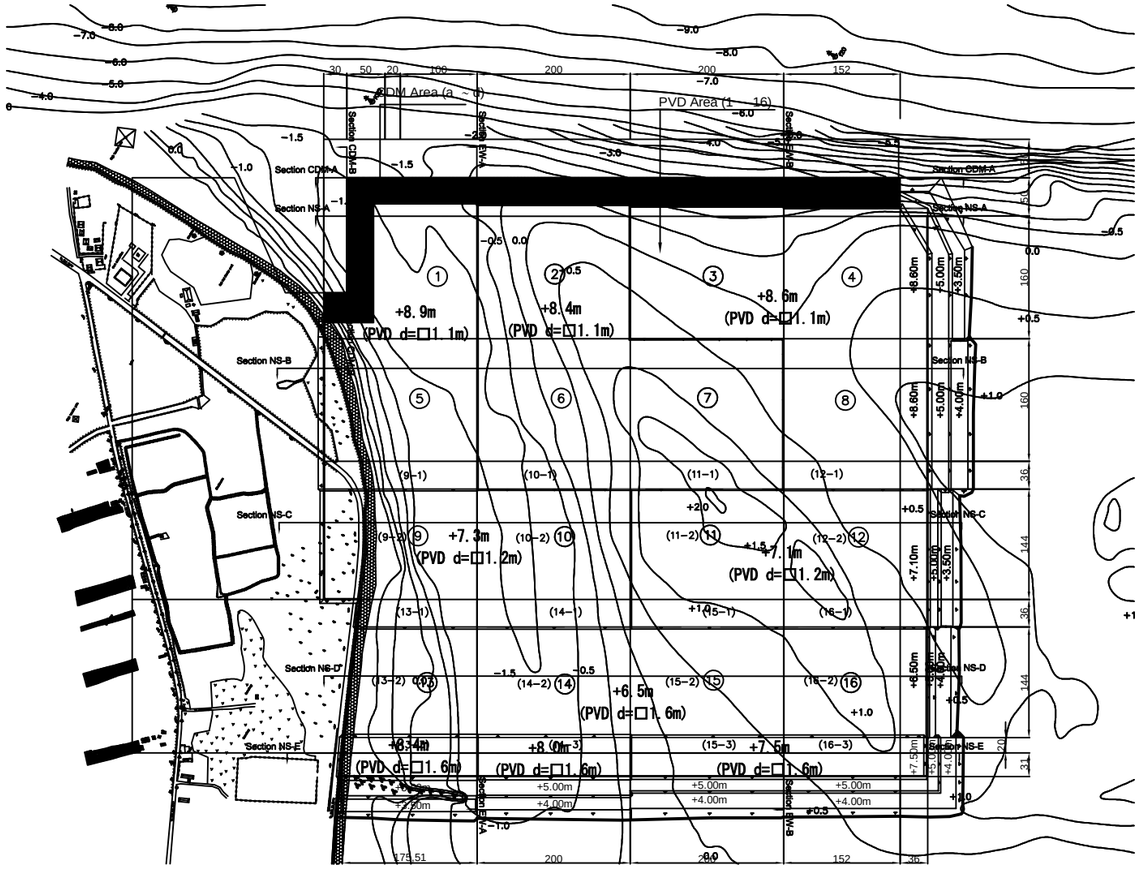
Appendix 16-1

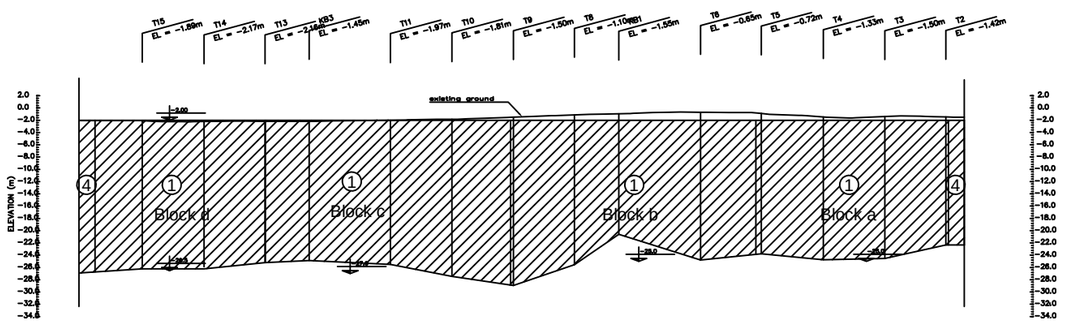
Drawings of Soil Improvement

CDM LAYOUT PLAN

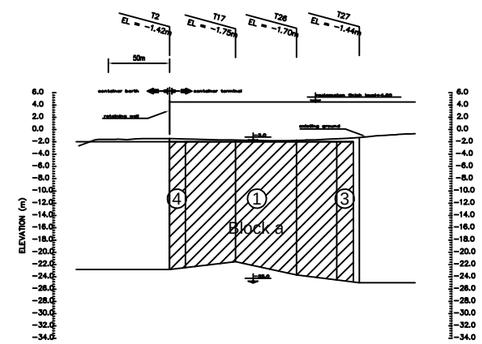
Scale: 1/8000



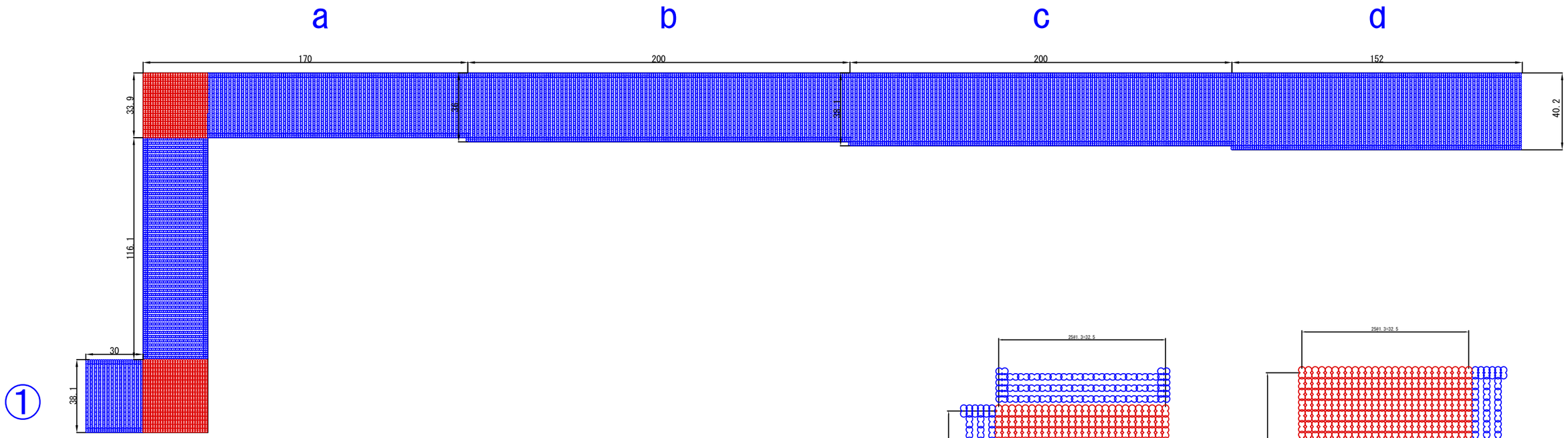
Cross Section (CDM – A)



Cross Section (CDM–B)

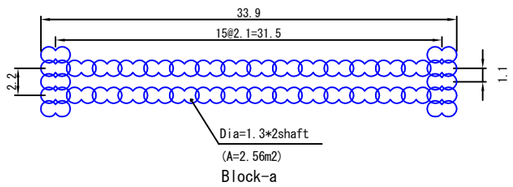


CDM DETAILED LAYOUT PLAN

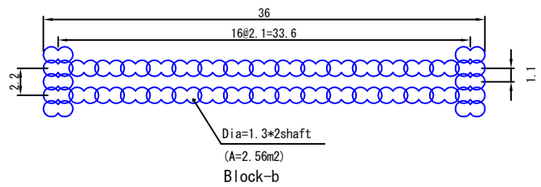


Standard Layout of CDM Piles

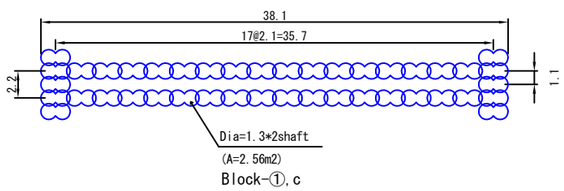
Beside Steel Sheet Pipe Pile



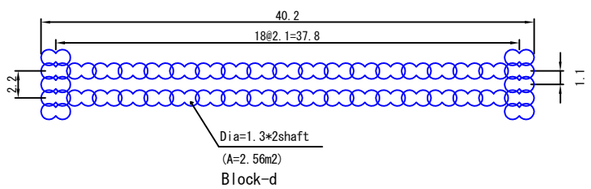
Block-a



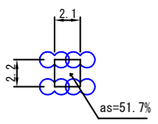
Block-b

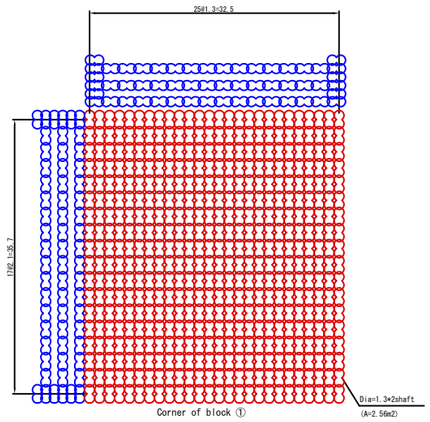


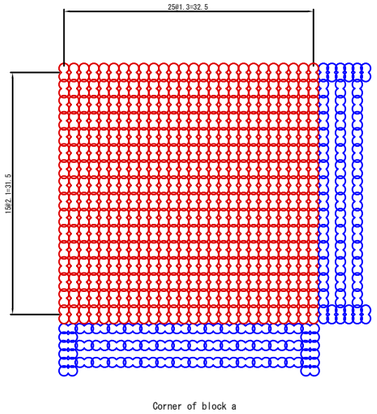
Block-①,c



Block-d







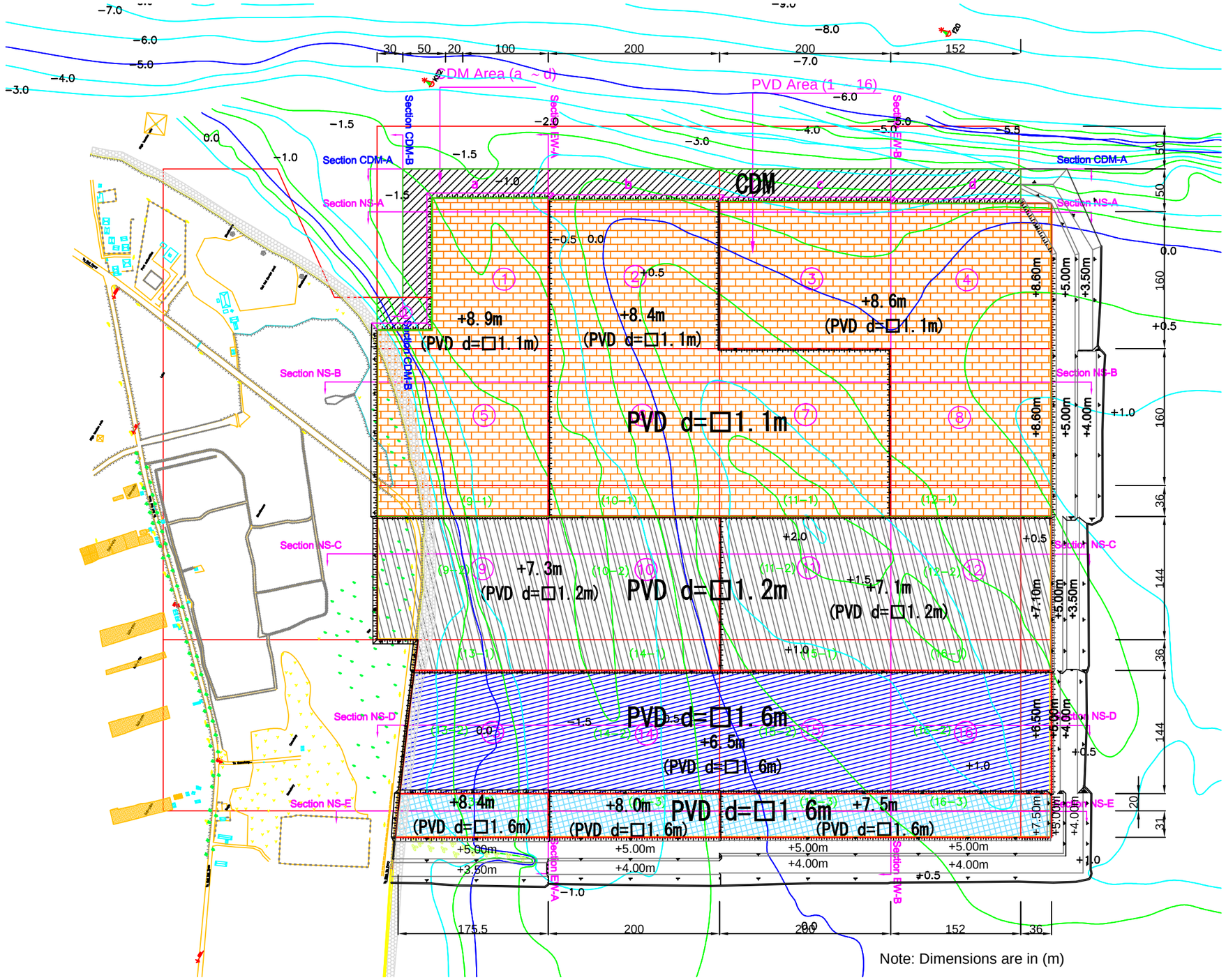
Note:

- Dimensions are in (m)

Block	Area	Length of area	Number of piles per 1m of length	Piles of improvement	Specification of improvement					Soil volume of improvement	
					Formation level	Upper end	Lower end	Length of unimprovement	Length of improvement	Part of unimprovement	Part of improvement
		(m)	(piles/m)	(piles)	CDL (m)	CDL (m)	CDL (m)	(m)	(m)	(m3)	(m3)
①		204.0	3.64	746.0	5.0	-2.0	-26.0	7.0	24.0	13,368.3	45,834.2
a		640.0	3.64	2,485.0	5.0	-2.0	-25.0	7.0	23.0	44,531.2	146,316.8
b		472.0	3.64	1,727.0	5.0	-2.0	-25.0	7.0	23.0	30,947.8	101,685.8
c		476.2	3.64	1,821.0	5.0	-2.0	-27.0	7.0	25.0	32,632.3	116,544.0
d		384.7	3.64	1,450.0	5.0	-2.0	-26.5	7.0	24.5	25,984.0	90,944.0
Total		2,176.9		8,229.0						147,463.7	501,324.8

PRELOAD LAYOUT PLAN

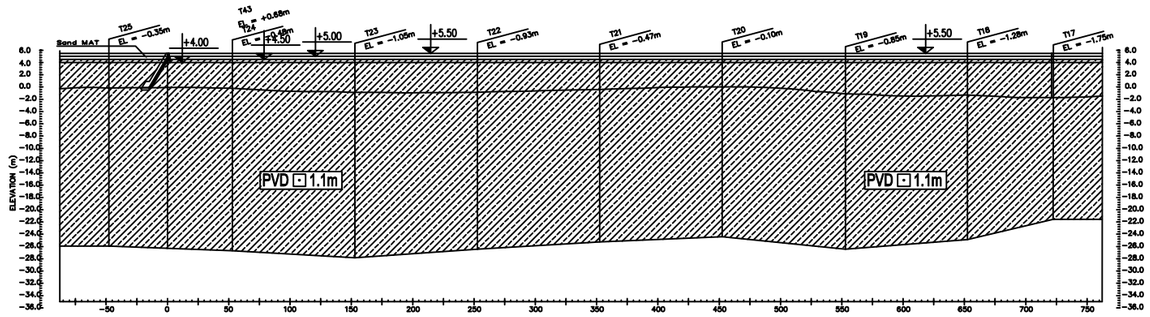
SCALE: 1/5000



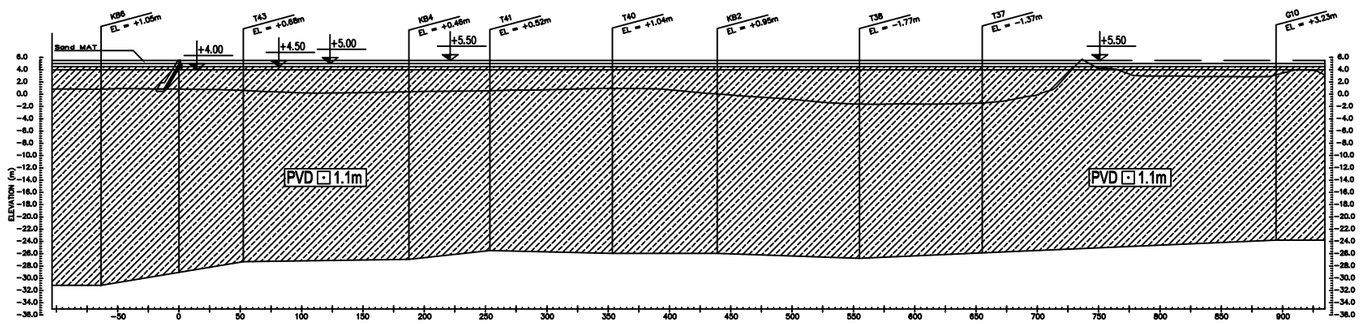
PVD CROSS SECTIONS (1/3)

Vertical scale: 1/1000
Horizontal scale: 1/5000

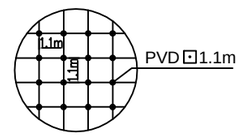
Section NS - A



Section NS - B



PVD arrangement



Note:

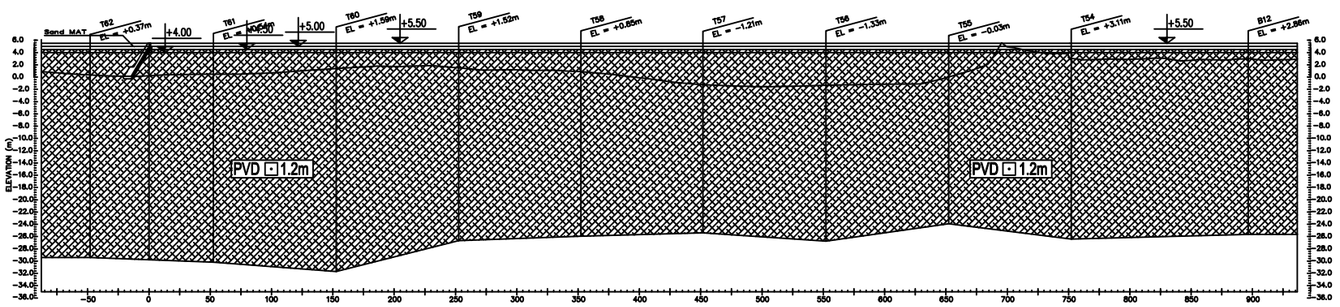
Soil improvement (PVD ⊡ 1.1m)

- Dimensions are in (m)
- Elevetions are in (m) - chart datum

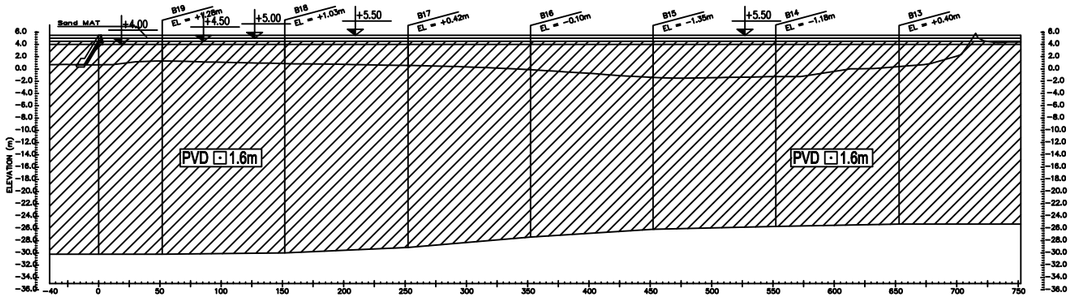
PVD CROSS SECTIONS (2/3)

Vertical scale: 1/1000
Horizontal scale: 1/5000

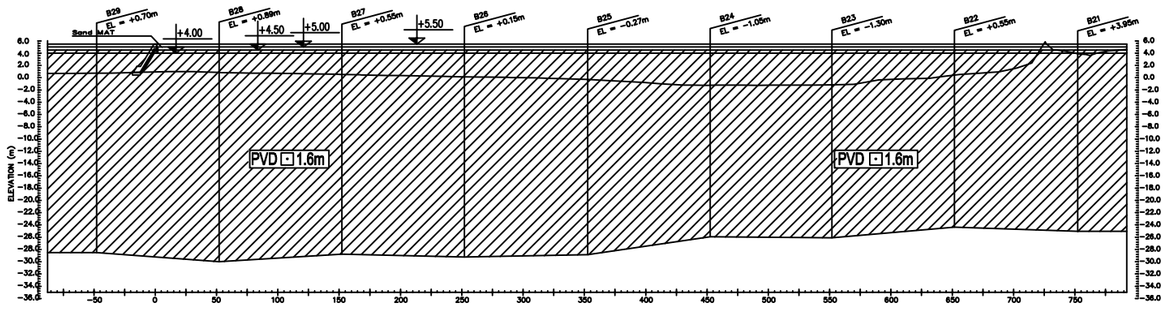
Section NS - C



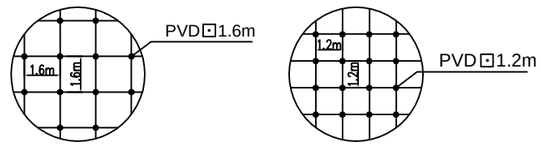
Section NS - D



Section NS - E



PVD arrangement



Note:

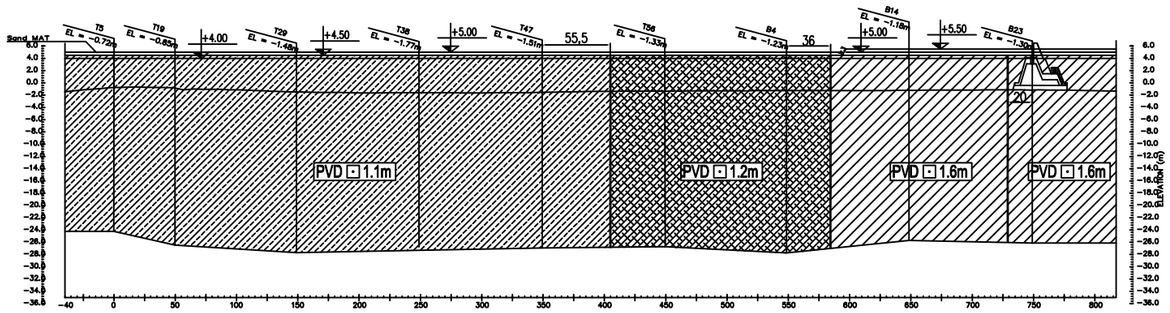
- Soil improvement (PVD ⊡1.6m)
- Soil improvement (PVD ⊡1.2m)

- Dimensions are in (m)
- Elevetions are in (m) - chart datum

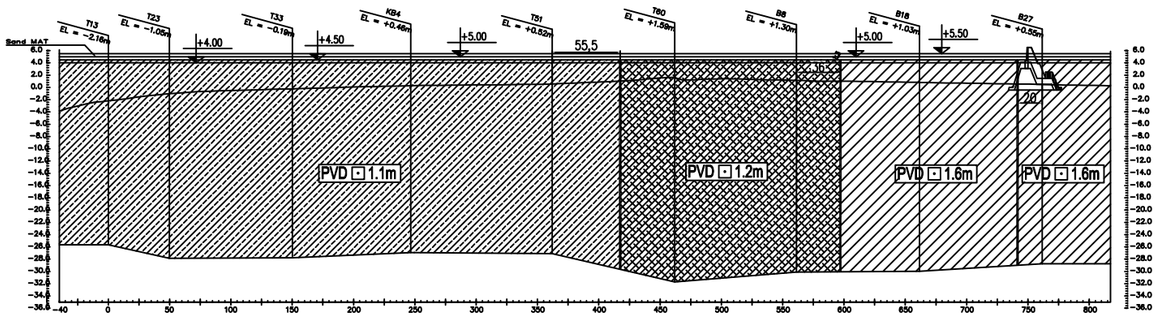
PVD CROSS SECTIONS (3/3)

Vertical scale: 1/1000
Horizontal scale: 1/5000

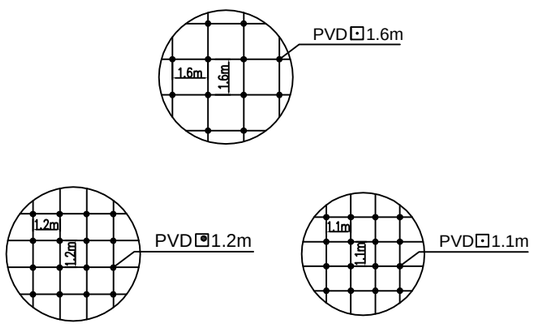
Section EW - A



Section EW - B



PVD arrangement



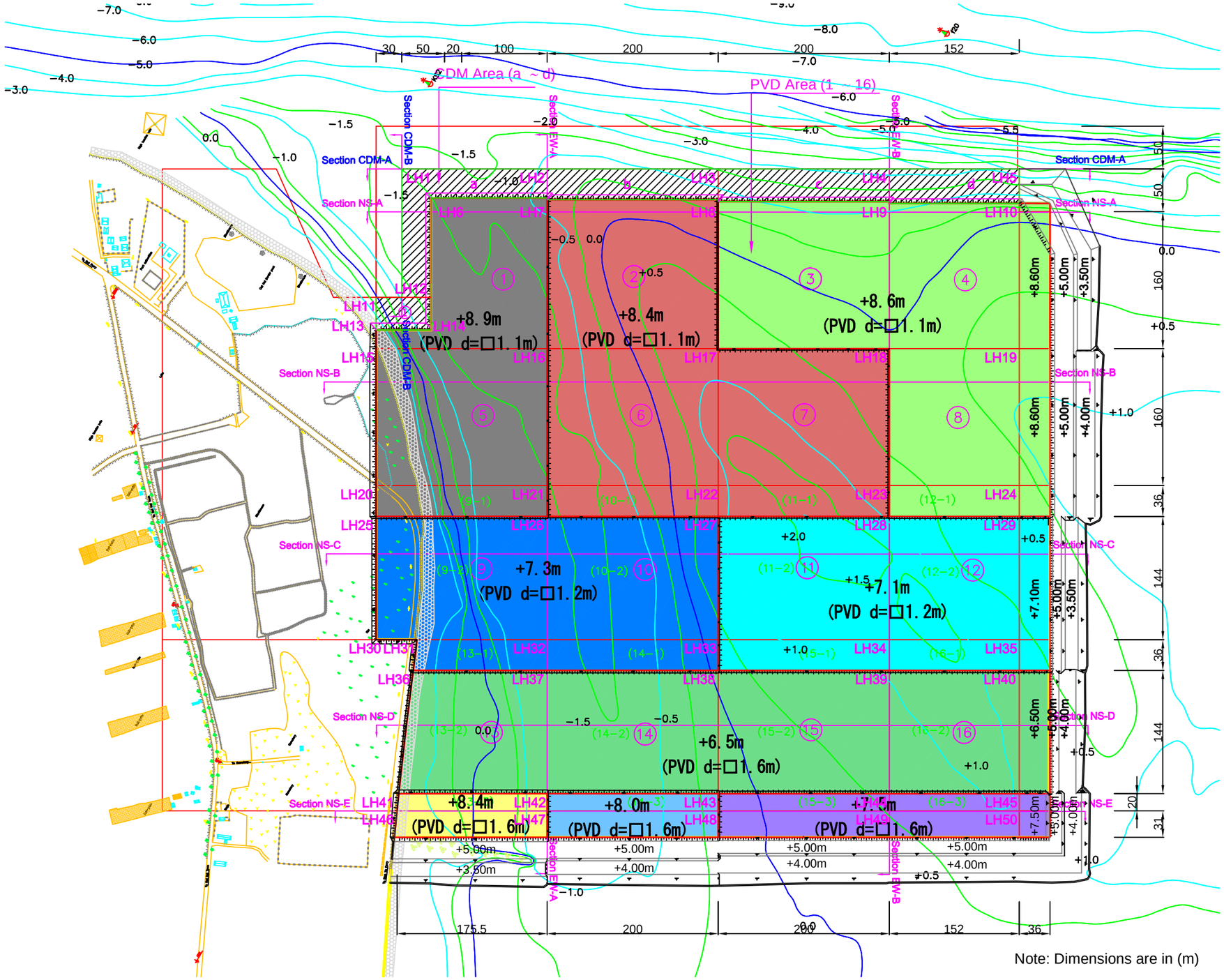
Note:

- Soil improvement (PVD ⊡1.1m)
- Soil improvement (PVD ⊡1.6m)
- Soil improvement (PVD ⊡1.2m)

- Dimensions are in (m)
- Elevetions are in (m) - chart datum

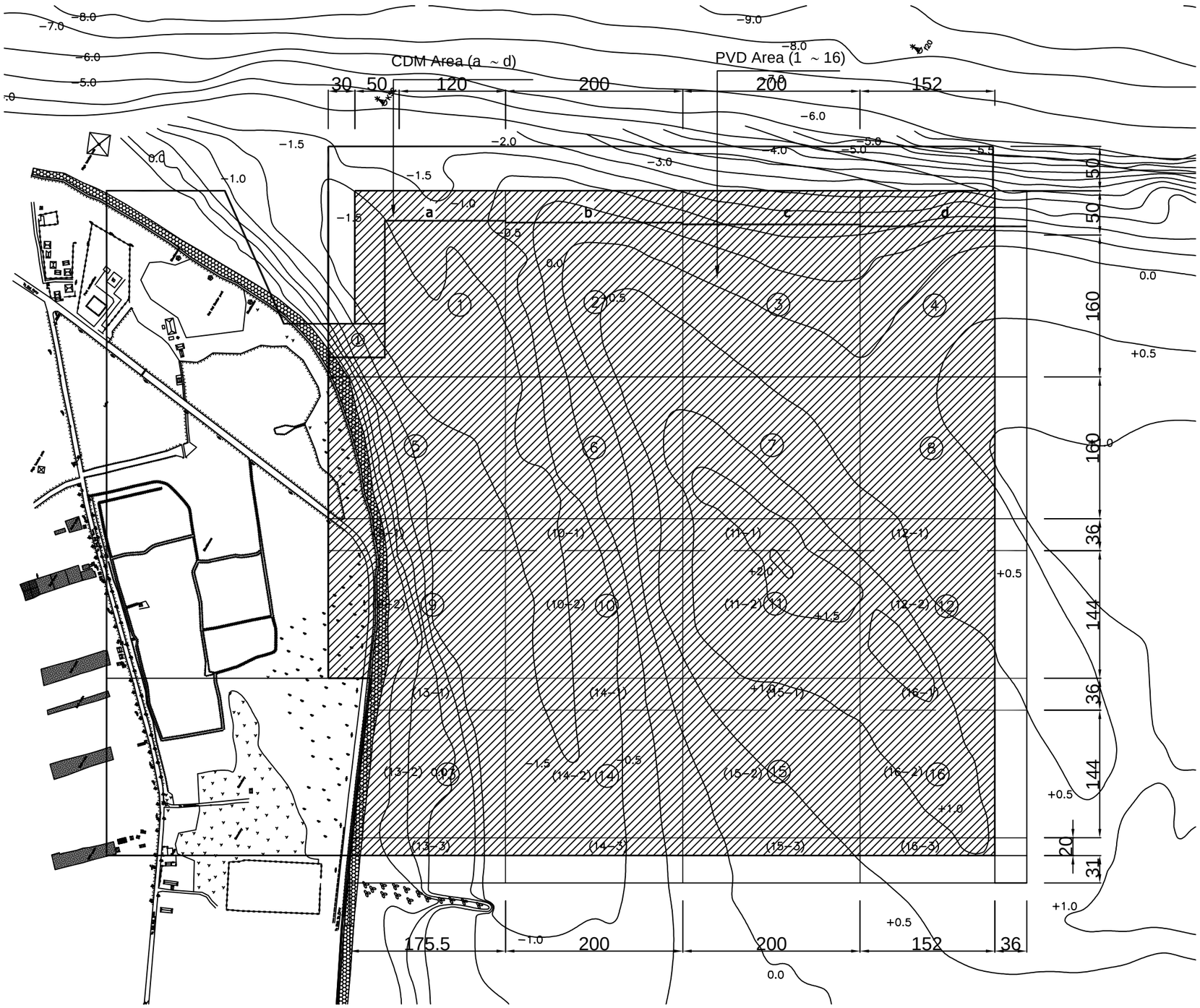
PRELOAD LAYOUT PLAN

SCALE: 1/5000



CONTROLLING POINT'S COORDINATES OF RECLAMATION AREA

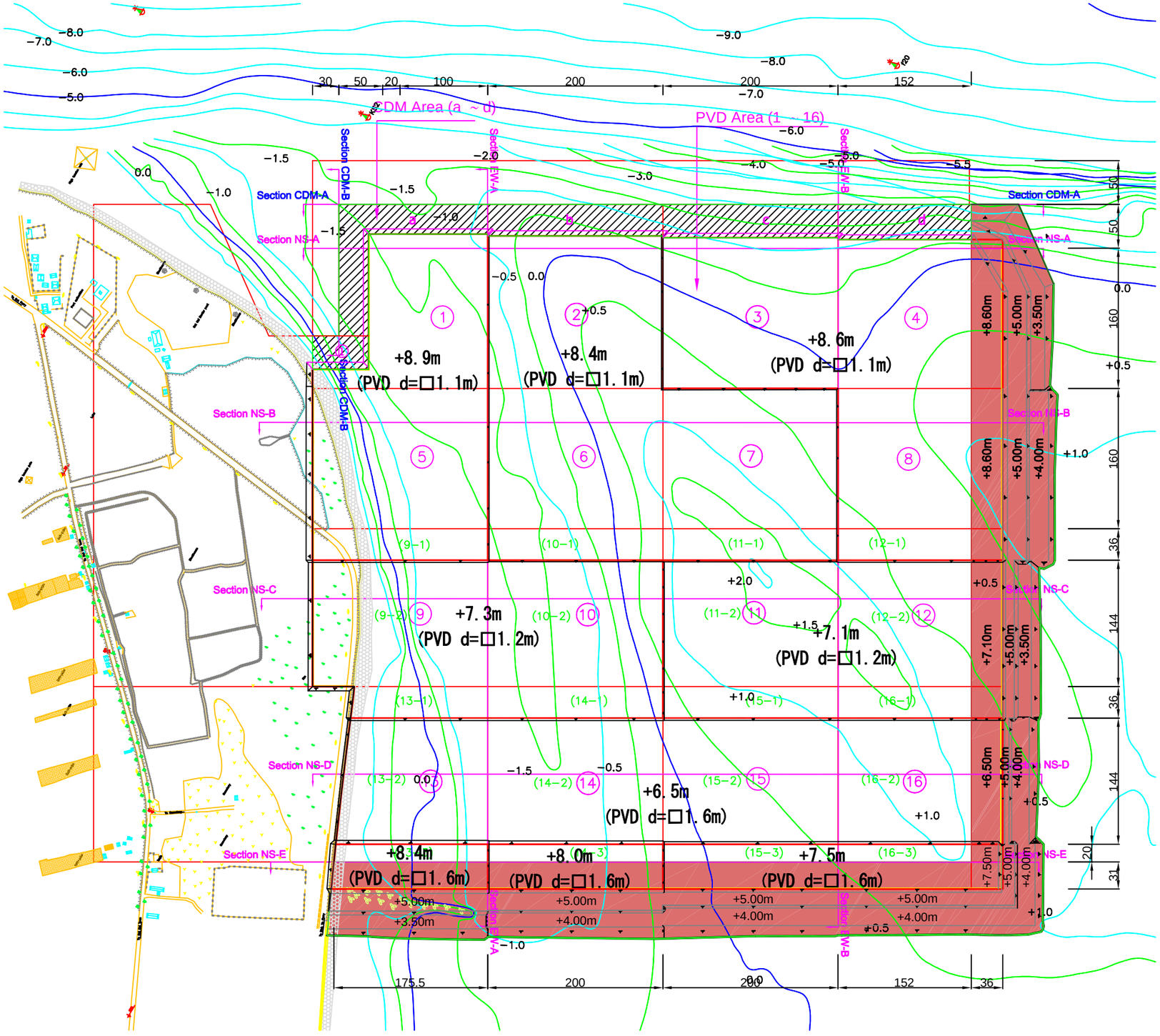
Coordinate		
Name	X	Y
LH1	620,134.700	2,301,485.748
LH2	620,221.865	2,301,339.795
LH3	620,324.413	2,301,168.086
LH4	620,426.960	2,300,996.377
LH5	620,504.896	2,300,865.878
LH6	620,122.991	2,301,439.270
LH7	620,192.774	2,301,322.422
LH8	620,293.519	2,301,149.636
LH9	620,394.263	2,300,976.850
LH10	620,470.397	2,300,845.274
LH11	619,990.536	2,301,434.594
LH12	620,005.918	2,301,408.838
LH13	619,957.836	2,301,415.072
LH14	619,990.603	2,301,360.206
LH15	619,939.021	2,301,403.834
LH16	620,041.571	2,301,232.121
LH17	620,144.118	2,301,060.411
LH18	620,246.666	2,300,888.702
LH19	620,324.602	2,300,758.203
LH20	619,801.656	2,301,321.792
LH21	619,904.204	2,301,150.083
LH22	620,006.751	2,300,978.373
LH23	620,109.298	2,300,806.664
LH24	620,187.235	2,300,676.165
LH25	619,770.748	2,301,303.333
LH26	619,873.296	2,301,131.624
LH27	619,975.843	2,300,959.915
LH28	620,078.391	2,300,788.206
LH29	620,156.327	2,300,657.707
LH30	619,647.118	2,301,229.499
LH31	619,671.583	2,301,188.534
LH32	619,749.665	2,301,057.790
LH33	619,852.213	2,300,886.081
LH34	619,954.760	2,300,714.372
LH35	620,032.696	2,300,583.873
LH36	619,638.518	2,301,173.688
LH37	619,718.758	2,301,039.331
LH38	619,821.305	2,300,867.622
LH39	619,923.853	2,300,695.913
LH40	620,001.789	2,300,565.414
LH41	619,506.218	2,301,114.369
LH42	619,595.127	2,300,965.497
LH43	619,697.675	2,300,793.788
LH44	619,800.222	2,300,622.079
LH45	619,878.158	2,300,491.580
LH46	619,487.964	2,301,105.928
LH47	619,577.956	2,300,955.242
LH48	619,680.504	2,300,783.533
LH49	619,783.051	2,300,611.824
LH50	619,860.987	2,300,481.325

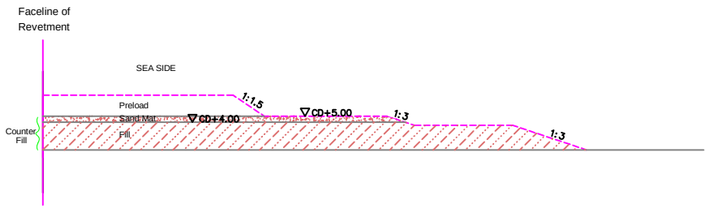


		Preload			Sand mat (CD+4.0m to +5.0m)		
		Area	Height	Quantity	Area	Height	Quantity
		(m2)	(m)	(m3)	(m2)	(m)	(m3)
CDM Area	a	9,699.5	-	-	9,699.5	1.0	9,699.5
	b	7,200.0	-	-	7,200.0	1.0	7,200.0
	c	7,611.6	-	-	7,611.6	1.0	7,611.6
	d	6,110.4	-	-	6,110.4	1.0	6,110.4
	①	2,434.8	-	-	2,434.8	1.0	2,434.8
Reclamation Area	1	25,365.7	3.9	98,926.3	25,365.7	1.0	25,365.7
	2	34,800.0	3.4	118,320.0	34,800.0	1.0	34,800.0
	3	34,388.4	3.6	123,798.3	34,388.4	1.0	34,388.4
	4	25,809.6	3.6	92,914.6	25,809.6	1.0	25,809.6
	5	32,000.0	3.9	124,800.0	32,000.0	1.0	32,000.0
	6	32,000.0	3.4	108,800.0	32,000.0	1.0	32,000.0
	7	32,000.0	3.4	108,800.0	32,000.0	1.0	32,000.0
	8	24,320.0	3.6	87,552.0	24,320.0	1.0	24,320.0
	9-1	7,200.0	3.9	28,080.0	7,200.0	1.0	7,200.0
	9-2	28,800.0	2.3	66,240.0	28,800.0	1.0	28,800.0
	10-1	7,200.0	3.4	24,480.0	7,200.0	1.0	7,200.0
	10-2	28,800.0	2.3	66,240.0	28,800.0	1.0	28,800.0
	11-1	7,200.0	3.4	24,480.0	7,200.0	1.0	7,200.0
	11-2	28,800.0	2.1	60,480.0	28,800.0	1.0	28,800.0
	12-1	5,472.0	3.6	19,699.2	5,472.0	1.0	5,472.0
	12-2	21,888.0	2.1	45,964.8	21,888.0	1.0	21,888.0
	13-1	5,551.1	2.3	12,767.4	5,551.1	1.0	5,551.1
	13-2	23,787.0	1.5	35,680.6	23,787.0	1.0	23,787.0
	13-3	3,489.3	3.4	11,863.5	3,489.3	1.0	3,489.3
	14-1	7,200.0	2.3	16,560.0	7,200.0	1.0	7,200.0
	14-2	28,800.0	1.5	43,200.0	28,800.0	1.0	28,800.0
	14-3	4,000.0	3.0	12,000.0	4,000.0	1.0	4,000.0
	15-1	7,200.0	2.1	15,120.0	7,200.0	1.0	7,200.0
	15-2	28,800.0	1.5	43,200.0	28,800.0	1.0	28,800.0
	15-3	4,000.0	2.5	10,000.0	4,000.0	1.0	4,000.0
	16-1	5,472.0	2.1	11,491.2	5,472.0	1.0	5,472.0
	16-2	21,888.0	1.5	32,832.0	21,888.0	1.0	21,888.0
	16-3	3,040.0	2.5	7,600.0	3,040.0	1.0	3,040.0
Total		552,327.3		1,451,889.8	552,327.3		552,327.3

TEMPORARY COUNTER FILL LAYOUT PLAN

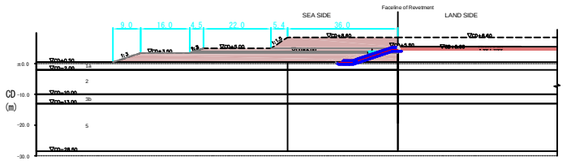
SCALE: 1/5000



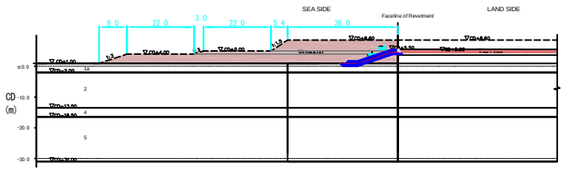


Note: Dimensions are in (m)

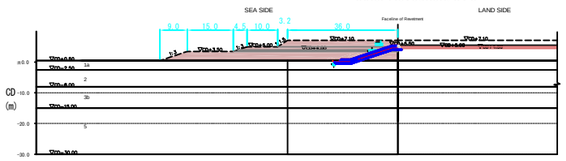
Inner Revetment IR-1



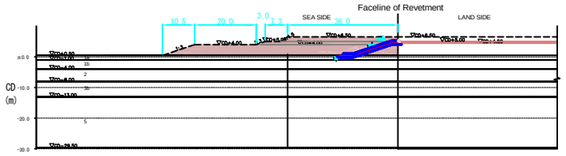
Inner Revetment IR-2



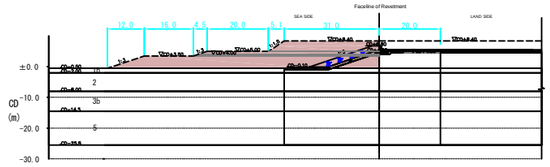
Inner Revetment IR-3



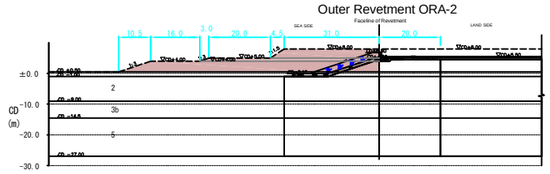
Inner Revetment IR-4



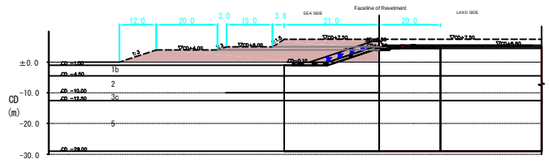
Outer Revetment ORA-1



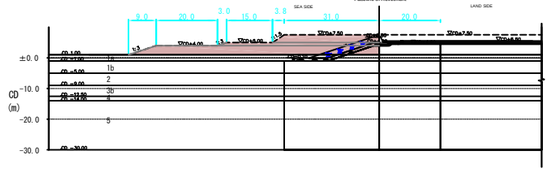
Outer Revetment ORA-2



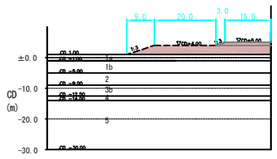
Outer Revetment ORA-3



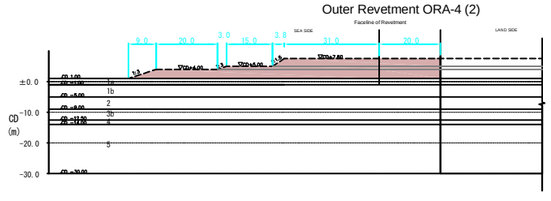
Outer Revetment ORA-4

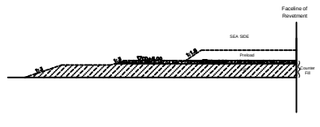


Outer Revetment ORA-4 (3)

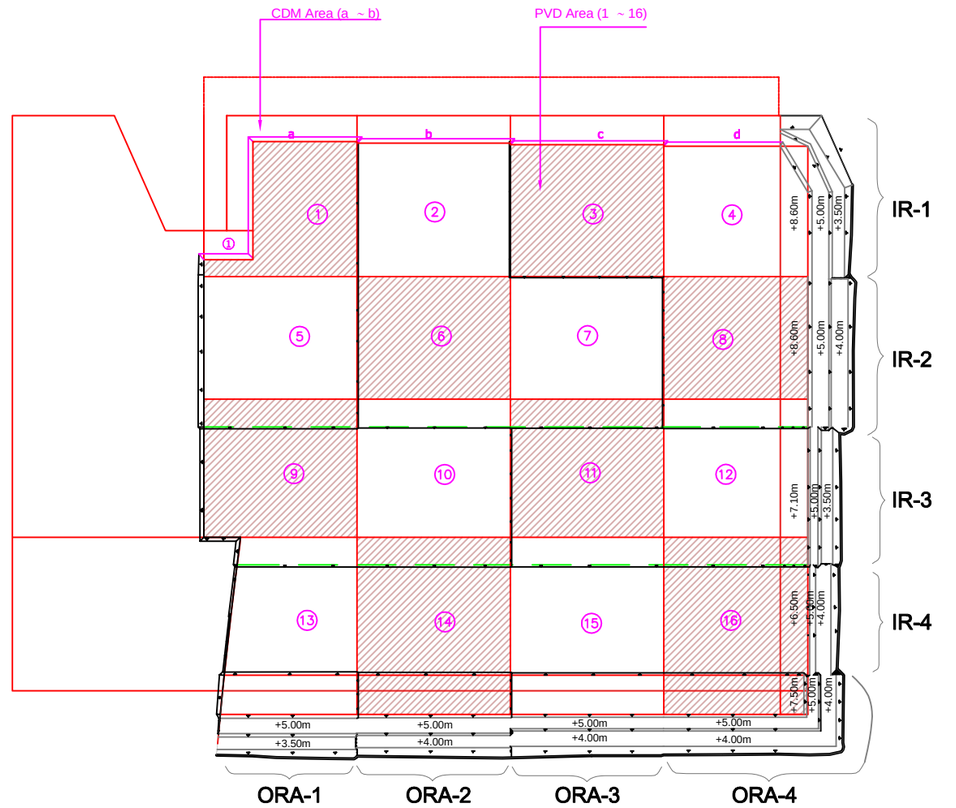


Outer Revetment ORA-4 (2)





SCALE: 1/2000



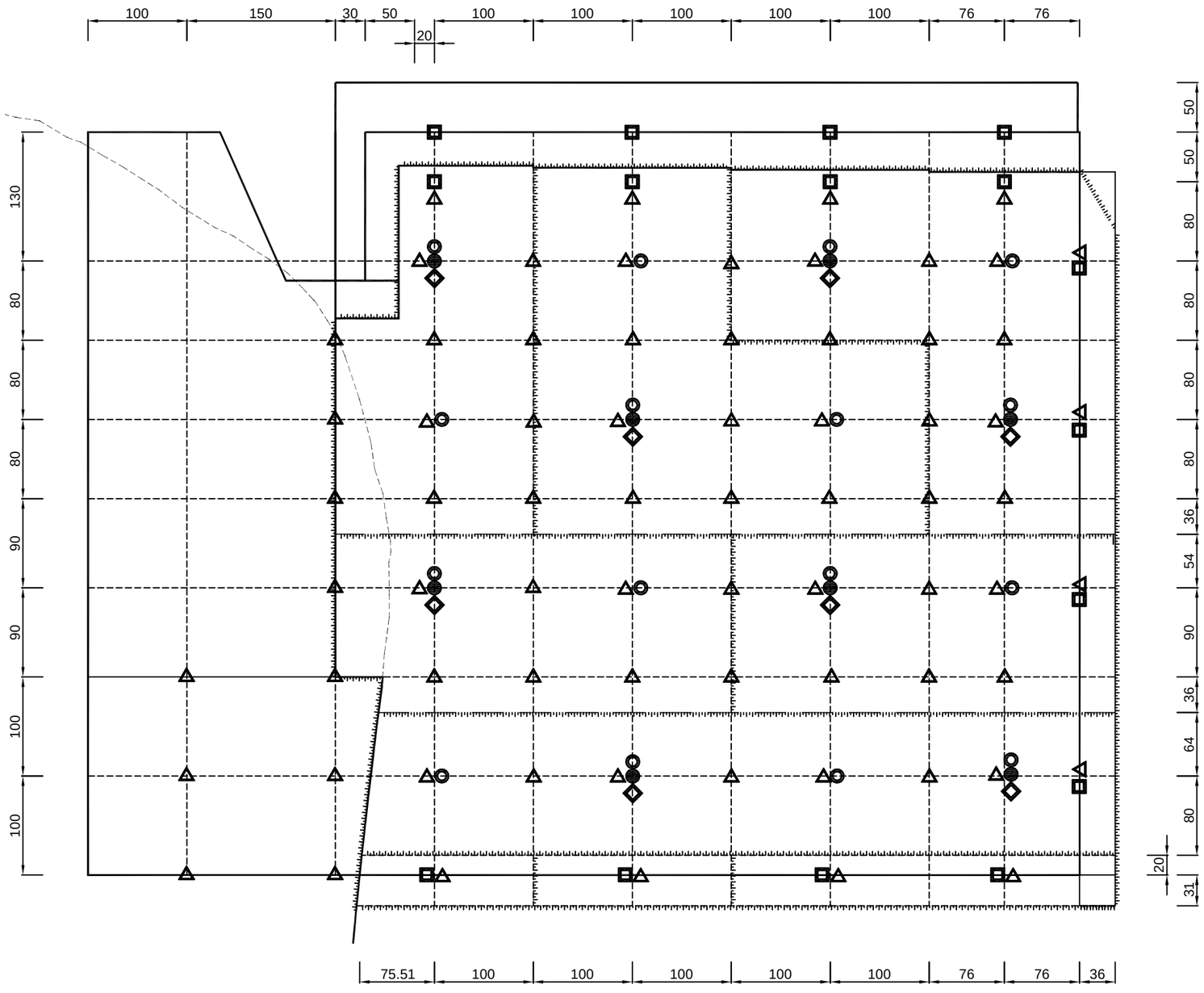
SCALE: 1/8000

TABLE OF QUANTITIES

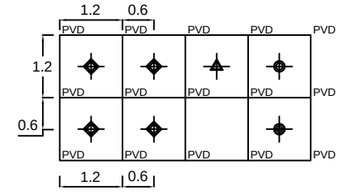
		1st Counter Fill (< CD+4.0m)				2nd Counter Fill (Upto CD+4.0m)				Sand mat (CD+4.0m to +5.0m)				Preload (> CD+5.0m)				Fill protection sectional length	Fill protection area
		Sectional Area	Height	Distance along Revet.	Volume	Sectional Area	Height	Distance along Revet.	Volume	Sectional Area	Height	Distance along Revet.	Volume	Sectional Area	Height	Distance along Revet.	Volume		
		(m2)	(m)	(m)	(m3)	(m2)	(m)	(m)	(m3)	(m2)	(m)	(m)	(m3)	(m2)	(m)	(m)	(m3)	(m)	(m2)
IR-1	1-1	265.2	3.0	110.0	29,172.0	33.6	0.5	110.0	3,692.7	64.9	1.0	110.0	7,139.0	139.3	3.6	110.0	15,325.2	30.2	3,325.3
	1-2				33,851.1				2,225.4				3,607.3				4,575.6	27.6	3,508.2
IR-2		278.7	3.0	196.0	54,625.2					64.9	1.0	196.0	12,720.4	139.3	3.6	196.0	27,306.7	34.7	6,791.4
IR-3		219.5	3.0	180.0	39,501.0	26.5	0.5	180.0	4,761.0	50.7	1.0	180.0	9,117.0	78.9	2.1	180.0	14,203.8	29.2	5,261.4
IR-4		245.0	3.5	144.0	35,280.0					43.4	1.0	144.0	6,242.4	55.7	1.5	144.0	8,019.4	34.2	4,924.8
ORA-1		330.4	4.0	178.4	58,946.7	29.9	0.5	178.4	5,338.0	57.6	1.0	178.4	10,276.4	114.1	3.4	178.4	20,351.2	33.4	5,957.1
ORA-2		297.1	4.0	200.0	59,426.0					57.0	1.0	200.0	11,400.0	99.8	3.0	200.0	19,950.0	30.2	6,046.0
ORA-3		315.0	4.0	200.0	63,000.0					51.3	1.0	200.0	10,250.0	82.2	2.5	200.0	16,438.0	35.8	7,162.0
ORA-4	4-1	231.8	4.0	152.0	35,226.0					51.3	1.0	152.0	7,790.0	82.2	2.5	152.0	12,492.9	32.7	4,964.3
	4-2	291.8	3.0	36.0	10,503.0					71.3	1.0	36.0	2,565.0	132.2	2.5	36.0	4,758.8	32.7	1,175.4
	4-3	127.5	3.0	101.7	12,966.8					16.5	1.0	101.7	1,678.1					32.7	3,320.5
Total		2,601.9	34.5	1,498.1	432,497.7	89.9	1.5	468.4	16,017.1	528.7	10.0	1,498.1	82,785.6	923.6	24.7	1,396.4	143,421.6	353.3	52,436.4

