

Port of London Authority

PCC FLOODWALL

Inspection and Condition Report



PCC FLOODWALL STRUCTURAL REPORT

Inspection and Condition Report

PLA PROJECT NUMBER: CE0324

DATE: 03 FEBRUARY 2025

Port of London Authority
Civil Engineering Department
London River House
Royal Pier Road
Gravesend
Kent
DA12 2BG

01474 562200

PLA.CO.UK

PROJECT NUMBER		CE0324		PROJECT TITLE		PCC FLOODWALLSTRUCTURAL REPORT	
DOCUMENT TYPE		INSPECTION AND CONDITION REPORT		DOCUMENT REF		0324-PLA-V1-XX-RP-K-0001	
REV	STATUS	DATE	CHANGES		PREP	CHK	APP
1.0	ISSUED	03/02/25	-		MC	NJ	MF

BACKGROUND

Port of London Authority Vessel Navigation and other departments are based within the Port Control Centre Building (PCC) in Gravesend. The building fronts onto the river, with a flood wall along the river frontage. The 20m stretch of flood wall is constructed from Larssen 4A sheet piles with concrete capping beam and concrete faced rear to ground level.

The vertical flood wall is located within the Thames tidal area.

The Port of London Authority are seeking to discharge a planning condition referring to the condition of the flood defence adjacent to the Port Control Centre building and have produced this a condition report.

METHODOLOGY

Structural Inspection

The structural inspection was conducted by professionally qualified Civil Engineers from The Port of London Authority over the 22nd March – 23rd March 2023.

A tactile inspection was carried out where possible at periodic locations and visual inspections were carried out in areas where tactile access could not be gained. Access was gained by foot and via workboat.

The timings of inspections were targeted to maximise the amount of time spent at periods of low and high tides where required. This provided the best opportunity for the inspection engineer to identify corrosion or other issues. The scope of the inspection included the structural elements detailed in Table 1.

Port Control Centre Facility	Access Via	Time of Inspection
Capping beam	Foot/Workboat	Any
Riverside sheet pile wall	Foot/Workboat	High and low tides
Access ladder	Foot/workboat	High and low tides
Timber fenders	Foot/Workboat	High and low tides
Concrete faced sheet pile wall – landside	Foot	Any
Concrete faced sheet pile wall across car park and in front of building	Foot	Any

Table 1 – Table showing inspected structural elements.

PLA engineers obtained Ultrasonic Thickness Measurements (UTM) of the sheet piles where the face was accessible at or close to the low tide levels, at the splash zone and above. Where required, a grinder was used to clean the surface of the steelwork from corrosion and growth. The UTM equipment used was Wintact WT100A.

Visual inspections were conducted on visible parts of ties rods. There is no way to physically test the buried elements of the tie rod and is not the accepted practice to expose the end of the tie rod.

Observations

General Construction

PCC flood wall comprises of Larssen 4A sheet piles with concrete capping beam and concrete faced rear (landside).

Record drawings of the flood wall showed no changes since the installation in 1980's. The site inspection also showed no changes from original design.

Riverside Sheet Pile Wall

Visual Inspection

Visual inspection of the wall shows minimal vegetation grown at LW/bed level with minimal to no growth above this.

Above Splash Zone sheet pile and protective coating appear clean and generally free of corrosion.

The concrete capping beam was found in Overall Good Condition (OGC) with no areas of spalling, cracks or other visible damage. Movement joints between sections of concrete were found to be in OGC (See Photos 7-8).

The sheet pile appeared to be suffering from extensive Moderate Surface Corrosion (MSC) and delamination of 10-15mm in the splash zone. (See Photos 9-11).

Remainders of steel struts and anchors were found to be in Overall Fair Condition (OFC. No struts or anchors appeared visually to have become disconnected or suffered serious corrosive loss. However, all have suffered visible surface corrosion. Note, no caps/protection were removed as it is not accepted practice. (See Photos 11-12).

The sheet pile appeared in Overall Fair Condition (OFC) with MSC and delamination throughout. Vertical cracks were visible to the bended areas of the wall but after removal of delaminated corrosion, walls were solid and in OFC (See 13-14). There were no areas visible of full section loss.

There was no evidence of Accelerated Low Water Corrosion (ALWC) anywhere on the wall.

Tactile Inspection

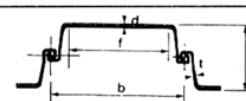
Tactile access to the wall was gained by workboat at high tide and foot at low tide. Patches of the sheet pile face was cleared of surface corrosion and delamination and ground back to bare metal before taking readings. (See Photos 15-16).

UTMs were undertaken and reported in full in Appendix C UMT Readings.

A calculation of the thickness loss of the sheet piles is also reported. This calculation is based on the provided record drawings of the wall constructed approximately in 1980. Record drawing show that the sheet piles comprise of Larssen 4A steel sheet piles. Figure 1 below gives a standard thickness of Larssen 4A as front section (d) 15.7mm and lateral section (t) 9.6mm.

STEEL PILES

Sheet



LARSEN STEEL SHEET PILING - Dimensions and Properties

Section	b mm (nom.)	h mm (nom.)	d mm	t mm (nom.)	f Flat of pan mm	Section area sq. cm per metre of wall	Unit weight kg per linear metre		Combined moment of inertia cm ⁴ per metre	Modulus of section cm ³ per metre
6W	525	212	7.8	6.4	331	108	44.7	85.1	6,371	601
9W	525	260	8.9	6.4	343	124	51.0	97.1	11,726	902
12W	525	306	9.0	8.5	343	147	60.4	115.1	18,345	1,199
16W	525	348	10.5	8.9	341	166	68.3	130.1	27,857	1,601
20W	525	400	11.3	9.4	333	188	77.3	147.2	40,180	2,009
25W	525	454	12.1	10.5	317	213	87.9	167.4	56,727	2,499
32W	525	454	17.0	10.5	317	252	103.6	197.4	73,003	3,216
4	400	250	14.1	8.5	248	108	62.2	155.5	16,080	1,360
4A	400	381	15.7	9.6	219	236	74.0	185.1	44,916	2,360
6	420	440	22.0	14.0	248	370	122.0	290.5	92,452	4,200
6	420	440	25.4	14.0	251	397	131.0	311.8	102,861	4,675
6	420	440	28.6	14.0	251	421	138.7	330.2	111,450	5,066
GSP3	400	250	13.0	8.6	271	191	60.0	150.0	16,800	1,340

Rolling margin is within 4 per cent over and 2.5 per cent under theoretical mass; 75 mm over and 50 mm under on length.

Figure 1 Larssen Sheet Piling Dimensions and Properties

From this, the average section loss across the sheet pile wall is shown in Table 2.

	Front Loss (mm)	Lateral Loss (mm)
Valid Measurements (no.)	19	22
Average Loss (mm)	-1.52	-2.16
Average Percentage Loss	-9.70%	-23%

Table 2 – Table showing summary of thickness testing results.

Access Ladder

The access ladder was found to be in OFC with extensive signs of MSC and delamination at splash and tidal zone. The ladder appeared to have lost up to 3 mm of thickness to rungs and stringers at tidal zone after delamination (See Photos 17-19).

Timber Fenders

The timber fenders appeared in OGC with no to negligible signs of decay and splits and shakes (See Photos 20-22). Grab chains fixed to timber fenders were installed in 2022 and are in overall good condition with minimal to zero corrosion.

Concrete Faced Sheet Pile Wall – Landside

Concrete faced wall sheet pile wall runs parallel to the river side. Concrete face is cast into the capping beam to ground level. Wall has movement joints every 5.5m in line with the capping beam. There is also a movement joint where the wall joins the perpendicular concrete retaining wall alongside Royal Terrace Pier.

Wall also has anchor bolts for the access ladder.

Overall, the wall and capping beam is OGC with no signs of spalling or movement. Movement joints are in OGC with joints remaining pliable with only a few sections of vegetation growth along the internal wall. (See Photos 23-24)

Sheet Pile Wall Across Car Park and In-front of Building

Running perpendicular to the river wall at the London River House end a concrete cap sheet pile wall extends inland. The internal Port Control Centre face has a capping beam and exposed protected face sheet piles. The external face, in the London River House carpark undercroft is faced with a brick wall to the underside of the capping beam.

Wall is in OGC with no signs of spalling to the capping beam. The internal protected face shows no sign of corrosion or damage to the protective coating. The external brick face is in OGC with small sections of mortar loss. (See Photos 25-27)

ANALYSIS

Steel Sheet Piles

It appeared that the protective coatings applied to the sheet walls has largely failed on the river face of the main wall. Extensive signs of MSC were observed to the splash and tidal zones of the piles. This is consistent with BS EN 1993-5, Table 4-2 (Figure 2) where is reported how the highest corrosion rates are typically found in the splash zone and low water levels. 10 to 15 mm of delamination were visible throughout the piles. However, no areas of total thickness loss were observed, even after removing areas of high delamination.

It is understood that the flood wall is approximately 43 years old. Therefore, the expected loss based on two sources is shown in Table 3 below.

Predicted Loss	BS EN 1993-5 Table 4.1 & 4.2						Larssen and Frodingham Sheet Pile Detailing	
	4.1 - Corrosion in Soils		4.2 - Corrosion in Fresh/Salt Water		Total Loss (mm/y)	Expect Loss 43 years	Minimum Effective Life... ...Various Service Environments	
	Condition	Loss (mm/y)	Condition	Loss (mm/y)			Loss/y	Expect Loss 43 years
Low Water	Undisturbed Natural Soils	0.012	Sea Water Intertidal	0.035	0.047	2.021	0.05	2.15
High Water	Undisturbed Natural Soils	0.012	Sea Water High Tide	0.076	0.088	3.784	0.09	3.87
Splash Zone	Concrete Backed	0	Sea Water High Tide	0.076	0.076	3.268	0.09	3.87

Table 3 Expected Corrosion Loss – BS EN 1993-5 & Larssen and Frodingham Sheet Pile Detailing

A graphic comparison between the UTMs (blue dots) and the minimum expected section loss based on Table 3 (orange line) is shown for each Zone (Low Water Figure 3, High Water Figure 4 and Splash Zone Figure 5). Table 4 shows the average thickness losses per zone.

The positive values of section loss are considered as anomalies, likely due to the presence of coating paint or delaminated material between UTM reader and sheet piles and are excluded from the analysis and averages.

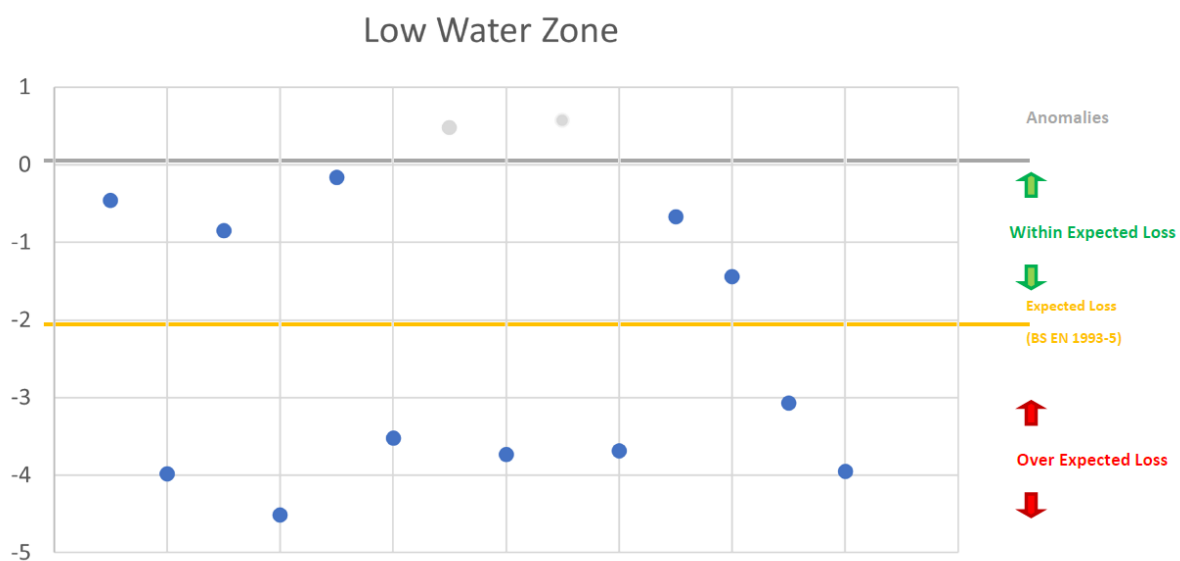


Figure 3 – Low Water UMT vs Expected Loss.

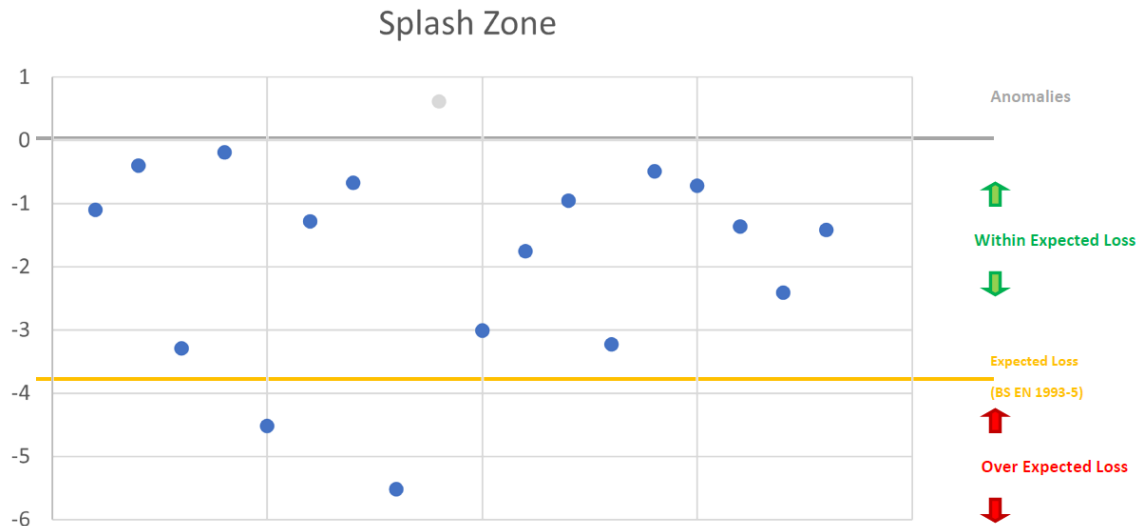


Figure 4 – Splash Zone UMT vs Expected Loss.

