3.2 Structural design of revetment

3.2.1 Structural Calculation of PC Sheet Pile Revetment

Location: WF.37 L

1.DESIGN CONDITION

(1) Calculation Method

Loading Combination : Normal and Earthquake

Position of Support : Balancing Point of Active and Passive Soil Pressure

Length of Sheet Pile : Balancing Point of Moment 1.0 (Normal)

Balancing Point of Moment 1.0 (Earthquake)

Earth Pressure of Cohesive Soil

: $\Sigma \gamma_h - 2C$ (Normal)

Port Formula (Earthquake)

Seismic Coefficient : K_h = 0.12

K_h' = 0.24 (Constant, Submarged)

Reduction of Seismic Forth under River-bed

: Non

(2) Soil Pressure

Background Surface : Horizontally

Live Load :

	Passive	Active Down	Active Up
Normal	0.00 t/m^2	0.00 t/m^2	1.00 t/m^2
Earthquake	0.00 t/m^2	0.00 t/m^2	0.50 t/m^2

Friction Angle to Wall : Non

Reduction of Water Pressure

: Non (Trapezoid)

(3) Dimensions of Steel Sheet Pile

Type : PC Sheet Pile (t=220 mm)

Efficiency of Splice : 0.800

Thickness of Corrosion : Non

Allowable Stress : Normal 160.0 kg/cm^2、Earthquake 240 kg/cm^2

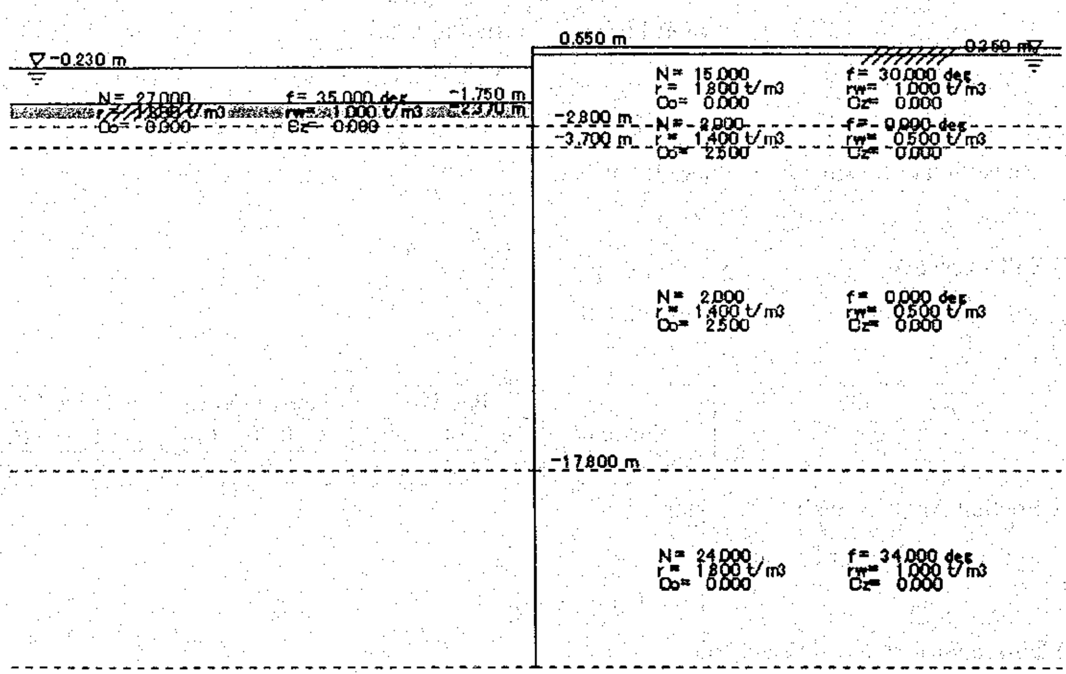
Allowable Deformation at Pile Head

: Normal 5.0 cm、Earthquake 7.5 cm

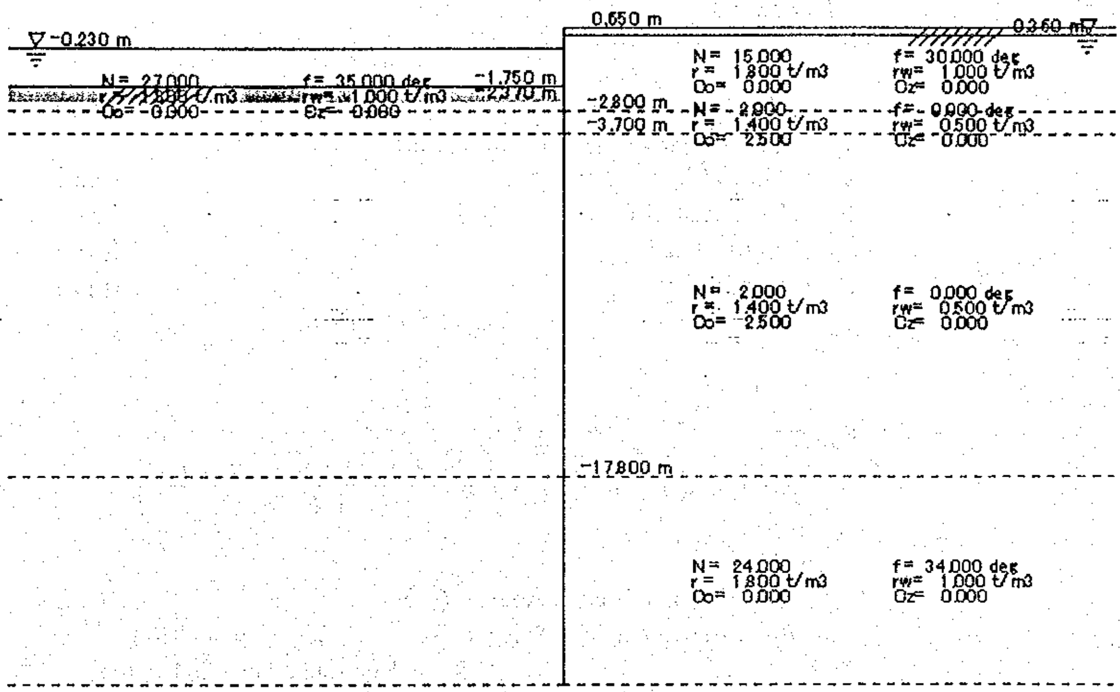
(4) Soil Condition

No	Elevation	Thick-ness	Avg. N-Value	Unit Weight			Internal Friction Angle	Cohesion	Horizontal K Value
				Wet	Sat.	Sub.			
	m	m		γ t/m³	γ t/m³	γ t/m³	ϕ (°)	Co	K
1	0.650 -2.800	3.450	15.0	1.80	2.00	1.00	30.0	0.000	2.07
2	-2.800 -3.700	0.900	2.0	1.40	1.40	0.50	0.0	2.500	0.92
3	-3.700 -17.800	14.100	2.0	1.40	1.40	0.50	0.0	2.500	0.92
4	-17.800 -999.999	982.199	24.0	1.80	2.00	1.00	34.0	0.000	2.51

【Normal Case】



【Seismic Case】



2. Load Calculation

(1) Formula of Soil Pressure

1) Sandy Soil : Active Soil Pressure

$$P_a = K_a \cdot \left(\sum \gamma h + \frac{q_a}{\cos \beta_a} \right) - 2 \cdot C \cdot \sqrt{K_a}$$

Where:

P_a	: Strength of Active Soil Pressure	(t/m^2)
K_p	: Coefficient of Active Soil Pressure	
γ	: Unit Weight of Soil	(t/m^3)
h	: Thickness of Layer	(m)
q_a	: Active Load	(t/m^2)
β_a	: Angle between G-Surface and Level Surface	(°)
C	: Cohesive	(t/m^2)

$$K_a = \frac{\cos(\phi - \theta) \cdot \cos \sigma}{\cos \theta \cdot \cos(\sigma + \theta) \cdot \left(1 + \sqrt{\dfrac{\sin(\phi + \sigma) \cdot \sin(\phi - \beta_a - \theta)}{\cos(\sigma + \theta) \cdot \cos \beta_a}} \right)}$$

Where:

ϕ : Internal Friction Angle (°)

θ : Active Angle of Seismic Force (°)、 $\theta = \tan^{-1}(K_h)$、

K_h : Horizontal Seismic Degree

δ : Friction Angle between Soil and Wall (°)

2) Sandy Soil : Passive Soil Pressure

$$P_p = K_p \cdot \left(\sum \gamma h + \frac{q_p}{\cos \beta_p} \right) + 2 \cdot C \cdot \sqrt{K_p}$$

Where:

P_p	: Strength of Passive Soil Pressure	(t/m^2)
K_p	: Coefficient of Passive Soil Pressure	
γ	: Unit Weight of Soil	(t/m^3)
h	: Thickness of Layer	(m)
q_p	: Active Load	(t/m^2)
C	: Cohesive	(t/m^2)
β_p	: Angle between G-Surface and Level Surface	(°)

$$K_p = \frac{\cos(\phi - \theta) \cdot \cos \sigma}{\cos \theta \cdot \cos(\sigma + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi + \sigma) \cdot \sin(\phi - \beta_p - \theta)}{\cos(\sigma + \theta) \cdot \cos \beta_p}} \right)}$$

Where:

ϕ : Internal Friction Angle (°)

θ : Active Angle of Seismic Force (°)、 $\theta = \tan^{-1}(K_h)$、

K_h : Horizontal Seismic Degree

δ : Friction Angle between Soil and Wall (°)

(2) Load Calculation (Normal Condition)

1) Soil Pressure & Water Pressure

【Normal · Active】

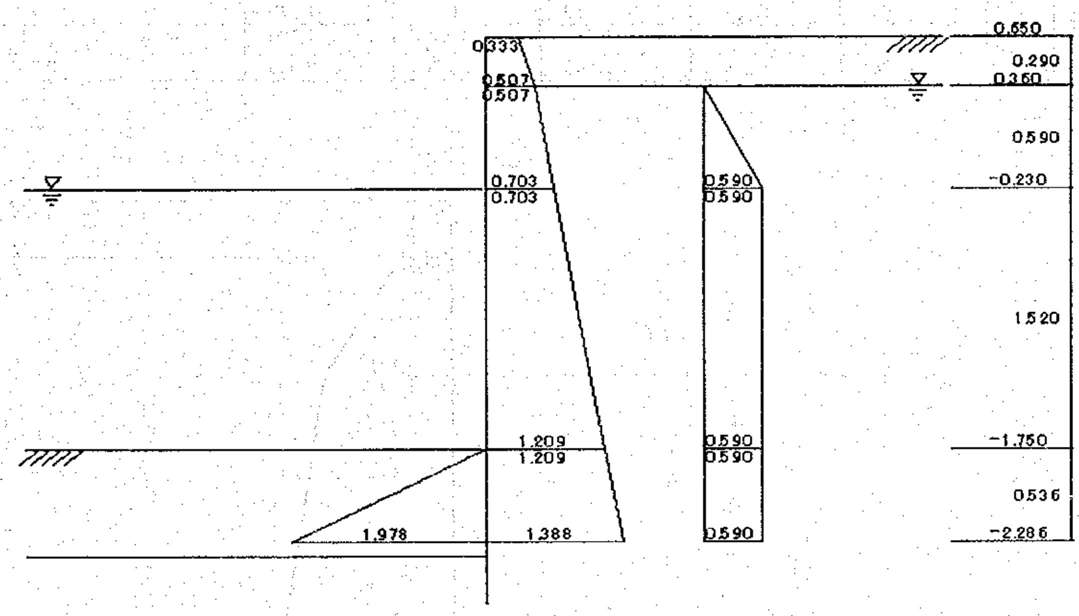
q = 0.00 t/m^2

No	Elevation El.m	Thickness m	γ t/m^3	ϕ °	c t/m^3	δ °	Seismic Degree	Ka	$\Sigma \gamma h$ t/m^3	Soil P. t/m^3	Water P. t/m^3
1	0.650	0.290	1.80	30.0	0.0	0.0	0.00	0.333	0.000	0.333	0.000
	0.360				0.0		0.00	0.333	0.522	0.507	0.000
2	0.360	0.590	1.00	30.0	0.0	0.0	0.00	0.333	0.522	0.507	0.000
	-0.230				0.0		0.00	0.333	1.112	0.703	0.590
3	-0.230	1.520	1.00	30.0	0.0	0.0	0.00	0.333	1.112	0.703	0.590
	-1.750				0.0		0.00	0.333	2.632	1.209	2.110
4	-1.750	0.536	1.00	30.0	0.0	0.0	0.00	0.333	2.632	1.209	2.110
	-2.286				0.0		0.00	0.333	3.168	1.388	2.646

【Normal・Passive】

q = 0.00 t／m²

No	Elevation El.m	Thickness m	γ t/m³	ϕ °	c t/m³	δ °	Seismic Degree	Ka	$\Sigma\gamma h$ t/m³	Soil P. t/m³	Water P. t/m³
1	0.650	0.290									
	0.360										
2	0.360	0.590									
	-0.230										
3	-0.230	1.520									0.000
	-1.750										1.520
4	-1.750	0.536	1.00	35.0	0.0	0.0	0.00	3.690	0.000	0.000	1.520
	-2.286				0.0		0.00	3.690	0.536	1.978	2.056

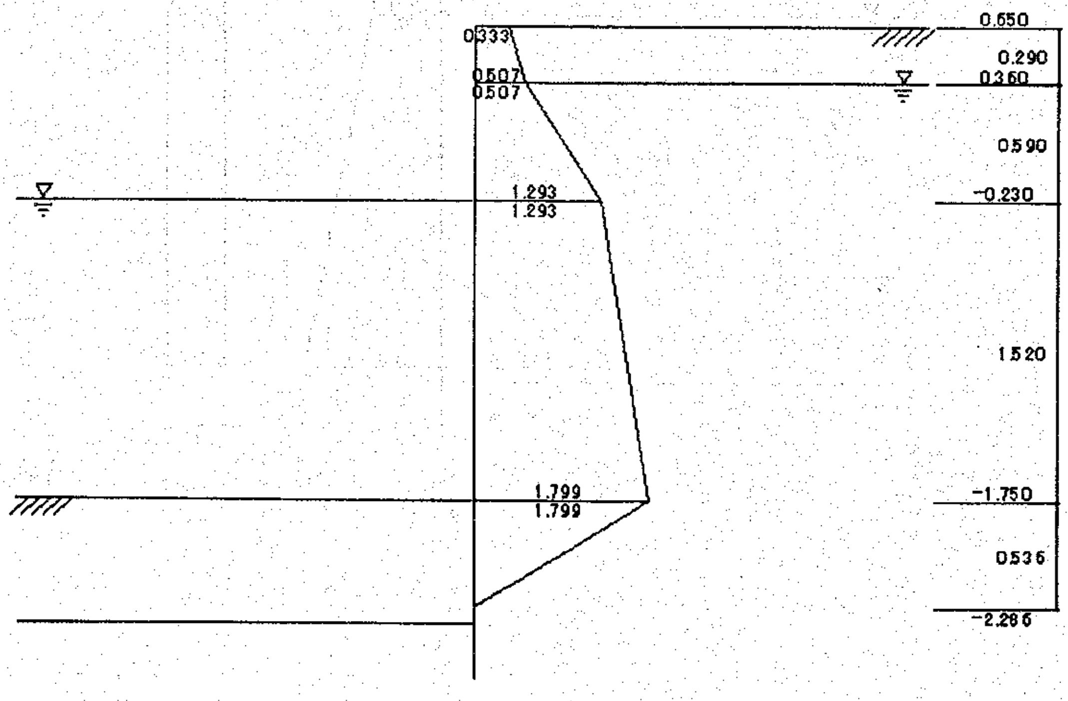


2) Acting Load

【Normal】

Balancing Pont of Active Force and Passive Force: EL. –2.286 m (0.536 m from Riverbed and 2.936 m from top of Pile).