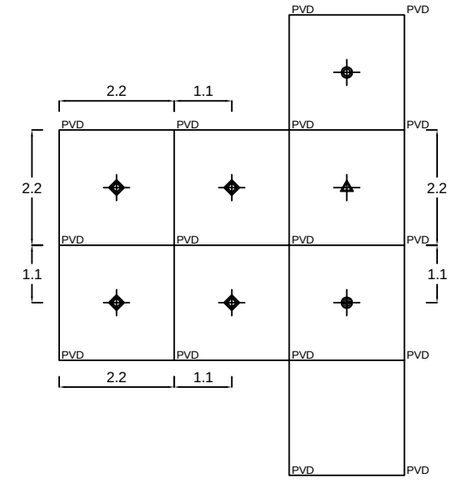
Note:

- Dimensions are in (m)



Detail:
Not to Scale





Frequency of Monitoring

Instrument	During construction of Surcharge Fill	After Completion of Surcharge Fill			After Removed Surcharge Fill
		Fisrt 1 month	1 to 3 months	Over 3 months	
Settlement Plate	Once a day	Once/2days	Once/1week	Once/2week	Timely
Extensometer	Once a day	Once/2days	Once/1week	Once/2week	Timely
Piezometers, Stand Pipe	Once a day	Once/2days	Once/1week	Once/2week	Timely
Stand Pipe	Once a day	Once/2days	Once/1week	Once/2week	Timely
Inclinometers	Once a day	Once/2days	Once/1week	Timely	—

Quantities of Monitoring Instruments

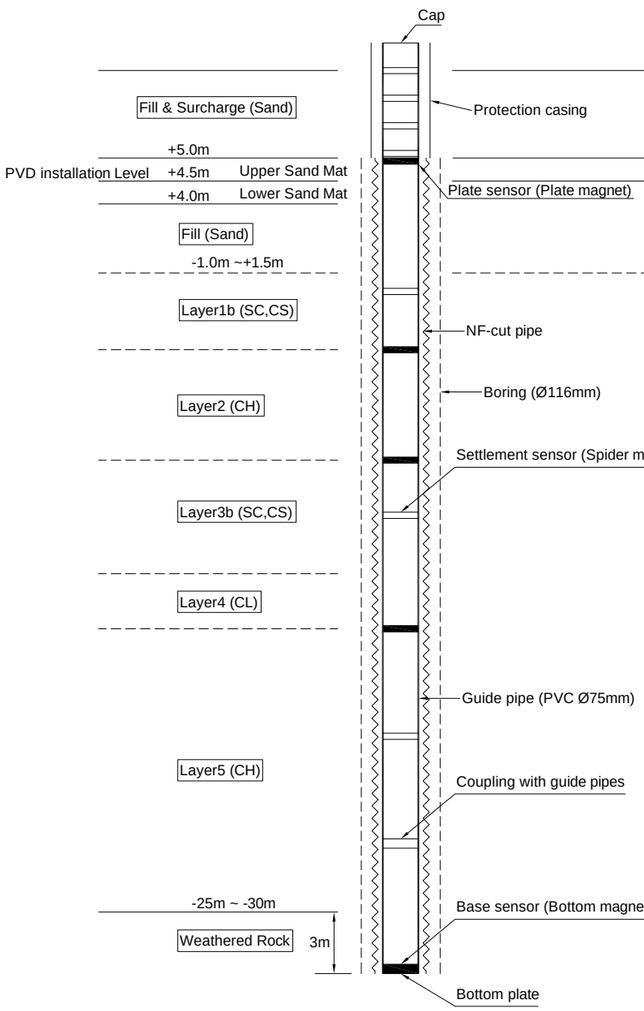
Legend	Monitoring Instruments	Units	Quantities	Remarks
△	Settlement Plate	Nos.	71	
◉	Magnet Extensometer	Nos.	8	
□	Inclinometer	Nos.	16	
○	Stand Pipe	Nos.	16	
◇	Electric Piezometer	Nos.	32	8 Locations x 4 layers

Notes:

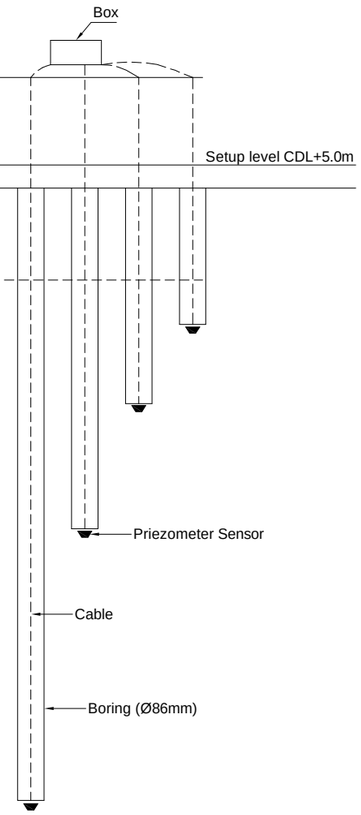
- Dimensions are in (m), Elevations are in (m) - "Hon Dau" Datum
- Monitoring plans as shown are for reference only, Actual locations and Nos, shall be decided at site
- Detail and Installation procedure of Monitoring instruments are shown in drawing No: IM-29
- Coordiantes of control points are shown in drawing No: IM-24
- Piezometer elevations show the Monitoring points of pore water pressure
- Settlement plate shall be placed on top of a layer of filling materials which is 0.5m thickness

INSTALLATION DETAILS
FOR MONITORING INSTRUMENTS

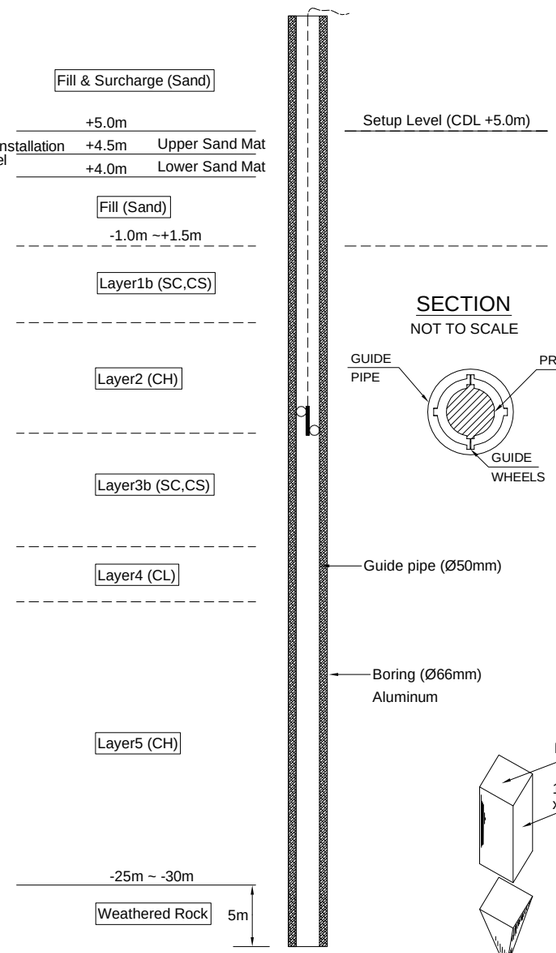
Extensometer



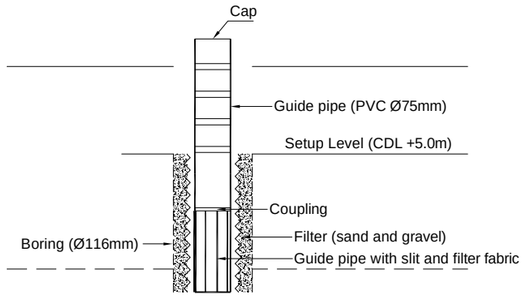
Piezometer



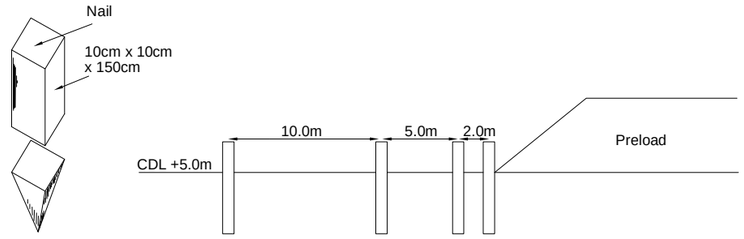
Inclinometer

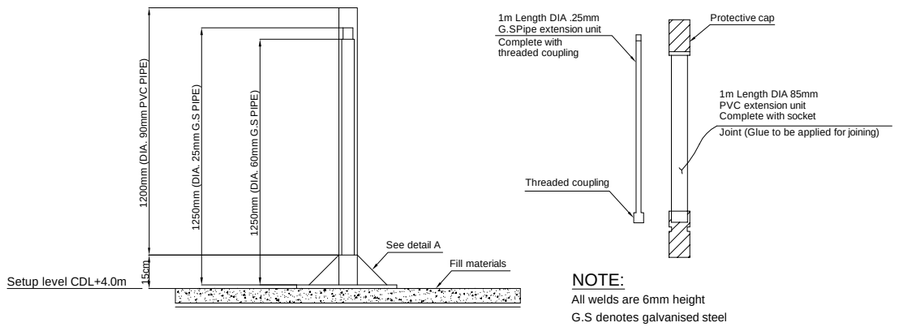


Stand pipe



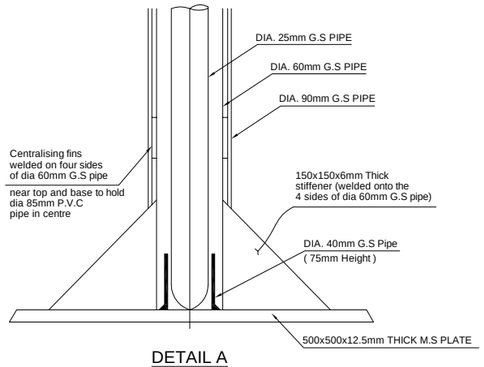
Alignment Stake





NOTE:
All welds are 6mm height
G.S denotes galvanised steel

SETTLEMENT PLATE
NOT TO SCALE



DETAIL A
NOT TO SCALE

Notes:

- Dimensions are in (m), Elevations are in (m) - "Hon Dau" Datum
- Monitoring plans of Reclamation Area are show in drawing No: IM-28
- Settlement plate shall be placed on top of a layer of filling materials which is 0.5m thickness
- Each Piezometer shall be installed in each one borehole

Appendix 16-2

Calculation of Anchor Block (L-Wall)

Design of Anchor Block (L-Wall)

1. Type of Anchor Block

The design of the ordinary slab anchorage shall satisfy the following based on the Technical Standards and Commentaries for Port and Harbour Facilities in Japan.

(a) Stability of concrete wall anchorage

The height and placing depth of concrete wall anchorage may be determined to satisfy equation (**5.7.1**), on the assumption that the tie rod tension and the active earth pressure behind the concrete wall anchorage are resisted by the passive earth pressure in front of the concrete wall anchorage (see **Fig. T- 5.7.4**).

$$F = E_P / (A_P + E_A) \qquad (5.7.1)$$

where

F : safety factor

A_P: reaction at the tie rod setting point according to **5.3.3 Bending Moment of Sheet Pile and Reaction at Tie Rod Setting Point** (N/m)

E_A : resultant active earth pressure acting on concrete wall anchorage (N/m)

E_P : resultant passive earth pressure acting on concrete wall anchorage (N/m)

In the calculation of the earth pressure acting on concrete wall anchorage, the surcharge should be assumed to act as shown in **Fig. T- 5.7.4** (i.e., the surcharge is only considered in the calculation of active earth pressure, and not of passive earth pressure). In this calculation, the safety factors should be 2.5 or larger in ordinary conditions and 2.0 or larger in extraordinary conditions.

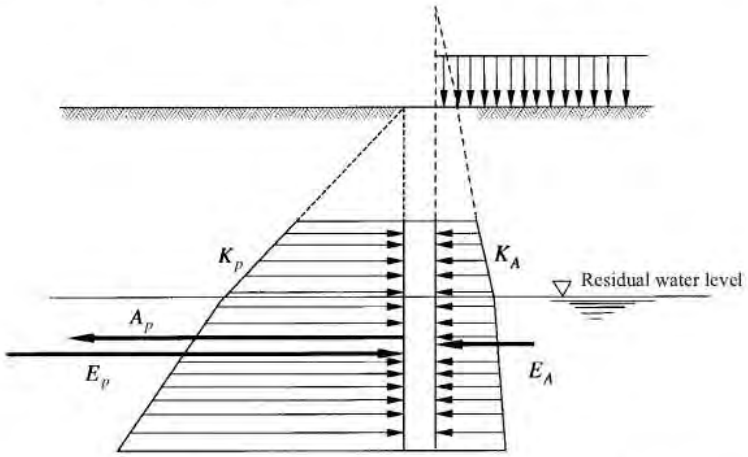


Fig. T- 5.7.4 External Forces Acting on Concrete Wall Anchorage

The above design method is applied in the case that the tie setting point is located at around the centroid of the resultant earth pressure.

If the simple slab anchorage is used, the tie setting point will be around +1.6 mCDL as shown in the trial calculation shown in the next page.

However, for the case of this project, the water level behind the retaining wall during the construction is estimated to be +2.5 mCDL ~ +3.55 mCDL and tie setting point 1.0m~2.0m below the water level would be difficult to be executed within the limited time frame.

For this reason, L-wall type anchor block with tie setting point at +3.0 mCDL is recommended.

[Traial calculation for ordinary slab anchorage]

After Completion

Elev	h	Passive Earth Pressure				Active Earth Pressure				Resultant Force		
		γh	Kp	pp	Pp	γh	Ka	pa	Pa	Pp-Pa	y	M
(mCD)	(m)	(kPa)		(kPa)	(kN/m)	(kPa)		(kPa)	(kN/m)	(kN/m)	(m)	(kNm/m)
5.50		0.00	4.806			30.00	0.291					
	1.20											
4.30		21.60	4.806			51.60	0.291					
4.30		21.60	4.806	103.81	38.9	51.60	0.291	15.02	5.6	33.3	4.25	141.5
	0.75											
3.55		35.10	4.806	168.69	63.3	65.10	0.291	18.94	7.1	56.2	4.00	224.6
3.55		35.10	4.806	168.69	316.3	65.10	0.291	18.94	35.5	280.8	2.50	701.9
	3.75											
-0.20		72.60	4.806	348.92	654.2	102.60	0.291	29.86	56.0	598.2	1.25	747.8
					1,072.7				104.2	968.5		1,815.9

Tie tension force (Block-1) T = 319.3 kN/m
Factor of Safety FOS = Pp / (T + Pa) = 2.53 > 2.5 ... OK
Center of earth pressure Elev = 1.675 mCD

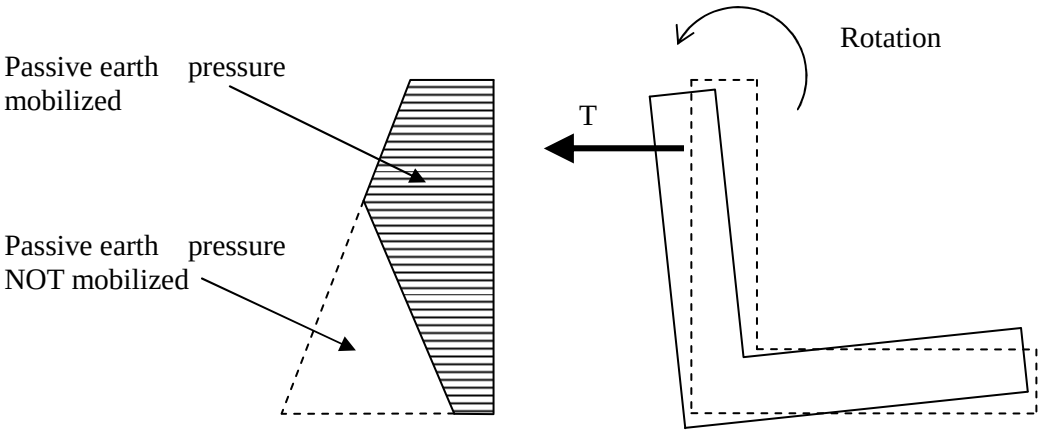
During Construction

Elev	h	Passive Earth Pressure				Active Earth Pressure				Resultant Force		
		γh	Kp	pp	Pp	γh	Ka	pa	Pa	Pp-Pa	y	M
(mCD)	(m)	(kPa)		(kPa)	(kN/m)	(kPa)		(kPa)	(kN/m)	(kN/m)	(m)	(kNm/m)
4.50		0.00	4.806			20.00	0.291					
	0.20											
4.30		3.60	4.806			23.60	0.291					
4.30		3.60	4.806	17.30	6.5	23.60	0.291	6.87	2.6	3.9	4.05	15.8
	0.75											
3.55		17.10	4.806	82.18	30.8	37.10	0.291	10.80	4.0	26.8	3.80	101.7
3.55		17.10	4.806	82.18	145.9	37.10	0.291	10.80	19.2	126.7	2.37	299.9
	3.55											
0.00		52.60	4.806	252.80	448.7	72.60	0.291	21.13	37.5	411.2	1.18	486.6
					631.9				63.3	568.6		904.1

Tie tension force (Block-1) T = 246.72 kN/m
Factor of Safety FOS = Pp / (T + Pa) = 2.04 > 2.0 ... OK
Center of earth pressure Elev = 1.590 mCD

2. Method of Verification

For the case of the L-wall type anchor block with tie setting point at +3.0 mCDL, a rotation of the L-wall would be an issue since the centroid of the passive earth pressure will be much lower than the tie setting point. Due to the rotation, a mobilization of the passive earth pressure at the lower portion of the wall would be insufficient.



In order to design the anchor block to meet the requirements of the Technical Standards and Commentaries for Port and Harbour Facilities in Japan, following design method is adopted.

- Rotation of the L-wall is considered in the design. The passive earth pressure and the ground reaction are obtained by the elasto-plastic method. For this purpose, linear soil springs are modeled on the front and bottom surfaces of the L-wall but the passive resistance is limited to the passive earth pressure.

- Following two cases are studied:
  - Working load case

    This analysis is based on the unfactored loads.

    The purpose of this analysis is to check the serviceability of the L-wall (displacement/rotation) as well as the structural details of the L-wall.

  - Ultimate load case

    This analysis is based on the factored tie tension and active earth pressure.

    The factors to be imposed are 2.5 for the permanent condition and 2.0 for the temporary condition (i.e., during construction).

    The purpose of this analysis is to check the ultimate capacity of the passive resistance of the L-wall in the case of the insufficient mobilization of the passive earth pressure due to the rotation of the L-wall.

- Following criteria are set for the acceptance of the design.
  - Rotation angle θ shall not exceed 0.02 rad in both of the working and ultimate load cases.
  - Lateral displacement at the tie setting point shall not exceed 30mm in working load case.

- Soil spring are set as follows:
  - SPT-N value of 5 is assumed.
  - Coefficient of ground reaction : $K = 2000 \times (\text{SPT-N})$ (kN/m^3)

- Superimposed loads of 30kPa (after completion) or 20 kPa (during construction) are considered for the calculation of the active earth pressure. During surcharging work for the PVD improvement behind the DMM, the surcharge soil will be filled just behind the L-wall. However, this effect will not be considered since such surcharge fill will not be loaded within the active failure surface behind the L-wall and any minor effects in relation to the surcharge soil (or surcharging work) is considered to be covered by the superimposed load of 20kPa.

3. Section of L-wall and Results of Analysis

Dimensions of the L-wall sections are as follows.

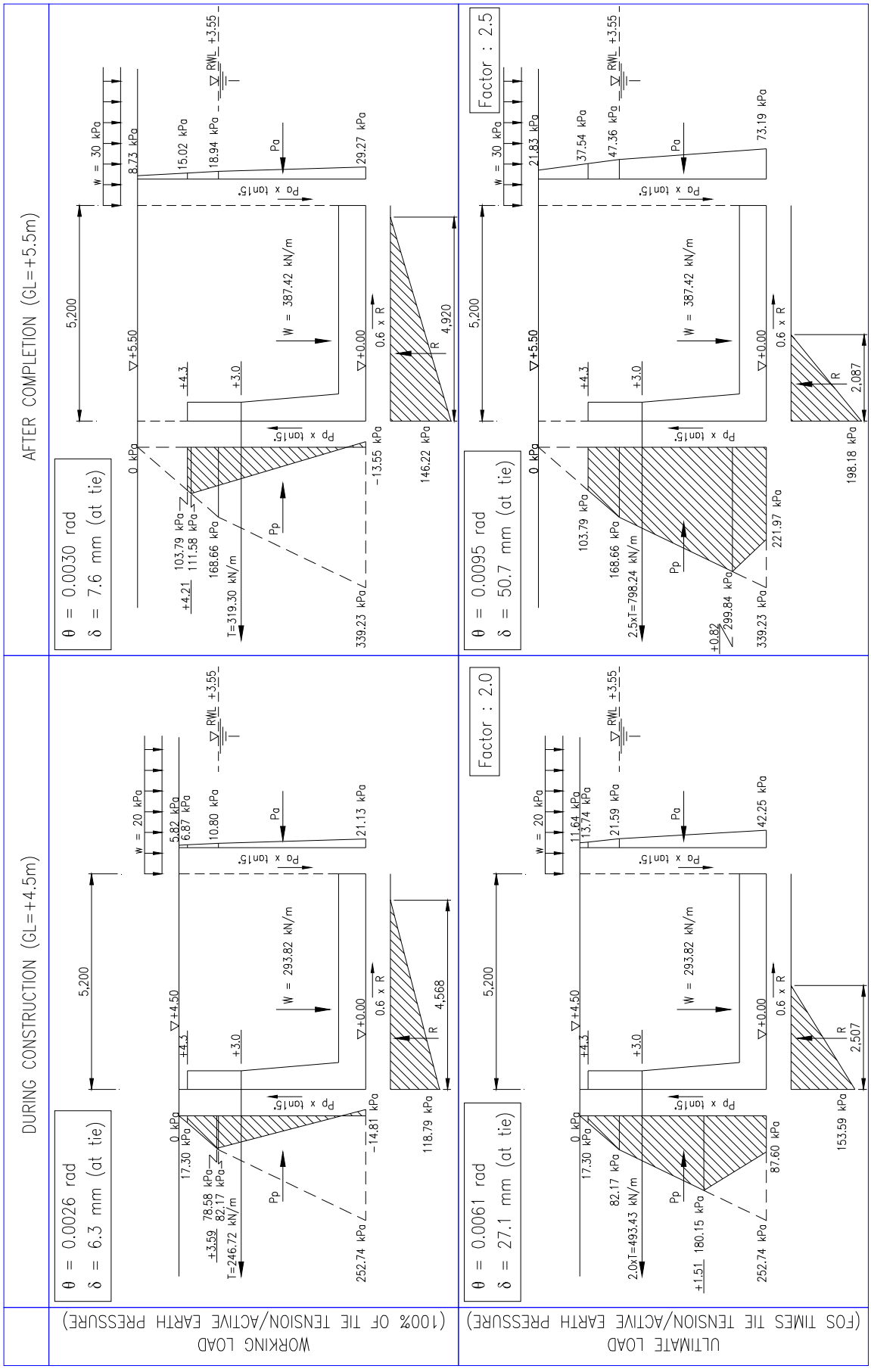
	Top Level	Bottom Level	Width	Thickness	
				Wall	Base Slab
Block-1	+4.3 mCD	+0.00 mCD	5.20 m	0.45 m	0.65 m
Block-a	+4.3 mCD	+0.30 mCD	4.00 m	0.45 m	0.65 m
Block-b	+4.3 mCD	+0.30 mCD	4.20 m	0.45 m	0.65 m
Block-c	+4.3 mCD	+0.30 mCD	4.20 m	0.45 m	0.65 m
Block-d	+4.3 mCD	+0.30 mCD	4.50 m	0.45 m	0.65 m

The design check was carried out along with the above procedure by using Microsoft Excel spreadsheet. The analysis results are shown in the following pages and summarized in the following table.

		Block-1		Block-a		Block-b		Block-c		Block-d	
		During Construction	After Completion	During Construction	After Completion	During Construction	After Completion	During Construction	After Completion	During Construction	After Completion
Working Load	Rotation angle θ	0.0026 rad	0.0030 rad	0.0030 rad	0.0034 rad	0.0029 rad	0.0033 rad	0.0029 rad	0.0033 rad	0.0027 rad	0.0031 rad
	Acceptance Criteria	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad
	Check	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	Horizontal Deflection δ	6.3 mm	7.6 mm	5.1 mm	6.3 mm	5.2 mm	6.4 mm	5.1 mm	6.3 mm	4.9 mm	6.1 mm
	Acceptance Criteria	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm	δ≤ 30mm
	Check	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Ultimate Load (Factored Load)	Factor imposed on Working Load	γ_f = 2.0	γ_f = 2.5	γ_f = 2.0	γ_f = 2.5	γ_f = 2.0	γ_f = 2.5	γ_f = 2.0	γ_f = 2.5	γ_f = 2.0	γ_f = 2.5
	Rotation angle θ	0.0061 rad	0.0095 rad	0.0072 rad	0.0101 rad	0.0077 rad	0.0140 rad	0.0069 rad	0.0101 rad	0.0047 rad	0.0052 rad
	Acceptance Criteria	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad	θ ≤ 0.02rad
	Check	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	Horizontal Deflection δ	27.1 mm	50.7 mm	22.2 mm	38.8 mm	24.5 mm	49.5 mm	22.9 mm	41.1 mm	19.4 mm	32.8 mm
	Acceptance Criteria	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Check	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Summary of the results is also included in **Attachment-6**.

Summary of Analysis (Block-1)



Design of Anchor Plate (Elast-plastic method)

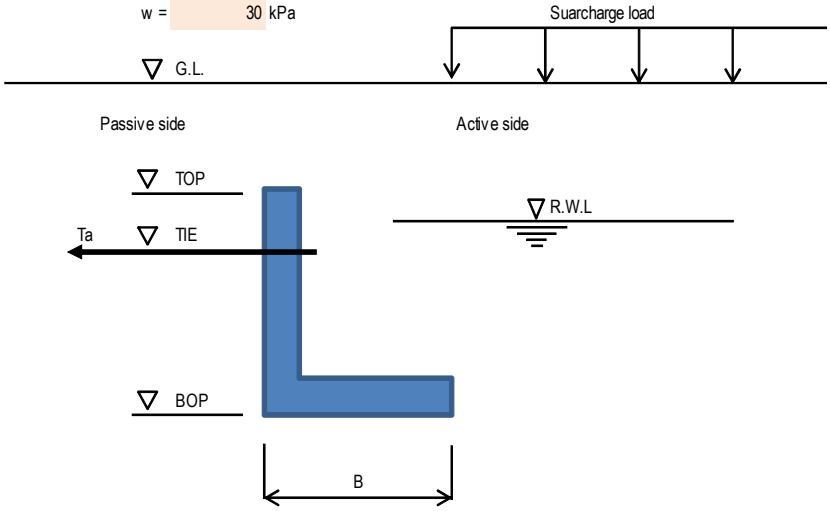
Block Block-1

Case : During Operation - - - Tie tension FOS = 2.5

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.00	m
Width of anchor plate	B	5.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	319.30	kN/m
Factor of safety	FOS	2.5	
	FOS×Ta =	798.2375	kN/m
	M =	2394.7125	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.00	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.00	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	299.36
	3.55				
0.00		70.60	4.805	339.23	602.14
					1,065.94

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	5.10	26.71
	1.20						
4.30		51.60	0.291	15.02	9.01	4.70	42.34
4.30		51.60	0.291	15.02	5.63	4.05	22.80
	0.75						
3.55		65.10	0.291	18.94	7.10	3.80	27.00
3.55		65.10	0.291	18.94	33.63	2.37	79.58
	3.55						
0.00		100.60	0.291	29.27	51.96	1.18	61.49
					112.57		259.93

Active earth pressure	Horiz. force	281.43	kN/m	(= Pa * FOS)
	Vertical force	75.41	kN/m	(= Pa * tan δ * FOS)
	Moment	453.76	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	5.20	0.65	13.90	2.60	46.98	122.15
Wall 1	underwater	0.45	2.90	13.90	0.23	18.14	4.08
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.75	2.90	10.00	2.83	137.75	389.14
Soil 2	above water	4.75	0.75	18.00	2.83	64.13	181.15
Soil 3	above water	5.20	1.20	18.00	2.60	112.32	292.03
						387.42	990.39

Anchor plate	Vertical force	387.42	kN/m	(= W)
	Moment	16.90	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

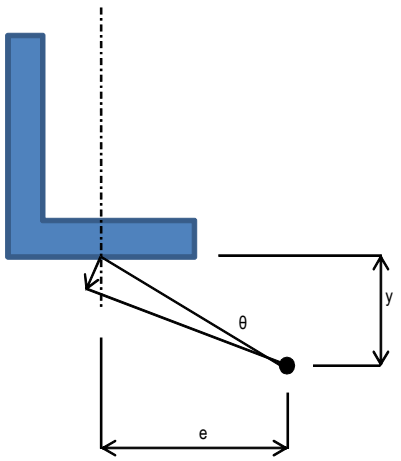
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	... = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	... = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	2.337	m
Horizontal distance	e	-0.513	m
Rotation anglr	θ	0.009497	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	7.84	0.00	744.33	0.00	0.00	5.50	0.00
	5.50		7.84	0.00	744.33	0.00	0.00	5.50	0.00
Plastic	5.50	1.20	7.84	0.00	744.33	0.00	0.00	5.10	0.00
	4.30		6.64	103.79	630.36	103.79	62.27	4.70	292.68
Plastic	4.30	0.00	6.64	103.79	630.36	103.79	0.00	4.30	0.00
	4.30		6.64	103.79	630.36	103.79	0.00	4.30	0.00
Plastic	4.30	0.75	6.64	103.79	630.36	103.79	38.92	4.05	157.63
	3.55		5.89	168.66	559.13	168.66	63.25	3.80	240.33
Plastic	3.55	2.73	5.89	168.66	559.13	168.66	230.23	2.64	607.79
	0.82		3.16	299.84	299.84	299.84	409.30	1.73	708.05
Elastic	0.82	0.82	3.16	299.84	299.84	299.84	122.91	0.55	67.18
	0.00		2.34	339.23	221.97	221.97	90.99	0.27	24.87
	Below the top of Anchor Wall only						955.60		1,805.85

Passive side pressure	Horiz. force	955.60 kN/m	(= Pp ')
	Vertical force	256.05 kN/m	(= Pp ' * tan δ)
	Moment	2,471.59 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	198.18 kPa	P1	206.77 kN/m	M1	393.8 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				206.77		393.8	
Effective contact area	A (A')	2.08668998 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	124.06 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	124.06 kN/m	(= Q)
	Vertical force	206.77 kN/m	(= P1+P2)
	Moment	393.78 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻	
Active earth pressure	281.43	75.41	453.76	
Weight of Plate	0.00	387.42	16.90	
Tie tension	798.24	0.00	2,394.71	
Passive soil pressure	-955.60	-256.05	-2,471.59	
Base reaction	-124.06	-206.77	-393.78	
Total	0.00	0.00	-0.00	<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	2.337 m				
Horizontal distance	e	-0.513 m				
Rotation angle	θ	0.0095 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 50.69 mm - - - no limitation

Design of Anchor Plate (Elast-plastic method)

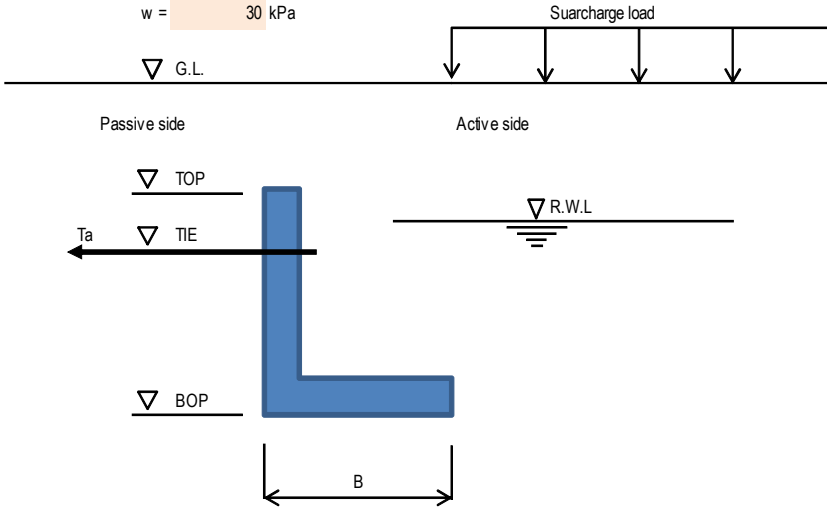
Block Block-1

Case : During Operation - - - Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.00	m
Width of anchor plate	B	5.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	319.30	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	319.295	kN/m
	M =	957.885	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.00	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.00	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	299.36
	3.55				
0.00		70.60	4.805	339.23	602.14
					1,065.94

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	5.10	26.71
	1.20						
4.30		51.60	0.291	15.02	9.01	4.70	42.34
4.30		51.60	0.291	15.02	5.63	4.05	22.80
	0.75						
3.55		65.10	0.291	18.94	7.10	3.80	27.00
3.55		65.10	0.291	18.94	33.63	2.37	79.58
	3.55						
0.00		100.60	0.291	29.27	51.96	1.18	61.49
					112.57		259.93

Active earth pressure	Horiz. force	112.57	kN/m	(= Pa * FOS)
	Vertical force	30.16	kN/m	(= Pa * tan δ * FOS)
	Moment	181.50	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	5.20	0.65	13.90	2.60	46.98	122.15
Wall 1	underwater	0.45	2.90	13.90	0.23	18.14	4.08
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.75	2.90	10.00	2.83	137.75	389.14
Soil 2	above water	4.75	0.75	18.00	2.83	64.13	181.15
Soil 3	above water	5.20	1.20	18.00	2.60	112.32	292.03
						387.42	990.39

Anchor plate	Vertical force	387.42	kN/m	(= W)
	Moment	16.90	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

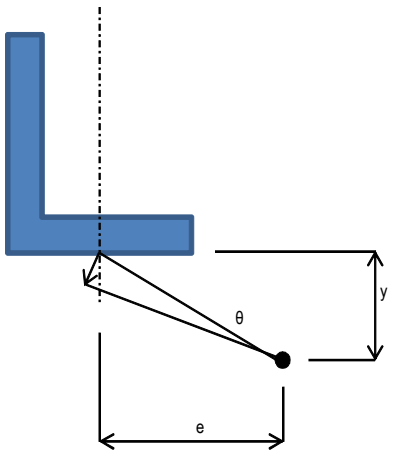
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.456	m
Horizontal distance	e	2.320	m
Rotation anglr	θ	0.002972	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	5.04	0.00	149.92	0.00	0.00	5.50	0.00
	5.50		5.04	0.00	149.92	0.00	0.00	5.50	0.00
Plastic	5.50	1.20	5.04	0.00	149.92	0.00	0.00	5.10	0.00
	4.30		3.84	103.79	114.26	103.79	62.27	4.70	292.68
Plastic	4.30	0.09	3.84	103.79	114.26	103.79	4.67	4.27	19.96
	4.21		3.75	111.58	111.58	111.58	5.03	4.24	21.31
Elastic	4.21	0.66	3.75	111.58	111.58	111.58	36.82	3.99	146.90
	3.55		3.09	168.66	91.96	91.96	30.34	3.77	114.40
Elastic	3.55	0.00	3.09	168.66	91.96	91.96	0.00	3.55	0.00
	3.55		3.09	168.66	91.96	91.96	0.00	3.55	0.00
Elastic	3.55	3.55	3.09	168.66	91.96	91.96	163.24	2.37	386.33
	0.00		-0.46	339.23	-13.55	-13.55	-24.05	1.18	-28.45
	Below the top of Anchor Wall only						216.05		660.44

Passive side pressure	Horiz. force	216.05 kN/m	(= Pp ')
	Vertical force	57.89 kN/m	(= Pp ' * tan δ)
	Moment	810.95 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	146.22 kPa	P1	359.69 kN/m	M1	345.3 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				359.69		345.3	
Effective contact area	A (A')	4.919746208 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	215.81 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	215.81 kN/m	(= Q)
	Vertical force	359.69 kN/m	(= P1+P2)
	Moment	345.33 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	112.57	30.16	181.50
Weight of Plate	0.00	387.42	16.90
Tie tension	319.30	0.00	957.89
Passive soil pressure	-216.05	-57.89	-810.95
Base reaction	-215.81	-359.69	-345.33
Total	-0.00	0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.456 m				
Horizontal distance	e	2.320 m				
Rotation angle	θ	0.0030 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	7.56 mm	<	Allowable deflection	30 mm	OK

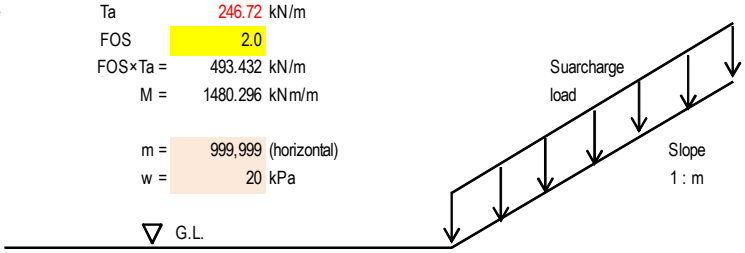
Design of Anchor Plate (Elast-plastic method)

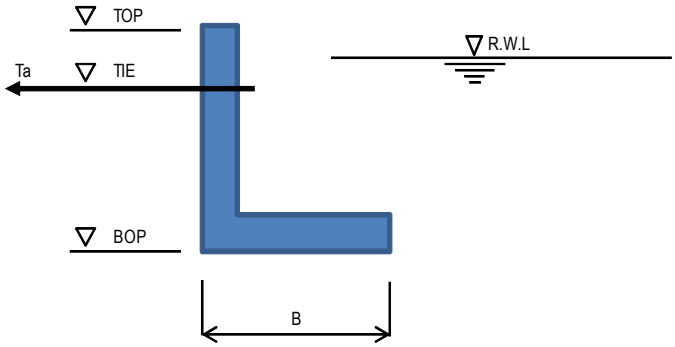
Block Block-1

Case : During Construction - - - Tie tension FOS = 2.0

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.00	m
Width of anchor plate	B	5.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	246.72	kN/m
Factor of safety	FOS	2.0	
	FOS×Ta =	493.432	kN/m
	M =	1480.296	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa





Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.00	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.00	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	145.84
	3.55				
0.00		52.60	4.805	252.74	448.62
					633.49

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.43	2.58
	0.20						
4.30		23.60	0.291	6.87	0.69	4.37	3.00
4.30		23.60	0.291	6.87	2.58	4.05	10.43
	0.75						
3.55		37.10	0.291	10.80	4.05	3.80	15.38
3.55		37.10	0.291	10.80	19.16	2.37	45.35
	3.55						
0.00		72.60	0.291	21.13	37.50	1.18	44.37
					64.56		121.12

Active earth pressure	Horiz. force	129.11	kN/m	(= Pa * FOS)
	Vertical force	34.60	kN/m	(= Pa * tan δ * FOS)
	Moment	152.29	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	5.20	0.65	13.90	2.60	46.98	122.15
Wall 1	underwater	0.45	2.90	13.90	0.23	18.14	4.08
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.75	2.90	10.00	2.83	137.75	389.14
Soil 2	above water	4.75	0.75	18.00	2.83	64.13	181.15
Soil 3	above water	5.20	0.20	18.00	2.60	18.72	48.67
						293.82	747.03

Anchor plate	Vertical force	293.82	kN/m	(= W)
	Moment	16.90	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

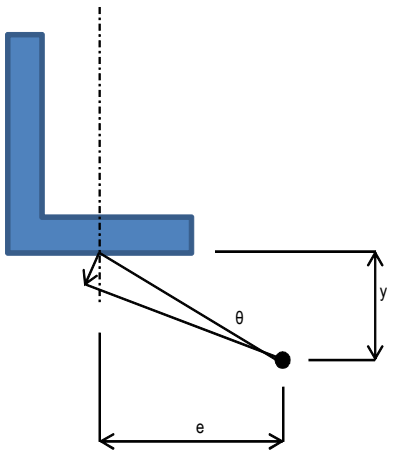
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	1.430	m
Horizontal distance	e	-0.093	m
Rotation anglr	θ	0.006125	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	5.93	0.00	363.25	0.00	0.00	4.50	0.00
	4.50		5.93	0.00	363.25	0.00	0.00	4.50	0.00
Plastic	4.50	0.20	5.93	0.00	363.25	0.00	0.00	4.43	0.00
	4.30		5.73	17.30	351.00	17.30	1.73	4.37	7.55
Plastic	4.30	0.00	5.73	17.30	351.00	17.30	0.00	4.30	0.00
	4.30		5.73	17.30	351.00	17.30	0.00	4.30	0.00
Plastic	4.30	0.75	5.73	17.30	351.00	17.30	6.49	4.05	26.27
	3.55		4.98	82.17	305.05	82.17	30.81	3.80	117.09
Plastic	3.55	2.04	4.98	82.17	305.05	82.17	83.77	2.87	240.45
	1.51		2.94	180.15	180.15	180.15	183.67	2.19	402.35
Elastic	1.51	1.51	2.94	180.15	180.15	180.15	136.09	1.01	137.07
	0.00		1.43	252.74	87.60	87.60	66.17	0.50	33.33
	Below the top of Anchor Wall only						507.01		956.56

Passive side pressure	Horiz. force	507.01 kN/m	(= Pp ')
	Vertical force	135.85 kN/m	(= Pp ' * tan δ)
	Moment	1,309.77 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	153.59 kPa	P1	192.56 kN/m	M1	339.7 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				192.56		339.7	
Effective contact area	A (A')	2.507421032 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	115.54 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	115.54 kN/m	(= Q)
	Vertical force	192.56 kN/m	(= P1+P2)
	Moment	339.71 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	129.11	34.60	152.29
Weight of Plate	0.00	293.82	16.90
Tie tension	493.43	0.00	1,480.30
Passive soil pressure	-507.01	-135.85	-1,309.77
Base reaction	-115.54	-192.56	-339.71
Total	-0.00	-0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	1.430 m				
Horizontal distance	e	-0.093 m				
Rotation angle	θ	0.0061 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 27.14 mm - - - no limitation

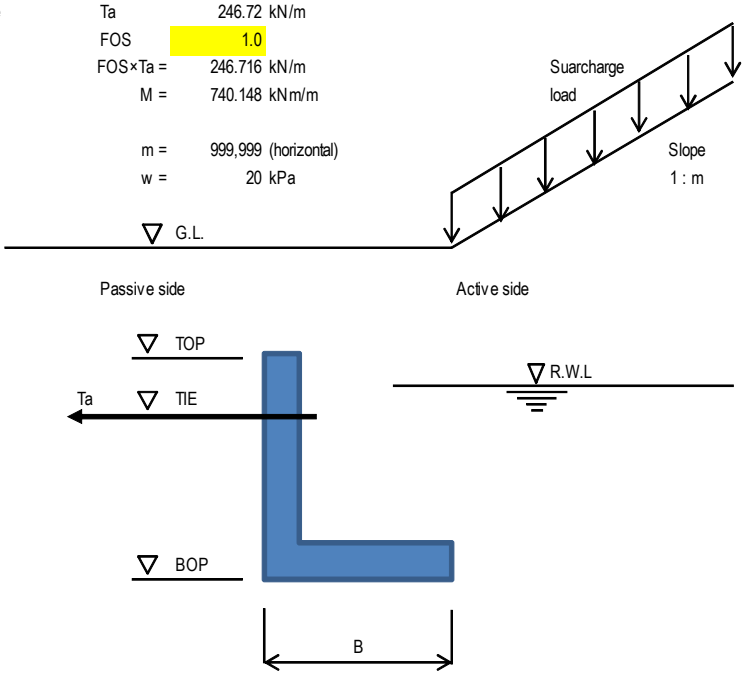
Design of Anchor Plate (Elast-plastic method)

Block Block-1

Case : During Construction --- Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.00	m
Width of anchor plate	B	5.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	246.72	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	246.716	kN/m
	M =	740.148	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.00	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.00	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	145.84
	3.55				
0.00		52.60	4.805	252.74	448.62
					633.49

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.43	2.58
	0.20						
4.30		23.60	0.291	6.87	0.69	4.37	3.00
4.30		23.60	0.291	6.87	2.58	4.05	10.43
	0.75						
3.55		37.10	0.291	10.80	4.05	3.80	15.38
3.55		37.10	0.291	10.80	19.16	2.37	45.35
	3.55						
0.00		72.60	0.291	21.13	37.50	1.18	44.37
					64.56		121.12

Active earth pressure	Horiz. force	64.56	kN/m	(= Pa * FOS)
	Vertical force	17.30	kN/m	(= Pa * tan δ * FOS)
	Moment	76.15	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	5.20	0.65	13.90	2.60	46.98	122.15
Wall 1	underwater	0.45	2.90	13.90	0.23	18.14	4.08
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.75	2.90	10.00	2.83	137.75	389.14
Soil 2	above water	4.75	0.75	18.00	2.83	64.13	181.15
Soil 3	above water	5.20	0.20	18.00	2.60	18.72	48.67
						293.82	747.03

Anchor plate	Vertical force	293.82	kN/m	(= W)
	Moment	16.90	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

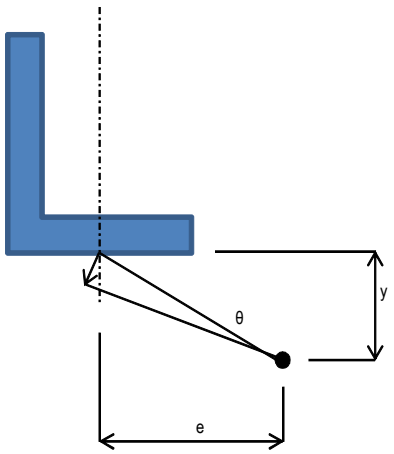
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.570	m
Horizontal distance	e	1.968	m
Rotation anglr	θ	0.002600	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	3.93	0.00	102.20	0.00	0.00	4.50	0.00
	4.50		3.93	0.00	102.20	0.00	0.00	4.50	0.00
Plastic	4.50	0.20	3.93	0.00	102.20	0.00	0.00	4.43	0.00
	4.30		3.73	17.30	97.00	17.30	1.73	4.37	7.55
Plastic	4.30	0.71	3.73	17.30	97.00	17.30	6.13	4.06	24.90
	3.59		3.02	78.58	78.58	78.58	27.84	3.83	106.55
Elastic	3.59	0.04	3.02	78.58	78.58	78.58	1.63	3.58	5.83
	3.55		2.98	82.17	77.50	77.50	1.61	3.56	5.73
Elastic	3.55	0.00	2.98	82.17	77.50	77.50	0.00	3.55	0.00
	3.55		2.98	82.17	77.50	77.50	0.00	3.55	0.00
Elastic	3.55	3.55	2.98	82.17	77.50	77.50	137.56	2.37	325.56
	0.00		-0.57	252.74	-14.81	-14.81	-26.29	1.18	-31.11
	Below the top of Anchor Wall only						148.47		437.46

Passive side pressure	Horiz. force	148.47 kN/m	(= Pp ')
	Vertical force	39.78 kN/m	(= Pp ' * tan δ)
	Moment	540.90 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	118.79 kPa	P1	271.33 kN/m	M1	292.3 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				271.33		292.3	
Effective contact area	A (A')	4.568235997 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	162.80 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	162.80 kN/m	(= Q)
	Vertical force	271.33 kN/m	(= P1+P2)
	Moment	292.29 kNm/m	(= M1+M2)

Balance of forces

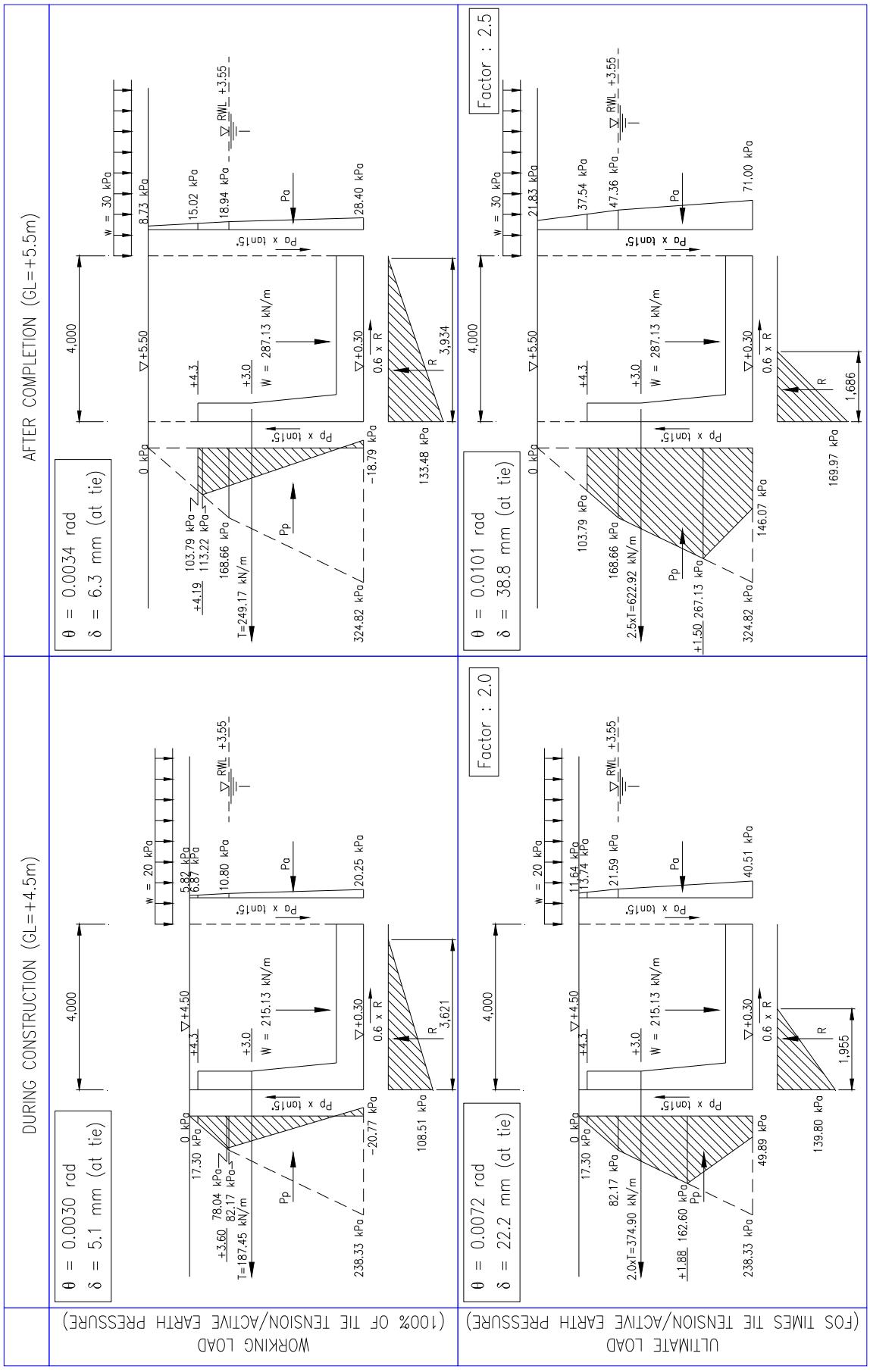
	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	64.56	17.30	76.15
Weight of Plate	0.00	293.82	16.90
Tie tension	246.72	0.00	740.15
Passive soil pressure	-148.47	-39.78	-540.90
Base reaction	-162.80	-271.33	-292.29
Total	0.00	0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.570 m				
Horizontal distance	e	1.968 m				
Rotation angle	θ	0.0026 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	6.32 mm	<	Allowable deflection	30 mm	OK

Summary of Analysis (Block-a)



Design of Anchor Plate (Elast-plastic method)

