
9	4.51- 5.25	0.74	48.37 50.22	17.90 18.58	1.23 0.99	22.07 18.34
10	5.25- 5.51	0.26	50.22 42.64	6.53 5.54	0.65 0.57	4.27 3.14
11	5.51- 5.99	0.48	42.45 28.28	10.19 6.79	0.32 0.16	3.26 1.69
			Σ P =	200.61	Σ M =	463.44

P₀ : active earth pressure + residual water pressure - passive earth pressure

P : load P₀ x h/2 x B

B : unit width = 1.000 m

Arbitrary load lateral load $P_i = 0.0 \text{ kN/m}$

depth to acting position $H_i = 0.00 \text{ m}$

moment $M_{i0} = 0.0 \text{ kN} \cdot \text{m/m}$

depth to acting position $H_{i0} = 0.00 \text{ m}$

Height from riverbed to top of coping $H = 5.25 \text{ m}$

Depth of Imaginary riverbed from riverbed $L_k = 0.74 \text{ m}$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{i0} = 0.00 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{dv} kN/m ²	Loads P _{dv} kN	Arm length Y m	Moment M _{dv} kN · m
1	3.30- 4.30	1.00	0.0 2.4	0.00 1.20	2.36 2.02	0.00 2.42
2	4.30- 5.25	0.95	2.4 3.3	1.14 1.59	1.37 1.06	1.56 1.68
			Σ P _{dv} =	3.92	Σ M _{dv} =	5.66

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{i0}}{\Sigma P + P_i + \Sigma P_{i0}}$$

$$= \frac{490.68}{211.31} = 2.27 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 211.31}{5.99} = 70.56 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Material name	10 H - H 700 -200 - 12-25-18
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 = 334800 cm ⁴ (original condition) I = 287928 cm ⁴ (after reduction by corrosion and section)
EI = 200000 × 10 ³ × 287928 × 10 ⁻⁸	= 5.759 × 10 ⁵

Y : height of acting position from imaginary riverbed

M : moment by load P x Y

Arbitrary load lateral load $P_i = 0.0 \text{ kN/m}$

depth to acting position $H_i = 0.0 \text{ m}$

moment $M_{i0} = 0.0 \text{ kN} \cdot \text{m/m}$

depth to acting position $H_{i0} = 0.00 \text{ m}$

Height from riverbed to top of coping $H = 5.25 \text{ m}$

Depth of Imaginary riverbed from riverbed $L_k = 0.74 \text{ m}$

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_i) + M_{i0} = 0.00 \text{ kN} \cdot \text{m}$$

h₀, Height of acting position of P₀ from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i}$$

$$= \frac{463.44}{200.61} = 2.31 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 200.61}{5.99} = 66.98 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.51	1.51	1.67 22.11	1.26 16.69	5.49 4.98	6.91 83.17
2	1.51- 2.02	0.51	22.11 29.01	5.64 7.40	4.31 4.14	24.29 30.62
3	2.02- 2.51	0.49	29.29 35.49	7.18 8.70	3.81 3.64	27.32 31.68
4	2.51- 2.81	0.79	35.49 45.49	14.02 17.97	3.22 2.95	45.10 53.06
5	3.30- 3.51	0.21	45.49 46.08	4.78 4.84	2.62 2.55	12.51 12.34
6	3.51- 3.99	0.48	46.08 47.45	11.06 11.39	2.32 2.16	25.66 24.60
7	3.99- 4.51	0.52	47.00 48.94	12.22 12.72	1.83 1.65	22.32 21.04
8	4.51- 5.25	0.74	48.94 51.70	18.11 19.13	1.23 0.99	22.33 18.87
9	5.25- 5.51	0.26	51.70 48.05	6.72 6.25	0.65 0.57	4.39 3.54
10	5.51- 5.99	0.48	47.87 41.04	11.49 9.85	0.32 0.16	3.68 1.58
			Σ P =	207.39	Σ M =	475.02

P₀ : active earth pressure + residual water pressure - passive earth pressure

P : load P₀ 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

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

$$\phi_a = \frac{\sqrt{(1+2\beta h_0)^2+1}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1+2\beta h_0})$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1+2\beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1+\beta h_0}{\beta h_0}$$

$$M(x) = -\frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1+\beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction $K_b = 13752 \text{ kN/m}^3$

calculated value $\beta = 0.27797 \text{ m}^{-1}$

resultant earth force (lateral) $P_0 = 200.61 \text{ kN/m}$

height of acting position of load $h_0 = 2.31 \text{ m}$

moment $M_0 = 463.44 \text{ kN} \cdot \text{m/m}$

in consideration of $\psi_{00} = 1.285$,

maximum moment $M_{\max} = 595.58 \text{ kN} \cdot \text{m/m}$

depth of generated position of $M_{\max}$ $l_m = 1.484 \text{ m}$

depth of 1st fixed point $l_i = 4.310 \text{ m}$

6.2.2 Seismic Condition

modulus of lateral subgrade reaction $K_b = 26102 \text{ kN/m}^3$

calculated value $\beta = 0.32627 \text{ m}^{-1}$

resultant earth force (lateral) $P_0 = 211.31 \text{ kN/m}$

height of acting position of load $h_0 = 2.27 \text{ m}$

moment $M_0 = 480.68 \text{ kN} \cdot \text{m/m}$

in consideration of $\psi_{00} = 1.231$,

maximum moment $M_{\max} = 591.49 \text{ kN} \cdot \text{m/m}$

depth of generated position of $M_{\max}$ $l_m = 1.173 \text{ m}$

depth of 1st fixed point $l_i = 3.580 \text{ m}$

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name	10 H - H 700 -200 - 12-25-18
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 = 6370 cm ³ (original condition) Z = 5606 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

σ = Mmax / Z = (595.58 × 10^6) / (5606 × 10^3) = 106 N/mm² ≤ σs = 180 N/mm²

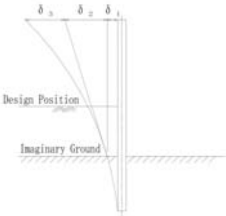
6.3.2 Seismic Condition

σ = Mmax / Z = (591.49 × 10^6) / (5606 × 10^3) = 106 N/mm² ≤ σs = 270 N/mm²

6.4 Displacement Calculation

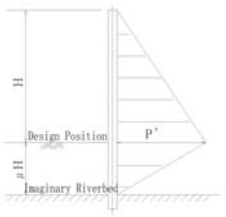
6.4.1 Normal Condition

Displacement Calculation



delta_1 = ((1 + beta * h_0) * P_0) / (2 * E * I * beta^3) = 0.01332 m
delta_2 = ((1 + 2 * beta * h_0) * P_0) / (2 * E * I * beta^2) * (H + L_0) = 0.03085 m
delta_3 = ((1 + 2 * 0.2780 * 2.31) * 200.61) / (2 * 2.00 * 10^8 * 287928 * 10^-8 * 0.2780^2) * (5.25 + 0.74) = 0.03085 m

delta_1 = ((1 + beta * h_0) * P_0) / (2 * E * I * beta^3) = 0.00920 m
delta_2 = ((1 + 2 * beta * h_0) * P_0) / (2 * E * I * beta^2) * (H + L_0) = 0.02565 m
delta_3 = ((1 + 2 * 0.3263 * 2.27) * 211.31) / (2 * 2.00 * 10^8 * 287928 * 10^-8 * 0.3263^2) * (5.25 + 0.74) = 0.02565 m



mu = L_k / H = 0.74 / 5.25 = 0.141
delta_3 = (P' * H^4) / (120 * E * I) * (4 + 20 * mu + 40 * mu^2 + 35 * mu^3 + 11 * mu^4) = 0.00599 m

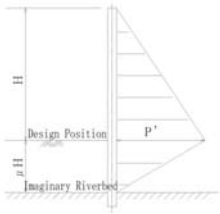
delta = delta_1 + delta_2 + delta_3 = 0.00920 + 0.02565 + 0.00599 = 0.04084 m
Size = 40.84 ≤ delta_a = 75.00 mm

Where,
delta_1 : Displacement at imaginary ground
delta_2 : Displacement by angle of inclination slope at imaginary ground
delta_3 : Displacement at higher part of imaginary ground as cantilever
delta : Displacement at top of SSP
delta_a : Allowable displacement

7 Penetration Depth

Corrosion rate and section efficiency for calculation of penetration depth of SSP are as below:

Table with 2 columns: Material Name, Unit width, Corrosion rate, Section efficiency, Young's modulus. Values include 10 H, H 700-200-12-25-18, B = 1.0000 m, eta = 1.00, mu = 1.00, E = 200000 N/mm².



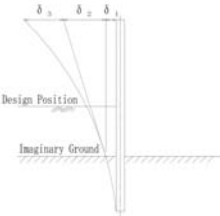
mu = L_k / H = 0.74 / 5.25 = 0.141
delta_3 = (P' * H^4) / (120 * E * I) * (4 + 20 * mu + 40 * mu^2 + 35 * mu^3 + 11 * mu^4) = 0.00568 m

delta = delta_1 + delta_2 + delta_3 = 0.01332 + 0.03085 + 0.00568 = 0.04984 m
Size = 49.84 ≤ delta_a = 50.00 mm

Where,
delta_1 : Displacement at imaginary ground
delta_2 : Displacement by angle of inclination slope at imaginary ground
delta_3 : Displacement at higher part of imaginary ground as cantilever
delta : Displacement at top of SSP
delta_a : Allowable displacement

6.4.2 Seismic Condition

Displacement Calculation



Inertia sectional moment I_0 = 334800 cm^4 (original condition)
I = 334800 cm^4 (after reduction by corrosion and section)
EI = 200000 * 10^3 * 334800 * 10^-8

7.1 Penetration Depth and Whole Length of SSP (Chang)
Based on the depth of imaginary riverbed as L_0, penetration depth of SSP (D) and whole length of SSP (L) are calculated as follows:

D = L_k + 3 / beta
L = H - H_0 + D
beta = 4 * sqrt((K_b * B) / (4 * E * I))

7.1.1 Normal Condition

Modules of lateral subgrade reaction K_b = 13752 kN/m³
Calculated value beta = 0.26768 m⁻¹
Penetration length of SSP D = 0.74 + 3 / 0.268 = 11.95 m
Whole length of SSP L = 5.25 - 0.40 + 11.95 = 16.80 m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction K_b = 26102 kN/m³
Calculated value beta = 0.31419 m⁻¹
Penetration length of SSP D = 0.74 + 3 / 0.314 = 10.29 m
Whole length of SSP L = 5.25 - 0.40 + 10.29 = 15.14 m

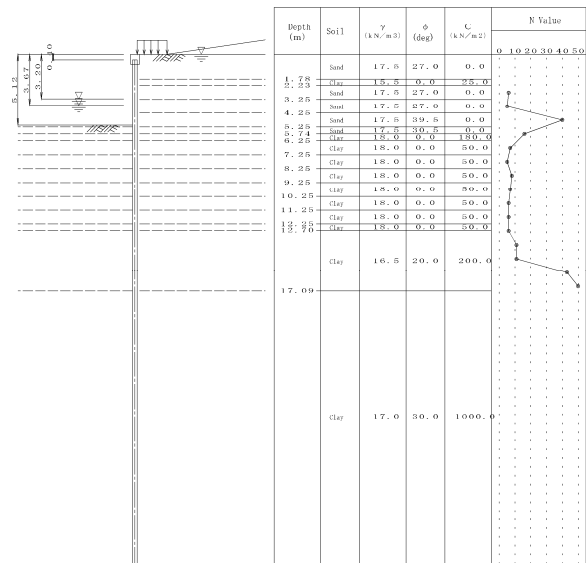
Therefore, the total length of the sheet pile is 17.00 m from the rounded length value of 0.50 m.

8 Calculation Result

Table with 5 columns: SSP, 10 H, H 700-200-12-25-18, Normal Condition, Seismic Condition. Rows include Inertia sectional moment, Sectional Modulus, Maximum bending moment, Stress intensity, Lateral displacement, Penetration depths, and Whole length of SSP.

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed	H	=	5.12 m
Depth from coping top to rear side ground	H ₀	=	0.00 m
Depth from coping top to SSP top	H _b	=	0.40 m
Landside WL	L _{wa}	=	0.00 m (Normal Condition)
	L _{wa'}	=	0.00 m (Seismic Condition)
Riverside WL	L _{wp}	=	3.67 m (Normal Condition)
	L _{wp'}	=	3.20 m (Seismic Condition)

1.3 Applied Formula

Formula for generated stress	Chang's formula
Penetration depths	$L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water	$\gamma_w = 9.8 \text{ kN/m}^3$
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	not considered
Wind load, Impact load	not considered
Minimum angle of rupture	$\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope	not considered
Angle of rupture (clayey soil)	$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$ $a = \sin \theta$ $b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$
Equilibrium factor of compression	K _c = 0.50 (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula	$K_{\Delta} = K_{\Delta 0} \left(\frac{B_{\Delta}}{0.3} \right)^{-3/4}$ $K_{\Delta 0} = \frac{1}{0.3} \alpha E_0$ (α: Normal Condition =1, Seismic Condition =2) $B_{\Delta} = 10.00 \text{ m}$ $E_0 = 2800 \text{ N}$
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	2.75	6	11	12.75	6
2	3.75	5	12	13.75	11
3	4.75	40	13	14.75	11
4	5.75	16	14	15.75	43
5	6.75	7	15	16.75	50
6	7.75	5			
7	8.75	8			
8	9.75	7			
9	10.75	6			
10	11.75	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 (Include Projection Length)	Thickness m (excluding projected length)
1	1.78	1.78
2	2.23	0.45
3	3.25	1.02
4	4.25	1.00
5	5.25	1.00
6	5.74	0.49
7	6.25	0.51
8	7.25	1.00
9	8.25	1.00
10	9.25	1.00
11	10.25	1.00
12	11.25	1.00
13	12.25	1.00
14	12.70	0.45
15	17.09	4.39
16	35.20	18.11

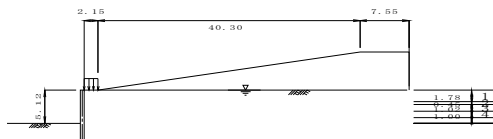
No	Depth m	earth Soil	N Value	γ	γ'	φ	C	a	k'	ζ (degree)
			kN/m³	kN/m³	degree	degree	kN/m²			Normal Condition
1	1.78	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto
2	2.23	C	6.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto
3	3.25	S	6.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto
4	4.25	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto
5	5.25	S	40.0	17.50	7.70	39.5	0.0	0.0	0.200	Auto
6	5.74	S	16.0	17.50	7.70	30.5	0.0	0.0	0.200	Auto
7	6.25	C	16.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto
8	7.25	C	7.0	18.00	8.20	0.0	80.0	0.0	0.200	Auto
9	8.25	C	5.0	18.00	8.20	0.0	80.0	0.0	0.200	Auto
10	9.25	C	8.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto
11	10.25	C	7.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto
12	11.25	C	6.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto
13	12.25	C	6.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto
14	12.70	C	6.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto
15	17.09	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto
16	35.20	C	121.5	17.00	7.20	30.0	1000.0	0.0	0.200	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_s : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness h m	soil single weight γ		internal friction angle ϕ degree	stickiness C kN/m ²	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		Normal Condition kN/m ³	Seismic Condition kN/m ³			Normal Condition degree	Seismic Condition degree
1	Sand	2.15	42.45	50.00	50.00	5.88	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	2.15	5.0	0.0

Angle of rupture in embankment calculated in consideration of embankment conditions

1.9 Steel Sheet Pile (SSP)

Material name	10 H H 850 -250 -14 -22 -18
Young's modulus	E = 200000 N/mm ²
Inertia sectional moment	I ₀ = 532300 cm ⁴
Sectional factor	Z ₀ = 8840 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 = 180 N/mm (Normal)
	σ_a' = 270 N/mm (Seismic)

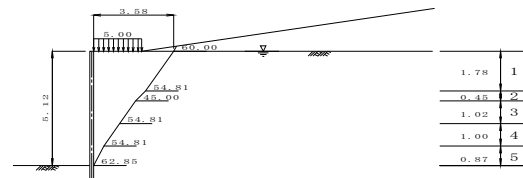
Allowable displacement	δ_a = 50.0 mm (Normal)
	δ_a' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus
Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I₀ applied to calculation of penetration depth
Reduced: I₀ 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/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ value kN/m ³	Angle of Rupture ζ degree
1	5.12 ~ 4.25	Sand	39.5	15.0	0.0	38.52	3.87	50.18	62.85

2.1.4 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qd kN/m
1	5.0	2.15	10.75
Σ			10.75

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

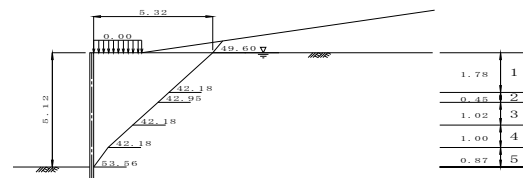
2.1.5 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{3.08 + 10.75 + 0.00}{3.58}$$

$$= 3.87 \text{ kN/m}^2$$

2.2 Seismic 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	γ value kN/m ³	k (k ⁻³)	θ degree	Angle of Rupture ζ degree
1	5.12 ~ 4.25	Sand	39.5	15.0	0.0	38.52	2.99	50.18	0.200	11.31	53.56
2	4.25 ~ 3.25	Sand	27.0	15.0	0.0	31.83	2.99	41.65	0.200	11.31	42.18
3	3.25 ~ 2.23	Sand	27.0	15.0	0.0	24.13	2.99	31.85	0.200	11.31	42.18
4	2.23 ~ 1.78	Clay	0.0	15.0	25.0	16.27	2.99	21.85	0.200	11.31	42.95
5	1.78 ~ 0.00	Sand	27.0	15.0	0.0	13.71	2.99	17.44	0.200	11.31	42.18
6		embankment	30.0	—	0.0	111.72	0.00	0.00	0.200	11.31	49.60

• Major collapse angle of Sand, intermediate soil, and split rock

2	4.25 ~ 3.25	Sand	27.0	15.0	0.0	31.83	3.87	41.65	54.81
3	3.25 ~ 2.23	Sand	27.0	15.0	0.0	24.13	3.87	31.85	54.81
4	2.23 ~ 1.78	Clay	0.0	15.0	25.0	16.27	3.87	21.85	45.00
5	1.78 ~ 0.00	Sand	27.0	15.0	0.0	13.71	3.87	17.44	54.81
6		embankment	30.0	—	0.0	111.72	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

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\Sigma \gamma h + Q}$$

Angle of active rupture of clayey soil ζ is set as 45° since $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	62.85	0.87	0.00	0.00	0.45	0.87
2	54.81	1.00	0.45	0.87	1.15	1.87
3	54.81	1.02	1.15	1.87	1.87	2.89
4	45.00	0.45	1.87	2.89	2.32	3.34
5	54.81	1.78	2.32	3.34	3.58	5.12
6	60.00	0.23	3.58	5.12	3.71	5.35

From the above table, the loading width (L) on the ground surface is 3.58 m.