No.	Loading Point El. m	Active SP Pa t/m²	Active WP Pwa t/m²	Passive SP Pp t/m²	Passive WP Pwp t/m²	Load Strength Pa+Pwa-Pp-Pwp t/m²
1	0.650	0.333	0.000	0.000	0.000	0.333
	0.360	0.507	0.000	0.000	0.000	0.507
2	0.360	0.507	0.000	0.000	0.000	0.507
	-0.230	0.703	0.590	0.000	0.000	1.293
3	-0.230	0.703	0.590	0.000	0.000	1.293
	-1.750	1.209	2.110	0.000	1.520	1.799
4	-1.750	1.209	2.110	0.000	1.520	1.799
	-2.286	1.388	2.646	1.978	2.056	0.000



3) Loading Point

【Normal】

No	Hi t/m	Yi m	Mi =Hi·yi	A =yi/H	B =(3-A)·A^2/6	Q =B·Hi
1	1/2×0.333×0.290=0.048	2.646+2/3×0.290=2.839	0.136	0.967	0.317	0.015
	0.290=0.074	2.646+1/3×0.290=2.743	0.203	0.934	0.301	0.022
2	1/2×0.507×0.590=0.150	2.056+2/3×0.590=2.449	0.367	0.834	0.251	0.038
	0.590=0.381	2.056+1/3×0.590=2.253	0.858	0.767	0.219	0.083
3	1/2×1.293×1.520=0.983	0.536+2/3×1.520=1.549	1.523	0.528	0.115	0.113
	1.520=1.367	0.536+1/3×1.520=1.043	1.426	0.355	0.056	0.076
4	1/2×1.799×0.536=0.482	2/3×0.536=0.357	0.172	0.122	0.007	0.003
	0.536=0.000	1/3×0.536=0.179	0.000	0.061	0.002	0.000
Total	3.485		4.685			0.351

Acting Point ho = ΣMi／Σhi = 4.686/3.485 = 1.344 m

3. Stress Calculation of PC Sheet Pile

【Normal】

1) Loading Condition (par m)

Derived from 2)Load to be act

Horizontal P_0	Acting Point h_0
3.485 t f/m	1.344 m

k Value of Grand Surface K
1.302 kgf/cm³

Coefficient of Reaction (k) : Average of "ki" below 1／β from the Fulcrum.

$1/\beta_1 \leqq L_1$: $K = K_1$

$1/\beta_1 > L_1$:

$$K = \frac{K_1 \times L_1 + K_2 \times L_2}{L_1 + L_2}$$

where:

K_1 : k value at the Fulcrum

K_2 : k value below the Fulcrum

L_1 : Thickness of layer from Fulcrum to boundary of next Layer.

$$L_2 = \frac{1 - \beta_1 \times L_1}{\beta_2}$$

β_1 : Specific characteristic of Sheet Pile (β)calculated by K_1

β_2 : Specific characteristic of Sheet Pile (β)calculated by K_2

2) Condition of PC Sheet Pile

Moment of Area I	Section Module Z	Elastic Module E
88700.0 cm^4/m	8000.0 cm^3/m	330000 kg/cm^2

Efficiency of Splice (α)	Reduction Ratio of Corrosion (λ)
0.80	1.00

Reduction Ratio of Corrosion (λ) is derived from the graph of "Thickness of Corrosion/Section Module".

Allowable Stress σa	Allowable Deformation δa
160.0 kg/cm^2	5.0 cm

Bending Stiffness EI	β
2342 $t \cdot m^2/m$	0.611 m^{-1}

Bending Stiffness EI'	β'
2927 $t \cdot m^2/m$	0.577 m^{-1}

① Deformation/Max. Moment

$$EI = E \times I \times \alpha \times \lambda$$
$$= 330000 \times 88700.0 \times 0.80 \times 1.00$$
$$= 23420000000 \ kg/cm^2/m$$
$$= 2342 \ t \cdot m^2/m$$

$$\beta = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI}}$$
$$= \sqrt[4]{\frac{1000 \times 1.302}{4 \times 2342}}$$
$$= 0.611 \ m^{-1}$$

② Embedding of Sheet Pile

$$EI' = E \times I$$
$$= 330000 \times 88700.0$$
$$= 29270000000 \ kg/cm^2/m$$
$$= 2927 \ t \cdot m^2/m$$

$$\beta' = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI'}}$$
$$= \sqrt[4]{\frac{1000 \times 1.302}{4 \times 2927}}$$
$$= 0.577 \ m^{-1}$$

3) Stress Calculation of Sheet Pile

Max. Bending Moment Mmax		Allowable cracking moment
5.611 $t \cdot m/m$	≦	13.20 tf-m/m ← OK

$$Mmax = M_t + M \times \phi = M_t + (P_0 \times h) + \phi$$

where

M_t : Moment at Top of Pile
h : Wall height = 2.936 m

$$\phi = \sqrt{\frac{(1+2\cdot\beta\cdot h)^2+1}{2\cdot\beta\cdot h}}\cdot\exp\left(-\tan^{-1}\frac{1}{1+2\cdot\beta\cdot h}\right)$$

$$= \sqrt{\frac{(1+2\times0.611\times1.344)^2+1}{2\times0.611\times1.344}}\cdot\exp\left(-\tan^{-1}\frac{1}{1+2\times0.611\times1.344}\right)$$

$$= 1.198$$

$$Mmax = M_t + M_0 \times \phi$$

$$= M_t + (P \times h) \times \phi$$

$$= 0.000 + 3.485 \times 1.344 \times 1.198$$

$$= 5.611\ t\cdot m/m$$

4) Deformation at Top of Sheet Pile

Deformation at Top of Sheet Pile $\Sigma\delta$
2.52 cm

$\leqq \delta a = 5.00cm \leftarrow$ OK

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

Where:

δ_1 : Deformation at Fulcrum.

δ_2 : Deformation by Deflection Angle Sheet Pile at Fulcrum.

δ_3 : Deformation of Sheet Pile as Cantilever above Fulcrum.

$$\delta_1 = \left(\frac{1+\beta\cdot h_0}{2\cdot EI\cdot\beta^3}\times P + \frac{Mt}{2\cdot EI\cdot\beta^2}\right)\times 100$$

$$= \left(\frac{1+0.611\times1.344}{2\times2342\times0.611^3}\times3.485 + \frac{0.000}{2\times2342\times0.611^2}\right)\times100$$

$$= 0.59\ cm$$

$$\delta_2 = \left(\frac{1+2\cdot\beta\cdot h_0}{2\cdot EI\cdot\beta^2}\times P + \frac{M_t}{2\cdot EI\cdot\beta}\right)\times H\times 100$$

$$= \left(\frac{1+2\times0.704\times0.703}{2\times2399\times0.704^2}\times1.677 + \frac{0.000}{2\times2399\times0.704}\right)\times1.805\times100$$

$$= 1.55\ cm$$

$$\delta_3 = \left(\frac{Q\cdot H^3}{EI} + \frac{Mt\cdot H^2}{2\cdot EI}\right)\times100$$

$$= \left(\frac{0.351 \times 2.9363}{2342} + \frac{0.000 \times 2.936}{2 \times 2342} \right) \times 100$$

$= 0.38$ cm

$\therefore \quad \Sigma\,\delta = 0.59 + 1.55 + 0.38$

$= 2.52$ cm

5) Stress Calculation for All Length of Sheet Pile

Total Length of Pile L
8.500 m

Driving Depth of Sheet Pile (Dz):

$Dz = \pi / \beta'$

$= \pi / 0.577$

$= 5.445$ m

Required Total Length of Sheet pile (L):

$L = H + Dz$

$= 2.936 + 5.445$

$= 8.381 \text{ m} < 8.500 \text{ m}$

(3) Load Calculation (Seismic Case)

1) Soil Pressure & Water Pressure

【Earthquake · Active】

$q = 0.00\ t/m^2$

No	Elevation El.m	Thickness m	γ t/m^3	ϕ °	c t/m^3	δ °	Seismic Degree	Ka	$\Sigma\gamma h$ t/m^3	Soil P. t/m^3	Water P. t/m^3
1	0.650	0.880	1.80	30.0	0.0	0.0	0.10	0.397	0.000	0.199	0.000
	-0.230				0.0		0.10	0.397	1.584	0.827	0.000
2	-0.230	1.520	1.00	30.0	0.0	0.0	0.20	0.473	1.584	0.986	0.000
	-1.750				0.0		0.20	0.473	3.104	1.705	1.520
3	-1.750	0.606	1.00	30.0	0.0	0.0	0.20	0.473	3.104	1.705	1.520
	-2.356				0.0		0.20	0.473	3.710	1.991	2.126

【Earthquake · Passive】

$q = 0.00\ t/m^2$

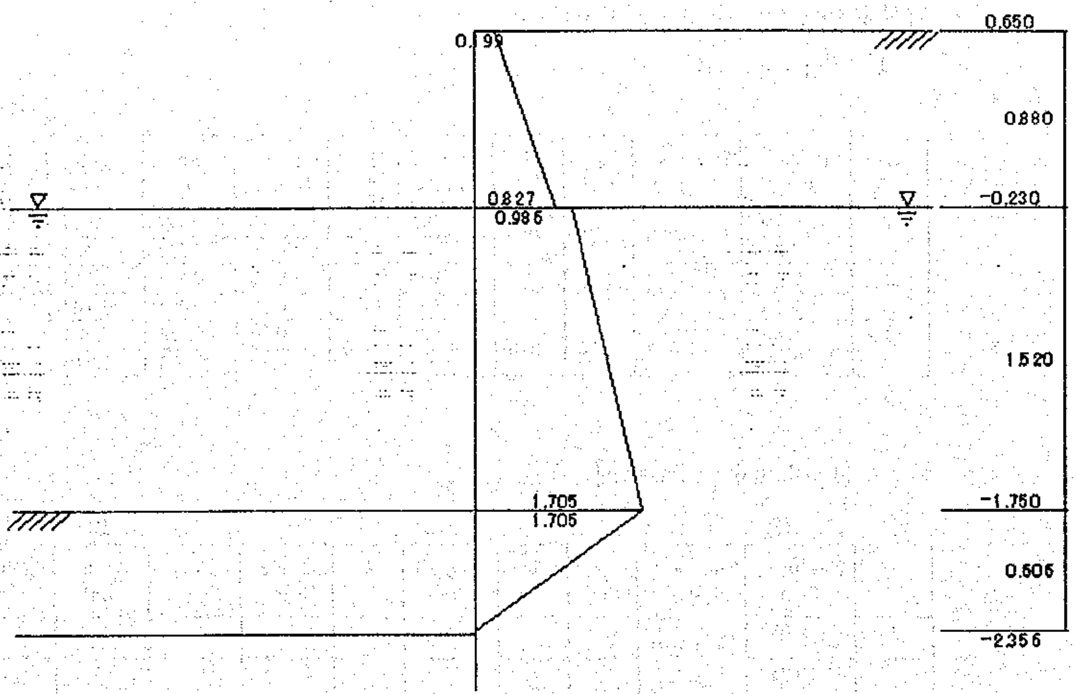
No	Elevation El.m	Thickness m	γ t/m^3	ϕ °	c t/m^3	δ °	Seismic Degree	Ka	$\Sigma\gamma h$ t/m^3	Soil P. t/m^3	Water P. t/m^3
1	0.650	0.880									
	-0.230										
2	-0.230	1.520									0.000
	-1.750										1.520
3	-1.750	0.606	1.00	35.0	0.0	0.0	0.20	3.285	0.000	0.000	1.520
	-2.356				0.0		0.20	3.285	0.606	1.991	2.126

2) Acting Load

【Earthquake】

Balancing Pont of Active Force and Passive Force: EL. –2.356 m (0.606 m from Riverbed and 3.006 m from top of Pile).