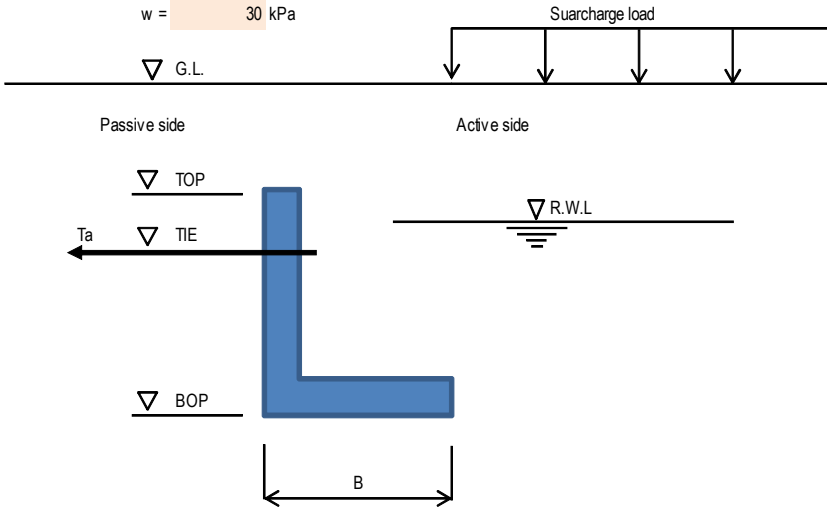
Block Block-a

Case : During Operation - - - Tie tension FOS = 2.5

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.00	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	249.17	kN/m
Factor of safety	FOS	2.5	
	FOS×Ta =	622.915	kN/m
	M =	1681.8705	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	259.80	kN/m	(= Pa * FOS)
	Vertical force	69.61	kN/m	(= Pa * tan δ * FOS)
	Moment	429.43	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.00	0.65	13.90	2.00	36.14	72.28
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.55	2.60	10.00	2.23	92.30	205.37
Soil 2	above water	3.55	0.75	18.00	2.23	47.93	106.63
Soil 3	above water	4.00	1.20	18.00	2.00	86.40	172.80
						287.13	562.56

Anchor plate	Vertical force	287.13	kN/m	(= W)
	Moment	11.69	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

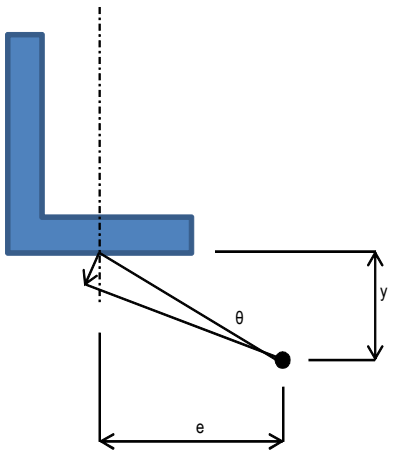
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	1.149	m
Horizontal distance	e	-0.314	m
Rotation anglr	θ	0.010084	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	6.65	0.00	670.43	0.00	0.00	5.20	0.00
	5.50		6.65	0.00	670.43	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	6.65	0.00	670.43	0.00	0.00	4.80	0.00
	4.30		5.45	103.79	549.43	103.79	62.27	4.40	274.00
Plastic	4.30	0.00	5.45	103.79	549.43	103.79	0.00	4.00	0.00
	4.30		5.45	103.79	549.43	103.79	0.00	4.00	0.00
Plastic	4.30	0.75	5.45	103.79	549.43	103.79	38.92	3.75	145.95
	3.55		4.70	168.66	473.80	168.66	63.25	3.50	221.36
Plastic	3.55	2.05	4.70	168.66	473.80	168.66	172.83	2.57	443.62
	1.50		2.65	267.13	267.13	267.13	273.74	1.88	515.64
Elastic	1.50	1.20	2.65	267.13	267.13	267.13	160.35	0.80	128.34
	0.30		1.45	324.82	146.07	146.07	87.68	0.40	35.09
	Below the top of Anchor Wall only						796.76		1,490.00

Passive side pressure	Horiz. force	796.76 kN/m	(= Pp ')
	Vertical force	213.49 kN/m	(= Pp ' * tan δ)
	Moment	1,916.98 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	169.97 kPa	P1	143.25 kN/m	M1	206.0 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				143.25		206.0	
Effective contact area	A (A')	1.685558347 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	85.95 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	85.95 kN/m	(= Q)
	Vertical force	143.25 kN/m	(= P1+P2)
	Moment	206.01 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	259.80	69.61	429.43
Weight of Plate	0.00	287.13	11.69
Tie tension	622.92	0.00	1,681.87
Passive soil pressure	-796.76	-213.49	-1,916.98
Base reaction	-85.95	-143.25	-206.01
Total	0.00	0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	1.149 m				
Horizontal distance	e	-0.314 m				
Rotation angle	θ	0.0101 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 38.81 mm - - - no limitation

Design of Anchor Plate (Elast-plastic method)

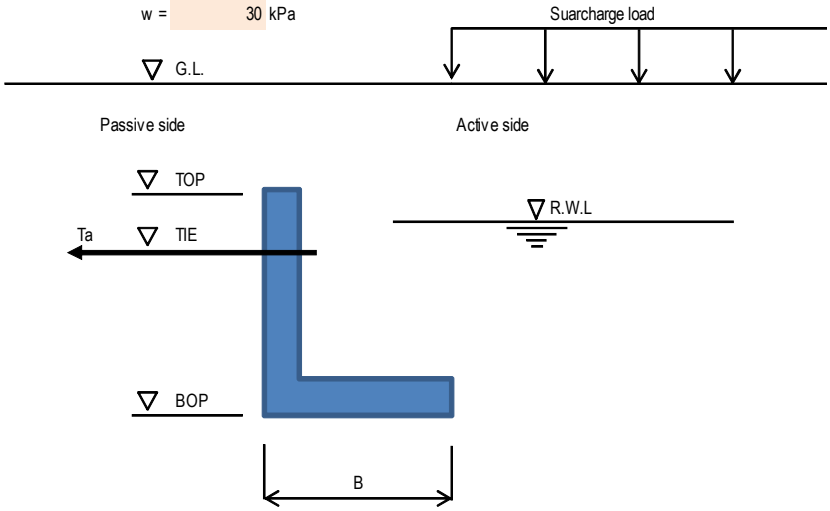
Block Block-a

Case : During Operation - - - Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.00	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	249.17	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	249.166	kN/m
	M =	672.7482	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	103.92	kN/m	(= Pa * FOS)
	Vertical force	27.85	kN/m	(= Pa * tan δ * FOS)
	Moment	171.77	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.00	0.65	13.90	2.00	36.14	72.28
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.55	2.60	10.00	2.23	92.30	205.37
Soil 2	above water	3.55	0.75	18.00	2.23	47.93	106.63
Soil 3	above water	4.00	1.20	18.00	2.00	86.40	172.80
						287.13	562.56

Anchor plate	Vertical force	287.13	kN/m	(= W)
	Moment	11.69	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

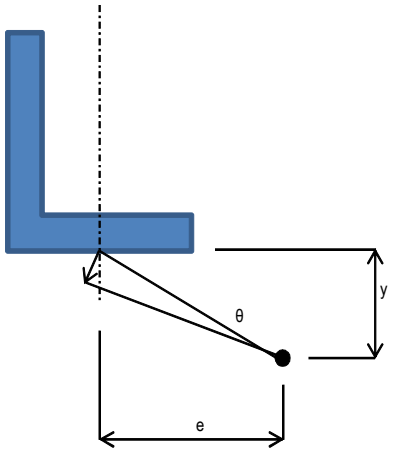
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.854	m
Horizontal distance	e	1.934	m
Rotation anglr	θ	0.003393	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	4.65	0.00	157.63	0.00	0.00	5.20	0.00
	5.50		4.65	0.00	157.63	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	4.65	0.00	157.63	0.00	0.00	4.80	0.00
	4.30		3.45	103.79	116.92	103.79	62.27	4.40	274.00
Plastic	4.30	0.11	3.45	103.79	116.92	103.79	5.66	3.96	22.43
	4.19		3.34	113.22	113.22	113.22	6.17	3.93	24.24
Elastic	4.19	0.64	3.34	113.22	113.22	113.22	36.28	3.68	133.43
	3.55		2.70	168.66	91.47	91.47	29.31	3.46	101.54
Elastic	3.55	0.00	2.70	168.66	91.47	91.47	0.00	3.25	0.00
	3.55		2.70	168.66	91.47	91.47	0.00	3.25	0.00
Elastic	3.55	3.25	2.70	168.66	91.47	91.47	148.64	2.17	322.06
	0.30		-0.55	324.82	-18.79	-18.79	-30.54	1.08	-33.08
	Below the top of Anchor Wall only						195.54		570.62

Passive side pressure	Horiz. force	195.54 kN/m	(= Pp ')
	Vertical force	52.39 kN/m	(= Pp ' * tan δ)
	Moment	675.41 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	133.48 kPa	P1	262.58 kN/m	M1	180.8 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				262.58		180.8	
Effective contact area	A (A')	3.934273112 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	157.55 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	157.55 kN/m	(= Q)
	Vertical force	262.58 kN/m	(= P1+P2)
	Moment	180.81 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	103.92	27.85	171.77
Weight of Plate	0.00	287.13	11.69
Tie tension	249.17	0.00	672.75
Passive soil pressure	-195.54	-52.39	-675.41
Base reaction	-157.55	-262.58	-180.81
Total	0.00	0.00	0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.854 m				
Horizontal distance	e	1.934 m				
Rotation angle	θ	0.0034 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	6.26 mm	<	Allowable deflection	30 mm	OK

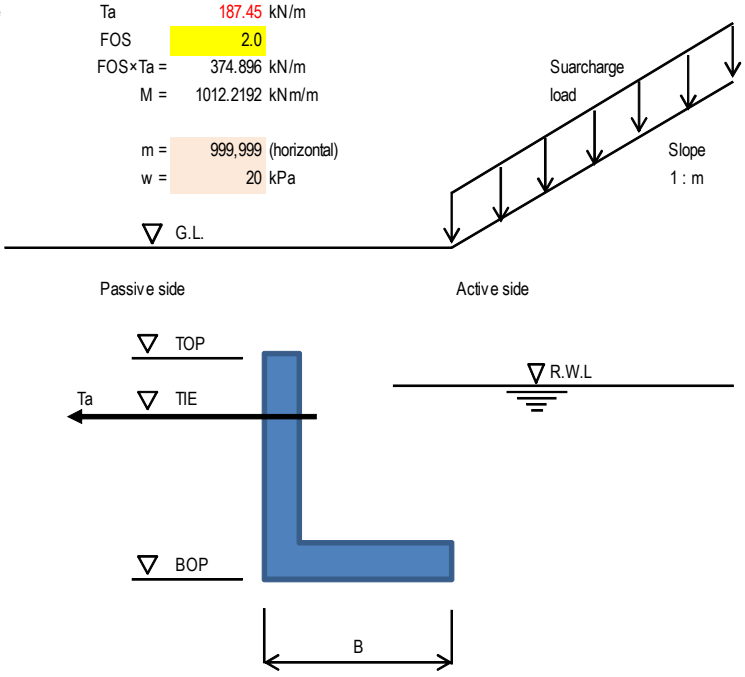
Design of Anchor Plate (Elast-plastic method)

Block Block-a

Case : During Construction --- Tie tension FOS = 2.0

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.00	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	187.45	kN/m
Factor of safety	FOS	2.0	
	FOS×Ta =	374.896	kN/m
	M =	1012.2192	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	116.70	kN/m	(= Pa * FOS)
	Vertical force	31.27	kN/m	(= Pa * tan δ * FOS)
	Moment	142.85	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.00	0.65	13.90	2.00	36.14	72.28
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.55	2.60	10.00	2.23	92.30	205.37
Soil 2	above water	3.55	0.75	18.00	2.23	47.93	106.63
Soil 3	above water	4.00	0.20	18.00	2.00	14.40	28.80
						215.13	418.56

Anchor plate	Vertical force	215.13	kN/m	(= W)
	Moment	11.69	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

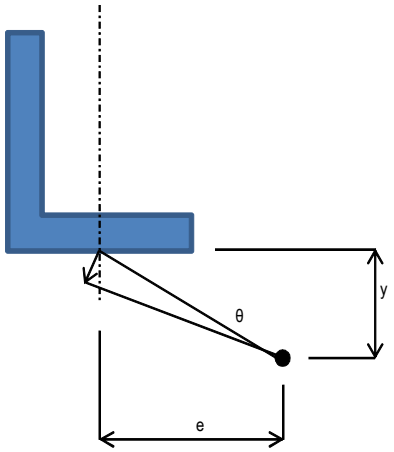
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	0.398	m
Horizontal distance	e	-0.045	m
Rotation anglr	θ	0.007151	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	4.90	0.00	350.24	0.00	0.00	4.20	0.00
	4.50		4.90	0.00	350.24	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	4.90	0.00	350.24	0.00	0.00	4.13	0.00
	4.30		4.70	17.30	335.94	17.30	1.73	4.07	7.03
Plastic	4.30	0.00	4.70	17.30	335.94	17.30	0.00	4.00	0.00
	4.30		4.70	17.30	335.94	17.30	0.00	4.00	0.00
Plastic	4.30	0.75	4.70	17.30	335.94	17.30	6.49	3.75	24.33
	3.55		3.95	82.17	282.31	82.17	30.81	3.50	107.84
Plastic	3.55	1.67	3.95	82.17	282.31	82.17	68.77	2.69	185.13
	1.88		2.27	162.60	162.60	162.60	136.09	2.13	290.42
Elastic	1.88	1.58	2.27	162.60	162.60	162.60	128.13	1.05	134.63
	0.30		0.70	238.33	49.89	49.89	39.32	0.53	20.65
	Below the top of Anchor Wall only						409.61		763.00

Passive side pressure	Horiz. force	409.61 kN/m	(= Pp ')
	Vertical force	109.75 kN/m	(= Pp ' * tan δ)
	Moment	982.51 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	139.80 kPa		P1	136.64 kN/m		M1	184.2 kNm/m
	p2	0.00 kPa		P2	0.00 kN/m		M2	0.0 kNm/m
					136.64			184.2
Effective contact area	A (A')	1.954867447 m2/m						
Base friction coefficient	μ	0.60						
Base shear force	Q	81.99 kN/m	(= μ * (Pa+P2))					

Base reaction force	Horiz. force	81.99 kN/m	(= Q)
	Vertical force	136.64 kN/m	(= P1+P2)
	Moment	184.25 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	116.70	31.27	142.85
Weight of Plate	0.00	215.13	11.69
Tie tension	374.90	0.00	1,012.22
Passive soil pressure	-409.61	-109.75	-982.51
Base reaction	-81.99	-136.64	-184.25
Total	-0.00	-0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	0.398 m				
Horizontal distance	e	-0.045 m				
Rotation angle	θ	0.0072 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 22.15 mm - - - no limitation

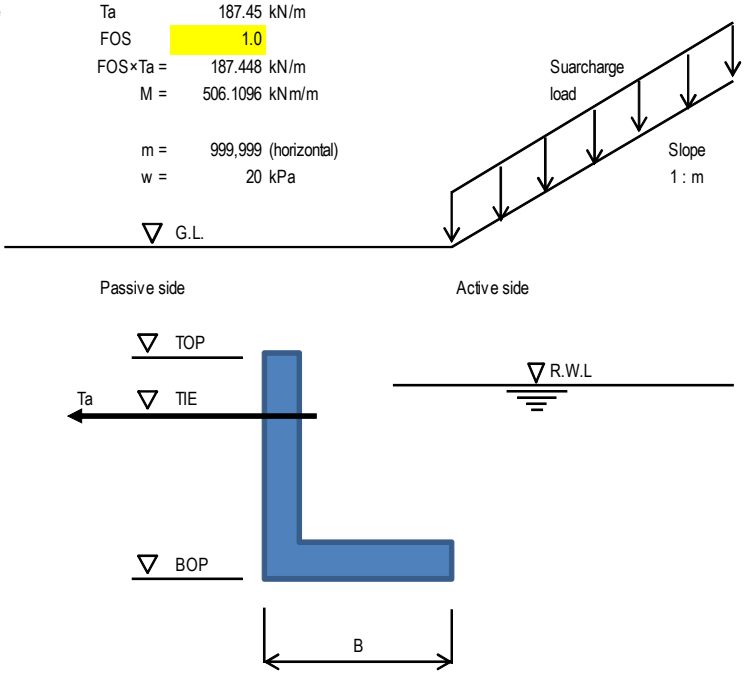
Design of Anchor Plate (Elast-plastic method)

Block Block-a

Case : During Construction --- Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.00	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	187.45	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	187.448	kN/m
	M =	506.1096	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	58.35	kN/m	(= Pa * FOS)
	Vertical force	15.63	kN/m	(= Pa * tan δ * FOS)
	Moment	71.42	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.00	0.65	13.90	2.00	36.14	72.28
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.55	2.60	10.00	2.23	92.30	205.37
Soil 2	above water	3.55	0.75	18.00	2.23	47.93	106.63
Soil 3	above water	4.00	0.20	18.00	2.00	14.40	28.80
						215.13	418.56

Anchor plate	Vertical force	215.13	kN/m	(= W)
	Moment	11.69	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

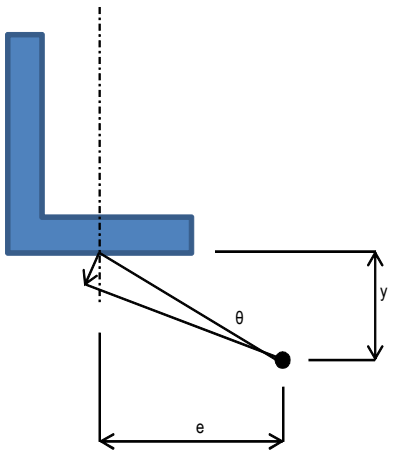
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.993	m
Horizontal distance	e	1.621	m
Rotation anglr	θ	0.002996	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	3.51	0.00	105.08	0.00	0.00	4.20	0.00
	4.50		3.51	0.00	105.08	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	3.51	0.00	105.08	0.00	0.00	4.13	0.00
	4.30		3.31	17.30	99.08	17.30	1.73	4.07	7.03
Plastic	4.30	0.70	3.31	17.30	99.08	17.30	6.07	3.77	22.87
	3.60		2.60	78.04	78.04	78.04	27.40	3.53	96.78
Elastic	3.60	0.05	2.60	78.04	78.04	78.04	1.86	3.28	6.11
	3.55		2.56	82.17	76.61	76.61	1.83	3.27	5.97
Elastic	3.55	0.00	2.56	82.17	76.61	76.61	0.00	3.25	0.00
	3.55		2.56	82.17	76.61	76.61	0.00	3.25	0.00
Elastic	3.55	3.25	2.56	82.17	76.61	76.61	124.49	2.17	269.73
	0.30		-0.69	238.33	-20.77	-20.77	-33.76	1.08	-36.57
	Below the top of Anchor Wall only						127.90		364.90

Passive side pressure	Horiz. force	127.90 kN/m	(= Pp ')
	Vertical force	34.27 kN/m	(= Pp ' * tan δ)
	Moment	433.44 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	108.51 kPa	P1	196.49 kN/m	M1	155.8 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				196.49		155.8	
Effective contact area	A (A')	3.621468697 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	117.89 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	117.89 kN/m	(= Q)
	Vertical force	196.49 kN/m	(= P1+P2)
	Moment	155.79 kNm/m	(= M1+M2)

Balance of forces

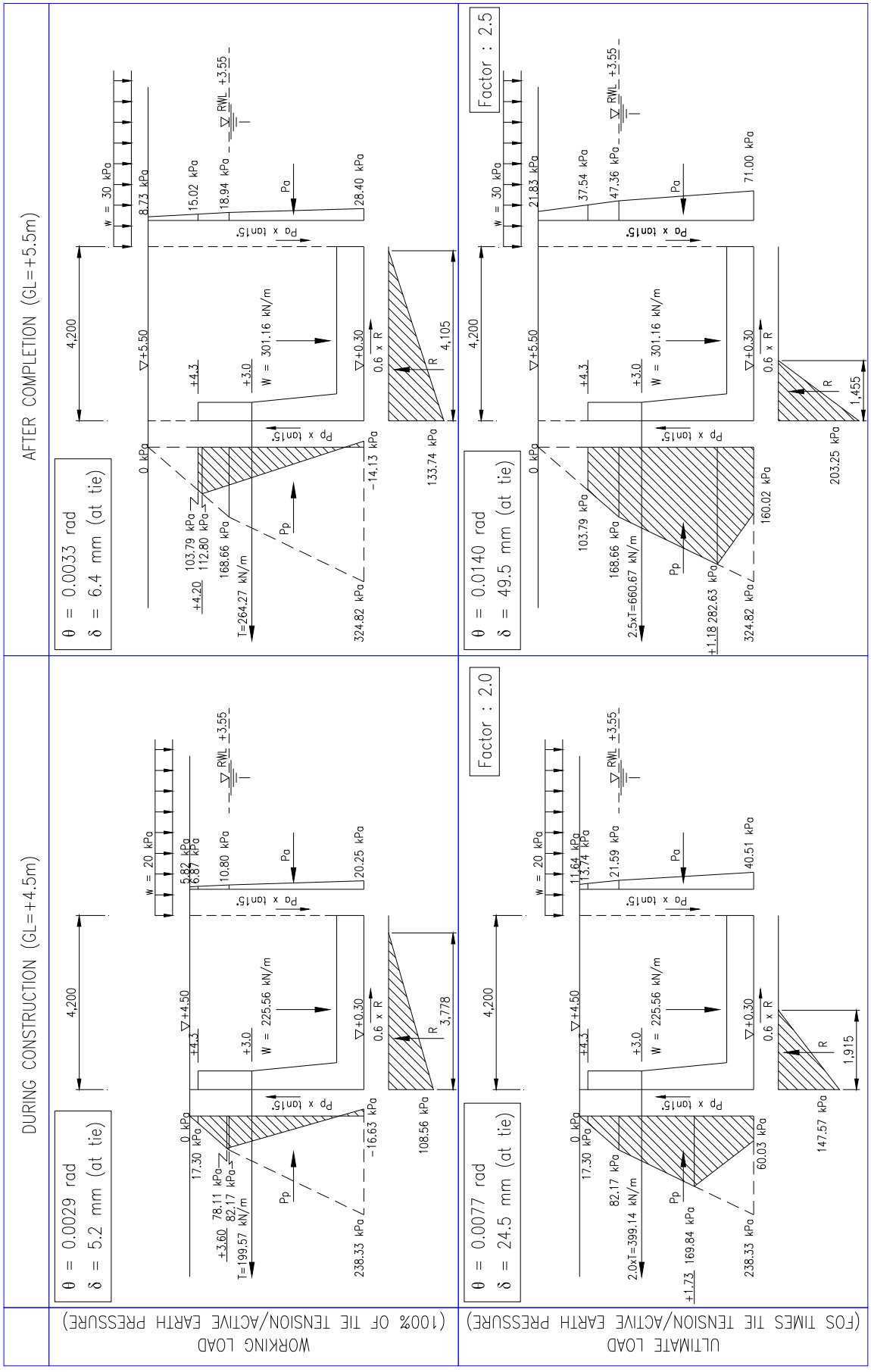
	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	58.35	15.63	71.42
Weight of Plate	0.00	215.13	11.69
Tie tension	187.45	0.00	506.11
Passive soil pressure	-127.90	-34.27	-433.44
Base reaction	-117.89	-196.49	-155.79
Total	0.00	0.00	0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.993 m				
Horizontal distance	e	1.621 m				
Rotation angle	θ	0.0030 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	5.11 mm	<	Allowable deflection	30 mm	OK

Summary of Analysis (Block-b)



Design of Anchor Plate (Elast-plastic method)

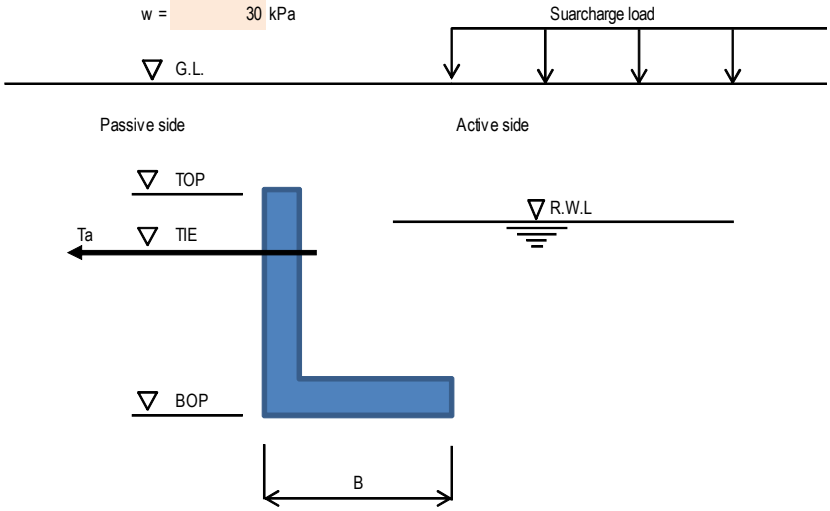
Block Block-b

Case : During Operation - - - Tie tension FOS = 2.5

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	264.27	kN/m
Factor of safety	FOS	2.5	
	FOS×Ta =	660.665	kN/m
	M =	1783.7955	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	259.80	kN/m	(= Pa * FOS)
	Vertical force	69.61	kN/m	(= Pa * tan δ * FOS)
	Moment	422.47	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	1.20	18.00	2.10	90.72	190.51
						301.16	620.07

Anchor plate	Vertical force	301.16	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

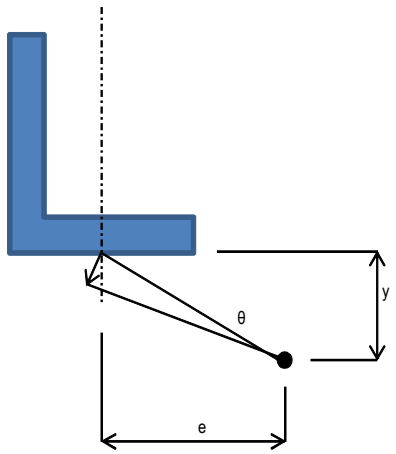
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	0.846	m
Horizontal distance	e	-0.645	m
Rotation anglr	θ	0.013965	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	6.35	0.00	886.18	0.00	0.00	5.20	0.00
	5.50		6.35	0.00	886.18	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	6.35	0.00	886.18	0.00	0.00	4.80	0.00
	4.30		5.15	103.79	718.60	103.79	62.27	4.40	274.00
Plastic	4.30	0.00	5.15	103.79	718.60	103.79	0.00	4.00	0.00
	4.30		5.15	103.79	718.60	103.79	0.00	4.00	0.00
Plastic	4.30	0.75	5.15	103.79	718.60	103.79	38.92	3.75	145.95
	3.55		4.40	168.66	613.87	168.66	63.25	3.50	221.36
Plastic	3.55	2.37	4.40	168.66	613.87	168.66	200.03	2.46	491.93
	1.18		2.02	282.63	282.63	282.63	335.20	1.67	559.34
Elastic	1.18	0.88	2.02	282.63	282.63	282.63	124.07	0.59	72.62
	0.30		1.15	324.82	160.02	160.02	70.25	0.29	20.56
	Below the top of Anchor Wall only						831.72		1,511.76

Passive side pressure	Horiz. force	831.72 kN/m	(= Pp ')
	Vertical force	222.86 kN/m	(= Pp ' * tan δ)
	Moment	1,979.76 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	203.25 kPa	P1	147.91 kN/m	M1	238.9 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				147.91		238.9	
Effective contact area	A (A')	1.455455519 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	88.75 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	88.75 kN/m	(= Q)
	Vertical force	147.91 kN/m	(= P1+P2)
	Moment	238.85 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	259.80	69.61	422.47
Weight of Plate	0.00	301.16	12.35
Tie tension	660.67	0.00	1,783.80
Passive soil pressure	-831.72	-222.86	-1,979.76
Base reaction	-88.75	-147.91	-238.85
Total	0.00	0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	0.846 m				
Horizontal distance	e	-0.645 m				
Rotation angle	θ	0.0140 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 49.52 mm - - - no limitation

Design of Anchor Plate (Elast-plastic method)

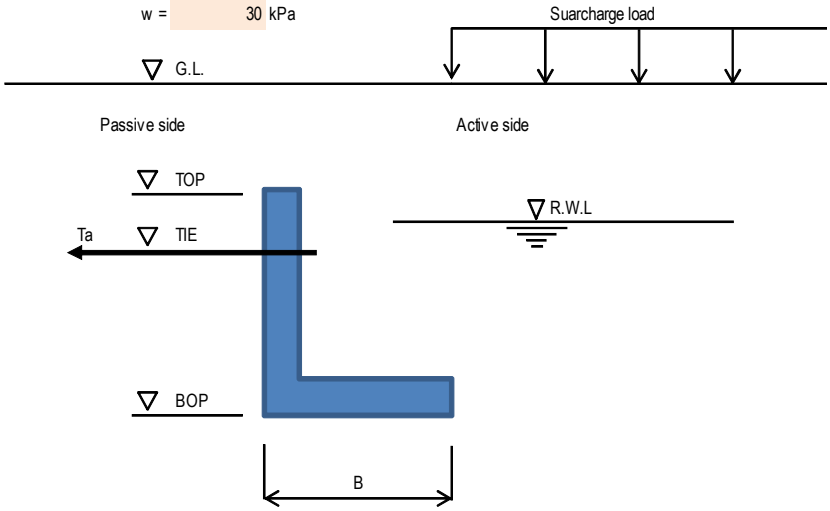
Block Block-b

Case : During Operation - - - Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	264.27	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	264.266	kN/m
	M =	713.5182	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	103.92	kN/m	(= Pa * FOS)
	Vertical force	27.85	kN/m	(= Pa * tan δ * FOS)
	Moment	168.99	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	1.20	18.00	2.10	90.72	190.51
						301.16	620.07

Anchor plate	Vertical force	301.16	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

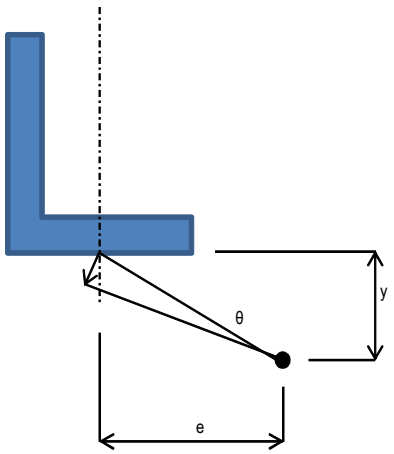
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.734	m
Horizontal distance	e	2.005	m
Rotation anglr	θ	0.003258	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	4.77	0.00	155.30	0.00	0.00	5.20	0.00
	5.50		4.77	0.00	155.30	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	4.77	0.00	155.30	0.00	0.00	4.80	0.00
	4.30		3.57	103.79	116.20	103.79	62.27	4.40	274.00
Plastic	4.30	0.10	3.57	103.79	116.20	103.79	5.41	3.97	21.45
	4.20		3.46	112.80	112.80	112.80	5.88	3.93	23.11
Elastic	4.20	0.65	3.46	112.80	112.80	112.80	36.42	3.68	134.05
	3.55		2.82	168.66	91.76	91.76	29.63	3.47	102.67
Elastic	3.55	0.00	2.82	168.66	91.76	91.76	0.00	3.25	0.00
	3.55		2.82	168.66	91.76	91.76	0.00	3.25	0.00
Elastic	3.55	3.25	2.82	168.66	91.76	91.76	149.12	2.17	323.08
	0.30		-0.43	324.82	-14.13	-14.13	-22.95	1.08	-24.87
	Below the top of Anchor Wall only						203.50		579.50

Passive side pressure	Horiz. force	203.50 kN/m	(= Pp ')
	Vertical force	54.53 kN/m	(= Pp ' * tan δ)
	Moment	694.01 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	133.74 kPa	P1	274.47 kN/m	M1	200.8 kNm/m
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m
				274.47		200.8
Effective contact area	A (A')	4.104694112 m2/m				
Base friction coefficient	μ	0.60				
Base shear force	Q	164.68 kN/m	(= μ * (Pa+P2))			

Base reaction force	Horiz. force	164.68 kN/m	(= Q)
	Vertical force	274.47 kN/m	(= P1+P2)
	Moment	200.85 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	103.92	27.85	168.99
Weight of Plate	0.00	301.16	12.35
Tie tension	264.27	0.00	713.52
Passive soil pressure	-203.50	-54.53	-694.01
Base reaction	-164.68	-274.47	-200.85
Total	0.00	0.00	0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.734 m			
Horizontal distance	e	2.005 m			
Rotation angle	θ	0.0033 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	6.41 mm	<	Allowable deflection	30 mm	OK

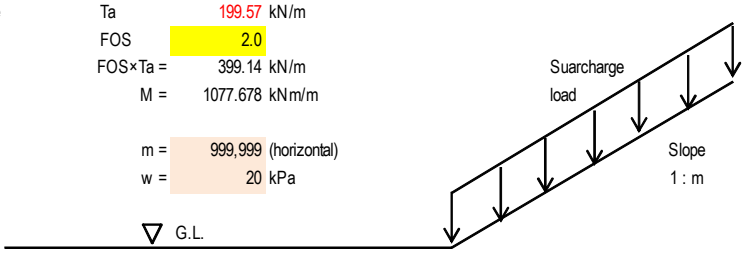
Design of Anchor Plate (Elast-plastic method)

Block Block-b

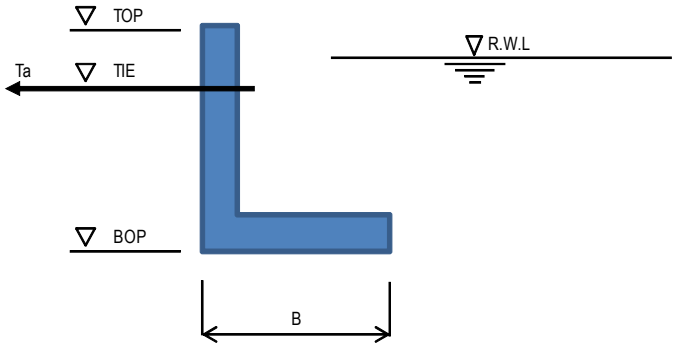
Case : During Construction - - - Tie tension FOS = 2.0

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	199.57	kN/m
Factor of safety	FOS	2.0	
	FOS×Ta =	399.14	kN/m
	M =	1077.678	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa



Passive side Active side



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	116.70	kN/m	(= Pa * FOS)
	Vertical force	31.27	kN/m	(= Pa * tan δ * FOS)
	Moment	139.72	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	0.20	18.00	2.10	15.12	31.75
						225.56	461.31

Anchor plate	Vertical force	225.56	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

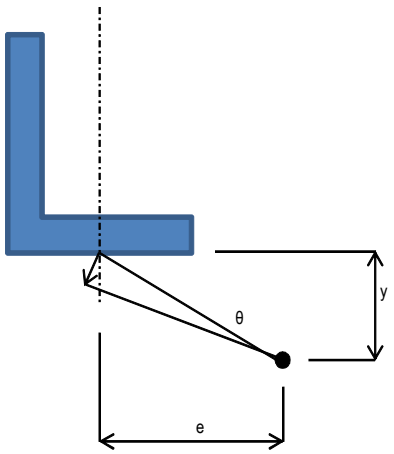
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	0.479	m
Horizontal distance	e	-0.185	m
Rotation anglr	θ	0.007705	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	4.98	0.00	383.62	0.00	0.00	4.20	0.00
	4.50		4.98	0.00	383.62	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	4.98	0.00	383.62	0.00	0.00	4.13	0.00
	4.30		4.78	17.30	368.21	17.30	1.73	4.07	7.03
Plastic	4.30	0.00	4.78	17.30	368.21	17.30	0.00	4.00	0.00
	4.30		4.78	17.30	368.21	17.30	0.00	4.00	0.00
Plastic	4.30	0.75	4.78	17.30	368.21	17.30	6.49	3.75	24.33
	3.55		4.03	82.17	310.43	82.17	30.81	3.50	107.84
Plastic	3.55	1.82	4.03	82.17	310.43	82.17	74.96	2.64	198.04
	1.73		2.20	169.84	169.84	169.84	154.96	2.03	315.11
Elastic	1.73	1.43	2.20	169.84	169.84	169.84	121.04	0.95	115.01
	0.30		0.78	238.33	60.03	60.03	42.78	0.48	20.33
	Below the top of Anchor Wall only						431.04		780.65

Passive side pressure	Horiz. force	431.04 kN/m	(= Pp ')
	Vertical force	115.50 kN/m	(= Pp ' * tan δ)
	Moment	1,023.19 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	147.57 kPa	P1	141.33 kN/m	M1	206.6 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				141.33		206.6	
Effective contact area	A (A')	1.915384235 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	84.80 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	84.80 kN/m	(= Q)
	Vertical force	141.33 kN/m	(= P1+P2)
	Moment	206.56 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	116.70	31.27	139.72
Weight of Plate	0.00	225.56	12.35
Tie tension	399.14	0.00	1,077.68
Passive soil pressure	-431.04	-115.50	-1,023.19
Base reaction	-84.80	-141.33	-206.56
Total	-0.00	-0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	0.479 m				
Horizontal distance	e	-0.185 m				
Rotation angle	θ	0.0077 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 24.49 mm - - - no limitation

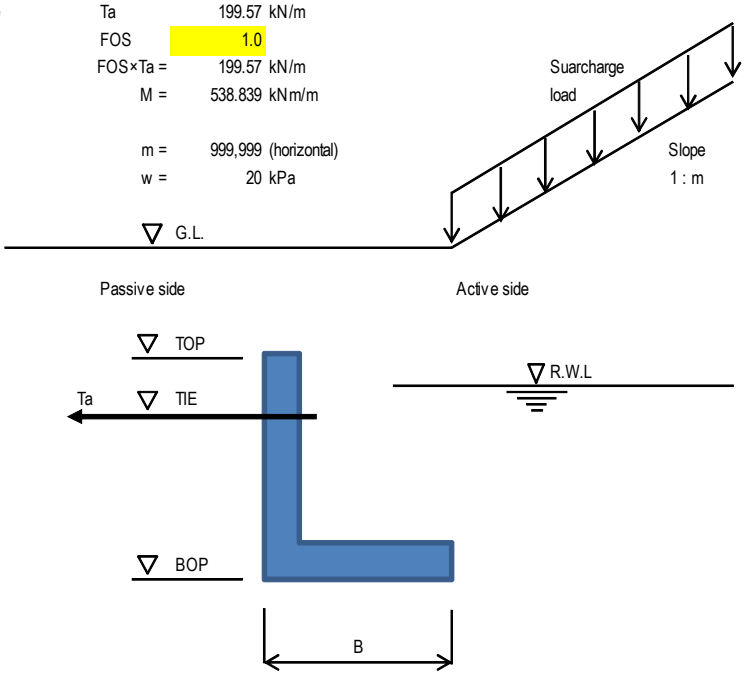
Design of Anchor Plate (Elast-plastic method)

Block Block-b

Case : During Construction --- Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	199.57	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	199.57	kN/m
	M =	538.839	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	58.35	kN/m	(= Pa * FOS)
	Vertical force	15.63	kN/m	(= Pa * tan δ * FOS)
	Moment	69.86	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	0.20	18.00	2.10	15.12	31.75
						225.56	461.31

Anchor plate	Vertical force	225.56	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

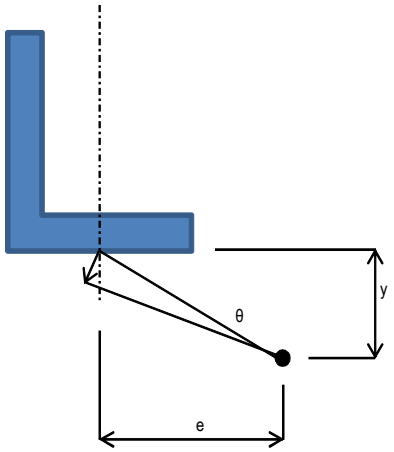
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.879	m
Horizontal distance	e	1.678	m
Rotation anglr	θ	0.002874	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	3.62	0.00	104.06	0.00	0.00	4.20	0.00
	4.50		3.62	0.00	104.06	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	3.62	0.00	104.06	0.00	0.00	4.13	0.00
	4.30		3.42	17.30	98.32	17.30	1.73	4.07	7.03
Plastic	4.30	0.70	3.42	17.30	98.32	17.30	6.08	3.77	22.90
	3.60		2.72	78.11	78.11	78.11	27.46	3.53	96.97
Elastic	3.60	0.05	2.72	78.11	78.11	78.11	1.83	3.28	6.01
	3.55		2.67	82.17	76.76	76.76	1.80	3.27	5.88
Elastic	3.55	0.00	2.67	82.17	76.76	76.76	0.00	3.25	0.00
	3.55		2.67	82.17	76.76	76.76	0.00	3.25	0.00
Elastic	3.55	3.25	2.67	82.17	76.76	76.76	124.74	2.17	270.27
	0.30		-0.58	238.33	-16.63	-16.63	-27.02	1.08	-29.27
	Below the top of Anchor Wall only						134.89		372.75

Passive side pressure	Horiz. force	134.89 kN/m	(= Pp ')
	Vertical force	36.14 kN/m	(= Pp ' * tan δ)
	Moment	448.66 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	108.56 kPa	P1	205.05 kN/m	M1	172.4 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				205.05		172.4	
Effective contact area	A (A')	3.777701481 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	123.03 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	123.03 kN/m	(= Q)
	Vertical force	205.05 kN/m	(= P1+P2)
	Moment	172.40 kNm/m	(= M1+M2)

Balance of forces

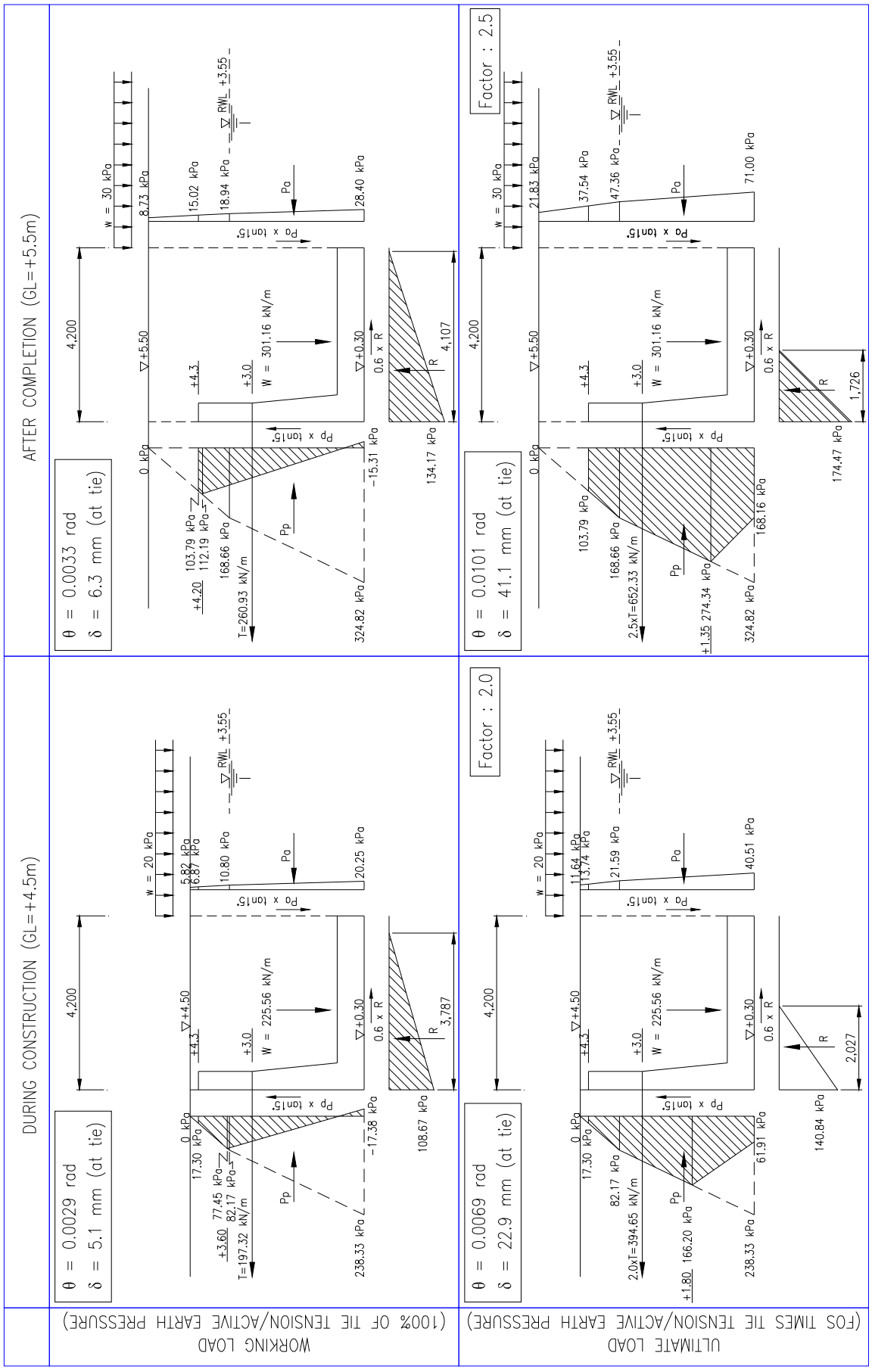
	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	58.35	15.63	69.86
Weight of Plate	0.00	225.56	12.35
Tie tension	199.57	0.00	538.84
Passive soil pressure	-134.89	-36.14	-448.66
Base reaction	-123.03	-205.05	-172.40
Total	-0.00	-0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.879 m				
Horizontal distance	e	1.678 m				
Rotation angle	θ	0.0029 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	5.23 mm	<	Allowable deflection	30 mm	OK

Summary of Analysis (Block-c)



Design of Anchor Plate (Elast-plastic method)

Block Block-c

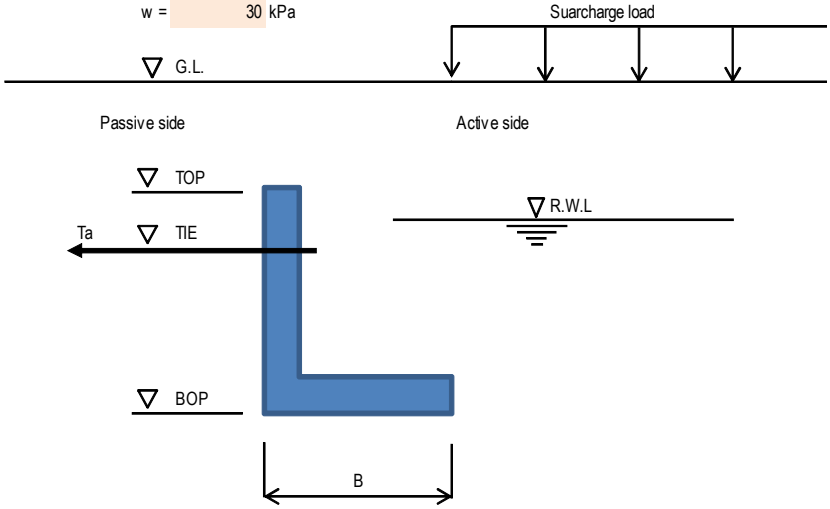
Case : During Operation - - - Tie tension FOS = 2.5

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m

Tie elevation	TIE	3.00	m
Tie tension force	Ta	260.93	kN/m
Factor of safety	FOS	2.5	
	FOS×Ta =	652.3275	kN/m
	M =	1761.28425	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	259.80	kN/m	(= Pa * FOS)
	Vertical force	69.61	kN/m	(= Pa * tan δ * FOS)
	Moment	422.47	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	1.20	18.00	2.10	90.72	190.51
						301.16	620.07

Anchor plate	Vertical force	301.16	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

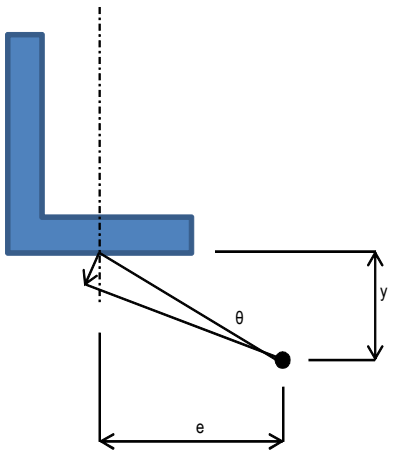
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	1.364	m
Horizontal distance	e	-0.374	m
Rotation anglr	θ	0.010108	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	6.86	0.00	693.77	0.00	0.00	5.20	0.00
	5.50		6.86	0.00	693.77	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	6.86	0.00	693.77	0.00	0.00	4.80	0.00
	4.30		5.66	103.79	572.48	103.79	62.27	4.40	274.00
Plastic	4.30	0.00	5.66	103.79	572.48	103.79	0.00	4.00	0.00
	4.30		5.66	103.79	572.48	103.79	0.00	4.00	0.00
Plastic	4.30	0.75	5.66	103.79	572.48	103.79	38.92	3.75	145.95
	3.55		4.91	168.66	496.67	168.66	63.25	3.50	221.36
Plastic	3.55	2.20	4.91	168.66	496.67	168.66	185.48	2.52	466.83
	1.35		2.71	274.34	274.34	274.34	301.71	1.78	538.15
Elastic	1.35	1.05	2.71	274.34	274.34	274.34	144.09	0.70	100.91
	0.30		1.66	324.82	168.16	168.16	88.33	0.35	30.93
	Below the top of Anchor Wall only						821.78		1,504.12

Passive side pressure	Horiz. force	821.78 kN/m	(= Pp ')
	Vertical force	220.20 kN/m	(= Pp ' * tan δ)
	Moment	1,966.54 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	174.47 kPa	P1	150.57 kN/m	M1	229.6 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				150.57		229.6	
Effective contact area	A (A')	1.726066166 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	90.34 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	90.34 kN/m	(= Q)
	Vertical force	150.57 kN/m	(= P1+P2)
	Moment	229.57 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	259.80	69.61	422.47
Weight of Plate	0.00	301.16	12.35
Tie tension	652.33	0.00	1,761.28
Passive soil pressure	-821.78	-220.20	-1,966.54
Base reaction	-90.34	-150.57	-229.57
Total	0.00	0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	1.364 m				
Horizontal distance	e	-0.374 m				
Rotation angle	θ	0.0101 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 41.08 mm - - - no limitation

Design of Anchor Plate (Elast-plastic method)

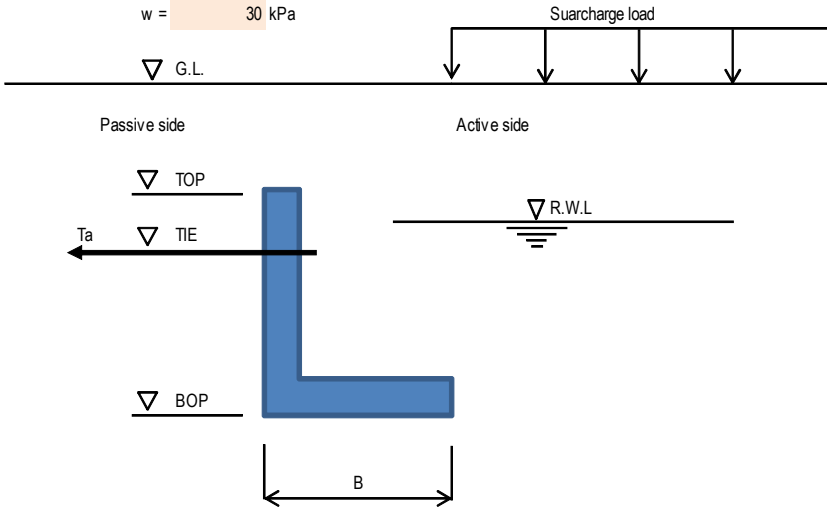
Block Block-c

Case : During Operation - - - Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	260.93	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	260.931	kN/m
	M =	704.5137	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	103.92	kN/m	(= Pa * FOS)
	Vertical force	27.85	kN/m	(= Pa * tan δ * FOS)
	Moment	168.99	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	1.20	18.00	2.10	90.72	190.51
						301.16	620.07

Anchor plate	Vertical force	301.16	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

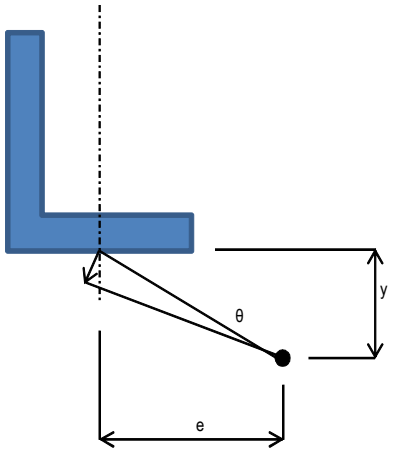
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.769	m
Horizontal distance	e	2.007	m
Rotation anglr	θ	0.003267	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	4.73	0.00	154.56	0.00	0.00	5.20	0.00
	5.50		4.73	0.00	154.56	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	4.73	0.00	154.56	0.00	0.00	4.80	0.00
	4.30		3.53	103.79	115.36	103.79	62.27	4.40	274.00
Plastic	4.30	0.10	3.53	103.79	115.36	103.79	5.04	3.97	19.99
	4.20		3.43	112.19	112.19	112.19	5.45	3.94	21.43
Elastic	4.20	0.65	3.43	112.19	112.19	112.19	36.62	3.69	134.97
	3.55		2.78	168.66	90.86	90.86	29.66	3.47	102.85
Elastic	3.55	0.00	2.78	168.66	90.86	90.86	0.00	3.25	0.00
	3.55		2.78	168.66	90.86	90.86	0.00	3.25	0.00
Elastic	3.55	3.25	2.78	168.66	90.86	90.86	147.64	2.17	319.89
	0.30		-0.47	324.82	-15.31	-15.31	-24.88	1.08	-26.96
	Below the top of Anchor Wall only						199.53		572.18