2.1.3 Acting Load by Embankment

No	γ kN/m ³	A m ²	$\gamma \times A$ kN/m
1	19.0	0.16	3.08
2			3.08

γ : unit weight of embankment soil

A: sectional area of embankment enclosed by line of active rupture

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}}{\sin(\phi - \theta) \cos(\phi + \delta)}$$

• Major collapse angle of cohesive soil

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2 C \cos \theta}{\sum \gamma h + Q}$$

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)

$$\theta = \tan^{-1}k \text{ or } \theta = \tan^{-1}k'$$

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	53.56	0.87	0.00	0.00	0.64	0.87
2	42.18	1.00	0.64	0.87	1.75	1.87
3	42.18	1.02	1.75	1.87	2.87	2.89
4	42.95	0.45	2.87	2.89	3.36	3.34
5	42.18	1.78	3.36	3.34	5.32	5.12
6	49.60	0.53	5.32	5.12	5.77	5.65

From the above table, the loading width (L) on the ground surface is 5.32 m.

2.2.3 Acting Load by Embankment

No	γ kN/m3	A m2	γ × A kN/m
1	19.0	0.84	15.90
Σ			15.90

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	Qxl kN/m
1	0.0	2.15	0.00
Σ			0.00

Q: width of surcharge load set by line of active rupture

8	5.25-5.74	Sand	7.7	30.5	—	43.392 47.165	0.29571 0.29571	0.28563 0.28563
9	5.74-6.25	Clay	8.2	—	180.0 180.0	47.165 51.347	—	—
10	6.25-7.25	Clay	8.2	—	50.0 50.0	51.347 59.547	—	—
11	7.25-8.25	Clay	8.2	—	50.0 50.0	59.547 67.747	—	—
12	8.25-9.25	Clay	8.2	—	50.0 50.0	67.747 75.947	—	—
13	9.25-10.25	Clay	8.2	—	50.0 50.0	75.947 84.147	—	—
14	10.25-11.25	Clay	8.2	—	50.0 50.0	84.147 92.347	—	—
15	11.25-12.18	Clay	8.2	—	50.0 50.0	92.347 100.000	—	—
16	12.18-12.25	Clay	8.2	—	50.0 50.0	100.000 100.547	—	—
17	12.25-12.70	Clay	8.2	—	50.0 50.0	100.547 104.237	—	—
18	12.70-17.09	Clay	6.7	—	200.0 200.0	104.237 133.650	—	—
19	17.09-35.20	Clay	7.2	—	1000.0 1000.0	133.650 264.042	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$$\delta = 15.00, \beta = 0.00, \theta = 0.00$$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qp kN/m2	Kp	Kp × cos δ
7	5.12-5.25	Sand	7.7	39.5	—	0.000 1.001	8.59467 8.59467	8.30181 8.30181
8	5.25-5.74	Sand	7.7	30.5	—	1.001 4.774	5.11035 5.11035	4.93622 4.93622
9	5.74-6.25	Clay	8.2	0.0	180.0 180.0	4.774 8.956	—	—
10	6.25-7.25	Clay	8.2	0.0	50.0 50.0	8.956 17.156	—	—
11	7.25-8.25	Clay	8.2	0.0	50.0 50.0	17.156 25.356	—	—
12	8.25-9.25	Clay	8.2	0.0	50.0 50.0	25.356 33.556	—	—
13	9.25-10.25	Clay	8.2	0.0	50.0 50.0	33.556 41.756	—	—
14	10.25-11.25	Clay	8.2	0.0	50.0 50.0	41.756 49.956	—	—
15	11.25-12.18	Clay	8.2	0.0	50.0 50.0	49.956 57.609	—	—

l: Loading width of uniform load surrounded by main collapse line

2.2.5 Calculated Load

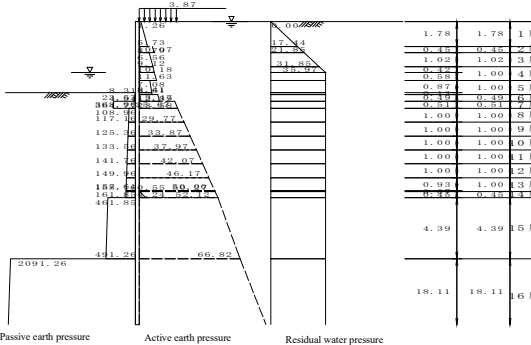
$$Q = \frac{\sum (\gamma \times A) + \sum (Q \times l) + \sum P}{L}$$

$$= \frac{15.90 + 0.00 + 0.00}{5.32}$$

$$= 2.99 \text{ kN/m}^2$$

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

	Depth, m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qa kN/m2	Ka	Ka × cos δ
1	0.00-1.78	Sand	7.7	27.0	—	3.867 17.573	0.33738 0.33738	0.32589 0.32589
2	1.78-2.23	Clay	5.7	—	25.0 25.0	17.573 20.138	—	—
3	2.23-3.25	Sand	7.7	27.0	—	20.138 27.992	0.33738 0.33738	0.32589 0.32589
4	3.25-3.67	Sand	7.7	27.0	—	27.992 31.226	0.33738 0.33738	0.32589 0.32589
5	3.67-4.25	Sand	7.7	27.0	—	31.226 35.692	0.33738 0.33738	0.32589 0.32589
6	4.25-5.12	Sand	7.7	39.5	—	35.692 42.391	0.20544 0.20544	0.19844 0.19844
7	5.12-5.25	Sand	7.7	39.5	—	42.391 43.392	0.20544 0.20544	0.19844 0.19844

16	12.18-12.25	Clay	8.2	0.0	50.0 50.0	57.609 58.156	—	—
17	12.25-12.70	Clay	8.2	0.0	50.0 50.0	58.156 61.846	—	—
18	12.70-17.09	Clay	6.7	20.0	200.0 200.0	61.846 91.259	—	—
19	17.09-35.20	Clay	7.2	30.0	1000.0 1000.0	91.259 221.651	—	—

Coefficient of passive earth pressure of sandy soil Ka is calculated by the formula below;

$$\delta = -15.00, \beta = 0.00, \theta = 0.00$$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2	Pw kN/m2	Pp kN/m2
1	0.00-1.78	1.26 5.73	—	1.26 5.73	0.00 17.44	—
2	1.78-2.23	-32.43 -29.86	8.79 10.07	8.79 10.07	17.44 21.85	—
3	2.23-3.25	6.56 9.12	—	6.56 9.12	21.85 31.85	—
4	3.25-3.67	9.12 10.18	—	9.12 10.18	31.85 35.97	—
5	3.67-4.25	10.18 11.63	—	10.18 11.63	35.97 35.97	—
6	4.25-5.12	7.08 8.41	—	7.08 8.41	35.97 35.97	—
7	5.12-5.25	8.41 8.61	—	8.41 8.61	35.97 35.97	0.00 8.31
8	5.25-5.74	12.39 13.47	—	12.39 13.47	35.97 35.97	4.94 23.57
9	5.74-6.25	-312.84 -308.65	23.58 25.67	23.58 25.67	35.97 35.97	364.77 368.96
10	6.25-7.25	-48.65 -40.45	25.67 28.77	25.67 28.77	35.97 35.97	108.96 117.16
11	7.25-8.25	-40.45 -32.25	28.77 33.87	28.77 33.87	35.97 35.97	117.16 125.36
12	8.25-9.25	-32.25 -24.05	33.87 37.97	33.87 37.97	35.97 35.97	125.36 133.56
13	9.25-10.25	-24.05 -15.85	37.97 42.07	37.97 42.07	35.97 35.97	133.56 141.76
14	10.25-11.25	-15.85 -7.65	42.07 46.17	42.07 46.17	35.97 35.97	141.76 149.96
15	11.25-12.18	-7.65 0.00	46.17 50.00	46.17 50.00	35.97 35.97	149.96 157.61

16	12.18- 12.25	0.00 0.55	50.00 50.27	50.00 50.27	35.97 35.97	157.61 158.16
17	12.25- 12.70	0.55 4.24	50.27 52.12	50.27 52.12	35.97 35.97	158.16 161.85
18	12.70- 17.09	-295.76 -266.35	52.12 66.82	52.12 66.82	35.97 35.97	461.85 491.26
19	17.09- 35.20	-1866.35 -1735.96	66.82 132.02	66.82 132.02	35.97 35.97	2091.26 2221.65

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

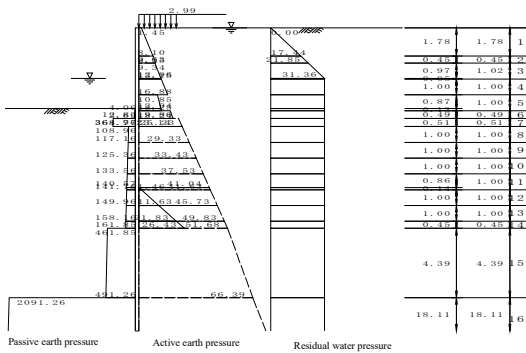
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

3.2 Seismic Condition



$$\zeta = 45^\circ - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

$$a = \sin \theta$$

$$b = \sin \theta + \frac{2C \cos \theta}{\Sigma \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	γ_{wbu} kN/m ²	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
7	5.12- 5.25	Sand	7.70	39.5	—	0.000 1.001	0.00 1.27	0.200 0.200	11.31 11.31	4.05365 4.05365	4.05365 4.05365
8	5.25- 5.74	Sand	7.70	30.5	—	1.001 4.774	1.27 6.08	0.200 0.200	11.31 11.31	2.68732 2.68732	2.68732 2.68732
9	5.74- 6.25	Clay	8.20	0.0	180.0 180.0	4.774 8.956	6.08 11.07	0.200 0.200	11.31 11.31	—	—
10	6.25- 7.25	Clay	8.20	0.0	50.0 50.0	8.956 17.156	11.07 20.87	0.200 0.200	11.31 11.31	—	—
11	7.25- 8.25	Clay	8.20	0.0	50.0 50.0	17.156 25.356	20.87 30.67	0.200 0.200	11.31 11.31	—	—
12	8.25- 9.25	Clay	8.20	0.0	50.0 50.0	25.356 33.556	30.67 40.47	0.200 0.200	11.31 11.31	—	—
13	9.25- 10.11	Clay	8.20	0.0	50.0 50.0	33.556 40.373	40.47 —	0.200 —	11.31 —	—	—
14	10.11- 10.25	Clay	8.20	0.0	50.0 50.0	40.373 41.756	— 50.27	— 0.200	— 11.31	—	—
15	10.25- 11.25	Clay	8.20	0.0	50.0 50.0	41.756 49.956	50.27 60.07	0.200 0.200	11.31 11.31	—	—
16	11.25- 12.25	Clay	8.20	0.0	50.0 50.0	49.956 58.156	60.07 69.87	0.200 0.200	11.31 11.31	—	—
17	12.25- 12.70	Clay	8.20	0.0	50.0 50.0	58.156 61.846	69.87 74.28	0.200 0.200	11.31 11.31	—	—
18	12.70- 17.09	Clay	6.70	20.0	200.0 200.0	61.846 91.259	74.28 117.31	0.200 0.200	11.31 11.31	—	—
19	17.09- 35.20	Clay	7.20	30.0	1000.0 1000.0	91.259 221.651	117.31 294.78	0.200 0.200	11.31 11.31	—	—

- The coefficient of passive earth pressure (Kp) of Sand is obtained by the following equation.

$\delta = 0.00$ degrees, $\beta = 0.00$ degrees

Seismic composite angle $\theta = \tan^{-1} k$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.2.3 Lateral Forth

No	Depth, m	Active			Residual water pressure	Passive
		Pa1 kN/m ²	Pa2 kN/m ²	Pa kN/m ²	Pw kN/m ²	
1	0.00- 1.78	1.45 8.10	—	1.45 8.10	0.00 17.44	—

3.2.1 Soil Modulus of Active Side

No	Depth, m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q$ kN/m ²	γ_{wbu} kN/m ²	k (k ²)	θ degree	Ka	Ka $\times \cos \delta$	ζ degree
1	0.00- 1.78	Sand	7.7	27.0	—	2.99 16.70	0.00 17.44	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
2	1.78- 2.23	Clay	5.7	—	25.0 25.0	16.70 19.26	17.44 21.85	0.200 0.200	11.31 11.31	—	—	41.21 42.95
3	2.23- 3.20	Sand	7.7	27.0	—	19.26 26.73	21.85 31.36	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
4	3.20- 3.25	Sand	7.7	27.0	—	26.73 27.11	31.36 31.85	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
5	3.25- 4.25	Sand	7.7	27.0	—	27.11 34.81	31.85 41.65	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	—
6	4.25- 5.12	Sand	7.7	39.5	—	34.81 41.51	41.65 50.18	0.200 0.200	11.31 11.31	0.32266 0.32266	0.31166 0.31166	—
7	5.12- 5.25	Sand	7.7	39.5	—	41.51 42.51	50.18 51.45	0.200 0.200	11.31 11.31	0.32266 0.32266	0.31166 0.31166	—
8	5.25- 5.74	Sand	7.7	30.5	—	42.51 46.29	51.45 56.25	0.200 0.200	11.31 11.31	0.44421 0.44421	0.42907 0.42907	—
9	5.74- 6.25	Clay	8.2	—	180.0 180.0	46.29 50.47	56.25 61.25	0.200 0.200	11.31 11.31	—	—	44.28 44.22
10	6.25- 7.25	Clay	8.2	—	50.0 50.0	50.47 58.67	61.25 71.05	0.200 0.200	11.31 11.31	—	—	42.37 41.99
11	7.25- 8.25	Clay	8.2	—	50.0 50.0	58.67 66.87	71.05 80.85	0.200 0.200	11.31 11.31	—	—	41.99 41.61
12	8.25- 9.25	Clay	8.2	—	50.0 50.0	66.87 75.07	80.85 90.65	0.200 0.200	11.31 11.31	—	—	41.61 41.25
13	9.25- 10.11	Clay	8.2	—	50.0 50.0	75.07 82.09	90.65 —	0.200 —	11.31 —	—	—	41.25 —
14	10.11- 10.25	Clay	8.2	—	50.0 50.0	82.09 83.27	— 100.45	— 0.200	— 11.31	—	—	— 40.90
15	10.25- 11.25	Clay	8.2	—	50.0 50.0	83.27 91.47	100.45 110.25	0.200 0.200	11.31 11.31	—	—	40.90 40.55
16	11.25- 12.25	Clay	8.2	—	50.0 50.0	91.47 99.67	110.25 120.05	0.200 0.200	11.31 11.31	—	—	40.55 40.22
17	12.25- 12.70	Clay	8.2	—	50.0 50.0	99.67 103.36	120.05 124.46	0.200 0.200	11.31 11.31	—	—	40.22 40.07
18	12.70- 17.09	Clay	6.7	—	200.0 200.0	103.36 132.77	124.46 167.48	0.200 0.200	11.31 11.31	—	—	43.59 43.22
19	17.09- 35.20	Clay	7.2	—	1000.0 1000.0	132.77 263.16	167.48 344.96	0.200 0.200	11.31 11.31	—	—	44.62 44.27

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z, m	water level y m	p _{dw} kN/m ²
1	3.20	0.00	0.00
2	4.30	1.00	2.38
3	5.12	1.92	3.29

$$p_{dw} = \pm \frac{7}{8} k_{10} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

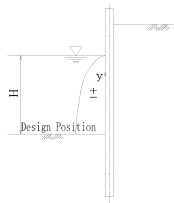
Where,

k₁₀: design seismic coefficient

γ_w: unit weight of water

H: water depth of riverside

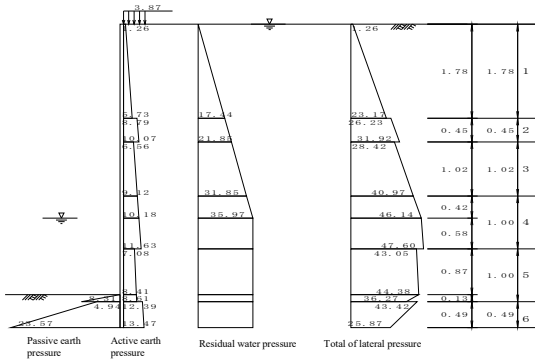
y: depth from water surface to the point where active water pressure is calculated