No	Loading Point El. m	Active SP Pa t/m^2	Active WP Pwa t/m^2	Passive SP Pp t/m^2	Passive WP Pwp t/m^2	Load Strength Pa+Pwa-Pp-Pwp t/m^2
1	0.650	0.199	0.000	0.000	0.000	0.199
	-0.230	0.827	0.000	0.000	0.000	0.827
2	-0.230	0.986	0.000	0.000	0.000	0.986
	-1.750	1.705	1.520	0.000	1.520	1.705
3	-1.750	1.705	1.520	0.000	1.520	1.705
	-2.356	1.991	2.126	1.991	2.126	0.000



3) Loading Point

【Earthquake】

No.	Hi t /m	Yi m	Mi =Hi·yi	A =yi/H	B =(3-A)· $A^2/6$	Q =B·Hi
1	1/2×0.199×0.880=0.088	2.126+2/3×0.880=2.713	0.239	0.903	0.285	0.025
	0.880=0.364	2.126+1/3×0.880=2.419	0.881	0.805	0.237	0.086
2	1/2×0.986×1.520=0.749	0.606+2/3×1.520=1.619	1.213	0.539	0.119	0.089
	1.520=1.296	0.606+1/3×1.520=1.113	1.442	0.370	0.060	0.078
3	1/2×1.705×0.606=0.517	2/3×0.606=0.404	0.209	0.134	0.009	0.004
	0.606=0.000	1/3×0.606=0.202	0.000	0.067	0.002	0.000
Total	3.014		3.984			0.283

Acting Point ho = $\Sigma Mi / \Sigma hi$ = 3.984/3.014 = 1.322 m

3. Stress Calculation of PC Sheet Pile

【Earthquake】

1) Loading Condition (par m)

Derived from 2)Load to be act

Horizontal P_0	Acting Point h_0
3.014 t /m	1.322 m

k Value of Grand Surface K
1.225 Kg/cm^3

Coefficient of Reaction (k) : Average of "ki" below $1/\beta$ from the Fulcrum.

$1/\beta_1 \leqq L_1 : K = K_1$

$1/\beta_1 > L_1$:

$$K = \frac{K_1 \times L_1 + K_2 \times L_2}{L_1 + L_2}$$

where:

K_1 : k value at the Fulcrum

K_2 : k value below the Fulcrum

L_1 : Thickness of layer from Fulcrum to boundary of next Layer.

$$L_2 = \frac{1 - \beta_1 \times L_1}{\beta_2}$$

β_1 : Specific characteristic of Sheet Pile (β)calculated by K_1

β_2 : Specific characteristic of Sheet Pile (β)calculated by K_2

2) Condition of PC Sheet Pile

Moment of Area I	Section Module Z	Elastic Module E
88700.0 cm^4/m	8000.0 cm^3/m	330000 kg/cm^2

Efficiency of Splice (α)	Reduction Ratio of Corrosion (λ)
0.80	1.00

Reduction Ratio of Corrosion (λ) is derived from the graph of "Thickness of Corrosion/Section Module".

Allowable Stress σa	Allowable Deformation δa
240.0 kg/cm^2	7.5 cm

Bending Stiffness EI	β
2342 $t \cdot m^2/m$	0.601 m^{-1}

Bending Stiffness EI'	β'
2927 $t \cdot m^2/m$	0.569 m^{-1}

① Deformation/Max. Moment

$EI = E \times I \times \alpha \times \lambda$

$= 330000 \times 88700.0 \times 0.80 \times 1.00$

$= 23420000000\ kg/cm^2/m$

$= 2342\ t \cdot m^2/m$

② Embedding of Sheet Pile

$EI' = E \times I$

$= 330000 \times 88700.0$

$= 29270000000\ kg/cm^2/m$

$= 2927\ t \cdot m^2/m$

$$\beta = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI}} = \sqrt[4]{\frac{1000 \times 1.225}{4 \times 2342}} = 0.601\ m^{-1}$$

$$\beta' = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI'}} = \sqrt[4]{\frac{1000 \times 1.225}{4 \times 2927}} = 0.569\ m^{-1}$$

3) Stress Calculation of PC Sheet Pile

Max. Bending Moment Mmax		Allowable cracking moment
4.813 t·m/m	≦	13.20 tf-m/m ← OK

$$Mmax = M_t + M \times \phi = Mt + (P_0 \times h) + \phi$$

where

M_t : Moment at Top of Pile

H : Wall height = 3.006 m

$$\phi = \sqrt{\frac{(1+2\cdot\beta\cdot h)^2+1}{2\cdot\beta\cdot h}} \cdot \exp\left(-\tan^{-1}\frac{1}{1+2\cdot\beta\cdot h}\right)$$

$$= \sqrt{\frac{(1+2\times0.601\times1.322)^2+1}{2\times0.601\times1.322}} \cdot \exp\left(-\tan^{-1}\frac{1}{1+2\times0.601\times1.322}\right)$$

$$= 1.208$$

$$Mmax = M_t + M_0 \times \phi$$

$$= M_t + (P \times h) \times \phi$$

$$= 0.000 + 3.014 \times 1.322 \times 1.208$$

$$= 4.813\ t \cdot m/m$$

4) Deformation at Top of Sheet Pile

Deformation at Top of Sheet Pile $\Sigma\delta$		
2.25 Cm	≦ δa =7.50cm	← OK

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

Where:

δ_1 : Deformation at Fulcrum.

δ_2 : Deformation by Deflection Angle Sheet Pile at Fulcrum.

δ_3 : Deformation of Sheet Pile as Cantilever above Fulcrum.

$$\delta_1 = \left(\frac{1+\beta\cdot h_0}{2\cdot EI\cdot \beta^3}\times P + \frac{Mt}{2\cdot EI\cdot \beta^2}\right)\times 100$$

$$= \left(\frac{1+0.601\times 1.322}{2\times 2342\times 0.601^3}\times 3.014 + \frac{0.000}{2\times 2342\times 0.601^2}\right)\times 100$$

$= 0.53$ cm

$$\delta_2 = \left(\frac{1+2\cdot\beta\cdot h_0}{2\cdot EI\cdot \beta^2}\times P + \frac{Mt}{2\cdot EI\cdot \beta}\right)\times H\times 100$$

$$= \left(\frac{1+2\times 0.601\times 1.322}{2\times 2342\times 0.601^2}\,3.014 + \frac{0.000}{2\times 2342\times 0.601}\right)\times 3.006\times 100$$

$= 1.39$ cm

$$\delta_3 = \left(\frac{Q\cdot H^3}{EI} + \frac{Mt\cdot H^2}{2\cdot EI}\right)\times 100$$

$$= \left(\frac{0.283\times 3.006^3}{2342} + \frac{0.000\times 3.006^2}{2\times 2342}\right)\times 100$$

$= 0.33$ cm

$\therefore \Sigma\,\delta = 0.53 + 1.39 + 0.33$

$= 2.25$ cm

5) Stress Calculation for All Length of Sheet Pile

Total Length of Pile L
9.000 m

Driving Depth of Sheet Pile (Dz):

$Dz = \pi / \beta'$

$= \pi / 0.569$

$= 5.521$ m

Required Total Length of Sheet pile (L):

$L = H + D_z$

$= 3.006 + 5.521$

$= 8.527 \text{ m} < 9.000 \text{ m}$

Location: WF.50 L

DESIGN CONDITION

(1) Caluculation Method

Loading Combination : Normal and Earthquake

Position of Support : Balancing Point of Active and Passive Soil Pressure

Length of Sheet Pile : Balancing Point of Moment 1.0 (Normal)

Balancing Point of Moment 1.0 (Earthquake)

Earth Pressure of Cohesive Soil

: $\Sigma \gamma_h - 2C$ (Normal)

Port Formula (Earthquake)

Seismic Coefficient : K_h = 0.12

K_h' = 0.24 (Constant, Submarged)

Reduction of Seismic Forth under River-bed

: Non

(2) Soil Pressure

Background Surface : Horizontally

Live Load :

	Passive	Active Down	Active Up
Normal	0.00 t/m²	0.00 t/m²	1.00 t/m²
Earthquake	0.00 t/m²	0.00 t/m²	0.50 t/m²

Friction Angle to Wall : Non

Reduction of Water Pressure

: Non (Trapezoid)

(3) Dimensions of Steel Sheet Pile

Type : PC Sheet Pile (t=220 mm)

Efficiency of Splice : 0.800

Thickness of Corrosion : Non

Allowable Stress : Normal 160.0 kg/cm^2、Earthquake 240 kg/cm^2

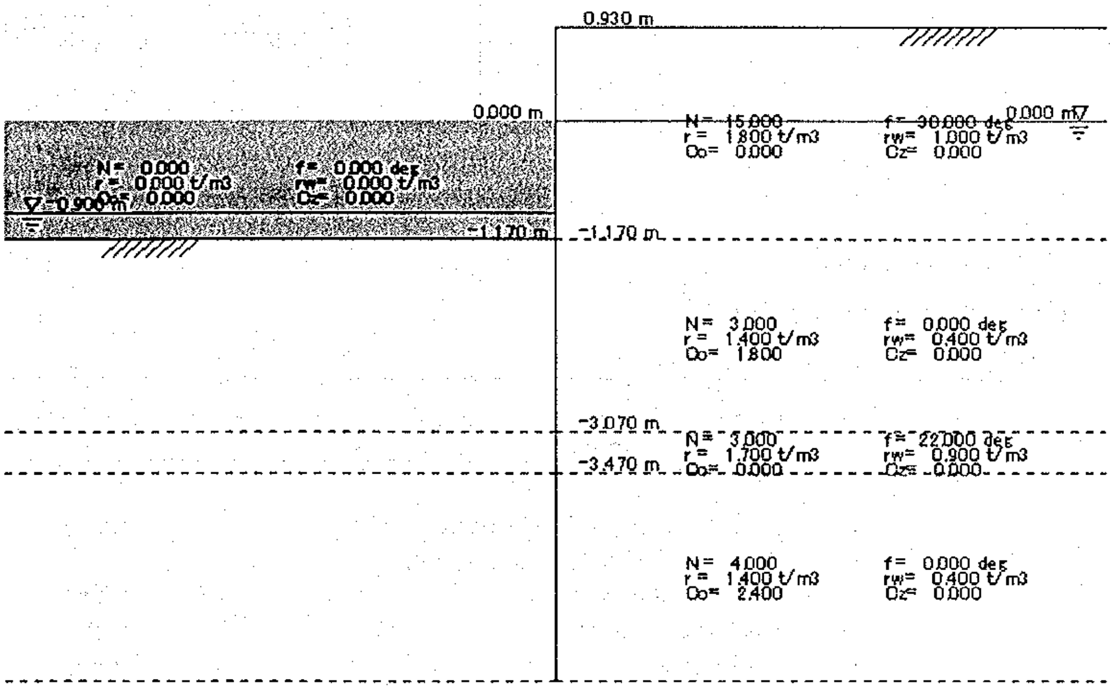
Allowable Deformation at Pile Head

: Normal 5.0 cm、Earthquake 7.5 cm

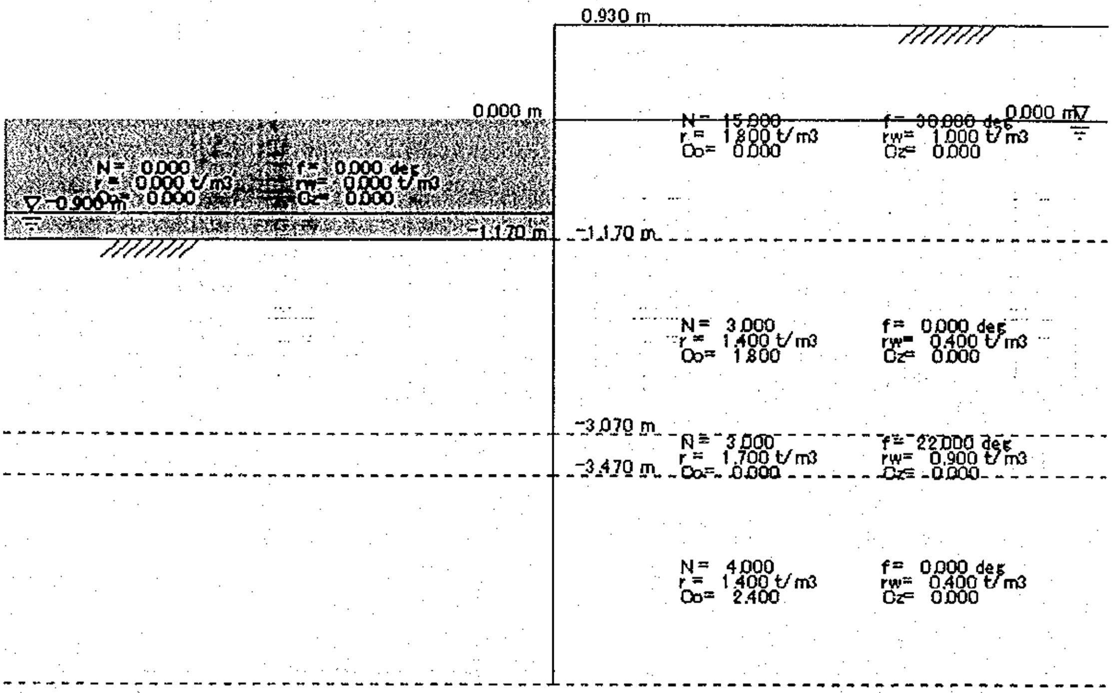
(4) Soil Condition

No	Elevation m	Thick-ness m	Avg. N-Value	Unit Weight Wet γ t/m³	 Sat. γ t/m³	 Sub. γ t/m³	Internal Friction Angle ϕ (°)	Cohesion Co	Horizontal K Value K
1	0.930 -1.170	2.100	15.0	1.80	2.00	1.00	30.0	0.000	2.07
2	-1.170 -3.070	1.900	3.0	1.40	1.40	0.40	0.0	1.800	0.69
3	-3.070 -3.470	0.400	3.0	1.70	1.90	0.90	22.0	0.000	0.92
4	-3.470 -999.999	996.529	4.0	1.40	1.40	0.40	0.0	2.400	2.51