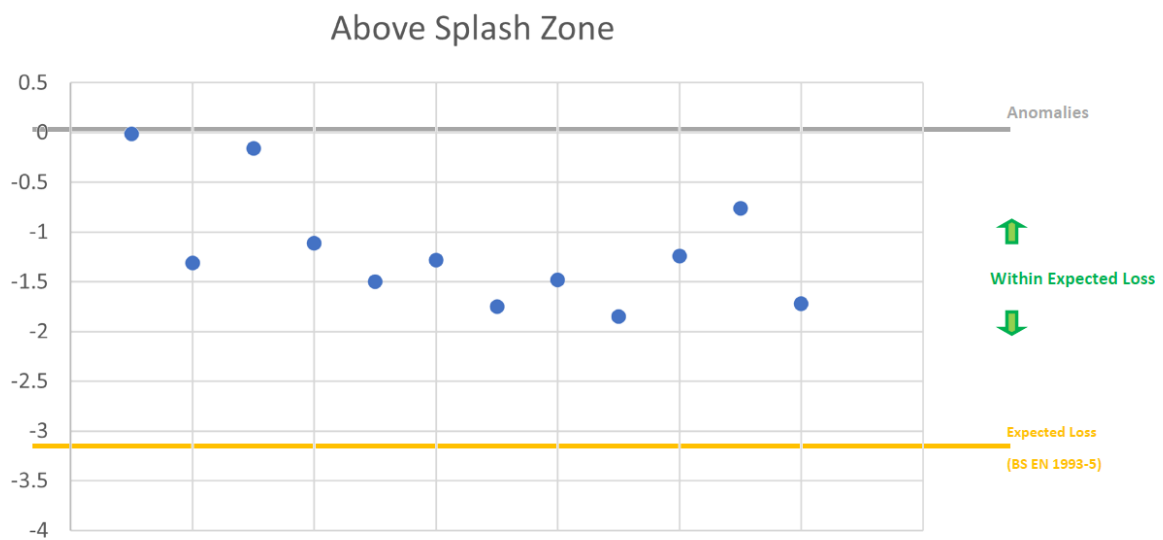


Figure 5 – Above Splash Zone UMT vs Expected Loss.

	Av Loss Flange	Av Loss Webb	Av Loss Overall
Low Water	-1.04mm	-3.55mm	-2.29mm
Splash	-2.21mm	-1.62mm	-1.92mm
Above Splash	-1.01mm	-1.36mm	-1.18mm

Table 4 Average Loss Per Zone

Overall, the majority of the UMT readings are below expected loss. The loss is also on average lower than expected based on BS1993-5 or Larssen and Frodingham Sheet Pile Detailing.

The loss in the key structural flange elements is well below expected, with all readings below the Larssen and Frodingham Sheet Pile Detailing maximum allowance of 5mm. Based on the worst-case average loss projected forward, no sections would reach this critical loss within the next 25 years.

Structural Assessment

Using the average losses from the UMT survey and using ground conditions from the recent borehole undertaken as part of the structural assessment of the Port Control Centre, a structural assessment was carried out on the sheet pile wall for as-built condition in 1980, condition when tested in 2023 and projected condition in 2045. The drawings in Appendix B show the sheet piles are only retaining the soil loading behind. Loading from PCC building itself is taken through the buildings significantly deeper cast piles. The worst-case scenario for bending moment is during low tide, when the force of water is not resisting the force of the retained soil behind the structure. Soil makeup and properties were taken from a local recent borehole commissioned as part of the structural assessment of the PCC building. Sheet pile properties were input as per Table 5 below:

Worst Case Av Loss as measured in 2023 (mm)	mm/y	Projected Loss in 2045 mm
-2.3	-0.053	-3.5

Sheet Pile Thickness			
	1980 (design thickness)	2023 (measured)	2045 (projected)
Flange	15.7	13.4	12.2
Webb	9.6	7.3	6.1

Table 5 Sheet Pile Thickness and Projections for Structural Assessments

Full calculations are available in Appendix D. Table 6 shows that in all circumstances the sheet pile passes all structural checks within the current average loss rate.

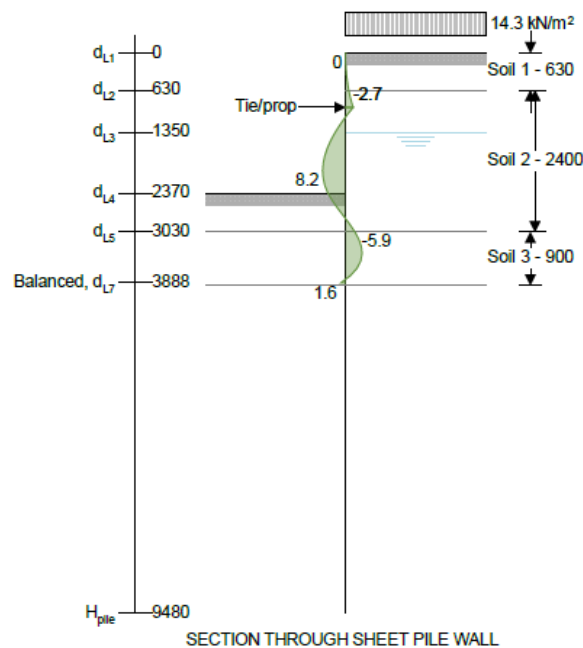


Figure 6 Extract from calculations sheet showing cross section of flood wall

	Unit	Design resistance required	Resistance force provided 1980	Resistance force provided 2023	Resistance force provided 2045	P/F
Moment	kNm	9.2 ⁽¹⁾	453.1	447.4	385.9	PASS
Shear Force	kN	32.7 ⁽²⁾	1214.8	904.3	779.3	PASS

Table 6 Structural Calculation Results for Each Thickness (Worst loading case design requirements ⁽¹⁾⁽²⁾)

The results from the calculations show that the piles were originally capable of retaining 453kNm of bending moment but were only required to resist 9.2kNm in the worst-case scenario. With thickness loss projected to 2045, the piles will be capable of retaining 385kNm of bending moment. Therefore, at the current loss rate based on actual UMT measurement averages the sheet pile will still function structurally in 2045.

RECOMMENDATIONS

Remedial recommendations are presented in Table 8 below. Recommendations provided consider the severity of defects observed and PLA's aspirations to maintain the structural and operational integrity of the vital PCC building. Each recommendation provided is allocated a "risk" of low, medium, high or very high and relates to both safety and cost. Intended application of each risk level is denoted in Table 7 below.

Risk Level	Application
Low	Monitor only. Superficial defect with no action required.
Medium	Cost penalties may be incurred, or safety may be compromised in the future if recommendation is not addressed.
High	Cost penalties will be incurred, or safety will be compromised if recommendation is not addressed.
Very high	The structural or operational integrity is lapsed. Immediate action or closure is required.

Table 7 – Table showing risk level intended application.

Ref	Defect	Recommendation	Risk Level
1.0	Sheet Piles		
1.1	Larssen thickness	A regime of inspections to measure the thicknesses of the piles should be established to ensure excessive loss of section is not occurring. The frequency of these inspections is recommended to be biennial in current condition, 5 yearly if protective coating is reinstated.	Low
1.2	Protective Coating and corrosion	Mechanically clean and reapply suitable protective coating to the splash zone and low water zones on all river facing sheet piles. Where sections of high loss are above 3mm, these areas are to be plate welded prior to application of protective coating. Cathodic protection was considered as part of this report and has been excluded from recommendations as it is unlikely to provide an efficient solution given the tidal range. It should be noted that if cathodic protection is applied to the piles, the requirement for protective coating to the tidal zone will be of less importance however would still be recommended.	Medium
2.0	Timber Fenders		
2.1	Decay and splits and shakes	A regime of inspections to check whether the timber fenders have signs of increasing decay, and splits and shakes should be established to ensure that excessive loss of protection capacity is not occurring. The frequency of these inspections should be biennial. No current remedial work required	Low
3.0	Ladder		
3.1	Corrosion	Mechanically clean and apply a suitable protective coating system to corroded areas of the ladders to maintain their design life.	Medium
3.2	Corrosion	A regime of yearly inspections to check the integrity of the ladder and its fixings should be established and recorded.	Medium

Table 8 – Table Showing PCC Flood Wall Recommendations.

REMEDIAL WORKS

Remedial works were completed to flood wall in July-September 2024.

The scope of works included the application of protective coating and surface preparation of the approximately 6m high steel sheet piles which extend roughly 20m on the riverside of the Port Control Centre including steel ladders. The new coating extends 250mm below existing bed levels to the soffit of the concrete beam. The protective system was required to achieve a minimum dry film thickness of 600 μm and provide a minimum 15-year guarantee.

Prior to application of the protective coating, the wall was hydroblasted to remove corrosion and reveal unseen defects. Strengthening repair plates were fillet welded to the sheet piles where thickness loss of over 3mm had been detected. Further UTM tests were completed throughout the works to ensure all areas were sufficient thickness.

All timber fenders were replaced with new Accoya timber fenders.

Photos of the completed works can be found in Appendix A (photos 28-33)

CONCLUSION

This report, and associated calculations, show that the PCC flood wall is in sufficient condition to resist the worst-case scenario forces. Using projected pile thickness-loss based on actual UTM readings, the wall will also resist the forces expected in 2045, satisfying the planning permission condition.

The remedial works completed on the wall extend the life of the flood wall, preventing corrosion for a minimum of 15 years, further satisfying the planning permission condition.

Appendix A - Photos



1 - River Face LW



2 - River face HW



3 - River face rear



4 - Car park face rear



5 - Car park face front



6 - Riverside capping beam



7 – Riverside capping beam



8 - Riverside capping beam movement joint



9 - Surface corrosion visual inspection



10 - Surface corrosion visual inspection



11 - Surface corrosion visual inspection



12 – Tie bar and surface corrosion



13 - Delamination example before



14 - Delamination example after



15 - UMT inspection example



16 - UMT inspection example



17 - Access Ladder



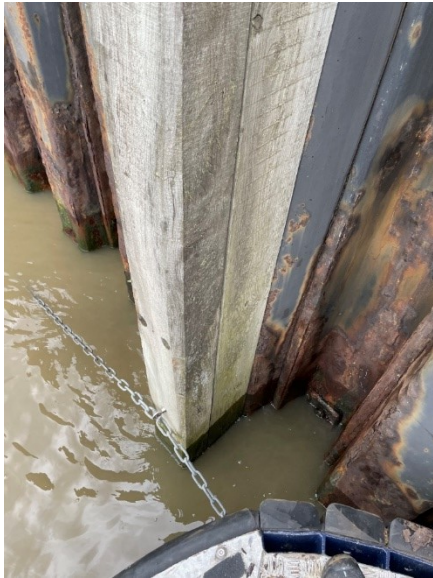
18 - Access ladder



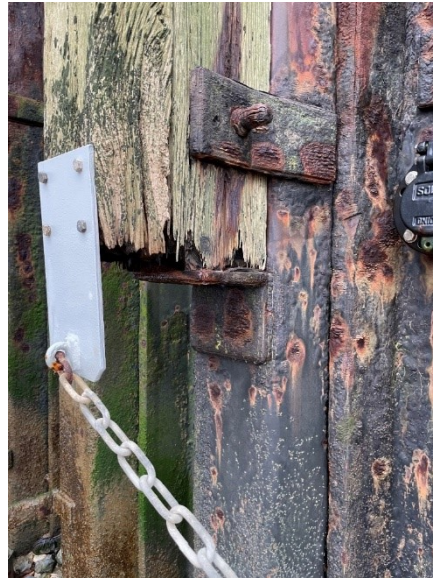
19 - Access Ladder



20 – Fender example top



21 – Fender middle example



22 – Fender example bottom



23 – River face rear



24 – River face rear movement joint



25 – Car park face rear



26 – Car park face rear



27 – Bin store concrete face



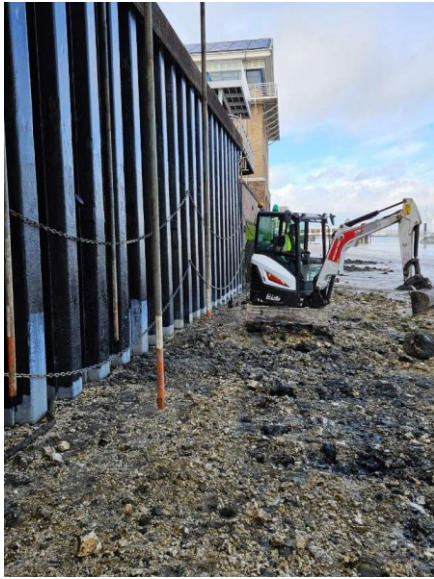
28 – Bin store car park brick face



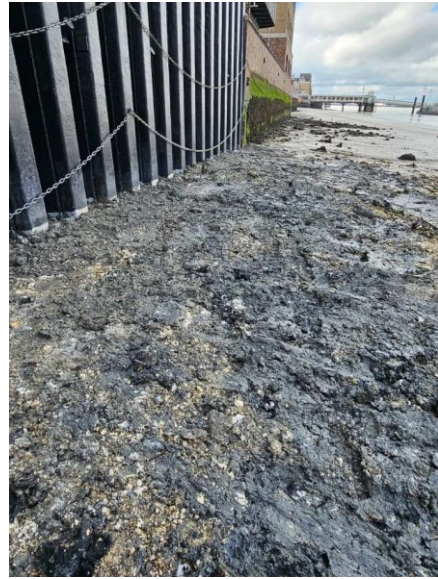
27 – Car park under-croft brick face



28 – LW following remedial works – note discolouration of piles due to saline water reacting with paint dye. The coating has not been compromised.