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



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.78	1.26 5.73	0.00 17.44	— —	1.26 23.17
2	1.78- 2.23	8.79 10.07	17.44 21.85	— —	26.23 31.92
3	2.23- 3.25	6.56 9.12	21.85 31.85	— —	28.42 40.97
4	3.25- 3.67	9.12 10.18	31.85 35.97	— —	40.97 46.14
5	3.67- 4.25	10.18 11.63	35.97 35.97	— —	46.14 47.60
6	4.25- 5.12	7.08 8.41	35.97 35.97	— —	43.05 44.38
7	5.12- 5.25	8.41 8.61	35.97 35.97	0.00 8.31	44.38 36.27
8	5.25- 5.74	12.39 13.47	35.97 35.97	4.94 23.57	43.42 25.87
9	5.74- 6.25	23.58 25.67	35.97 35.97	364.77 368.96	-305.23 -307.32

P_a: Active earth pressure

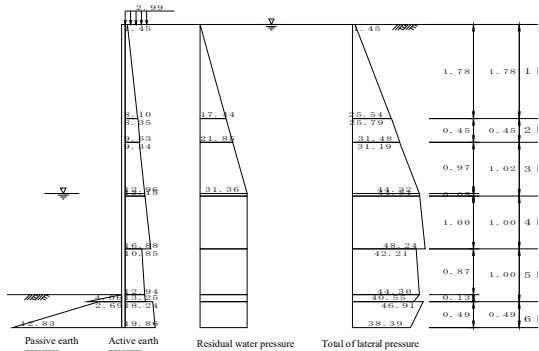
P_w: Residual water pressure

P_p: Passive earth pressure

P_s: Lateral pressure P_s = P_a + P_w - P_p

Imaginary riverbed L_k: 0.62 m (GL -5.74 m)

4.2 Seismic Condition



No	Depth m	P _a kN/m ²	P _w kN/m ²	P _p kN/m ²	P _s kN/m ²
1	0.00- 1.78	1.45 8.10	0.00 17.44	— —	1.45 25.54
2	1.78- 2.23	8.35 9.63	17.44 21.85	— —	25.79 31.48
3	2.23- 3.20	9.34 12.96	21.85 31.36	— —	31.19 44.32
4	3.20- 3.25	12.96 13.15	31.36 31.36	— —	44.32 44.51
5	3.25- 4.25	13.15 16.88	31.36 31.36	— —	44.51 48.24
6	4.25- 5.12	10.85 12.94	31.36 31.36	— —	42.21 44.30
7	5.12- 5.25	12.94 13.25	31.36 31.36	0.00 4.06	44.30 40.55
8	5.25- 5.74	18.24 19.86	31.36 31.36	2.69 12.83	46.91 38.39
9	5.74- 6.25	23.14 25.23	31.36 31.36	364.77 368.96	-310.27 -312.36

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: 0.62 m (GL -5.74 m)

Let the virtual ground surface L_k = 0.62 m (GL -5.74 m).

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of 1/β from the virtual ground surface.

The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_b = K_{10} \left(\frac{B}{0.3} \right)^{-3/4} \quad (B = 10.00m)$$

$$K_{10} = \frac{1}{0.3} \alpha E_0 \quad (\alpha: \text{Normal Condition}=1, \text{Seismic Condition}=2)$$

$$E_b = 2800N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material Name	10 H_H 850 -250 -14 -22 -18
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 = 532300 cm ⁴ (original condition)
Inertia sectional moment	I = 457778 cm ⁴ (after reduction by corrosion and section)
Inertia sectional moment	EI = 200000 × 10 ³ × 457779 × 10 ⁻⁸ = 9.156 × 10 ⁵

No	Depth m	N Value	No	Depth m	N Value
1	2.75	6	11	12.75	6
2	3.75	5	12	13.75	11
3	4.75	40	13	14.75	11
4	5.75	16	14	15.75	42
5	6.75	7	15	16.75	50
6	7.75	5			
7	8.75	8			
8	9.75	7			
9	10.75	6			
10	11.75	6			

5.2 Normal Condition

Assuming K_h = 5089 kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.193 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 5.18 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.74 m) to 5.18 m depth (GL -10.92 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.74	0.01	16.2	16.0	0.16
2	5.75	1.00	16.0	7.0	11.50
3	6.75	1.00	7.0	5.0	6.00
4	7.75	1.00	5.0	4.0	6.50
5	8.75	1.00	8.0	7.0	7.50
6	9.75	1.00	7.0	6.0	6.50
7	10.75	0.17	6.0	6.0	1.02
L = $\Sigma h = 5.18$			$\Sigma A = 39.18$		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{39.18}{5.18} \\ &= 7.56 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 7.56 = 21181 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 21181 = 70602 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 70602(10.00/0.3)^{-3/4} = 5089 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 5089 kN/m³.

5.3 Seismic Condition

Assuming Kh = 10523 kN/m³,

$$\begin{aligned} \beta &= 4\sqrt{\frac{K_b \cdot B}{4EI}} = 0.232 \text{ m}^{-1} \\ L &= \frac{1}{\beta} = 4.32 \text{ m} \end{aligned}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.74 m) and 4.32 m depth (GL -10.06 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.74	0.01	16.2	16.0	0.16
2	5.75	1.00	16.0	7.0	11.50
3	6.75	1.00	7.0	5.0	6.00
4	7.75	1.00	5.0	8.0	6.50
5	8.75	1.00	8.0	7.0	7.50
6	9.75	0.31	7.0	6.7	2.12
L = $\Sigma h = 4.32$			$\Sigma A = 33.78$		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{33.78}{4.32} \\ &= 7.82 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 7.82 = 21897 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 21897 = 145980 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B_u/0.3)^{-3/4} = 145980(10.00/0.3)^{-3/4} = 10523 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 10523 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.78	1.78	1.26 23.17	1.12 20.62	5.15 4.55	5.77 93.90
2	1.78- 2.23	0.45	26.23 31.92	5.90 7.18	3.81 3.66	22.49 36.29
3	2.23- 3.25	1.02	28.42 40.97	14.49 20.90	3.17 2.83	45.94 59.14
4	3.25- 3.67	0.42	40.97 46.14	8.60 9.69	2.35 2.21	20.22 21.41
5	3.67- 4.25	0.58	46.14 47.60	13.38 13.80	1.88 1.68	25.11 23.24
6	4.25- 5.12	0.87	43.05 44.38	18.73 19.30	1.20 0.91	22.47 17.57
7	5.12- 5.25	0.13	44.38 36.27	2.88 2.36	0.58 0.55	1.66 1.26
8	5.25- 5.74	0.49	43.42 25.87	10.64 6.34	0.33 0.16	3.47 1.04
$\Sigma P = 175.94$			$\Sigma M = 390.97$			

P₁ : 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

$$\begin{aligned} \text{Arbitrary load lateral load } P_1 &= 0.0 \text{ kN/m} \\ \text{depth to acting position } H_1 &= 0.0 \text{ m} \\ \text{moment } M_{10} &= 0.0 \text{ kN} \cdot \text{m/m} \end{aligned}$$

$$\begin{aligned} \text{depth to acting position } H_0 &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 5.12 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.62 \text{ m} \end{aligned}$$

Moment M₁ by arbitrary load is as below

$$M_1 = P_1 \cdot (H + L_k - H_1) + M_{10} = 0.00 \text{ kN} \cdot \text{m}$$

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_1}{\Sigma P + P_1} \\ &= \frac{390.97}{175.94} = 2.22 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 175.94}{5.74} = 61.30 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.78	1.78	1.45 25.54	1.29 22.73	5.15 4.55	6.64 103.90
2	1.78- 2.23	0.45	25.79 31.48	5.80 7.08	3.81 3.66	22.11 25.93
3	2.23- 3.20	0.97	31.19 44.32	15.13 21.50	3.19 2.86	48.21 61.55
4	3.20- 3.25	0.05	44.32 44.51	1.11 1.11	2.52 2.51	2.80 2.79
5	3.25- 4.25	1.00	44.51 48.24	22.25 24.12	2.16 1.82	47.99 43.98
6	4.25- 5.12	0.87	42.21 44.30	18.36 19.27	1.20 0.91	22.03 17.54
7	5.12- 5.25	0.13	44.30 40.55	2.88 2.64	0.58 0.53	1.66 1.41
8	5.25- 5.74	0.49	46.91 38.39	11.49 9.41	0.33 0.16	3.75 1.54
$\Sigma P = 186.17$			$\Sigma M = 413.42$			

P₁ : 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

$$\begin{aligned} \text{Arbitrary load lateral load } P_1 &= 0.0 \text{ kN/m} \\ \text{depth to acting position } H_1 &= 0.00 \text{ m} \\ \text{moment } M_{10} &= 0.0 \text{ kN} \cdot \text{m/m} \end{aligned}$$

$$\begin{aligned} \text{depth to acting position } H_0 &= 0.00 \text{ m} \\ \text{Height from riverbed to top of coping } H &= 5.12 \text{ m} \\ \text{Depth of Imaginary riverbed from riverbed } L_k &= 0.62 \text{ m} \end{aligned}$$

Moment M₁ by arbitrary load is as below

$$M_1 = P_1 \cdot (H + L_k - H_1) + M_{10} = 0.00 \text{ kN} \cdot \text{m}$$

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	3.20- 4.20	1.00	0.0 2.4	0.00 1.19	2.21 1.87	0.00 2.23
2	4.20- 5.12	0.92	2.4 3.3	1.09 1.51	1.23 0.93	1.35 1.40
$\Sigma P_{0w} = 3.80$			$\Sigma M_{0w} = 4.98$			

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_1 + \Sigma M_{0w}}{\Sigma P + P_1 + \Sigma P_{0w}} \\ &= \frac{418.40}{189.97} = 2.20 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 189.97}{5.74} = 66.19 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name	10 H ₈₅₀ -250-14-22-18
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 = 552300 cm ⁴ (original condition)
	I = 457778 cm ⁴ (after reduction by corrosion and section)
	= 9.156 × 10 ⁸

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4EI}}$$

$$\phi_a = \frac{\sqrt{(1 + 2\beta h_0)^{+1}}}{2\beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2\beta h_0})$$

$$M_{10w} = M_0 \cdot \phi_a$$

$$1_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2\beta h_0}$$

$$1_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{10} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K_a	=	5089 kN/m ³
calculated value	β	=	0.19308 m ⁻¹
resultant earth force (lateral)	P_0	=	175.94 kN/m
height of acting position of load	h_0	=	2.22 m
moment	M_0	=	390.97 kN·m/m
in consideration of $\psi_{tm} = 1.501$, maximum moment	M_{max}	=	586.80 kN·m/m
depth of generated position of M_{max}	l_m	=	2.557 m
depth of 1 st fixed point	l_i	=	6.625 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K_a	=	10523 kN/m ³
calculated value	β	=	0.23152 m ⁻¹
resultant earth force (lateral)	P_0	=	189.97 kN/m
height of acting position of load	h_0	=	2.20 m
moment	M_0	=	418.40 kN·m/m
in consideration of $\psi_{tm} = 1.396$, maximum moment	M_{max}	=	583.88 kN·m/m
depth of generated position of M_{max}	l_m	=	1.986 m
depth of 1 st fixed point	l_i	=	5.378 m

6.3 Stress Intensity

Corrosion rate and section efficiency for check of stresses intensity are set as followings:

Material Name	10 H _ H 850 -250 -14 -22 -18
Corrosion margin	$t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)
Corrosion rate	$\eta = 0.88$
Section efficiency	$\mu = 1.00$
Module of section	$Z_0 = 8840$ cm ³ (original condition)
	$Z = 7779$ cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{586.80 \times 10^6}{7779 \times 10^3} = 75 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{583.88 \times 10^6}{7779 \times 10^3} = 75 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

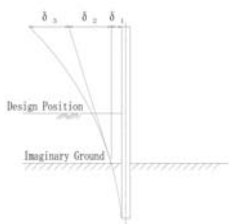
$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01908 + 0.02749 + 0.00271 \\ &= 0.04928 \text{ m} \\ \text{Size} &= 49.28 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

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

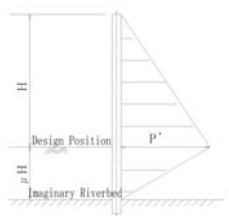
6.4.2 Seismic Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2315 \times 2.20) \times 189.97}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2315^3} = 0.01262 \text{ m} \end{aligned}$$

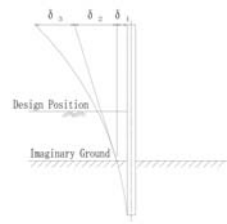
$$\begin{aligned} \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) \\ &= \frac{(1 + 2 \times 0.2315 \times 2.20) \times 189.97}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.2315^2} \times (5.12 + 0.62) = 0.02244 \text{ m} \end{aligned}$$



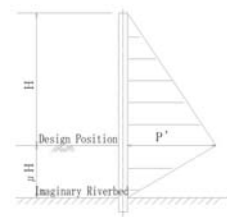
6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.1931 \times 2.22) \times 175.94}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.1931^3} = 0.01908 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) \\ &= \frac{(1 + 2 \times 0.1931 \times 2.22) \times 175.94}{2 \times 2.00 \times 10^8 \times 457778 \times 10^{-8} \times 0.1931^2} \times (5.12 + 0.62) = 0.02749 \text{ m} \end{aligned}$$



$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{0.62}{5.12} = 0.121 \\ \delta_3 &= \frac{P^1 H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{61.30 \times 5.12^4}{120 \times 2.00 \times 10^8 \times 457778 \times 10^{-8}} (4 + 20 \times 0.121 + 40 \times 0.121^2 + 35 \times 0.121^3 + 11 \times 0.121^4) \\ &= 0.00271 \text{ m} \end{aligned}$$

$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{0.62}{5.12} = 0.121 \\ \delta_3 &= \frac{P^1 H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) \\ &= \frac{66.19 \times 5.12^4}{120 \times 2.00 \times 10^8 \times 457778 \times 10^{-8}} (4 + 20 \times 0.121 + 40 \times 0.121^2 + 35 \times 0.121^3 + 11 \times 0.121^4) \\ &= 0.00293 \text{ m} \end{aligned}$$

$$\begin{aligned} \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01262 + 0.02244 + 0.00293 \\ &= 0.03799 \text{ m} \\ \text{Size} &= 37.99 \leq \delta_a = 75.00 \text{ mm} \end{aligned}$$

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:

Material Name	10 H _ H 850 -250 -14 -22 -18
Unit width	$B = 1.0000$ m
Corrosion rate	$\eta = 1.00$
Section efficiency	$\mu = 1.00$
Young's modulus	$E = 200000$ N/mm ²
Inertia sectional moment	$I_0 = 532300$ cm ⁴ (original condition)
	$I = 532300$ cm ⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 532300 \times 10^{-8}$	$= 1.065 \times 10^8$

7.1 Penetration Depth and Whole Length of SSP (Chang)

Based on the depth of imaginary riverbed as L_u , penetration depth of SSP (D) and whole length of SSP (L) are calculated as followings:

$$\begin{aligned} D &= L_i + \frac{3}{\beta} \\ L &= H - H_{it} + D \\ \beta &= \sqrt[4]{\frac{K_a \cdot B}{4 E I}} \end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	$K_a = 5089$ kN/m ³
Calculated value	$\beta = 0.18593$ m ⁻¹

Penetration length of SSP	$D = 0.62 + \frac{3}{0.186} = 16.75$ m
Whole length of SSP	$L = 5.12 - 0.40 + 16.75 = 21.47$ m

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 10523 \text{ kN/m}^3$
Calculated value $\beta = 0.22296 \text{ m}^{-1}$

Penetration length of SSP $D = 0.62 + \frac{3}{0.223} = 14.08 \text{ m}$
Whole length of SSP $L = 5.12 - 0.40 + 14.08 = 18.80 \text{ m}$

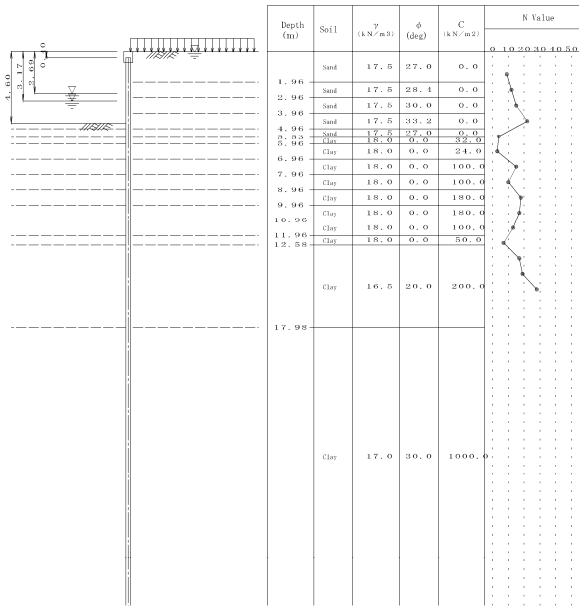
Therefore, the total length of the sheet pile is 21.50 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H_H 850-250-14-22-18				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	522300		
Sectional Modulus	Z (cm ³)	8849		
Maximum bending moment	Mmax (kN · m · m)		586.80	583.88
Stress intensity	σ (N/mm ²)		75 (180)	75 (200)
Lateral displacement	δ (mm)		49.28 (50.0)	37.99 (35.0)
Penetration depths	D (m)		16.75	14.08
Whole length of SSP	L (m)	21.50		

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 4.60 \text{ m}$
Depth from coping top to rear side ground $H_0 = 0.00 \text{ m}$
Depth from coping top to SSP top $H_b = 0.40 \text{ m}$
Landside WL $L_{wa} = 0.00 \text{ m}$ (Normal Condition)
 $L_{wa} = 0.00 \text{ m}$ (Seismic Condition)
Landside WL $L_{wa} = 3.17 \text{ m}$ (Normal Condition)
 $L_{op} = 2.69 \text{ m}$ (Seismic Condition)

Block No. : R-40
Sta. : 13+100~13+220

Design Cross Section : Sta 13+140
Boring Name : BMRL-39

Specification : SSP SP-10H
(Combined) : H 700-200-12-16-18

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered
 $\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$
Angle of rupture (clayey soil) $a = \sin \theta$
 $b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{b0} \left(\frac{B_B}{0.3} \right)^{-3/4}$
 $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_B = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
Average N-value calculated from average N-value between imaginary riverbed and depth as $1/\beta$

No	Depth m	N Value	No	Depth m	N Value
1	1.46	9	11	11.46	13
2	2.46	12	12	12.46	7
3	3.46	15	13	13.46	17
4	4.46	22	14	14.46	19
5	5.46	4	15	15.46	28
6	6.46	3			
7	7.46	15			
8	8.46	10			
9	9.46	18			
10	10.46	17			

Soil Modulus		
No	Depth m (Include Projection Length)	Thickness m (excluding projected length)
1	1.96	1.96
2	2.96	1.00
3	3.96	1.00
4	4.96	1.00
5	5.53	0.57
6	5.96	0.43
7	6.96	1.00
8	7.96	1.00
9	8.96	1.00
10	9.96	1.00
11	10.96	1.00
12	11.96	1.00
13	12.58	0.62
14	17.98	5.40
15	34.70	16.72

Note)	depth :	from top of coping to bottom of the layer	C_o :	soil adhesion
	soil :	sandy(S), clayey(C), mixed (M)	a :	slope of soil adhesion
	N-value :	average N-value in the layer	k' :	design seismic coefficient (underwater)
	γ :	wet unit weight of soil	ζ_i :	angle of active rupture
	γ' :	saturated unit weight of soil	kh :	modulus of subgrade reaction
	ϕ :	internal friction angle of soil		

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

Figure 1 shows a structural frame with a vertical column of height 4.40 and a horizontal beam of total length 10.00. A diagonal member connects the base of the column to the beam at a point 3.10 units from the column. The beam is divided into four segments with lengths 0.64, 1.00, 1.00, and 1.96. The diagonal member has a total length of 5.45 and is divided into three segments with lengths 0.95, 0.78, and 0.51. The beam is supported by a fixed base at the left end.