Passive side pressure	Horiz. force	199.53 kN/m	(= Pp ')
	Vertical force	53.46 kN/m	(= Pp ' * tan δ)
	Moment	684.45 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	134.17 kPa	P1	275.54 kN/m	M1	201.4 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				275.54		201.4	
Effective contact area	A (A')	4.10717768 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	165.32 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	165.32 kN/m	(= Q)
	Vertical force	275.54 kN/m	(= P1+P2)
	Moment	201.40 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	103.92	27.85	168.99
Weight of Plate	0.00	301.16	12.35
Tie tension	260.93	0.00	704.51
Passive soil pressure	-199.53	-53.46	-684.45
Base reaction	-165.32	-275.54	-201.40
Total	0.00	0.00	0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.769 m				
Horizontal distance	e	2.007 m				
Rotation angle	θ	0.0033 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	6.31 mm	<	Allowable deflection	30 mm	OK

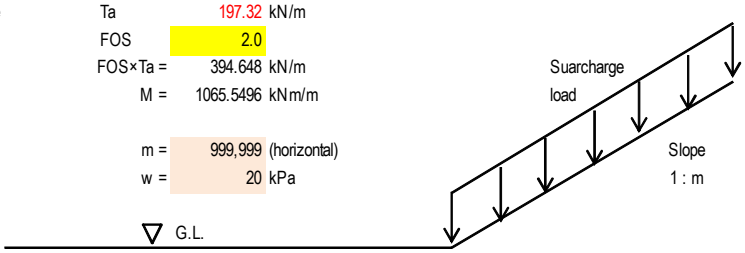
Design of Anchor Plate (Elast-plastic method)

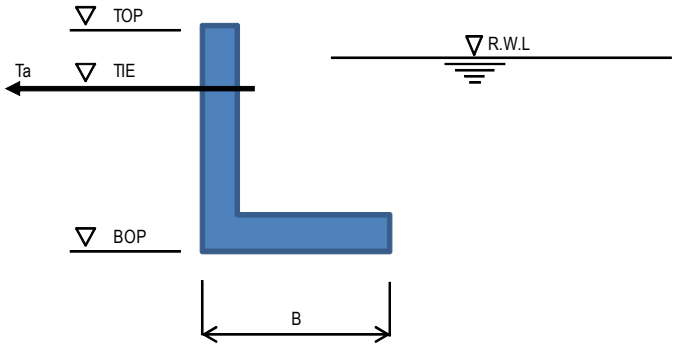
Block Block-c

Case : During Construction --- Tie tension FOS = 2.0

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	197.32	kN/m
Factor of safety	FOS	2.0	
	FOS×Ta =	394.648	kN/m
	M =	1065.5496	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa





Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	116.70	kN/m	(= Pa * FOS)
	Vertical force	31.27	kN/m	(= Pa * tan δ * FOS)
	Moment	139.72	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	0.20	18.00	2.10	15.12	31.75
						225.56	461.31

Anchor plate	Vertical force	225.56	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

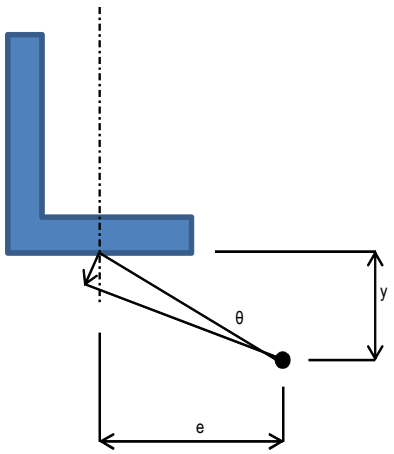
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	0.591	m
Horizontal distance	e	-0.073	m
Rotation anglr	θ	0.006948	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	5.09	0.00	353.71	0.00	0.00	4.20	0.00
	4.50		5.09	0.00	353.71	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	5.09	0.00	353.71	0.00	0.00	4.13	0.00
	4.30		4.89	17.30	339.81	17.30	1.73	4.07	7.03
Plastic	4.30	0.00	4.89	17.30	339.81	17.30	0.00	4.00	0.00
	4.30		4.89	17.30	339.81	17.30	0.00	4.00	0.00
Plastic	4.30	0.75	4.89	17.30	339.81	17.30	6.49	3.75	24.33
	3.55		4.14	82.17	287.71	82.17	30.81	3.50	107.84
Plastic	3.55	1.75	4.14	82.17	287.71	82.17	71.85	2.67	191.62
	1.80		2.39	166.20	166.20	166.20	145.33	2.08	302.88
Elastic	1.80	1.50	2.39	166.20	166.20	166.20	124.74	1.00	124.83
	0.30		0.89	238.33	61.91	61.91	46.47	0.50	23.25
	Below the top of Anchor Wall only						425.69		774.76

Passive side pressure	Horiz. force	425.69 kN/m	(= Pp ')
	Vertical force	114.06 kN/m	(= Pp ' * tan δ)
	Moment	1,014.29 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	140.84 kPa	P1	142.76 kN/m	M1	203.3 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				142.76		203.3	
Effective contact area	A (A')	2.027229109 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	85.66 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	85.66 kN/m	(= Q)
	Vertical force	142.76 kN/m	(= P1+P2)
	Moment	203.33 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	116.70	31.27	139.72
Weight of Plate	0.00	225.56	12.35
Tie tension	394.65	0.00	1,065.55
Passive soil pressure	-425.69	-114.06	-1,014.29
Base reaction	-85.66	-142.76	-203.33
Total	-0.00	-0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	0.591 m			
Horizontal distance	e	-0.073 m			
Rotation angle	θ	0.0069 rad	<	Allowable rotation angle	0.02 rad OK

Horizontal deflection at tie δ 22.87 mm - - - no limitation

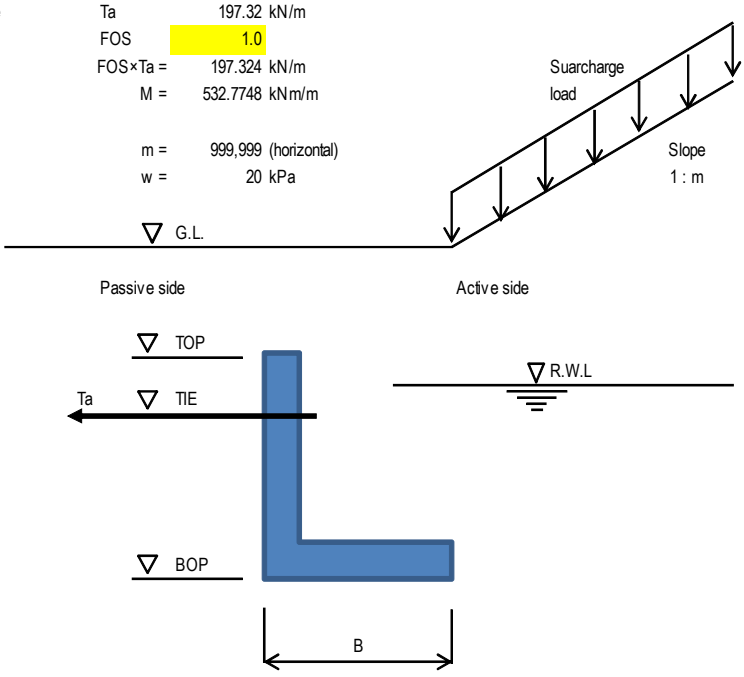
Design of Anchor Plate (Elast-plastic method)

Block Block-c

Case : During Construction --- Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.20	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	197.32	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	197.324	kN/m
	M =	532.7748	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	58.35	kN/m	(= Pa * FOS)
	Vertical force	15.63	kN/m	(= Pa * tan δ * FOS)
	Moment	69.86	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.20	0.65	13.90	2.10	37.95	79.69
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	3.75	2.60	10.00	2.33	97.50	226.69
Soil 2	above water	3.75	0.75	18.00	2.33	50.63	117.70
Soil 3	above water	4.20	0.20	18.00	2.10	15.12	31.75
						225.56	461.31

Anchor plate	Vertical force	225.56	kN/m	(= W)
	Moment	12.35	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)	
Below the plate	N =	5	(rock)	

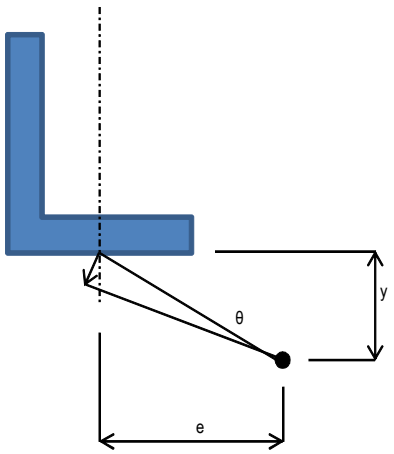
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.905	m
Horizontal distance	e	1.687	m
Rotation anglr	θ	0.002870	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	3.59	0.00	103.15	0.00	0.00	4.20	0.00
	4.50		3.59	0.00	103.15	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	3.59	0.00	103.15	0.00	0.00	4.13	0.00
	4.30		3.39	17.30	97.41	17.30	1.73	4.07	7.03
Plastic	4.30	0.70	3.39	17.30	97.41	17.30	6.02	3.77	22.67
	3.60		2.70	77.45	77.45	77.45	26.94	3.54	95.25
Elastic	3.60	0.05	2.70	77.45	77.45	77.45	2.11	3.29	6.93
	3.55		2.64	82.17	75.89	75.89	2.07	3.27	6.76
Elastic	3.55	0.00	2.64	82.17	75.89	75.89	0.00	3.25	0.00
	3.55		2.64	82.17	75.89	75.89	0.00	3.25	0.00
Elastic	3.55	3.25	2.64	82.17	75.89	75.89	123.32	2.17	267.20
	0.30		-0.61	238.33	-17.38	-17.38	-28.24	1.08	-30.59
	Below the top of Anchor Wall only						132.21		368.22

Passive side pressure	Horiz. force	132.21 kN/m	(= Pp ')
	Vertical force	35.43 kN/m	(= Pp ' * tan δ)
	Moment	442.61 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	108.67 kPa	P1	205.76 kN/m	M1	172.4 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				205.76		172.4	
Effective contact area	A (A')	3.786835623 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	123.46 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	123.46 kN/m	(= Q)
	Vertical force	205.76 kN/m	(= P1+P2)
	Moment	172.37 kNm/m	(= M1+M2)

Balance of forces

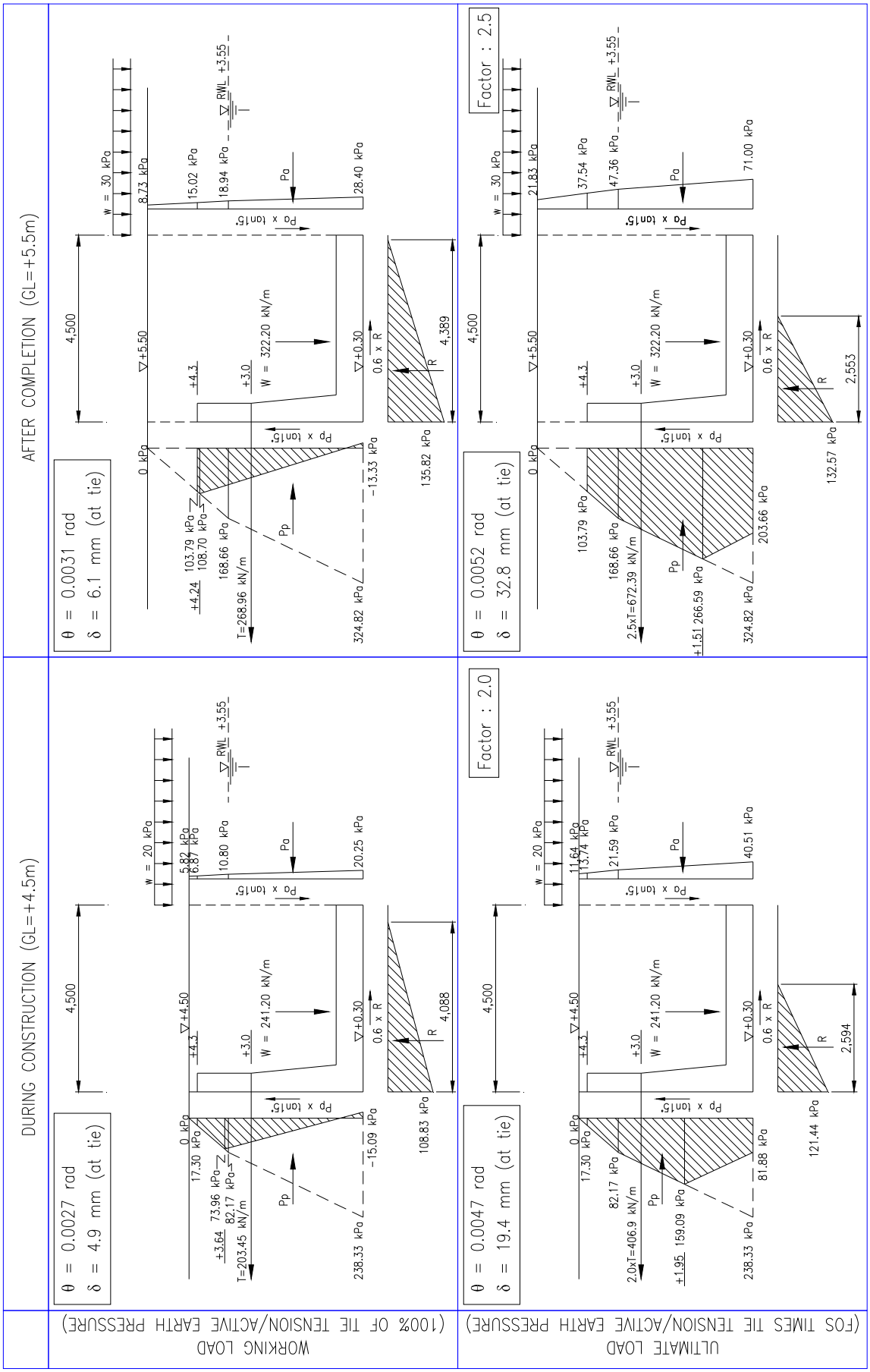
	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	58.35	15.63	69.86
Weight of Plate	0.00	225.56	12.35
Tie tension	197.32	0.00	532.77
Passive soil pressure	-132.21	-35.43	-442.61
Base reaction	-123.46	-205.76	-172.37
Total	0.00	0.00	0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.905 m				
Horizontal distance	e	1.687 m				
Rotation angle	θ	0.0029 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	5.15 mm	<	Allowable deflection	30 mm	OK

Summary of Analysis (Block-d)



Design of Anchor Plate (Elast-plastic method)

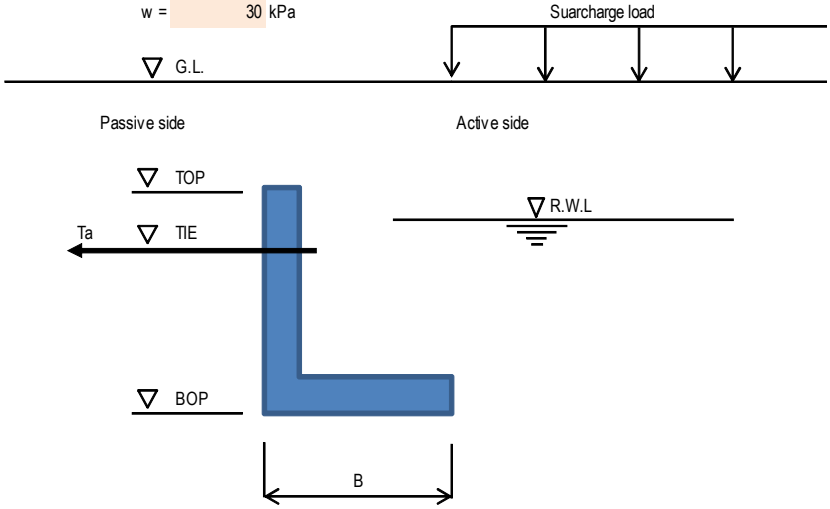
Block Block-d

Case : During Operation - - - Tie tension FOS = 2.5

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.50	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	268.96	kN/m
Factor of safety	FOS	2.5	
	FOS×Ta =	672.39	kN/m
	M =	1815.453	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	259.80	kN/m	(= Pa * FOS)
	Vertical force	69.61	kN/m	(= Pa * tan δ * FOS)
	Moment	412.02	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.50	0.65	13.90	2.25	40.66	91.48
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.05	2.60	10.00	2.48	105.30	260.62
Soil 2	above water	4.05	0.75	18.00	2.48	54.68	135.32
Soil 3	above water	4.50	1.20	18.00	2.25	97.20	218.70
						322.20	711.60

Anchor plate	Vertical force	322.20	kN/m	(= W)
	Moment	13.34	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

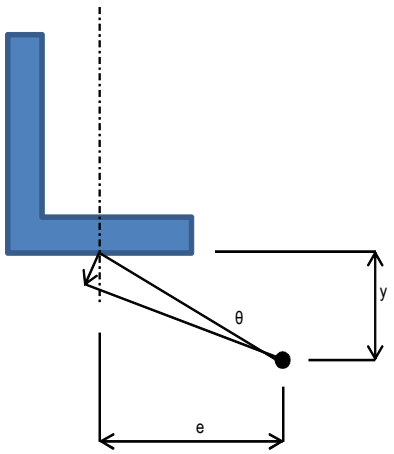
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	3.622	m
Horizontal distance	e	0.303	m
Rotation anglr	θ	0.005192	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	9.12	0.00	473.67	0.00	0.00	5.20	0.00
	5.50		9.12	0.00	473.67	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	9.12	0.00	473.67	0.00	0.00	4.80	0.00
	4.30		7.92	103.79	411.36	103.79	62.27	4.40	274.00
Plastic	4.30	0.00	7.92	103.79	411.36	103.79	0.00	4.00	0.00
	4.30		7.92	103.79	411.36	103.79	0.00	4.00	0.00
Plastic	4.30	0.75	7.92	103.79	411.36	103.79	38.92	3.75	145.95
	3.55		7.17	168.66	372.42	168.66	63.25	3.50	221.36
Plastic	3.55	2.04	7.17	168.66	372.42	168.66	171.87	2.57	441.81
	1.51		5.13	266.59	266.59	266.59	271.67	1.89	513.79
Elastic	1.51	1.21	5.13	266.59	266.59	266.59	161.54	0.81	130.51
	0.30		3.92	324.82	203.66	203.66	123.41	0.40	49.85
	Below the top of Anchor Wall only						830.65		1,503.28

Passive side pressure	Horiz. force	830.65 kN/m	(= Pp ')
	Vertical force	222.57 kN/m	(= Pp ' * tan δ)
	Moment	2,004.06 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	132.57 kPa	P1	169.24 kN/m	M1	236.8 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				169.24		236.8	
Effective contact area	A (A')	2.553143148 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	101.54 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	101.54 kN/m	(= Q)
	Vertical force	169.24 kN/m	(= P1+P2)
	Moment	236.76 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	259.80	69.61	412.02
Weight of Plate	0.00	322.20	13.34
Tie tension	672.39	0.00	1,815.45
Passive soil pressure	-830.65	-222.57	-2,004.06
Base reaction	-101.54	-169.24	-236.76
Total	-0.00	-0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	3.622 m				
Horizontal distance	e	0.303 m				
Rotation angle	θ	0.0052 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 32.83 mm - - - no limitation

Design of Anchor Plate (Elast-plastic method)

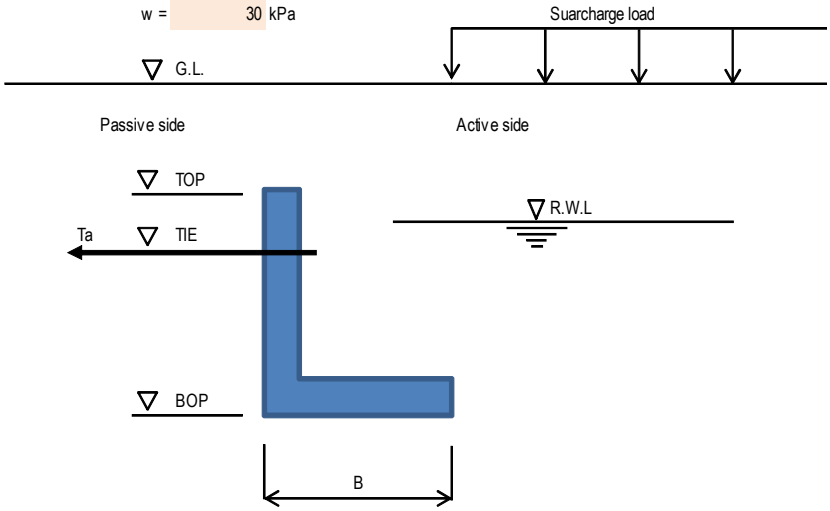
Block Block-d

Case : During Operation - - - Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	5.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.50	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	268.96	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	268.956	kN/m
	M =	726.1812	kNm/m

Surcharge load w = 30 kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	5.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
5.50		0.00	4.805	0.00	0.00
	1.20				
4.30		21.60	4.805	103.79	62.27
4.30		21.60	4.805	103.79	38.92
	0.75				
3.55		35.10	4.805	168.66	63.25
3.55		35.10	4.805	168.66	274.07
	3.25				
0.30		67.60	4.805	324.82	527.83
					966.33

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
5.50		30.00	0.291	8.73	5.24	4.80	25.14
	1.20						
4.30		51.60	0.291	15.02	9.01	4.40	39.64
4.30		51.60	0.291	15.02	5.63	3.75	21.12
	0.75						
3.55		65.10	0.291	18.94	7.10	3.50	24.86
3.55		65.10	0.291	18.94	30.78	2.17	66.70
	3.25						
0.30		97.60	0.291	28.40	46.15	1.08	50.00
					103.92		227.46

Active earth pressure	Horiz. force	103.92	kN/m	(= Pa * FOS)
	Vertical force	27.85	kN/m	(= Pa * tan δ * FOS)
	Moment	164.81	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.50	0.65	13.90	2.25	40.66	91.48
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.05	2.60	10.00	2.48	105.30	260.62
Soil 2	above water	4.05	0.75	18.00	2.48	54.68	135.32
Soil 3	above water	4.50	1.20	18.00	2.25	97.20	218.70
						322.20	711.60

Anchor plate	Vertical force	322.20	kN/m	(= W)
	Moment	13.34	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

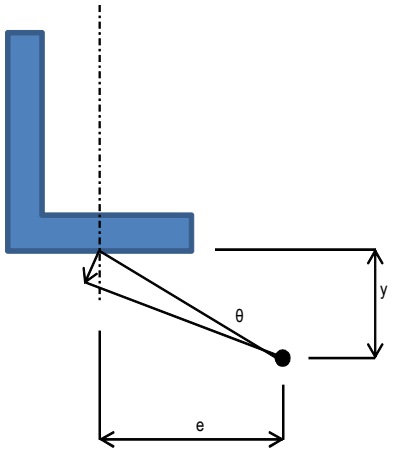
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.731	m
Horizontal distance	e	2.139	m
Rotation anglr	θ	0.003095	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	5.50	0.00	4.77	0.00	147.59	0.00	0.00	5.20	0.00
	5.50		4.77	0.00	147.59	0.00	0.00	5.20	0.00
Plastic	5.50	1.20	4.77	0.00	147.59	0.00	0.00	4.80	0.00
	4.30		3.57	103.79	110.45	103.79	62.27	4.40	274.00
Plastic	4.30	0.06	3.57	103.79	110.45	103.79	2.94	3.98	11.72
	4.24		3.51	108.70	108.70	108.70	3.08	3.96	12.22
Elastic	4.24	0.69	3.51	108.70	108.70	108.70	37.68	3.71	139.86
	3.55		2.82	168.66	87.24	87.24	30.24	3.48	105.27
Elastic	3.55	0.00	2.82	168.66	87.24	87.24	0.00	3.25	0.00
	3.55		2.82	168.66	87.24	87.24	0.00	3.25	0.00
Elastic	3.55	3.25	2.82	168.66	87.24	87.24	141.77	2.17	307.16
	0.30		-0.43	324.82	-13.33	-13.33	-21.67	1.08	-23.47
	Below the top of Anchor Wall only						194.05		552.77

Passive side pressure	Horiz. force	194.05 kN/m	(= Pp ')
	Vertical force	51.99 kN/m	(= Pp ' * tan δ)
	Moment	669.76 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	135.82 kPa	P1	298.05 kN/m	M1	234.6 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				298.05		234.6	
Effective contact area	A (A')	4.388866672 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	178.83 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	178.83 kN/m	(= Q)
	Vertical force	298.05 kN/m	(= P1+P2)
	Moment	234.58 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	103.92	27.85	164.81
Weight of Plate	0.00	322.20	13.34
Tie tension	268.96	0.00	726.18
Passive soil pressure	-194.05	-51.99	-669.76
Base reaction	-178.83	-298.05	-234.58
Total	-0.00	0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.731 m				
Horizontal distance	e	2.139 m				
Rotation angle	θ	0.0031 rad	<	Allowable rotation angle	0.02 rad	OK
Horizontal deflection at tie	δ	6.09 mm	<	Allowable deflection	30 mm	OK

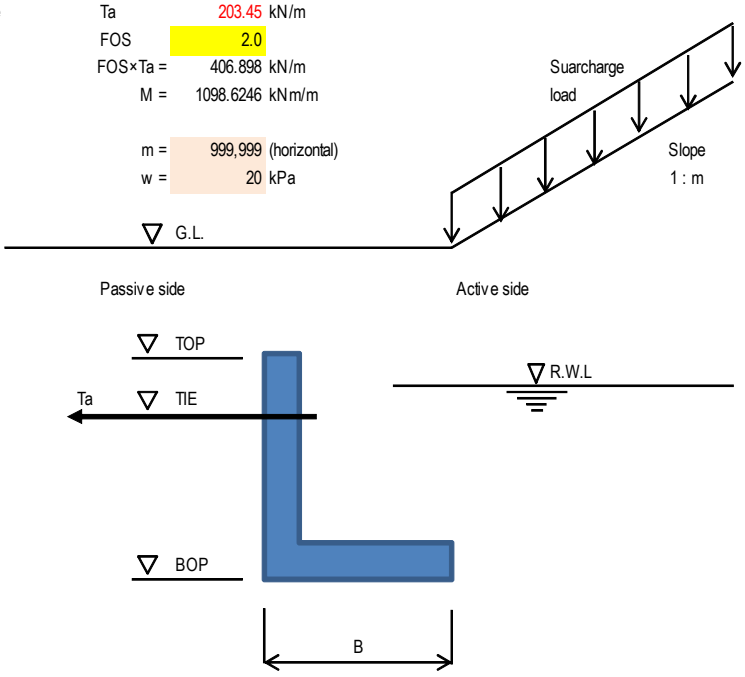
Design of Anchor Plate (Elast-plastic method)

Block Block-d

Case : During Construction --- Tie tension FOS = 2.0

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.50	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	203.45	kN/m
Factor of safety	FOS	2.0	
	FOS×Ta =	406.898	kN/m
	M =	1098.6246	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa



Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	116.70	kN/m	(= Pa * FOS)
	Vertical force	31.27	kN/m	(= Pa * tan δ * FOS)
	Moment	135.03	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.50	0.65	13.90	2.25	40.66	91.48
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.05	2.60	10.00	2.48	105.30	260.62
Soil 2	above water	4.05	0.75	18.00	2.48	54.68	135.32
Soil 3	above water	4.50	0.20	18.00	2.25	16.20	36.45
						241.20	529.35

Anchor plate	Vertical force	241.20	kN/m	(= W)
	Moment	13.34	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

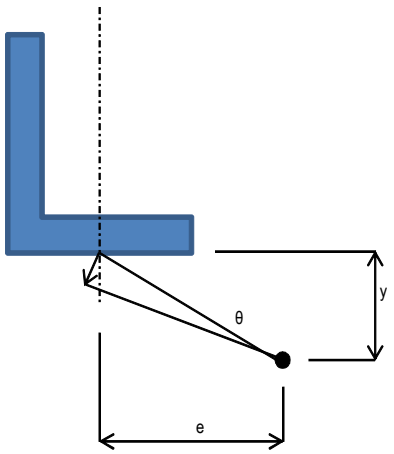
Soil Spring

Horizontal (Plate)	KH =	10,000	kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000	kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	1.449	m
Horizontal distance	e	0.344	m
Rotation anglr	θ	0.004682	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	5.95	0.00	278.53	0.00	0.00	4.20	0.00
	4.50		5.95	0.00	278.53	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	5.95	0.00	278.53	0.00	0.00	4.13	0.00
	4.30		5.75	17.30	269.16	17.30	1.73	4.07	7.03
Plastic	4.30	0.00	5.75	17.30	269.16	17.30	0.00	4.00	0.00
	4.30		5.75	17.30	269.16	17.30	0.00	4.00	0.00
Plastic	4.30	0.75	5.75	17.30	269.16	17.30	6.49	3.75	24.33
	3.55		5.00	82.17	234.05	82.17	30.81	3.50	107.84
Plastic	3.55	1.60	5.00	82.17	234.05	82.17	65.77	2.72	178.66
	1.95		3.40	159.09	159.09	159.09	127.35	2.18	277.96
Elastic	1.95	1.65	3.40	159.09	159.09	159.09	131.18	1.10	144.21
	0.30		1.75	238.33	81.88	81.88	67.51	0.55	37.11
	Below the top of Anchor Wall only						429.10		770.11

Passive side pressure	Horiz. force	429.10 kN/m	(= Pp ')
	Vertical force	114.98 kN/m	(= Pp ' * tan δ)
	Moment	1,028.81 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	121.44 kPa	P1	157.49 kN/m	M1	218.2 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				157.49		218.2	
Effective contact area	A (A')	2.593702963 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	94.49 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	94.49 kN/m	(= Q)
	Vertical force	157.49 kN/m	(= P1+P2)
	Moment	218.19 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	116.70	31.27	135.03
Weight of Plate	0.00	241.20	13.34
Tie tension	406.90	0.00	1,098.62
Passive soil pressure	-429.10	-114.98	-1,028.81
Base reaction	-94.49	-157.49	-218.19
Total	-0.00	-0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	1.449 m				
Horizontal distance	e	0.344 m				
Rotation angle	θ	0.0047 rad	<	Allowable rotation angle	0.02 rad	OK

Horizontal deflection at tie δ 19.42 mm - - - no limitation

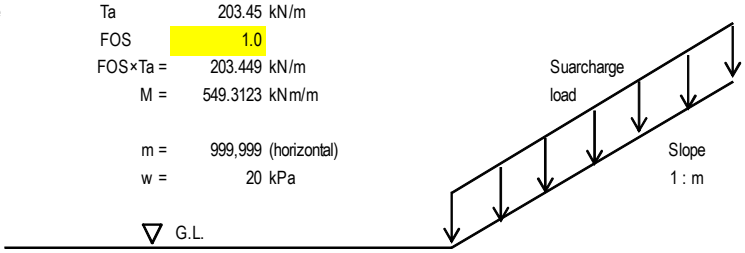
Design of Anchor Plate (Elast-plastic method)

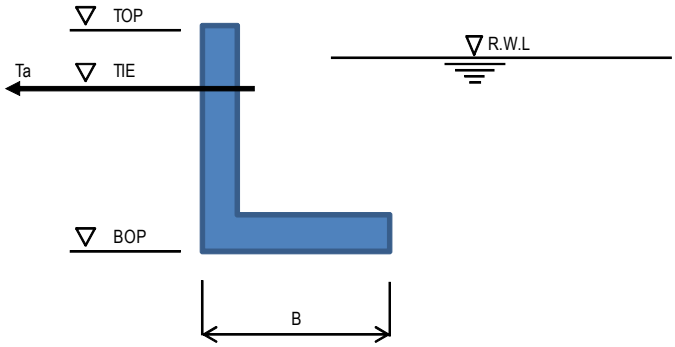
Block Block-d

Case : During Construction --- Tie tension FOS = 1.0 (Working tension load)

1. Design Conditions

Ground level	GL	4.50	m
Residual water level	RWL	3.55	m
Top of anchor plate	TOP	4.30	m
Bottom of anchor plate	BOP	0.30	m
Width of anchor plate	B	4.50	m
Tie elevation	TIE	3.00	m
Tie tension force	Ta	203.45	kN/m
Factor of safety	FOS	1.0	
	FOS×Ta =	203.449	kN/m
	M =	549.3123	kNm/m
Ground slope	m =	999,999	(horizontal)
Surcharge load	w =	20	kPa





Soil conditions

Passive side

	Elevation		γ	φ	δ	Kp cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	-15	4.805
layer-2	4.30	3.55	18	30	-15	4.805
layer-3	3.55	0.30	10	30	-15	4.805

Active side

	Elevation		γ	φ	δ	Ka cosδ
	Top	Bottom	(kN/m3)	(deg)	(deg)	
layer-1	4.50	4.30	18	30	15	0.291
layer-2	4.30	3.55	18	30	15	0.291
layer-3	3.55	0.30	10	30	15	0.291

2. Earth Pressure

Passive earth pressure

Elev. (m)	h (m)	γh (kPa)	Kp cosδ	pp (kPa)	Pp (kN/m)
4.50		0.00	4.805	0.00	0.00
	0.20				
4.30		3.60	4.805	17.30	1.73
4.30		3.60	4.805	17.30	6.49
	0.75				
3.55		17.10	4.805	82.17	30.81
3.55		17.10	4.805	82.17	133.52
	3.25				
0.30		49.60	4.805	238.33	387.28
					559.83

* Note that the above calculated values is the limit of the passive pressure which may not be fully mobilised depending on the soil strain based on the analysis.

Active earth pressure

Elev. (m)	h (m)	γh (kPa)	Ka cosδ	pa (kPa)	Pa (kN/m)	y (m)	Ma (kNm/m)
4.50		20.00	0.291	5.82	0.58	4.13	2.41
	0.20						
4.30		23.60	0.291	6.87	0.69	4.07	2.79
4.30		23.60	0.291	6.87	2.58	3.75	9.66
	0.75						
3.55		37.10	0.291	10.80	4.05	3.50	14.17
3.55		37.10	0.291	10.80	17.54	2.17	38.01
	3.25						
0.30		69.60	0.291	20.25	32.91	1.08	35.65
					58.35		102.69

Active earth pressure	Horiz. force	58.35	kN/m	(= Pa * FOS)
	Vertical force	15.63	kN/m	(= Pa * tan δ * FOS)
	Moment	67.51	kNm/m	(= (Ma - V * B/2) * FOS)

3. Weight of Anchor Plate (w/ soil)

Weight of anchor plate and soil

Wall thickness	b	0.45	m	Concrete	above water	γ=	24.00 kN/m3
Base slab thickness	t	0.65	m		underwater	γ'=	13.90 kN/m3

		b (m)	h (m)	γ (kN/m3)	x (m)	W (kN/m)	Wx (kNm/m)
Base	underwater	4.50	0.65	13.90	2.25	40.66	91.48
Wall 1	underwater	0.45	2.60	13.90	0.23	16.26	3.66
Wall 2	above water	0.45	0.75	24.00	0.23	8.10	1.82
Soil 1	underwater	4.05	2.60	10.00	2.48	105.30	260.62
Soil 2	above water	4.05	0.75	18.00	2.48	54.68	135.32
Soil 3	above water	4.50	0.20	18.00	2.25	16.20	36.45
						241.20	529.35

Anchor plate	Vertical force	241.20	kN/m	(= W)
	Moment	13.34	kNm/m	(=W * B/2 - Wx)

4. Soil Spring and Center of Rotation

SPT-N values

In front of the plate	N =	5	(sand)
Below the plate	N =	5	(rock)

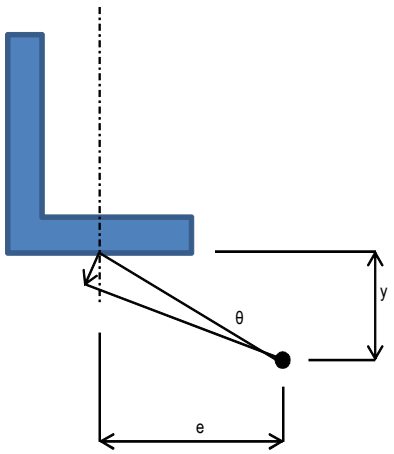
Soil Spring

Horizontal (Plate)	KH =	10,000 kN/m3	… = 2000 N
Vertical (base reaction)	KV =	10,000 kN/m3	… = 2000 N

Center of rotation

Center of rotation and rotation angle are assumed as follows:

Vertical distance	y	-0.867	m
Horizontal distance	e	1.838	m
Rotation anglr	θ	0.002662	rad



5. Soil Reaction Forces

Passive side soil reaction	Elev. (m)	h (m)	y ' (m)	pp * note 1 (kPa)	KH y'θ * note 2 (kPa)	pp ' * note 3 (kPa)	Pp ' (kN/m)	y (m)	Mp (kNm/m)
Plastic	4.50	0.00	3.63	0.00	96.72	0.00	0.00	4.20	0.00
	4.50		3.63	0.00	96.72	0.00	0.00	4.20	0.00
Plastic	4.50	0.20	3.63	0.00	96.72	0.00	0.00	4.13	0.00
	4.30		3.43	17.30	91.40	17.30	1.73	4.07	7.03
Plastic	4.30	0.66	3.43	17.30	91.40	17.30	5.67	3.78	21.43
	3.64		2.78	73.96	73.96	73.96	24.22	3.56	86.31
Elastic	3.64	0.09	2.78	73.96	73.96	73.96	3.51	3.31	11.63
	3.55		2.68	82.17	71.43	71.43	3.39	3.28	11.13
Elastic	3.55	0.00	2.68	82.17	71.43	71.43	0.00	3.25	0.00
	3.55		2.68	82.17	71.43	71.43	0.00	3.25	0.00
Elastic	3.55	3.25	2.68	82.17	71.43	71.43	116.07	2.17	251.49
	0.30		-0.57	238.33	-15.09	-15.09	-24.53	1.08	-26.57
	Below the top of Anchor Wall only						128.33		355.41

Passive side pressure	Horiz. force	128.33 kN/m	(= Pp ')
	Vertical force	34.39 kN/m	(= Pp ' * tan δ)
	Moment	432.78 kNm/m	(= Mp + V * B/2)

* note 1 : Passive earth pressure obtained in section 2.
* note 2 : Soil reaction obtained based on soil strain.
* note 3 : Smaller of pp and KH y' θ

Base reaction force	p1	108.83 kPa	P1	222.44 kN/m	M1	197.4 kNm/m	
	p2	0.00 kPa	P2	0.00 kN/m	M2	0.0 kNm/m	
				222.44		197.4	
Effective contact area	A (A')	4.08790852 m2/m					
Base friction coefficient	μ	0.60					
Base shear force	Q	133.47 kN/m	(= μ * (Pa+P2))				

Base reaction force	Horiz. force	133.47 kN/m	(= Q)
	Vertical force	222.44 kN/m	(= P1+P2)
	Moment	197.39 kNm/m	(= M1+M2)

Balance of forces

	Horiz force (+)←	Vert force (+)↓	Moment (+)↻
Active earth pressure	58.35	15.63	67.51
Weight of Plate	0.00	241.20	13.34
Tie tension	203.45	0.00	549.31
Passive soil pressure	-128.33	-34.39	-432.78
Base reaction	-133.47	-222.44	-197.39
Total	-0.00	0.00	-0.00

<== All values are nearly ZERO !!

Therefore, assumed center of rotation and rotation angle as shown below are correct !

Vertical distance	y	-0.867 m			
Horizontal distance	e	1.838 m			
Rotation angle	θ	0.0027 rad	<	Allowable rotation angle	0.02 rad OK
Horizontal deflection at tie	δ	4.88 mm	<	Allowable deflection	30 mm OK

4. Design of RC Section

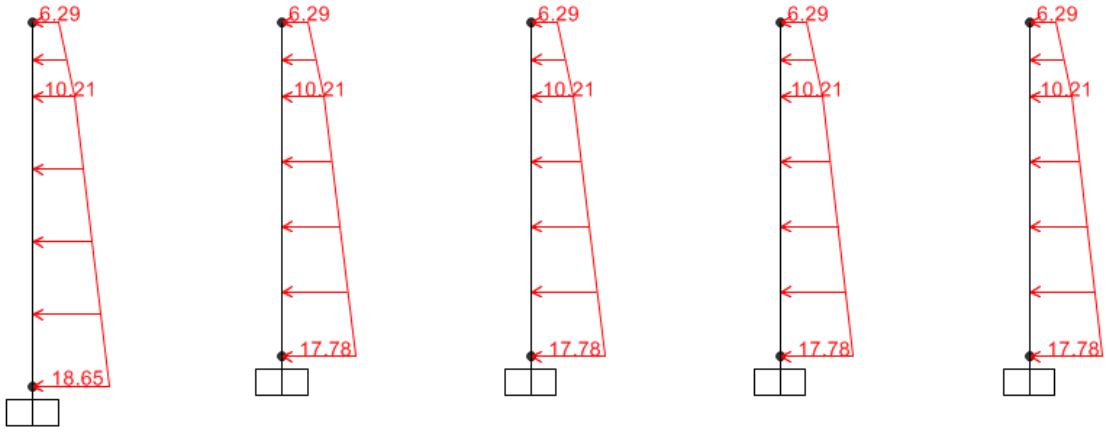
4.1 General

From section 3, it is obvious that the design forces under operation (after completion) are greater than that under construction. Therefore, the design of RC section uses the forces under operation.

4.2 Design force on front wall

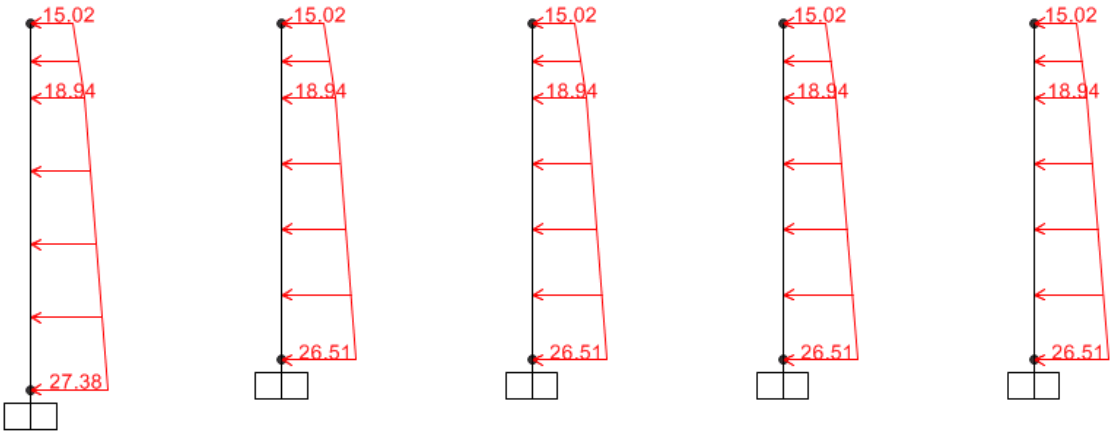
1) Design load

- Active earth pressure (w=0kPa) : Pa0



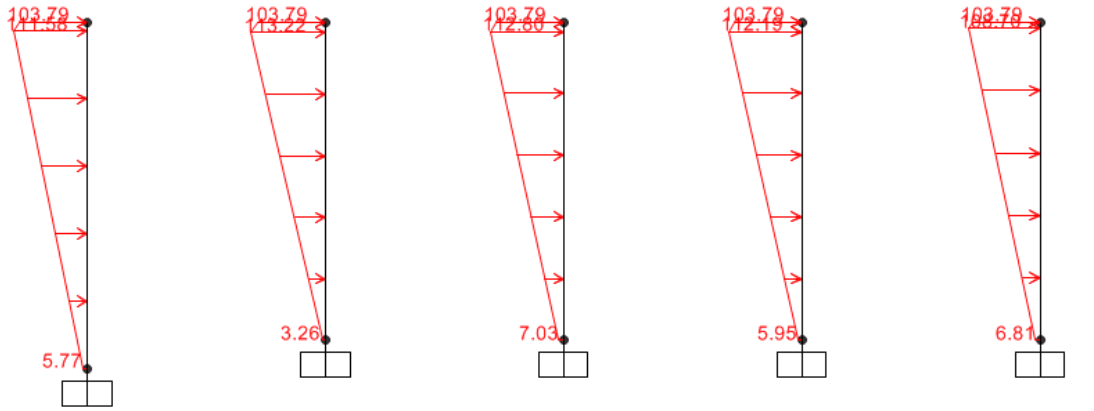
Block-1 Block-a Block-b Block-c Block-d

- Active earth pressure (w=30kPa) : Pa30



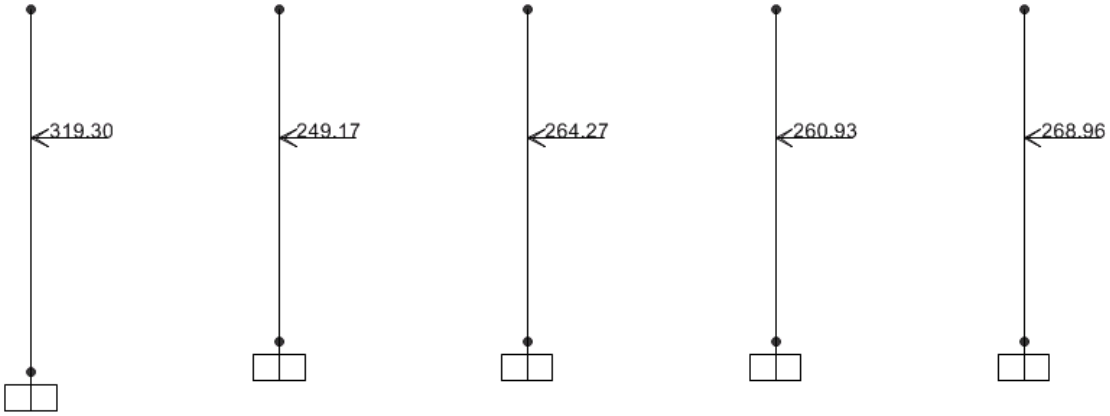
Block-1 Block-a Block-b Block-c Block-d

- Passive earth pressure : Pp



Block-1 Block-a Block-b Block-c Block-d

- Tie tension force : T



Block-1 Block-a Block-b Block-c Block-d

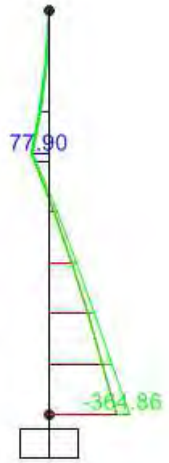
2) Analysis results

Analysis was made using SAP2000 for both of the following combinations:

- Pa0 + Pp + T
- Pa30 + Pp + T

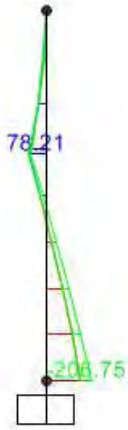
Enveloped results of the above two combinations are shown as follows.

- Bending moment (per meter, envelope)

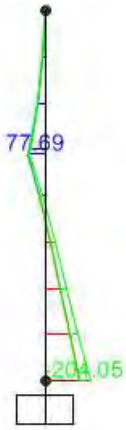


Block-1

Block-a



Block-b



Block-c

Block-d

		Bending Moment kNm/m
Block-1	positive	77.90
	negative	-364.86
Block-a	positive	78.32
	negative	-179.85
Block-b	positive	78.21
	negative	-206.75
Block-c	positive	77.69
	negative	-204.05
Block-d	positive	74.66
	negative	-235.97

note : positive moment induces tensile stress in seaside rebar.
negative moment induces tensile stress in landside reabar.

- Shear force (per meter, envelope)

Block-1

Block-a

Block-b

Block-c

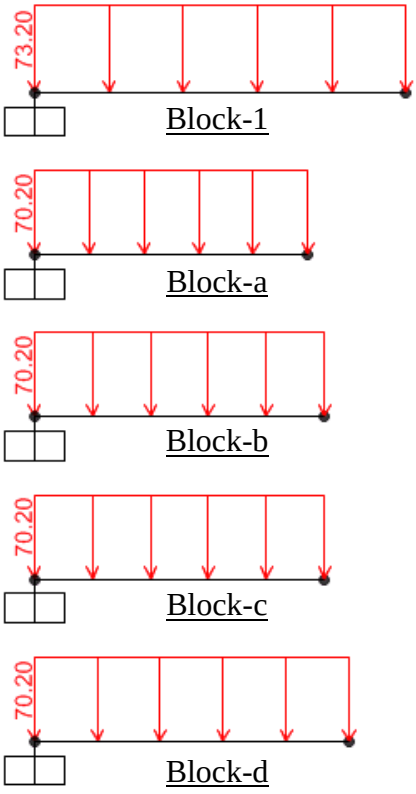
Block-d

	Shear Force kN/m
Block-1	219.95
Block-a	150.13
Block-b	165.10
Block-c	162.63
Block-d	175.20

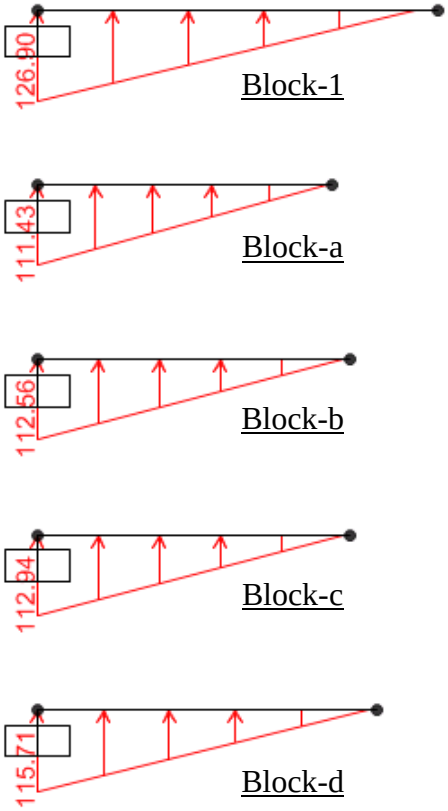
4.3 Design force on base slab

1) Design load

Vertical load : V



Base Reaction : R



* Vertical load:

Block-1 : w = (5.5-3.55)×18 + (3.55-0.65)×10 + (0.65-0.0)×(24-10) = 73.2 kPa

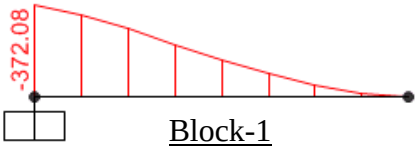
Block-a, b, c & d : w = (5.5-3.55)×18 + (3.55-0.95)×10 + (0.95-0.3)×(24-10) = 70.2 kPa

2) Analysis results

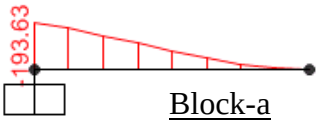
Analysis was made using SAP2000 for the following combination:

- V + R

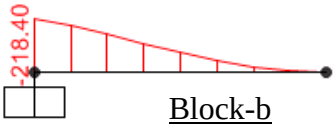
Bending Moment : M



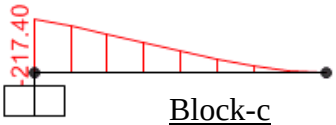
Block-1



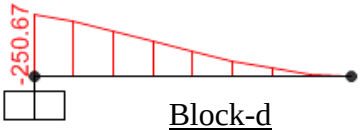
Block-a



Block-b



Block-c



Block-d

Shear Force : V

Block-1

Block-a

Block-b

Block-c

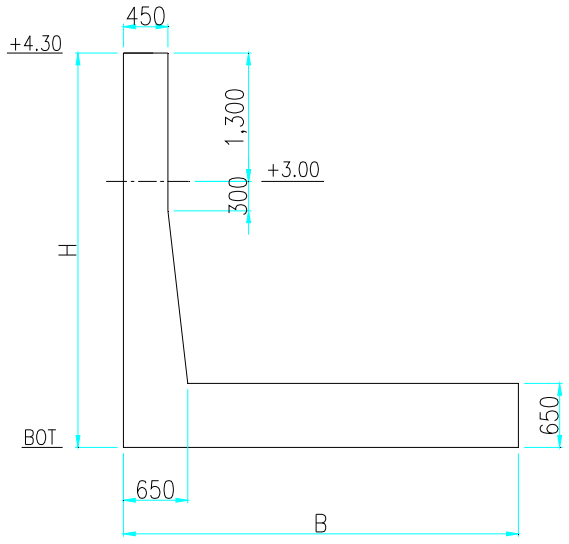
Block-d

	Bending Moment (kNm/m)	Shear Force (kN/m)
Block-1	-372.08	110.49
Block-a	-193.63	77.23
Block-b	-218.40	82.28
Block-c	-217.40	81.94
Block-d	-250.67	87.41

note : negative moment induces tensile stress in upper rebar.

4.4 RC section check

The dimensions of anchor block are shown below.



	B (mm)	H (mm)	BOT (mCDL)
Block-a	4,000	4,000	+0.30
Block-b	4,200	4,000	+0.30
Block-c	4,200	4,000	+0.30
Block-d	4,500	4,000	+0.30
Block-1	5,200	4,300	±0.00

The concrete sections were checked as following page and the results are all satisfactory.