【Normal Case】



【Seismic Case】



2. Load Calculation

(1) Formula of Soil Pressure

1) Sandy Soil : Active Soil Pressure

$$P_a = K_a \cdot \left(\sum \gamma h + \frac{q_a}{\cos \beta_a} \right) - 2 \cdot C \cdot \sqrt{K_a}$$

Where:

P_a	: Strength of Active Soil Pressure	(t/m^2)
K_p	: Coefficient of Active Soil Pressure	
γ	: Unit Weight of Soil	(t/m^3)
h	: Thickness of Layer	(m)
q_a	: Active Load	(t/m^2)
β_a	: Angle between G-Surface and Level Surface	(°)
C	: Cohesive	(t/m^2)

$$K_a = \frac{\cos(\phi - \theta) \cdot \cos \sigma}{\cos \theta \cdot \cos(\sigma + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi + \sigma) \cdot \sin(\phi - \beta_a - \theta)}{\cos(\sigma + \theta) \cdot \cos \beta_a}} \right)}$$

Where:

ϕ : Internal Friction Angle (°)

θ : Active Angle of Seismic Force (°), $\theta = \tan^{-1}(K_h)$,

K_h : Horizontal Seismic Degree

δ : Friction Angle between Soil and Wall (°)

2) Sandy Soil : Passive Soil Pressure

$$P_p = K_p \cdot \left(\sum \gamma h + \frac{q_p}{\cos \beta_p} \right) + 2 \cdot C \cdot \sqrt{K_p}$$

Where:

P_p	: Strength of Passive Soil Pressure	(t/m^2)
K_p	: Coefficient of Passive Soil Pressure	
γ	: Unit Weight of Soil	(t/m^3)
h	: Thickness of Layer	(m)
q_p	: Active Load	(t/m^2)
C	: Cohesive	(t/m^2)
β_p	: Angle between G-Surface and Level Surface	(°)

$$K_p = \frac{\cos(\phi - \theta) \cdot \cos\sigma}{\cos\theta \cdot \cos(\sigma + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi + \sigma) \cdot \sin(\phi - \beta_p - \theta)}{\cos(\sigma + \theta) \cdot \cos\beta_p}} \right)}$$

Where:

ϕ : Internal Friction Angle (°)

θ : Active Angle of Seismic Force (°)、 $\theta = \tan^{-1}(K_h)$、

K_h : Horizontal Seismic Degree

δ : Friction Angle between Soil and Wall (°)

(2) Load Calculation (Normal Condition)

1) Soil Pressure & Water Pressure

【Normal・Active】

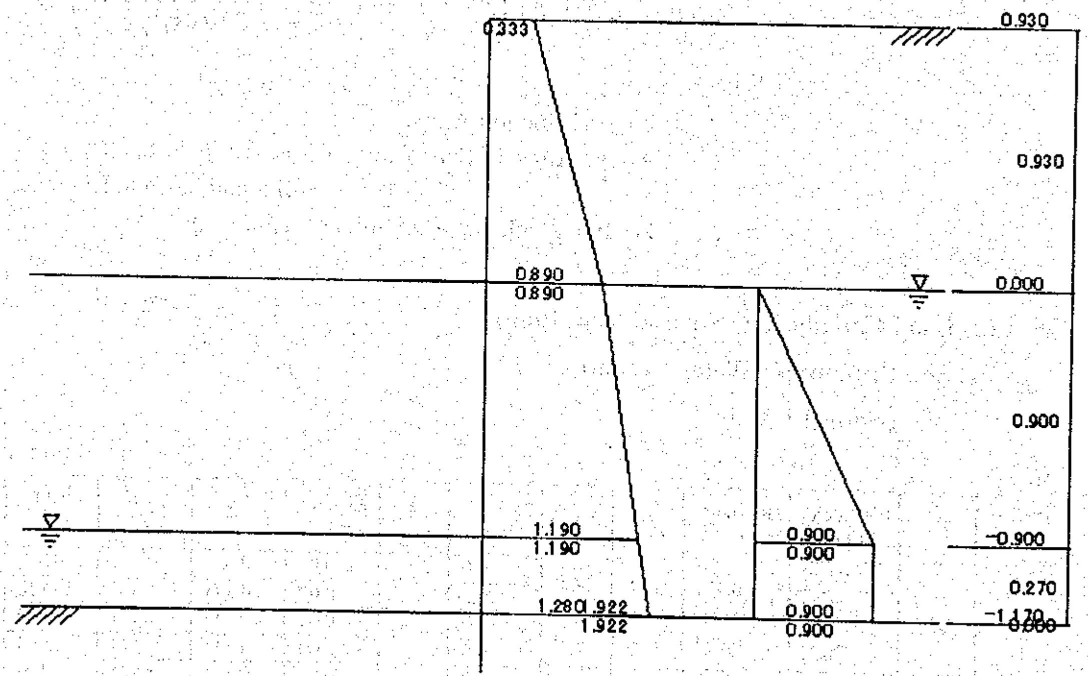
$q = 0.00\ t/m^2$

No	Elevation El.m	Thickness m	γ t/m^3	ϕ °	c t/m^3	δ °	Seismic Degree	Ka	$\Sigma\gamma h$ t/m^3	Soil P. t/m^3	Water P. t/m^3
1	0.930	0.930	1.80	30.0	0.0	0.0	0.00	0.333	0.000	0.333	0.000
	0.000				0.0		0.00	0.333	1.674	0.890	0.000
2	0.000	0.900	1.00	30.0	0.0	0.0	0.00	0.333	1.674	0.890	0.000
	-0.900				0.0		0.00	0.333	2.574	1.190	0.900
3	-0.900	0.270	1.00	30.0	0.0	0.0	0.00	0.333	2.574	1.190	0.900
	-1.170				0.0		0.00	0.333	2.844	1.280	1.170
4	-1.170	0.000	0.40	0.0	1.8	0.0	0.00	1.000	2.844	1.922	1.170
	-1.170				1.8		0.00	1.000	2.844	1.922	1.170

【Normal · Passive】

q = 0.00 t／m²

No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σγh t/m³	Soil P. t/m³	Water P. t/m³
1	0.930	0.930									
	0.000										
2	0.000	0.900									
	-0.900										
3	-0.900	0.270									0.000
	-1.170										0.270
4	-1.170	0.000									0.270
	-1.170										0.270

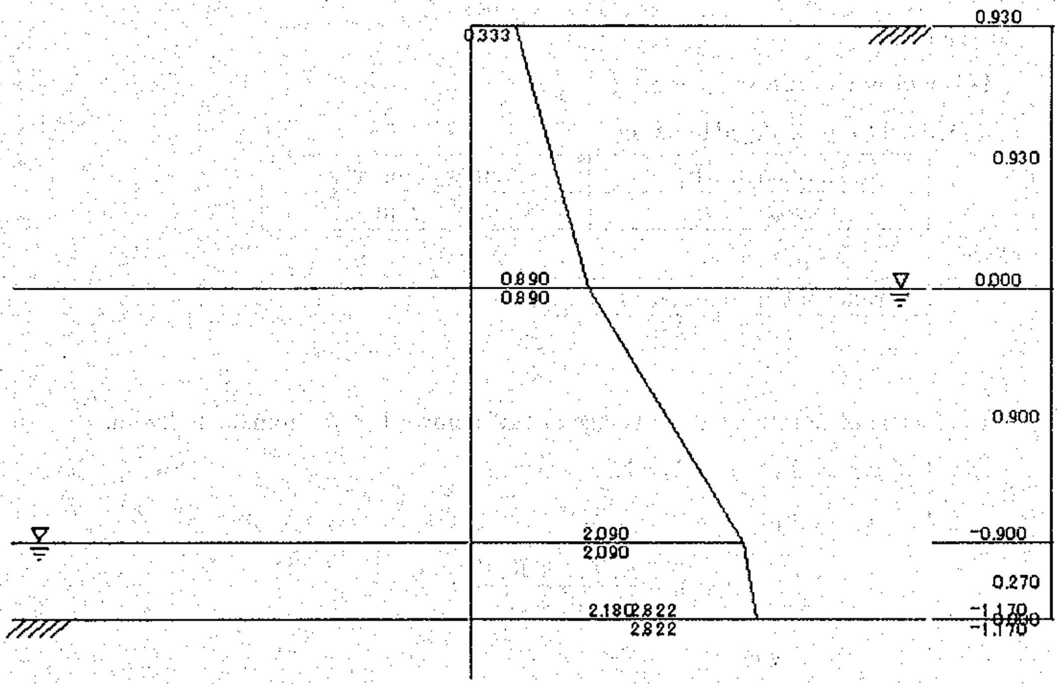


2) Acting Load

【Normal】

Balancing Pont of Active Force and Passive Force: EL. -1.170 m (0.000 m from Riverbed and 2.100 m from top of Pile).

No	Loading Point El. m	Active SP Pa t/m²	Active WP Pwa t/m²	Passive SP Pp t/m²	Passive WP Pwp t/m²	Load Strength Pa+Pwa-Pp-Pwp t/m²
1	0.930	0.333	0.000	0.000	0.000	0.333
	0.000	0.890	0.000	0.000	0.000	0.890
2	0.000	0.890	0.000	0.000	0.000	0.890
	-0.900	1.190	0.900	0.000	0.000	2.090
3	-0.900	1.190	0.900	0.000	0.000	2.090
	-1.170	1.280	1.170	0.000	0.270	2.180
4	-1.170	1.922	1.170	0.000	0.270	2.822
	-1.170	1.922	1.170	0.000	0.270	2.822



3) Loading Point

【Normal】

No	Hi t /m	Yi m	Mi =Hi·yi	A =yi/H	B =(3-A)·A^2/6	Q =B·Hi
1	1/2×0.333×0.930=0.155	1.170+2/3×0.930=1.790	0.277	0.852	0.260	0.040
	0.930=0.414	1.170+1/3×0.930=1.480	0.613	0.705	0.190	0.079
2	1/2×0.890×0.900=0.401	0.270+2/3×0.900=0.870	0.349	0.414	0.074	0.030
	0.900=0.941	0.270+1/3×0.900=0.570	0.536	0.271	0.034	0.032
3	1/2×2.090×0.270=0.282	0.000+2/3×0.270=0.180	0.051	0.086	0.004	0.001
	0.270=0.294	0.000+1/3×0.270=0.090	0.026	0.043	0.001	0.000
4	1/2×2.822×0.000=0.000	2/3×0.000=0.000	0.000	0.000	0.000	0.000
	0.000=0.000	1/3×0.000=0.000	0.000	0.000	0.000	0.000
Total	2.487		1.852			0.181

Acting Point ho = $\Sigma Mi / \Sigma hi$ = 1.852/2.487 = 0.745 m

3. Stress Calculation of PC Sheet Pile

【Normal】

1) Loading Condition (par m)

Derived from 2)Load to be act

Horizontal P_0	Acting Point h_0
2.487 t /m	0.745 m

k Value of Grand Surface K
0.693 kg/cm^3

Coefficient of Reaction (k) : Average of "ki" below $1/\beta$ from the Fulcrum.

$1/\beta_1 \leqq L_1$: $K = K_1$

$1/\beta_1 > L_1$:

$$K = \frac{K_1 \times L_1 + K_2 \times L_2}{L_1 + L_2}$$

where:

K_1 : k value at the Fulcrum

K_2 : k value below the Fulcrum

L_1 : Thickness of layer from Fulcrum to boundary of next Layer.

$$L_2 = \frac{1 - \beta_1 \times L_1}{\beta_2}$$

β_1 : Specific characteristic of Sheet Pile (β)calculated by K_1

β_2 : Specific characteristic of Sheet Pile (β)calculated by K_2

2) Condition of PC Sheet Pile

Moment of Area I	Section Module Z	Elastic Module E
88700.0 cm^4/m	8000.0 cm^3/m	330000 kg/cm^2

Efficiency of Splice (α)	Reduction Ratio of Corrosion (λ)
0.80	1.00

Reduction Ratio of Corrosion (λ) is derived from the graph of "Thickness of Corrosion/Section Module".

Allowable Stress σa	Allowable Deformation δa
160.0 kg/cm^2	5.0 cm

Bending Stiffness EI	β
2342 $t \cdot m^2/m$	0.522 m^{-1}

Bending Stiffness EI'	β'
2927 $t \cdot m^2/m$	0.493 m^{-1}

① Deformation/Max. Moment

$$EI = E \times I \times \alpha \times \lambda$$
$$= 330000 \times 88700.0 \times 0.80 \times 1.00$$
$$= 23420000000 \ kg/cm^2/m$$
$$= 2342 \ t \cdot m^2/m$$

$$\beta = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI}}$$
$$= \sqrt[4]{\frac{1000 \times 0.693}{4 \times 2342}}$$
$$= 0.522 \ m^{-1}$$

② Embedding of Sheet Pile

$$EI' = E \times I$$
$$= 330000 \times 88700.0$$
$$= 29270000000 \ kg/cm^2/m$$
$$= 2927 \ t \cdot m^2/m$$

$$\beta' = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI'}}$$
$$= \sqrt[4]{\frac{1000 \times 0.693}{4 \times 2927}}$$
$$= 0.493 \ m^{-1}$$

3) Stress Calculation of Sheet Pile

Max. Bending Moment Mmax		Allowable cracking moment
2.911 $t \cdot m/m$	≦	13.20 tf-m/m ← OK

$$Mmax = M_t + M \times \phi = M_t + (P_0 \times h) + \phi$$

where

M_t : Moment at Top of Pile
h : Wall height = 2.100 m

$$\phi = \sqrt{\frac{(1+2\cdot\beta\cdot h)^2+1}{2\cdot\beta\cdot h}}\cdot\exp\left(-\tan^{-1}\frac{1}{1+2\cdot\beta\cdot h}\right)$$

$$= \sqrt{\frac{(1+2\times0.522\times0.745)^2+1}{2\times0.522\times0.745}}\cdot\exp\left(-\tan^{-1}\frac{1}{1+2\times0.522\times0.745}\right)$$

$$= 1.571$$

$$\begin{aligned} Mmax &= M_t + M_0 \times \phi \\ &= M_t + (P \times h) \times \phi \\ &= 0.000 + 2.487 \times 0.745 \times 1.571 \\ &= 2.911\ t\cdot m/m \end{aligned}$$

4) Deformation at Top of Sheet Pile

Deformation at Top of Sheet Pile $\Sigma\delta$
1.32 cm

$\leqq$ δa =5.00cm ← OK

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

Where:

δ_1 : Deformation at Fulcrum.