No	Depth, m	Soil	ϕ degree	δ degree	C kN/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γw_{hw} kN/m ²	Angle of Rupture ζ degree
1	4.60 ~ 3.96	Sand	33.2	15.0	0.0	35.42	6.53	45.08	58.95

Angle of wall friction	Normal Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1,96	1
1,00	2
1,00	3

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m		b m	Normal Condition kN/m ³			Seismic Condition kN/m ³	ϕ degree
1	Sand	12.17	12.17	40.00	40.00	2.44	19.0	19.0	30.0	0.0	Auto	Auto

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	2.15	5.0	0.0
2	2.15	11.55	10.0	5.0

2	3.96 ~ 2.96	Sand	30.0	15.0	0.0	30.49	6.53	38.81	56.86
3	2.96 ~ 1.96	Sand	28.4	15.0	0.0	22.79	6.53	29.01	55.78
4	1.96 ~ 0.00	Sand	27.0	15.0	0.0	15.09	6.53	19.21	54.81

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$
$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$

Where,

- ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)
- δ : internal friction angle (degree)
- ϕ : 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)

No	Angle of Rupture γ , degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	58.95	0.64	0.00	0.00	0.39	0.64
2	56.86	1.00	0.39	0.64	1.04	1.64
3	55.78	1.00	1.04	1.64	1.72	2.64
4	54.81	1.96	1.72	2.64	3.10	4.60

No	Q kN/m ²	l m	Qd kN/m
1	5.0	2.15	10.75
2	10.0	0.95	9.50
Σ			20.25

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

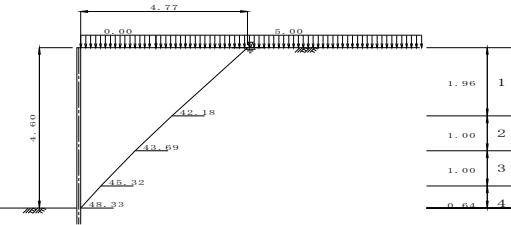
2.1.4 Calculated Load

Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (0.00 + 20.25 + 0.00) / 3.10

= 6.53 kN/m²

2.2 Seismic Condition



2.2.1 Angle of Active Rupture

No	Depth m	Soil	φ degree	δ degree	C kN/m2	Σ γ h kN/m2	Q kN/m2	γ wnw kN/m2	k (k)	θ degree	Angle of Rupture ζ degree
1	4.60~3.96	Sand	33.2	15.0	0.0	35.42	2.75	45.08	0.200	11.31	48.33
2	3.96~2.96	Sand	30.0	15.0	0.0	30.49	2.75	38.81	0.200	11.31	45.32
3	2.96~1.96	Sand	28.4	15.0	0.0	22.79	2.75	29.01	0.200	11.31	43.69
4	1.96~0.00	Sand	27.0	15.0	0.0	15.09	2.75	19.21	0.200	11.31	42.18

• Major collapse angle of Sand, intermediate soil, and split rock

ζ = 90 - tan⁻¹ [(sin(φ + δ) * √(cos(δ + θ) * sin(φ + δ) / sin(φ - θ))) / cos(φ + δ)]

• Major collapse angle of cohesive soil

ζ = 45 - 1/2 tan⁻¹ (a / √(b² - a²))

a = sin θ

b = sin θ + (2 C cos θ) / (Σ γ h + Q)

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⁻¹ k or θ = 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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	48.33	0.64	0.00	0.00	0.57	0.64
2	45.32	1.00	0.57	0.64	1.56	1.64
3	43.69	1.00	1.56	1.64	2.61	2.64
4	42.18	1.96	2.61	2.64	4.77	4.60

From the above table, the loading width (L) on the ground surface is 4.77 m.

2.2.3 Acting Load by Surcharge Load

No	Q kN/m2	l m	Qd kN/m
1	0.0	2.15	0.00
2	5.0	2.62	13.09
Σ			13.09

Q: width of surcharge load set by line of active rupture
l: Loading width of uniform load surrounded by main collapse line

2.2.4 Calculated Load

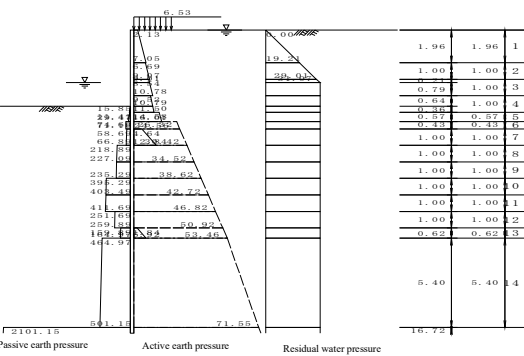
Q = (Σ (γ × A) + Σ (Q × 1) + Σ P) / L

= (0.00 + 13.09 + 0.00) / 4.77

= 2.75 kN/m²

3 Lateral Forth

3.1 Normal Condition



3.1.1 Soil Modulus of Active Side

Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qa kN/m2	Ka	Ka × cos δ
1	0.00~1.96	Sand	7.7	27.0	6.53 21.625	0.33738 0.33738	0.32589 0.32589
2	1.96~2.96	Sand	7.7	28.4	21.625 29.325	0.32022 0.32022	0.30931 0.30931
3	2.96~3.17	Sand	7.7	30.0	29.325 30.942	0.30142 0.30142	0.29115 0.29115
4	3.17~3.96	Sand	7.7	30.0	30.942 37.025	0.30142 0.30142	0.29115 0.29115
5	3.96~4.60	Sand	7.7	33.2	37.025 41.953	0.26623 0.26623	0.25716 0.25716
6	4.60~4.96	Sand	7.7	33.2	41.953 44.725	0.26623 0.26623	0.25716 0.25716
7	4.96~5.53	Sand	7.7	27.0	44.725 49.114	0.33738 0.33738	0.32589 0.32589
8	5.53~5.96	Clay	8.2	—	49.114 52.640	—	—
9	5.96~6.96	Clay	8.2	—	52.640 60.840	—	—
10	6.96~7.96	Clay	8.2	—	60.840 69.040	—	—
11	7.96~8.96	Clay	8.2	—	69.040 77.240	—	—
12	8.96~9.96	Clay	8.2	—	77.240 85.440	—	—

13	9.96~10.96	Clay	8.2	—	180.0 180.0	85.440 93.640	—	—
14	10.96~11.96	Clay	8.2	—	180.0 180.0	93.640 101.840	—	—
15	11.96~12.58	Clay	8.2	—	50.0 50.0	101.840 106.924	—	—
16	12.58~17.98	Clay	6.7	—	200.0 200.0	106.924 143.104	—	—
17	17.98~34.70	Clay	7.2	—	1000.0 1000.0	143.104 263.488	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
δ = 15.00, β = 0.00, θ = 0.00

Ka = cos²(φ - θ) / (cos θ * cos(δ + θ) * [1 + √(sin(φ + δ) * sin(φ - β - θ) / cos(δ + θ) * cos(-β))])²

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m3	φ degree	C kN/m2	Σ γ h + Qp kN/m2	Kp	Kp × cos δ
6	4.60~4.96	Sand	7.7	33.2	—	0.000 2.772	5.9181 5.9181	5.71809 5.71809
7	4.96~5.53	Sand	7.7	27.0	—	2.772 7.161	4.26080 4.26080	4.11561 4.11561
8	5.53~5.96	Clay	8.2	0.0	32.0 32.0	7.161 10.687	—	—
9	5.96~6.96	Clay	8.2	0.0	24.0 24.0	10.687 18.887	—	—
10	6.96~7.96	Clay	8.2	0.0	100.0 100.0	18.887 27.087	—	—
11	7.96~8.96	Clay	8.2	0.0	100.0 100.0	27.087 35.287	—	—
12	8.96~9.96	Clay	8.2	0.0	180.0 180.0	35.287 43.487	—	—
13	9.96~10.96	Clay	8.2	0.0	180.0 180.0	43.487 51.687	—	—
14	10.96~11.96	Clay	8.2	0.0	100.0 100.0	51.687 59.887	—	—
15	11.96~12.58	Clay	8.2	0.0	50.0 50.0	59.887 64.971	—	—
16	12.58~17.98	Clay	6.7	20.0	200.0 200.0	64.971 101.151	—	—
17	17.98~34.70	Clay	7.2	30.0	1000.0 1000.0	101.151 221.535	—	—

Coefficient of passive earth pressure of sandy soil Kp is calculated by the formula below;
δ = -15.00, β = 0.00, θ = 0.00

Kp = cos²(φ - θ) / (cos θ * cos(δ - θ) * [1 - √(sin(φ - δ) * sin(φ + β - θ) / cos(δ - θ) * cos(-β))])²

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2		Pp kN/m2
1	0.00- 1.96	2.13 7.65	-----	2.13 7.65	0.00 19.21	-----
2	1.96- 2.96	6.69 9.07	-----	6.69 9.07	19.21 29.01	-----
3	2.96- 3.17	8.54 9.01	-----	8.54 9.01	29.01 31.07	-----
4	3.17- 3.96	9.01 10.78	-----	9.01 10.78	31.07 31.07	-----
5	3.96- 4.60	9.52 10.79	-----	9.52 10.79	31.07 31.07	-----
6	4.60- 4.96	10.79 11.50	-----	10.79 11.50	31.07 31.07	0.00 15.85
7	4.96- 5.53	14.58 16.01	-----	14.58 16.01	31.07 31.07	11.41 29.47
8	5.53- 5.96	-14.89 -11.36	24.56 26.32	24.56 26.32	31.07 31.07	71.16 74.69
9	5.96- 6.96	4.64 12.84	26.32 30.42	26.32 30.42	31.07 31.07	58.69 66.89
10	6.96- 7.96	-139.16 -130.96	30.42 34.52	30.42 34.52	31.07 31.07	218.89 227.09
11	7.96- 8.96	-130.96 -122.76	34.52 38.62	34.52 38.62	31.07 31.07	227.09 235.29
12	8.96- 9.96	-282.76 -274.56	38.62 42.72	38.62 42.72	31.07 31.07	395.29 403.49
13	9.96- 10.96	-274.56 -266.36	42.72 46.82	42.72 46.82	31.07 31.07	403.49 411.69
14	10.96- 11.96	-106.36 -98.16	46.82 50.92	46.82 50.92	31.07 31.07	251.69 259.89
15	11.96- 12.58	1.84 6.92	50.92 53.46	50.92 53.46	31.07 31.07	159.89 164.97
16	12.58- 17.98	-293.08 -256.80	53.46 71.55	53.46 71.55	31.07 31.07	464.97 501.15
17	17.98- 34.70	-1856.90 -1736.51	71.55 131.74	71.55 131.74	31.07 31.07	2101.15 2221.53

- Formula for active earth pressure

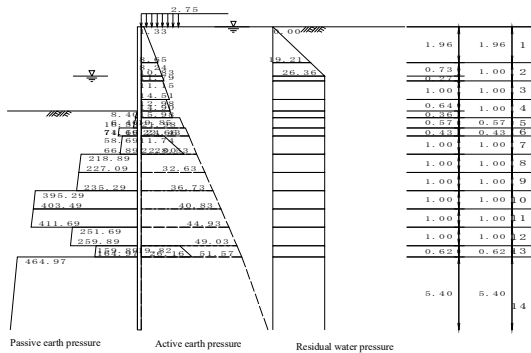
Sand $P_{a1} = K_a \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_{a1} = \sum \gamma h + Q - 2C$
 $P_{a2} = K_a \cdot (\sum \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a (\sum \gamma h + Q) - 2C \sqrt{K_a}] \cdot \cos \delta$

- Formula for passive earth pressure

Sand $P_p = K_p \cdot \left[\sum \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
Clay $P_p = \sum \gamma h + Q + 2C$
Mixed soil $P_p = [K_p (\sum \gamma h + Q) + 2C \sqrt{K_p}] \cdot \cos \delta$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\sum \gamma h + Q$ kN/m2	γ_{whw} kN/m2	k (k ²)	θ degree	Ka	Ka $\times \cos \delta$	ζ degree
1	0.00- 1.96	Sand	7.7	27.0	-----	2.75 17.84	0.00 19.21	0.00 0.300	11.31	0.50201 0.50201	0.48490 0.48490	-----
2	1.96- 2.69	Sand	7.7	28.4	-----	2.69 23.46	19.21 26.36	0.200 0.300	11.31	0.47800 0.47800	0.46172 0.46172	-----
3	2.69- 2.96	Sand	7.7	28.4	-----	2.96 25.54	26.36 29.01	0.300 0.300	11.31	0.47800 0.47800	0.46172 0.46172	-----
4	2.96- 3.96	Sand	7.7	30.0	-----	3.96 33.24	29.01 38.81	0.300 0.300	11.31	0.45203 0.45203	0.43663 0.43663	-----
5	3.96- 4.60	Sand	7.7	33.2	-----	4.60 38.17	38.81 45.08	0.300 0.300	11.31	0.40414 0.40414	0.39037 0.39037	-----
6	4.60- 4.96	Sand	7.7	33.2	-----	4.96 40.94	45.08 46.61	0.300 0.300	11.31	0.40414 0.40414	0.39037 0.39037	-----
7	4.96- 5.53	Sand	7.7	27.0	-----	5.53 45.33	46.61 54.19	0.300 0.300	11.31	0.50201 0.50201	0.48490 0.48490	-----
8	5.53- 5.96	Clay	8.2	-----	32.0 44.83	45.33 54.19	54.19 58.41	0.200 0.300	11.31	-----	-----	41.44 41.19
9	5.96- 6.96	Clay	8.2	-----	24.0 44.0	58.41 57.05	58.41 68.21	0.200 0.300	11.31	-----	-----	40.13 39.46

10	6.96- 7.96	Clay	8.2	-----	100.0 100.0	57.05 65.25	68.21 78.01	0.200 0.200	11.31	-----	-----	43.45 43.24
11	7.96- 8.96	Clay	8.2	-----	100.0 100.0	65.25 73.45	78.01 87.81	0.200 0.200	11.31	-----	-----	43.24 43.04
12	8.96- 9.96	Clay	8.2	-----	180.0 180.0	73.45 81.65	87.81 97.61	0.200 0.200	11.31	-----	-----	43.08 43.76
13	9.96- 10.96	Clay	8.2	-----	180.0 180.0	81.65 89.85	97.61 107.41	0.200 0.200	11.31	-----	-----	43.76 43.64
14	10.96- 11.96	Clay	8.2	-----	100.0 100.0	89.85 98.05	107.41 117.21	0.200 0.200	11.31	-----	-----	42.64 42.44
15	11.96- 12.58	Clay	8.2	-----	50.0 50.0	98.05 103.14	117.21 123.28	0.200 0.200	11.31	-----	-----	40.28 40.08
16	12.58- 17.98	Clay	6.7	-----	200.0 200.0	103.14 129.32	123.28 176.20	0.200 0.200	11.31	-----	-----	43.59 43.13
17	17.98- 34.70	Clay	7.2	-----	1000.0 1000.0	139.32 259.70	176.20 340.06	0.200 0.200	11.31	-----	-----	44.61 44.27

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;
 $\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

$$\zeta = 45 - \frac{1}{2} \tan^{-1} \frac{a}{\sqrt{b^2 - a^2}}$$
$$a = \sin \theta$$
$$b = \sin \theta + \frac{2C \cos \theta}{\sum \gamma h + Q}$$