29 – LW following remedial works



30 – LW following remedial works



31 – LW following remedial works

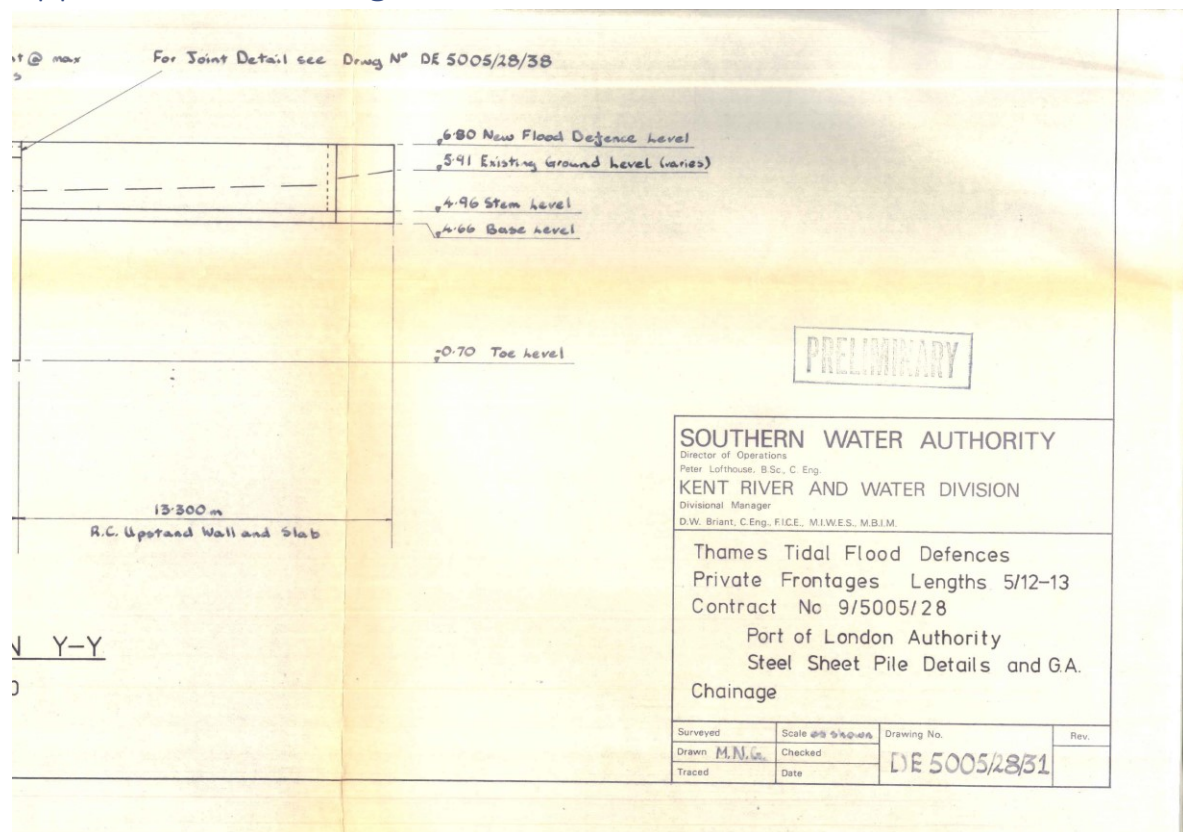


32 – Steel plate repair

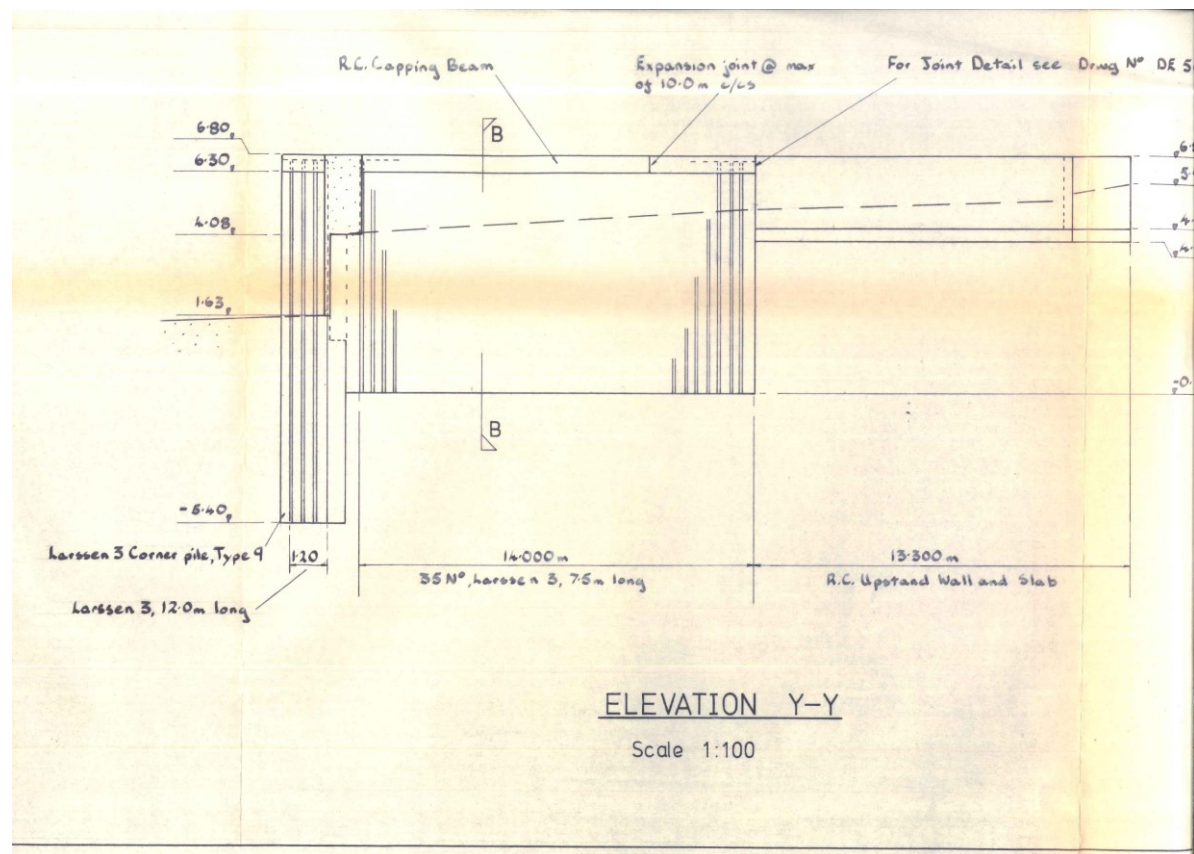


33 – Steel plate repair

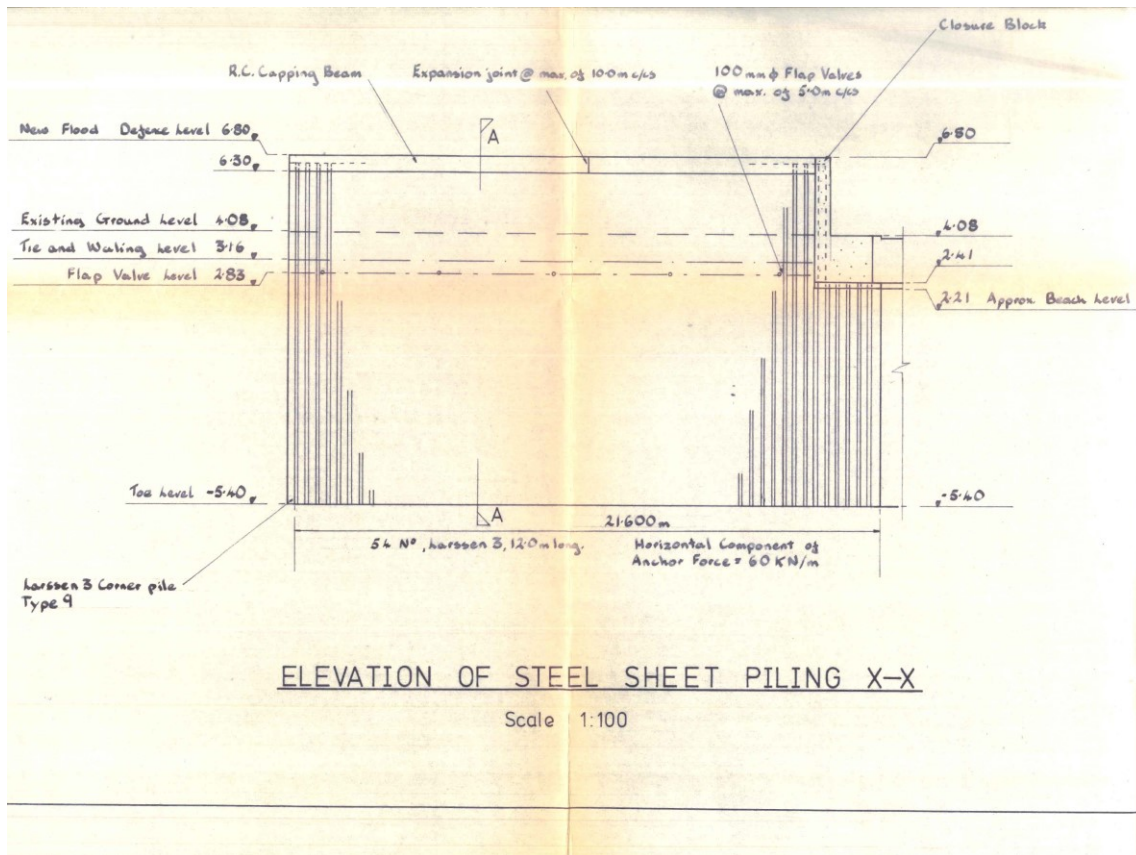
Appendix B – Drawings



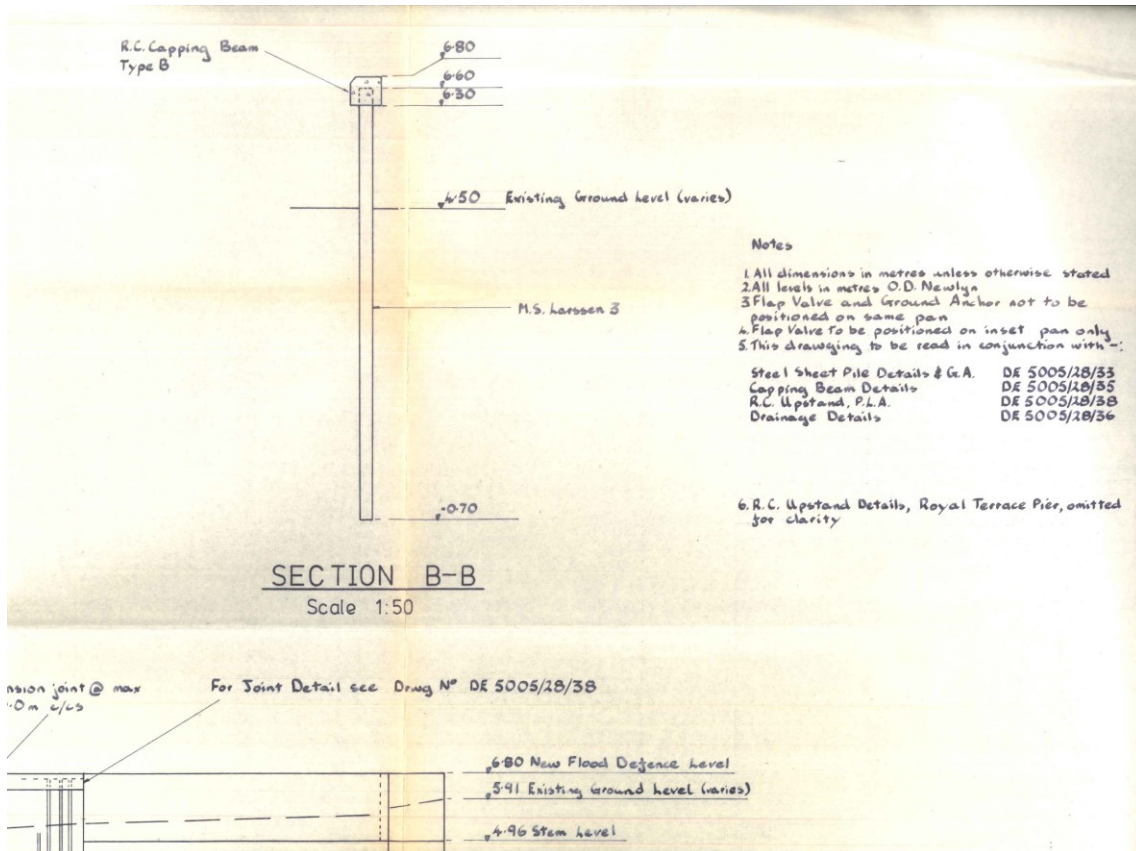
Drawing DE5005/28/31 extract - 1



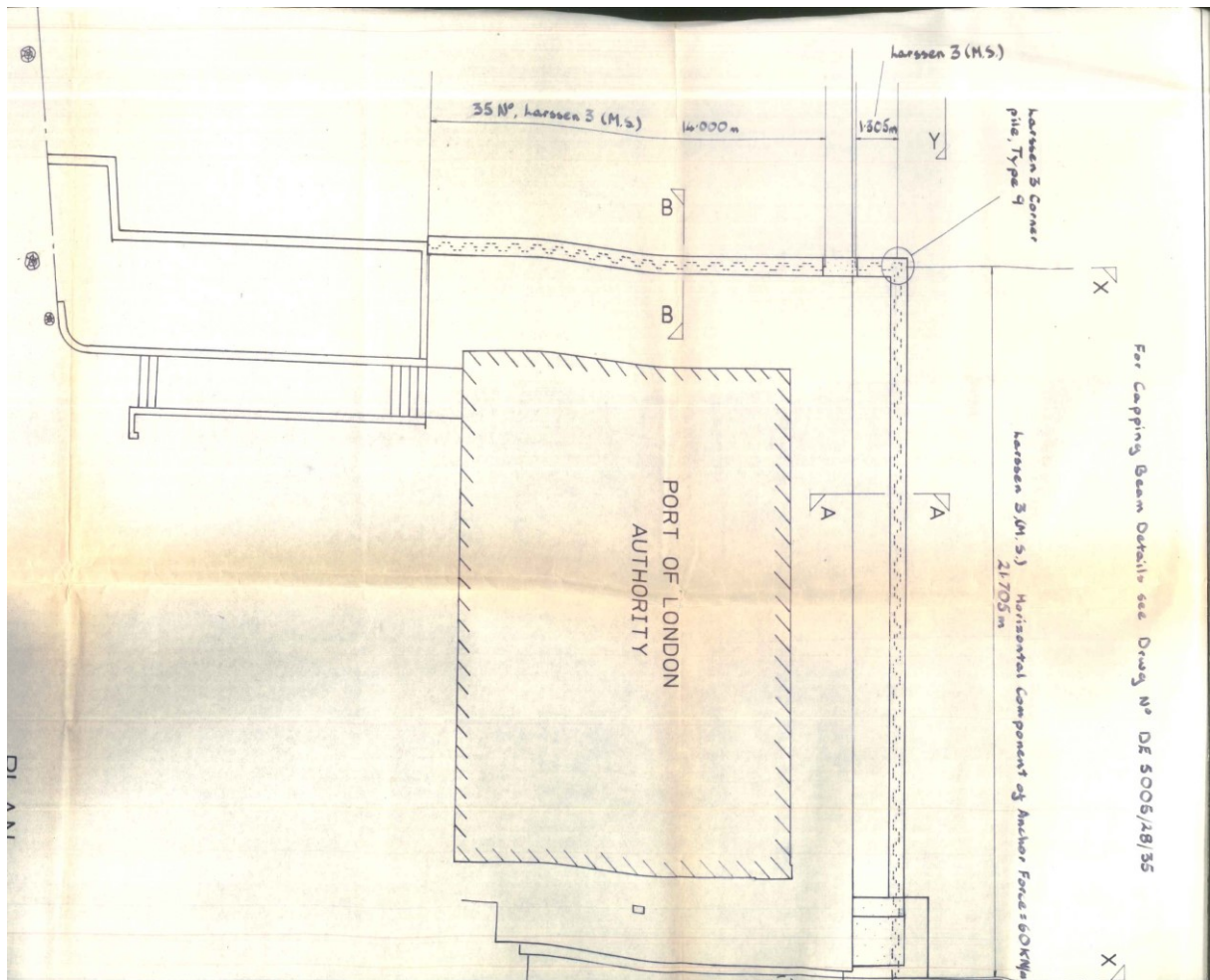
Drawing DE5005/28/31 extract - 2