- For the front wall (seaside rebar) and the base slab (lower rebar)

Concrete Section Design by Allowable Stress Method

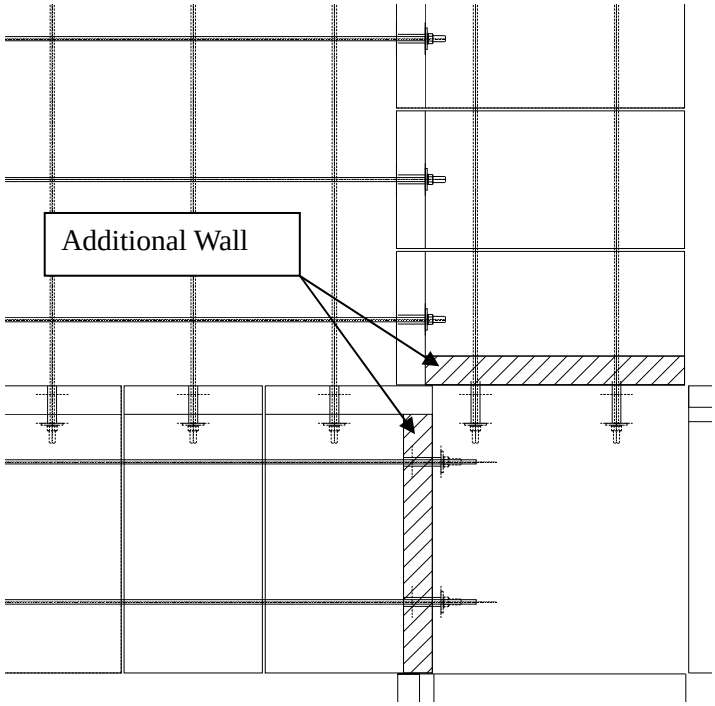
		Sym.	Unit	Block-1	Block-a	Block-b	Block-c	Block-d
Type of Member								
				Slab	**Slab**	**Slab**	**Slab**	**Slab**
Section Property								
Breadth of Section		b	mm	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Height of Section		h	mm	**450**	**450**	**450**	**450**	**450**
Effective height for tensile bar		d	mm	**364**	**364**	**364**	**364**	**364**
Design Load								
Bending Moment		M	kNm	77.90	78.32	78.21	77.69	74.66
Shear Force		S	kN	219.95	150.13	165.10	162.63	175.20
Allowable Stress - Reinforcement								
Material				**SD295**	**SD295**	**SD295**	**SD295**	**SD295**
Allowable stress		σsa	MPa	180	180	180	180	180
Allowable Stress - Concrete								
Standard Strength 28 days cylinder		σck	MPa	**30**	**30**	**30**	**30**	**30**
Allowable bending compressive stress		σca	MPa	11.0	11.0	11.0	11.0	11.0
Allowable shear stress without links		τa	MPa	1.00	1.00	1.00	1.00	1.00
Young's modulus ratio		n		7.14	7.14	7.14	7.14	7.14
Rebar Arrangement								
<Tensile bar>		Bar-1		**6.67 -D22**	**6.67 -D22**	**6.67 -D22**	**6.67 -D22**	**6.67 -D22**
		Bar-2		**0 -D16**	**0 -D16**	**0 -D16**	**0 -D16**	**0 -D16**
		As	mm^2	2,535	2,535	2,535	2,535	2,535
		p		0.006966	0.006966	0.006966	0.006966	0.006966
Cover		C	mm	75	75	75	75	75
Spacing		Cs	mm	150	150	150	150	150
<Link>				**0 -D13**	**0 -D13**	**0 -D13**	**0 -D13**	**0 -D13**
		Area	mm^2	0	0	0	0	0
		Spacing	mm	200	200	200	200	200
Working Stress								
Increment Factor for Allowable Stress				**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Concrete Compressive Stress	Working stress	σc	MPa	4.79	4.82	4.81	4.78	4.59
	Allowable stress	σca	MPa	11.00	11.00	11.00	11.00	11.00
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**
Steel Reinforcement	Working stress	σs	MPa	92.74	93.24	93.11	92.49	88.88
	Allowable stress	σsa	MPa	180.00	180.00	180.00	180.00	180.00
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**
Shear	Working stress	τ	MPa	0.66	0.45	0.50	0.49	0.53
	Allowable stress	τa	MPa	1.00	1.00	1.00	1.00	1.00
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**
Crack Width								
Flexural Crack	Calculated crack width	w	mm	0.263	0.264	0.264	0.262	0.255
	Allowable crack width	wa	mm	0.300	0.300	0.300	0.300	0.300
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**

- For the front wall (landside rebar) and the base slab (upper rebar)

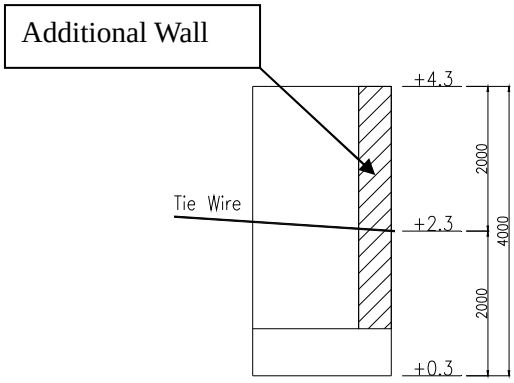
Concrete Section Design by Allowable Stress Method

		Sym.	Unit	Block-1	Block-a	Block-b	Block-c	Block-d
Type of Member								
				Slab	**Slab**	**Slab**	**Slab**	**Slab**
Section Property								
Breadth of Section		b	mm	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Height of Section		h	mm	**650**	**650**	**650**	**650**	**650**
Effective height for tensile bar		d	mm	**559.0**	**564.0**	**564.0**	**564.0**	**562.5**
Design Load								
Bending Moment		M	kNm	372.08	193.63	218.40	217.40	250.67
Shear Force		S	kN	219.95	150.13	165.10	162.63	175.20
Allowable Stress - Reinforcement								
Material				**SD295**	**SD295**	**SD295**	**SD295**	**SD295**
Allowable stress		σsa	MPa	180	180	180	180	180
Allowable Stress - Concrete								
Standard Strength 28 days cylinder		σck	MPa	**30**	**30**	**30**	**30**	**30**
Allowable bending compressive stress		σca	MPa	11.0	11.0	11.0	11.0	11.0
Allowable shear stress without links		τa	MPa	1.00	1.00	1.00	1.00	1.00
Young's modulus ratio		n		7.14	7.14	7.14	7.14	7.14
Rebar Arrangement								
<Tensile bar>		Bar-1		**5 -D32**	**5 -D22**	**5 -D22**	**5 -D22**	**5 -D25**
		Bar-2		**5 -D25**	**5 -D19**	**5 -D22**	**5 -D22**	**5 -D22**
		As	mm^2	6,476	3,318	3,801	3,801	4,355
		p		0.011584	0.005884	0.006740	0.006740	0.007742
Cover		C	mm	75	75	75	75	75
Spacing		Cs	mm	100	100	100	100	100
<Link>				**0 -D13**	**0 -D13**	**0 -D13**	**0 -D13**	**0 -D13**
		Area	mm^2	0	0	0	0	0
		Spacing	mm	150	150	150	150	150
Working Stress								
Increment Factor for Allowable Stress				**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Concrete Compressive Stress	Working stress	σc	MPa	8.06	5.29	5.67	5.64	6.20
	Allowable stress	σca	MPa	11.00	11.00	11.00	11.00	11.00
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**
Steel Reinforcement	Working stress	σs	MPa	115.60	112.90	111.77	111.26	112.94
	Allowable stress	σsa	MPa	180.00	180.00	180.00	180.00	180.00
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**
Shear	Working stress	τ	MPa	0.44	0.29	0.32	0.32	0.34
	Allowable stress	τa	MPa	1.00	1.00	1.00	1.00	1.00
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**
Crack Width								
Flexural Crack	Calculated crack width	w	mm	0.278	0.279	0.277	0.276	0.277
	Allowable crack width	wa	mm	0.300	0.300	0.300	0.300	0.300
	Check !!			**OK**	**OK**	**OK**	**OK**	**OK**

4.5 Check for additional wall of corner location

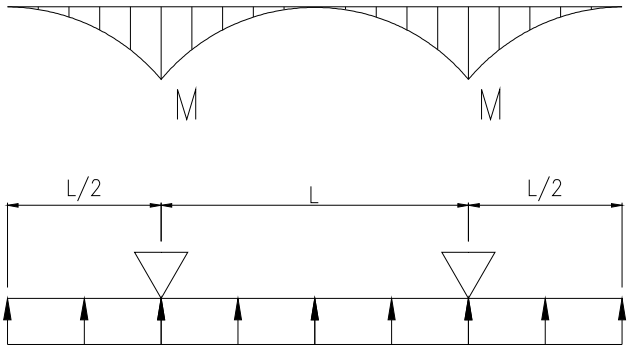


Plan View of Additional Wall



Side View of Additional Wall

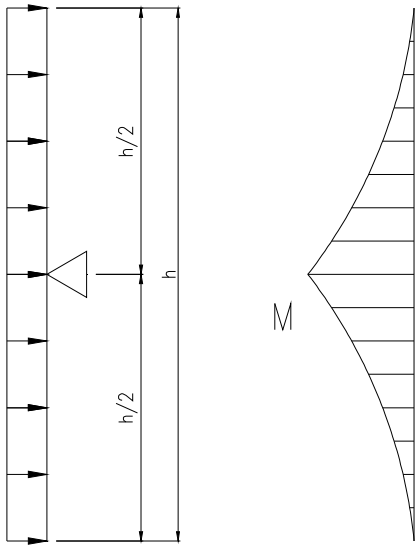
- Horizontal direction



$M = (T \times L^2) / (8 \times h)$

	T (kN/m)	L (m)	h (m)	M (kNm)
Block-a	249.17	1.96	4.0	29.91
Block-d	268.96	1.96	4.0	32.29

- Vertical direction



$M = T \times h / 8$

	T (kN/m)	h (m)	M (kNm)
Block-a	249.17	4.0	124.59
Block-d	268.96	4.0	134.48

Concrete Section Design by Allowable Stress Method

		Sym.	Unit	Horizontal Direction	Vertical Direction
Type of Member					
				Slab	**Slab**
Section Property					
Breadth of Section		b	mm	**1,000**	**1,000**
Height of Section		h	mm	**450**	**450**
Effective height for tensile bar		d	mm	**345**	**364**
Design Load					
Bending Moment		M	kNm	32.29	134.48
Shear Force		S	kN		
Allowable Stress - Reinforcement					
Material				**SD295**	**SD295**
Allowable stress		σsa	MPa	180	180
Allowable Stress - Concrete					
Standard Strength 28 days cylinder		σck	MPa	**30**	**30**
Allowable bending compressive stress		σca	MPa	11.0	11.0
Allowable shear stress without links		τa	MPa	1.00	1.00
Young's modulus ratio		n		7.14	7.14
Rebar Arrangement					
<Tensile bar>		Bar-1		**6.67 -D16**	**5 -D22**
		Bar-2		**0 -D16**	**5 -D22**
		As	mm^2	1,341	3,801
		p		0.003887	0.010443
	Cover	C	mm	75	75
	Spacing	Cs	mm	150	100
<Link>				**0 -D13**	**0 -D13**
		Area	mm^2	0	0
		Spacing	mm	200	200
Working Stress					
Increment Factor for Allowable Stress				**1.00**	**1.00**
Concrete Compressive Stress	Working stress	σc	MPa	2.78	7.12
	Allowable stress	σca	MPa	11.00	11.00
	Check !!			**OK**	**OK**
Steel Reinforcement	Working stress	σs	MPa	75.03	108.75
	Allowable stress	σsa	MPa	180.00	180.00
	Check !!			**OK**	**OK**
Shear	Working stress	τ	MPa	0.00	0.00
	Allowable stress	τa	MPa	1.00	1.00
	Req'd area of rebar	Aw req	mm^2	0.00	0.00
	Rebar provided	Aw	mm^2	0.00	0.00
	Check !!			**OK**	**OK**
Crack Width					
Flexural Crack	Calculated crack width	w	mm	0.227	0.271
	Allowable crack width	wa	mm	0.300	0.300
	Check !!			**OK**	**OK**

Appendix 16-3

Examination Result on Reclaimed Ground Deformations Using the analysis program GEOASIA

Lach Huyen Port Infrastructure Construction Project

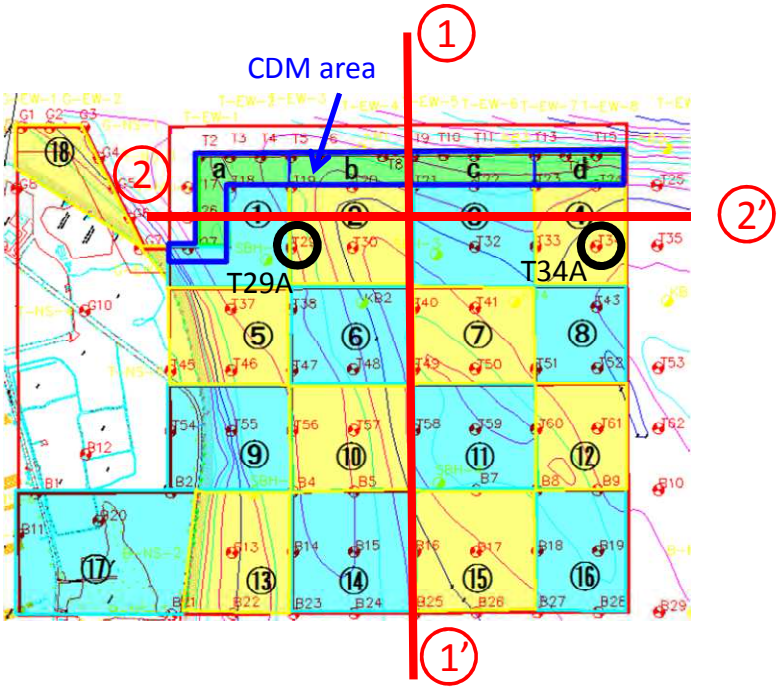
Examination Result on
Reclaimed Ground Deformations
Using the analysis program ***GEOASIA***

All Soils All States All Round Geo-analysis Integration

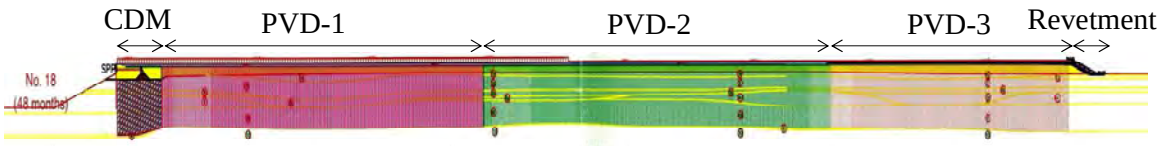
GEOASIA Research Society

Outline of the analysis

The Lach Huyen Port Infrastructure Construction Project consists of the construction of land reclamation and ground improvement by using PVD and surcharge for the terminal area, and CDM behind the retaining wall. In this analysis, the deformation behavior of the reclaimed ground was examined in consideration of the construction and reclamation histories. The typical cross sections 1-1' and 2-2' shown in Figure.1 were targeted for the analysis under 2-dintionatl plane strain conditions. The soil-water coupled finite deformation analysis was employed using the analysis program ***GEOASIA***, in which the constitutive equation for the soil skeleton is mounted with the SYS Cam-clay model.



[1-1' section]



[2-2' section]

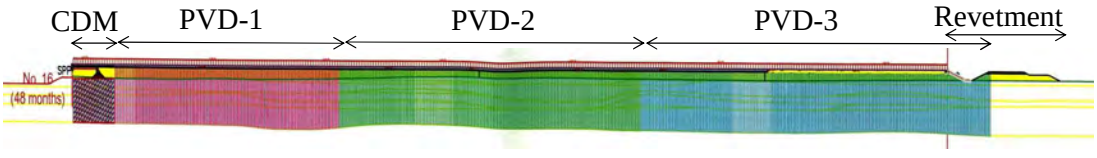


Figure 1. Sections targeted for the analysis

Determination of the layer structure of initial ground

Before determining the analysis parameters, the layer structure of the initial ground to be analyzed was decided first by considering the columnar sections. In the site targeted for the analysis, the boring investigations were carried out additionally in 2011 at the points of T29A and T34A in Figure 1, for the purpose of getting the higher accuracy in soil data. In this study, the columnar section of the point T34A, is considered in the determination of the layer structure of initial ground as shown in Figure 2, because the layer-2 which is capable of causing failure and settlement is thicker at the point of T34A than T29A. And, for simplicity, the initial ground was modeled assuming the horizontally stratified conditions (i.e., it was assumed in this analysis that the difference of deformation characteristics between 1-1' section and 2-2' section depends on not the initial ground conditions, but the construction history. The details were described later.)

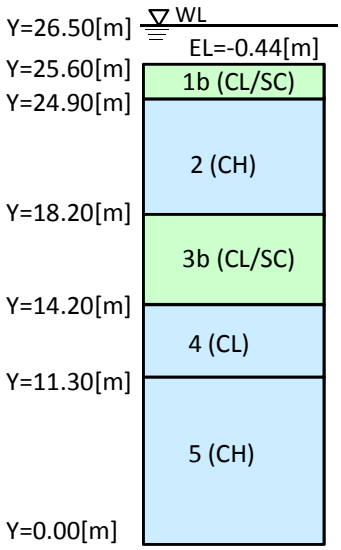


Figure 2. Determination of the layer structure of the initial ground

Results of laboratory tests and determination of the analytical parameters of initial ground

The material parameters were determined by simulating the result of the oedometer tests on undisturbed and disturbed specimens as well as those of the undrained triaxial tests of undisturbed specimens thorough the response of the SYS Cam-clay model. In other words, by using the same material parameters for each layer and by varying only the initial values at the time of commencement of the laboratory tests, those parameters that would describe their behavior best were determined through trial and error.

The results of the laboratory tests and simulations with respect to Layer-1b to 5 are illustrated in Figures 3 to 7. The open circle and the solid lines indicate the laboratory test results, and the simulation results, respectively. In the undrained triaxial test results, the stresses have been converted to show the *p'-q* relationship.

From the compression index and sensitivity ratios (the Figures of test results are omitted), it can be said that the soils targeted for analysis are sensitive to disturbance and that the compressibilities of the in-situ soils are higher than those of the specimen of the laboratory tests, especially in Layer-2, and 5. So, the

initial conditions of the in-situ soils were deduced using the oedometer results of the undisturbed samples, giving due the consideration to the effects of disturbance, employing the method proposed by Inagaki et al. (2010), which draws on the Schmertmann's graphic method(1953). In Figures 3 to 7, the purple bold line indicate the deduced in-situ compression curves of initial grounds

Table 1 shows the material parameters and in-situ initial conditions of the each layer of initial ground as determined by the method of computation described above. The permeability of each layer was estimated from the results of the oedometer tests on undisturbed specimens, and for simplicity, was assumed to be unaffected by variations in the pore ratios and always remain constant.

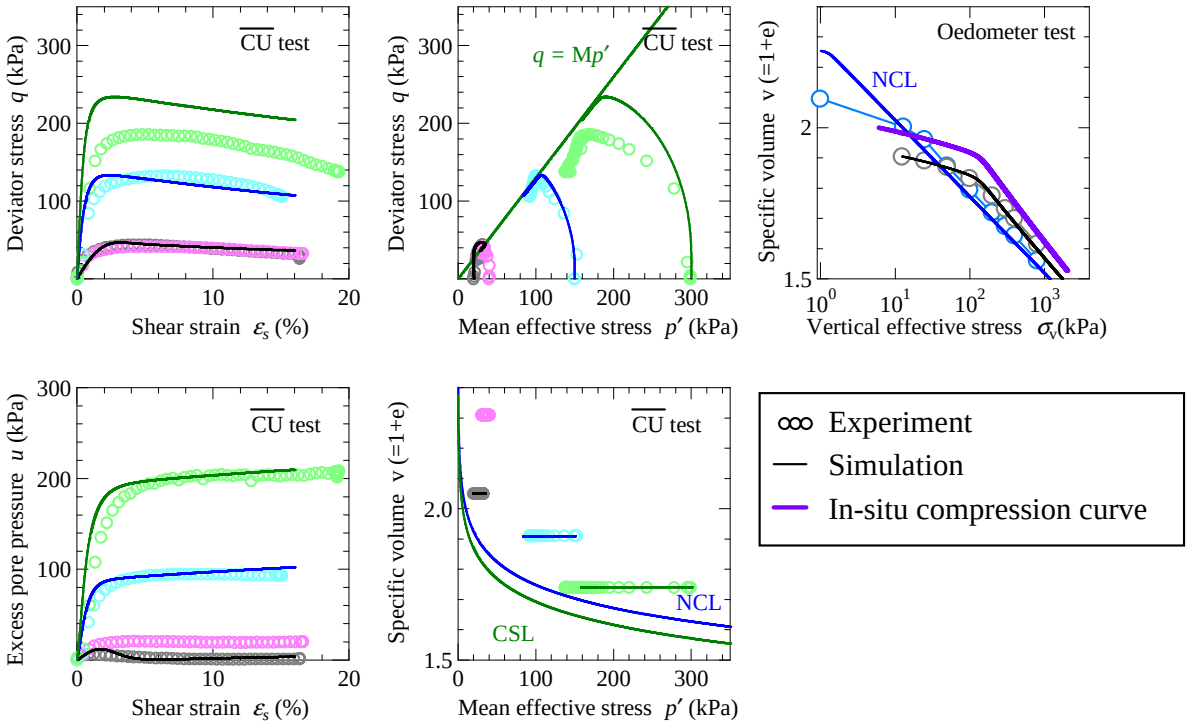


Figure 3. Results of simulation and deduced in-situ compression curve of Layer-1b

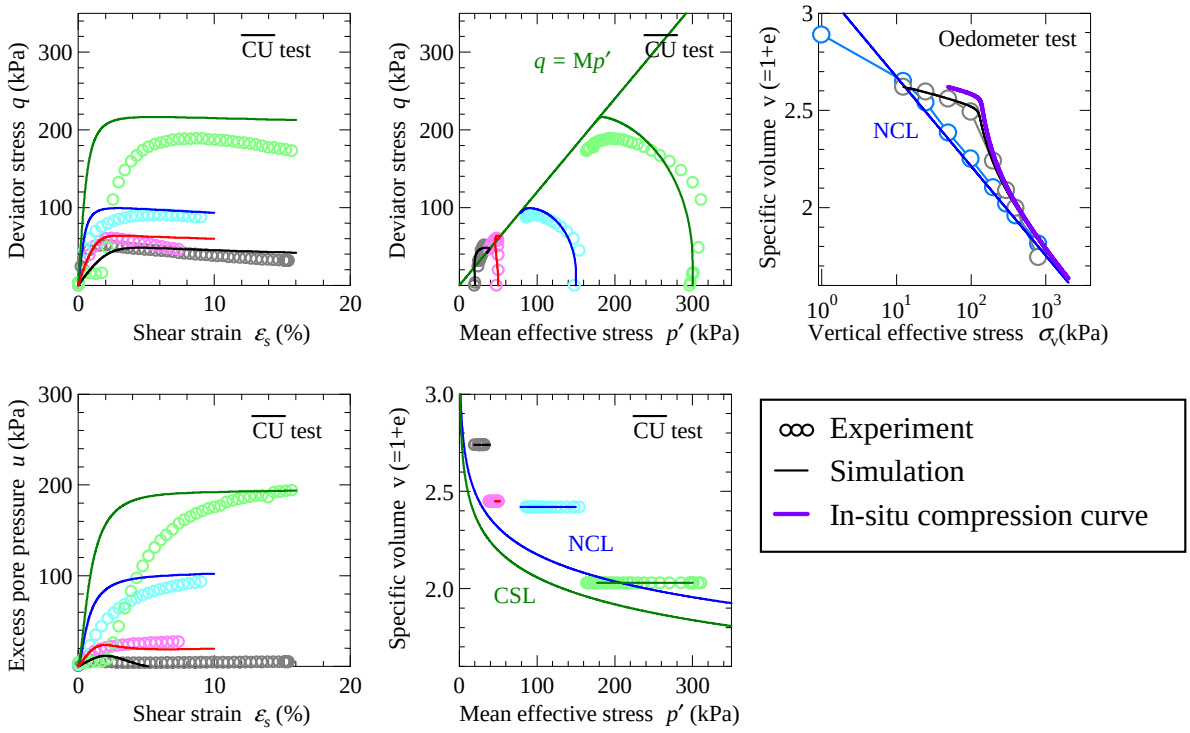


Figure 4. Results of simulation and deduced in-situ compression curve of Layer-2

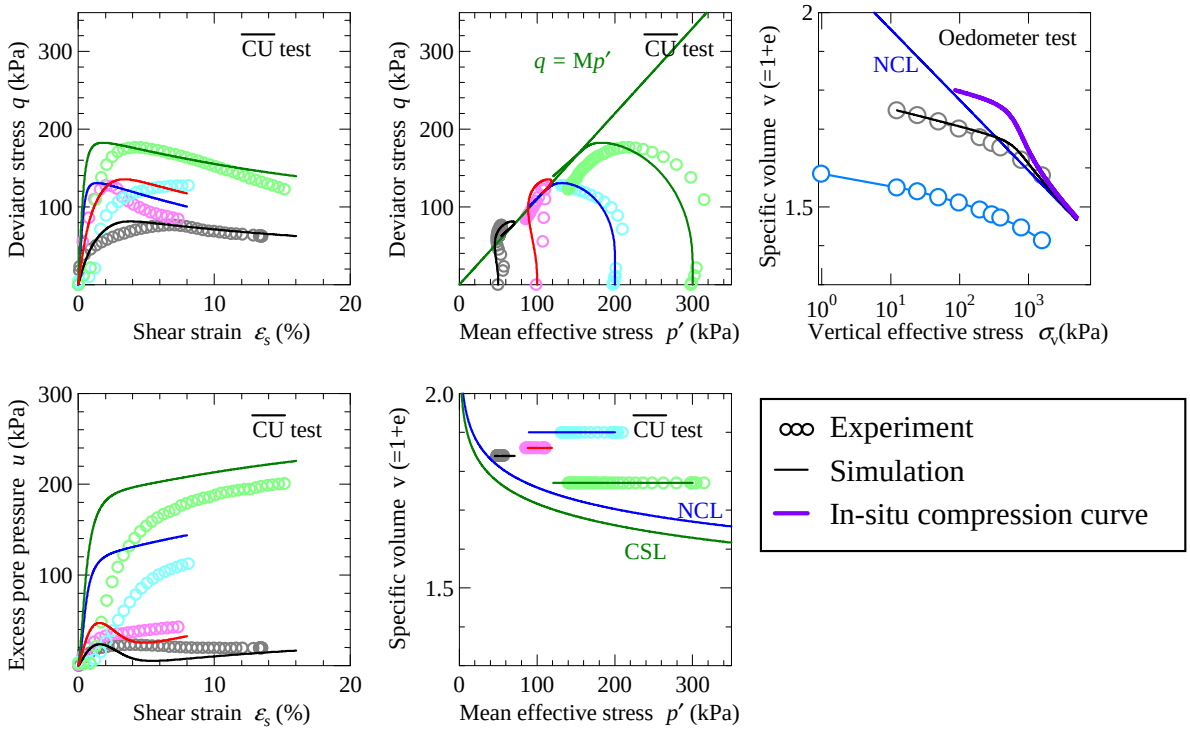


Figure 5. Results of simulation and deduced in-situ compression curve of Layer-3b

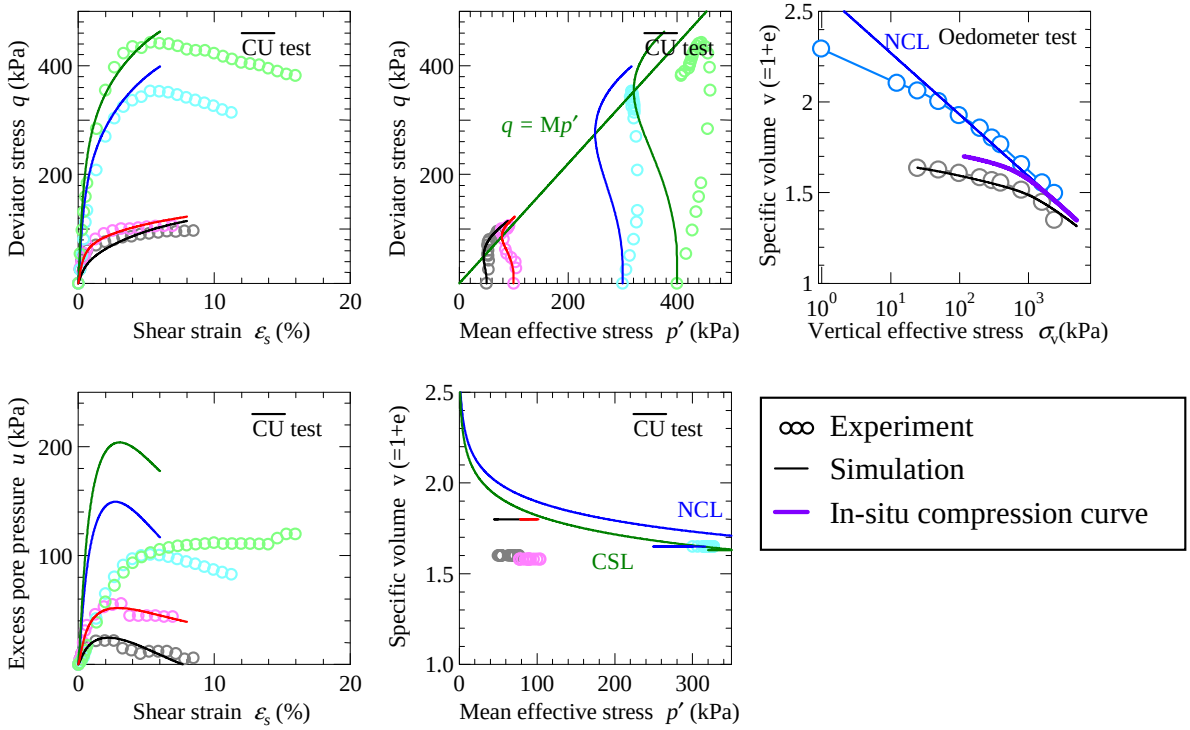


Figure 6. Results of simulation and deduced in-situ compression curve of Layer-4

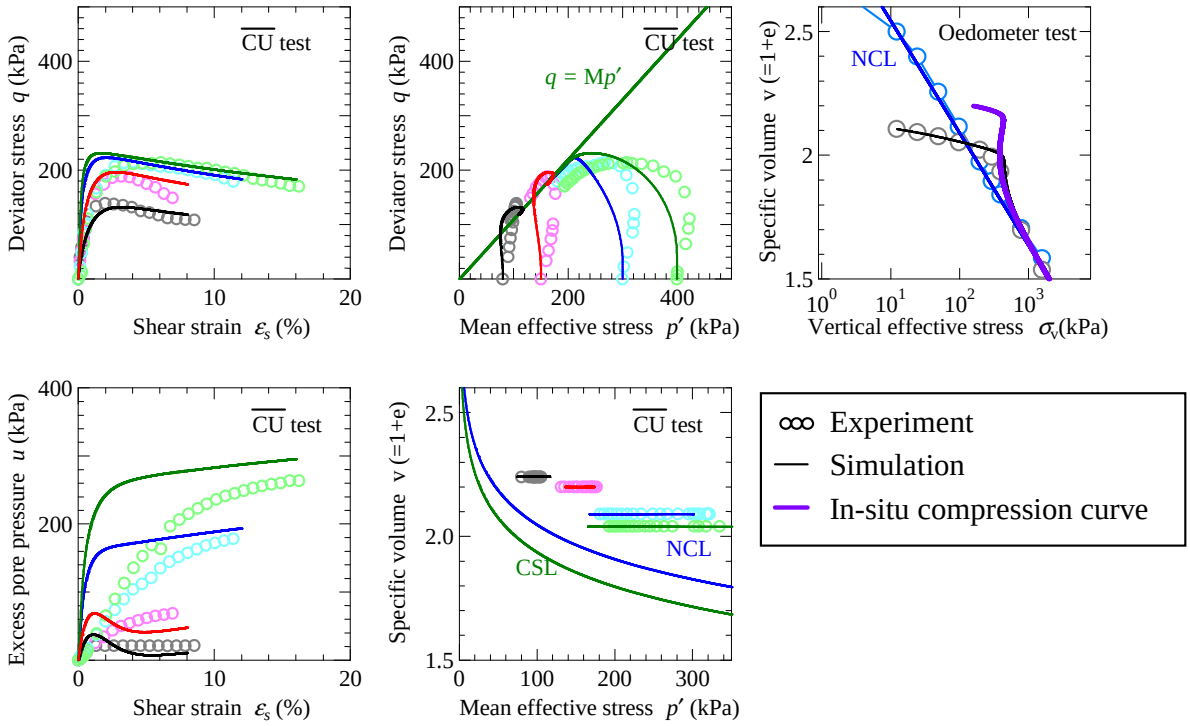


Figure 7. Results of simulation and deduced in-situ compression curve of Layer-5

Table1. Material parameters and deduced in-situ initial conditions of initial ground

	Layer-1b	Layer-2	Layer-3b	Layer-4	Laer-5
Elasto-plastic parameters					
Compressive index $\tilde{\lambda}$	0.11	0.20	0.08	0.15	0.20
Swelling index $\tilde{\kappa}$	0.03	0.05	0.02	0.04	0.03
Critical state constant M	1.30	1.20	1.10	1.10	1.10
NCL intercept N	1.75	2.18	1.76	1.90	2.05
Poisson's ratio ν	0.20	0.20	0.30	0.30	0.10
Evolution parameters					
Normal consolidation index m	5.0	10.0	1.0	0.5	10.0
Structural degradation index a	0.3	0.8	1.0	0.8	1.5
" b	1.0	1.0	1.0	1.0	1.0
" c_s	0.3	0.1	0.2	0.5	0.2
Rotational hardening index b_r	0.01	0.01	0.10	0.10	0.10
Rotational hardening limit m_b	1.0	1.0	1.0	1.0	1.0
Permeability k (cm/sec)	5.0×10^{-7}	2.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}	2.0×10^{-7}
Density of soil ρ_s (t/m^3)	2.70	2.71	2.70	2.71	2.71
In- situ conditions					
Void ratio v_0	2.00	2.62	1.80	1.70	2.20
Degree of $1/R^*_0$	8.0	15.0	11.0	2.0	10.0
Stress ratio η_0	0.75	0.75	0.75	0.75	0.75
Degree of anisotropy ζ_0	0.10	0.10	0.10	0.10	0.10

Determination of the analytical parameters of the materials added on the ground under the constructions

Table 2 and 3 show the analytical parameters of the elasto-plastic materials and the elastic ones respectively, that are added on the initial ground in the process of the reclamation and the ground improvement.

Since laboratory mechanical tests using sampled specimens ware not conducted with respect to the materials other than the initial ground, the land reclamation material was assumed to consist of the medium sand with a unit weight of 18.0kN/m3. For the rubble mound and the covering block, the material parameters of rock were decided from the results of drain triaxial tests using the crashed granite.

In this analysis, it was assumed that the soil improvement using PVD is equivalent to improve permeability 100 times in comparison with the original soil (but any other parameter is same as in the original).

The soil improvement by CDM and the construction of Anchor wall and Sheet Pile were simulated by the method of replacing the relevant elements as the elastic materials as shown in Tab. 3.

Table 2. Material parameters and initial conditions of the elasto-plastic materials added on the ground under the constructions

	Rock	Sand	After improving using PVD					
			Sand	Layer-1b	Layer-2	Layer-3	Layer-4	Laer-5
Elasto-plastic parameters								
$\tilde{\lambda}$	0.105	0.05	Same as Table 1					
$\tilde{\kappa}$	0.0005	0.012						
M	1.70	1.00						
N	1.90	1.98						
ν	0.3	0.3						
Evolution parameters								
m	1.2	0.1	Same as Table 1					
a	2.0	2.2						
b	1.0	1.0						
c_s	1.0	1.0						
b_r	1.0	3.5						
m_b	0.001	0.7						
k (cm/sec)	1.0×10^{-3}	1.0×10^{-3}	5.0×10^{-3}	5.0×10^{-5}	2.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	2.0×10^{-5}
ρ_s (t/m^3)	2.593	2.578	Same as Table 1					
In- situ conditions								
v_0	1.593	1.88	Same as the conditions before PVD improvement					
$1/R^*_0$	1.0	2.04						
η_0	0.0	0.75						
ζ_0	0.776	0.13						

Table 3 Elastic material parameters

	CDM (2-phase)	Anchor wall (concrete)	Sheet Pile
Young's modulus E (kN/m^2)	3.06×10^4	1.50×10^3	2.26×10^5
Poisson's ratio ν	0.45	0.35	0.30
Unit weight (g/cm^3)	2.0	2.35	7.845
Permeability k (cm/sec)	1.0×10^{-7}	—	—

Construction Schedule on the analysis

The construction and reclamation were simulated by the method of adding/removing elements to/from the ground as needed. Table 4 and 5 show the construction schedules of 1-1' and 2-2' section respectively, which are simplified for analysis.

Table 4 Construction schedule of 1-1' section

Stage	At the end of each stage	Process (area)
No.2	1 month	・ Excavation: DL-2.0m (ahead of CDM-area)
No.4	6 months	・ Reclamation: CD+4.0m (1/3 of the area from PVD-1 to PVD-2)
No.5	9 months	・ Reclamation: CD+4.0m (2/3 of the area from PVD-1 to PVD-2) ・ Improvement by CDM (CDM-area) ・ Construction of Sheet Pile (CDM-area)
No.6	12 months	・ Construction of rubble mound (CDM-area) ・ Construction of Anchor wall (CDM-area) ・ Connection between Sheet Pile and Anchor wall using Tie-rod (CDM-area) ・ Reclamation: CD+4.0m (PVD-1area and PVD-2 area)
No.7	15 months	・ Improvement by PVD (PVD-1 area) ・ Sand mat: CD+4.5m (CDM area and PVD-1 area)
No.8	18 months	・ Reclamation: CD+4.0m (1/2 of PVD-3 area) ・ Construction of 1st Preload: CD+5.0m (CDM area and PVD-1 area)
No.9	21 months	・ Reclamation: CD+4.0m (PVD-3 area) ・ Improvement by PVD (PVD-2 area) ・ Sand mat: CD+4.5m (PVD-2 area) ・ Construction of 2nd Preload: CD+8.4m (PVD-1 area)
No.10	24 months	・ Construction of 1st Preload: CD+5.0m (PVD-2 area)
No.11	27 months	・ Improvement by PVD (PVD-3 area) ・ Preload removal: CD+4.5m (PVD-1 area) ・ Construction of 2nd Preload: CD+7.3 (PVD-2 area) ・ Construction of 2nd Preload: CD+8.4 (1/2 of PVD-2 area)
No.12	30 months	・ Preloading (PVD-3 area) ・ Preloading (Revetment area) ・ Excavation: DL-16.0m (ahead of CDM-area)
No.13	33 months	・ Preload removal: CD+4.5m (PVD-2 area)
No.15	39 months	・ Preload removal: CD+5.5m (PVD-3 area)
No.16	42 months	・ Preload removal: CD+4.0m (Revetment area) ・ Excavation (Revetment area)
No.17	45months	・ Construction of rubble mound (Revetment area) ・ Covering the excavated slope with rubble (Revetment area) ・ Pavement (CDM, PVD-1, PVD-2 and PVD-3 area)
No.18	48months	・ Surcharge load in Service (CDM, PVD-1, and 1/2 of PVD-3 area)

Table 5 Construction schedule of 2-2' section

Stage	At the end of each stage	Process (area)
No.2	1 month	・ Excavation: DL-2.0m (ahead of CDM-area)
No.3	3 months	・ Improvement by CDM (CDM-area)
No.4	6 months	・ Construction of Sheet Pile (CDM-area)
No.5	9 months	・ Construction of rubble mound (CDM-area) ・ Construction of Anchor wall (CDM-area) ・ Connection between Sheet Pile and Anchor wall using Tie-rod (CDM-area) ・ Reclamation: CD+4.0m (PVD-1 area and 1/2 of PVD-2 area)
No.6	12 months	・ Reclamation: CD+4.0m (PVD-2 area) ・ Sand mat: CD+4.5m (CDM area and PVD-1 area) ・ Improvement by PVD (PVD-1 area)
No.7	14 months	・ Reclamation: CD+4.0m (PVD-3 area) ・ Sand mat: CD+4.5m (PVD-2 area) ・ Improvement by PVD (PVD-2 area) ・ Construction of 1st Preload: CD+5.0m (CDM area and PVD-1 area)
No.8	16 months	・ Sand mat: CD+4.5m (PVD-3 area) ・ Improvement by PVD (PVD-3 area) ・ Construction of 1st Preload: CD+5.0m (PVD-2 area) ・ Construction of 2nd Preload: CD+8.9m (PVD-1 area)
No.9	19months	・ Construction of 1st Preload: CD+5.0m (PVD-3 area) ・ Construction of 2nd Preload: CD+8.6 (PVD-2 area)
No.10	22months	・ Construction of 2nd Preload: CD+8.6 (PVD-3 area) ・ Preload removal: CD+4.5m (PVD-1 area)
No.11	25months	・ Preload removal: CD+4.5m (PVD-2 area) ・ Excavation (ahead of CDM area)
No.12	28months	・ Preload removal: CD+4.5m (PVD-3 area without Revetment area)
No.13	31months	・ Preload removal: CD+4.5m (Revetment area) ・ Excavation (Revetment area)
No.14	33months	・ Construction of rubble mound (Revetment area) ・ Covering the excavated slope with rubble (Revetment area)
No.15	45months	・ Pavement (CDM, PVD-1, PVD-2 and PVD-3 area)
No.16	48months	・ Surcharge load in Service (CDM, PVD-1, PVD-2 and PVD-3 area)

Finite element mesh and boundary conditions

Figure 8 shows the finite element meshes and the boundary conditions of the1-1' and 2-2' sections which were used for the analysis at the end of constructions (Stage No.16). Although the actual ground inevitably possesses some sort of initial irregularity, the initial ground was modeled assuming the horizontally stratified conditions under two-dimensional plane strain conditions for the sake of simplicity. The ground surface above sea level was taken as the hydraulic boundary and was made to coincide with the water level by making the water pressure always zero. By assuming a hard layer with low-permeability to exist below it, the bottom surface of the ground was taken to be the impermeable boundary. The lateral faces were made to be impermeable boundaries.

Figure 9 shows the outline of constructions. In this analysis, tie-rod, which connects between sheet pile and anchor wall, was expressed by allotting distance invariance constraint conditions to the finite element node intervals under consideration, for simplicity.

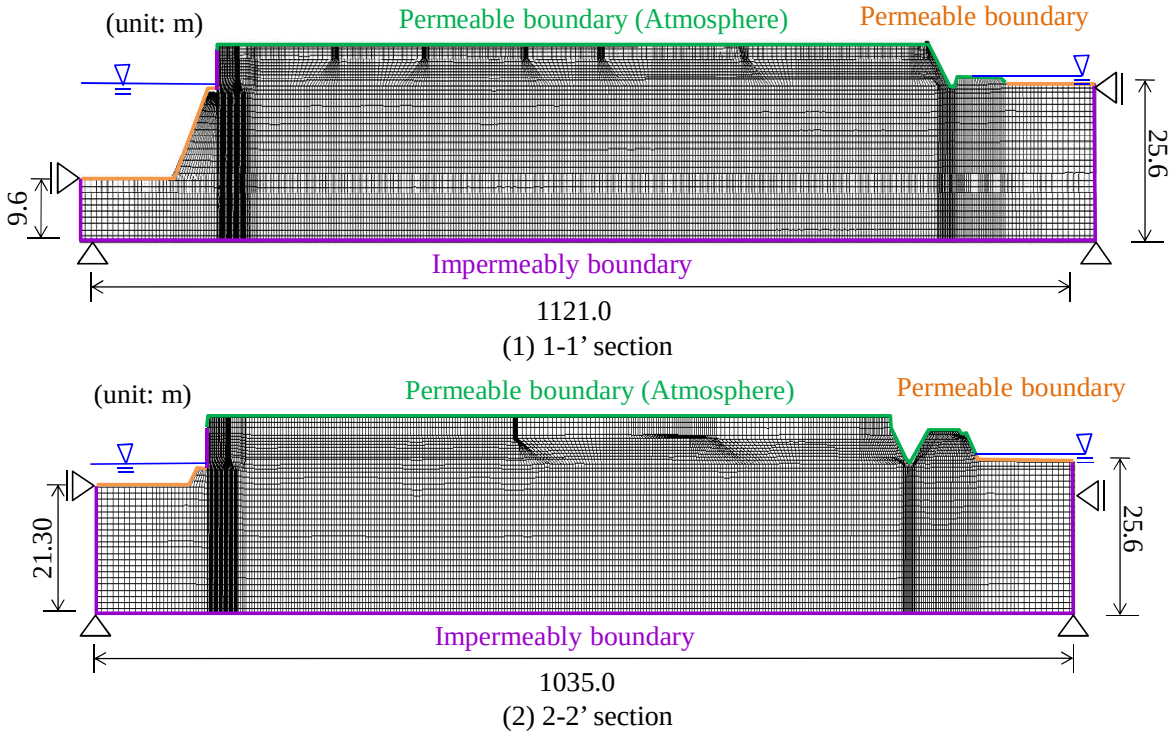


Figure 8. Finite element meshes and boundary conditions

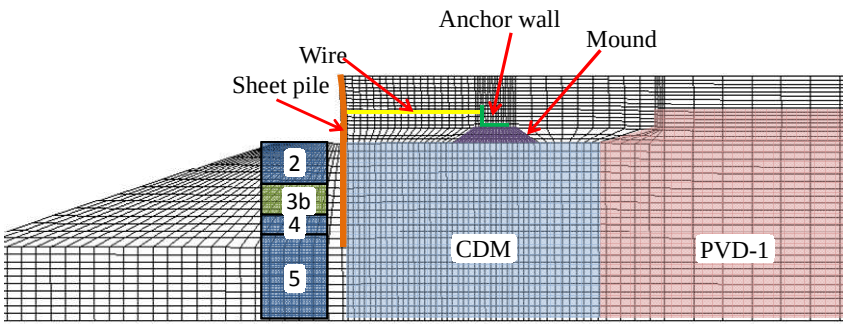
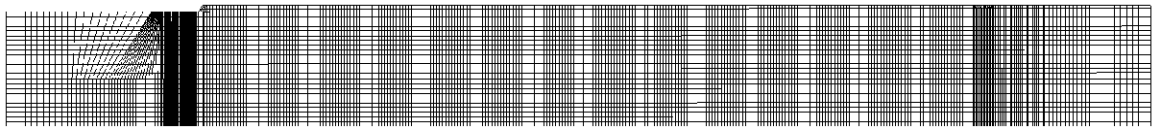


Figure 9. Outline of the constructions around CDM-area.

Results of the Computations

(1) Finite element mesh at the typical stage

[1-1' section]



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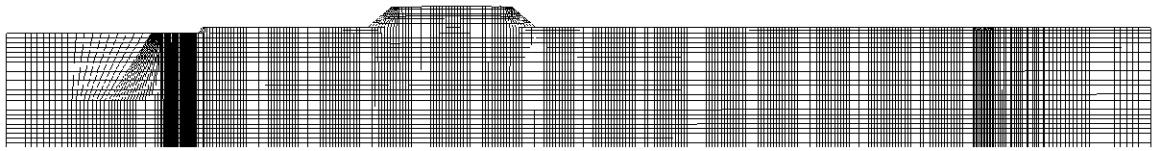

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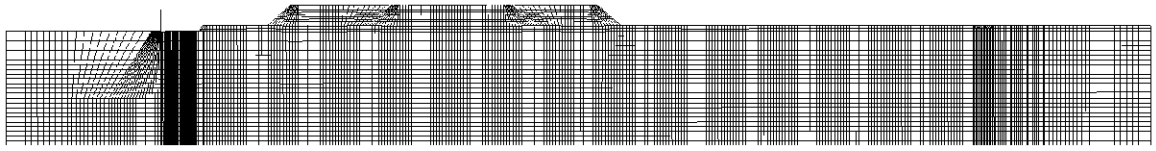

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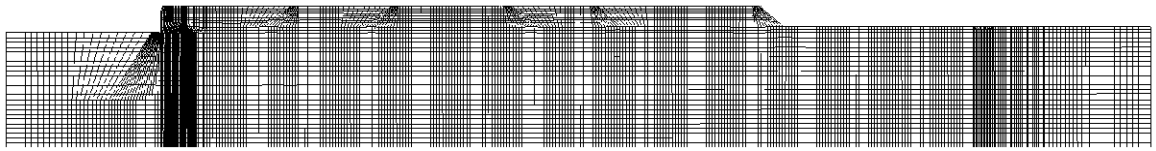

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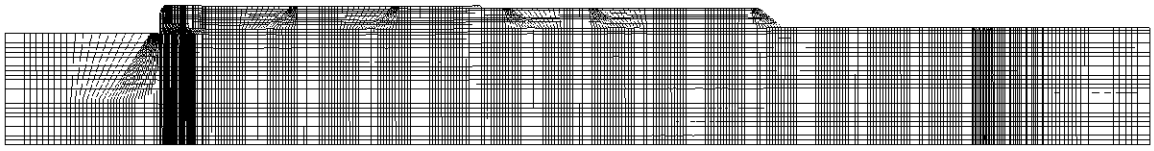

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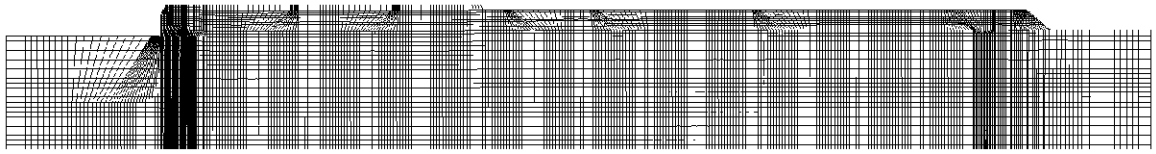

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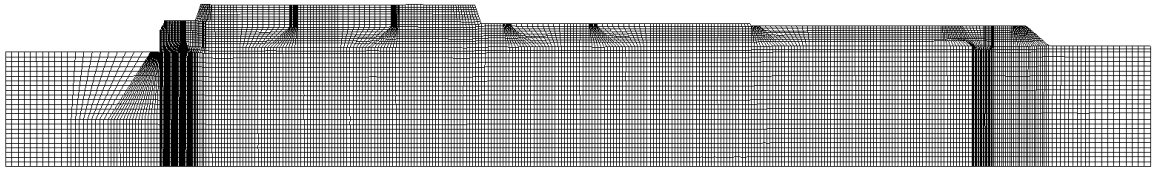

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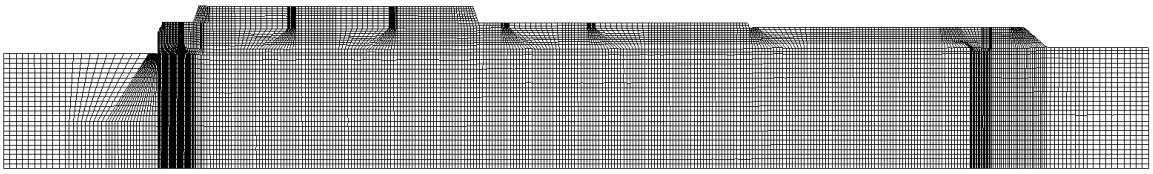

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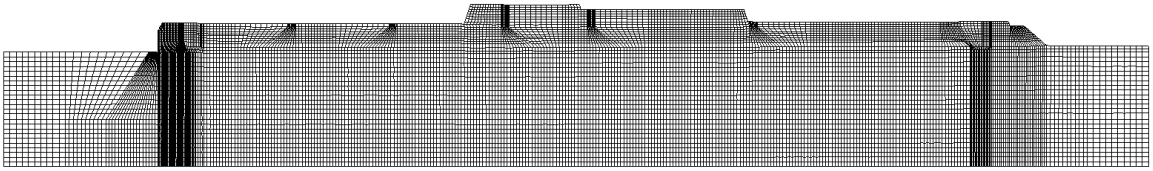

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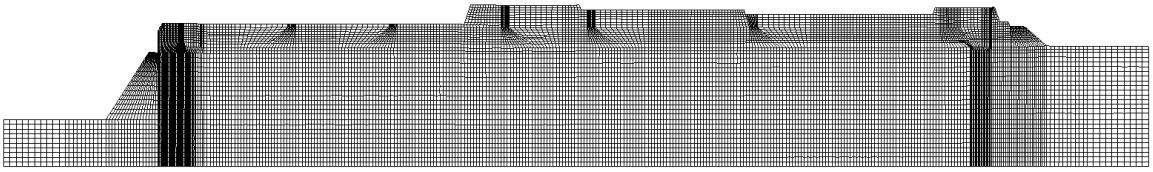

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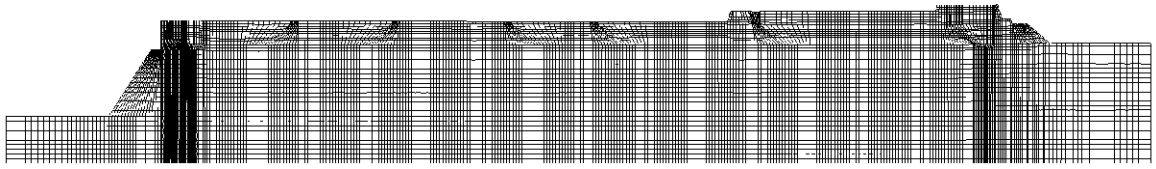

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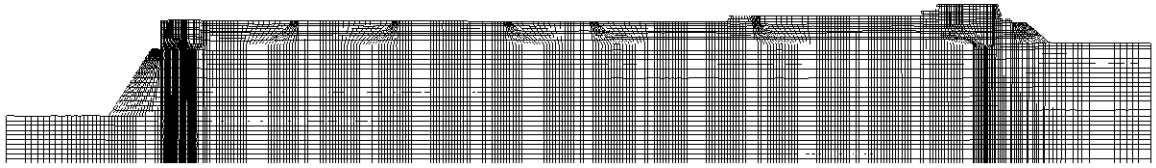

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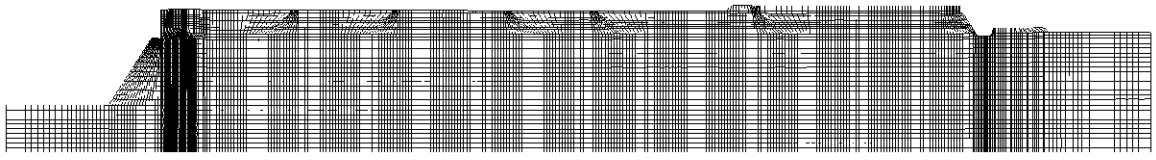