3.2.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\sum \gamma h + Q_p$ kN/m2	γ_{whw} kN/m2	k (k ²)	θ degree	Kp	Kp $\times \cos \delta$
6	4.60- 4.96	Sand	7.70	33.2	-----	0.000 2.772	0.00 3.53	0.200 0.200	11.31 11.31	3.02888 3.02888	3.02888 3.02888
7	4.96- 5.53	Sand	7.70	27.0	-----	2.772 7.161	3.53 9.11	0.200 0.200	11.31 11.31	2.30874 2.30874	2.30874 2.30874
8	5.53- 5.96	Clay	8.20	0.0	32.0 32.0	7.161 10.687	9.11 13.33	0.200 0.200	11.31 11.31	-----	-----
9	5.96- 6.96	Clay	8.20	0.0	24.0 24.0	10.687 18.887	13.33 23.13	0.200 0.200	11.31 11.31	-----	-----
10	6.96- 7.96	Clay	8.20	0.0	100.0 100.0	18.887 27.087	23.13 32.93	0.200 0.200	11.31 11.31	-----	-----
11	7.96- 8.96	Clay	8.20	0.0	100.0 100.0	27.087 35.287	32.93 42.73	0.200 0.200	11.31 11.31	-----	-----
12	8.96- 9.96	Clay	8.20	0.0	180.0 180.0	35.287 43.487	42.73 52.53	0.200 0.200	11.31 11.31	-----	-----
13	9.96- 10.96	Clay	8.20	0.0	180.0 180.0	43.487 51.687	52.53 62.33	0.200 0.200	11.31 11.31	-----	-----
14	10.96- 11.96	Clay	8.20	0.0	100.0 100.0	51.687 59.887	62.33 72.13	0.200 0.200	11.31 11.31	-----	-----
15	11.96- 12.58	Clay	8.20	0.0	50.0 50.0	59.887 64.971	72.13 78.20	0.200 0.200	11.31 11.31	-----	-----

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure	Passive
		Pa1 kN/m2	Pa2 kN/m2	Pa kN/m2		Pp kN/m2
1	0.00- 1.96	1.33 8.65	-----	1.33 8.65	0.00 19.21	-----
2	1.96- 2.69	8.24 10.83	-----	8.24 10.83	19.21 26.36	-----
3	2.69- 2.96	10.83 11.79	-----	10.83 11.79	26.36 26.36	-----
4	2.96- 3.96	11.15 14.51	-----	11.15 14.51	26.36 26.36	-----
5	3.96- 4.60	12.98 14.90	-----	12.98 14.90	26.36 26.36	-----
6	4.60- 4.96	14.90 15.98	-----	14.90 15.98	26.36 26.36	0.00 8.40
7	4.96- 5.53	19.85 21.98	-----	19.85 21.98	26.36 26.36	6.40 16.53
8	5.53- 5.96	-8.90 -4.55	22.66 24.43	22.66 24.43	26.36 26.36	71.16 74.69
9	5.96- 6.96	11.74 22.00	24.43 28.53	24.43 28.53	26.36 26.36	58.69 66.89
10	6.96- 7.96	-131.20 -121.25	28.53 32.63	28.53 32.63	26.36 26.36	218.89 227.09
11	7.96- 8.96	-121.25 -111.28	32.63 36.73	32.63 36.73	26.36 26.36	227.09 235.29
12	8.96- 9.96	-271.55 -261.63	36.73 40.83	36.73 40.83	26.36 26.36	395.29 403.49
13	9.96- 10.96	-261.63 -251.71	40.83 44.93	40.83 44.93	26.36 26.36	403.49 411.69
14	10.96- 11.96	-91.31 -81.30	44.93 49.03	44.93 49.03	26.36 26.36	251.69 259.89
15	11.96- 12.58	19.82 26.16	49.03 51.57	49.03 51.57	26.36 26.36	159.89 164.97
16	12.58- 17.98	-275.68 -231.79	51.57 69.66	51.57 69.66	26.36 26.36	464.97 501.15
17	17.98- 34.70	-1832.62 -1687.67	69.66 129.85	69.66 129.85	26.36 26.36	2101.15 2221.53

- Formula for active earth pressure

Sand $P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
 Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : 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

Sand $P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$
 Clay $P_p = \Sigma \gamma h + Q + 2C$
 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	water level y m	pds kN/m2
1	2.00	0.00	0.00
2	3.00	1.00	2.37
3	4.00	1.91	3.28

$$p_{de} = \pm \frac{7}{8} k_{sa} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

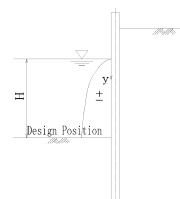
Where,

k_{sa} : design seismic coefficient

γ_w : unit weight of water

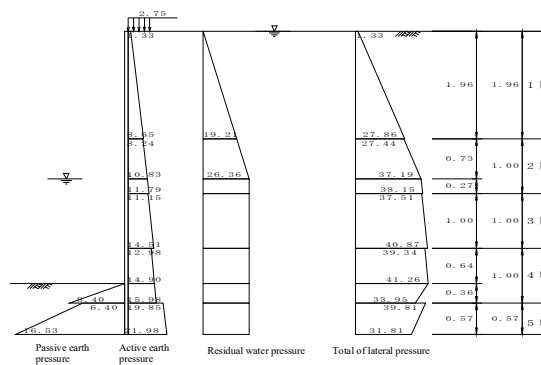
H: water depth of riverside

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.



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 1.96	1.33 8.65	0.00 19.21	— —	1.33 27.86
2	1.96- 2.69	8.24 10.83	19.21 26.36	— —	27.44 37.19
3	2.69- 2.96	10.83 11.79	26.36 26.36	— —	37.19 38.15
4	2.96- 3.96	11.15 14.51	26.36 26.36	— —	37.51 40.87
5	3.96- 4.60	12.98 14.90	26.36 26.36	— —	39.34 41.26
6	4.60- 4.96	14.90 15.98	26.36 26.36	0.00 8.40	41.26 33.95
7	4.96- 5.53	19.85 21.98	26.36 26.36	6.40 16.53	39.81 31.81
8	5.53- 5.96	22.66 24.43	26.36 26.36	71.16 74.69	-22.14 -23.90

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 0.93 m (GL -5.53 m)

5 Modulus of Lateral Subgrade Reaction

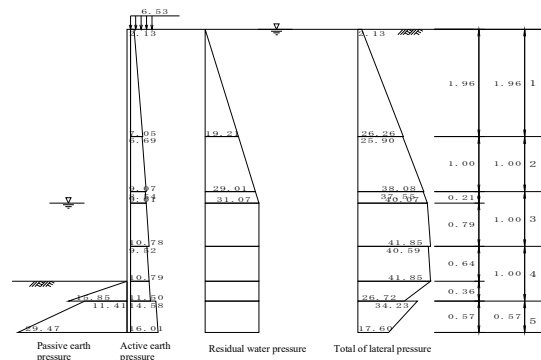
5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface.

Average N-value is calculated depending on the sectional area.

The lateral subgrade reaction coefficient is calculated by the following equation.

4.1 Normal Condition



No	Depth m	Pa kN/m2	Pw kN/m2	Pp kN/m2	Ps kN/m2
1	0.00- 1.96	2.13 7.05	0.00 19.21	— —	2.13 26.26
2	1.96- 2.96	6.69 9.07	19.21 26.01	— —	25.90 38.08
3	2.96- 3.17	8.54 9.01	26.01 31.07	— —	37.55 40.07
4	3.17- 3.96	9.01 10.78	31.07 31.07	— —	40.07 41.85
5	3.96- 4.60	9.52 10.79	31.07 31.07	— —	40.59 41.85
6	4.60- 4.96	10.79 11.50	31.07 31.07	0.00 15.85	41.85 26.72
7	4.96- 5.53	14.58 16.01	31.07 31.07	11.41 29.47	34.23 17.60
8	5.53- 5.96	24.56 26.32	31.07 31.07	71.16 74.69	-15.54 -17.30

P_a : Active earth pressure

P_w : Residual water pressure

P_p : Passive earth pressure

P_s : Lateral pressure $P_s = P_a + P_w - P_p$

Imaginary riverbed L_k : 0.93 m (GL -5.53 m)

4.2 Seismic Condition

$$K_a = K_{a0} \left(\frac{B_{II}}{0.3} \right)^{-3/4} \quad (B_{II} = 10.00m)$$

$$K_{a0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha : \text{Normal Condition} = 1, \text{Seismic Condition} = 2)$$

$$E_0 = 28000 N'$$

where:

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

Material name 10 H H 700 -200 - 12-16-18

Unit width B = 1.0000 m

Corrosion margin $t_1 = 1.00$ mm (active side) $t_2 = 1.00$ mm (passive side)

Corrosion rate $\eta = 0.83$

Section efficiency $\mu = 1.00$

Young's modulus E = 200000 N/mm²

Inertia sectional moment $I_0 = 281600$ cm⁴(original condition)

Inertia sectional moment I = 233728 cm⁴(after reduction by corrosion and section)

Inertia sectional moment EI = 200000 $\times 10^3 \times 233728 \times 10^{-8} = 4.675 \times 10^5$

No	Depth m	N Value	No	Depth m	N Value
1	1.46	9	11	11.46	13
2	2.46	12	12	12.46	7
3	3.46	15	13	13.46	17
4	4.46	22	14	14.46	19
5	5.46	4	15	15.46	28
6	6.46	3			
7	7.46	15			
8	8.46	10			
9	9.46	18			
10	10.46	17			

5.2 Normal Condition

Assuming $K_h = 6815$ kN/m³,

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}} = 0.246 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.07 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.53 m) to 4.07 m depth (GL -9.60 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.53	0.93	3.9	3.0	3.22
2	6.46	1.00	3.0	15.0	9.00
3	7.46	1.00	15.0	10.0	12.50
4	8.46	1.00	10.0	18.0	14.00
5	9.46	0.14	18.0	17.9	2.51
L = Σ h = 4.07			Σ A = 41.23		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{41.23}{4.07} \\ &= 10.13 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 10.13 = 28364 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 28364 = 94548 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B/0.3)^{-3/4} = 94548(10.00/0.3)^{-3/4} = 6815 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Normal Condition) is 6815 kN/m³.

5.3 Seismic Condition

Assuming Kh = 12230 kN/m³,

$$\begin{aligned} \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} = 0.284 \text{ m}^{-1} \\ L &= \frac{1}{\beta} = 3.52 \text{ m} \end{aligned}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -5.53 m) and 3.52 m depth (GL -9.05 m).

No	Depth Z m	Thickness h m	N Value		Area A
			upper	lower	
1	5.53	0.93	3.9	3.0	3.22
2	6.46	1.00	3.0	15.0	9.00
3	7.46	1.00	15.0	10.0	12.50
4	8.46	0.59	10.0	14.7	7.24
L = Σ h = 3.52			Σ A = 31.96		

$$A: (\text{upper N-value} + \text{lower N-value}) \times h/2$$

Height from riverbed to top of coping H = 4.60 m
Depth of Imaginary riverbed from riverbed L_k = 0.93 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_0) + M_{0i} = 0.0 \text{ kN} \cdot \text{m}$$

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i}{\Sigma P + P_i} \\ &= \frac{346.62}{153.81} = 2.25 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 153.81}{5.53} = 55.63 \text{ kN/m}$$

6.1.2 Seismic Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.96	1.96	1.33 27.86	1.30 27.30	4.88 4.22	6.36 115.30
2	1.96- 2.69	0.73	27.44 37.19	10.02 13.58	3.33 3.08	33.32 41.86
3	2.69- 2.96	0.27	37.19 38.15	5.02 5.15	2.75 2.66	13.81 13.70
4	2.96- 3.96	1.00	37.51 40.57	18.76 20.44	2.24 1.90	41.95 38.90
5	3.96- 4.60	0.64	39.34 41.26	12.59 13.20	1.36 1.14	17.08 15.10
6	4.60- 4.96	0.36	41.26 33.95	7.43 6.11	0.81 0.69	6.02 4.22
7	4.96- 5.53	0.57	39.81 31.81	11.35 9.07	0.38 0.19	4.31 1.72
Σ P = 161.30			Σ M = 353.64			

P_i : active earth pressure + residual water pressure - passive earth pressure
P : load P_i 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_i = 0.00 kN/m
depth to acting position H_i = 0.00 m
moment M_{0i} = 0.00 kN·m/m
depth to acting position H_{0i} = 0.00 m
Height from riverbed to top of coping H = 4.60 m
Depth of Imaginary riverbed from riverbed L_k = 0.93 m

Moment M_i by arbitrary load is as below

$$M_i = P_i \cdot (H + L_k - H_0) + M_{0i} = 0.00 \text{ kN} \cdot \text{m}$$

$$\begin{aligned} \text{Average N-value } N' &= \frac{\Sigma A}{L} \\ &= \frac{31.96}{3.52} \\ &= 9.09 \end{aligned}$$

Kh is recalculated from the calculated average N value.

$$\begin{aligned} E_0 &= 2800N' = 2800 \times 9.09 = 25449 \text{ kN/m}^2 \\ K_{10} &= \frac{1}{0.3} \times \alpha \times 25449 = 169663 \text{ kN/m}^3 \quad (\alpha: \text{Normal Condition}=1, \text{Seismi Condition}=2) \\ K_b &= K_{10}(B/0.3)^{-3/4} = 169663(10.00/0.3)^{-3/4} = 12230 \text{ kN/m}^3 \end{aligned}$$

Thus, the assumed Kh is equal to the recalculated Kh.
The lateral subgrade reaction coefficient Kh (Seismic Condition) is 12230 kN/m³.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

No	Depth Z m	Thickness h m	Lateral Forth P ₀ kN/m ²	Loads P kN	Arm length Y m	Moment M kN · m
1	0.00- 1.96	1.96	2.13 26.26	2.09 25.73	4.88 4.22	10.17 108.67
2	1.96- 2.96	1.00	25.90 38.08	12.95 19.04	3.24 2.90	41.91 55.28
3	2.96- 3.17	0.21	37.55 40.07	3.94 4.21	2.45 2.43	9.86 10.23
4	3.17- 3.96	0.79	40.07 43.85	15.83 16.53	2.10 1.83	33.19 30.30
5	3.96- 4.60	0.64	40.59 41.85	12.99 13.39	1.36 1.14	17.62 15.31
6	4.60- 4.96	0.36	41.85 26.72	7.53 4.81	0.81 0.69	6.10 3.32
7	4.96- 5.53	0.57	34.23 17.60	9.76 5.02	0.38 0.19	3.71 0.95
Σ P = 153.81			Σ M = 346.62			

P_i : active earth pressure + residual water pressure - passive earth pressure

P : load P_i 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_i = 0.0 kN/m
depth to acting position H_i = 0.0 m
moment M_{0i} = 0.0 kN·m/m
depth to acting position H_{0i} = 0.00 m

Hydrodynamic Pressure

No	Depth Z m	Thickness h m	Hydrodynamic Pressure p ₀ kN/m ²	Loads P ₀ kN	Arm length Y m	Moment M ₀ kN · m
1	2.69- 3.69	1.00	0.0 2.4	0.00 1.19	2.51 2.17	0.00 2.58
2	3.69- 4.60	0.91	2.4 3.3	1.08 1.49	1.54 1.23	1.66 1.84
Σ P ₀ = 3.75			Σ M ₀ = 6.07			

h₀, Height of acting position of P₀ from imaginary riverbed

$$\begin{aligned} h_0 &= \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{0i}}{\Sigma P + P_i + \Sigma P_{0i}} \\ &= \frac{359.71}{165.06} = 2.18 \text{ m} \end{aligned}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P) is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_k)} = \frac{2 \times 165.06}{5.53} = 59.70 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as follows:

Material name 10 H₇₀₀-200-12-16-18
Unit width B = 1.0000 m
Corrosion margin t₁ = 1.00 mm (active side) t₂ = 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 I₀ = 281600 cm⁴ (original condition)
I = 281600 cm⁴ (after reduction by corrosion and section)
EI = 200000 × 10³ × 281600 × 10⁻⁸ = 5.632 × 10⁶

$$\begin{aligned} \beta &= \sqrt[4]{\frac{K_b \cdot B}{4 E I}} \\ \phi_a &= \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0}) \end{aligned}$$

$$M_{\max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$

6.2.1 Normal Condition

modulus of lateral subgrade reaction calculated value	K_a	=	6815	kN/m ³
resultant earth force (lateral)	β	=	0.23453	m ⁻¹
height of acting position of load moment	P_0	=	153.81	kN/m
	h_0	=	2.25	m
	M_0	=	346.62	kN·m/m
in consideration of $\psi_{in} = 1.376$, maximum moment	M_{max}	=	477.04	kN·m/m
depth of generated position of M_{max}	l_m	=	1.929	m
depth of 1 st fixed point	l_i	=	5.278	m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction calculated value	K_a	=	12230	kN/m ³
resultant earth force (lateral)	β	=	0.27144	m ⁻¹
height of acting position of load moment	P_0	=	165.06	kN/m
	h_0	=	2.18	m
	M_0	=	359.71	kN·m/m
in consideration of $\psi_{in} = 1.321$, maximum moment	M_{max}	=	475.14	kN·m/m
depth of generated position of M_{max}	l_m	=	1.582	m
depth of 1 st fixed point	l_i	=	4.476	m

6.3 Stress Intensity

Material Name	10 H - H 700 -200 - 12-16-18		
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	=	5130 cm ³ (original condition)
	Z	=	4361 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{477.04 \times 10^6}{4361 \times 10^3} = 109 \text{ N/mm}^2 \leq \sigma_s = 180 \text{ N/mm}^2$$

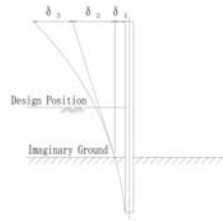
6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{475.14 \times 10^6}{4361 \times 10^3} = 109 \text{ N/mm}^2 \leq \sigma_s = 270 \text{ N/mm}^2$$