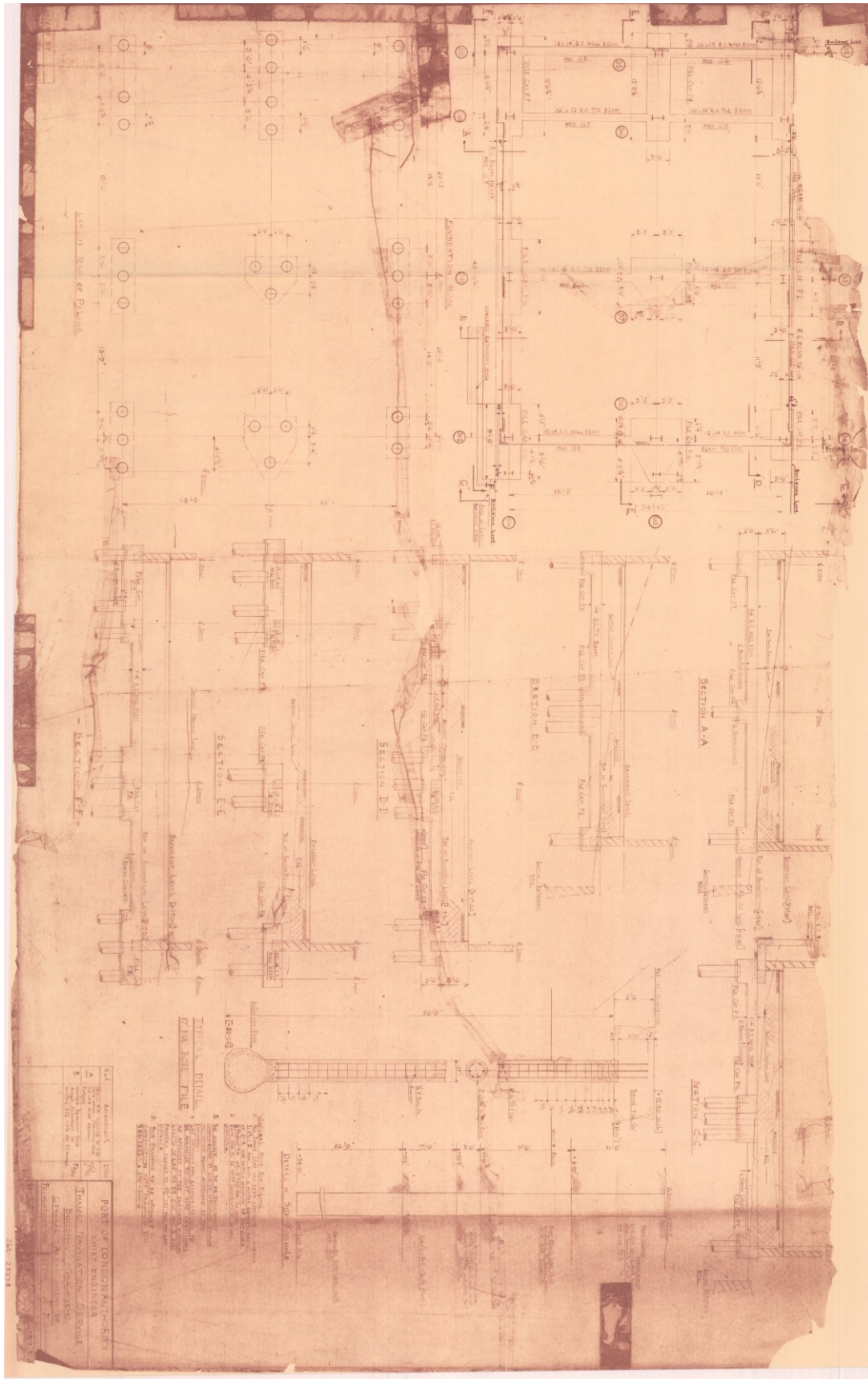
Drawing DE5005/28/31 extract - 3



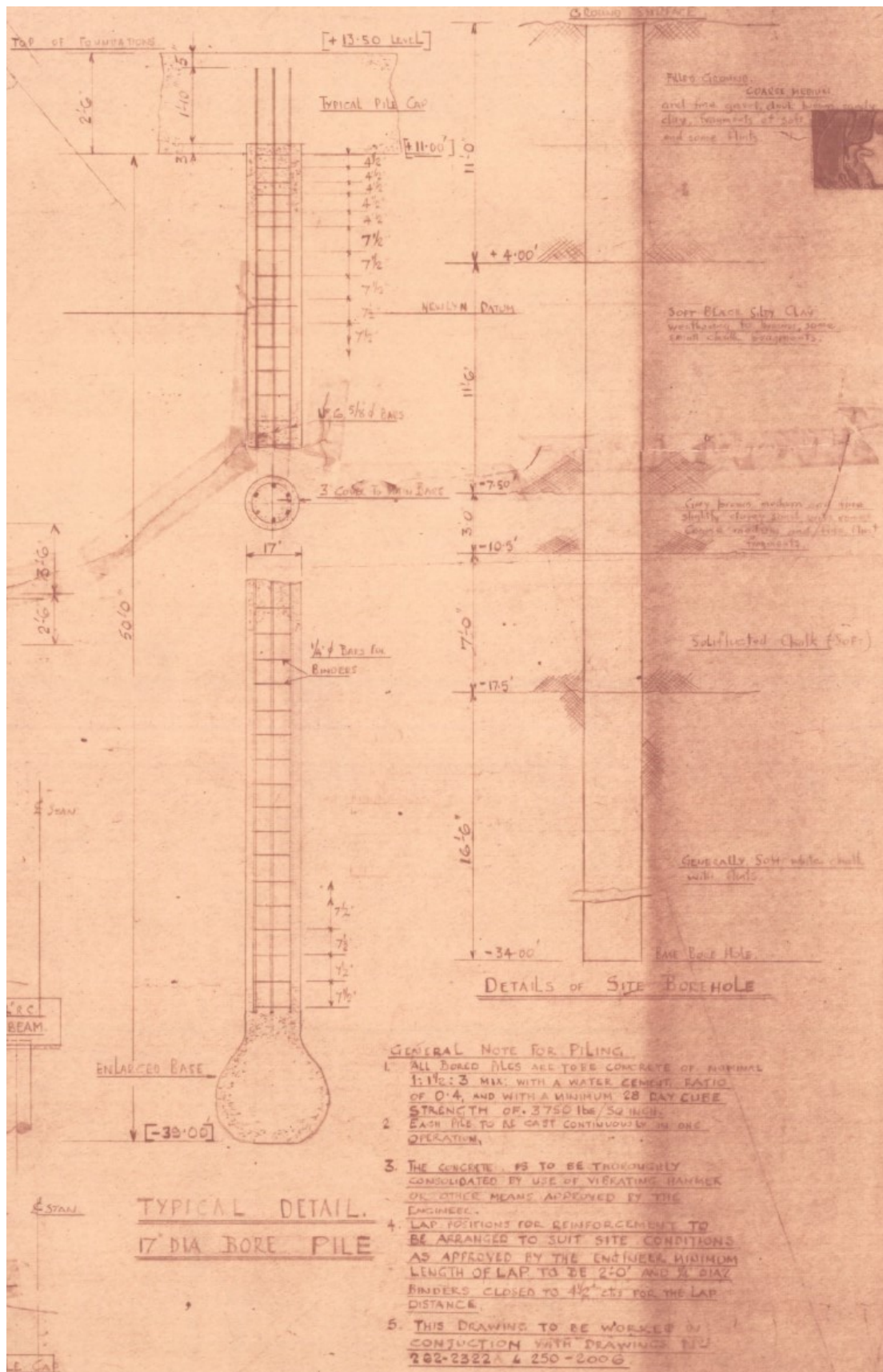
Drawing DE5005/28/31 extract - 4



Drawing DE5005/28/31 extract - 5

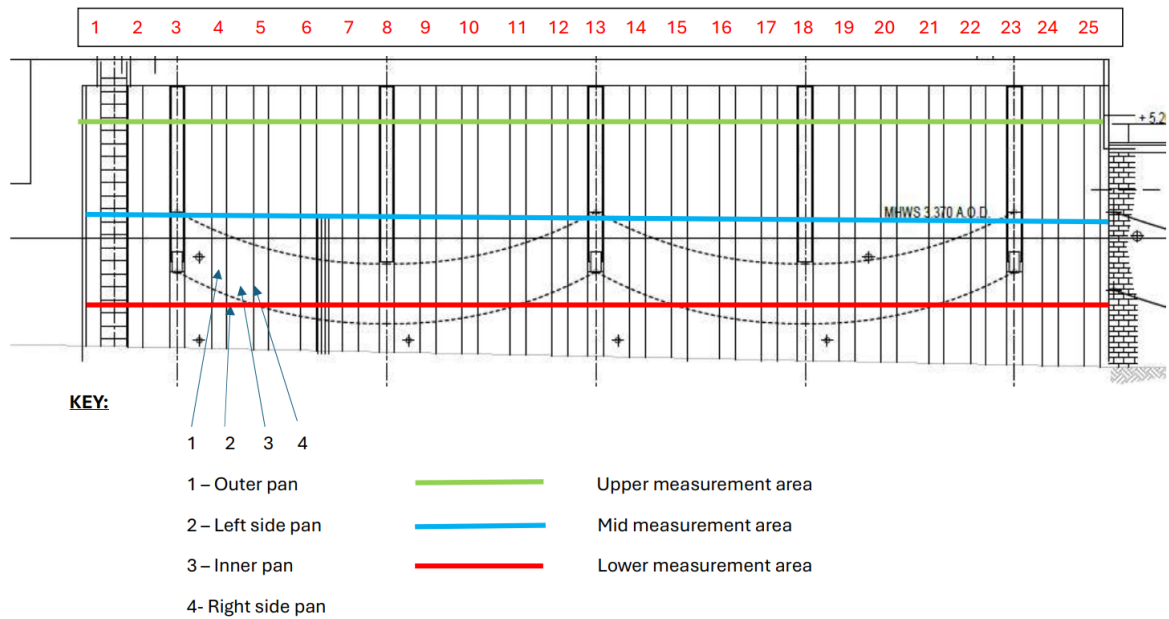


Thames Navigational Building Gravesend, General Arrangement of Foundations and Setting Out Dimensions - 1958



Extract of Thames Navigational Building Gravesend, General Arrangement of Foundations and Setting Out Dimensions – 1958 showing pile toe depth