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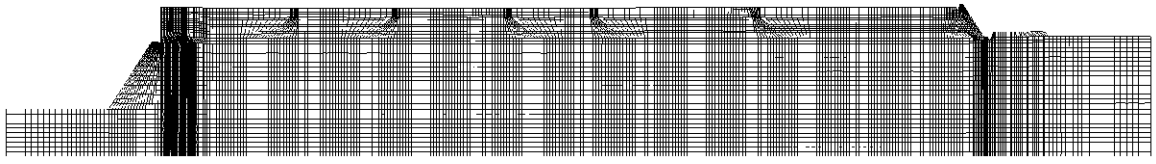
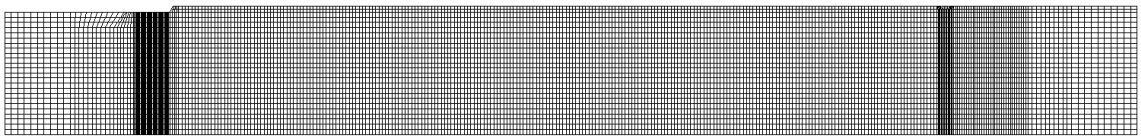


No.17

[2-2’ section]



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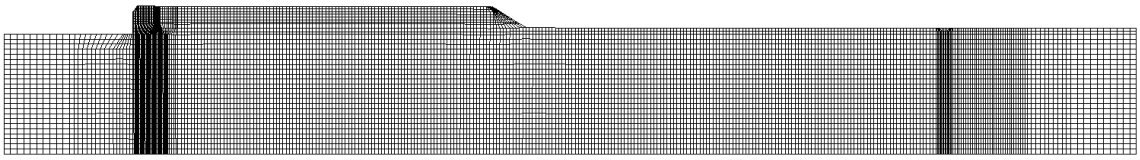

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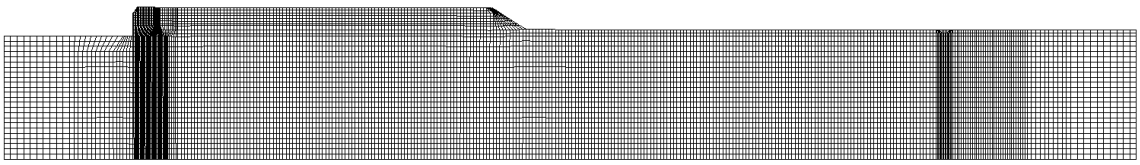

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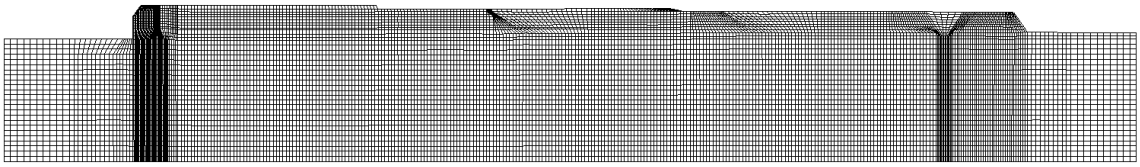

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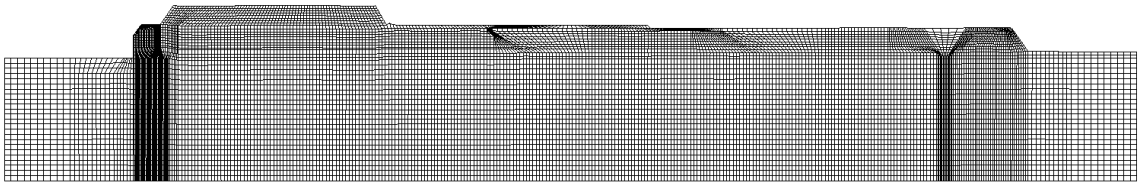

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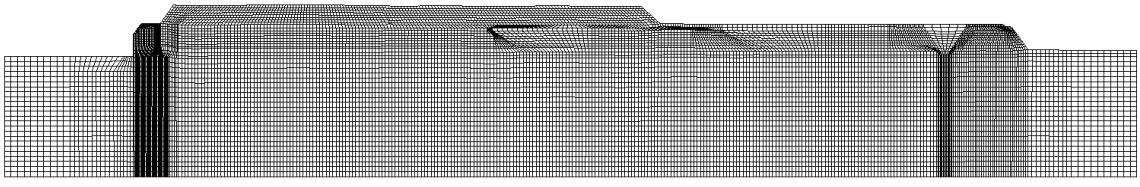
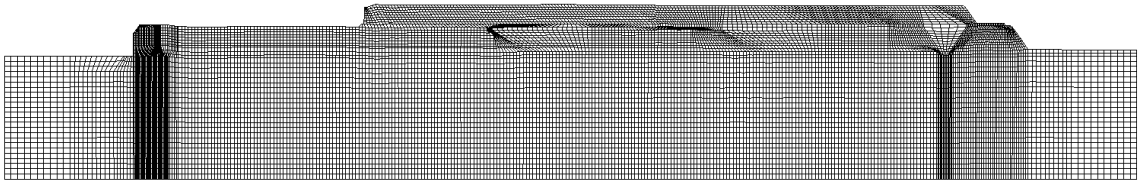
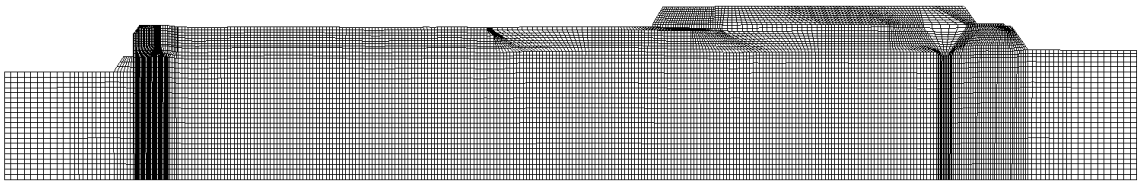


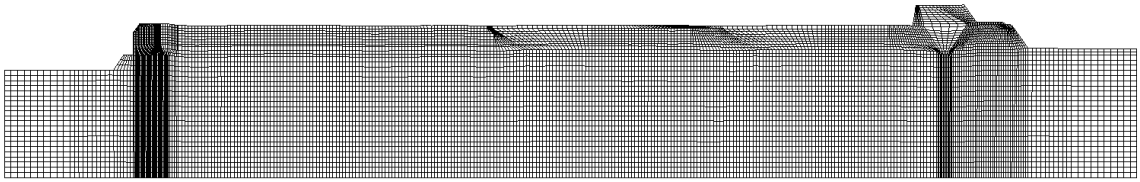
No.9



No.10



No.11



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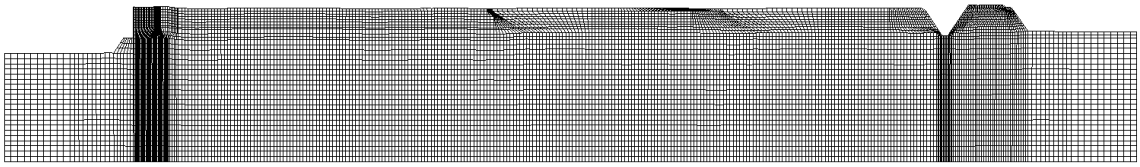
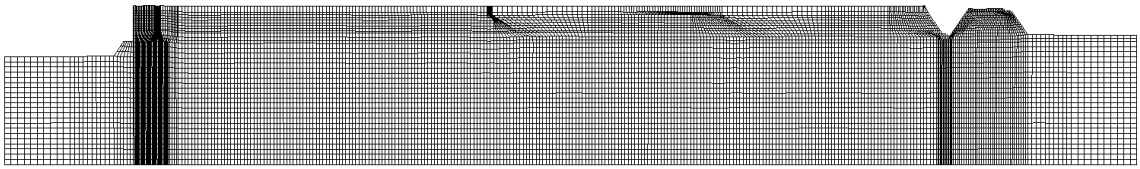


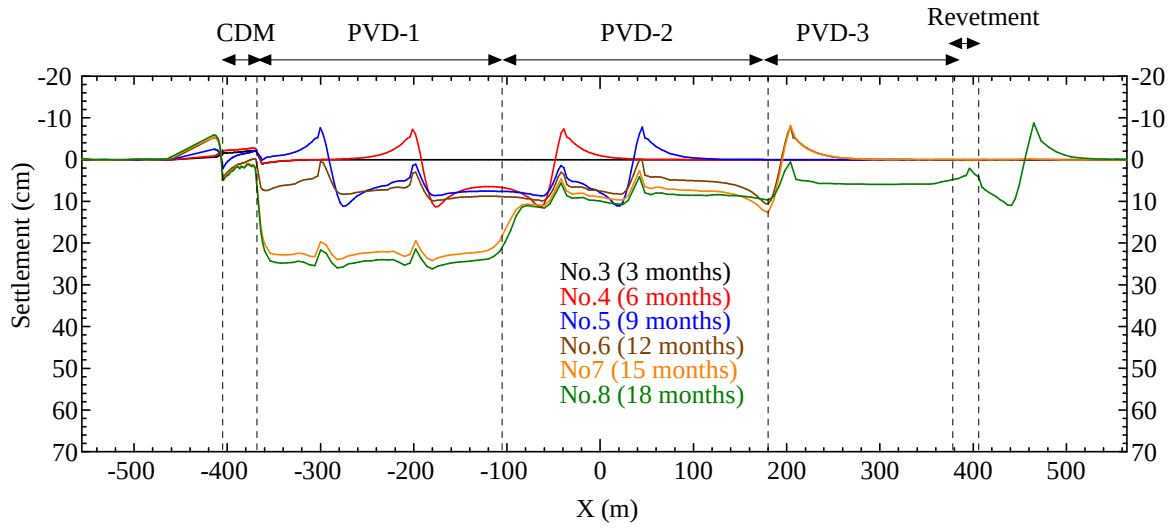
No.13

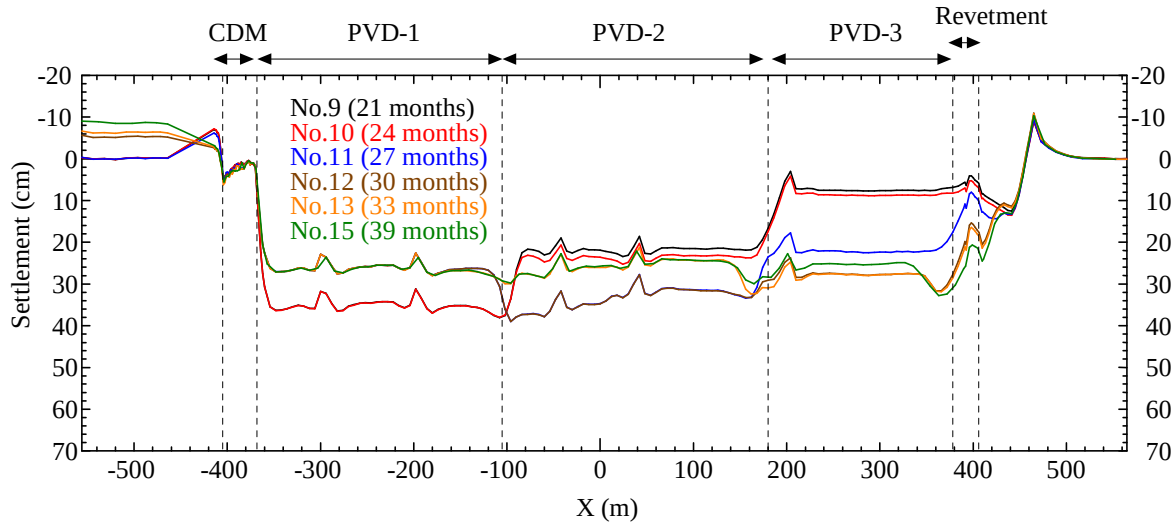


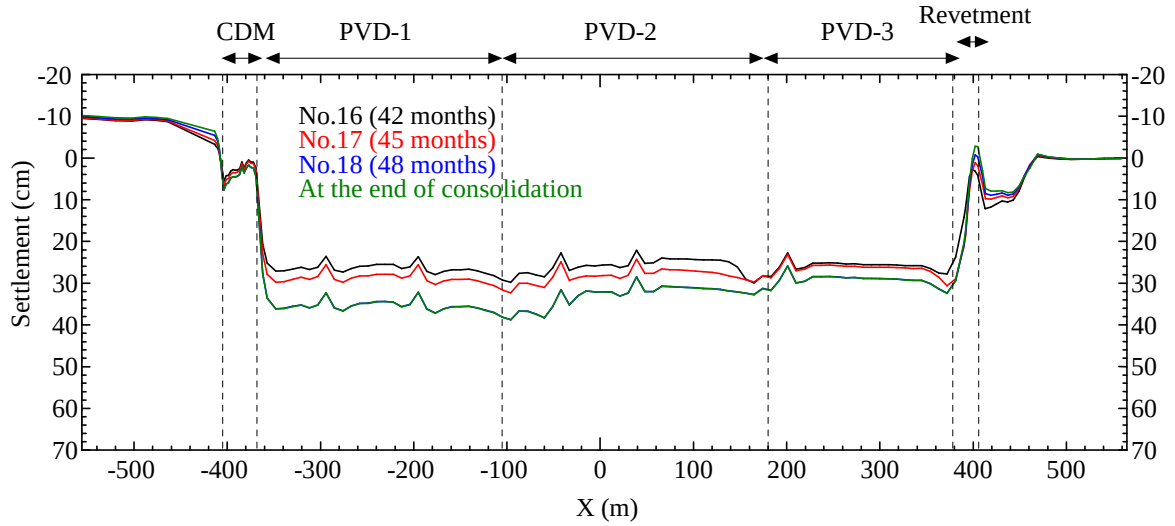
No.15

(2) Settlement profiles of ground surface at the end of each stage

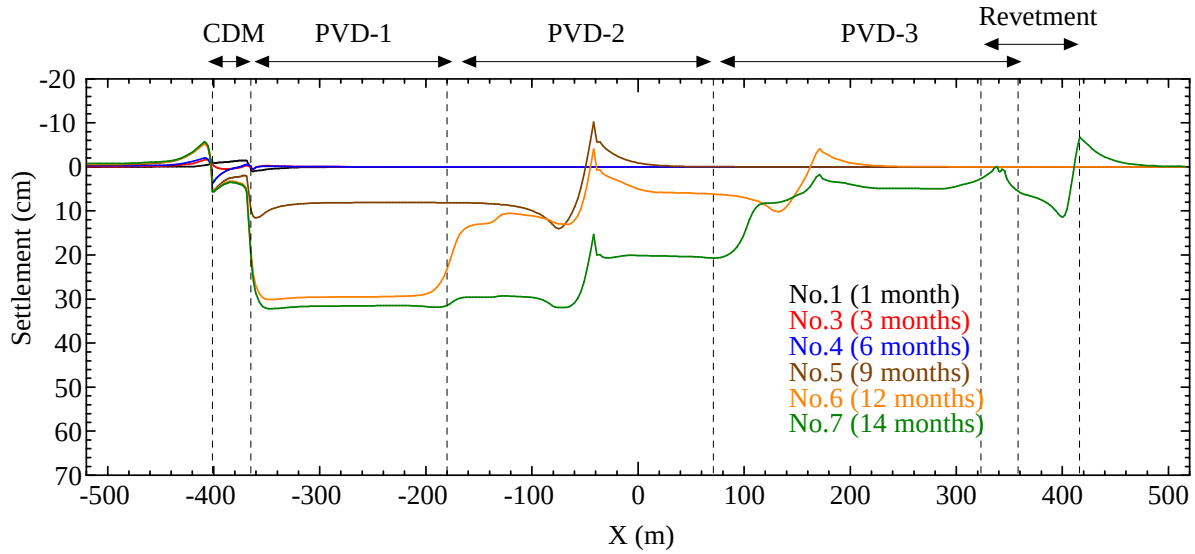
[1-1' section]

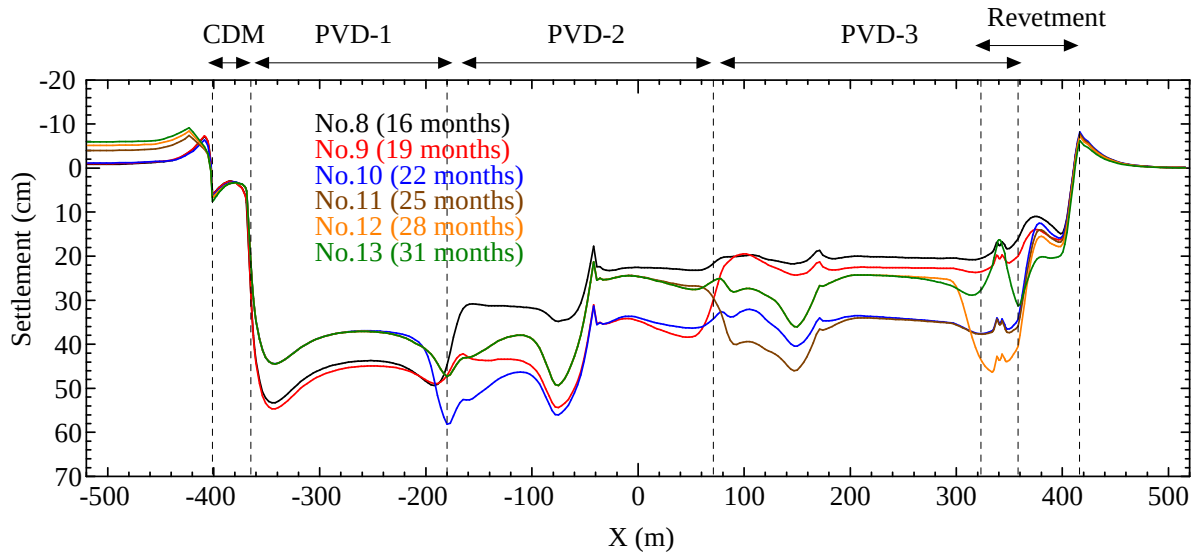


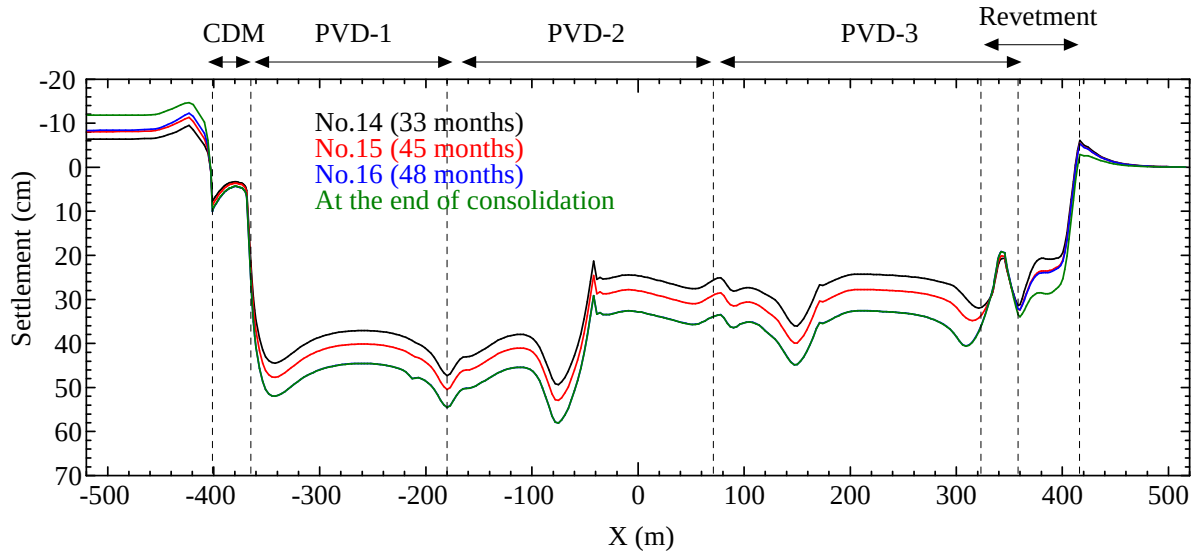




[2-2' section]


CDM
PVD-1
PVD-2
PVD-3
Revetment
Settlement (cm)
X (m)
No.1 (1 month)
No.3 (3 months)
No.4 (6 months)
No.5 (9 months)
No.6 (12 months)
No.7 (14 months)


CDM
PVD-1
PVD-2
PVD-3
Revetment
Settlement (cm)
X (m)
No.8 (16 months)
No.9 (19 months)
No.10 (22 months)
No.11 (25 months)
No.12 (28 months)
No.13 (31 months)


CDM
PVD-1
PVD-2
PVD-3
Revetment
Settlement (cm)
X (m)
No.14 (33 months)
No.15 (45 months)
No.16 (48 months)
At the end of consolidation

- The ground upheaval by the excavation ahead of CDM-area in maximum

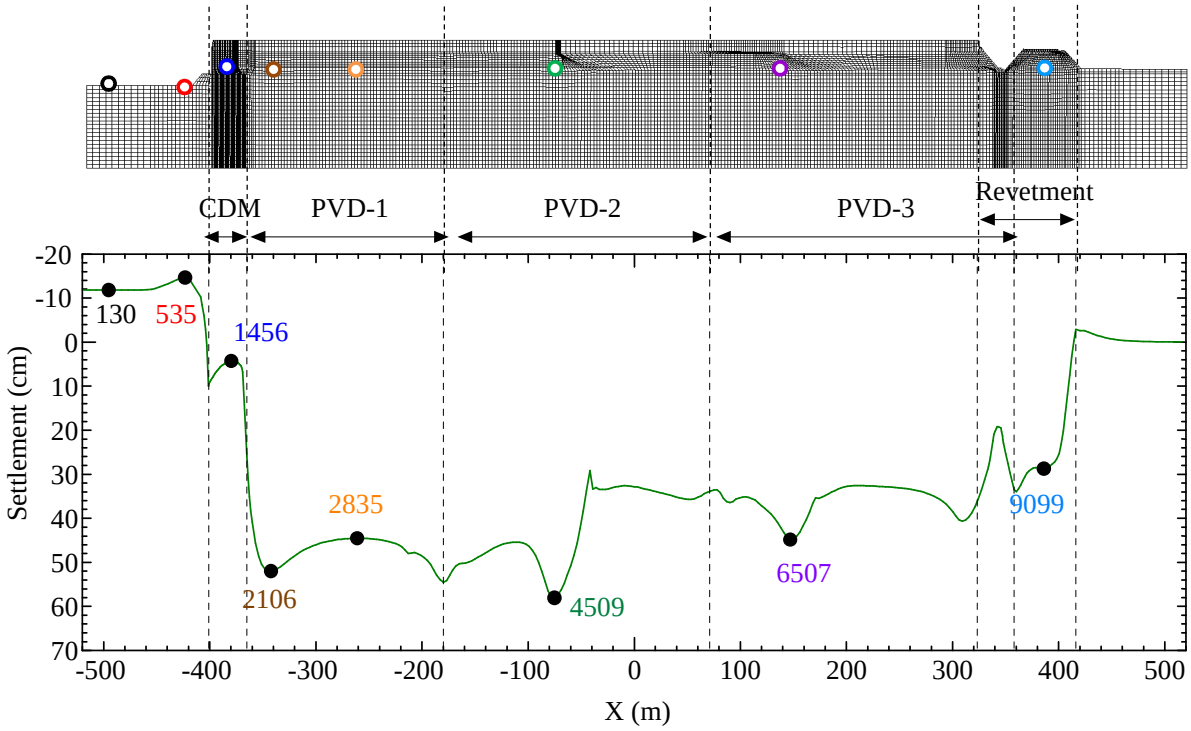
  1-1’ section = about 10cm

  2-2’ section = about 15cm

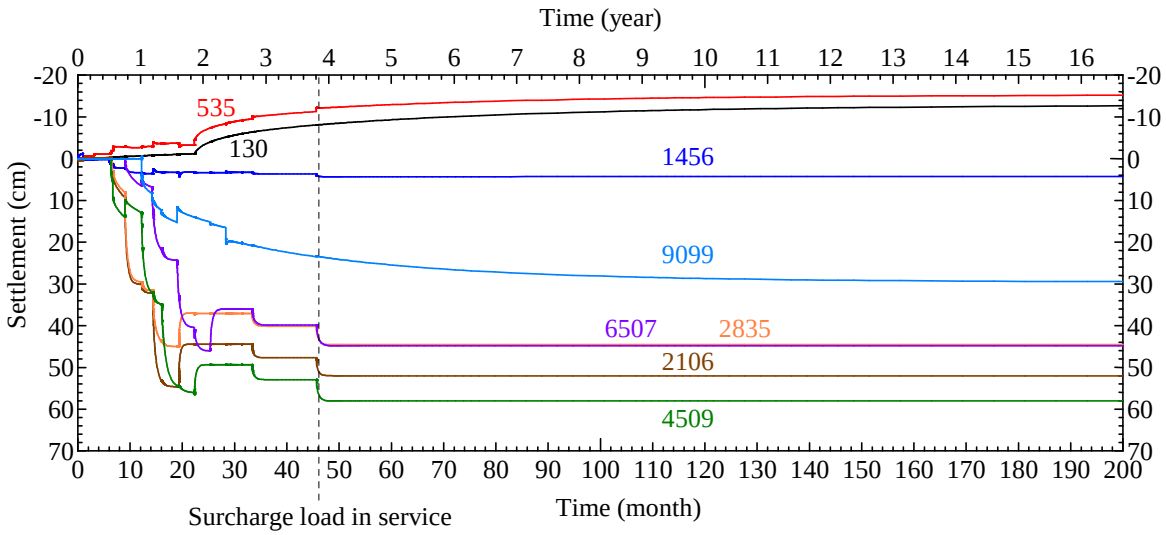
  This difference is because the reclamation was started from the area that is near the sea in 2-2’ section.
- The settlement of ground surface in CDM-area is the minimum in the reclaimed ground, which ranges from about 5cm to about 10cm.
- In 2-2’ section, the largest settlement is obtained in areas from PVD-1 to a half of PVD-2, where the ground reclamation is carried out at early stage. The maximum settlement of about 58cm is obtained at PVD-2 area.
- In 2-2’ section, settlement of the ground under the rubble-mound revetment does not subside sooner, because the ground is not improved by PVD.
- Since the previous information provided for this analysis was not sufficient, the reclamation and the excavation are assumed to be carried out under the instant loading and unloading condition, for the safety side evaluation. Because of this, the ground upheaval may be estimated larger than the actual phenomenon.

(3) Time-settlement behaviors at the typical points of ground surface

(as an example, shown the case of 2-2' section)



Location of the typical points and node numbers (2-2'section)

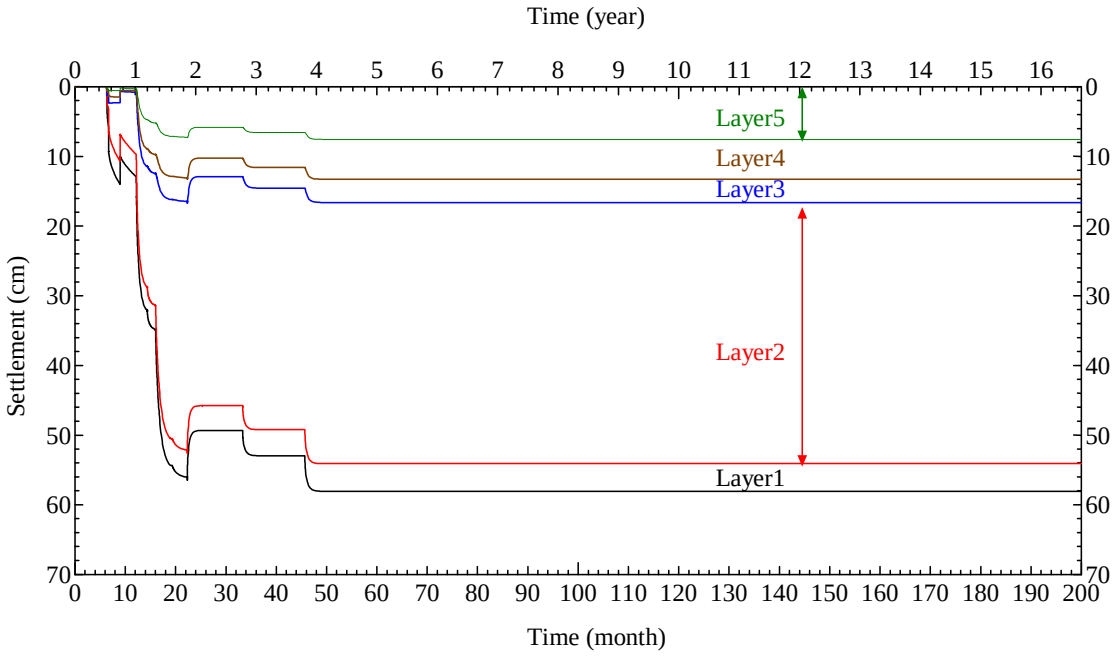


Time-settlement behaviors of the nodes illustrated in the upper figure (2-2'section)

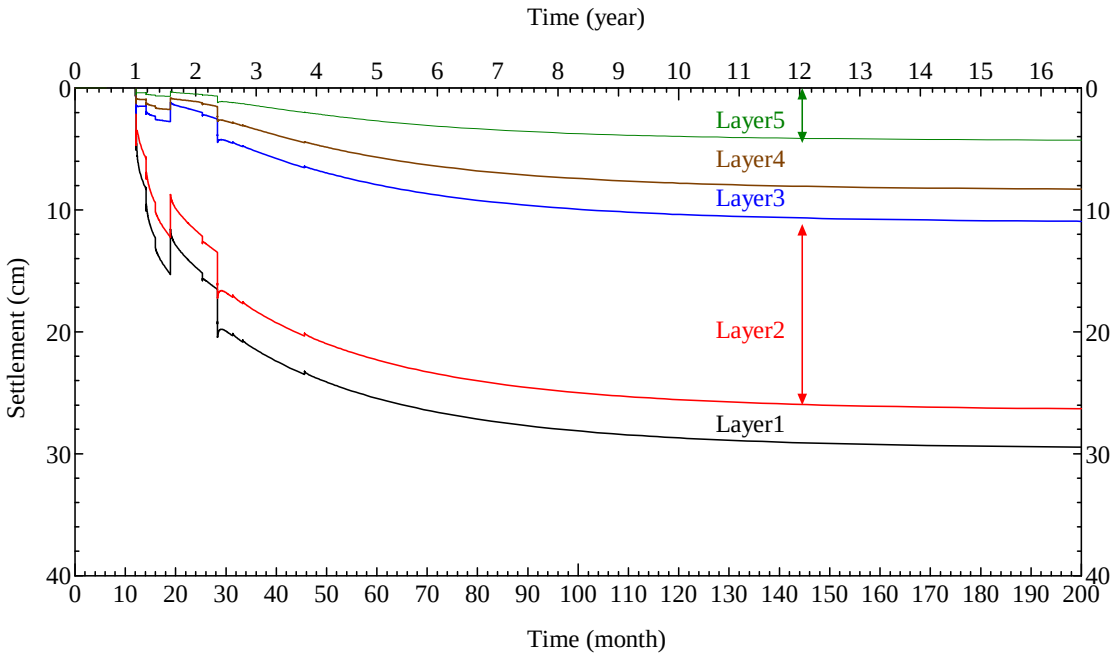
- In the point where the ground is improved by PVD (node-2106, 2835, 4509, 6507), the settlement subsides sooner and the residual settlement after the entry of service is small.
- In the point without PVD (node-535, 130, 9099), the settlement continues over about 10-year period.
- It is better that the ground under the counter fill is also improved by PVD for safety.

(4) Settlement of each layer

(as an example, shown the case of 2-2' section)



Settlement of each layer on the vertical section concluding node-4509 (improved by PVD)



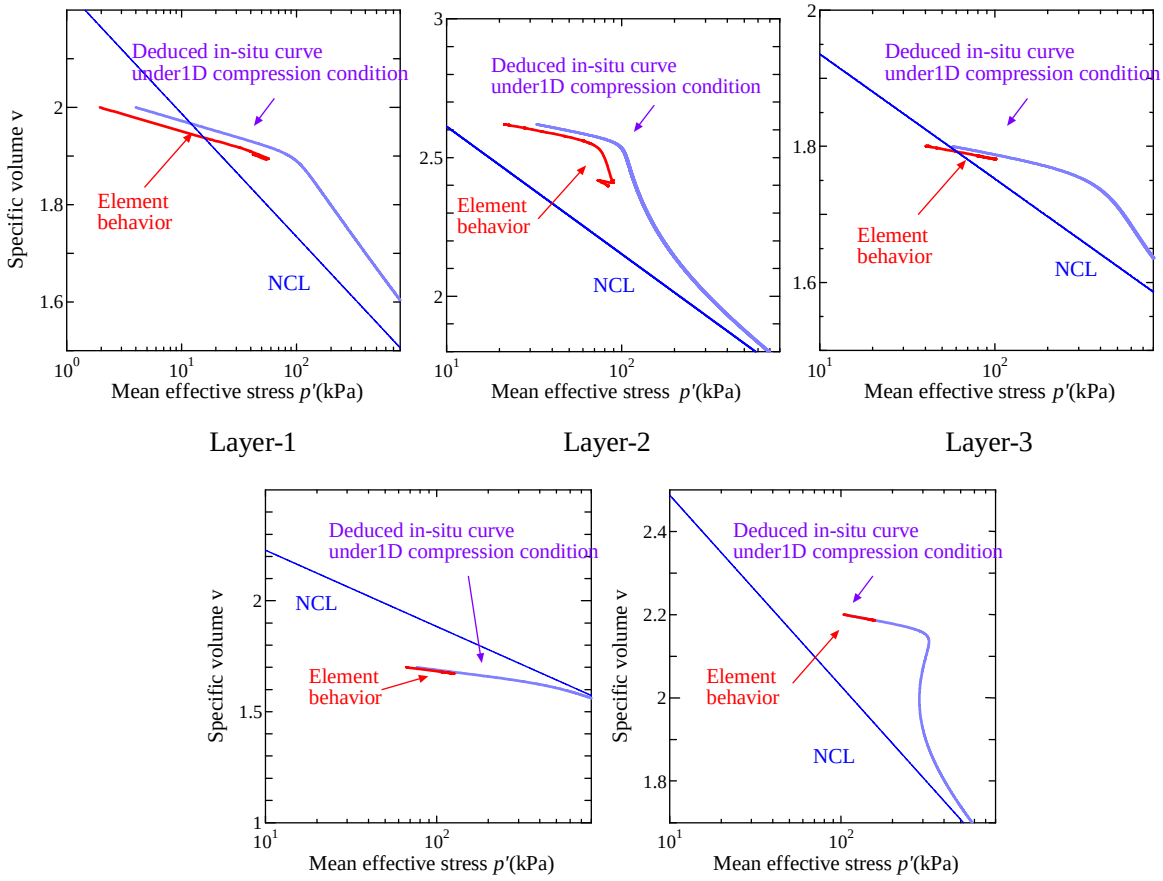
Settlement of each layer on the vertical section concluding node-9099 (without PVD improvement)

- Layer2 is the most dominant layer of ground settlement.
- Although Layer5 is the thickest, its settlement is small. It is expected that the stress states of layer 5 does not exceed the consolidation yield stress by reclamation loading (see next section).
- In the ground improvement by PVD (node-4509), all layer's settlement subside sooner.

・ In the ground without PVD improvement, the settlement of deep layers such as Layer4 and Layer5 continues for a long time.

(5) Behaviors of the typical elements at the middle depth of each layer

(as an example, shown the case of 2-2' section)



Behaviors of the elements at the middle depth of each layer on the vertical section concluding node-4509

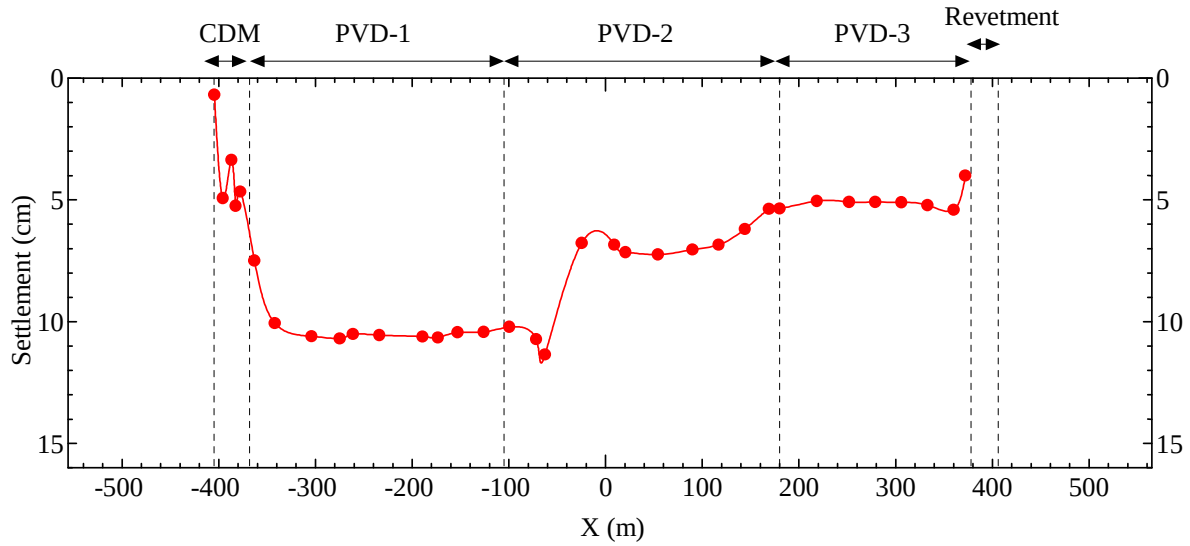
・ The deduced in-situ curves illustrated in the each figures by purple lines, are same as those in Figures 3 to 7, which are obtained by the responses of SYS Cam-clay model under 1D compression condition.

・ The element behaviors shown by red lines are calculated by ***GEOASIA*** under the loading histories, such as reclamation, excavation, preloading, and so on.

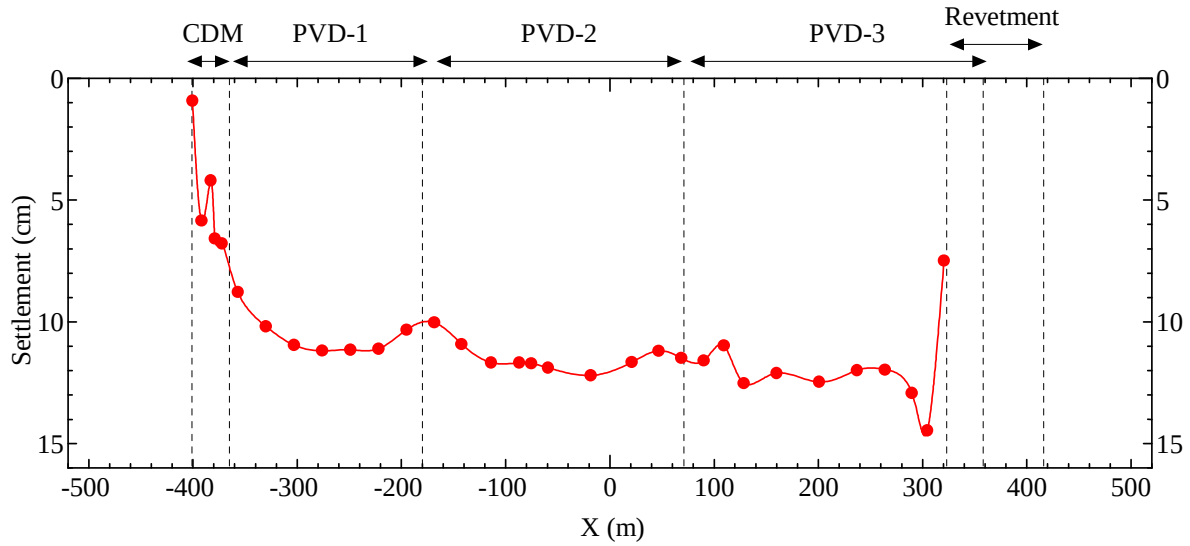
・ In Layer-2 only, the stress state exceeds the consolidation yield stress, and it caused the large compression.

(6) Settlement of the paved surface from the end of construction to the end of consolidation

[1-1' section]



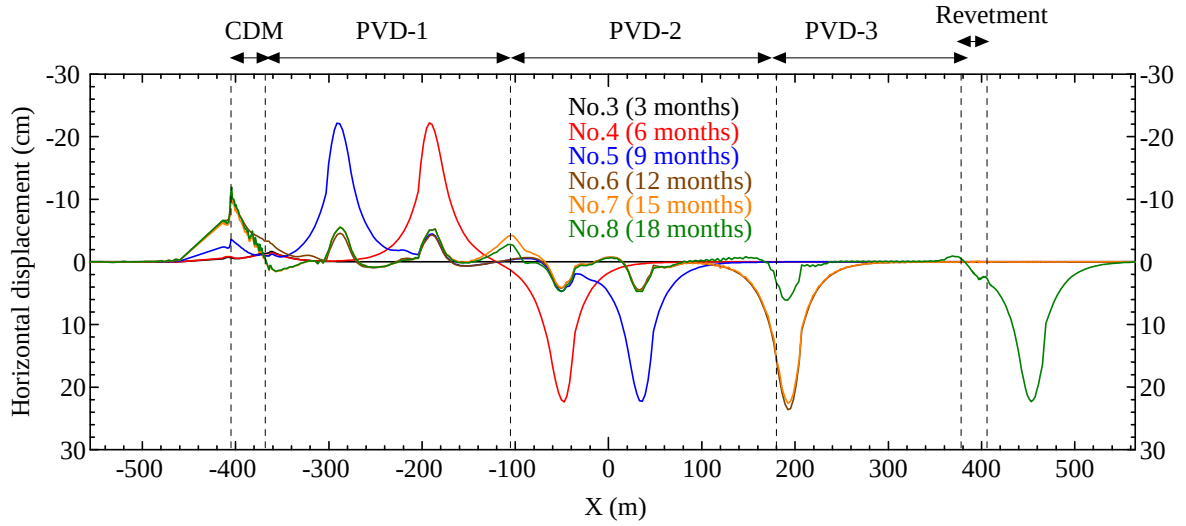
[2-2'section]

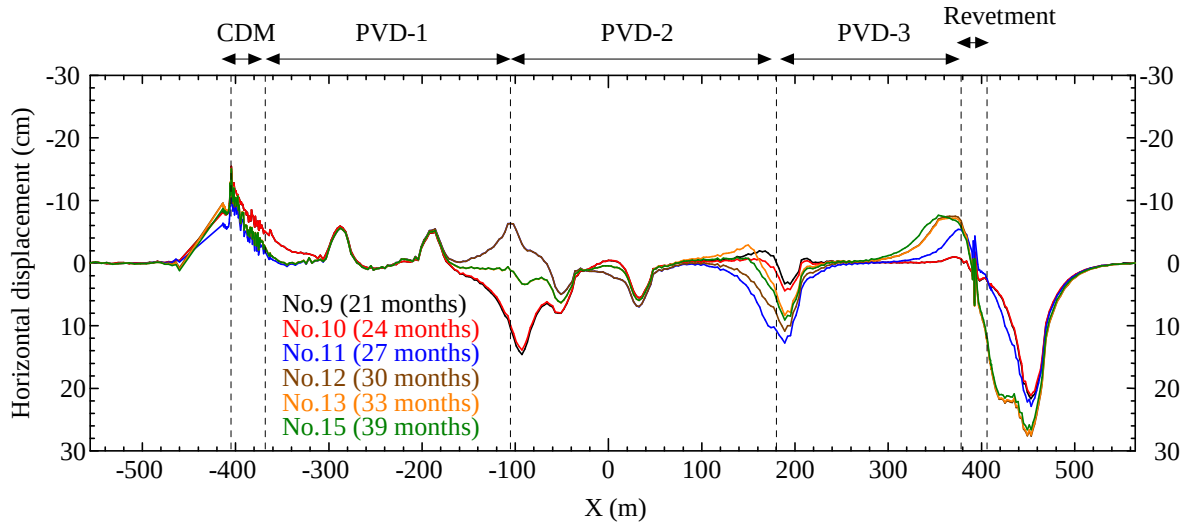


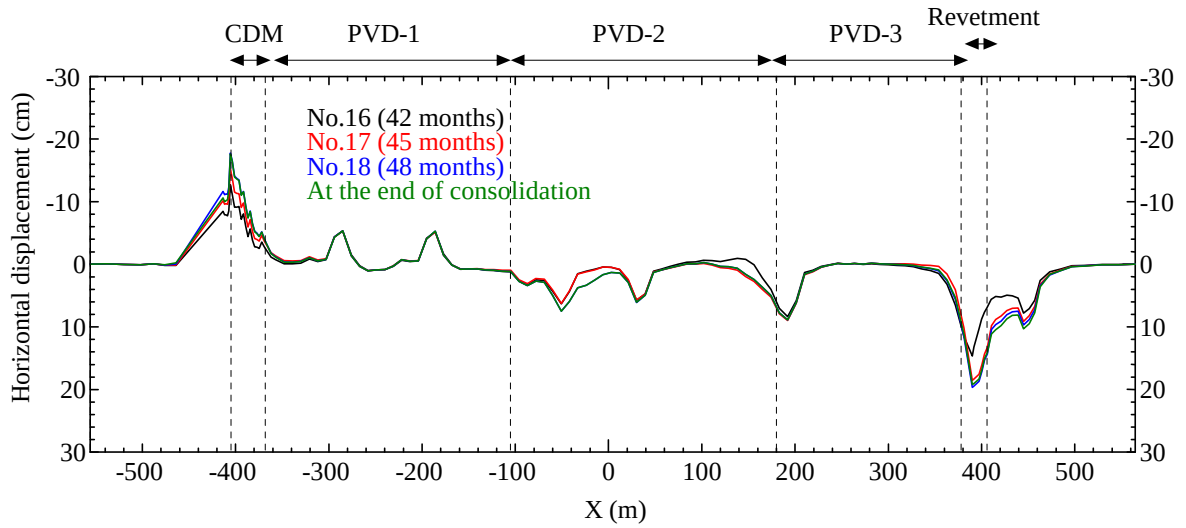
- In 1-1' section, the settlement of paved surface is larger in the left area (PVD-1 area) because surcharge load in service was larger.
- In the area improved by CDM, the settlement of paved surface is smaller.
- If the surcharge load is added uniformly, the point where larger settlement has already occurred by preloading tends to cause smaller settlement of the paved surface.
- Near the rubble-mound revetment, the settlement of paved surface is affected by the continuous settlement of the non-PVD ground under the counter fill

(7) Horizontal displacements of ground surface at the end of each stage

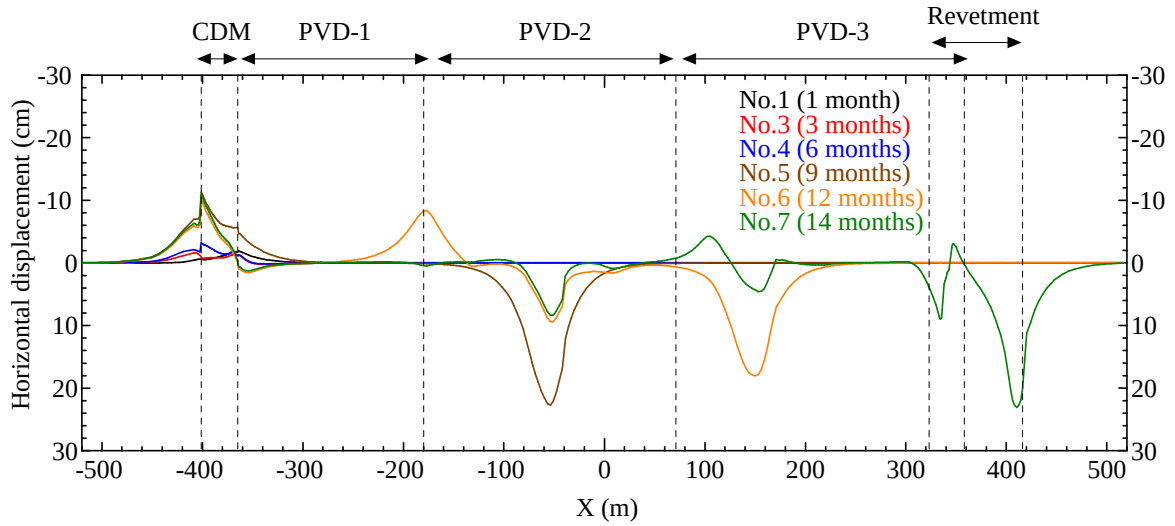
[1-1' section]

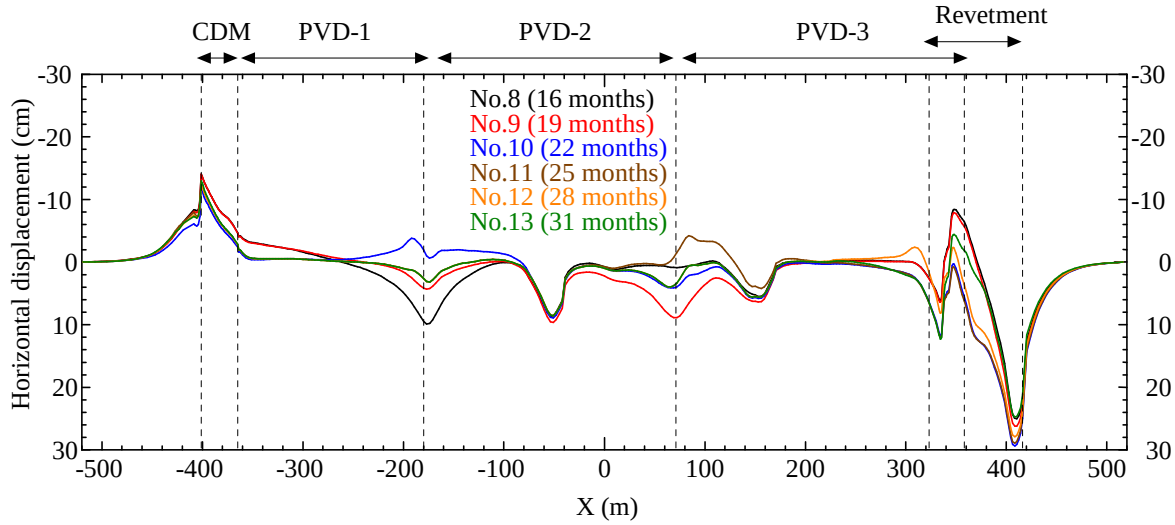


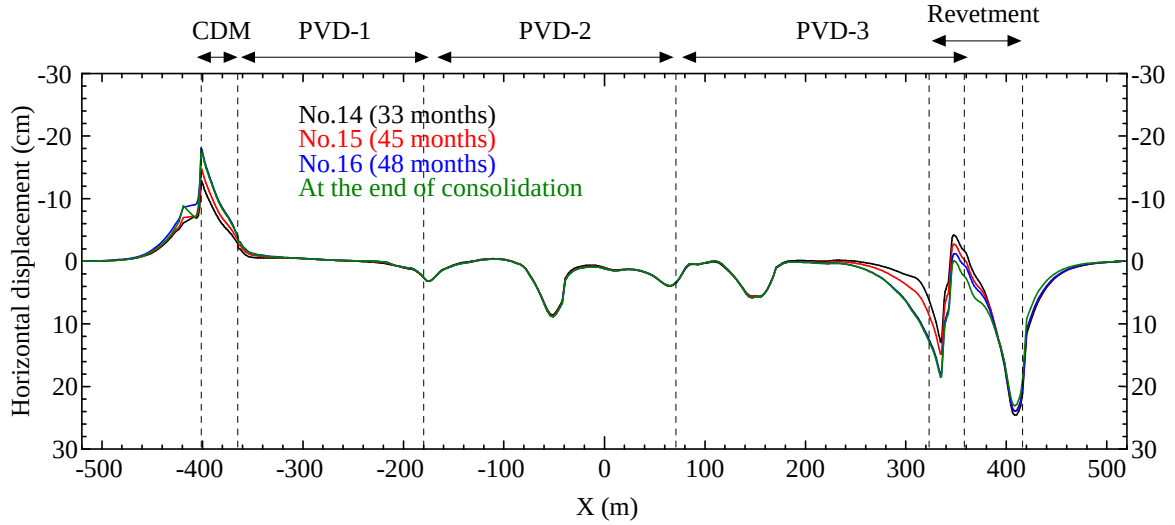




[2-2' section]





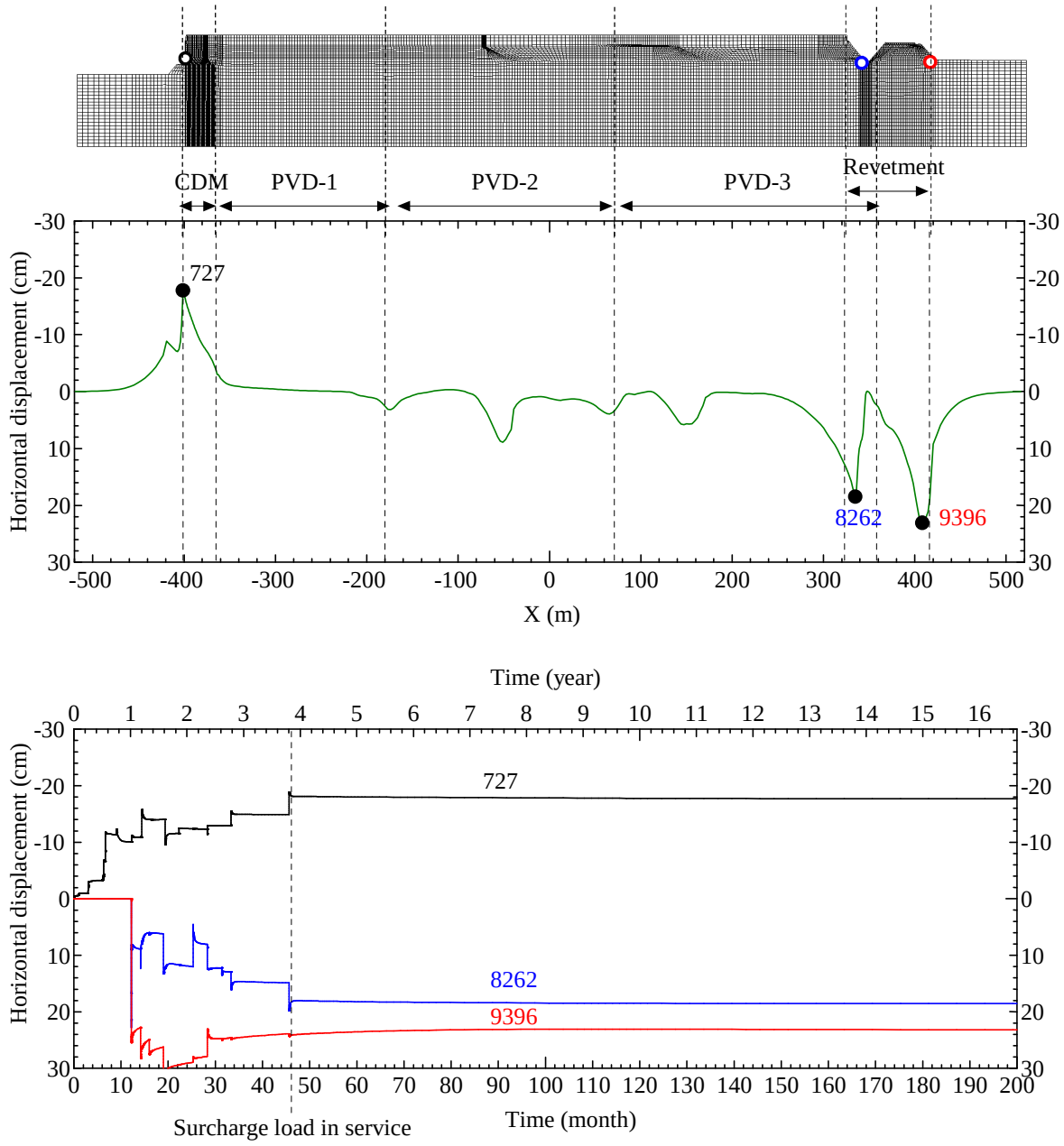


- Both of the sheet-pile revetment and the counter fill force out tosea-side.