δ_2 : Deformation by Deflection Angle Sheet Pile at Fulcrum.

δ_3 : Deformation of Sheet Pile as Cantilever above Fulcrum.

$$\delta_1 = \left(\frac{1+\beta\cdot h_0}{2\cdot EI\cdot\beta^3}\times P + \frac{Mt}{2\cdot EI\cdot\beta^2}\right)\times100$$

$$= \left(\frac{1+0.522\times0.745}{2\times2342\times0.522^3}\times2.487 + \frac{0.000}{2\times2342\times0.522^2}\right)\times100$$

$$= 0.52\ cm$$

$$\delta_2 = \left(\frac{1+2\cdot\beta\cdot h_0}{2\cdot EI\cdot\beta^2}\times P + \frac{M_t}{2\cdot EI\cdot\beta}\right)\times H\times100$$

$$= \left(\frac{1+2\times0.522\times0.745}{2\times2342\times0.522^2}\times2.487 + \frac{0.000}{2\times2342\times0.522}\right)\times2.100\times100$$

$$= 0.73\ cm$$

$$\delta_3 = \left(\frac{Q\cdot H^3}{EI} + \frac{Mt\cdot H^2}{2\cdot EI}\right)\times100$$

$$= \left(\frac{0.181\times2.1003}{2342} + \frac{0.000\times2.100}{2\times2342}\right)\times100$$

$= 0.07$ cm

$\therefore \quad \Sigma\delta = 0.52 + 0.73 + 0.07$

$= 1.32$cm

5) Stress Calculation for All Length of Sheet Pile

Total Length of Pile L
8.500 m

Driving Depth of Sheet Pile (Dz):

$Dz = \pi / \beta'$

$= \pi / 0.493$

$= 6.372$ m

Required Total Length of Sheet pile (L):

$L = H + Dz$

$= 2.100 + 6.372$

$= 8.472 \text{ m} < 8.500 \text{ m}$

(3) Load Calculation (Seismic Case)

1) Soil Pressure & Water Pressure

【Earthquake・Active】

q = 0.00 t/m²

No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σγh t/m³	Soil P. t/m³	Water P. t/m³
1	0.930	0.930	1.80	30.0	0.0	0.0	0.10	0.397	0.000	0.199	0.000
	0.000				0.0		0.10	0.397	1.674	0.863	0.000
2	0.000	0.230	1.80	30.0	0.0	0.0	0.10	0.397	1.674	0.863	0.000
	-0.230				0.0		0.10	0.397	2.088	1.027	0.000
3	-0.230	0.940	1.00	30.0	0.0	0.0	0.20	0.473	2.088	1.224	0.000
	-1.170				0.0		0.20	0.473	3.028	1.669	0.940
4	-1.170	0.000	0.40	0.0	1.8	0.0	0.20	1.000	3.028	1.764	0.940
	-1.170				1.8		0.20	1.000	3.028	1.764	0.940

【Earthquake・Passive】

q = 0.00 t／m²

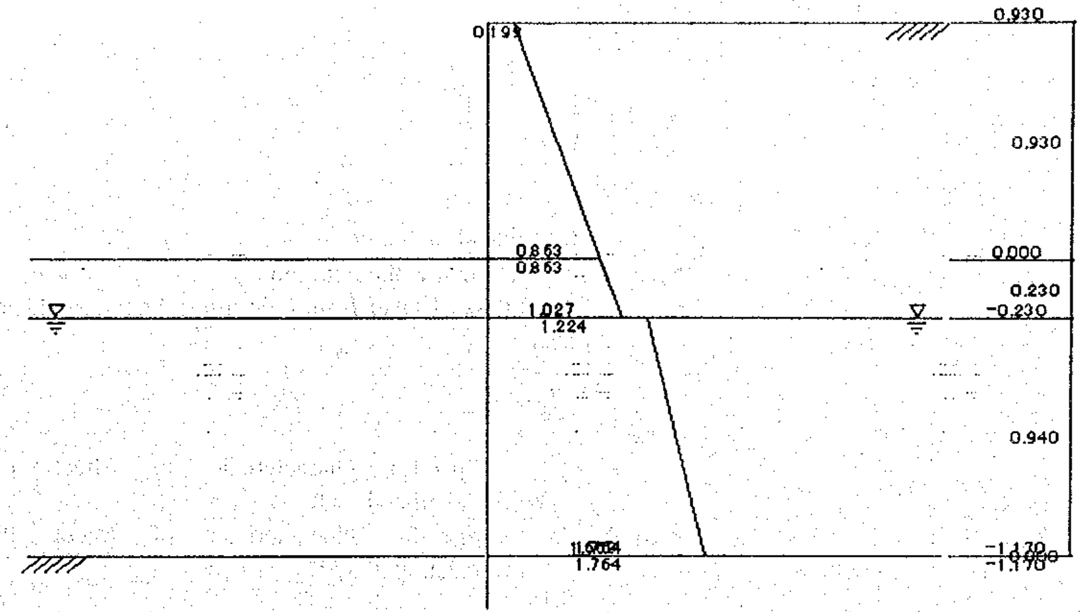
No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σγh t/m³	Soil P. t/m³	Water P. t/m³
1	0.930	0.930									
	0.000										
2	0.000	0.230									
	-0.230										
3	-0.230	0.940									0.000
	-1.170										0.940
4	-1.170	0.000									0.940
	-1.170										0.940

2) Acting Load

【Earthquake】

Balancing Pont of Active Force and Passive Force: EL. –1.170 m (0.000 m from Riverbed and 2.1006 m from top of Pile).

No	Loading Point El. m	Active SP Pa t/m²	Active WP Pwa t/m²	Passive SP Pp t/m²	Passive WP Pwp t/m²	Load Strength Pa+Pwa-Pp-Pwp t/m²
1	0.930	0.199	0.000	0.000	0.000	0.199
	0.000	0.863	0.000	0.000	0.000	0.863
2	0.000	0.863	0.000	0.000	0.000	0.863
	-0.230	1.027	0.000	0.000	0.000	1.027
3	-0.230	1.224	0.000	0.000	0.000	1.224
	-1.170	1.669	0.940	0.000	0.940	1.669
4	-1.170	1.764	0.940	0.000	0.940	1.764
	-1.170	1.764	0.940	0.000	0.940	1.764



3) Loading Point

【Earthquake】

No	Hi t/m	Yi m	Mi =Hi·yi	A =yi/H	B =(3-A)·A^2/6	Q =B·Hi
1	1/2×0.199×0.930=0.093	1.170+2/3×0.930=1.790	0.166	0.852	0.260	0.024
	0.930=0.401	1.170+1/3×0.930=1.480	0.593	0.705	0.190	0.076
2	1/2×0.863×0.230=0.099	0.940+2/3×0.230=1.093	0.108	0.520	0.112	0.011
	0.230=0.118	0.940+1/3×0.230=1.017	0.120	0.484	0.098	0.012
3	1/2×1.224×0.940=0.575	0.000+2/3×0.940=0.627	0.361	0.299	0.040	0.023
	0.940=0.784	0.000+1/3×0.940=0.313	0.245	0.149	0.011	0.008
4	1/2×1.764×0.000=0.000	2/3×0.000=0.000	0.000	0.000	0.000	0.000
	0.000=0.000	1/3×0.000=0.000	0.000	0.000	0.000	0.000
Total	2.070		1.593			0.154

Acting Point ho = $\Sigma Mi / \Sigma hi$ = 1.593 / 2.070 = 0.770 m

3. Stress Calculation of PC Sheet Pile

【Earthquake】

1) Loading Condition (par m)

Derived from 2)Load to be act

Horizontal P_0	Acting Point h_0
2.070 t/m	0.770 m

k Value of Grand Surface K
0.693 Kg/cm^3

Coefficient of Reaction (k) : Average of "ki" below $1/\beta$ from the Fulcrum.

$1/\beta_1 \leqq L_1 : K = K_1$

$1/\beta_1 > L_1$:

$$K = \frac{K_1 \times L_1 + K_2 \times L_2}{L_1 + L_2}$$

where:

K_1 : k value at the Fulcrum

K_2 : k value below the Fulcrum

L_1 : Thickness of layer from Fulcrum to boundary of next Layer.

$$L_2 = \frac{1 - \beta_1 \times L_1}{\beta_2}$$

β_1 : Specific characteristic of Sheet Pile (β)calculated by K_1

β_2 : Specific characteristic of Sheet Pile (β)calculated by K_2

2) Condition of PC Sheet Pile

Moment of Area I	Section Module Z	Elastic Module E
88700.0 cm^4/m	8000.0 cm^3/m	330000 kg/cm^2

Efficiency of Splice (α)	Reduction Ratio of Corrosion (λ)
0.80	1.00

Reduction Ratio of Corrosion (λ) is derived from the graph of "Thickness of Corrosion/Section Module".

Allowable Stress σa	Allowable Deformation δa
240.0 kg/cm^2	7.5 cm

Bending Stiffness EI	β
2342 $t \cdot m^2/m$	0.522 m^{-1}

Bending Stiffness EI'	β'
2927 $t \cdot m^2/m$	0.493 m^{-1}

① Deformation/Max. Moment

$EI = E \times I \times \alpha \times \lambda$

$= 330000 \times 88700.0 \times 0.80 \times 1.00$

$= 23420000000\ kg/cm^2/m$

$= 2342\ t \cdot m^2/m$

② Embedding of Sheet Pile

$EI' = E \times I$

$= 330000 \times 88700.0$

$= 29270000000\ kg/cm^2/m$

$= 2927\ t \cdot m^2/m$

$$\beta = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI}} = \sqrt[4]{\frac{1000 \times 0.693}{4 \times 2342}} = 0.522\ m^{-1}$$

$$\beta' = \sqrt[4]{\frac{1000 \cdot K}{4 \cdot EI'}} = \sqrt[4]{\frac{1000 \times 0.693}{4 \times 2927}} = 0.493\ m^{-1}$$

3) Stress Calculation of PC Sheet Pile

Max. Bending Moment Mmax		Allowable cracking moment
2.466 t·m/m	≦	13.20 tf-m/m ← OK

$$Mmax = M_t + M \times \phi = Mt + (P_0 \times h) + \phi$$

where

M_t : Moment at Top of Pile

H : Wall height = 2.100 m

$$\phi = \sqrt{\frac{(1 + 2 \cdot \beta \cdot h)^2 + 1}{2 \cdot \beta \cdot h}} \cdot \exp\left(-\tan^{-1}\frac{1}{1 + 2 \cdot \beta \cdot h}\right)$$

$$= \sqrt{\frac{(1 + 2 \times 0.522 \times 0.770)^2 + 1}{2 \times 0.522 \times 0.770}} \cdot \exp\left(-\tan^{-1}\frac{1}{1 + 2 \times 0.522 \times 0.770}\right)$$

$$= 1.547$$

$$Mmax = M_t + M_0 \times \phi$$

$$= M_t + (P \times h) \times \phi$$

$$= 0.000 + 2.070 \times 0.770 \times 1.547$$

$$= 2.466\ t \cdot m/m$$

4) Deformation at Top of Sheet Pile

Deformation at Top of Sheet Pile $\Sigma\delta$	
1.11 Cm	< δa =7.50cm ← OK

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

Where:

δ_1 : Deformation at Fulcrum.

δ_2 : Deformation by Deflection Angle Sheet Pile at Fulcrum.

δ_3 : Deformation of Sheet Pile as Cantilever above Fulcrum.

$$\delta_1 = \left(\frac{1+\beta \cdot h_0}{2 \cdot EI \cdot \beta^3} \times P + \frac{Mt}{2 \cdot EI \cdot \beta^2}\right) \times 100$$

$$= \left(\frac{1+0.522 \times 0.770}{2 \times 2342 \times 0.522^3} \times 2.070 + \frac{0.000}{2 \times 2342 \times 0.522^2}\right) \times 100$$

$= 0.44$ cm

$$\delta_2 = \left(\frac{1+2 \cdot \beta \cdot h_0}{2 \cdot EI \cdot \beta^2} \times P + \frac{Mt}{2 \cdot EI \cdot \beta}\right) \times H \times 100$$

$$= \left(\frac{1+2 \times 0.522 \times 0.770}{2 \times 2342 \times 0.522^2} 2.070 + \frac{0.000}{2 \times 2342 \times 0.522}\right) \times 2.100 \times 100$$

$= 0.61$ cm

$$\delta_3 = \left(\frac{Q \cdot H^3}{EI} + \frac{Mt \cdot H^2}{2 \cdot EI}\right) \times 100$$

$$= \left(\frac{0.154 \times 2.100^3}{2342} + \frac{0.000 \times 2.100^2}{2 \times 2342}\right) \times 100$$

$= 0.06$ cm

$\therefore \Sigma \delta = 0.44 + 0.61 + 0.06$

$= 1.11$ cm

5) Stress Calculation for All Length of Sheet Pile

Total Length of Pile L
8.500 m

Driving Depth of Sheet Pile (Dz):

$Dz = \pi / \beta'$

$= \pi / 0.493$

$= 6.372$ m

Required Total Length of Sheet pile (L):

$L = H + D_z$

$= 2.100 + 6.372$

$= 8.472 \text{ m} < 8.500 \text{ m}$

Location: WF.117 R

1.DESIGN CONDITION

(1) Calculation Method

Loading Combination : Normal and Earthquake

Position of Support : Balancing Point of Active and Passive Soil Pressure

Length of Sheet Pile : Balancing Point of Moment 1.5 (Normal)

Balancing Point of Moment 1.2 (Earthquake)

Earth Pressure of Cohesive Soil

: $\Sigma \gamma_h - 2C$ (Normal)

Port Formula (Earthquake)