Appendix C – UTM Readings



Pile 1	Pile 2	Pile 3	Pile 4	Pile 5	Pile 6	Pile 7	Pile 8	Pile 9	Pile 10
1 13.5	13.2	12.3	15.5	16.1	15.2	15.1	15.9	15.8	14.9
2 10.3	9.9	10.3	9.1	9.9	12.6	9.6	10.0	9.6	9.0
3 15.7	15.2	15.3	15.3	15.7	15.1	13.5	15.1	13.9	15.9
4 9.5	10.1	9.4	9.6	9.5	9.8	9.2	9.6	9.6	7.7
1 13.4	14.1	14.0	15.5	15.9	14.9	14.5	15.8	15.8	14.3
2 8.3	8.1	8.4	8.5	9.6	9.8	8.4	7.4	9.8	9.6
3 13.5	15.2	13.2	12.3	16.2	15.2	14.7	12.6	12.1	16.1
4 8.9	8.8	8.3	9.1	9.3	9.9	8.8	7.5	9.1	7.8
1 15.9	14.1	12.6	16.0	15.1	16.0	15.7	16.1	13.5	14.1
2 9.4	11.2	9.2	8.2	9.0	7.4	9.9	7.4	7.9	9.8
3 14.6	15.3	14.4	15.1	15.8	15.7	16.3	16.4	14.6	15.4
4 9.5	10.2	7.9	8.9	9.1	8.6	8.2	8.9	8.9	9.6
Pile 11	Pile 12	Pile 13	Pile 14	Pile 15	Pile 16	Pile 17	Pile 18	Pile 19	Pile 20
1 15.2	16.4	15.2	15.5	15.5	15.9	15.6	15.2	15.4	16.1
2 9.8	9.6	9.5	9.6	9.5	9.3	9.3	10.0	9.6	10.2
3 16.4	16.4	15.8	15.6	16.7	14.9	15.8	16.2	15.7	16.1
4 10.1	9.5	8.7	10.4	10.0	10.0	9.9	9.9	9.8	9.6
1 13.2	16.1	14.1	15.9	15.5	13.3	14.1	14.3	12.1	14.5
2 7.9	9.3	9.6	8.7	10.5	9.3	9.5	9.9	8.5	8.8
3 13.9	13.8	13.2	14.5	14.4	12.1	15.7	13.5	12.3	15.4
4 8.1	9.1	10.3	9.7	9.1	8.3	9.6	9.1	9.6	9.4
1 15.1	14.9	15.2	14.1	16.2	16.1	15.1	15.3	13.5	16.1
2 7.8	7.7	7.8	9.1	10.4	9.1	8.9	9.8	9.7	9.7
3 14.5	15.3	15.1	16.1	16.7	15.1	16.4	16.3	15.5	15.4
4 9.1	8.3	8.2	9.6	8.7	10.3	9.0	9.2	10.2	9.4

	Pile 21	Pile 22	Pile 23	Pile 24	Pile 25
1	15.4	15.7	15.2	15.4	14.1
2	9.5	9.6	9.4	9.4	
3	15.7	15.9	15.6	15.1	
4	9.7	9.2	9.7	9.5	
1	14.6	12.2	14.1	13.4	15.7
2	9.0	7.3	8.9	9.9	
3	15.1	15.1	16.0	15.1	
4	9.7	8.1	9.4	7.7	
1	15.6	15.4	13.7	14.6	15.1
2	9.1	9.1	9.9	10.1	
3	15.9	16.1	14.1	15.1	
4	9.8	9.9	8.6	9.1	

Appendix D - Calculations



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 1980 Design Check				Start page no./Revision 1980 1 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

STEEL SHEET PILING ANALYSIS & DESIGN

In accordance with BS EN1997-1:2004 - Code of Practice for Geotechnical design and the UK National Annex

Tedds calculation version 2.0.07

Design summary

Combination 1

Description	Unit	Provided	Required	Utilisation	Result
Total length required	mm	9480	4117	2.303	PASS
Moment capacity	kNm/m	453.1	8.2	54.970	PASS
Shear capacity	kN/m	1214.8	32.7	37.111	PASS
Force in tie/prop 24.0 kN/m					

Combination 2

Description	Unit	Provided	Required	Utilisation	Result
Total length required	mm	9480	4694	2.020	PASS
Moment capacity	kNm/m	453.1	9.2	49.496	PASS
Shear capacity	kN/m	1214.8	30.7	39.627	PASS
Force in tie/prop 23.2 kN/m					

Geometry

Design method	Fixed earth support
Total length of sheet pile provided	$H_{pile} = 9480$ mm
Number of different types of soil	$N_s = 6$
Retained height	$d_{ret} = 1870$ mm
Depth of unplanned excavation	$d_{ex} = 500$ mm
Total retained height	$d_s = 2370$ mm
Angle of retained slope	$\beta = 0.0$ deg
Depth from ground level to tie	$d_t = 920$ mm
Depth from GL to top of water table retained side	$d_w = 1350$ mm
Depth from GL to top of water table retaining side	$d_{wp} = 2370$ mm

Loading

Permanent surcharge	$p_{o,G} = 5.0$ kN/m ²
Variable surcharge	$p_{o,Q} = 5.0$ kN/m ²

Soil layer 1

Characteristic shearing resistance angle	$\phi'_{k_s1} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s1} = 28.0$ deg
Moist density of soil	$\gamma_{m_s1} = 17.5$ kN/m ³
Characteristic saturated density of retained soil	$\gamma_{s_s1} = 21.0$ kN/m ³
Height of soil 1	$h_1 = 630$ mm

Soil layer 2

Characteristic shearing resistance angle	$\phi'_{k_s2} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s2} = 28.0$ deg
Moist density of soil	$\gamma_{m_s2} = 17.5$ kN/m ³
Characteristic saturated density of retained soil	$\gamma_{s_s2} = 20.0$ kN/m ³
Height of soil 2	$h_2 = 2400$ mm

Soil layer 3

Characteristic shearing resistance angle	$\phi'_{k_s3} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s3} = 28.0$ deg
Moist density of soil	$\gamma_{m_s3} = 14.0$ kN/m ³

	Project PCC Retaining Flood Wall Check				Job no.	
	Calcs for 1980 Design Check				Start page no./Revision 1980 2 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Characteristic saturated density of retained soil $\gamma_{s_s3} = 18.0 \text{ kN/m}^3$
Height of soil 3 $h_3 = 900 \text{ mm}$

Soil layer 4

Characteristic shearing resistance angle $\phi'_{k_s4} = 30.0 \text{ deg}$
Characteristic wall friction angle $\delta_{k_s4} = 28.0 \text{ deg}$
Moist density of soil $\gamma_{m_s4} = 15.0 \text{ kN/m}^3$
Characteristic saturated density of retained soil $\gamma_{s_s4} = 19.0 \text{ kN/m}^3$
Height of soil 4 $h_4 = 1100 \text{ mm}$

Soil layer 5

Characteristic shearing resistance angle $\phi'_{k_s5} = 30.0 \text{ deg}$
Characteristic wall friction angle $\delta_{k_s5} = 25.0 \text{ deg}$
Moist density of soil $\gamma_{m_s5} = 14.0 \text{ kN/m}^3$
Characteristic saturated density of retained soil $\gamma_{s_s5} = 19.0 \text{ kN/m}^3$
Height of soil 5 $h_5 = 1100 \text{ mm}$

Soil layer 6

Characteristic shearing resistance angle $\phi'_{k_s6} = 30.0 \text{ deg}$
Characteristic wall friction angle $\delta_{k_s6} = 30.0 \text{ deg}$
Moist density of soil $\gamma_{m_s6} = 14.0 \text{ kN/m}^3$
Characteristic saturated density of retained soil $\gamma_{s_s6} = 19.0 \text{ kN/m}^3$
Height of soil 6 $h_6 = 5700 \text{ mm}$

Partial factors on actions - Section A.3.1 - Combination 1

Permanent unfavourable action $\gamma_G = 1.35$
Permanent favourable action $\gamma_{G,f} = 1.00$
Variable unfavourable action $\gamma_Q = 1.50$
Angle of shearing resistance $\gamma_{\phi'} = 1.00$
Weight density $\gamma_\gamma = 1.00$

Design soil properties - soil 1

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 30.0 \text{ deg}$
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 28.0 \text{ deg}$
Design moist density of retained soil $\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.5 \text{ kN/m}^3$
Design saturated density of retained soil $\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 21.0 \text{ kN/m}^3$
Design buoyant density of retained soil $\gamma_{d,d1} = \gamma_{s,d1} - \gamma_w = 11.2 \text{ kN/m}^3$
Active pressure using Coulomb theory $K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.296$
Passive pressure using Coulomb theory $K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = 9.012$

Design soil properties - soil 2

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 30.0 \text{ deg}$
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 28.0 \text{ deg}$
Design moist density of retained soil $\gamma_{m,d2} = \gamma_m / \gamma_\gamma = 17.5 \text{ kN/m}^3$
Design saturated density of retained soil $\gamma_{s,d2} = \gamma_s / \gamma_\gamma = 20.0 \text{ kN/m}^3$
Design buoyant density of retained soil $\gamma_{d,d2} = \gamma_{s,d2} - \gamma_w = 10.2 \text{ kN/m}^3$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 1980 Design Check			Start page no./Revision 1980 3 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Active pressure using Coulomb theory

$$K_{a2} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p2} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 3

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{28.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m,d3} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s,d3} = \gamma_s / \gamma_r = \mathbf{18.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d,d3} = \gamma_{s,d3} - \gamma_w = \mathbf{8.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a3} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p3} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 4

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{28.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m,d4} = \gamma_m / \gamma_r = \mathbf{15.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s,d4} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d,d4} = \gamma_{s,d4} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a4} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p4} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 5

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{25.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m,d5} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s,d5} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d,d5} = \gamma_{s,d5} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a5} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p5} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{7.704}$$

Design soil properties - soil 6

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m,d6} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s,d6} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d,d6} = \gamma_{s,d6} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

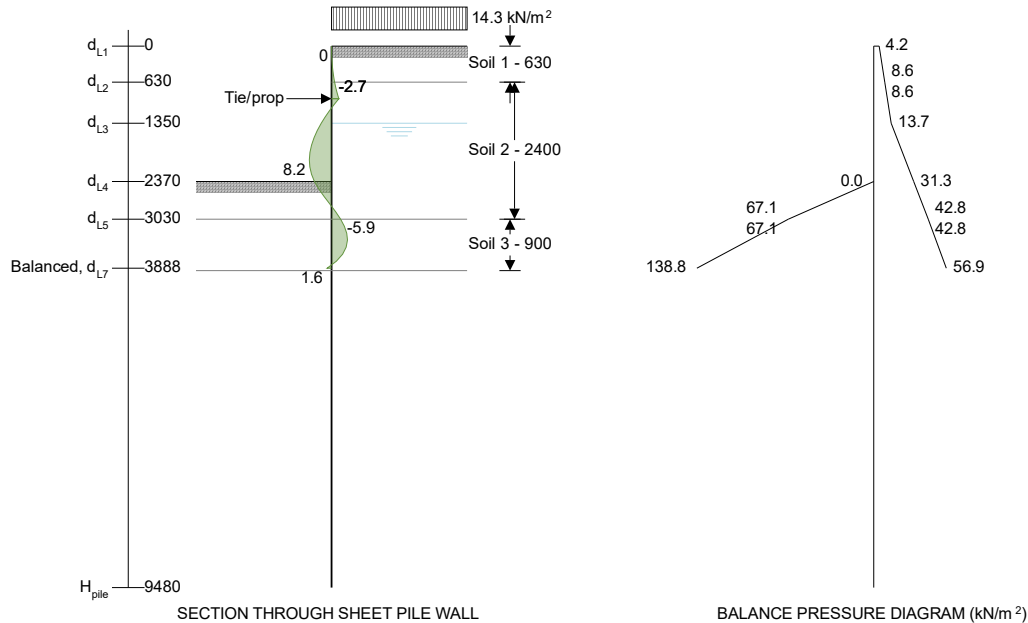
$$K_{a6} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.297}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 1980 Design Check				Start page no./Revision 1980 4 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Passive pressure using Coulomb theory

$$K_{p6} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = 10.095$$



Overburden on active side

- Overburden at 0 mm below GL in soil 1
- Overburden at 630 mm below GL in soil 1
- Overburden at 630 mm below GL in soil 2
- Overburden at 1350 mm below GL in soil 2
- Overburden at 2370 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 3
- Overburden at 3888 mm below GL in soil 3

$$\begin{aligned} OB'_{a11} &= (p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q) = 14.3 \text{ kN/m}^2 \\ OB'_{a21} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 29.1 \text{ kN/m}^2 \\ OB'_{a22} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 29.1 \text{ kN/m}^2 \\ OB'_{a31} &= \gamma_G \times \gamma_{m,d2} \times h_{a2} + OB'_{a22} = 46.1 \text{ kN/m}^2 \\ OB'_{a41} &= \gamma_G \times \gamma_{d,d2} \times h_{a3} + OB'_{a31} = 60.2 \text{ kN/m}^2 \\ OB'_{a51} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = 69.3 \text{ kN/m}^2 \\ OB'_{a52} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = 69.3 \text{ kN/m}^2 \\ OB'_{a61} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = 78.7 \text{ kN/m}^2 \end{aligned}$$

Overburden on passive side

- Overburden at 2370 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 3
- Overburden at 3888 mm below GL in soil 3

$$\begin{aligned} OB'_{p41} &= 0 \text{ kN/m}^2 = 0.0 \text{ kN/m}^2 \\ OB'_{p51} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = 6.7 \text{ kN/m}^2 \\ OB'_{p52} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = 6.7 \text{ kN/m}^2 \\ OB'_{p61} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = 13.8 \text{ kN/m}^2 \end{aligned}$$

Pressure on active side

- Active at 0 mm below GL in soil 1
- Active at 630 mm below GL in soil 1
- Active at 630 mm below GL in soil 2
- Active at 1350 mm below GL in soil 2
- Active at 2370 mm below GL in soil 2
- Active at 3030 mm below GL in soil 2
- Active at 3030 mm below GL in soil 3
- Active at 3888 mm below GL in soil 3

$$\begin{aligned} p'_{a11} &= K_{a1} \times OB'_{a11} = 4.2 \text{ kN/m}^2 \\ p'_{a21} &= K_{a1} \times OB'_{a21} = 8.6 \text{ kN/m}^2 \\ p'_{a22} &= K_{a2} \times OB'_{a22} = 8.6 \text{ kN/m}^2 \\ p'_{a31} &= K_{a2} \times OB'_{a31} = 13.7 \text{ kN/m}^2 \\ p'_{a41} &= K_{a2} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = 31.3 \text{ kN/m}^2 \\ p'_{a51} &= K_{a2} \times OB'_{a51} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = 42.8 \text{ kN/m}^2 \\ p'_{a52} &= K_{a3} \times OB'_{a52} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = 42.8 \text{ kN/m}^2 \\ p'_{a61} &= K_{a3} \times OB'_{a61} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = 56.9 \text{ kN/m}^2 \end{aligned}$$