・ In 2-2’ section, the deformation of the rubble-mound revetment is reduced by the counter fill.

(8) Time-Horizontal displacement behaviors at the typical points of ground surface

(as an example, shown the case of 2-2’ section)



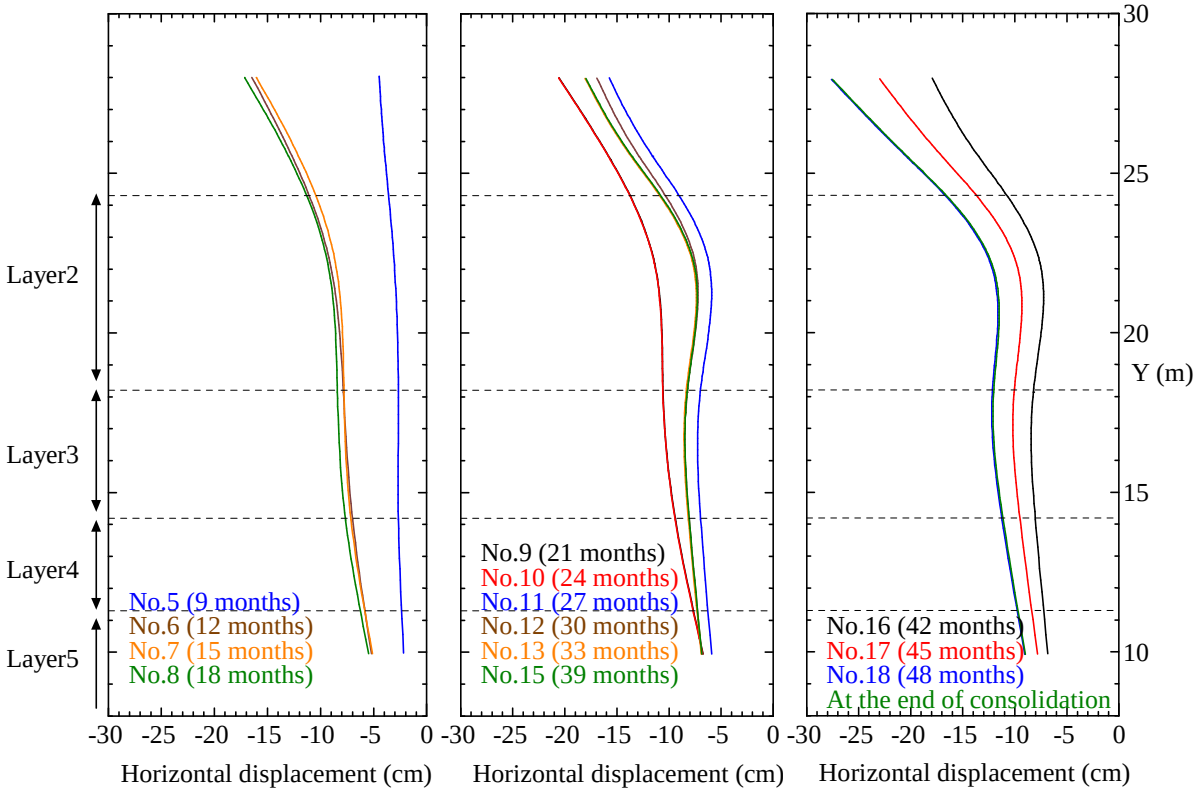
・ The outward deformation by reclamation and the inward deformation by unloading and consolidation are repeated. The horizontal displacement converges sooner than the settlement.

・ The sheet-pile revetment (node-727) and the rubble-mound revetment (node-8262) are forced out to sea-side by the pavement loading and the service loading. However, these deformations change inside immediately, and stabilized sooner.

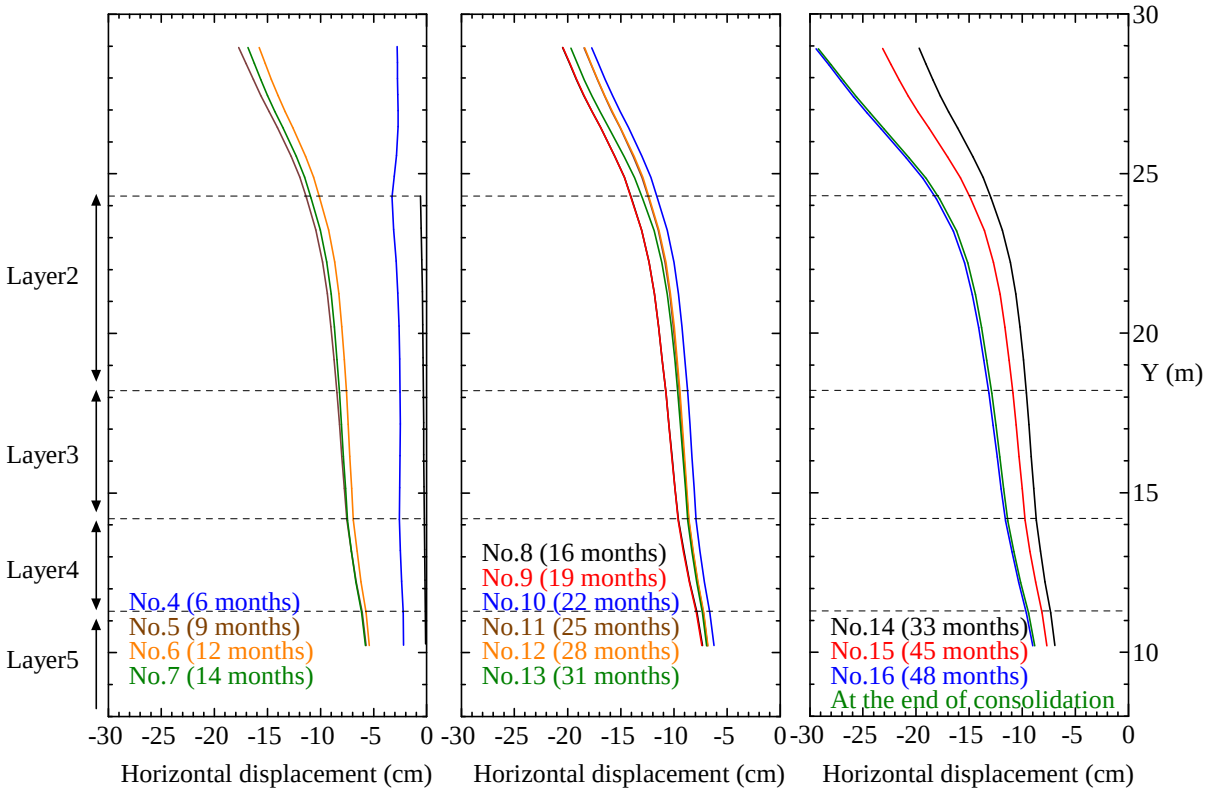
・ The small deformation to out-side of the counter fill continues after the entry of service, because the ground is not improved by PVD.

(9) Horizontal displacements of sheet pile at the end of each stage

[1-1' section]



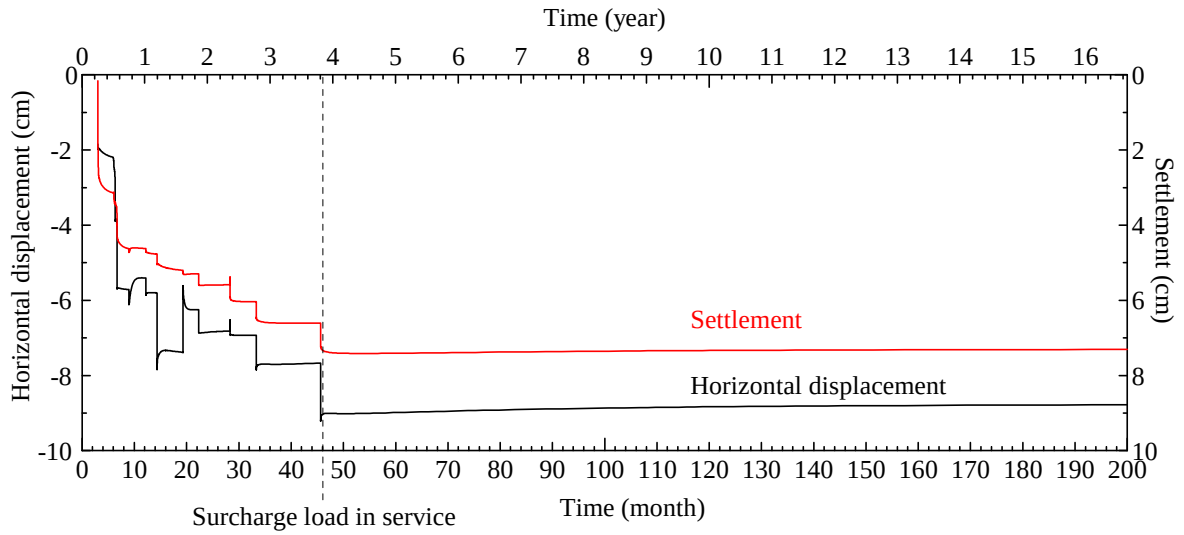
[2-2'section]



- The maximum horizontal displacements to out-side (sea-side) at the bottom and top of sheet-pile are about 10cm and about 30cm respectively.
- The displacement is lager in Layer2.

(10) Time-deformation behaviors at the bottom of sheet pile

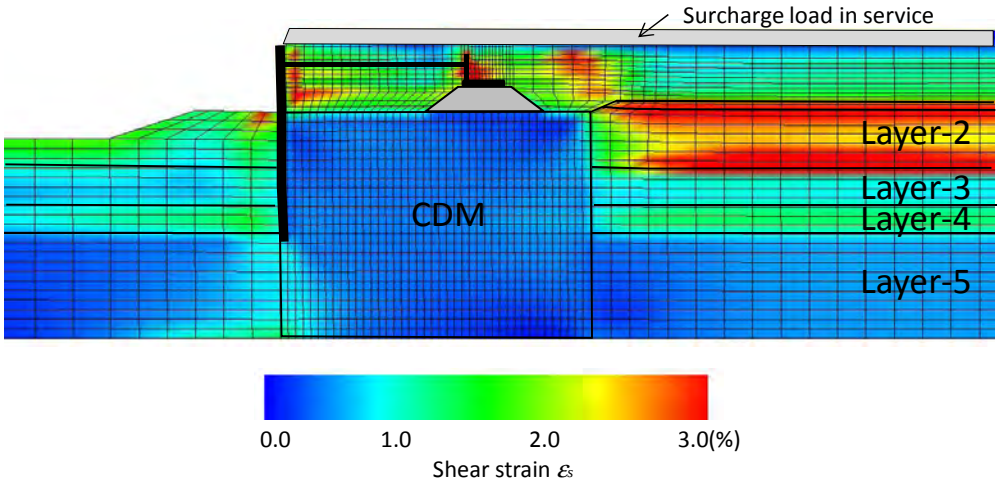
(as an example, shown the case of 2-2' section)



- In this analysis, the bottom of sheet pile is assumed to be located in the shallow part of Layer-5. As a result, the settlement is caused about 7cm, and the horizontal displacement to sea-side is about 9cm.
- After the entry of service, the small inward-deformation continues because the outside ground of sheet pile is not improved by PVD.

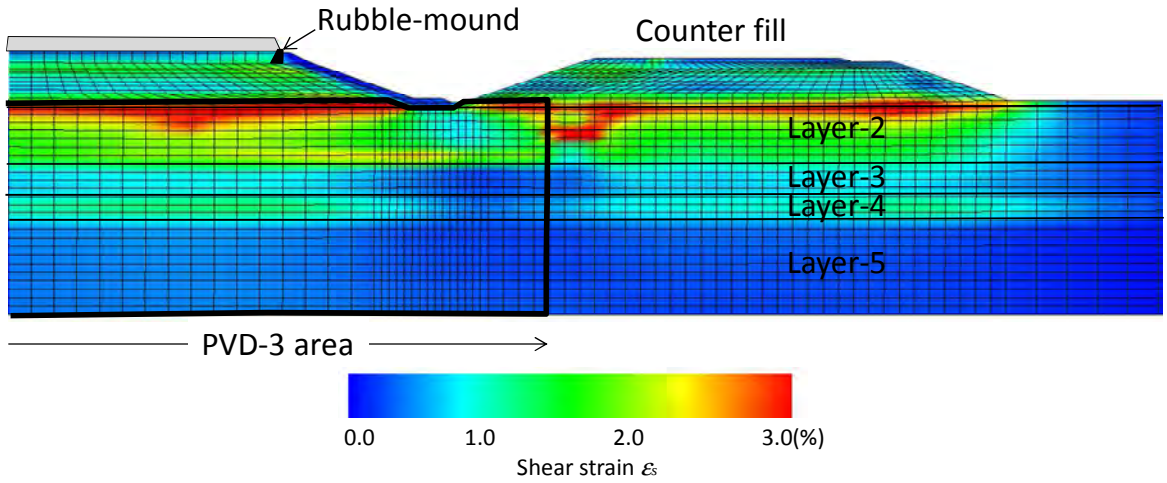
(11) Distribution of shear strain at the end of consolidation

[Sheet pile revetment and CDM-area (as an example, shown the case of 2-2' section)]



- Improvement by CDM is effective to reduce the ground deformation.
- Layer2 possesses the highest compressibility.
- The ground around the bottom of sheet pile is disturbed by the settlement of the pile.
- The reclaimed soils behind the sheet pile and the anchor wall are deformed in association with the outward deformation of sheet pile.

[Rubble-mound revetment (as an example, shown the case of 2-2' section)]



- The larger shear strain is observed in Layer2 directly below the left top of the counter fill and near the boundary line between improved and non-improved area by PVD, although it is not the levels that cause slip failure. However it is better that ground under the counter fill is also improved by PVD for safety constructions.

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1) Asaoka, A., Nakano, M. and Noda, T. (1994): Soil-water coupled behavior of saturated clay near/at critical state, *Soils and Foundations*, **34** (1), pp. 91-105.
2) Asaoka, A., Noda, T., Yamada, E., Kaneda, K. and Nakano, M. (2002): An elasto-plastic description of two distinct volume change mechanisms of soils, *Soils and Foundations*, **42** (5), pp. 47-57.
3) Asaoka, A. and Noda, T. (2007): All soils all states all round geo-analysis integration, International Workshop on Constitutive Modeling - Development, Implementation, Evaluation, and Application, Hong Kong, China, pp. 11-27.
4) Noda, T., Asaoka, A. and Nakano, M. (2008): Soil-water coupled finite deformation analysis based on a rate-type equation of motion incorporating the SYS Cam-clay model, *Soils and Foundations*, **48** (6), pp. 771-790.
5) Inagaki, M., Nakano, M., Noda, T., Tashiro, M., and Asaoka, A. (2010): Proposal of simple method of judging naturally deposited clay grounds exhibiting large long-term settlement due to embankment loading, *Soils and Foundations*, **50** (1), pp. 109-122.
6) Schmertmann, J.H. (1953): Estimating the true consolidation behavior of clay from laboratory test results, Proceedings ASCE, **79** (312), pp. 1-26.

Appendix

The quantified expression of structure, overconsolidation, anisotropy, and their respective evolution rules

Naturally deposited soils, whether clayey or sandy, generally exist in a 'structured' and overconsolidated state. To describe the deformation behavior of a soil in this state, we have to start from the base of an elasto-plastic model of a de-structured soil in a state of normal consolidation. Given that a soil in this unstructured and normally consolidated state still possesses anisotropy, we take for our 'base' in this paper the corrected Cam-clay model of Roscoe and Burland (1968) with the introduced addition of the rotational hardening concept of Sekiguchi and Ohta (1977), which treats stress parameter η^* and its evolution rule as an expression of anisotropy. The degrees of structure and overconsolidation are then introduced and quantified by means of the two concepts of the superloading surface for structure (Asaoka et al., 1998a, 2000, 2002), and the subloading surface for overconsolidation (Hashiguchi, 1978, 1989; Asaoka et al., 1997). That is to say, the degree of structure is expressed by means of a superloading surface situated on the outside of the Cam-clay normal-yield surface and similar to it (the center of similarity being the origin $p' = q = 0$ and the similarity rate being given by R^* $(0 < R^* \leq 1)$, while the overconsolidation state is expressed by means of a subloading surface situated on the inside of the superloading surface and again similar to it (center of similarity $p' = q = 0$, similarity rate R $(0 < R \leq 1)$; reciprocal $1/R$ is the overconsolidation ratio). p' here is the mean effective stress and q is the shear stress. Using effective stress tensor $\boldsymbol{T}'$ (tension: positive), we can say: $p' = -\mathrm{tr}\boldsymbol{T}'/3$, $q = \sqrt{3/2\,\boldsymbol{S}\cdot\boldsymbol{S}}$.

The closer R^* is to 0 the higher the degree of structure, but with the loss of structure that accompanies progressive plastic deformation R^* will approach 1 (evolution rule for R^*). Similarly, the closer R is to 0 the more overconsolidated the state of the soil, but as R increases toward 1 with plastic deformation, the state of the soil will also approach normal consolidation (evolution rule for R). It can thus be assumed that the loss of structure with progressive plastic deformation brings a simultaneous release from overconsolidation (a transition to the normally consolidated state), resulting finally in conditions that match those in the Cam-clay model. The relative positions of the three loading surfaces, assuming conditions of axial symmetry, are as shown in Fig. A1-1.

If we start from Cam-clay equation (A1-1) below as our base, given that the current effective stress exists on the subloading surface, we first need to adapt relations to the subloading surface through the application of various elasto-plastic principles such as the associated flow rule and Prager's consistency condition, so as to give equation (A1-2).

The Cam-clay potential:

$$\mathrm{MD}\ln\frac{\tilde{p}'}{\tilde{p}_0'} + \mathrm{MD}\ln\frac{\mathrm{M}^2+\eta^{*2}}{\mathrm{M}^2} + \int_0^t J\mathrm{tr}\boldsymbol{D}^p d\tau = f(\tilde{p}', \eta^*) + \int_0^t J\mathrm{tr}\boldsymbol{D}^p d\tau = 0 \tag{A1-1}$$

The subloading surface:

$$f(p', \eta^*) + \mathrm{MD}\ln R^* - \mathrm{MD}\ln R + \int_0^t J\mathrm{tr}\boldsymbol{D}^p d\tau = 0 \tag{A1-2}$$

Here, $\mathrm{D} = (\tilde{\lambda} - \tilde{\kappa})/\mathrm{M}/(1+\mathrm{e}_0)$ is the dilatancy coefficient, and M, $\tilde{\lambda}$, $\tilde{\kappa}$ and e_0 are the critical state constant,

compression index, swelling index, and initial void ratio. $J = (1+\mathrm{e})/(1+\mathrm{e}_0)$ (e is the void ratio at time $t = t$).

$-\int_0^t J\mathrm{tr}\boldsymbol{D}^p d\tau$ (compression: positive) corresponds to the plastic volumetric strain η^*, the expression of anisotropy, is obtained using the rotational hardening variable $\boldsymbol{\beta}$, from the calculation $\eta^* = \sqrt{3/2\ \hat{\boldsymbol{\eta}}\cdot\hat{\boldsymbol{\eta}}}$, $\hat{\boldsymbol{\eta}} = \boldsymbol{\eta} - \boldsymbol{\beta}$, $\boldsymbol{\eta} = \boldsymbol{S}/p'$, $\boldsymbol{S} = \boldsymbol{T}' + p'\boldsymbol{I}$. $\boldsymbol{\beta} = \boldsymbol{0}$ expresses a state of no anisotropy. In the present paper, the evolution rules for R^*, R and $\boldsymbol{\beta}$ are given by the following equations.

$$\text{Evolution rule for } R^* : \dot{R}^* = JU^*\left\{c_s\sqrt{2/3}\left\|\mathbf{D}_s{}^p\right\| + (1-c_s)\left(-D_v{}^p\right)\right\},\ U^* = \frac{a}{\mathrm{D}}R^{*b}(1-R^*)^c \tag{A1-3}$$

$$\text{Evolution rule for } R : \dot{R} = JU\left\|\boldsymbol{D}^p\right\|,\ U = -\frac{m}{\mathrm{D}}\ln R \tag{A1-4}$$

$$\text{Evolution rule for } \boldsymbol{\beta} : \overset{\circ}{\boldsymbol{\beta}} = J\frac{br}{\mathrm{D}}\sqrt{\frac{2}{3}}\left\|\boldsymbol{D}_s^p\right\|\ \left\|\hat{\boldsymbol{\eta}}\right\|\left(m_b\frac{\hat{\boldsymbol{\eta}}}{\left\|\hat{\boldsymbol{\eta}}\right\|} - \boldsymbol{\beta}\right) \tag{A1-5}$$

$\boldsymbol{D}^p$ here is the plastic stretching tensor, $\boldsymbol{D}_s{}^p$ is the deviator component of $\boldsymbol{D}^p$, $-D_v{}^p$ is the volumetric component of $\boldsymbol{D}^p$, and $\|\ \|$ represents its norms. $\overset{\circ}{\boldsymbol{\beta}}$ in equation (A1-5) is the Green and Nahdhi's (1965) rate of $\boldsymbol{\beta}$. The parameter groups for the evolution rules in equations (A1-3) – (A1-5) all consists of constants, and from their respective functions we may call *a*, *b*, *c*, c_s the degradation indices of structure, *m* the degradation index of overconsolidation, *br* the rotational hardening index, and m_b the rotational hardening limit constant.

A new evolution rule for R^* is proposed to replace Eq. (A1-3) for expressing structural upgradation, dividing the contribution of plastic deformation to the change of soil structure into the deviator of the plastic stretching $\sqrt{2/3}\mathbf{D}_s{}^p$ and volumetric component $-D_v{}^p$. The ratio between these terms is given by c_s ($0 \le c_s \le 1$).

The associated flow rule and the constitutive equation

$$\text{Associated flow rule : } \boldsymbol{D}^p = \lambda\frac{\partial f}{\partial \boldsymbol{T}'},\quad \lambda = \frac{\frac{\partial f}{\partial \boldsymbol{T}'}\cdot\overset{\circ}{\boldsymbol{T}}'}{J\ \frac{\mathrm{MD}}{p'(\mathrm{M}^2+\eta^{*2})}(\mathrm{M}_s{}^2-\eta^2)} > 0 \tag{A1-6}$$

$$\text{Constitutive equation : } \overset{\circ}{\boldsymbol{T}}' = \boldsymbol{E}\boldsymbol{D} - \Lambda\boldsymbol{E}\frac{\partial f}{\partial \boldsymbol{T}'} \tag{A1-7}$$

$\boldsymbol{E}$ is the elastic modulus tensor, $\overset{\circ}{\boldsymbol{T}}'$ is the Green and Naghdi's (1965) rate of $\boldsymbol{T}'$, and Λ is the expression of plastic multiplier λ in terms to stretching $\boldsymbol{D}$. Further, we can establish the relations

$$\mathrm{M}_s{}^2 = \mathrm{M}_a{}^2 + br\frac{4\mathrm{M}\eta^{*2}}{\mathrm{M}^2+\eta^{*2}}\left(m_b\eta^* - \sqrt{\frac{3}{2}}\hat{\boldsymbol{\eta}}\cdot\boldsymbol{\beta}\right) - \mathrm{MD}\left(\frac{U^*}{R^*}2\eta^* + \frac{U}{R}\sqrt{6\eta^{*2} + \frac{1}{3}(\mathrm{M}_a{}^2-\eta^2)^2}\right) \tag{A1-8}$$

and

$$\mathrm{M}_a{}^2 = \mathrm{M}^2 + \zeta^2,\quad \zeta = \sqrt{3/2}\left\|\boldsymbol{\beta}\right\| \tag{A1-9}$$

The slope M_s of the threshold between hardening and softening $q = \mathrm{M}_s p'$, obtained under loading

conditions $\lambda > 0$, varies according to structural degradation, loss of overconsolidation and development or loss of anisotropy, as well as with the current stress ratio. Similarly, the slope M_a of the threshold between plastic compression and expansion $q = \mathrm{M}_a p'$ varies in response to the development or loss of anisotropy. For details, the reader is referred to Asaoka et al., 2002.

Appendix 17

Calculation Analysis of Outer Revetment A & B

APPENDIX 17: CALCULATION ANALYSIS OF OUTER REVETMENT A & B

Table of Contents

17.1. ARMOR WEIGHT CALCULATION

(Shore Protection Manual - US Army Corps of Engineers-1984)

Hudson Formula:

$$W = \frac{\rho_s H_s^3}{K_D \cdot \left(\frac{\rho_s}{\rho_w} - 1\right)^3 \cot \alpha}$$

Where in:

ρ_s - *mass density of armor units* = 2 t/m3

ρ_w - *mass density of water (t/m*^{3} = 1.025t/m3

K_D - *stability cofficient* Tetrapod **= 6.93** *breaking zone*

α - *slope angle*

H_s - *characteristic wave height*

Concrete layer placing Qty. 2

Ord.	Wave height H1/3 (m)	Tetrapod (tons)								Remark
		Slope	W (tons)	Type (tons)	Thickness (m)	Bs (m)	Row of block placing on top	B (m)	B' (m)	
1	3.0	1 : 3	1.55	**2.00**	1.90	1.30	2	1.60	2.20	ORA
2	2.7	1 : 4/3	2.55	**3.20**	2.20	1.50	2	1.80	2.50	ORB_A&B
3	3.2	1 : 4/3	4.24	**5.00**	2.60	1.80	2	2.10	2.90	ORB_C&D

17.2. THICKNESS OF UNDERLAYER

$$r = nk_\Delta \left(\frac{W}{w_a}\right)^{1/3}$$

Where: r - average thickness of armour layer or underlayer (m)

n - number of quarrystone or concrete armor units in tl = 2.00

W - weight of individual armor units

w_a - specific weight of the armor unit material = 2.65 t/m3

k_Δ - layer coefficient, table VI-5-51 EM 1110-2-1100 = 1.00

Equivalent diameter of Stone

$$D_s = 1.24\left(\frac{W_s}{\gamma_s}\right)^{1/3}$$

Where: W_s - stone weight (t)

γ_s - stone specific weight in compatible units (t/m3)

W (kg)	200	300	400	500	600	700	800	1000
r (m)	0.85	0.97	1.06	1.15	1.22	1.28	1.34	1.45
D_s (m)	0.52	0.60	0.66	0.71	0.76	0.80	0.83	0.90

17.1.(1) ARMOR WEIGHT CALCULATION (for reference)
(Shore Protection Manual - US Army Corps of Engineers-1984)

Hudson Formula:

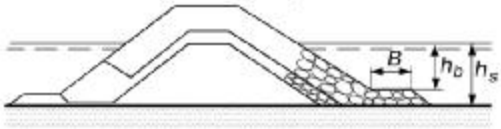
$$W = \frac{\rho_s H_s^3}{K_D \left(\frac{\rho_s}{\rho_w} - 1 \right)^3 \cot \alpha}$$

Where in:

ρ_s - *mass density of armor units*	=	2.3	t/m3
ρ_w - *mass density of water*	=	1.025	t/m3
K_D - *stability coefficient*	RAKUNA-IV=	10.8	(*for sloping breakwater*)
α - *slope angle*			
H_s - *characteristic wave height*			
Concrete layer	=	2	layers

Ord.	Wave height $H_{1/3}$ (m)	RAKUNA-IV (tons)								Remark
		Slope	W (tons)	Type (tons)	Thickness (m)	Bs (m)	Row of block placing on top	B (m)	B' (m)	
1	3	1 : 3	1.01	2	1.8	1.2	2	1.66	1.95	ORA
2	2.7	1 : 4/3	1.65	2	1.8	1.2	2	1.66	2.26	ORB_A&B
3	3.2	1 : 4/3	2.75	4	2.2	1.5	2	2.03	2.76	ORB_C&D

17.3. WIDTH OF STONE BERM (Table VI-5-45, Part VI, pVI-5-105)



Two layer armor stone toe berm for exposed sides of rubble-mound breakwaters and jetties (CERC 1986)

$B = 3t$ for (W_{50}) berm
where $t = (W_{50} / \gamma)^{1/3}$

W_{50} (t)	2	3	4	5
γ (t/m3)	2.65	2.65	2.65	2.65
t (m)	0.91	1.04	1.15	1.24
B (m)	2.73	**3.13**	3.44	3.71

17.4. STABILITY OF TOE BERM OF OUTER REVETMENT
(According to "The Rock Manual, CIRIA 683")

Van der Meer (1995) formular:

$$\frac{H_s}{\Delta D_{n50}} = \left(2 + 6.2\left(\frac{h_t}{h}\right)^{2.7}\right) N_{od}^{0.15} \qquad (5.188)$$

$$M_{n50} = \rho_r D^3_{n50}$$

Hudson formular:

$$M_{50} = \frac{\rho_s}{K_D \Delta^3 cot\alpha} H^3_s \qquad (5.133)$$

Where:

Hs - significant wave height, $H_{1/3}$ of the incident waves at the toe of the structure (m)

Δ - relative buoyant density, ρ_s/ρ_w-1

D_{n50} - equivalent cube length of median stone (m)

M_{n50} - medium mass of rocks

ρ_s (t/m^3)	ρ_w (t/m^3)	Δ (t/m^3)	N_{od}	cotα	K_D
2.65	1.025	1.59	0.5	2	3.5

Pos	Seabed Level (m)	Berm Level (m)	Water level (m)	Hs (m)	h (m)	h_t (m)	h_t/h	$H_s/\Delta D_{n50}$ (m)	D_{n50} (m)	M_{n50} (kg)		
										Van der Meer	Hudson	**Selected**
ORA-1	-0.5	0.4	HHWL +4.43	3.00	4.93	4.03	0.82	**5.04**	0.38	140	-	**200**
ORA-2	-1.0	-0.1	HHWL +4.43	3.00	5.43	4.53	0.83	**5.23**	0.36	126	-	**200**
ORA-3	0.0	0.9	HHWL +4.43	3.00	4.43	3.53	0.80	**4.83**	0.39	159	-	**200**
ORA-4	1.0	1.9	HHWL +4.43	3.00	3.43	2.53	0.74	**4.26**	0.44	232	-	**200**
ORB-A	1.0	2.0	HHWL +4.43	2.70	3.43	2.43	0.71	**4.01**	0.43	204	-	**300**
ORB-B	1.5	2.5	HHWL +4.43	2.70	2.93	1.93	0.66	**3.61**	0.47	278	-	**300**
ORB-C	0.0	1.0	HHWL +4.43	3.20	4.43	3.43	0.77	**4.60**	0.44	223	-	**300**
ORB-D	0.0	1.0	HHWL +4.43	3.20	4.43	3.43	0.77	**4.60**	0.44	223	-	**300**
ORA-1	-0.50	0.40	LWL +0.43	0.87	0.93	0.03	0.03	**1.80**	0.30	75	63	**200**
ORA-2	-1.00	-0.10	LWL +0.43	0.87	1.43	0.53	0.37	**2.19**	0.25	42	63	**200**
ORA-3	0.00	0.90	LWL +0.43	0.87	0.43	-0.47	-1.09	**Out of range => Using Hudson's formular to check stability of armour stone**			63	**200**
ORA-4	1.00	1.90	LWL +0.43	0.87	-0.57	-1.47	2.58				63	**200**
ORB-A	1.00	2.00	LWL +0.43	0.80	-0.57	-1.57	2.75				49	**300**
ORB-B	1.50	2.50	LWL +0.43	0.80	-1.07	-2.07	1.93				49	**300**
ORB-C	0.00	1.00	LWL +0.43	0.80	0.43	-0.57	-1.33				49	**300**
ORB-D	0.00	1.00	LWL +0.43	0.90	0.43	-0.57	-1.33				69	**300**

17.5. ARMOR STONE CALCULATION
(According to "The Rock Manual, 2nd edition" applied for Shalow water condition)
Armour Stone Layer of channel side of Outer revetment B

Stability parameter:

$$N_s = \frac{H_s}{\Delta D_n} = \frac{(K_D cot \propto)^{\frac{1}{3}}}{1.27} \qquad (Eq. 5.134)$$

$$W_n = {D_n}^3 \rho_s$$

Where: Ns - stability parameter
Hs - significant wave height, $H_{1/3}$ of the incident waves at the toe of the structure (m)
Δ - relative buoyant density, ρ_r/ρ_w-1
α - slope angle (^{o})

Surf similarity parameter, using the energy wave pediod $T_{m-1,0}$:

$$\xi_{s-1,0} = \frac{tan\alpha}{\sqrt{\frac{2\pi H_s}{g{T_{m-1,0}}^2}}}$$

Critical surf similarity parameter:

$$\xi_{cr} = \left[\frac{c_{pl}}{c_s} P^{0.31} \sqrt{tan\alpha}\right]^{\frac{1}{P+0.5}} \qquad (Eq. 5.138)$$

For $\xi_{s-1,0} < \xi_{cr}$ wave are plunging and Equation (5.139) applies:

$$\frac{H_s}{\Delta D_n} = c_{pl} P^{0.18} \left(\frac{S_d}{\sqrt{N}}\right)^{0.2} \left(\frac{H_s}{H_{2\%}}\right) \left(\xi_{s-1,0}\right)^{-0.5} \qquad (Eq. 139)$$

For $\xi_{s-1,0} > \xi_{cr}$ wave are surging and Equation (5.140) applies:

$$\frac{H_s}{\Delta D_n} = c_s P^{-0.13} \left(\frac{S_d}{\sqrt{N}}\right)^{0.2} \left(\frac{H_s}{H_{2\%}}\right) \sqrt{cot\alpha} \left(\xi_{s-1,0}\right)^{P} \qquad (Eq. 140)$$

Where: c_{pl} = 8.4, with a standard deviation of σ = 0.7
c_s = 1.3, with a standard deviation of σ = 0.15
P - notional permeability of structure, 0.1 < P <0.6 (see Fig. 5.39)
N - number of incident waves at the toe, which depends on the duration of the wave conditions
$H_{2\%}$ - wave height exceeded by 2 per cent of the incident waves at the toe (m), $H_{2\%}$ = (1.2÷1.4)H_s
$T_{m-1,0}$ - the spectral mean energy period (s)

$$T_{m-1,0} = \frac{T_p}{1.1} \qquad (Eq. 4.62) \qquad T_p = \frac{T_{1/3}}{(0.9 \div 0.96)}$$

ρ_r (t/m^3)	ρ_w (t/m^3)	Δ (t/m^3)	α (^{o})	H_s (m)	$T_{1/3}$ (s)	$H_{2\%}$ (m)	T_p (s)	$T_{m-1,0}$ (s)	g (m/s^2)
2.65	1.025	1.59	33.69	2.4	5.98	3.12	6.43	5.85	9.81

P	S_d	Damage level (%)	N in 3 hours	$\xi_{s-1,0}$	ξ_{cr}	N_s	D_n	W_s (t)	**W_s (t) Selected**
0.5	10	10-15	1848	3.14	4.26	2.40	0.63	0.66	**0.70**

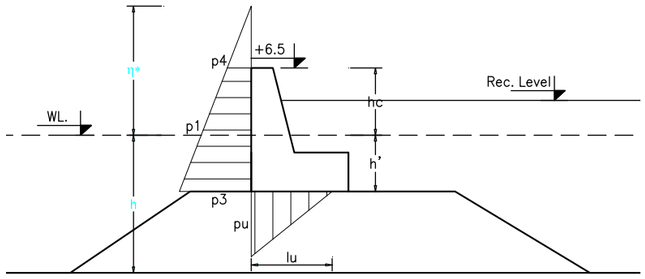
17.6. STABILITY CALCULATION OF CONCRETE CAP OF OUTER REVETMENT A

A. Wave Force under Wave Crest

1. Input data:

	50 years	5 years
- Tide Level - HHWL (CDL):	1 % (100 yr)	20 % (20 yr)
	4.43	**3.92**
- Crest Level (CDL):	**+ 6.5**	
- Bottom Upright Wall Level (CDL):	+ 3.7	
- Bottom Width of Upright Wall (m):	2.5	
- Reclamation Level (CDL):	+ 5.5	
- Crest Level of Armor stone (CDL):		
- Seabed slope:		
- Seabed Surface Level (CDL):	0.5	
- Significant Wave Height ($H_{1/3}$), m:	3	2.8
- H_{max} (Goda's Index), m:	3.9	3.57
- Wave Period (T), sec:	13.3	11
- Wave Length (L), m:	81.05	70

2. Wave Pressure on the Front Face of an Upright Wall



Wave Pressure Distribution Used in Design Calculation

$$p_1 = 0.5(1+\cos\beta)\lambda\alpha_1\rho_0 g H_D$$

$$p_3 = pu = \alpha_3 p_1$$

$$\lambda = \exp[-10\left(\frac{h}{L}\right)^{1.5}\left(1-\frac{h'}{h}\right)^{5}]$$

$$\alpha_1 = 0.6 + \frac{1}{2}\left[\frac{4\pi h/L}{\sinh(\frac{4\pi h}{L})}\right]^2$$

$$\alpha_3 = 1 + \frac{h'}{\eta}(if\ h' \le 0)$$

$$\eta^* = 0.75(1+cos\beta)\lambda_1 H_D$$

3. Uplift beneath Upright Wall

$$p_3 = pu = \alpha_3 p_1$$

$$l_u = \min\{B, 0.2\frac{(\eta^* + h')}{|h'|}$$

4. Wave Height and Wavelength Used in the Wave Pressure Calculation

H_D = Hmax

5. Results of Calculation

5.1. Input data

	50 years	5 years
β (deg) =	32	
cos β:	0.848	
H_D (m):	3.9	3.57
L (m):	81.0474397	70
HHWL (CDL):	4.43	3.92
Sea bed Level (CDL):	0.5	
Crest Level (CDL):	6.5	
h (m):	3.93	3.42
h' (m)	0.73	0.22
ρ_0 (t/m3):	1.025	
g (m/s2):	9.81	
h_c (m):	2.07	2.58
4 πh/L	0.609	0.614
2 πh/L	0.305	0.307
λ	0.963	0.925

5.2. Wave pressure on the front face of an Upright wall

η* =	5.20	4.58
α_1 =	1.042	1.042
α_3 =	0.992	0.997
h_c* = min{η* , h_c}	2.07	2.58
α_4 =	0.602	0.437
(1+cosβ)	1.848	
$\alpha_1 \lambda \rho_0 H_D$	4.011	3.528
p_1 (t/m2) =	3.71	3.26
p_3 (t/m2) =	3.68	3.25
p_4 (t/m2) =	2.23	1.42
p_c (at crest level), (t/m2) =	1.94	1.35

5.3. Uplift beneath Upright Wall

p_u (t/m2) =	3.68	3.25
l_u (m) =	1.63	2.50

5.4. Total wave pressure on Upright Wall

P (t/m) =	8.27	6.54
U (t/m) =	2.99	4.06

B. Effect of Reclamation Soil

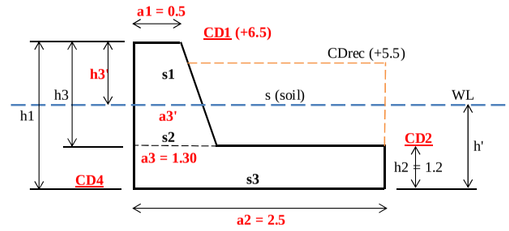
	50 years	5 years
H (m)	1.8	
ϕ (deg)	30.0	
γ_s (t/m3)	1.6	
γ'_s (t/m3)	1.03	
h_{dry} (m)	1.1	1.6
h_{wet} (m)	0.7	0.2
Kp = $\tan^2(45^o+\phi/2)$	3.0	
p_p (dry), t/m2	5.14	7.58
p_p (wet), t/m2	7.38	8.26
Pp (dry), t/m	2.75	5.99
Pp (wet), t/m	4.57	1.74
Pp(final), t/m	**7.32**	**7.73**

C. Safety Factor

μ (friction factor between conc. & stone):	0.60	
W (total), t/m	8.79	10.09
μ (friction factor between stone & stone):	0.80	

Sliding	**S.F. (Normal)**	**0.42**	**0.55**
	S.F. (Soil effect)	**3.65**	**OK**

Overturning	Mp	10.63	7.97
	M_{Pp}	4.55	4.66
	Mw (=W*t)	13.64	15.28
	S.F. (Soil Effect)	**1.28**	**2.58**



	50 years	5 years	
CD1	+ 6.5	+ 6.5	m
CD2	+ 4.9	+ 4.9	m
CD4	+ 3.7	+ 3.7	m
CD Rec.	+ 5.5	+ 5.5	m
WL	**+ 4.43**	**+ 3.92**	m
a1	0.5	0.5	m
a2	2.5	2.5	m
a3	1.30	1.3	m
a3'	**1.300**	**1.300**	m
h1	2.8	2.8	m
h2	1.2	1.2	m
h3	1.60	1.6	m
h3'	**1.6**	**1.6**	m
h'	0.73	0.22	m
s1	1.44	1.44	m2
s2	0.00	0.00	m2
s3upperWL	1.175	2.45	m2
s3underWL	1.825	0.55	m2
ΣS	**4.44**	**4.44**	m3
γ	2.4	2.4	t/m3
γ'	1.375	1.375	t/m3
W (s1)	3.46	3.46	t/m
W (s2)	0.00	0.00	t/m
W (s3)	5.33	6.64	t/m
W (total)	**8.79**	**10.09**	t/m

Conc.	x_{s1}	2.02	2.02	m
	M (s1)	6.98	6.98	t.m/m
	x_{s2}	0.00	0.00	m
	M (s2)	0.00	0.00	t.m/m
	x_{s3}	1.25	1.25	m
	M (s3)	6.66	8.30	t.m/m
	Mw	**13.64**	**15.28**	t.m/m
Soil pressure	Pp upperWL	2.75	5.99	t/m
	Pp underWL	4.57	1.74	t/m
	$y_{p.upper}$	1.087	0.747	m
	$y_{p.under}$	0.343	0.108	m
	$Mp_{upperWL}$	2.99	4.47	t.m/m
	$Mp_{underWL}$	1.57	0.19	t.m/m
	Mp (total)	**4.55**	**4.66**	t.m/m
Wave	P	8.27	6.54	t/m
	U	2.99	4.06	t/m
	y_p	1.286	1.218	m
	x_u	1.958	1.667	m
	Mp	**10.63**	**7.97**	t.m/m
	Mu	**5.85**	**6.77**	t.m/m
	M total	16.48	14.74	t.m/m

17.6.(1) STABILITY CALCULATION OF CONCRETE CAP OF OUTER REVETMENT A (for reference)

A. Wave Force under Wave Crest

1. Input data:

	50 years	5 years
Tidal Level HHWL(CDL):	1%(100 yr)	20%(20 yr)
	4.43	3.92
Crest Level(CDL):	6.5	
Bottom Upright Wall Level (CDL):	3.8	
Bottom Width of Upright wall (m):	2.5	
Reclamation Level (CDL):	5.5	
Crest Level of Armor stone (CDL):		
Seabed slope:		
Seabed sSurface Level (CDL):	0.5	
Significunt Wave Height ($H_{1/3}$),m:	3	2.8
H_{max}(Goda's Index),m:	3.9	3.57
Wave Period (T),sec:	13.3	11
Wave Length (L),m:	81.05	70

2. Results of Calculation

2.1. Input data

	50 years	5 years
β(deg)=	32	
cosβ:	0.848	
H_D(m):	3.9	3.57
L(m):	81.05	70
HHWL(CDL):	4.43	3.92
Sea bed Level(CDL):	0.5	
Crest Level(m):	6.5	
h (m):	3.93	3.42
h' (m):	0.63	0.12
ρ_0 (t/m^3):	1.025	
g (m/s^2)	9.81	
hc (m):	2.07	2.58
4 πh/L	0.609	0.614
2 πh/L	0.305	0.307
λ	0.956	0.914

2.2. Wave pressure on the front face of an Upright wall

η^*=	5.17	4.52
α_1=	1.042	1.042
α_3=	0.993	0.998
h_c^*=min(η^*,h_c)	2.07	2.58
α_4=	0.600	0.429
(1+cosβ)	1.848	
$\alpha_1\lambda\rho_0 H_D$	3.986	3.482
p_1(t/m^2)	3.68	3.22
p_3(t/m^2)	3.66	3.21
p_4(t/m^2)	2.21	1.38
p_c(at crest level),(t/m^2)=	1.92	1.31

2.3. Uplift beneath Upright Wall

Pu	3.66	3.21
lu	1.84	2.50

2.4. Total wave pressure on Upright Wall

P	8.41	6.32
U	3.37	4.02

B. Effect of Reclamation Soil

	50 years	5 years
H(m)	1.7	
φ(deg)	30	
γs(t/m3)	1.8	
γ's(t/m3)	1	
h_{dry}(m)	1.07	1.58
h_{wet}(m)	0.63	0.12
Kp=tan^2(45°+φ/2)	3	
P_p(dry),t/m2	5.78	8.53
P_p(wet),t/m2	7.67	8.89
Pp(dry),t/m	3.09	6.74
Pp(wet),t/m	4.24	1.05
Pp(final),t/m	7.33	7.79

C. Safety Factor

μ(coc.&stone)	0.6	
W	8.44	9.75
μ(stone&stone)	0.8	

Sliding	S.F.(normal)	0.36	0.54
	S.F.(soil effect)	1.23	1.78

Overturning	Mp	10.42	7.40
	MPp	4.38	4.42
	Mw	13.21	14.85
	S.F.(Normal)	0.87	1.10
	S.F.(Soil effect)	1.29	1.70

Concrete Cap

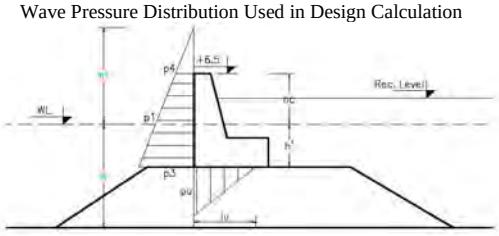
	50 years	5 years
CD1	6.5	6.5
CD2	4.9	4.9
CD4	3.8	3.8
CD Rec.	5.5	5.5
WL	4.43	3.92
a1	0.5	0.5
a2	2.5	2.5
a3	1.3	1.3
a3'	1.3	1.3
h1	2.7	2.7
h2	1.1	1.1
h3	1.6	1.6
h3'	1.6	1.6
h'	0.63	0.12
s1	1.44	1.44
s2	0E+00	0E+00
s3upperWL	1.175	2.45
s3underWL	1.575	0.3
ΣS	4.19	4.19
γ	2.4	2.4
γ'	1.375	1.375
W (s1)	3.46	3.46
W (s2)	0.00	0.00
W (s3)	4.99	6.29
W (total)	8.44	9.75

Concrete	x_{s1}	2.02	2.02
	M (s1)	6.98	6.98
	x_{s2}	0	0
	M (s2)	0	0
	x_{s3}	1.25	1.25
	M (s3)	6.23	7.87
	Mw	13.21	14.85

Soil pressure	Pp upperWL	3.09	6.74
	Pp underWL	4.24	1.05
	yp.upper	0.99	0.65
	yp.under	0.315	0.06
	Mp upperWL	3.05	4.36
	Mp underWL	1.33	0.06
	Mp total	4.38	4.42

Wave	P	8.41	6.32
	U	3.37	4.02
	yp	1.24	1.17
	xu	1.23	1.67
	Mp	10.42	7.40
	Mu	4.13	6.69
	M total	14.55	14.09

Wave Pressure Distribution Used in Design Calculation



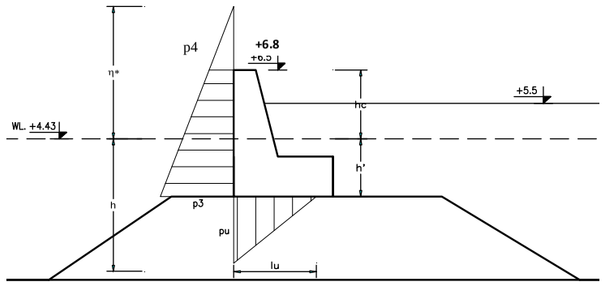
17.7. STABILITY CALCULATION OF CONCRETE CAP OF OUTER REVETMENT B (ORB-A & ORB-B)

A. Wave Force under Wave Crest

1. Input data:

	50 years	5 years
- Tide Level - HHWL (CDL):	1 % (100 yr)	20 % (20 yr)
	4.43	3.92
- Crest Level (CDL):	6.8	
- Bottom Upright Wall Level (CDL):	4.6	
- Bottom Width of Upright Wall (m):	2.5	
- Reclamation Level (CDL):	5.5	
- Crest Level of Armor stone (CDL):		
- Seabed slope:		
- Seabed Surface Level (CDL):	1.0	
- Significant Wave Height ($H_{1/3}$), m:	2.7	2.3
- H_{max} (Goda's Index), m:	3.5	3.1
- Wave Period (T), sec:	13.3	11
- Wave Length (L), m:	76.90	59.62

2. Wave Pressure on the Front Face of an Upright Wall



Wave Pressure Distribution Used in Design Calculation

$$p_1 = 0.5(1+\cos\beta)\lambda\alpha_1\rho_0 g H_D$$

$$p_3 = pu = \alpha_3 p_1$$

$$\lambda = \exp[-10\left(\frac{h}{L}\right)^{1.5}\left(1-\frac{h'}{h}\right)^{5}]$$

$$\alpha_1 = 0.6 + \frac{1}{2}\left[\frac{4\pi h/L}{\sinh(\frac{4\pi h}{L})}\right]^2$$

$$\alpha_3 = 1 + \frac{h'}{\eta^*}(if\ h' \le 0)$$

$$\eta^* = 0.75(1+cos\beta)\lambda_1 H_D$$

3. Uplift beneath Upright Wall

$$p_3 = pu = \alpha_3 p_1$$

$$l_u = \min\{B, 0.2\frac{(\eta^* + h')}{|h'|}$$

4. Wave Height and Wavelength Used in the Wave Pressure Calculation

H_D = Hmax

5. Results of Calculation

5.1. Input data

	50 years	5 years
β (deg) =	41	
cos β:	0.755	
H_D (m):	3.5	3.1
L (m):	76.90	59.62
HHWL (CDL):	4.43	3.92
Sea bed Level (CDL):	1.0	
Crest Level (CDL):	6.8	
h (m):	3.43	2.92
h' (m)	-0.17	-0.68
ρ_0 (t/m3):	1.025	
g (m/s2):	9.81	
h_c (m):	2.37	2.88
4 πh/L	0.561	0.615
2 πh/L	0.280	0.308
λ	0.887	0.734

5.2. Wave pressure on the front face of an Upright wall

η* =	4.09	3.00
α_1 =	1.051	1.041
α_3 =	0.958	0.773
h_c* = min{η* , h_c}	2.37	2.88
α_4 =	0.420	0.039
(1+cosβ)	1.755	
$\alpha_1 \lambda \rho_0 H_D$	3.343	2.430
p_1 (t/m2) =	2.93	2.13
p_3 (t/m2) =	2.81	1.65
p_4 (t/m2) =	1.23	0.08
p_c (at crest level), (t/m2) =	1.13	0.05

5.3. Uplift beneath Upright Wall

p_u (t/m2) =	2.81	1.65
l_u (m) =	2.50	0.68

5.4. Total wave pressure on Upright Wall

P (t/m) =	4.45	1.90
U (t/m) =	3.51	0.56

II. Effect of Reclamation Soil

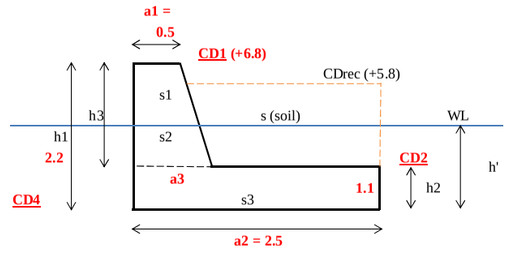
	50 years	5 years
H (m)	0.9	
ϕ (deg)	30.0	
γ_s (t/m3)	1.6	
γ'_s (t/m3)	1.0	
h_{dry} (m)	0.9	0.9
h_{wet} (m)	0.0	0.0
Kp = $\tan^2(45^o+\phi/2)$	3.0	
p_p (dry), t/m2	4.32	4.32
p_p (wet), t/m2	0.00	0.00
Pp (dry), t/m	1.94	1.94
Pp (wet), t/m	0.00	0.00
Pp(final), t/m	**1.94**	**1.94**