Seismic Coefficient : K_h = 0.12

K_h' = 0.24 (Constant, Submarged)

Reduction of Seismic Forth under River-bed

: Non

(2) Soil Pressure

Background Surface : Type of berm

Width of berm B = 4.500 m

Grade of slope I = 1:2.0

Height of berm H = 3.360 m

Live Load :

	Passive	Active Down	Active Up
Normal	0.00 t/m^2	0.00 t/m^2	1.00 t/m^2
Earthquake	0.00 t/m^2	0.00 t/m^2	0.50 t/m^2

Friction Angle to Wall : Non

Reduction of Water Pressure

: Non (Trapezoid)

(3) Dimensions of Steel Sheet Pile

Type : PC Sheet Pile (t=220 mm)

Efficiency of Splice : 0.800

Thickness of Corrosion : Non

Allowable Stress : Normal 160.0 kg/cm^2、Earthquake 240 kg/cm^2

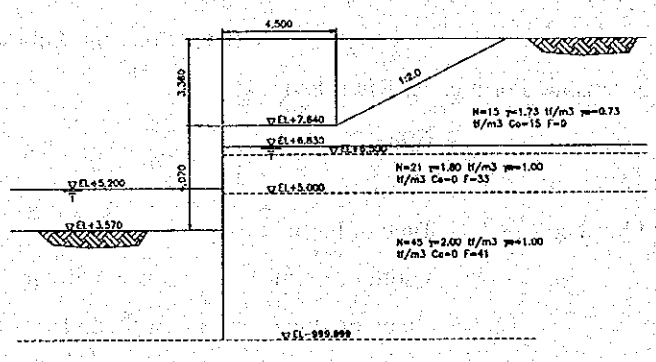
Allowable Deformation at Pile Head

: Normal 5.0 cm、Earthquake 7.5 cm

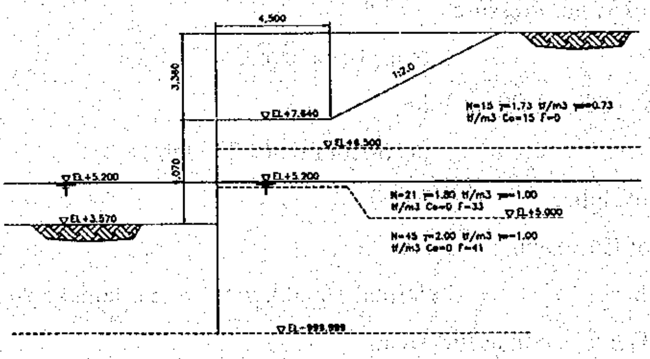
(4) Soil Condition

No	Elevation	Thick-ness	Avg. N-Value	Unit Weight			Internal Friction Angle	Cohesion	Horizontal K Value
				Wet	Sat.	Sub.			
	m	m		γ t/m^3	γ t/m^3	γ t/m^3	ϕ (°)	Co	K
1	7.640 6.500	1.140	15.0	1.73	1.73	0.73	0.0	15.000	2.07
2	6.500 5.000	1.500	21.0	1.80	2.00	1.00	33.0	0.000	2.38
3	5.000 -999.999	1005.000	45.0	2.00	2.00	1.00	41.0	0.000	3.24

【Normal Case】



【Seismic Case】



2 . Load Calculation

(1) Formula of Soil Pressure

1) Sandy Soil : Active Soil Pressure

$$P_a = K_a \cdot \left(\sum \gamma h + \frac{q_a}{\cos \beta_a} \right) - 2 \cdot C \cdot \sqrt{K_a}$$

Where:

P_a	: Strength of Active Soil Pressure	(t/m^2)
K_p	: Coefficient of Active Soil Pressure	
γ	: Unit Weight of Soil	(t/m^3)
h	: Thickness of Layer	(m)
q_a	: Active Load	(t/m^2)
β_a	: Angle between G-Surface and Level Surface	(°)
C	: Cohesive	(t/m^2)

$$K_a = \frac{\cos(\phi - \theta) \cdot \cos \sigma}{\cos \theta \cdot \cos(\sigma + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi + \sigma) \cdot \sin(\phi - \beta_a - \theta)}{\cos(\sigma + \theta) \cdot \cos \beta_a}} \right)}$$

Where:

ϕ : Internal Friction Angle (°)

θ : Active Angle of Seismic Force (°)、 $\theta = \tan^{-1}(K_h)$、

K_h : Horizontal Seismic Degree

δ : Friction Angle between Soil and Wall (°)

2) Sandy Soil : Passive Soil Pressure

$$P_p = K_p \cdot \left(\sum \gamma h + \frac{q_p}{\cos \beta_p} \right) + 2 \cdot C \cdot \sqrt{K_p}$$

Where:

P_p	: Strength of Passive Soil Pressure	(t/m^2)
K_p	: Coefficient of Passive Soil Pressure	
γ	: Unit Weight of Soil	(t/m^3)
h	: Thickness of Layer	(m)
q_p	: Active Load	(t/m^2)
C	: Cohesive	(t/m^2)
β_p	: Angle between G-Surface and Level Surface	(°)

$$K_p = \frac{\cos(\phi - \theta) \cdot \cos \sigma}{\cos \theta \cdot \cos(\sigma + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi + \sigma) \cdot \sin(\phi - \beta_p - \theta)}{\cos(\sigma + \theta) \cdot \cos \beta_p}} \right)}$$

Where:

ϕ : Internal Friction Angle (°)

θ : Active Angle of Seismic Force (°)、 $\theta = \tan^{-1}(K_h)$、

K_h : Horizontal Seismic Degree

δ : Friction Angle between Soil and Wall (°)

(2) Load Calculation (Normal Condition)

Depth of embedment of PC sheet pile shall be installed in depth balancing active pressure side with passive pressure side.

Estimating length of PC sheet pile at 8.5 m, balance of moment is considered.

1) Soil Pressure & Water Pressure

【Normal · Active】

q = 0.00 t/m²

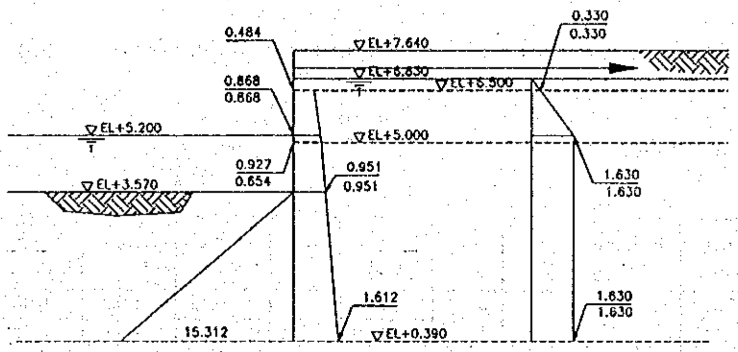
No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σ γ h t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500	173	0.0	15.0	0.0	0.00	1.000	0.000	0.000	0.000
	7.140				15.0		0.00	1.000	0.865	0.000	0.000
2	7.140	0.310	1.73	0.0	15.0	0.0	0.00	1.000	0.865	0.000	0.000
	6.830				15.0		0.00	1.000	1.401	0.000	0.000
3	6.830	0.330	0.73	0.0	15.0	0.0	0.00	1.000	1.401	0.000	0.000
	6.500				15.0		0.00	1.000	1.642	0.000	0.330
4	6.500	1.300	1.00	33.0	0.0	0.0	0.00	0.295	1.642	0.484	0.330
	5.200				0.0		0.00	0.295	2.942	0.868	1.630
5	5.200	0.200	1.00	33.0	0.0	0.0	0.00	0.295	2.942	0.868	1.630
	5.000				0.0		0.00	0.295	3.142	0.927	1.830
6	5.000	1.430	1.00	41.0	0.0	0.0	0.00	0.208	3.142	0.654	1.830
	3.570				0.0		0.00	0.208	4.572	0.951	3.260
7	3.570	3.180	1.00	41.0	0.0	0.0	0.00	0.208	4.572	0.951	3.260
	0.390				0.0		0.00	0.208	7.752	1.612	6.440

【Normal · Passive】

q = 0.00 t／m²

No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σ γ h t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500									
	7.140										
2	7.140	0.310									
	6.830										
3	6.830	0.330									
	6.500										
4	6.500	1.300									
	5.200										
5	5.200	0.200									0.000
	5.000										0.200
6	5.000	1.430									0.200
	3.570										1.630
7	3.570	3.180	1.00	41.0	0.0	0.0	0.00	4.815	0.000	0.000	1.630
	0.390				0.0		0.00	4.815	3.180	15.312	4.810

【Normal Case】



Moment around tie rod joint

【Normal・Active】

No.	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi ・ Yi (tf-m/m)
1	1/2×0.000×0.500=0.000	-0.500+1/3×0.500=-0.333	0.000×-0.333=0.000
	1/2×0.000×0.500=0.000	-0.500+2/3×0.500=-0.167	0.000×-0.167=0.000
2	1/2×0.000×0.310=0.000	0.000+1/3×0.310=0.000	0.000×0.000=0.000
	1/2×0.000×0.310=0.000	0.000+2/3×0.310=0.000	0.000×0.000=0.000
3	1/2×0.000×0.330=0.000	0.310+1/3×0.330=0.420	0.000×0.420=0.000
	1/2×0.330×0.330=0.054	0.310+2/3×0.330=0.530	0.054×0.530=0.029
4	1/2×0.814×1.300=0.529	0.640+1/3×1.300=1.073	0.529×1.073=0.568
	1/2×2.498×1.300=1.624	0.640+2/3×1.300=1.507	1.624×1.507=2.446
5	1/2×2.498×0.200=0.250	1.940+1/3×0.200=2.007	0.250×2.007=0.501
	1/2×2.757×0.200=0.276	1.940+2/3×0.200=2.073	0.276×2.073=0.572
6	1/2×2.484×1.430=1.776	2.140+1/3×1.430=2.617	1.776×2.617=4.647
	1/2×4.211×1.430=3.011	2.140+2/3×1.430=3.093	3.011×3.093=9.314
7	1/2×4.211×3.180=6.695	3.570+1/3×3.180=4.630	6.695×4.630=31.000
	1/2×8.052×3.180=12.803	3.570+2/3×3.180=5.690	12.803×5.690=72.847
Total			Ma = 121.924

【Normal・Passive】

No.	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi ・ Yi (tf-m/m)
1	1/2×0.000×0.500=0.000	-0.500+1/3×0.500=-0.333	0.000×-0.333=0.000
	1/2×0.000×0.500=0.000	-0.500+2/3×0.500=-0.167	0.000×-0.167=0.000
2	1/2×0.000×0.310=0.000	0.000+1/3×0.310=0.000	0.000×0.000=0.000
	1/2×0.000×0.310=0.000	0.000+2/3×0.310=0.000	0.000×0.000=0.000
3	1/2×0.000×0.330=0.000	0.310+1/3×0.330=0.420	0.000×0.420=0.000
	1/2×0.000×0.330=0.000	0.310+2/3×0.330=0.530	0.000×0.530=0.000
4	1/2×0.000×1.300=0.000	0.640+1/3×1.300=1.073	0.000×1.073=0.000
	1/2×0.000×1.300=0.000	0.640+2/3×1.300=1.507	0.000×1.507=0.000
5	1/2×0.000×0.200=0.000	1.940+1/3×0.200=2.007	0.000×2.007=0.000
	1/2×0.200×0.200=0.020	1.940+2/3×0.200=2.073	0.020×2.073=0.041
6	1/2×0.200×1.430=0.143	2.140+1/3×1.430=2.617	0.143×2.617=0.374
	1/2×1.630×1.430=1.165	2.140+2/3×1.430=3.093	1.165×3.093=3.605
7	1/2×1.630×3.180=2.592	3.570+1/3×3.180=4.630	2.592×4.630=12.000
	1/2×20.122×3.180=31.994	3.570+2/3×3.180=5.690	31.994×5.690=182.046
Total			Mp = 198.066

Consideration of depth of embedment of PC sheet pile

Ma / Mp = 198.066 / 121.924 = 1.62 (Normal case: Safety factor = 1.50) ....O.K

【Seismic · Active】

q = 0.00 t/m²

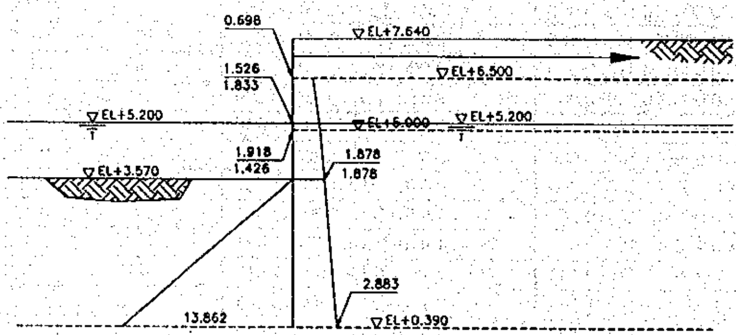
No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σγh t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500	173	0.0	15.0	0.0	0.12	1.000	0.000	0.000	0.000
	7.140				15.0		0.12	1.000	0.865	0.000	0.000
2	7.140	0.640	1.73	0.0	15.0	0.0	0.12	1.000	0.865	0.000	0.000
	6.500				15.0		0.12	1.000	1.972	0.000	0.000
3	6.500	1.300	1.80	33.0	0.0	0.0	0.12	0.354	1.972	0.698	0.000
	5.200				0.0		0.12	0.354	4.312	1.526	0.000
4	5.200	0.200	1.00	33.0	0.0	0.0	0.24	0.425	4.312	1.833	0.000
	5.000				0.0		0.24	0.425	4.512	1.918	0.200
5	5.000	1.430	1.00	41.0	0.0	0.0	0.24	0.316	4.512	1.426	0.200
	3.570				0.0		0.24	0.316	5.942	1.878	1.630
6	3.570	3.180	1.00	41.0	0.0	0.0	0.24	0.316	5.942	1.878	1.630
	0.390				0.0		0.24	0.316	9.122	2.883	4.810