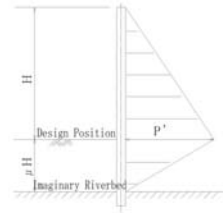
6.4 Displacement Calculation

6.4.1 Normal Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2345 \times 2.25) \times 153.81}{2 \times 2.00 \times 10^8 \times 281600 \times 10^{-8} \times 0.2345^3} = 0.01618 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) \\ &= \frac{(1 + 2 \times 0.2345 \times 2.25) \times 153.81}{2 \times 2.00 \times 10^8 \times 281600 \times 10^{-8} \times 0.2345^2} \times (4.60 + 0.93) = 0.02824 \text{ m} \end{aligned}$$



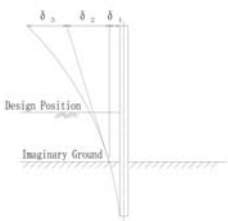
$$\begin{aligned} \mu &= \frac{L_k}{H} = \frac{0.93}{4.60} = 0.202 \\ \delta_3 &= \frac{P^* H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4) \\ &= \frac{55.63 \times 4.60^4}{120 \times 2.00 \times 10^8 \times 281600 \times 10^{-8}} (4 + 20 \times 0.202 + 40 \times 0.202^2 + 35 \times 0.202^3 + 11 \times 0.202^4) \\ &= 0.00368 \text{ m} \\ \delta &= \delta_1 + \delta_2 + \delta_3 \\ &= 0.01618 + 0.02824 + 0.00368 \\ &= 0.04810 \text{ m} \\ \text{Size} &= 48.10 \leq \delta_a = 50.00 \text{ mm} \end{aligned}$$

Where,

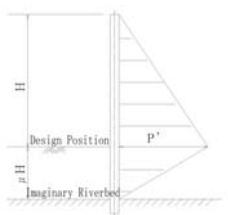
- δ_1 : Displacement at imaginary ground
- δ_2 : Displacement by angle of inclination slope at imaginary ground
- δ_3 : Displacement at higher part of imaginary ground as cantilever
- δ : Displacement at top of SSP
- δ_a : Allowable displacement

6.4.2 Seismic Condition

Displacement Calculation



$$\begin{aligned} \delta_1 &= \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^3} \\ &= \frac{(1 + 0.2714 \times 2.18) \times 165.06}{2 \times 2.00 \times 10^8 \times 281600 \times 10^{-8} \times 0.2714^3} = 0.01166 \text{ m} \\ \delta_2 &= \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) \\ &= \frac{(1 + 2 \times 0.2714 \times 2.18) \times 165.06}{2 \times 2.00 \times 10^8 \times 281600 \times 10^{-8} \times 0.2714^2} \times (4.60 + 0.93) = 0.02401 \text{ m} \end{aligned}$$



7 Penetration Depth

Material Name	10 H - H 700 -200 - 12-16-18		
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	=	281600 cm ⁴ (original condition)
	I	=	281600 cm ⁴ (after reduction by corrosion and section)
$EI = 200000 \times 10^3 \times 281600 \times 10^{-8}$		=	5.632×10^6

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is L_k , the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

$$\begin{aligned} D &= L_k + \frac{3}{\beta} \\ L &= H - H_{ik} + D \\ \beta &= \sqrt[4]{\frac{K_a \cdot B}{4 E I}} \end{aligned}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	K_a	=	6815 kN/m ³
Calculated value	β	=	0.23453 m ⁻¹
Penetration length of SSP	D	=	$0.93 + \frac{3}{0.235} = 13.72 \text{ m}$
Whole length of SSP	L	=	$4.60 - 0.40 + 13.72 = 17.92 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction $K_b = 12230 \text{ kN/m}^3$
Calculated value $\beta = 0.27144 \text{ m}^{-1}$

Penetration length of SSP $D = 0.93 + \frac{3}{0.271} = 11.98 \text{ m}$
Whole length of SSP $L = 4.60 - 0.40 + 11.98 = 16.18 \text{ m}$

Therefore, the total length of the sheet pile is 18.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP 10 H _ H 700 -200 - 12-16-18				
			Normal Condition	Seismic Condition
Inertia sectional moment	I (cm ⁴)	281600		
Sectional Modulus	Z (cm ³)	5139		
Maximum bending moment	Mmax (kN · m · m)		477.04	475.14
Stress intensity	σ (N/mm ²)		109 (180)	109 (270)
Lateral displacement	δ (mm)		48.10 (50.0)	39.42 (35.0)
Penetration depths	D (m)		13.72	11.98
Whole length of SSP	L (m)	18.00		

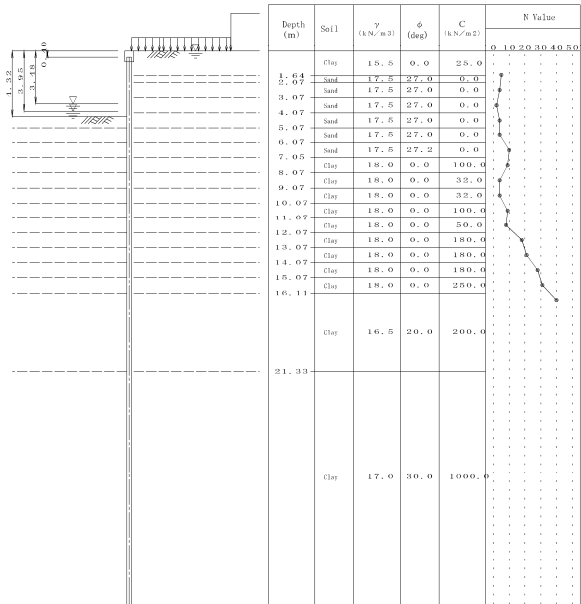
Block No. : R-41
Sta. : 13+220~13+375

Design Cross Section : Sta 13+380
Boring Name : BMRL-40

Specification : SSP SP-10H
(Combined) : H 900-250-14-25-18

1 Design Condition

1.1 Longitudinal Section of SSP & Considered Geological Survey Log



1.2 Dimensions of Structure

Depth from coping top to riverbed $H = 4.32 \text{ m}$
Depth from coping top to rear side ground $H_0 = 0.00 \text{ m}$
Depth from coping top to SSP top $H_b = 0.40 \text{ m}$
Landside WL $L_{wa} = 0.00 \text{ m}$ (Normal Condition)
 $L_{wb} = 0.00 \text{ m}$ (Seismic Condition)
Riverside WL $L_{wp} = 3.95 \text{ m}$ (Normal Condition)
 $L_{wp} = 3.48 \text{ m}$ (Seismic Condition)

1.3 Applied Formula

Formula for generated stress Chang's formula
Penetration depths $L = \frac{3}{\beta}$

1.4 Design Constant

Unit weight of water $\gamma_w = 9.8 \text{ kN/m}^3$
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 not considered
Wind load, Impact load not considered
Minimum angle of rupture $\zeta_0 = 10 \text{ degrees}$
Rear side angle of slope not considered
Angle of rupture (clayey soil) $\zeta = \tan^{-1} \sqrt{1 - \frac{\sum \gamma h + 2Q}{2C} \cdot \tan \theta}$
Equilibrium factor of compression $K_c = 0.50$ (considered in Seismic Condition)

1.5 Modulus of Lateral Subgrade Reaction

Applied formula $K_b = K_{b0} \left(\frac{B_B}{0.3} \right)^{-3/4}$
 $K_{b0} = \frac{1}{0.3} \alpha E_0$ (α : Normal Condition =1, Seismic Condition =2)
 $B_B = 10.00 \text{ m}$
 $E_0 = 2800 \text{ N}$
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	1.57	5	11	11.57	8
2	2.57	4	12	12.57	18
3	3.57	2	13	13.57	21
4	4.57	4	14	14.57	28
5	5.57	4	15	15.57	31
6	6.57	10	16	16.57	40
7	7.57	9			
8	8.57	4			
9	9.57	4			
10	10.57	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 (Include Projection Length)	Thickness m (excluding projected length)
1	1.64	1.64
2	2.07	0.43
3	3.07	1.00
4	4.07	1.00
5	5.07	1.00
6	6.07	1.00
7	7.05	0.98
8	8.07	1.02
9	9.07	1.00
10	10.07	1.00
11	11.07	1.00
12	12.07	1.00
13	13.07	1.00
14	14.07	1.00
15	15.07	1.00
16	16.11	1.04
17	21.33	5.22
18	35.50	14.17

No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
1	1.64	C	5.0	15.50	5.70	0.0	25.0	0.0	0.200	Auto	Auto
2	2.07	S	5.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
3	3.07	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
4	4.07	S	2.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
5	5.07	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
6	6.07	S	4.0	17.50	7.70	27.0	0.0	0.0	0.200	Auto	Auto
7	7.05	S	10.0	17.50	7.70	27.2	0.0	0.0	0.200	Auto	Auto
8	8.07	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
9	9.07	C	4.0	18.00	8.20	0.0	32.0	0.0	0.200	Auto	Auto
10	10.07	C	4.0	18.00	8.20	0.0	32.0	0.0	0.200	Auto	Auto
11	11.07	C	9.0	18.00	8.20	0.0	100.0	0.0	0.200	Auto	Auto
12	12.07	C	8.0	18.00	8.20	0.0	50.0	0.0	0.200	Auto	Auto

1.9 Steel Sheet Pile (SSP)

Material name 10 H H 900 -250 -14 -25 -18
Young's modulus E = 200000 N/mm²
Inertia sectional moment I₀ = 631400 cm⁴
Sectional factor Z₀ = 10120 cm³

Corrosion margin t₁ = 1.00 mm (riverside) t₂ = 1.00 mm (landside)

Corrosion rate (to I₀) η = 0.87
Corrosion rate (to Z₀) η = 0.88
Section efficiency (to I₀) μ = 1.00
Section efficiency (to Z₀) μ = 1.00

Round unit of SSP length 0.50 m

Allowable stress σ_s = 180 N/mm (Normal)
 σ_s' = 270 N/mm (Seismic)

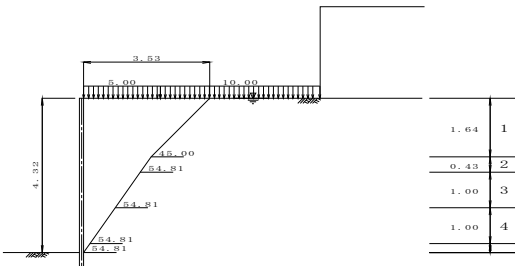
Allowable displacement δ_s = 50.0 mm (Normal)
 δ_s' = 75.0 mm (Seismic)

Bending of cantilever beam calculated as distributed load of each layer

Reduction of material modulus Reduced: I₀ applied to calculation of lateral coefficient of subgrade reaction
Not reduced: I₀ applied to calculation of penetration depth
Reduced: I₀ 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/m ²	$\Sigma \gamma h$ kN/m ²	Q kN/m ²	γ when kN/m ³	Angle of Rupture ζ degree
1	4.32 ~ 4.07	Sand	27.0	15.0	0.0	29.98	6.95	42.34	54.81

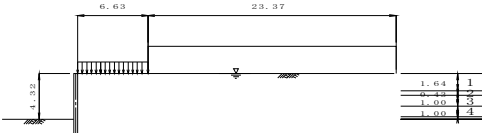
No	Depth m	earth Soil	N Value	γ kN/m ³	γ' kN/m ³	ϕ degree	C kN/m ²	a	k'	ζ (degree)	
										Normal Condition	Seismic Condition
13	13.07	C	18.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
14	14.07	C	21.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
15	15.07	C	28.0	18.00	8.20	0.0	180.0	0.0	0.200	Auto	Auto
16	16.11	C	31.0	18.00	8.20	0.0	250.0	0.0	0.200	Auto	Auto
17	21.33	C	63.5	16.50	6.70	20.0	200.0	0.0	0.200	Auto	Auto
18	35.50	C	121.5	17.00	7.20	30.0	1000.0	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
 C₀ : 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 Condition	Seismic Condition
Active	15.00 °	15.00 °
Passive	-15.00 °	0.00 °

1.8 Embankment on Landside



Fill shape and soil constants

No	Soil	X Coordinate				Thickness	soil single weight γ		internal friction angle	stickiness	decay angle ζ	
		Bottom Left m	Top Left m	Top Right m	Bottom Right m	h m	Normal Condition kN/m ³	Seismic Condition kN/m ³	ϕ degree	C kN/m ²	Normal Condition degree	Seismic Condition degree
1	Sand	6.63	6.63	30.00	30.00	2.57	19.0	19.0	30.0	0.0	Auto	Auto

Surcharge load acting on embankment

No	load area		load strength	
	From m	End point m	Normal Condition kN/m ²	Seismic Condition kN/m ²
1	0.00	2.15	5.0	0.0
2	2.15	6.62	10.0	5.0

Angle of rupture in embankment calculated in consideration of embankment conditions

2	4.07 ~ 3.07	Sand	27.0	15.0	0.0	28.06	6.95	39.89	54.81
3	3.07 ~ 2.07	Sand	27.0	15.0	0.0	20.36	6.95	30.09	54.81
4	2.07 ~ 1.64	Sand	27.0	15.0	0.0	12.66	6.95	20.29	54.81
5	1.64 ~ 0.00	Clay	0.0	15.0	25.0	9.35	6.95	16.07	45.00

• 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 $\theta = 0^\circ$

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)

2.1.2 Coordinates of Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	54.81	0.25	0.00	0.00	0.18	0.25
2	54.81	1.00	0.18	0.25	0.88	1.25
3	54.81	1.00	0.88	1.25	1.59	2.25
4	54.81	0.43	1.59	2.25	1.89	2.68
5	45.00	1.64	1.89	2.68	3.53	4.32

From the above table, the loading width (L) on the ground surface is 3.53 m.

2.1.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Ql kN/m
1	5.0	2.15	10.75
2	10.0	1.38	13.80
Σ			24.55

Q : width of surcharge load set by line of active rupture

l : Loading width of uniform load surrounded by main collapse line

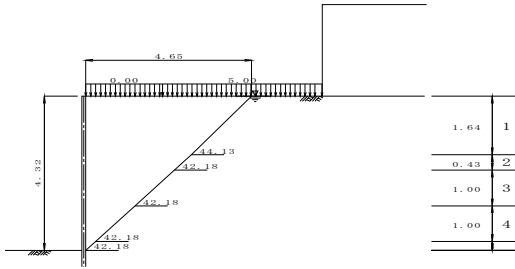
2.1.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{0.00 + 24.55 + 0.00}{3.53}$$

$$= 6.95 \text{ kN/m}^2$$

2.2 Seismic 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	$\gamma \text{ whw}$ kN/m ²	k (ϕ°)	θ degree	Angle of Rupture ζ degree
1	4.32~4.07	Sand	27.0	15.0	0.0	29.98	2.69	42.34	0.200	11.31	42.18
2	4.07~3.07	Sand	27.0	15.0	0.0	28.06	2.69	39.89	0.200	11.31	42.18
3	3.07~2.07	Sand	27.0	15.0	0.0	20.36	2.69	30.09	0.200	11.31	42.18
4	2.07~1.64	Sand	27.0	15.0	0.0	12.66	2.69	20.29	0.200	11.31	42.18
5	1.64~0.00	Clay	0.0	15.0	25.0	9.35	2.69	16.07	0.200	11.31	44.13

Major collapse angle of Sand, intermediate soil, and split rock

$$\zeta = 90 - \tan^{-1} \frac{-\sin(\phi + \delta) + \sqrt{\frac{\cos(\delta + \theta) \cdot \sin(\phi + \delta)}{\sin(\phi - \theta)}}}{\cos(\phi + \delta)}$$

Major collapse angle of cohesive soil

$$\zeta = \tan^{-1} \sqrt{1 - \frac{\Sigma \gamma h + 2Q}{2C} \cdot \tan \theta}$$

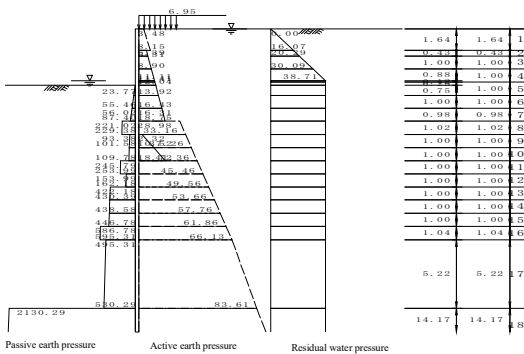
Where,

ζ : angle of active rupture (degree, $\zeta \geq 10.00^\circ$)

ϕ : internal friction angle (degree)

3 Lateral Forth

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	$\Sigma \gamma h + Q_0$ kN/m ²	Ka	Ka $\times \cos \delta$
1	0.00~ 1.64	Clay	5.7	—	25.0 25.0	6.95 16.303	— —	— —
2	1.64~ 2.07	Sand	7.7	27.0	—	16.303 19.614	0.33738 0.33738	0.32589 0.32589
3	2.07~ 3.07	Sand	7.7	27.0	—	19.614 27.314	0.33738 0.33738	0.32589 0.32589
4	3.07~ 3.95	Sand	7.7	27.0	—	27.314 34.090	0.33738 0.33738	0.32589 0.32589
5	3.95~ 4.07	Sand	7.7	27.0	—	34.090 35.014	0.33738 0.33738	0.32589 0.32589
6	4.07~ 4.32	Sand	7.7	27.0	—	35.014 36.599	0.33738 0.33738	0.32589 0.32589
7	4.32~ 5.07	Sand	7.7	27.0	—	36.599 42.714	0.33738 0.33738	0.32589 0.32589
8	5.07~ 6.07	Sand	7.7	27.0	—	42.714 50.414	0.33738 0.33738	0.32589 0.32589
9	6.07~ 7.05	Sand	7.7	27.2	—	50.414 57.960	0.33489 0.33489	0.32348 0.32348
10	7.05~ 8.07	Clay	8.2	—	100.0 100.0	57.960 66.324	— —	— —
11	8.07~ 9.07	Clay	8.2	—	—	66.324 74.524	— —	— —
12	9.07~ 10.07	Clay	8.2	—	32.0 32.0	74.524 82.724	— —	— —

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 Collapse Line

No	Angle of Rupture ζ degree	Thickness Z m	bottom coordinate		top coordinate	
			X (m)	Y (m)	X (m)	Y (m)
1	42.18	0.25	0.00	0.00	0.28	0.25
2	42.18	1.00	0.28	0.25	1.38	1.25
3	42.18	1.00	1.38	1.25	2.48	2.25
4	42.18	0.43	2.48	2.25	2.96	2.68
5	44.13	1.64	2.96	2.68	4.65	4.32

From the above table, the loading width (L) on the ground surface is 4.65 m.