Pressure on passive side

- Passive at 2370 mm below GL in soil 2

$$p'_{p41} = K_{p2} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = 0.0 \text{ kN/m}^2$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 1980 Design Check				Start page no./Revision 1980 5 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Passive at 3030 mm below GL in soil 2

$$p'_{p51} = K_{p2} \times OB'_{p51} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{67.1 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 3

$$p'_{p52} = K_{p3} \times OB'_{p52} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{67.1 \text{ kN/m}^2}$$

Passive at 3888 mm below GL in soil 3

$$p'_{p61} = K_{p3} \times OB'_{p61} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{138.8 \text{ kN/m}^2}$$

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2742 \text{ mm}}$$

Sum of active moments about contraflexure point

$$\Sigma M_{\text{ac}} = \mathbf{44.6 \text{ kNm/m}}$$

Sum of passive moments about contraflexure point

$$\Sigma M_{\text{pc}} = \mathbf{0.9 \text{ kNm/m}}$$

Force in tie

$$T = (\Sigma M_{\text{ac}} - \Sigma M_{\text{pc}}) / (d_{\text{contra}} - d_t) = \mathbf{24.0 \text{ kN/m}}$$

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 3888 mm as follows:-

Active moment about 3888 mm

Moment level 1

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = \mathbf{4.9 \text{ kNm/m}}$$

Moment level 1

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = \mathbf{9.4 \text{ kNm/m}}$$

Moment level 2

$$M_{a21} = 0.5 \times p'_{a22} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = \mathbf{9.4 \text{ kNm/m}}$$

Moment level 2

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = \mathbf{13.7 \text{ kNm/m}}$$

Moment level 3

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = \mathbf{15.3 \text{ kNm/m}}$$

Moment level 3

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = \mathbf{29.7 \text{ kNm/m}}$$

Moment level 4

$$M_{a41} = 0.5 \times p'_{a41} \times h_{a4} \times ((H - d_{L5}) + 2/3 \times h_{a4}) = \mathbf{13.4 \text{ kNm/m}}$$

Moment level 4

$$M_{a42} = 0.5 \times p'_{a51} \times h_{a4} \times ((H - d_{L5}) + 1/3 \times h_{a4}) = \mathbf{15.2 \text{ kNm/m}}$$

Moment level 5

$$M_{a51} = 0.5 \times p'_{a52} \times h_{a5} \times ((H - d_{L6}) + 2/3 \times h_{a5}) = \mathbf{10.5 \text{ kNm/m}}$$

Moment level 5

$$M_{a52} = 0.5 \times p'_{a61} \times h_{a5} \times ((H - d_{L6}) + 1/3 \times h_{a5}) = \mathbf{7.0 \text{ kNm/m}}$$

Passive moment about 3888 mm

Moment level 4

$$M_{p41} = 0.5 \times p'_{p41} \times h_{p4} \times ((H - d_{L5}) + 2/3 \times h_{p4}) = \mathbf{0.0 \text{ kNm/m}}$$

Moment level 4

$$M_{p42} = 0.5 \times p'_{p51} \times h_{p4} \times ((H - d_{L5}) + 1/3 \times h_{p4}) = \mathbf{23.9 \text{ kNm/m}}$$

Moment level 5

$$M_{p51} = 0.5 \times p'_{p52} \times h_{p5} \times ((H - d_{L6}) + 2/3 \times h_{p5}) = \mathbf{16.5 \text{ kNm/m}}$$

Moment level 5

$$M_{p52} = 0.5 \times p'_{p61} \times h_{p5} \times ((H - d_{L6}) + 1/3 \times h_{p5}) = \mathbf{17.0 \text{ kNm/m}}$$

Moment about toe for tie/prop

$$M_{\text{pt}} = T \times (H - d_t) = \mathbf{71.2 \text{ kNm/m}}$$

Total moments about 3888 mm

Total active moment

$$\Sigma M_a = \mathbf{128.5 \text{ kNm/m}}$$

Total passive moment

$$\Sigma M_p = \mathbf{128.6 \text{ kNm/m}}$$

Required pile length

Length of pile required to balance moments

$$H = \mathbf{3888 \text{ mm}}$$

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2742 \text{ mm}}$$

Add 20% below this point

$$d_{\text{e_add}} = 1.2 \times (H - d_{\text{contra}}) = \mathbf{1376 \text{ mm}}$$

Minimum required pile length

$$H_{\text{total}} = d_{\text{contra}} + d_{\text{e_add}} = \mathbf{4117 \text{ mm}}$$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis)

$$M_{\text{pile}} = \max(\text{abs}(M_{\text{min}}), \text{abs}(M_{\text{max}})) / 1\text{m} = \mathbf{8.2 \text{ kNm/m}}$$

Maximum shear force in pile (from analysis)

$$V_{\text{pile}} = \mathbf{32.7 \text{ kN/m}}$$

Nominal yield strength of pile

$$f_{y_pile} = \mathbf{240 \text{ N/mm}^2}$$

User defined section

Plastic modulus of pile

$$W_{\text{pl,y}} = \mathbf{2360 \text{ cm}^3/\text{m}}$$

Thickness of web

$$s = \mathbf{9.6 \text{ mm}}$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 1980 Design Check			Start page no./Revision 1980 6 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Thickness of flange $t = 15.7$ mm
Overall height $h = 381$ mm
Section width $b = 400$ mm
Web incline angle $\alpha_{pile} = 67.0$ deg

Shear buckling of web (cl.5.2.2(6))

Width of section $c = (h - t) / \sin(\alpha_{pile}) = 397$ mm
Thickness of web $t_w = s = 9.6$ mm
 $\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y_pile})} = 0.990$
 $c / t_w = 41.3 = 41.8 \times \varepsilon \leq 72 \times \varepsilon$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2) $\beta_B = 0.8$
Design bending resistance (eqn.5.2) $M_{c,Rd} = W_{pl,y} \times f_{y_pile} \times \beta_B / \gamma_{M0} = 453.1$ kNm/m

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6) $A_v = s \times (h - t) = 3507$ mm²
Design shear resistance (eqn.5.5) $V_{pl,Rd} = A_v \times f_{y_pile} / (\sqrt{3} \times \gamma_{M0}) / b = 1214.8$ kN/m

PASS - Shear capacity exceeds shear in pile

Partial factors on actions - Section A.3.1 - Combination 2

Permanent unfavourable action $\gamma_G = 1.00$
Permanent favourable action $\gamma_{G,f} = 1.00$
Variable unfavourable action $\gamma_Q = 1.30$
Angle of shearing resistance $\gamma_{\phi'} = 1.25$
Weight density $\gamma_\gamma = 1.00$

Design soil properties - soil 1

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 24.8$ deg
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 23.0$ deg
Design moist density of retained soil $\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.5$ kN/m³
Design saturated density of retained soil $\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 21.0$ kN/m³
Design buoyant density of retained soil $\gamma_{d,d1} = \gamma_{s,d1} - \gamma_w = 11.2$ kN/m³
Active pressure using Coulomb theory $K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.358$
Passive pressure using Coulomb theory $K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = 5.106$

Design soil properties - soil 2

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 24.8$ deg
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 23.0$ deg
Design moist density of retained soil $\gamma_{m,d2} = \gamma_m / \gamma_\gamma = 17.5$ kN/m³
Design saturated density of retained soil $\gamma_{s,d2} = \gamma_s / \gamma_\gamma = 20.0$ kN/m³
Design buoyant density of retained soil $\gamma_{d,d2} = \gamma_{s,d2} - \gamma_w = 10.2$ kN/m³
Active pressure using Coulomb theory $K_{a2} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.358$
Passive pressure using Coulomb theory $K_{p2} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = 5.106$

	Project PCC Retaining Flood Wall Check				Job no.	
	Calcs for 1980 Design Check				Start page no./Revision 1980 7 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Design soil properties - soil 3

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{23.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d3} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d3} = \gamma_s / \gamma_r = \mathbf{18.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d3} = \gamma_{s.d3} - \gamma_w = \mathbf{8.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a3} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

$$K_{p3} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.106}$$

Design soil properties - soil 4

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{23.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d4} = \gamma_m / \gamma_r = \mathbf{15.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d4} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d4} = \gamma_{s.d4} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a4} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

$$K_{p4} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.106}$$

Design soil properties - soil 5

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{20.5 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d5} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d5} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d5} = \gamma_{s.d5} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a5} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.360}$$

Passive pressure using Coulomb theory

$$K_{p5} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{4.622}$$

Design soil properties - soil 6

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d6} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d6} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d6} = \gamma_{s.d6} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

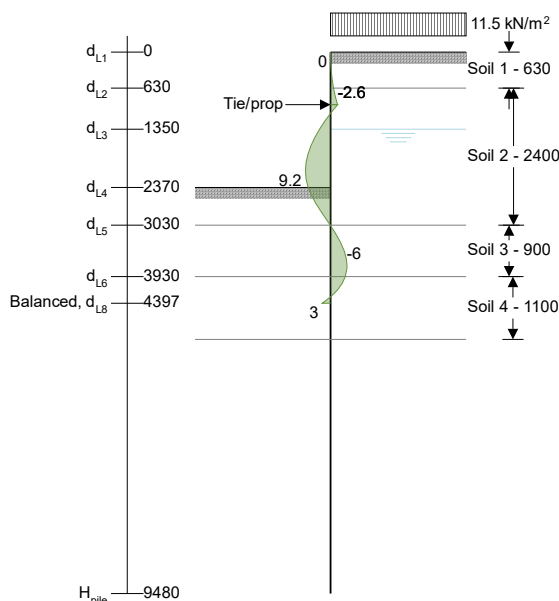
$$K_{a6} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

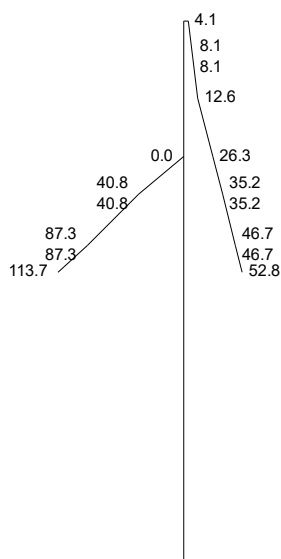
$$K_{p6} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.480}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 1980 Design Check				Start page no./Revision 1980 8 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date



SECTION THROUGH SHEET PILE WALL



BALANCE PRESSURE DIAGRAM (kN/m²)

Overburden on active side

Overburden at 0 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 2
 Overburden at 1350 mm below GL in soil 2
 Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 4
 Overburden at 4397 mm below GL in soil 4

$$\begin{aligned} OB'_{a11} &= (p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q) = \mathbf{11.5 \text{ kN/m}^2} \\ OB'_{a21} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = \mathbf{22.5 \text{ kN/m}^2} \\ OB'_{a22} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = \mathbf{22.5 \text{ kN/m}^2} \\ OB'_{a31} &= \gamma_G \times \gamma_{m,d2} \times h_{a2} + OB'_{a22} = \mathbf{35.1 \text{ kN/m}^2} \\ OB'_{a41} &= \gamma_G \times \gamma_{d,d2} \times h_{a3} + OB'_{a31} = \mathbf{45.5 \text{ kN/m}^2} \\ OB'_{a51} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = \mathbf{52.2 \text{ kN/m}^2} \\ OB'_{a52} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = \mathbf{52.2 \text{ kN/m}^2} \\ OB'_{a61} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = \mathbf{59.6 \text{ kN/m}^2} \\ OB'_{a62} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = \mathbf{59.6 \text{ kN/m}^2} \\ OB'_{a71} &= \gamma_G \times \gamma_{d,d4} \times h_{a6} + OB'_{a62} = \mathbf{63.9 \text{ kN/m}^2} \end{aligned}$$

Overburden on passive side

Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 4
 Overburden at 4397 mm below GL in soil 4

$$\begin{aligned} OB'_{p41} &= 0 \text{ kN/m}^2 = \mathbf{0.0 \text{ kN/m}^2} \\ OB'_{p51} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = \mathbf{6.7 \text{ kN/m}^2} \\ OB'_{p52} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = \mathbf{6.7 \text{ kN/m}^2} \\ OB'_{p61} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = \mathbf{14.1 \text{ kN/m}^2} \\ OB'_{p62} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = \mathbf{14.1 \text{ kN/m}^2} \\ OB'_{p71} &= \gamma_{G,f} \times \gamma_{d,d4} \times h_{p6} + OB'_{p62} = \mathbf{18.4 \text{ kN/m}^2} \end{aligned}$$

Pressure on active side

Active at 0 mm below GL in soil 1
 Active at 630 mm below GL in soil 1
 Active at 630 mm below GL in soil 2
 Active at 1350 mm below GL in soil 2
 Active at 2370 mm below GL in soil 2
 Active at 3030 mm below GL in soil 2
 Active at 3030 mm below GL in soil 3
 Active at 3930 mm below GL in soil 3

$$\begin{aligned} p'_{a11} &= K_{a1} \times OB'_{a11} = \mathbf{4.1 \text{ kN/m}^2} \\ p'_{a21} &= K_{a1} \times OB'_{a21} = \mathbf{8.1 \text{ kN/m}^2} \\ p'_{a22} &= K_{a2} \times OB'_{a22} = \mathbf{8.1 \text{ kN/m}^2} \\ p'_{a31} &= K_{a2} \times OB'_{a31} = \mathbf{12.6 \text{ kN/m}^2} \\ p'_{a41} &= K_{a2} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = \mathbf{26.3 \text{ kN/m}^2} \\ p'_{a51} &= K_{a2} \times OB'_{a51} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = \mathbf{35.2 \text{ kN/m}^2} \\ p'_{a52} &= K_{a3} \times OB'_{a52} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = \mathbf{35.2 \text{ kN/m}^2} \\ p'_{a61} &= K_{a3} \times OB'_{a61} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = \mathbf{46.7 \text{ kN/m}^2} \end{aligned}$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 1980 Design Check			Start page no./Revision 1980 9 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Active at 3930 mm below GL in soil 4

$$p'_{a62} = K_{a4} \times OB'_{a62} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = \mathbf{46.7 \text{ kN/m}^2}$$