C. Safety Factor

μ (friction factor between conc. & stone):	0.60	
W (total), t/m	8.65	8.65
μ (friction factor between stone & stone):	0.80	

Sliding	**S.F. (Normal)**	**0.69**	**2.55**
	S.F. (Soil effect)	**1.23**	**OK**

Overturning	Mu	5.86	0.94
	Mp	4.25	1.46
	S.F. (Normal)	**1.57**	**7.93**
	S.F. (Soil Effect)	**1.82**	**13.20**



	5 years	50 years	
CD1	6.8		
CD2	5.7		
CD4	4.6		
WL	**3.92**	**4.43**	
a1	0.5		m
a2	2.5		m
a3	1.05		m
a3'	**1.05**	**1.05**	m
h1	2.2		m
h2	1.1		m
h3	1.1		m
h3'	**1.1**	**1.1**	m
h'	-0.68	-0.17	m
s1	0.85	0.85	m2
s2	0.00	0.00	m2
s3upperWL	2.75	2.75	m2
s3underWL	0	0	m2
γ	2.4		t/m3
γ'	1.37		
W (s1)	2.05	2.05	t
W (s2)	0.00	0.00	t
W (s3)	6.60	6.60	t
W (total)	**8.65**	**8.65**	t

Conc.	x_{s1}	2.10	2.10	
	M (s1)	4.29	4.29	
	x_{s2}	0.00	0.00	
	M (s2)	0.00	0.00	
	x_{s3}	1.25	1.25	
	M (s3)	8.25	8.25	
	Mw	**12.54**	**12.54**	
Soil pressure	Pp upperWL	1.94	1.94	
	Pp underWL	0.00	0.00	
	$y_{p.upper}$	0.3000	0.3000	
	$y_{p.under}$	0.0000	0.0000	
	Mp up	0.58	0.58	
	Mp un	0.00	0.00	
	Mp (total)	**0.58**	**0.58**	
Wave	P	1.90	4.45	
	U	0.56	3.51	
	y_p	0.768	0.957	
	x_u	1.667	1.67	
	Mp	1.46	4.25	
	Mu	0.94	5.86	
	M total	**2.40**	**10.11**	

17.7.(1) STABILITY CALCULATION OF CONCRETE CAP OF OUTER REVETMENT B (ORB-A&ORB-B) (for reference)

A. Wave Force under Wave Crest

1. Input data:

	50 years	5 years
Tidal Level HHWL(CDL):	1%(100 yr)	20%(20 yr)
	4.43	3.92
Crest Level(CDL):	6.8	
Bottom Upright Wall Level (CDL):	5.0	
Bottom Width of Upright wall (m):	2.5	
Reclamation Level (CDL):	5.5	
Crest Level of Armor stone (CDL):		
Seabed slope:		
Seabed sSurface Level (CDL):	0.5	
Significunt Wave Height ($H_{1/3}$),m:	2.7	2.3
H_{max}(Goda's Index),m:	3.5	3.1
Wave Period (T),sec:	13.3	11
Wave Length (L),m:	76.9	59.62

2. Results of Calculation

2.1. Input data

	50 years	5 years
β(deg)=	41	
cosβ:	0.755	
H_D(m):	3.5	3.1
L(m):	76.9	59.62
HHWL(CDL):	4.43	3.92
Sea bed Level(CDL):	0.5	
Crest Level(m):	6.8	
h (m):	3.93	3.42
h' (m):	-0.57	-1.08
ρ_0 (t/m^3):	1.025	
g (m/s^2)	9.81	
hc (m):	2.07	2.58
4 πh/L	0.642	0.721
2 πh/L	0.321	0.360
λ	0.797	0.582

2.2. Wave pressure on the front face of an Upright wall

η^*=	3.67	2.37
α_1=	1.037	1.022
α_3=	1.007	1.019
h_c^*=min(η^*,h_c)	2.07	2.37
α_4=	0.436	0.000
(1+cosβ)	1.755	
$\alpha_1\lambda\rho_0 H_D$	2.962	1.888
p_1(t/m^2)	2.60	1.66
p_3(t/m^2)	2.62	1.69
p_4(t/m^2)	1.13	0.00
p_c(at crest level),(t/m^2)=	1.03	-0.03

2.3. Uplift beneath Upright Wall

Pu	2.62	1.69
lu	2.50	0.31

2.4. Total wave pressure on Upright Wall

P	3.86	1.97
U	3.27	0.26

B. Effect of Reclamation Soil

	50 years	5 years
H(m)	0.5	
φ(deg)	30	
γs(t/m3)	1.8	
γ's(t/m3)	1	
h_{dry}(m)	0.5	0.5
h_{wet}(m)	0	0
Kp=tan^2(45°+φ/2)	3	
P_p(dry),t/m2	2.70	2.70
P_p(wet),t/m2	0.00	0.00
Pp(dry),t/m	0.68	0.68
Pp(wet),t/m	0.00	0.00
Pp(final),t/m	0.68	0.68

C. Safety Factor

μ(coc.&stone)	0.6	
W	9.86	9.86
μ(stone&stone)	0.8	

Sliding	S.F.(normal)	1.02	2.93
	S.F.(soil effect)	1.20	3.27

Overturning	Mp	2.51	0.98
	MPp	0.11	0.11
	Mw	12.58	12.58
	S.F.(Normal)	2.83	12.16
	S.F.(Soil effect)	2.88	12.28

Concrete Cap

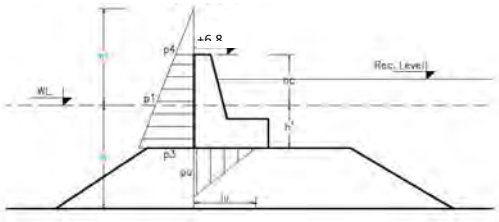
	50 years	5 years
CD1	6.8	6.8
CD2	5.9	5.9
CD4	5	5
CD Rec.	5.5	5.5
WL	4.43	3.92
a1	0.5	0.5
a2	2.5	2.5
a3	0.6	0.6
a3'	0.6	0.6
h1	1.8	1.8
h2	1.6	1.6
h3	0.2	0.2
h3'	0.2	0.2
h'	-0.57	-1.08
s1	0.11	0.11
s2	0	0
s3upperWL	4	4
s3underWL	0	0
ΣS	4.11	4.11
γ	2.4	2.4
γ'	1.375	1.375
W (s1)	0.26	0.26
W (s2)	0.00	0.00
W (s3)	9.60	9.60
W (total)	9.86	9.86

Concrete	x_{s1}	2.2	2.2
	M (s1)	0.58	0.58
	x_{s2}	0	0
	M (s2)	0	0
	x_{s3}	1.25	1.25
	M (s3)	12.00	12.00
	Mw	12.58	12.58

Soil pressure	Pp upperWL	0.68	0.68
	Pp underWL	0.00	0.00
	yp.upper	0.17	0.17
	yp.under	0	0
	Mp upperWL	0.11	0.11
	Mp underWL	0.00	0.00
	Mp total	0.11	0.11

Wave	P	3.86	1.97
	U	3.27	0.26
	yp	0.65	0.50
	xu	1.67	2.40
	Mp	2.51	0.98
	Mu	5.45	0.63
	M total	7.97	1.61

Wave Pressure Distribution Used in Design Calculation



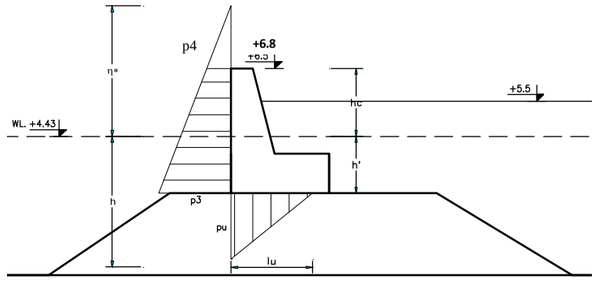
17.8. STABILITY CALCULATION OF CONCRETE CAP OF OUTER REVETMENT B (ORB-C & ORB-D)

A. Wave Force under Wave Crest

1. Input data:

	50 years	5 years
- Tide Level - HHWL (CDL):	1 % (100 yr)	20 % (20 yr)
	4.43	3.92
- Crest Level (CDL):	6.8	
- Bottom Upright Wall Level (CDL):	4.3	
- Bottom Width of Upright Wall (m):	2.5	
- Reclamation Level (CDL):	5.5	
- Crest Level of Armor stone (CDL):		
- Seabed slope:		
- Seabed Surface Level (CDL):	0	
- Significant Wave Height ($H_{1/3}$), m:	3.2	2.6
- H_{max} (Goda's Index), m:	4.3	3.4
- Wave Period (T), sec:	13.3	11
- Wave Length (L), m:	84.97	62.33

2. Wave Pressure on the Front Face of an Upright Wall



Wave Pressure Distribution Used in Design Calculation

$$p_1 = 0.5(1+\cos\beta)\lambda\alpha_1\rho_0 g H_D$$

$$p_3 = pu = \alpha_3 p_1$$

$$\lambda = \exp[-10\left(\frac{h}{L}\right)^{1.5}\left(1-\frac{h'}{h}\right)^{5}]$$

$$\alpha_1 = 0.6 + \frac{1}{2}\left[\frac{4\pi h/L}{\sinh(\frac{4\pi h}{L})}\right]^2$$

$$\alpha_3 = 1 + \frac{h'}{\eta^*}(if\ h' \le 0)$$

$$\eta^* = 0.75(1+cos\beta)\lambda_1 H_D$$

3. Uplift beneath Upright Wall

$$p_3 = pu = \alpha_3 p_1$$

$$l_u = \min\{B, 0.2\frac{(\eta^* + h')}{|h'|}$$

4. Wave Height and Wavelength Used in the Wave Pressure Calculation

H_D = Hmax

5. Results of Calculation

5.1. Input data

	50 years	5 years
β (deg) =	66	
cos β:	0.407	
H_D (m):	4.3	3.4
L (m):	84.97	62.33
HHWL (CDL):	4.43	3.92
Sea bed Level (CDL):	0	
Crest Level (CDL):	6.8	
h (m):	4.43	3.92
h' (m)	0.13	-0.38
ρ_0 (t/m3):	1.025	
g (m/s2):	9.81	
h_c (m):	2.37	2.88
4 πh/L	0.655	0.790
2 πh/L	0.328	0.395
λ	0.903	0.778

5.2. Wave pressure on the front face of an Upright wall

η* =	4.09	2.79
α_1 =	1.034	1.008
α_3 =	0.998	0.864
h_c* = min{η* , h_c}	2.37	2.79
α_4 =	0.421	0.000
(1+cosβ)	1.407	
α_1 λ ρ_0 H_D	4.114	2.734
p_1 (t/m2) =	2.89	1.92
p_3 (t/m2) =	2.89	1.66
p_4 (t/m2) =	1.22	0.00
p_c (at crest level), (t/m2) =	1.18	-0.05

5.3. Uplift beneath Upright Wall

p_u (t/m2) =	2.89	1.66
l_u (m) =	2.50	1.27

5.4. Total wave pressure on Upright Wall

P (t/m) =	5.13	2.08
U (t/m) =	3.61	1.05

B. Effect of Reclamation Soil

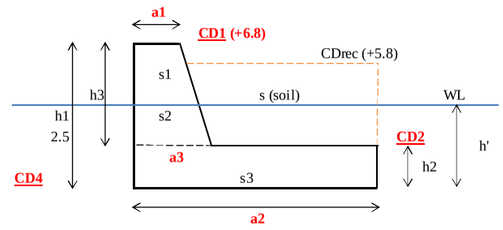
	50 years	5 years
H (m)	1.2	
ϕ (deg)	30.0	
γ_s (t/m3)	1.6	
γ'_s (t/m3)	1.0	
h_{dry} (m)	1.1	1.2
h_{wet} (m)	0.1	0.0
Kp = $\tan^2(45^o+\phi/2)$	3.0	
p_p (dry), t/m2	5.14	5.76
p_p (wet), t/m2	5.53	0.00
Pp (dry), t/m	2.75	3.46
Pp (wet), t/m	0.69	0.00
Pp(final), t/m	**3.44**	**3.46**

C. Safety Factor

μ (friction factor between conc. & stone):	0.60	
W (total), t/m	9.44	9.77
μ (friction factor between stone & stone):	0.80	

Sliding	**S.F. (Normal)**	**0.68**	**2.52**
	S.F. (Soil effect)	**2.06**	**OK**

Overturning	Mu	6.02	1.76
	Mp	5.55	1.73
	M_{Pp}	1.38	1.38
	Mw (=W*t)	13.90	14.32
	S.F. (Normal)	**1.42**	**7.26**
	S.F. (Soil Effect)	**1.89**	**36.10**



	5 years	50 years	
CD1	6.8		
CD2	5.5		
CD4	4.3		
WL	**3.92**	**4.43**	
a1	0.5		m
a2	2.5		m
a3	1.15		m
a3'	**1.15**	**1.15**	m
h1	2.5		m
h2	1.2		m
h3	1.3		m
h3'	**1.3**	**1.3**	m
h'	-0.38	0.13	m
s1	1.0725	1.07	m2
s2	0.00	0.00	m2
s3upperWL	3	2.675	m2
s3underWL	0	0.325	m2
γ	2.4		t/m3
γ'	1.37		
W (s1)	2.57	2.57	t
W (s2)	0.00	0.00	t
W (s3)	7.20	6.87	t
W (total)	**9.77**	**9.44**	t

Conc.	x_{s1}	2.07	2.07	
	M (s1)	5.32	5.32	
	x_{s2}	0.00		
	M (s2)	0.00	0.00	
	x_{s3}	1.25	1.25	
	M (s3)	9.00	8.58	
	Mw	**14.32**	**13.90**	
Soil pressure	Pp upperWL	3.46	2.75	
	Pp underWL	0.00	0.69	
	$y_{p.upper}$	0.4000	0.4867	
	$y_{p.under}$	0.0000	0.0642	
	Mp up	1.38	1.34	
	Mp un	0.00	0.04	
	Mp (total)	**1.38**	**1.38**	
Wave	P	2.08	5.13	
	U	1.05	3.61	
	y_p	0.833	1.081	
	x_u	1.667	1.67	
	Mp	1.73	5.55	
	Mu	1.76	6.02	
	M total	**3.49**	**11.57**	

17.8.(1) STABILITY CALCULATION OF CONCRETE CAP OF OUTER REVETMENT C (ORB-C&ORB-D) (for reference)

A. Wave Force under Wave Crest

1. Input data:

	50 years	5 years
Tidal Level HHWL(CDL):	1%(100 yr)	20%(20 yr)
	4.43	3.92
Crest Level(CDL):	6.8	
Bottom Upright Wall Level (CDL):	4.6	
Bottom Width of Upright wall (m):	2.5	
Reclamation Level (CDL):	5.5	
Crest Level of Armor stone (CDL):		
Seabed slope:		
Seabed sSurface Level (CDL):	0	
Significunt Wave Height ($H_{1/3}$),m:	3.2	2.3
H_{max}(Goda's Index),m:	4.3	3.4
Wave Period (T),sec:	13.3	11
Wave Length (L),m:	84.97	62.33

2. Results of Calculation

2.1. Input data

	50 years	5 years
β(deg)=	66	
cosβ:	0.407	
H_D(m):	4.3	3.4
L(m):	84.97	62.33
HHWL(CDL):	4.43	3.92
Sea bed Level(CDL):	0	
Crest Level(m):	6.8	
h (m):	4.43	3.92
h' (m):	-0.17	-0.68
ρ_0 (t/m^3):	1.025	
g (m/s^2)	9.81	
hc (m):	2.07	2.58
4 πh/L	0.655	0.790
2 πh/L	0.328	0.395
λ	0.866	0.704

2.2. Wave pressure on the front face of an Upright wall

η^*=	3.93	2.53
α_1=	1.034	1.008
α_3=	1.002	1.013
h_c^*=min(η^*,h_c)	2.07	2.53
α_4=	0.473	0.000
(1+cosβ)	1.407	
$\alpha_1\lambda\rho_0 H_D$	3.948	2.472
p_1(t/m^2)	2.78	1.74
p_3(t/m^2)	2.78	1.76
p_4(t/m^2)	1.31	0.00
p_c(at crest level),(t/m^2)=	1.28	-0.05

2.3. Uplift beneath Upright Wall

Pu	2.78	1.76
lu	2.50	1.00

2.4. Total wave pressure on Upright Wall

P	4.23	2.20
U	3.48	0.88

B. Effect of Reclamation Soil

	50 years	5 years
H(m)	0.9	
φ(deg)	30	
γs(t/m3)	1.8	
γ's(t/m3)	1	
h_{dry}(m)	0.9	0.9
h_{wet}(m)	0	0
Kp=tan^2(45°+φ/2)	3	
P_p(dry),t/m2	4.86	4.86
P_p(wet),t/m2	0.00	0.00
Pp(dry),t/m	2.19	2.19
Pp(wet),t/m	0.00	0.00
Pp(final),t/m	2.19	2.19

C. Safety Factor

μ(coc.&stone)	0.6	
W	8.65	8.65
μ(stone&stone)	0.8	

Sliding	S.F.(normal)	0.73	2.12
	S.F.(soil effect)	1.25	3.12

Overturning	Mp	3.54	1.39
	MPp	0.66	0.66
	Mw	12.55	12.55
	S.F.(Normal)	1.91	7.65
	S.F.(Soil effect)	2.09	8.12

Concrete Cap

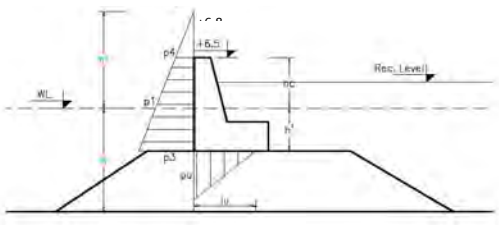
	50 years	5 years
CD1	6.8	6.8
CD2	5.7	5.7
CD4	4.6	4.6
CD Rec.	5.5	5.5
WL	4.43	3.92
a1	0.5	0.5
a2	2.5	2.5
a3	1.05	1.05
a3'	1.05	1.05
h1	2.2	2.2
h2	1.1	1.1
h3	1.1	1.1
h3'	1.1	1.1
h'	-0.17	-0.68
s1	0.8525	0.8525
s2	0	0
s3upperWL	2.75	2.75
s3underWL	0	0
ΣS	3.6025	3.6025
γ	2.4	2.4
γ'	1.37	1.37
W (s1)	2.05	2.05
W (s2)	0.00	0.00
W (s3)	6.60	6.60
W (total)	8.65	8.65

Concrete	x_{s1}	2.1	2.1
	M (s1)	4.30	4.30
	x_{s2}	0	0
	M (s2)	0	0
	x_{s3}	1.25	1.25
	M (s3)	8.25	8.25
	Mw	12.55	12.55

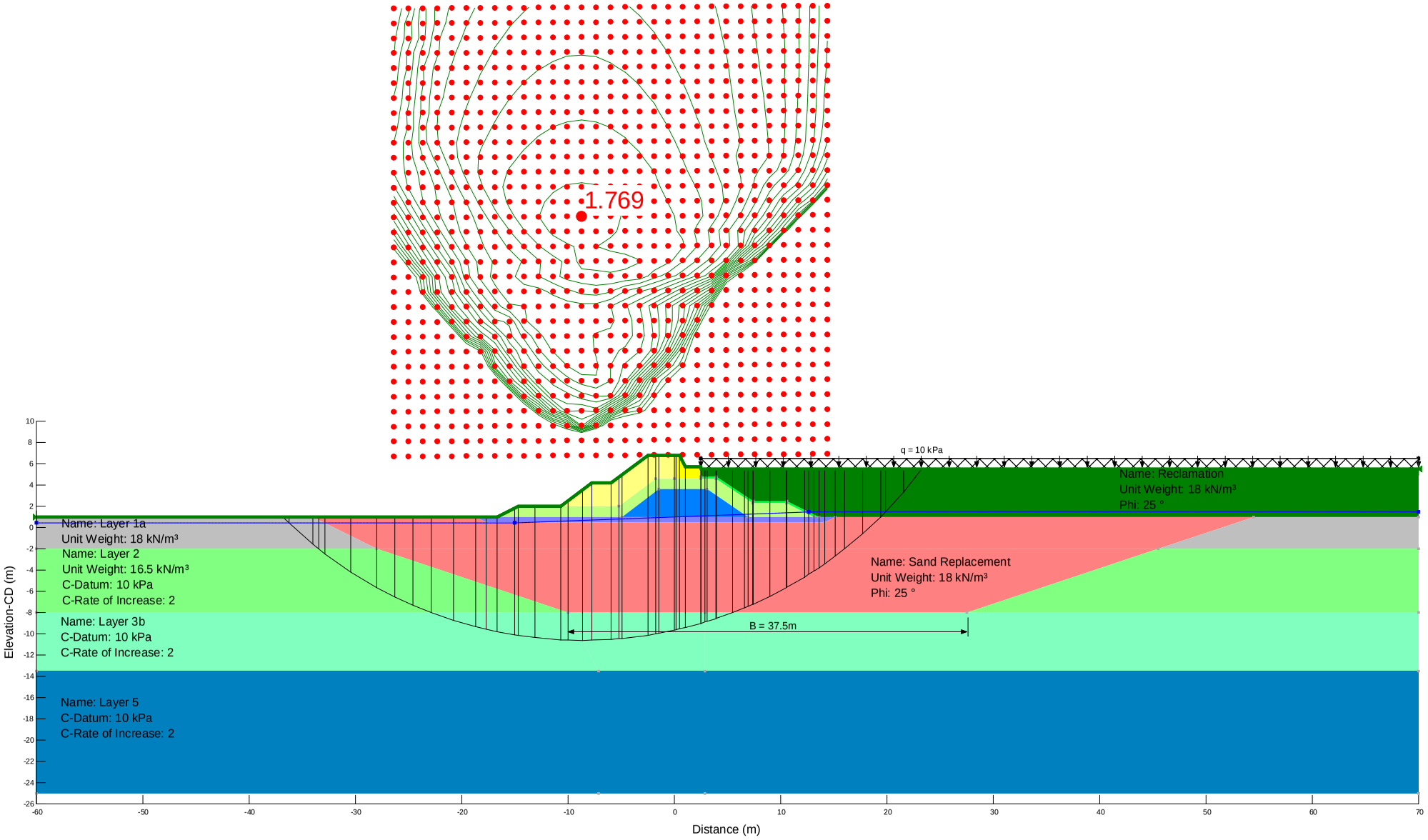
Soil pressure	Pp upperWL	2.19	2.19
	Pp underWL	0.00	0.00
	yp.upper	0.30	0.30
	yp.under	0	0
	Mp upperWL	0.66	0.66
	Mp underWL	0.00	0.00
	Mp total	0.66	0.66

Wave	P	4.23	2.20
	U	3.48	0.88
	yp	0.84	0.63
	xu	1.67	2.17
	Mp	3.54	1.39
	Mu	5.80	1.91
	M total	9.34	3.30

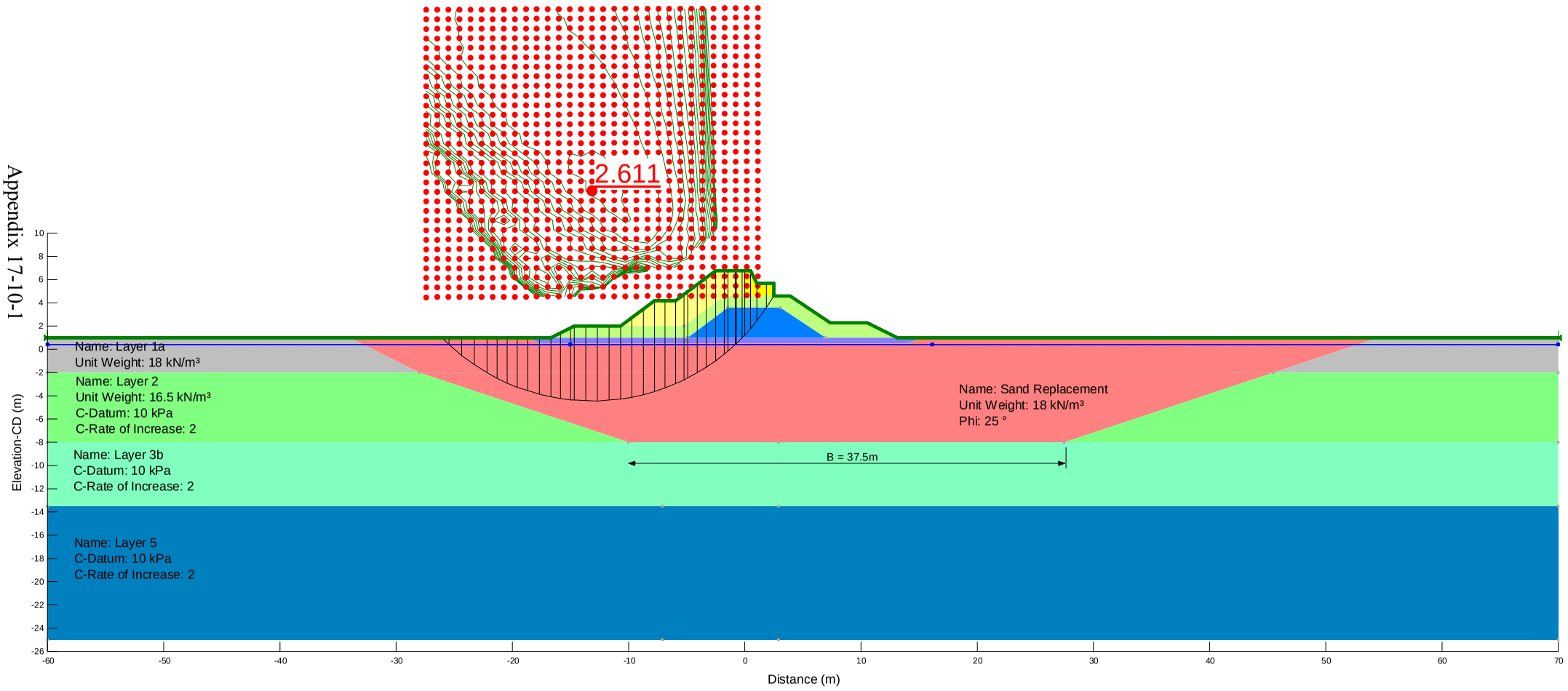
Wave Pressure Distribution Used in Design Calculation



REVETMENT B_AFTER 5 YRS - RECOMMENDED
(FELLENIUS METHOD - LONG TERM)
Soil Condition at ORB-A

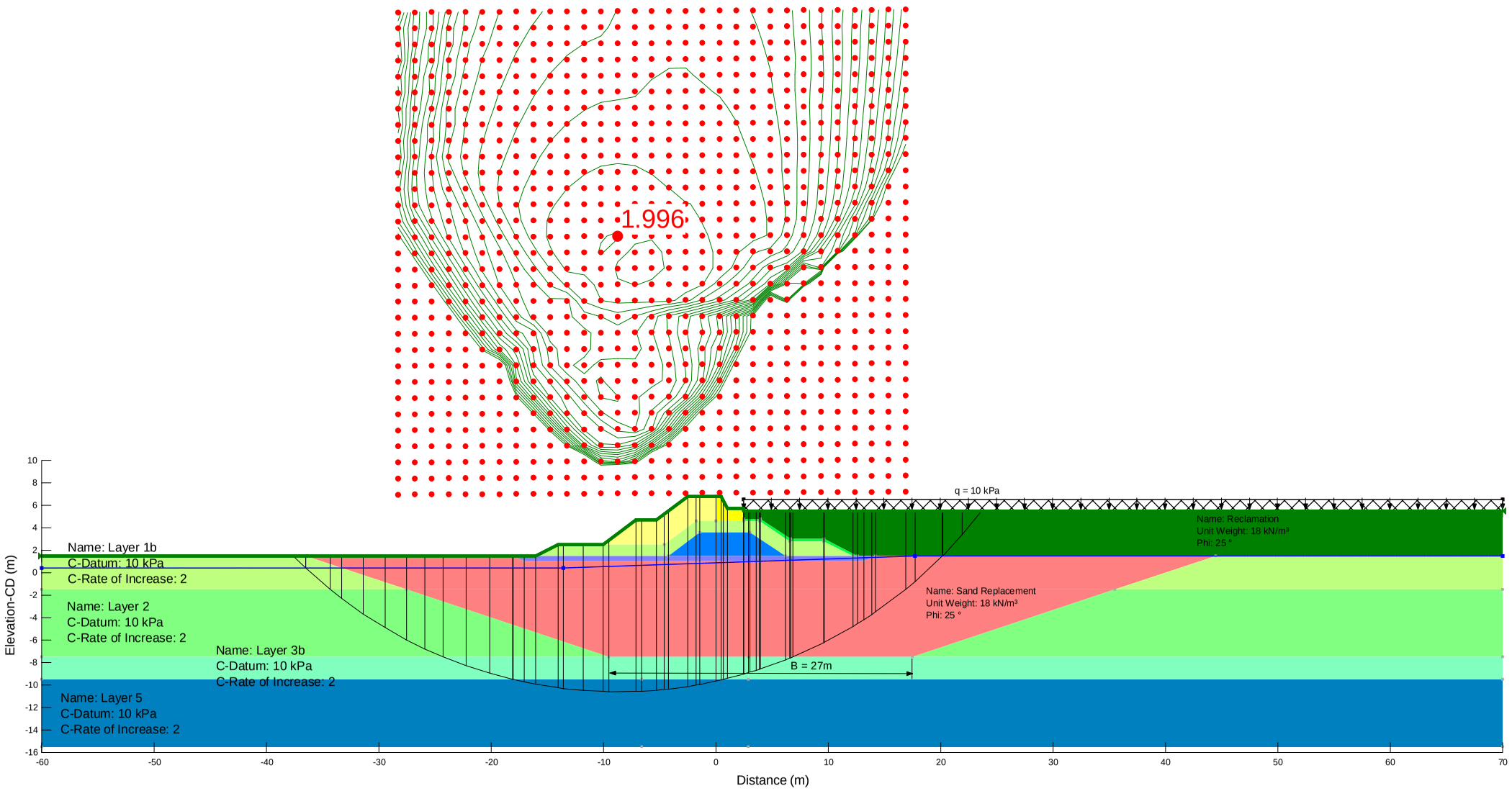


REVETMENT B_UNTIL 5 YRS - RECOMMENDED
(FELLENIUS METHOD - SHORT TERM)
Soil Condition at ORB-A

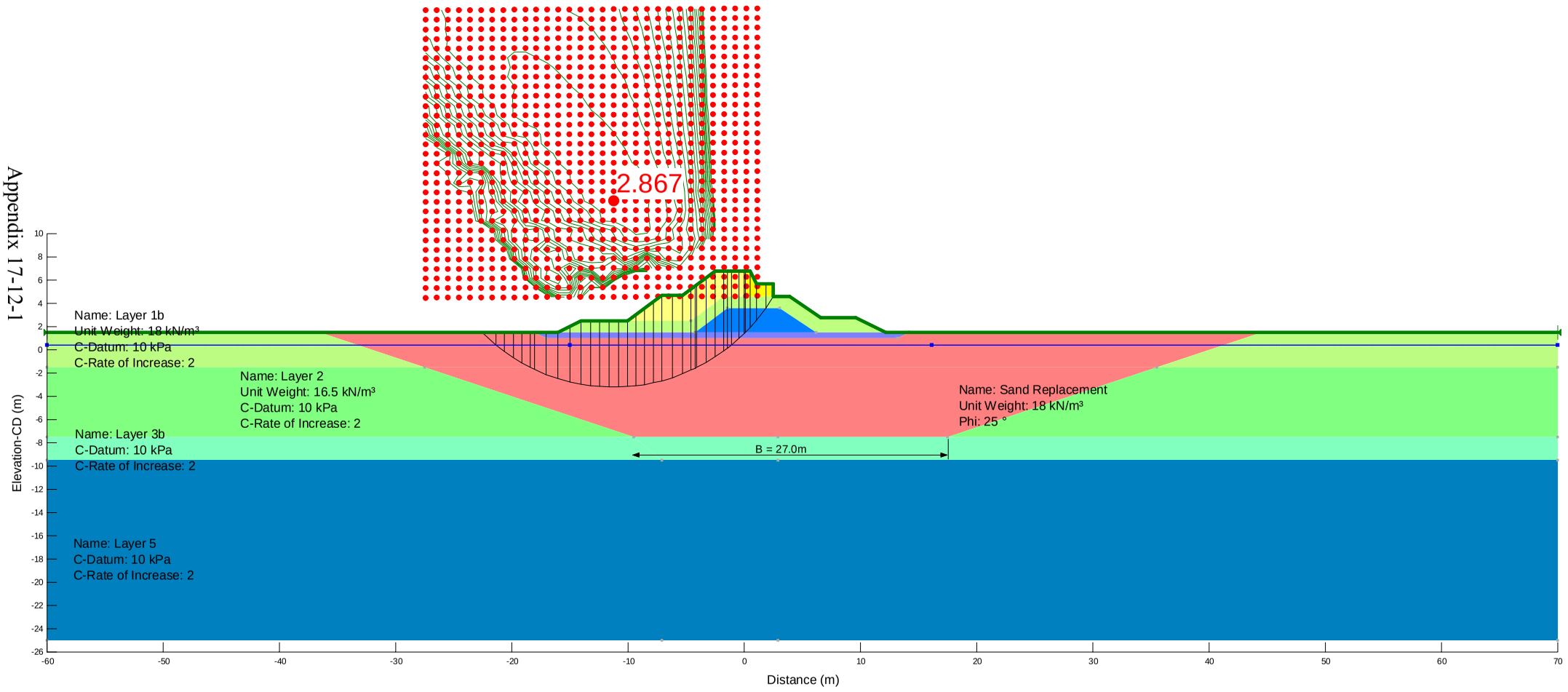


Appendix 17-10-1

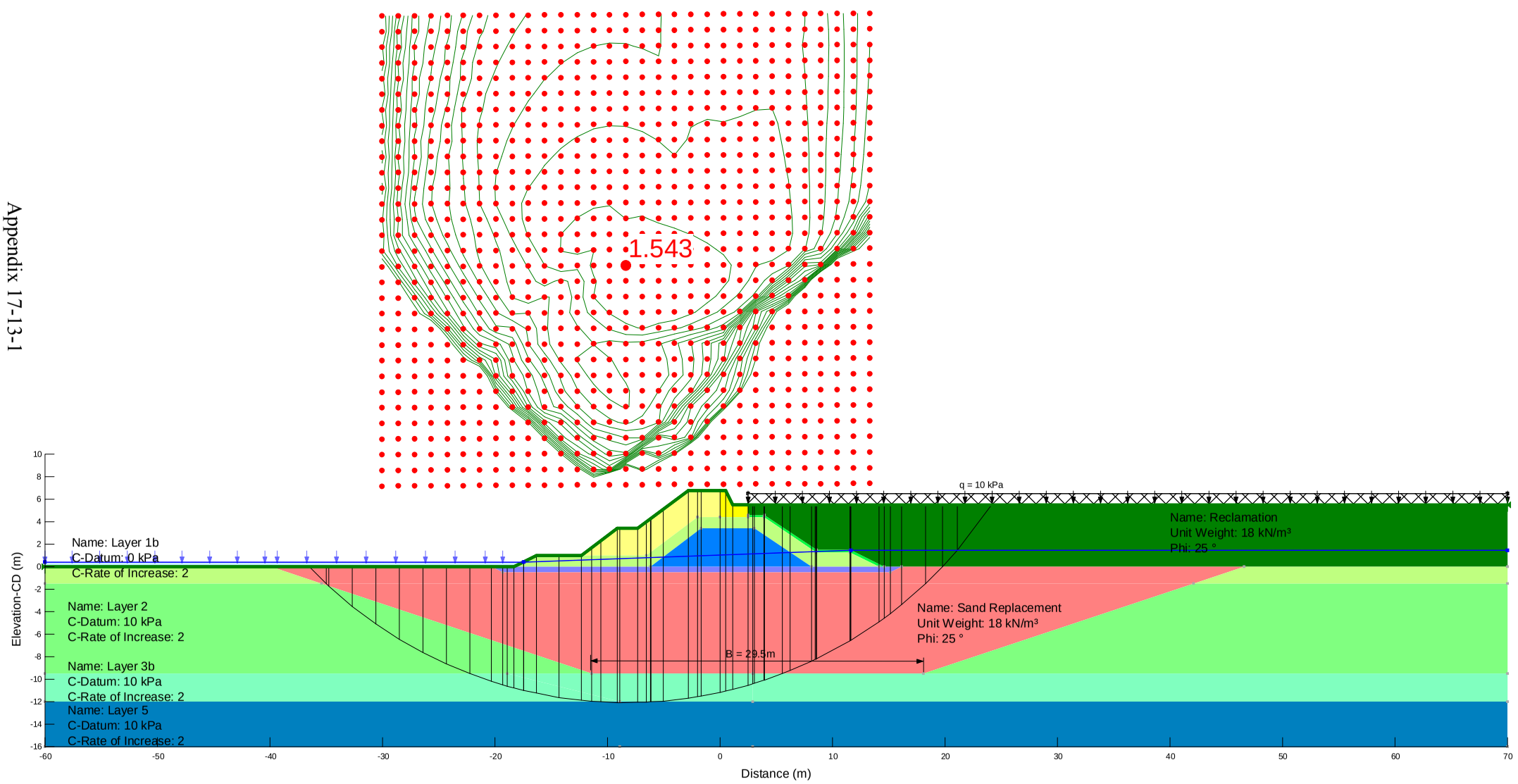
REVETMENT B_AFTER 5 YRS - RECOMMENDED
(FELLENIUS METHOD - LONG TERM)
Soil Condition at ORB-B



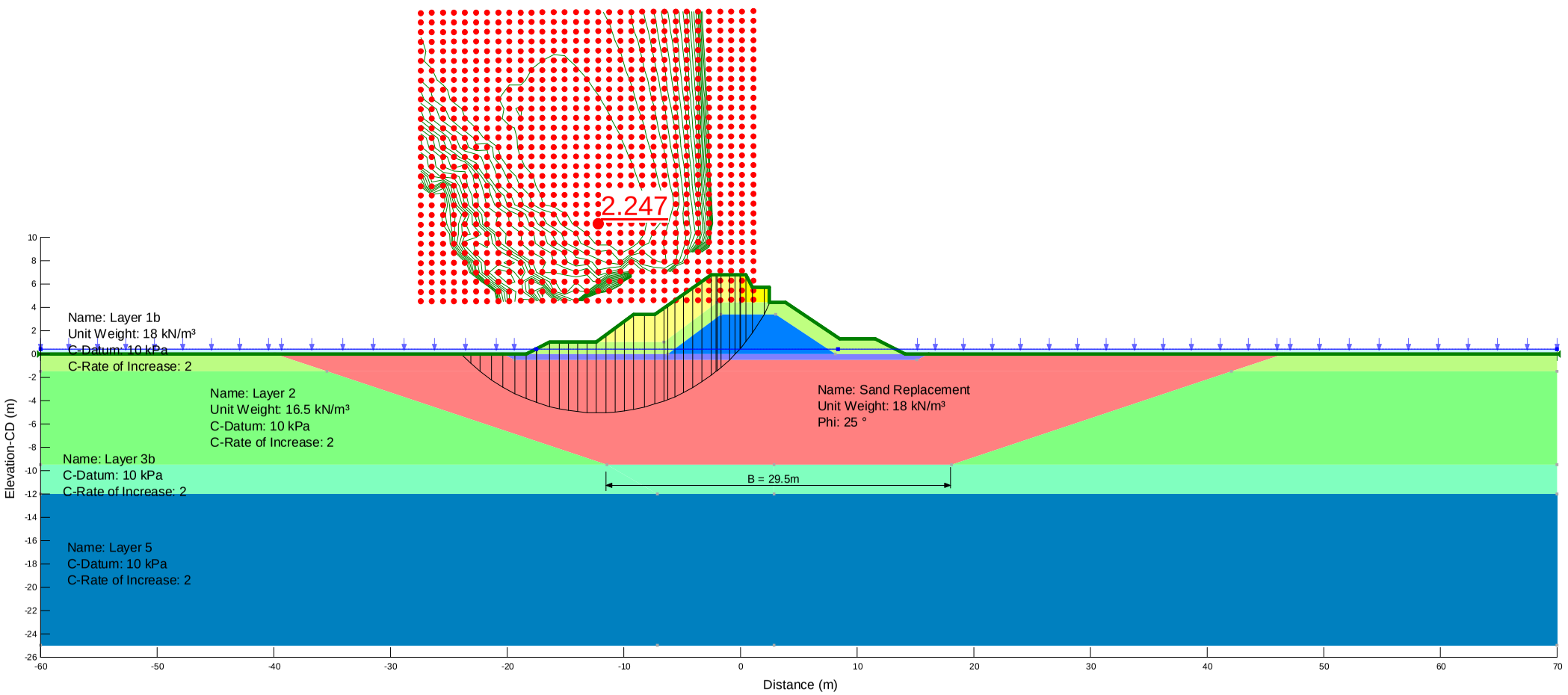
REVETMENT B_UNTIL 5 YRS - RECOMMENDED
(FELLENIUS METHOD - SHORT TERM)
Soil Condition at ORB-B



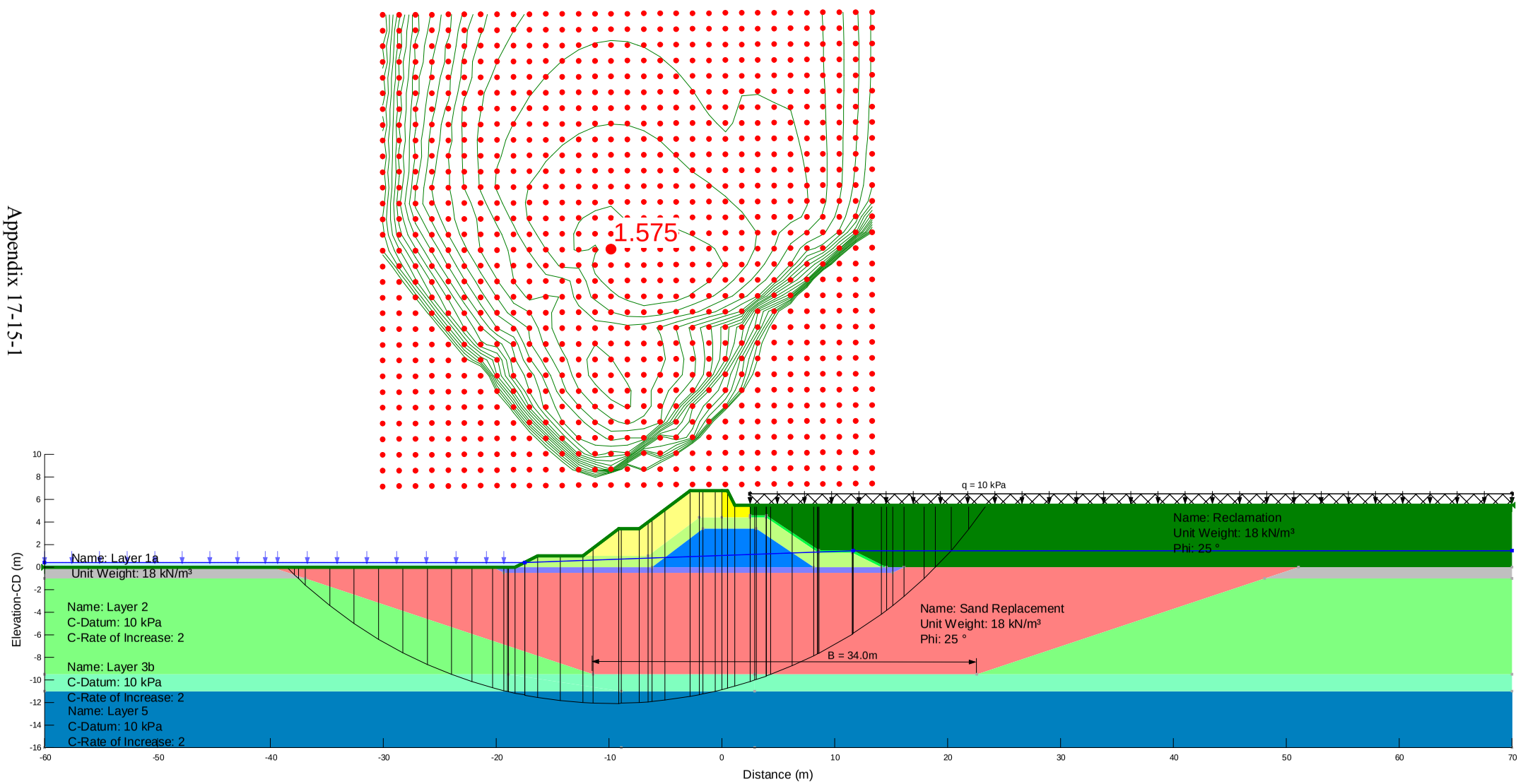
REVETMENT B_AFTER 5 YRS - RECOMMENDED
(FELLENIUS METHOD - LONG TERM)
Soil Condition at ORB-C



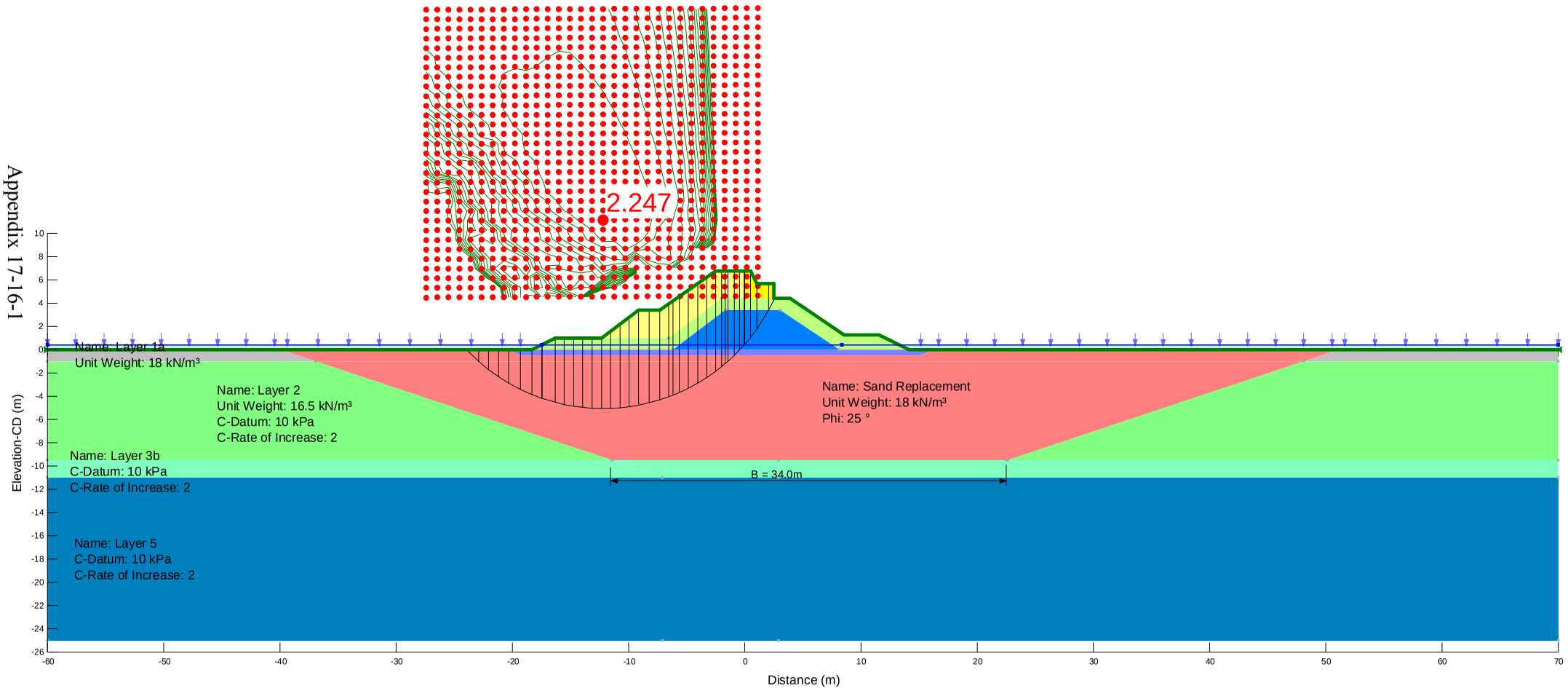
REVETMENT B_UNTIL 5 YRS - RECOMMENDED
(FELLENIUS METHOD - SHORT TERM)
Soil Condition at ORB-C



REVETMENT B_AFTER 5 YRS - RECOMMENDED
(FELLENIUS METHOD - LONG TERM)
Soil Condition at ORB-D



REVETMENT B_UNTIL 5 YRS - RECOMMENDED
(FELLENIUS METHOD - SHORT TERM)
Soil Condition at ORB-D



Appendix 18-1

Cathodic Protection System for Steel Sheet Pile

1. GENERAL

This specification covers the design of the cathodic protection system for the steel sheet pile of LACH HUYEN PORT PROJECT.

2. CODES AND STANDARDS

・Corrosion Protection and Repair Manual for Port and Harbor Steel Structures(2009) (Coastal Development Institute & Technology, Japan)

3. DESIGN CONDITIONS

(a) Protection Method

Galvanic anode system using aluminum alloy anodes

(b) Seawater Resistivity

Sea water: 35 ohm-cm as average

It is based on the following site survey results

Salinity: Min.8.9, Max.31.8, Ave. 25.5ppm (Middle, High Tide)

Salinity: Min.10.2, Max.31.7, Ave. 22.6ppm (Middle, Low Tide)

Salinity: Min.8.9, Max.31.8, Ave. 24.05ppm

$$S(\%) = 2.320186 \times 10^{-16} \times C_3^4 - 4.83885888 \times 10^{-12} \times C_3^3 + 4.2677569 \times 10^{-8} \times C_3^2 + 5.0714273 \times 10^{-4} \times C_3 - 1.4470907 \times 10^{-3}$$

S(%): Salinity, C(mS/m): Conductivity

Source: The Chemical Society of Japan, Kagaku Binran (Handbook of Chemistry) (Only Japanese version)

Chloride ion (Cl^-) (ppm) is calculated with the following formula

Cl^- (ppm)= Salinity (NaCl) (%) x 10000(ppm/%) x Cl(g/mol) / NaCl(g/mol)

= Salinity (NaCl) (%) x 10000(ppm/%) x 35.45 / 58.44

= Salinity (NaCl) (%) x 6066

Calculation Result

Resistivity: Min.20 ohm.cm, Ave.27 ohm.cm, Max.80 ohm.cm

{Cl^- (ppm): Min.5400ppm, Ave.14590 ppm, Max.19300 ppm} from salinity

(c) Anode Life : 50 years

(d) Seawater evaluation (clean or polluted)

Criteria of Corrosion Protection and Repair Manual for Port and Harbor Steel Structures (2009)	
Polluted	Cl^- (ppm): <17800 $NH4^+$(ppm): >0.1 DO(ppm): <6
Clean	Cl^- (ppm): >17800 $NH4^+$(ppm):<0.1 DO(ppm): >6

Data(Middle only)	Judgment
Cl^- (ppm): Ave.14590 (<17800) $NH4^+$(ppm): Ave.0.4975(>0.1) DO(ppm): Ave.5.78(<6)	**Polluted**

Criteria of Corrosion Protection and Repair Manual for Port and Harbor Steel Structures (2009)	
Polluted or Clean	Protective Current Density(A/sq.m)
Clean	In Seawater:0.1, In sea mud:0.02
Polluted	**In Seawater:0.13 to 0.15, In sea mud:0.026 to 0.03**

(e) Protective Current Density
In Sea water: 0.13 A/m^2 (Initial), 0.065 A/m^2 (Average)
In Sea mud: 0.026 A/m^2 (Initial), 0.013 A/m^2 (Average)

(f) Object to be cathodically protected
Steel Sheet Pile exposed to sea water and sea mud (below L.W.L-1.03m),
L.W.L=+0.43m
Note
1) Current drain (Loss current) ; Bare pile connection(+1m to -0.6m) 10% of surface area
2) Coating: Polyethylene or Polyurethane (above L.W.L-1.03m)(Coating damage: negligible)
3) Current speed: Max.0.5m/sec.
4) Floating sand attack to the pile surface: negligible
5) Storm effect: negligible
6) Corrosion by biological bacteria (SRB) in sea mud: negligible

4. STRUCTURE TO BE PROTECTED
Steel Sheet Pile (VL), h=200mm, w=500mm, Surface factor:1.7
Concrete Bottom Level: +1.0m
L.W.L:+0.43m
Coating Bottom Level: -0.6m
Seabed Level: -5m
Pile Toe Level: -14m

5. PROTECTED AREA AND REQUIRED PROTECTIVE CURRENT
(1)Bare Pile Connection in Seawater:
346.743 X 1.7 X (1+0.6) X 0.1=94.3sq.m
94.3sq.m x 0.13A/sq.m =12.3A
(2)Bare in Seawater:
346.743 X 1.7 X (5-0.6) =2593.6sq.m
2593.6sq.m x 0.13A/sq.m=337.2A
(3)Bare in Sea mud:
346.743 X 1.7 X (14-5) =5305.2sq.m
5305.2sq.m x 0.026A/sq.m=137.9A

Total 487.4A

6. ANODE TO BE USED

Material	Aluminum alloy anode :
Dimension	(255+300) x 280 x 1420
Net weight [kg]	295.6
Gross weight [kg]	312.0
Capacity[Ah/kg]	2600
Closed circuit Potential(mV vs. SCE)	-1050
Output current (Initial) [A/pc.] At 35 ohm.cm	3.5
Output current (Average) [A/pc.]	1.75
Life time[year]	50

7. ANODE QUANTITY
140pcs. (487.4A / 3.5A/pc.)

8. POTENTIAL MEASURING TERMINAL
Specification of potential measuring terminal
Material: Stainless Steel SS304
Dimension: 120mm Dia.x 20mm high
Quantity: Total 7 pcs.