2.2.3 Acting Load by Surcharge Load

No	Q kN/m ²	l m	Qel kN/m
1	0.0	2.15	0.00
2	5.0	2.50	12.49
Σ			12.49

Q : width of surcharge load set by line of active rupture

l : Loading width of uniform load surrounded by main collapse line

2.2.4 Calculated Load

$$Q = \frac{\Sigma (\gamma \times A) + \Sigma (Q \times l) + \Sigma P}{L}$$

$$= \frac{0.00 + 12.49 + 0.00}{4.65}$$

$$= 2.69 \text{ kN/m}^2$$

13	10.07~ 11.07	Clay	8.2	—	100.0 100.0	82.724 90.924	—	—
14	11.07~ 12.07	Clay	8.2	—	50.0 50.0	90.924 99.124	—	—
15	12.07~ 13.07	Clay	8.2	—	180.0 180.0	99.124 107.324	—	—
16	13.07~ 14.07	Clay	8.2	—	180.0 180.0	107.324 115.524	—	—
17	14.07~ 15.07	Clay	8.2	—	180.0 180.0	115.524 123.724	—	—
18	15.07~ 16.11	Clay	8.2	—	250.0 250.0	123.724 132.252	—	—
19	16.11~ 21.33	Clay	6.7	—	200.0 200.0	132.252 167.226	—	—
20	21.33~ 35.50	Clay	7.2	—	1000.0 1000.0	167.226 269.250	—	—

Coefficient of active earth pressure of sandy soil Ka is calculated by the formula below;

$\delta = 15.00, \beta = 0.00, \theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.2 Soil Modulus of Passive Side

No	Depth m	Soil	γ kN/m ³	ϕ degree	C kN/m ²	$\Sigma \gamma h + Q_p$ kN/m ²	Kp	Kp $\times \cos \delta$
7	4.32~ 5.07	Sand	7.7	27.0	—	0.000 5.775	4.26080 4.26080	4.11561 4.11561
8	5.07~ 6.07	Sand	7.7	27.0	—	5.775 13.475	4.26080 4.26080	4.11561 4.11561
9	6.07~ 7.05	Sand	7.7	27.2	—	13.475 21.021	4.30428 4.30428	4.15761 4.15761
10	7.05~ 8.07	Clay	8.2	0.0	100.0 100.0	21.021 29.385	— —	— —
11	8.07~ 9.07	Clay	8.2	0.0	32.0 32.0	29.385 37.585	— —	— —
12	9.07~ 10.07	Clay	8.2	0.0	32.0 32.0	37.585 45.785	— —	— —
13	10.07~ 11.07	Clay	8.2	0.0	100.0 100.0	45.785 53.985	— —	— —
14	11.07~ 12.07	Clay	8.2	0.0	50.0 50.0	53.985 62.185	— —	— —
15	12.07~ 13.07	Clay	8.2	0.0	180.0 180.0	62.185 70.385	— —	— —
16	13.07~ 14.07	Clay	8.2	0.0	180.0 180.0	70.385 78.585	— —	— —
17	14.07~ 15.07	Clay	8.2	0.0	180.0 180.0	78.585 86.785	— —	— —
18	15.07~ 16.11	Clay	8.2	0.0	250.0 250.0	86.785 95.313	— —	— —
19	16.11~ 21.33	Clay	6.7	20.0	200.0 200.0	95.313 130.287	— —	— —

20	21.33- 35.50	Clay	7.2	30.0	1000.0 1000.0	130.287 232.311	————	————

Coefficient of passive earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = -15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_p = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta - \theta) \cdot \left[1 - \sqrt{\frac{\sin(\phi - \delta) \cdot \sin(\phi + \beta - \theta)}{\cos(\delta - \theta) \cdot \cos(-\beta)}} \right]^2}$$

3.1.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Ps kN/m2	Pw kN/m2	Pp kN/m2		
1	0.00- 1.64	-43.05 -33.70	3.48 8.15	3.48 8.15	0.00 16.07	————		
2	1.64- 2.07	5.31 6.39	————	5.31 6.39	16.07 20.29	————		
3	2.07- 3.07	6.39 8.90	————	6.39 8.90	20.29 30.09	————		
4	3.07- 3.95	8.90 11.11	————	8.90 11.11	30.09 38.71	————		
5	3.95- 4.07	————	————	11.11 11.41	38.71 38.71	————		
6	4.07- 4.32	————	————	11.41 12.04	38.71 38.71	————		
7	4.32- 5.07	12.04 13.92	————	12.04 13.92	38.71 38.71	0.00 23.77		
8	5.07- 6.07	13.92 16.43	————	13.92 16.43	38.71 38.71	23.77 55.46		
9	6.07- 7.05	16.31 18.75	————	16.31 18.75	38.71 38.71	56.02 87.40		
10	7.05- 8.07	-142.04 -133.68	28.98 33.16	28.98 33.16	38.71 38.71	221.02 229.38		
11	8.07- 9.07	2.32 10.52	33.16 37.26	33.16 37.26	38.71 38.71	92.38 101.58		
12	9.07- 10.07	10.52 18.72	37.26 41.36	37.26 41.36	38.71 38.71	101.58 109.78		
13	10.07- 11.07	-117.28 -109.08	41.36 45.46	41.36 45.46	38.71 38.71	245.79 253.99		
14	11.07- 12.07	-9.08 -0.88	45.46 49.56	45.46 49.56	38.71 38.71	153.99 162.18		
15	12.07- 13.07	-260.88 -252.68	49.56 53.66	49.56 53.66	38.71 38.71	422.18 430.39		
16	13.07- 14.07	-252.68 -244.48	53.66 57.76	53.66 57.76	38.71 38.71	430.39 438.58		
17	14.07- 15.07	-244.48 -236.28	57.76 61.86	57.76 61.86	38.71 38.71	438.58 446.78		
18	15.07- 16.11	-376.28 -367.75	61.86 66.13	61.86 66.13	38.71 38.71	586.78 595.31		

19	16.11- 21.33	-267.75 -232.77	66.13 83.61	66.13 83.61	38.71 38.71	495.31 530.29
20	21.33- 35.50	-1832.77 -1730.75	83.61 134.62	83.61 134.62	38.71 38.71	2130.29 2232.31

- Formula for active earth pressure

$$\text{Sand } P_{a1} = K_a \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_{a1} = \Sigma \gamma h + Q - 2C$$

$$P_{a2} = K_a \cdot (\Sigma \gamma h + Q)$$

K_a : Equilibrium coefficient of compression: 0.5

Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

$$\text{Mixed soil } P_{a1} = [K_a (\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$$

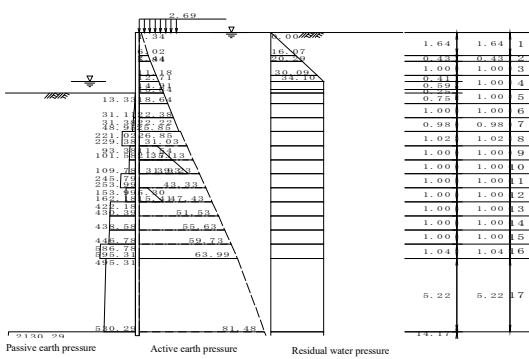
- Formula for passive earth pressure

$$\text{Sand } P_p = K_p \cdot \left[\Sigma \gamma h + \frac{Q}{\cos(-\beta)} \right] \cdot \cos \delta$$

$$\text{Clay } P_p = \Sigma \gamma h + Q + 2C$$

$$\text{Mixed soil } P_p = [K_p (\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$$

3.2 Seismic Condition



3.2.1 Soil Modulus of Active Side

No	Depth m	Soil	γ kN/m3	ϕ degree	C kN/m2	$\Sigma \gamma h + Q$ kN/m2	γ when kN/m2	k (k ²)	θ degree	K_a	$K_a \times \cos \delta$	ζ degree
1	0.00- 1.64	Clay	5.7	————	25.0 12.04	2.69 16.07	0.00 0.200	0.200 11.31	11.31	————	————	44.69 44.13
2	1.64- 2.07	Sand	7.7	27.0	————	12.04 15.35	16.07 20.29	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
3	2.07- 3.07	Sand	7.7	27.0	————	15.35 23.05	20.29 30.09	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
4	3.07- 3.48	Sand	7.7	27.0	————	23.05 26.20	30.09 34.10	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
5	3.48- 4.07	Sand	7.7	27.0	————	26.20 30.75	34.10 39.89	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
6	4.07- 4.32	Sand	7.7	27.0	————	30.75 32.67	39.89 42.34	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
7	4.32- 5.07	Sand	7.7	27.0	————	32.67 38.45	42.34 49.69	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
8	5.07- 6.07	Sand	7.7	27.0	————	38.45 46.15	49.69 59.49	0.200 0.200	11.31 11.31	0.50201 0.50201	0.48490 0.48490	————
9	6.07- 7.05	Sand	7.7	27.2	————	46.15 53.69	59.49 69.09	0.200 0.200	11.31 11.31	0.49850 0.49850	0.48152 0.48152	————
10	7.05- 8.07	Clay	8.2	————	100.0 100.0	53.69 62.06	69.09 79.09	0.200 0.200	11.31 11.31	————	————	44.17 44.04
11	8.07- 9.07	Clay	8.2	————	32.0 32.0	62.06 70.26	79.09 88.89	0.200 0.200	11.31 11.31	————	————	41.77 41.30
12	9.07- 10.07	Clay	8.2	————	32.0 32.0	70.26 78.46	88.89 98.69	0.200 0.200	11.31 11.31	————	————	41.30 40.83
13	10.07- 11.07	Clay	8.2	————	100.0 100.0	78.46 86.66	98.69 108.49	0.200 0.200	11.31 11.31	————	————	43.79 43.66
14	11.07- 12.07	Clay	8.2	————	50.0 50.0	86.66 94.86	108.49 118.29	0.200 0.200	11.31 11.31	————	————	42.18 41.90
15	12.07- 13.07	Clay	8.2	————	180.0 180.0	94.86 103.06	118.29 128.09	0.200 0.200	11.31 11.31	————	————	44.28 44.13
16	13.07- 14.07	Clay	8.2	————	180.0 180.0	103.06 111.26	128.09 137.89	0.200 0.200	11.31 11.31	————	————	44.13 44.06
17	14.07- 15.07	Clay	8.2	————	180.0 180.0	111.26 119.46	137.89 147.69	0.200 0.200	11.31 11.31	————	————	44.06 43.99
18	15.07- 16.11	Clay	8.2	————	250.0 250.0	119.46 127.98	147.69 157.88	0.200 0.200	11.31 11.31	————	————	44.28 44.23
19	16.11- 21.33	Clay	6.7	————	200.0 200.0	127.98 162.96	157.88 209.03	0.200 0.200	11.31 11.31	————	————	44.03 43.76
20	21.33- 35.50	Clay	7.2	————	1000.0 1000.0	162.96 264.98	209.03 347.90	0.200 0.200	11.31 11.31	————	————	44.76 44.61

Coefficient of active earth pressure of sandy soil K_a is calculated by the formula below;
 $\delta = 15.00$, $\beta = 0.00$, $\theta = 0.00$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos \theta \cdot \cos(\delta + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta - \theta)}{\cos(\delta + \theta) \cdot \cos(-\beta)}} \right]^2}$$

Angle between surface of collapse and level surface of clayey soil ζ is calculated by the formula below;

3.2.3 Lateral Forth

No	Depth m	Active			Residual water pressure		Passive	
		Pa1 kN/m2	Pa2 kN/m2	Pp kN/m2	Pw kN/m2	Pp kN/m2		
1	0.00- 1.64	-46.77 -35.51	1.34 6.02	1.34 6.02	0.00 16.07	————		
2	1.64- 2.07	5.84 7.44	————	5.84 7.44	16.07 20.29	————		

3	2.07~ 3.07	7.44 11.18	----- -----	7.44 11.18	20.29 30.09	----- -----
4	3.07~ 3.48	11.18 12.71	----- -----	11.18 12.71	30.09 34.10	----- -----
5	3.48~ 4.07	12.71 14.91	----- -----	12.71 14.91	34.10 34.10	----- -----
6	4.07~ 4.32	14.91 15.84	----- -----	14.91 15.84	34.10 34.10	----- -----
7	4.32~ 5.07	15.84 18.64	----- -----	15.84 18.64	34.10 34.10	0.00 13.33
8	5.07~ 6.07	18.64 22.38	----- -----	18.64 22.38	34.10 34.10	13.33 31.11
9	6.07~ 7.05	22.38 25.85	----- -----	22.38 25.85	34.10 34.10	31.38 48.95
10	7.05~ 8.07	-135.34 -125.22	26.85 31.03	26.85 31.03	34.10 34.10	221.02 229.38
11	8.07~ 9.07	11.54 21.71	31.03 35.13	31.03 35.13	34.10 34.10	93.58 101.58
12	9.07~ 10.07	21.71 31.03	35.13 39.23	35.13 39.23	34.10 34.10	101.58 109.78
13	10.07~ 11.07	-105.35 -95.40	39.23 43.33	39.23 43.33	34.10 34.10	245.79 253.99
14	11.07~ 12.07	5.30 15.41	43.33 47.43	43.33 47.43	34.10 34.10	153.99 162.18
15	12.07~ 13.07	-245.78 -235.86	47.43 51.53	47.43 51.53	34.10 34.10	422.18 430.39
16	13.07~ 14.07	-235.86 -225.95	51.53 55.63	51.53 55.63	34.10 34.10	430.39 438.58
17	14.07~ 15.07	-225.95 -216.02	55.63 59.73	55.63 59.73	34.10 34.10	438.58 446.78
18	15.07~ 16.11	-356.20 -345.90	59.73 63.99	59.73 63.99	34.10 34.10	586.78 595.31
19	16.11~ 21.33	-245.77 -203.38	63.99 81.48	63.99 81.48	34.10 34.10	495.31 530.29
20	21.33~ 35.50	-1804.25 -1681.48	81.48 132.49	81.48 132.49	34.10 34.10	2130.29 2232.31

- Formula for active earth pressure

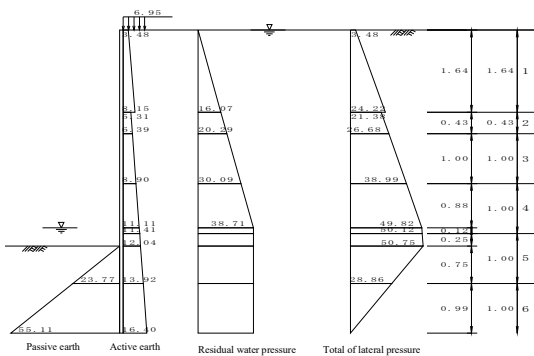
Sand $P_{a1} = K_a \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_{a1} = \Sigma \gamma h + Q - 2C$
 $P_{a1} = K_a \cdot (\Sigma \gamma h + Q)$
 K_a : Equilibrium coefficient of compression: 0.5
Larger of Pa1 or Pa2 is applied as active earth pressure (Pa)

Mixed soil $P_{a1} = [K_a(\Sigma \gamma h + Q) - 2C\sqrt{K_a}] \cdot \cos \delta$

- Formula for passive earth pressure

Sand $P_p = K_p \cdot [\Sigma \gamma h + \frac{Q}{\cos(-\beta)}] \cdot \cos \delta$
Clay $P_p = \Sigma \gamma h + Q + 2C$
Mixed soil $P_p = [K_p(\Sigma \gamma h + Q) + 2C\sqrt{K_p}] \cdot \cos \delta$

4.1 Normal Condition



No	Depth m	P_a kN/m²	P_w kN/m²	P_p kN/m²	P_s kN/m²
1	0.00~ 1.64	3.48 8.15	0.00 16.07	----- -----	3.48 24.22
2	1.64~ 2.07	5.31 6.39	16.07 20.29	----- -----	21.38 26.68
3	2.07~ 3.07	6.39 8.90	20.29 30.09	----- -----	26.68 38.99
4	3.07~ 3.95	8.90 11.11	30.09 38.71	----- -----	38.99 49.82
5	3.95~ 4.07	11.11 11.41	38.71 38.71	----- -----	49.82 50.12
6	4.07~ 4.32	11.41 12.04	38.71 38.71	----- -----	50.12 50.75
7	4.32~ 5.07	12.04 13.92	38.71 38.71	0.00 23.77	50.75 28.86
8	5.07~ 6.06	13.92 16.40	38.71 38.71	23.77 55.11	28.86 0.00
9	6.06~ 6.07	16.40 16.43	38.71 38.71	55.11 55.46	0.00 -0.32

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 : 1.74 m (GL -6.06 m)

3.2.4 Dynamic Water Pressure due to Earthquake

No	Depth Z m	water level y m	pdw kN/m²
1	3.48	0.00	0.00
2	4.32	0.84	1.44

$$P_{dw} = \pm \frac{7}{8} k_{dw} \cdot \gamma_w \cdot \sqrt{H \cdot y}$$

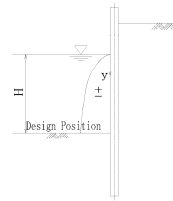
Where,

k_{dw} : design seismic coefficient

γ_w : unit weight of water

H : water depth of riverside

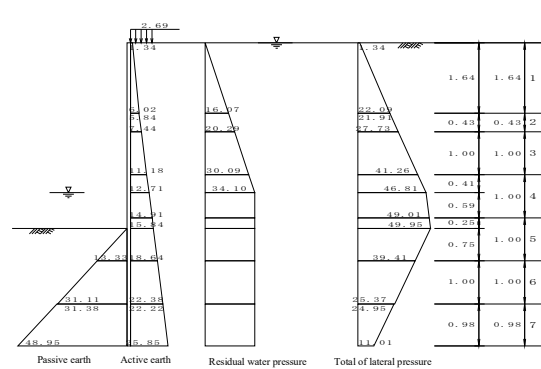
y : depth from water surface to the point where active water pressure is calculated



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.