Active at 4397 mm below GL in soil 4

$$p'_{a71} = K_{a4} \times OB'_{a71} + \gamma_G \times \gamma_w \times (d_{L7} - d_w) = \mathbf{52.8 \text{ kN/m}^2}$$

Pressure on passive side

Passive at 2370 mm below GL in soil 2

$$p'_{p41} = K_{p2} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = \mathbf{0.0 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 2

$$p'_{p51} = K_{p2} \times OB'_{p51} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{40.8 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 3

$$p'_{p52} = K_{p3} \times OB'_{p52} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{40.8 \text{ kN/m}^2}$$

Passive at 3930 mm below GL in soil 3

$$p'_{p61} = K_{p3} \times OB'_{p61} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{87.3 \text{ kN/m}^2}$$

Passive at 3930 mm below GL in soil 4

$$p'_{p62} = K_{p4} \times OB'_{p62} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{87.3 \text{ kN/m}^2}$$

Passive at 4397 mm below GL in soil 4

$$p'_{p71} = K_{p4} \times OB'_{p71} + \gamma_{G,f} \times \gamma_w \times (d_{L7} - \max(d_s, d_w)) = \mathbf{113.8 \text{ kN/m}^2}$$

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2914 \text{ mm}}$$

Sum of active moments about contraflexure point

$$\Sigma M_{ac} = \mathbf{47.9 \text{ kNm/m}}$$

Sum of passive moments about contraflexure point

$$\Sigma M_{pc} = \mathbf{1.7 \text{ kNm/m}}$$

Force in tie

$$T = (\Sigma M_{ac} - \Sigma M_{pc}) / (d_{\text{contra}} - d_t) = \mathbf{23.2 \text{ kN/m}}$$

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 4397 mm as follows:-

Active moment about 4397 mm

Moment level 1

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = \mathbf{5.4 \text{ kNm/m}}$$

Moment level 1

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = \mathbf{10.1 \text{ kNm/m}}$$

Moment level 2

$$M_{a21} = 0.5 \times p'_{a22} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = \mathbf{10.2 \text{ kNm/m}}$$

Moment level 2

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = \mathbf{14.9 \text{ kNm/m}}$$

Moment level 3

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = \mathbf{17.4 \text{ kNm/m}}$$

Moment level 3

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = \mathbf{31.8 \text{ kNm/m}}$$

Moment level 4

$$M_{a41} = 0.5 \times p'_{a41} \times h_{a4} \times ((H - d_{L5}) + 2/3 \times h_{a4}) = \mathbf{15.7 \text{ kNm/m}}$$

Moment level 4

$$M_{a42} = 0.5 \times p'_{a51} \times h_{a4} \times ((H - d_{L5}) + 1/3 \times h_{a4}) = \mathbf{18.4 \text{ kNm/m}}$$

Moment level 5

$$M_{a51} = 0.5 \times p'_{a52} \times h_{a5} \times ((H - d_{L6}) + 2/3 \times h_{a5}) = \mathbf{16.9 \text{ kNm/m}}$$

Moment level 5

$$M_{a52} = 0.5 \times p'_{a61} \times h_{a5} \times ((H - d_{L6}) + 1/3 \times h_{a5}) = \mathbf{16.1 \text{ kNm/m}}$$

Moment level 6

$$M_{a61} = 0.5 \times p'_{a62} \times h_{a6} \times ((H - d_{L7}) + 2/3 \times h_{a6}) = \mathbf{3.4 \text{ kNm/m}}$$

Moment level 6

$$M_{a62} = 0.5 \times p'_{a71} \times h_{a6} \times ((H - d_{L7}) + 1/3 \times h_{a6}) = \mathbf{1.9 \text{ kNm/m}}$$

Passive moment about 4397 mm

Moment level 4

$$M_{p41} = 0.5 \times p'_{p41} \times h_{p4} \times ((H - d_{L5}) + 2/3 \times h_{p4}) = \mathbf{0.0 \text{ kNm/m}}$$

Moment level 4

$$M_{p42} = 0.5 \times p'_{p51} \times h_{p4} \times ((H - d_{L5}) + 1/3 \times h_{p4}) = \mathbf{21.4 \text{ kNm/m}}$$

Moment level 5

$$M_{p51} = 0.5 \times p'_{p52} \times h_{p5} \times ((H - d_{L6}) + 2/3 \times h_{p5}) = \mathbf{19.6 \text{ kNm/m}}$$

Moment level 5

$$M_{p52} = 0.5 \times p'_{p61} \times h_{p5} \times ((H - d_{L6}) + 1/3 \times h_{p5}) = \mathbf{30.1 \text{ kNm/m}}$$

Moment level 6

$$M_{p61} = 0.5 \times p'_{p62} \times h_{p6} \times ((H - d_{L7}) + 2/3 \times h_{p6}) = \mathbf{6.3 \text{ kNm/m}}$$

Moment level 6

$$M_{p62} = 0.5 \times p'_{p71} \times h_{p6} \times ((H - d_{L7}) + 1/3 \times h_{p6}) = \mathbf{4.1 \text{ kNm/m}}$$

Moment about toe for tie/prop

$$M_{pt} = T \times (H - d_t) = \mathbf{80.7 \text{ kNm/m}}$$

Total moments about 4397 mm

Total active moment

$$\Sigma M_a = \mathbf{162.2 \text{ kNm/m}}$$

Total passive moment

$$\Sigma M_p = \mathbf{162.2 \text{ kNm/m}}$$

Required pile length

Length of pile required to balance moments

$$H = \mathbf{4397 \text{ mm}}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 1980 Design Check				Start page no./Revision 1980 10 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Depth to point of contraflexure

$$d_{\text{contra}} = 2914 \text{ mm}$$

Add 20% below this point

$$d_{\text{e_add}} = 1.2 \times (H - d_{\text{contra}}) = 1780 \text{ mm}$$

Minimum required pile length

$$H_{\text{total}} = d_{\text{contra}} + d_{\text{e_add}} = 4694 \text{ mm}$$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis)

$$M_{\text{pile}} = \max(\text{abs}(M_{\text{min}}), \text{abs}(M_{\text{max}})) / 1\text{m} = 9.2 \text{ kNm/m}$$

Maximum shear force in pile (from analysis)

$$V_{\text{pile}} = 30.7 \text{ kN/m}$$

Nominal yield strength of pile

$$f_{y_pile} = 240 \text{ N/mm}^2$$

User defined section

Plastic modulus of pile

$$W_{\text{pl.y}} = 2360 \text{ cm}^3/\text{m}$$

Thickness of web

$$s = 9.6 \text{ mm}$$

Thickness of flange

$$t = 15.7 \text{ mm}$$

Overall height

$$h = 381 \text{ mm}$$

Section width

$$b = 400 \text{ mm}$$

Web incline angle

$$\alpha_{\text{pile}} = 67.0 \text{ deg}$$

Shear buckling of web (cl.5.2.2(6))

Width of section

$$c = (h - t) / \sin(\alpha_{\text{pile}}) = 397 \text{ mm}$$

Thickness of web

$$t_w = s = 9.6 \text{ mm}$$

$$\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y_pile})} = 0.990$$

$$c / t_w = 41.3 = 41.8 \times \varepsilon \leq 72 \times \varepsilon$$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2)

$$\beta_B = 0.8$$

Design bending resistance (eqn.5.2)

$$M_{c,Rd} = W_{\text{pl.y}} \times f_{y_pile} \times \beta_B / \gamma_{M0} = 453.1 \text{ kNm/m}$$

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6)

$$A_v = s \times (h - t) = 3507 \text{ mm}^2$$

Design shear resistance (eqn.5.5)

$$V_{\text{pl,Rd}} = A_v \times f_{y_pile} / (\sqrt{3} \times \gamma_{M0}) / b = 1214.8 \text{ kN/m}$$

PASS - Shear capacity exceeds shear in pile



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2023 Design Check				Start page no./Revision 2023 1 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

STEEL SHEET PILING ANALYSIS & DESIGN

In accordance with BS EN1997-1:2004 - Code of Practice for Geotechnical design and the UK National Annex

Tedds calculation version 2.0.07

Design summary

Combination 1

Description	Unit	Provided	Required	Utilisation	Result
Total length required	mm	9480	4117	2.303	PASS
Moment capacity	kNm/m	447.4	8.2	54.272	PASS
Shear capacity	kN/m	904.3	32.7	27.625	PASS
Force in tie/prop 24.0 kN/m					

Combination 2

Description	Unit	Provided	Required	Utilisation	Result
Total length required	mm	9480	4694	2.020	PASS
Moment capacity	kNm/m	447.4	9.2	48.867	PASS
Shear capacity	kN/m	904.3	30.7	29.498	PASS
Force in tie/prop 23.2 kN/m					

Geometry

Design method	Fixed earth support
Total length of sheet pile provided	$H_{pile} = 9480$ mm
Number of different types of soil	$N_s = 6$
Retained height	$d_{ret} = 1870$ mm
Depth of unplanned excavation	$d_{ex} = 500$ mm
Total retained height	$d_s = 2370$ mm
Angle of retained slope	$\beta = 0.0$ deg
Depth from ground level to tie	$d_t = 920$ mm
Depth from GL to top of water table retained side	$d_w = 1350$ mm
Depth from GL to top of water table retaining side	$d_{wp} = 2370$ mm

Loading

Permanent surcharge	$p_{o,G} = 5.0$ kN/m ²
Variable surcharge	$p_{o,Q} = 5.0$ kN/m ²

Soil layer 1

Characteristic shearing resistance angle	$\phi'_{k_s1} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s1} = 28.0$ deg
Moist density of soil	$\gamma_{m_s1} = 17.5$ kN/m ³
Characteristic saturated density of retained soil	$\gamma_{s_s1} = 21.0$ kN/m ³
Height of soil 1	$h_1 = 630$ mm

Soil layer 2

Characteristic shearing resistance angle	$\phi'_{k_s2} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s2} = 28.0$ deg
Moist density of soil	$\gamma_{m_s2} = 17.5$ kN/m ³
Characteristic saturated density of retained soil	$\gamma_{s_s2} = 20.0$ kN/m ³
Height of soil 2	$h_2 = 2400$ mm

Soil layer 3

Characteristic shearing resistance angle	$\phi'_{k_s3} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s3} = 28.0$ deg
Moist density of soil	$\gamma_{m_s3} = 14.0$ kN/m ³

	Project			Job no.	
	PCC Retaining Flood Wall Check			Start page no./Revision	
	Calcs for			2023 Design Check	
Calcs by	Calcs date	Checked by	Checked date	Approved by	Approved date
MC	27/03/2023				

Characteristic saturated density of retained soil
Height of soil 3

$$\gamma_{s_s3} = 18.0 \text{ kN/m}^3$$

$$h_3 = 900 \text{ mm}$$

Soil layer 4

Characteristic shearing resistance angle
Characteristic wall friction angle

$$\phi'_{k_s4} = 30.0 \text{ deg}$$

$$\delta_{k_s4} = 28.0 \text{ deg}$$

Moist density of soil

$$\gamma_{m_s4} = 15.0 \text{ kN/m}^3$$

Characteristic saturated density of retained soil
Height of soil 4

$$\gamma_{s_s4} = 19.0 \text{ kN/m}^3$$

$$h_4 = 1100 \text{ mm}$$

Soil layer 5

Characteristic shearing resistance angle
Characteristic wall friction angle

$$\phi'_{k_s5} = 30.0 \text{ deg}$$

$$\delta_{k_s5} = 25.0 \text{ deg}$$

Moist density of soil

$$\gamma_{m_s5} = 14.0 \text{ kN/m}^3$$

Characteristic saturated density of retained soil
Height of soil 5

$$\gamma_{s_s5} = 19.0 \text{ kN/m}^3$$

$$h_5 = 1100 \text{ mm}$$

Soil layer 6

Characteristic shearing resistance angle
Characteristic wall friction angle

$$\phi'_{k_s6} = 30.0 \text{ deg}$$

$$\delta_{k_s6} = 30.0 \text{ deg}$$

Moist density of soil

$$\gamma_{m_s6} = 14.0 \text{ kN/m}^3$$

Characteristic saturated density of retained soil
Height of soil 6

$$\gamma_{s_s6} = 19.0 \text{ kN/m}^3$$

$$h_6 = 5700 \text{ mm}$$

Partial factors on actions - Section A.3.1 - Combination 1

Permanent unfavourable action

$$\gamma_G = 1.35$$

Permanent favourable action

$$\gamma_{G,f} = 1.00$$

Variable unfavourable action

$$\gamma_Q = 1.50$$

Angle of shearing resistance

$$\gamma_{\phi'} = 1.00$$

Weight density

$$\gamma_\gamma = 1.00$$

Design soil properties - soil 1

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 30.0 \text{ deg}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 28.0 \text{ deg}$$

Design moist density of retained soil

$$\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.5 \text{ kN/m}^3$$

Design saturated density of retained soil

$$\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 21.0 \text{ kN/m}^3$$

Design buoyant density of retained soil

$$\gamma_{d,d1} = \gamma_{s,d1} - \gamma_w = 11.2 \text{ kN/m}^3$$

Active pressure using Coulomb theory

$$K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.296$$

Passive pressure using Coulomb theory

$$K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = 9.012$$

Design soil properties - soil 2

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 30.0 \text{ deg}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 28.0 \text{ deg}$$