【Seismic · Passive】

q = 0.00 t/m²

No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σγh t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500									
	7.140										
2	7.140	0.640									
	6.500										
3	6.500	1.300									
	5.200										
4	5.200	0.200									0.000
	5.000										0.200
5	5.000	1.430									0.200
	3.570										1.630
6	3.570	3.180	1.00	41.0	0.0	0.0	0.24	4.359	0.000	0.000	1.630
	0.390				0.0		0.24	4.359	3.180	13.862	4.810

【Seismic Case】



Moment around tie rod joint

【Seismic・Active】

No	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi・Yi (tf-m/m)
1	1/2×0.000×0.500=0.000	-0.500+1/3×0.500=-0.333	0.000×-0.333=0.000
	1/2×0.000×0.500=0.000	-0.500+2/3×0.500=-0.167	0.000×-0.167=0.000
2	1/2×0.000×0.640=0.000	0.000+1/3×0.640=0.213	0.000×0.213=0.000
	1/2×0.000×0.640=0.000	0.000+2/3×0.640=0.427	0.000×0.427=0.000
3	1/2×0.698×1.300=0.454	0.640+1/3×1.300=1.073	0.454×1.073=0.487
	1/2×1.526×1.300=0.992	0.640+2/3×1.300=1.507	0.992×1.507=1.494
4	1/2×1.833×0.200=0.183	1.940+1/3×0.200=2.007	0.183×2.007=0.368
	1/2×2.118×0.200=0.212	1.940+2/3×0.200=2.073	0.212×2.073=0.439
5	1/2×1.626×1.430=1.163	2.140+1/3×1.430=2.617	1.163×2.617=3.042
	1/2×3.508×1.430=2.508	2.140+2/3×1.430=3.093	2.508×3.093=7.759
6	1/2×3.508×3.180=5.578	3.570+1/3×3.180=4.630	5.578×4.630=25.825
	1/2×7.693×3.180=12.232	3.570+2/3×3.180=5.690	12.232×5.690=69.599
Total			Ma = 109.013

【Seismic・Passive】

No	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi・Yi (tf-m/m)
1	1/2×0.000×0.500=0.000	-0.500+1/3×0.500=-0.333	0.000×-0.333=0.000
	1/2×0.000×0.500=0.000	-0.500+2/3×0.500=-0.167	0.000×-0.167=0.000
2	1/2×0.000×0.640=0.000	0.000+1/3×0.640=0.213	0.000×0.213=0.000
	1/2×0.000×0.640=0.000	0.000+2/3×0.640=0.427	0.000×0.427=0.000
3	1/2×0.000×1.300=0.000	0.640+1/3×1.300=1.073	0.000×1.073=0.000
	1/2×0.000×1.300=0.000	0.640+2/3×1.300=1.507	0.000×1.507=0.000
4	1/2×0.000×0.200=0.000	1.940+1/3×0.200=2.007	0.000×2.007=0.000
	1/2×0.200×0.200=0.020	1.940+2/3×0.200=2.073	0.020×2.073=0.041
5	1/2×0.200×1.430=0.143	2.140+1/3×1.430=2.617	0.143×2.617=0.374
	1/2×1.630×1.430=1.165	2.140+2/3×1.430=3.093	1.165×3.093=3.605
6	1/2×1.630×3.180=2.592	3.570+1/3×3.180=4.630	2.592×4.630=12.000
	1/2×18.672×3.180=29.689	3.570+2/3×3.180=5.690	29.689×5.690=168.927
Total			Mp = 184.948

Consideration of depth of embedment of PC sheet pile

Ma / Mp = 184.948 / 109.013 = 1.70 (Seismic case: Safety factor = 1.20)............O.K

Therefore, it is adopted that length of PC sheet pile is 8.50 m.

3. Stress Calculation of PC Sheet Pile

Balance point that depend on active pressure and passive pressure is estimated fulcurm.

In structural calculation of PC sheet pile, sheet pile is regarded as simple beam between tie rod joint and estimated fulcrum.

Calculations of earth pressure and water pressure

【Normal・Active】

q = 0.00 t/m²

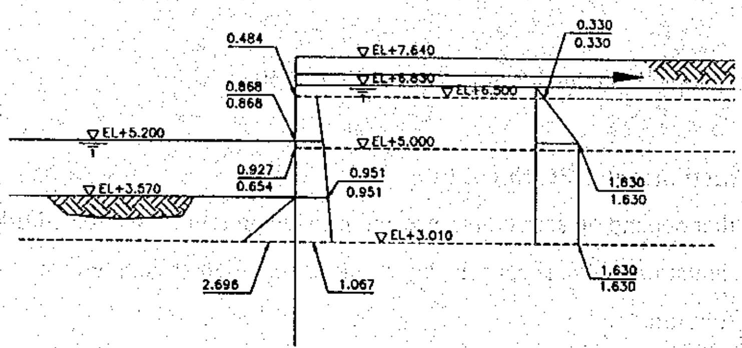
No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σγh t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500	173	0.0	15.0	0.0	0.00	1.000	0.000	0.000	0.000
	7.140				15.0		0.00	1.000	0.865	0.000	0.000
2	7.140	0.310	1.73	0.0	15.0	0.0	0.00	1.000	0.865	0.000	0.000
	6.830				15.0		0.00	1.000	1.401	0.000	0.000
3	6.830	0.330	0.73	0.0	15.0	0.0	0.00	1.000	1.401	0.000	0.000
	6.500				15.0		0.00	1.000	1.642	0.000	0.330
4	6.500	1.300	1.00	33.0	0.0	0.0	0.00	0.295	1.642	0.484	0.330
	5.200				0.0		0.00	0.295	2.942	0.868	1.630
5	5.200	0.200	1.00	33.0	0.0	0.0	0.00	0.295	2.942	0.868	1.630
	5.000				0.0		0.00	0.295	3.142	0.927	1.830
6	5.000	1.430	1.00	41.0	0.0	0.0	0.00	0.208	3.142	0.654	1.830
	3.570				0.0		0.00	0.208	4.572	0.951	3.260
7	3.570	0.560	1.00	41.0	0.0	0.0	0.00	0.208	4.572	0.951	3.260
	3.010				0.0		0.00	0.208	5.132	1.067	3.820

【Normal・Passive】

q = 0.00 t／m²

No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σγh t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500									
	7.140										
2	7.140	0.310									
	6.830										
3	6.830	0.330									
	6.500										
4	6.500	1.300									
	5.200										
5	5.200	0.200									0.000
	5.000										0.200
6	5.000	1.430									0.200
	3.570										1.630
7	3.570	0.560	1.00	41.0	0.0	0.0	0.00	4.815	0.000	0.000	1.630
	3.010				0.0		0.00	4.815	0.560	2.696	2.190

【Normal Case】



Load calculation

No	Elevation El.m	Thickness m	Passive earth pressure tf/m²	Passive water pressure tf/m²	Active earth pressure tf/m²	Active water pressure tf/m²	Load tf/m²
1	7.640	0.500	0.000	0.000	0.000	0.000	0.000
	7.140		0.000	0.000	0.000	0.000	0.000
2	7.140	0.310	0.000	0.000	0.000	0.000	0.000
	6.830		0.000	0.000	0.000	0.000	0.000
3	6.830	0.330	0.000	0.000	0.000	0.000	0.000
	6.500		0.000	0.000	0.000	0.330	0.330
4	6.500	1.300	0.000	0.000	0.484	0.330	0.814
	5.200		0.000	0.000	0.868	1.630	2.498
5	5.200	0.200	0.000	0.000	0.868	1.630	2.498
	5.000		0.000	0.200	0.927	1.830	2.557
6	5.000	1.430	0.000	0.200	0.654	1.830	2.284
	3.570		0.000	1.630	0.951	3.260	2.581
7	3.570	0.560	0.000	1.630	0.951	3.260	2.581
	3.010		2.696	2.190	1.067	3.820	0.001

Load = (Active earth pressure + Active water Pressure) – (Passive earth pressure + Passive water pressure)

Maximum bending moment of PC sheet pile

No	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi · Yi (tf-m/m)
2	1/2×0.000×0.310=0.000	0.000+1/3×0.310=0.000	0.000×0.000=0.000
	1/2×0.000×0.310=0.000	0.000+2/3×0.310=0.000	0.000×0.000=0.000
3	1/2×0.000×0.330=0.000	0.310+1/3×0.330=0.420	0.000×0.420=0.000
	1/2×0.330×0.330=0.054	0.310+2/3×0.330=0.530	0.054×0.530=0.029
4	1/2×0.814×1.300=0.529	0.640+1/3×1.300=1.073	0.529×1.073=0.568
	1/2×2.498×1.300=1.624	0.640+2/3×1.300=1.507	1.624×1.507=2.446
5	1/2×2.498×0.200=0.250	1.940+1/3×0.200=2.007	0.250×2.007=0.501
	1/2×2.557×0.200=0.256	1.940+2/3×0.200=2.073	0.256×2.073=0.530
6	1/2×2.284×1.430=1.633	2.140+1/3×1.430=2.617	1.633×2.617=4.273
	1/2×2.581×1.430=1.845	2.140+2/3×1.430=3.093	1.845×3.093=5.708
7	1/2×2.581×0.560=0.723	3.570+1/3×0.560=3.757	0.723×3.757=2.715
	1/2×0.001×0.560=0.000	3.570+2/3×0.560=3.943	0.000×3.943=0.001
Total	ΣQ = 6.914		Ma = 16.772

Ma = 16.772 tf-m/m

Rb = Ma / L

Where

Rb: Reaction force at estimated fulcrum (tf/m)

Ma: Moment at estimated fulcrum (tf-m/m)

L: Length of beam between tie rod joint and estimated fulcrum (m)

$$Rb = {}^{16.772}\!/_{4.130} = 4.061 \text{ tf/m}$$

Ra = ΣQ – Rb

Where

Ra: Reaction force at tie rod joint (tf/m)

Q: Resultant Force (tf/m)

Rb: Reaction force at estimated fulcrum (tf/m)

Ra = 6.914 – 4.061 = 2.853 tf/m

Position (X0) where shearing stress is 0 tf/m is calculated. And bending moment is the maximum about PC sheet pile in the position.

X0 = EL+4.939 m

Mmax = 4.379 tf-m/m

Max. Bending Moment Mmax		Allowable cracking moment
4.379 t·m/m	>	13.20 tf-m/m ← OK

Calculations of earth pressure and water pressure

【Seismic · Active】

q = 0.00 t/m²

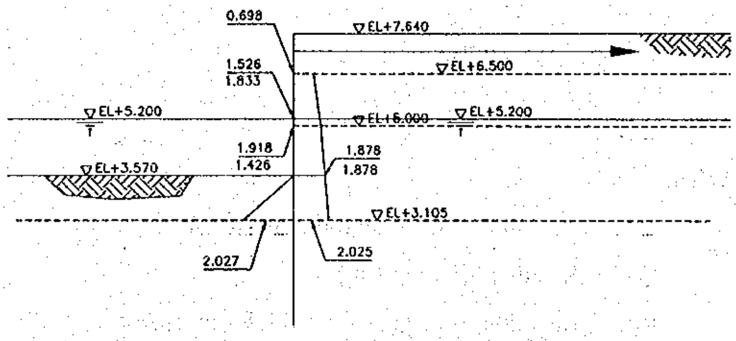
No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σ γ h t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500	173	0.0	15.0	0.0	0.12	1.000	0.000	0.000	0.000
	7.140				15.0		0.12	1.000	0.865	0.000	0.000
2	7.140	0.640	1.73	0.0	15.0	0.0	0.12	1.000	0.865	0.000	0.000
	6.500				15.0		0.12	1.000	1.972	0.000	0.000
3	6.500	1.300	1.80	33.0	0.0	0.0	0.12	0.354	1.972	0.698	0.000
	5.200				0.0		0.12	0.354	4.312	1.526	0.000
4	5.200	0.200	1.00	33.0	0.0	0.0	0.24	0.425	4.312	1.833	0.000
	5.000				0.0		0.24	0.425	4.512	1.918	0.200
5	5.000	1.430	1.00	41.0	0.0	0.0	0.24	0.316	4.512	1.426	0.200
	3.570				0.0		0.24	0.316	5.942	1.878	1.630
6	3.570	0.465	1.00	41.0	0.0	0.0	0.24	0.316	5.942	1.878	1.630
	3.105				0.0		0.24	0.316	6.407	2.025	2.095

【Seismic · Passive】

q = 0.00 t／m²

No	Elevation El.m	Thickness m	γ t/m³	φ °	c t/m³	δ °	Seismic Degree	Ka	Σ γ h t/m³	Soil P. t/m³	Water P. t/m³
1	7.640	0.500									
	7.140										
2	7.140	0.640									
	6.500										
3	6.500	1.300									
	5.200										
4	5.200	0.200									0.000
	5.000										0.200
5	5.000	1.430									0.200
	3.570										1.630
6	3.570	0.465	1.00	41.0	0.0	0.0	0.24	4.359	0.000	0.000	1.630
	3.105				0.0		0.24	4.359	0.465	2.027	2.095

【Seismic Case】



Load calculation

No	Elevation El.m	Thickness m	Passive earth pressure tf/m²	Passive water pressure tf/m²	Active earth pressure tf/m²	Active water pressure tf/m²	Load tf/m²
1	7.640	0.500	0.000	0.000	0.000	0.000	0.000
	7.140		0.000	0.000	0.000	0.000	0.000
2	7.140	0.640	0.000	0.000	0.000	0.000	0.000
	6.500		0.000	0.000	0.000	0.000	0.000
3	6.500	1.300	0.000	0.000	0.698	0.000	0.698
	5.200		0.000	0.000	1.526	0.000	1.526
4	5.200	0.200	0.000	0.000	1.833	0.000	1.833
	5.000		0.000	0.200	1.918	0.200	1.918
5	5.000	1.430	0.000	0.200	1.426	0.200	1.426
	3.570		0.000	1.630	1.878	1.630	1.878
6	3.570	0.465	0.000	1.630	1.878	1.630	1.878
	3.105		2.027	2.095	2.025	2.095	-0.002