4.2 Seismic Condition



No	Depth m	P_a kN/m²	P_w kN/m²	P_p kN/m²	P_s kN/m²
1	0.00~ 1.64	1.34 6.02	0.00 16.07	----- -----	1.34 22.09
2	1.64~ 2.07	5.84 7.44	16.07 20.29	----- -----	21.91 27.73
3	2.07~ 3.07	7.44 11.18	20.29 30.09	----- -----	27.73 41.26
4	3.07~ 3.48	11.18 12.71	30.09 34.10	----- -----	41.26 46.81
5	3.48~ 4.07	12.71 14.91	34.10 34.10	----- -----	46.81 49.01
6	4.07~ 4.32	14.91 15.84	34.10 34.10	----- -----	49.01 49.95
7	4.32~ 5.07	15.84 18.64	34.10 34.10	0.00 13.33	49.95 39.41
8	5.07~ 6.07	18.64 22.38	34.10 34.10	13.33 31.11	39.41 25.37
9	6.07~ 7.05	22.38 25.85	34.10 34.10	31.38 48.95	24.95 11.01
10	7.05~ 8.07	25.85 31.03	34.10 34.10	221.02 229.38	-160.07 -164.25

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 : 2.73 m (GL -7.05 m)

5 Modulus of Lateral Subgrade Reaction

5.1 Modulus of Lateral Subgrade Reaction

The lateral ground reaction coefficient is calculated by averaging a range of $1/\beta$ from the virtual ground surface. Average N-value is calculated depending on the sectional area. The lateral subgrade reaction coefficient is calculated by the following equation.

$$K_{\lambda} = K_{\lambda 0} \left(\frac{B_{\lambda}}{0.3} \right)^{-3/4} \quad (B_{\lambda}=10.00\text{m})$$

$$K_{\lambda 0} = \frac{1}{0.3} \alpha E_0 \quad (\alpha:\text{Normal Condition}=1, \text{Seismi Condition}=2)$$

$$E_0 = 2800\text{N}'$$

where:

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}}$$

Table with 2 columns: Material name, Unit width, Corrosion margin, Corrosion rate, Section efficiency, Young's modulus, Inertia sectional moment, Inertia sectional moment. Values include 10 H, H 900, 250, 14, 25, 18, B = 1.0000 m, t1 = 1.00 mm, t2 = 1.00 mm, eta = 0.87, mu = 1.00, E = 200000 N/mm^2, I0 = 631400 cm^4, I = 549318 cm^4, EI = 200000 x 10^3 x 549318 x 10^-8 = 1.099 x 10^6.

Table with 3 columns: No, Depth Z m, N Value. Rows 1-10 showing depth and N-value data.

5.2 Normal Condition

Assuming Kh = 4800 kN/m3,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.182 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 5.50 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -6.06 m) to 5.50 m depth (GL -11.56 m).

Average N-value N' = (sum A) / L
= 31.77 / 4.68
= 6.78

Kh is recalculated from the calculated average N value.

E0 = 2800N' = 2800 x 6.78 = 18988 kN/m^2
Klambda0 = (1/0.3) x alpha x 18988 = 126589 kN/m^3 (alpha: Normal Condition=1, Seismi Condition=2)
Klambda = Klambda0 (Blambda/0.3)^(-3/4) = 126589 (10.00/0.3)^(-3/4) = 9125 kN/m^3

Thus, the assumed Kh is equal to the recalculated Kh. The lateral subgrade reaction coefficient Kh (Seismic Condition) is 9125 kN/m3.

6 Sectional Forces and Displacement

The stress, displacement, and insertion length of the sheet pile are calculated by Chang's equation.

6.1 Calculation of Resultant Lateral Forth P0 and Acting Elevation h0

6.1.1 Normal Condition

Table with 7 columns: No, Depth Z m, Thickness h m, Lateral Forth Ps kN/m2, Loads P kN, Arm length Y m, Moment M kN x m. Rows 1-8 showing detailed data for normal condition.

Ps : active earth pressure + residual water pressure - passive earth pressure
P : load Ps 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

Table with 5 columns: No, Depth Z m, Thickness h m, N Value (upper, lower), Area A. Rows 1-6 showing data for upper and lower N values.

A: (upper N-value + lower N-value) x h/2

Average N-value N' = (sum A) / L
= 39.24 / 5.50
= 7.13

Kh is recalculated from the calculated average N value.

E0 = 2800N' = 2800 x 7.13 = 19976 kN/m^2
Klambda0 = (1/0.3) x alpha x 19976 = 66586 kN/m^3 (alpha: Normal Condition=1, Seismi Condition=2)
Klambda = Klambda0 (Blambda/0.3)^(-3/4) = 66586 (10.00/0.3)^(-3/4) = 4800 kN/m^3

Thus, the assumed Kh is equal to the recalculated Kh. The lateral subgrade reaction coefficient Kh (Normal Condition) is 4800 kN/m3.

5.3 Seismic Condition

Assuming Kh = 9125 kN/m3,

$$\beta = 4\sqrt{\frac{K_b \cdot B}{4 E I}} = 0.213 \text{ m}^{-1}$$

$$L = \frac{1}{\beta} = 4.68 \text{ m}$$

Therefore, average N-value is calculated on the actual N-value from imaginary riverbed (GL -7.05 m) and 4.68 m depth (GL -11.73 m).

Table with 5 columns: No, Depth Z m, Thickness h m, N Value (upper, lower), Area A. Rows 1-6 showing data for seismic condition.

A: (upper N-value + lower N-value) x h/2

Table with 2 columns: Arbitrary load lateral load, Height from riverbed to top of coping, Depth of Imaginary riverbed from riverbed. Values include Pi = 0.0 kN/m, Hi = 0.0 m, Ma = 0.0 kN.m/m, Ha = 0.00 m, H = 4.32 m, Lk = 1.74 m.

Moment M0 by arbitrary load is as below
M0 = Pi.(H + Lk - Hi) + Ma = 0.00 kN.m
h0, Height of acting position of P0 from imaginary riverbed

h0 = (M0 / (P0 * (H + Lk))) = (sum M + M0) / (sum P + P0)
= 457.10 / 167.69 = 2.73 m

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

P' = (2 x P0) / (H + Lk) = (2 x 167.69) / 6.06 = 55.35 kN/m

6.1.2 Seismic Condition

Table with 7 columns: No, Depth Z m, Thickness h m, Lateral Forth Ps kN/m2, Loads P kN, Arm length Y m, Moment M kN x m. Rows 1-9 showing detailed data for seismic condition.

Ps : active earth pressure + residual water pressure - passive earth pressure
P : load Ps 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

Table with 2 columns: Arbitrary load lateral load, Height from riverbed to top of coping, Depth of Imaginary riverbed from riverbed. Values include Pi = 0.00 kN/m, Hi = 0.00 m, Ma = 0.00 kN.m/m, Ha = 0.00 m, H = 4.32 m, Lk = 2.73 m.

Moment M_i by arbitrary load is as below
 $M_i = P_i \cdot (H + L_k - H_i) + M_m = 0.00 \text{ kN} \cdot \text{m}$

Hydrodynamic Pressure						
No	Depth Z m	Thickness h m	Hydrodynamic Pressure p _{hw} kN/m ²	Loads P _{hw} kN	Arm length Y m	Moment M _{hw} kN · m
1	3.48- 4.32	0.84	0.0 1.4	0.00 0.61	3.29 3.01	0.00 1.82
$\Sigma P_{hw} =$				0.61	$\Sigma M_{hw} =$	1.82

h_0 , Height of acting position of P_0 from imaginary riverbed

$$h_0 = \frac{M_0}{P_0} = \frac{\Sigma M + M_i + \Sigma M_{hw}}{\Sigma P + P_i + \Sigma P_{hw}} = \frac{659.81}{207.20} = 3.18 \text{ m}$$

When the resultant force of the Lateral Forth is assumed to be a triangular load, the load strength at the design surface position (P') is expressed as follows:

$$P' = \frac{2 \times P_0}{(H + L_u)} = \frac{2 \times 207.20}{7.05} = 58.78 \text{ kN/m}$$

6.2 Sectional Force

Corrosion rate and section efficiency for calculation of sectional forces and displacements are set as followings:

Material name	10 H _ H 900 -250 -14 -25 -18
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 = 631400 cm ⁴ (original condition) I = 549318 cm ⁴ (after reduction by corrosion and section)
EI	= 200000 × 10 ³ × 549318 × 10 ⁻⁸ = 1.099 × 10 ⁶

$$\beta = 4 \sqrt{\frac{K_b \cdot B}{4 E I}}$$

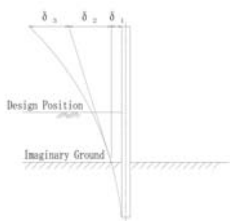
$$\phi_a = \frac{\sqrt{(1 + 2 \beta h_0)^2 + 1}}{2 \beta h_0} \times \exp(-\tan^{-1} \frac{1}{1 + 2 \beta h_0})$$

$$M_{max} = M_0 \cdot \phi_a$$

$$l_a = \frac{1}{\beta} \times \tan^{-1} \frac{1}{1 + 2 \beta h_0}$$

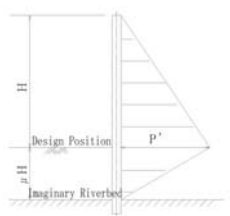
$$l_i = \frac{1}{\beta} \times \tan^{-1} \frac{1 + \beta h_0}{\beta h_0}$$

$$M_{(x)} = \frac{P_0}{\beta} \times \exp^{-\beta x} (\beta h_0 \cdot \cos \beta x + (1 + \beta h_0) \sin \beta x)$$



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^2} = \frac{(1 + 0.1818 \times 2.73) \times 167.69}{2 \times 2.00 \times 10^6 \times 549318 \times 10^{-8} \times 0.1818^2} = 0.01900 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) = \frac{(1 + 2 \times 0.1818 \times 2.73) \times 167.69}{2 \times 2.00 \times 10^6 \times 549318 \times 10^{-8} \times 0.1818^2} \times (4.32 + 1.74) = 0.02786 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{1.74}{4.32} = 0.403$$

$$\delta_3 = \frac{P' \cdot H^4}{120 E I} (4 + 20 \mu + 40 \mu^2 + 35 \mu^3 + 11 \mu^4) = \frac{55.35 \times 4.32^4}{120 \times 2.00 \times 10^6 \times 549318 \times 10^{-8}} (4 + 20 \times 0.403 + 40 \times 0.403^2 + 35 \times 0.403^3 + 11 \times 0.403^4) = 0.00309 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3 = 0.01900 + 0.02786 + 0.00309 = 0.04994 \text{ m}$$

Size = 49.94 ≤ δ a = 50.00 mm

6.2.1 Normal Condition

modulus of lateral subgrade reaction	K _b = 4800 kN/m ³
calculated value	β = 0.18179 m ⁻¹
resultant earth force (lateral)	P ₀ = 167.69 kN/m
height of acting position of load	h ₀ = 2.73 m
moment	M ₀ = 457.10 kN · m/m

in consideration of ψ _m = 1.412,	
maximum moment	M _{max} = 645.20 kN · m/m
depth of generated position of M _{max}	l _m = 2.560 m
depth of 1 st fixed point	l _i = 6.881 m

6.2.2 Seismic Condition

modulus of lateral subgrade reaction	K _b = 9125 kN/m ³
calculated value	β = 0.21347 m ⁻¹
resultant earth force (lateral)	P ₀ = 207.20 kN/m
height of acting position of load	h ₀ = 3.18 m
moment	M ₀ = 659.81 kN · m/m

in consideration of ψ _m = 1.262,	
maximum moment	M _{max} = 832.97 kN · m/m
depth of generated position of M _{max}	l _m = 1.878 m
depth of 1 st fixed point	l _i = 5.557 m

6.3 Stress Intensity

Material Name	10 H _ H 900 -250 -14 -25 -18
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 = 10120 cm ³ (original condition)
	Z = 8906 cm ³ (after reduction by corrosion and section)

6.3.1 Normal Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{645.20 \times 10^6}{8906 \times 10^3} = 72 \text{ N/mm}^2 \leq \sigma_a = 180 \text{ N/mm}^2$$

6.3.2 Seismic Condition

$$\sigma = \frac{M_{max}}{Z} = \frac{832.97 \times 10^6}{8906 \times 10^3} = 94 \text{ N/mm}^2 \leq \sigma_a = 270 \text{ N/mm}^2$$

6.4 Displacement Calculation

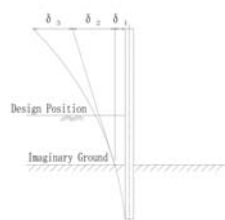
6.4.1 Normal Condition

Displacement Calculation

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

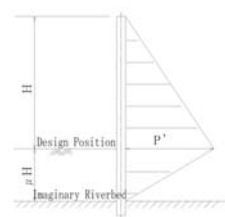
6.4.2 Seismic Condition

Displacement Calculation



$$\delta_1 = \frac{(1 + \beta h_0) \times P_0}{2 E I \beta^2} = \frac{(1 + 0.2135 \times 3.18) \times 207.20}{2 \times 2.00 \times 10^6 \times 549318 \times 10^{-8} \times 0.2135^2} = 0.01628 \text{ m}$$

$$\delta_2 = \frac{(1 + 2 \beta h_0) \times P_0}{2 E I \beta^2} \times (H + L_u) = \frac{(1 + 2 \times 0.2135 \times 3.18) \times 207.20}{2 \times 2.00 \times 10^6 \times 549318 \times 10^{-8} \times 0.2135^2} \times (4.32 + 2.73) = 0.03442 \text{ m}$$



$$\mu = \frac{L_k}{H} = \frac{2.73}{4.32} = 0.632$$

$$\delta_3 = \frac{P' H^4}{120 E I} (4 + 20\mu + 40\mu^2 + 35\mu^3 + 11\mu^4)$$

$$= \frac{58.78 \times 4.32^4}{120 \times 2.00 \times 10^8 \times 549318 \times 10^{-8}} (4 + 20 \times 0.632 + 40 \times 0.632^2 + 35 \times 0.632^3 + 11 \times 0.632^4)$$

$$= 0.00671 \text{ m}$$

$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$= 0.01628 + 0.03442 + 0.00671$$

$$= 0.05742 \text{ m}$$

$$\text{Size} = 57.42 \leq \delta_a = 75.00 \text{ mm}$$

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

7 Penetration Depth

Material Name	10 H _ H 900 -250 -14 -25 -18
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 = 631400 cm ⁴ (original condition)
	I = 631400 cm ⁴ (after reduction by corrosion and section)

$$EI = 200000 \times 10^3 \times 631400 \times 10^{-8} = 1.263 \times 10^6$$

7.1 Penetration Depth and Whole Length of SSP (Chang)

When the depth of the virtual ground surface is Lk, the grouting length (D) below the design surface and the total length (L) of the sheet pile are as follows.

$$D = L_k + \frac{3}{\beta}$$

$$L = H - H_{(1)} + D$$

$$\beta = \sqrt[4]{\frac{K_b \cdot B}{4 E I}}$$

7.1.1 Normal Condition

Modules of lateral subgrade reaction	$K_b = 4800 \text{ kN/m}^3$
Calculated value	$\beta = 0.17557 \text{ m}^{-1}$

Penetration length of SSP	$D = 1.74 + \frac{3}{0.176} = 18.83 \text{ m}$
Whole length of SSP	$L = 4.32 - 0.40 + 18.83 = 22.75 \text{ m}$

7.1.2 Seismic Condition

Modules of lateral subgrade reaction	$K_b = 9125 \text{ kN/m}^3$
Calculated value	$\beta = 0.20616 \text{ m}^{-1}$

Penetration length of SSP	$D = 2.73 + \frac{3}{0.206} = 17.28 \text{ m}$
Whole length of SSP	$L = 4.32 - 0.40 + 17.28 = 21.20 \text{ m}$

Therefore, the total length of the sheet pile is 23.00 m from the rounded length value of 0.50 m.

8 Calculation Result

SSP		10 H _ H 900 -250 -14 -25 -18			
				Normal Condition	Seismic Condition
Inertia sectional moment	I (cm4)	631400			
Sectional Modulus	Z (cm3)	10120			
Maximum bending moment	Mmax (kN × m × m)	645.20			832.97
Stress intensity	σ (N/mm2)	72 (180)			94 (270)
Lateral displacement	δ (mm)	49.84 (50.0)			57.42 (75.0)
Penetration depths	D (m)	18.83			17.28
Whole length of SSP	L (m)	23.00			