Load = (Active earth pressure + Active water Pressure) – (Passive earth pressure + Passive water pressure)

Maximum bending moment of PC sheet pile

No	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi · Yi (tf-m/m)
2	1/2×0.000×0.640=0.000	0.000+1/3×0.640=0.213	0.000×0.213=0.000
	1/2×0.000×0.640=0.000	0.000+2/3×0.640=0.427	0.000×0.640=0.000
3	1/2×0.698×1.300=0.454	0.640+1/3×1.300=1.073	0.454×1.073=0.487
	1/2×1.526×1.300=0.992	0.640+2/3×1.300=1.507	0.992×1.507=1.494
4	1/2×1.833×0.200=0.183	1.940+1/3×0.200=2.007	0.183×2.007=0.368
	1/2×1.918×0.200=0.192	1.940+2/3×0.200=2.073	0.192×2.073=0.398
5	1/2×1.426×1.430=1.020	2.140+1/3×1.430=2.617	1.020×2.617=2.668
	1/2×1.878×1.430=1.343	2.140+2/3×1.430=3.093	1.343×3.093=4.154
6	1/2×1.878×0.465=0.437	3.570+1/3×0.465=3.725	0.437×3.725=1.626
	1/2×-0.002×0.465=0.000	3.570+2/3×0.465=3.880	0.000×3.880=0.000
Total	ΣQ = 4.621		Ma = 11.193

Ma = 11.193 tf-m/m

Rb = Ma / L

Where

Rb: Reaction force at estimated fulcrum (tf/m)

Ma: Moment at estimated fulcrum (tf-m/m)

L: Length of beam between tie rod joint and estimated fulcrum (m)

$Rb = 11.193/4.035 = 2.774$ tf/m

Ra = ΣQ – Rb

Where

Ra: Reaction force at tie rod joint (tf/m)

Q: Resultant Force (tf/m)

Rb: Reaction force at estimated fulcrum (tf/m)

Ra = 4.619 – 2.774 = 1.845 tf/m

Position (X0) where shearing stress is 0 tf/m is calculated. And bending moment is the maximum about PC sheet pile in the position.

X0 = EL+4.983 m

Mmax = 2.800 tf-m/m

Max. Bending Moment Mmax		Allowable cracking moment
2.800 t·m/m	>	13.20 tf-m/m ← OK

4. Stress Calculation of Tie Rod Rope

Extension of tie rod rope

【Normal Case】

No	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi · Yi (tf-m/m)
1	1/2×0.000×0.500=0.000	-0.500+1/3×0.500=4.463	0.000×4.463=0.000
	1/2×0.000×0.500=0.000	-0.500+2/3×0.500=4.297	0.000×4.297=0.000
2	1/2×0.000×0.310=0.000	0.000+1/3×0.310=4.027	0.000×4.027=0.000
	1/2×0.000×0.310=0.000	0.000+2/3×0.310=3.923	0.000×3.923=0.000
3	1/2×0.000×0.330=0.000	0.310+1/3×0.330=3.710	0.000×3.710=0.000
	1/2×0.330×0.330=0.054	0.310+2/3×0.330=3.600	0.054×3.600=0.196
4	1/2×0.814×1.300=0.529	0.640+1/3×1.300=3.057	0.529×3.057=1.617
	1/2×2.498×1.300=1.624	0.640+2/3×1.300=2.623	1.624×2.623=4.260
5	1/2×2.498×0.200=0.250	1.940+1/3×0.200=2.123	0.250×2.123=0.530
	1/2×2.557×0.200=0.256	1.940+2/3×0.200=2.057	0.256×2.057=0.526
6	1/2×2.284×1.430=1.633	2.140+1/3×1.430=1.513	1.633×2.617=2.471
	1/2×2.581×1.430=1.845	2.140+2/3×1.430=1.037	1.845×3.093=1.913
7	1/2×2.581×0.560=0.723	3.570+1/3×0.560=0.373	0.723×0.373=0.270
	1/2×0.001×0.560=0.000	3.570+2/3×0.560=0.187	0.000×0.187=0.000
Total	ΣQ = 6.914		Ma = 11.783

Ma = 11.783 tf-m/m

Ra = Ma / L

Where

Ra: Reaction force at estimated fulcrum (tf/m)

Ma: Moment at estimated fulcrum (tf-m/m)

L: Length of beam between tie rod joint and estimated fulcrum (m)

$$Ra = {11.783}/{4.130} = 2.853 \text{ tf/m}$$

T = Ra×L

Where

Ra: Reaction force at tie rod joint (tf/m)

L: Interval of tie rod (m)

T = 2.853×2.00 = 5.706 tf/rope

Stress calculation of tie rod rope

Tie rod rope (SS41 or equivalent ϕ =32 mm) is adopted.

$$\sigma = \frac{T}{\pi/4 \times (\Phi - 2 \times t)^2}$$

Where

T: Extension force of tie rod (kgf/rope)

ϕ: Diameter of tie rod rope (cm)

t: Corrosion width (cm)

$$\sigma = \frac{5706}{\pi/4 \times (3.2 - 2 \times 0.1)^2} = 807 \text{ kgf/cm}^2$$

$\leq$ 900 kgf/cm² (Allowable capacity).. O.K

【Seismic Case】

No	Resultant Force Pi t f/m	Distance from joint point to Pi Yi m	Moment around tie rod joint Mi = Pi · Yi (tf-m/m)
1	1/2×0.000×0.500=0.000	-0.500+1/3×0.500=4.368	0.000×4.368=0.000
	1/2×0.000×0.500=0.000	-0.500+2/3×0.500=4.202	0.000×4.202=0.000
2	1/2×0.000×0.640=0.000	0.000+1/3×0.640=3.822	0.000×3.822=0.000
	1/2×0.000×0.640=0.000	0.000+2/3×0.640=3.608	0.000×3.608=0.000
3	1/2×0.698×1.300=0.454	0.640+1/3×1.300=2.962	0.454×2.962=1.344
	1/2×1.526×1.300=0.992	0.640+2/3×1.300=2.528	0.992×2.528=2.508
4	1/2×1.833×0.200=0.183	1.940+1/3×0.200=2.028	0.183×2.028=0.372
	1/2×1.918×0.200=0.192	1.940+2/3×0.200=1.962	0.192×1.962=0.376
5	1/2×1.426×1.430=1.020	2.140+1/3×1.430=1.418	1.020×1.418=1.446
	1/2×1.878×1.430=1.343	2.140+2/3×1.430=0.942	1.343×0.942=1.264
6	1/2×1.878×0.465=0.437	3.570+1/3×0.465=0.310	0.437×0.310=0.135
	1/2×-0.002×0.465=0.000	3.570+2/3×0.465=0.155	0.000×3.155=0.000
Total	ΣQ = 4.621		Ma = 7.445

Ma = 7.445 tf-m/m

Ra = Ma / L

Where

Ra: Reaction force at estimated fulcrum (tf/m)

Ma: Moment at estimated fulcrum (tf-m/m)

L: Length of beam between tie rod joint and estimated fulcrum (m)

$Ra = {}^{7.445}\!/_{4.035} = 1.845$ tf/m

$T = Ra \times L$

Where

Ra: Reaction force at tie rod joint (tf/m)

L: Interval of tie rod (m)

$T = 1.845 \times 2.00 = 3.690$ tf/rope

Stress calculation of tie rod rope

Tie rod rope (SS41 or equivalent ϕ =32 mm) is adopted.

$$\sigma = \frac{T}{\pi/4 \times (\Phi - 2 \times t)^2}$$

Where

T: Extension force of tie rod (kgf/rope)

ϕ: Diameter of tie rod rope (cm)

t: Corrosion width (cm)

$$\sigma = \frac{3690}{\pi/4 \times (3.2 - 2 \times 0.1)^2} = 522 \text{ kgf/cm}^2$$

$\leqq$ 1350 kgf/cm² (Allowable capacity)...................................... O.K

5. Stress Calculation of Waling

Waling is regarded as single beam between tie rod joint and estimated fulcrum.

$$M = T/4 \times L$$

Where

M: Bending moment toward waling (tf-m)

T: Extension stress of tie rod (tf/rope)

L: Interval tie rod rope (m)

【Normal Case】

$M = {}^{5.706}\!/_{4} \times 2.00 \qquad = 2.853$ tf-m

$\sigma = {}^{M}\!/_{Z}$

Where

σ	Bending stress of waling (kgf/cm^2)
M:	Bending moment toward waling (tf-m)
Z:	modulus of elasticity (cm^3)

U shape steel beam (2[150×75×6.5×10) for waling is adopted.

$\sigma = {}^{2.853 \times 100000}\!/_{230} \qquad = 1240$ kgf/cm^2

≦ 1400 kgf/cm^2 (Allowable capacity)....................................... O.K

【Seismic Case】

$M = {}^{3.690}\!/_{4} \times 2.00 \qquad = 1.845$ tf-m

$\sigma = {}^{M}\!/_{Z}$

Where

σ	Bending stress of waling (kgf/cm^2)
M:	Bending moment toward waling (tf-m)
Z:	Section modulus (cm^3)

U shape steel beam (2[150×75×6.5×10) for waling is adopted.

$\sigma = {}^{1.845 \times 100000}\!/_{230} \qquad = 802$ kgf/cm^2

≦ 2100 kgf/cm^2 (Allowable capacity) O.K

6. Consideration of Anchor work

Length of counterfort

Depth of embedment of counterfort is calculated with specific volume (β).

$$\beta = \sqrt[4]{\frac{kh \times B}{4EI}}$$

Where

kh:	Coefficient of horizontal subgrade reaction (kgf/cm^3)
B:	Width of member (cm)

E: modulus of elasticity (kgf/cm^2)

I: Geometrical moment of inertia (cm^4)

kh $= 0.691\ N^{0.406}$ $= 0.691\ (18)^{0.406} = 2.234\ kgf/cm^3$

N: N-volume N = 18

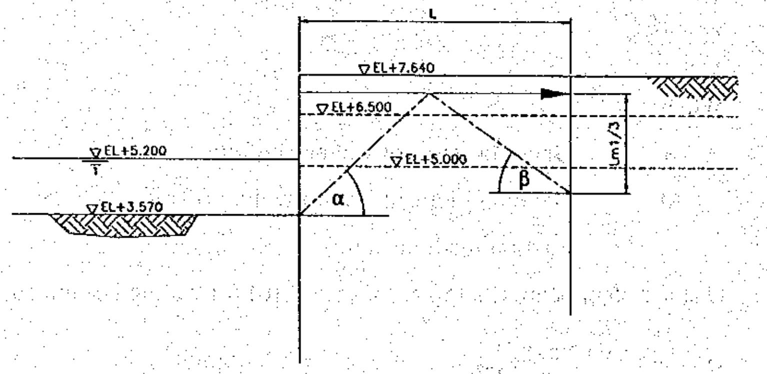
$$\beta = \sqrt[4]{\frac{2.234\times 50}{4\times 330000\times 44000}} = 6.622\times 10^{-3}\ cm^3 = 0.662\ m^{-1}$$

$$Lm1 = \pi/\beta = 3.14 / 0.662 = 4.74\ m$$

$$L = 4.74 + 0.25 = 4.99 \fallingdotseq 5.00\ m$$

Consideration of distance for counterfort

Internal friction angle $\phi°$	Wall friction angle $\delta°$		kh	Collapse angle	
	Active side	Passive side		Active side $\alpha°$	Passive side $\beta°$
33	0.00	0.00	0.00	60.00	30.00
			0.10	55.30	28.43
			0.20	49.60	26.50



【Normal Case】

$Lm1 / 3 = 4.74 / 3 = 1.58\ m$

$L1 = 3.570\times \tan 30° = 2.06$

$L2 = 1.580\times \tan 60° = 2.74$

$Ln = L1 + L2 = 2.06 + 2.74 = 4.80 \fallingdotseq 5.00\ m$

【Seismic Case】

$Lm1 / 3 = 1.58\ m$

$L1\text{-}w = 1.630\times \tan 40.4° = 1.39$

L1-L = 1.940×tan 34.7 ° = 1.34

L2 = 1.580×tan 61.57 ° = 2.92

Ls = L1-w + L1-L + L2 = 1.39 + 1.34 + 2.92 = 5.65 ≒ 6.00 m

Therefore,

It is adopted that distance for counterfort is above 6.00 m.

-Stress calculation of counterfort-

$$M \max = 0.322 \times \frac{T}{\beta}$$

Where

T: Extension stress of tie rod (tf/rope)

β: Specific volume (m^{-1})

【Normal Case】

$$M \max = 0.322 \times \frac{5.706}{0.662} = 2.775 \text{ tf-m}$$

Max. Bending Moment Mmax		Allowable cracking moment
2.775 t·m/m	≦	13.20 tf-m/m ← OK

【Seismic Case】

$$M \max = 0.322 \times \frac{3.690}{0.662} = 1.795 \text{ tf-m}$$

Max. Bending Moment Mmax		Allowable cracking moment
1.795 t·m/m	≦	13.20 tf-m/m ← OK

Displacement of counterfort

$$\delta = \frac{T}{2 \times E \times I \times \beta^3}$$

Where

T: Extension stress of tie rod (tf/rope)

β: Specific volume (m^{-1})

E: modulus of elasticity (kgf/cm^2)

I: Geometrical moment of inertia (cm^4)

【Normal Case】

$$\delta = \frac{5.706 \times 1000}{2 \times 330000 \times 44000 \times 0.006622^3} = 0.68 \text{ cm}$$

Deformation at Top of Sheet Pile $\Sigma\delta$
0.68 cm

$\leqq$ δa =5.00cm ← OK

【Seismic Case】

$$\delta = \frac{3.690\times1000}{2\times330000\times44000\times0.006622^3} = 0.44 \text{ cm}$$

Deformation at Top of Sheet Pile $\Sigma\delta$
0.44 cm

$\leqq$ δa =5.00cm ← OK