Design moist density of retained soil

$$\gamma_{m,d2} = \gamma_m / \gamma_\gamma = 17.5 \text{ kN/m}^3$$

Design saturated density of retained soil

$$\gamma_{s,d2} = \gamma_s / \gamma_\gamma = 20.0 \text{ kN/m}^3$$

Design buoyant density of retained soil

$$\gamma_{d,d2} = \gamma_{s,d2} - \gamma_w = 10.2 \text{ kN/m}^3$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 2023 Design Check			Start page no./Revision 2023 3 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Active pressure using Coulomb theory

$$K_{a2} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p2} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 3

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{28.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d3} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d3} = \gamma_s / \gamma_r = \mathbf{18.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d3} = \gamma_{s.d3} - \gamma_w = \mathbf{8.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a3} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p3} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 4

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{28.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d4} = \gamma_m / \gamma_r = \mathbf{15.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d4} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d4} = \gamma_{s.d4} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a4} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p4} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 5

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{25.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d5} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d5} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d5} = \gamma_{s.d5} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a5} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p5} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{7.704}$$

Design soil properties - soil 6

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d6} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d6} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d6} = \gamma_{s.d6} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

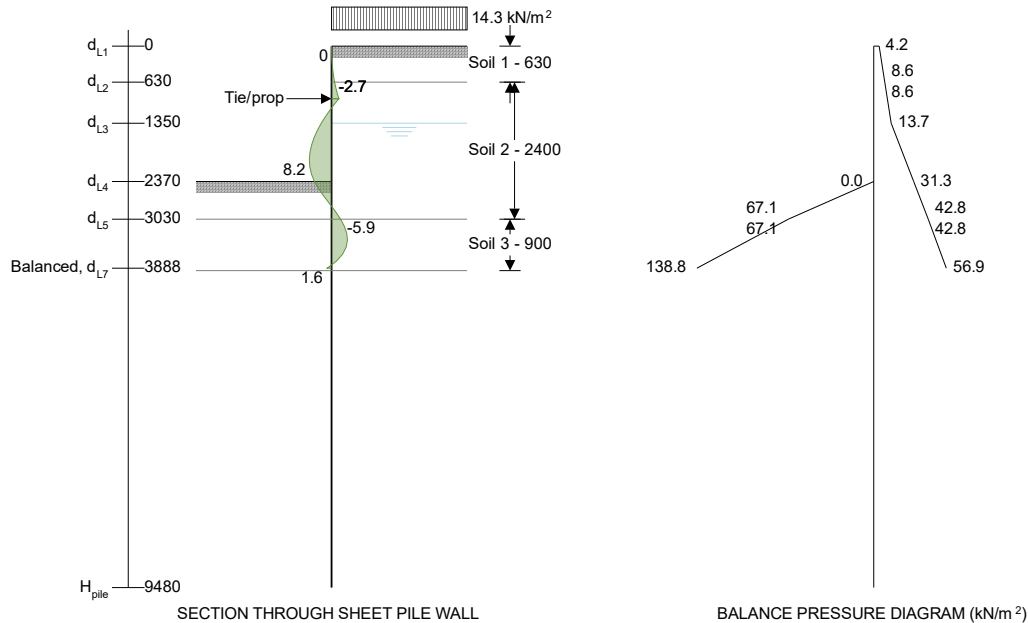
$$K_{a6} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.297}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2023 Design Check				Start page no./Revision 2023 4 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Passive pressure using Coulomb theory

$$K_{p6} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = 10.095$$



Overburden on active side

- Overburden at 0 mm below GL in soil 1
- Overburden at 630 mm below GL in soil 1
- Overburden at 630 mm below GL in soil 2
- Overburden at 1350 mm below GL in soil 2
- Overburden at 2370 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 3
- Overburden at 3888 mm below GL in soil 3

$$\begin{aligned} OB'_{a11} &= (p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q) = 14.3 \text{ kN/m}^2 \\ OB'_{a21} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 29.1 \text{ kN/m}^2 \\ OB'_{a22} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 29.1 \text{ kN/m}^2 \\ OB'_{a31} &= \gamma_G \times \gamma_{m,d2} \times h_{a2} + OB'_{a22} = 46.1 \text{ kN/m}^2 \\ OB'_{a41} &= \gamma_G \times \gamma_{d,d2} \times h_{a3} + OB'_{a31} = 60.2 \text{ kN/m}^2 \\ OB'_{a51} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = 69.3 \text{ kN/m}^2 \\ OB'_{a52} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = 69.3 \text{ kN/m}^2 \\ OB'_{a61} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = 78.7 \text{ kN/m}^2 \end{aligned}$$

Overburden on passive side

- Overburden at 2370 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 2
- Overburden at 3030 mm below GL in soil 3
- Overburden at 3888 mm below GL in soil 3

$$\begin{aligned} OB'_{p41} &= 0 \text{ kN/m}^2 = 0.0 \text{ kN/m}^2 \\ OB'_{p51} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = 6.7 \text{ kN/m}^2 \\ OB'_{p52} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = 6.7 \text{ kN/m}^2 \\ OB'_{p61} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = 13.8 \text{ kN/m}^2 \end{aligned}$$

Pressure on active side

- Active at 0 mm below GL in soil 1
- Active at 630 mm below GL in soil 1
- Active at 630 mm below GL in soil 2
- Active at 1350 mm below GL in soil 2
- Active at 2370 mm below GL in soil 2
- Active at 3030 mm below GL in soil 2
- Active at 3030 mm below GL in soil 3
- Active at 3888 mm below GL in soil 3

$$\begin{aligned} p'_{a11} &= K_{a1} \times OB'_{a11} = 4.2 \text{ kN/m}^2 \\ p'_{a21} &= K_{a1} \times OB'_{a21} = 8.6 \text{ kN/m}^2 \\ p'_{a22} &= K_{a2} \times OB'_{a22} = 8.6 \text{ kN/m}^2 \\ p'_{a31} &= K_{a2} \times OB'_{a31} = 13.7 \text{ kN/m}^2 \\ p'_{a41} &= K_{a2} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = 31.3 \text{ kN/m}^2 \\ p'_{a51} &= K_{a2} \times OB'_{a51} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = 42.8 \text{ kN/m}^2 \\ p'_{a52} &= K_{a3} \times OB'_{a52} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = 42.8 \text{ kN/m}^2 \\ p'_{a61} &= K_{a3} \times OB'_{a61} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = 56.9 \text{ kN/m}^2 \end{aligned}$$

Pressure on passive side

- Passive at 2370 mm below GL in soil 2

$$p'_{p41} = K_{p2} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = 0.0 \text{ kN/m}^2$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2023 Design Check				Start page no./Revision 2023 5 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Passive at 3030 mm below GL in soil 2

$$p'_{p51} = K_{p2} \times OB'_{p51} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{67.1 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 3

$$p'_{p52} = K_{p3} \times OB'_{p52} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{67.1 \text{ kN/m}^2}$$

Passive at 3888 mm below GL in soil 3

$$p'_{p61} = K_{p3} \times OB'_{p61} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{138.8 \text{ kN/m}^2}$$

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2742 \text{ mm}}$$

Sum of active moments about contraflexure point

$$\Sigma M_{\text{ac}} = \mathbf{44.6 \text{ kNm/m}}$$

Sum of passive moments about contraflexure point

$$\Sigma M_{\text{pc}} = \mathbf{0.9 \text{ kNm/m}}$$

Force in tie

$$T = (\Sigma M_{\text{ac}} - \Sigma M_{\text{pc}}) / (d_{\text{contra}} - d_t) = \mathbf{24.0 \text{ kN/m}}$$

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 3888 mm as follows:-

Active moment about 3888 mm

Moment level 1

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = \mathbf{4.9 \text{ kNm/m}}$$

Moment level 1

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = \mathbf{9.4 \text{ kNm/m}}$$

Moment level 2

$$M_{a21} = 0.5 \times p'_{a22} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = \mathbf{9.4 \text{ kNm/m}}$$

Moment level 2

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = \mathbf{13.7 \text{ kNm/m}}$$

Moment level 3

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = \mathbf{15.3 \text{ kNm/m}}$$

Moment level 3

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = \mathbf{29.7 \text{ kNm/m}}$$

Moment level 4

$$M_{a41} = 0.5 \times p'_{a41} \times h_{a4} \times ((H - d_{L5}) + 2/3 \times h_{a4}) = \mathbf{13.4 \text{ kNm/m}}$$

Moment level 4

$$M_{a42} = 0.5 \times p'_{a51} \times h_{a4} \times ((H - d_{L5}) + 1/3 \times h_{a4}) = \mathbf{15.2 \text{ kNm/m}}$$

Moment level 5

$$M_{a51} = 0.5 \times p'_{a52} \times h_{a5} \times ((H - d_{L6}) + 2/3 \times h_{a5}) = \mathbf{10.5 \text{ kNm/m}}$$

Moment level 5

$$M_{a52} = 0.5 \times p'_{a61} \times h_{a5} \times ((H - d_{L6}) + 1/3 \times h_{a5}) = \mathbf{7.0 \text{ kNm/m}}$$

Passive moment about 3888 mm

Moment level 4

$$M_{p41} = 0.5 \times p'_{p41} \times h_{p4} \times ((H - d_{L5}) + 2/3 \times h_{p4}) = \mathbf{0.0 \text{ kNm/m}}$$

Moment level 4

$$M_{p42} = 0.5 \times p'_{p51} \times h_{p4} \times ((H - d_{L5}) + 1/3 \times h_{p4}) = \mathbf{23.9 \text{ kNm/m}}$$

Moment level 5

$$M_{p51} = 0.5 \times p'_{p52} \times h_{p5} \times ((H - d_{L6}) + 2/3 \times h_{p5}) = \mathbf{16.5 \text{ kNm/m}}$$

Moment level 5

$$M_{p52} = 0.5 \times p'_{p61} \times h_{p5} \times ((H - d_{L6}) + 1/3 \times h_{p5}) = \mathbf{17.0 \text{ kNm/m}}$$

Moment about toe for tie/prop

$$M_{\text{pt}} = T \times (H - d_t) = \mathbf{71.2 \text{ kNm/m}}$$

Total moments about 3888 mm

Total active moment

$$\Sigma M_a = \mathbf{128.5 \text{ kNm/m}}$$

Total passive moment

$$\Sigma M_p = \mathbf{128.6 \text{ kNm/m}}$$

Required pile length

Length of pile required to balance moments

$$H = \mathbf{3888 \text{ mm}}$$

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2742 \text{ mm}}$$

Add 20% below this point

$$d_{\text{e_add}} = 1.2 \times (H - d_{\text{contra}}) = \mathbf{1376 \text{ mm}}$$

Minimum required pile length

$$H_{\text{total}} = d_{\text{contra}} + d_{\text{e_add}} = \mathbf{4117 \text{ mm}}$$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis)

$$M_{\text{pile}} = \max(\text{abs}(M_{\text{min}}), \text{abs}(M_{\text{max}})) / 1\text{m} = \mathbf{8.2 \text{ kNm/m}}$$

Maximum shear force in pile (from analysis)

$$V_{\text{pile}} = \mathbf{32.7 \text{ kN/m}}$$

Nominal yield strength of pile

$$f_{y_pile} = \mathbf{240 \text{ N/mm}^2}$$

User defined section

Plastic modulus of pile

$$W_{\text{pl.y}} = \mathbf{2330 \text{ cm}^3/\text{m}}$$

Thickness of web

$$s = \mathbf{7.3 \text{ mm}}$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 2023 Design Check			Start page no./Revision 2023 6 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Thickness of flange $t = 13.4$ mm
Overall height $h = 371$ mm
Section width $b = 400$ mm
Web incline angle $\alpha_{pile} = 67.0$ deg

Shear buckling of web (cl.5.2.2(6))

Width of section $c = (h - t) / \sin(\alpha_{pile}) = 388$ mm
Thickness of web $t_w = s = 7.3$ mm
 $\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y_pile})} = 0.990$
 $c / t_w = 53.2 = 53.8 \times \varepsilon \leq 72 \times \varepsilon$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2) $\beta_B = 0.8$
Design bending resistance (eqn.5.2) $M_{c,Rd} = W_{pl,y} \times f_{y_pile} \times \beta_B / \gamma_{M0} = 447.4$ kNm/m

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6) $A_v = s \times (h - t) = 2610$ mm²
Design shear resistance (eqn.5.5) $V_{pl,Rd} = A_v \times f_{y_pile} / (\sqrt{3} \times \gamma_{M0}) / b = 904.3$ kN/m

PASS - Shear capacity exceeds shear in pile

Partial factors on actions - Section A.3.1 - Combination 2

Permanent unfavourable action $\gamma_G = 1.00$
Permanent favourable action $\gamma_{G,f} = 1.00$
Variable unfavourable action $\gamma_Q = 1.30$
Angle of shearing resistance $\gamma_{\phi'} = 1.25$
Weight density $\gamma_\gamma = 1.00$

Design soil properties - soil 1

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 24.8$ deg
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 23.0$ deg
Design moist density of retained soil $\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.5$ kN/m³
Design saturated density of retained soil $\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 21.0$ kN/m³
Design buoyant density of retained soil $\gamma_{d,d1} = \gamma_{s,d1} - \gamma_w = 11.2$ kN/m³
Active pressure using Coulomb theory $K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))))^2} = 0.358$
Passive pressure using Coulomb theory $K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))]^2} = 5.106$

Design soil properties - soil 2

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 24.8$ deg
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 23.0$ deg
Design moist density of retained soil $\gamma_{m,d2} = \gamma_m / \gamma_\gamma = 17.5$ kN/m³
Design saturated density of retained soil $\gamma_{s,d2} = \gamma_s / \gamma_\gamma = 20.0$ kN/m³
Design buoyant density of retained soil $\gamma_{d,d2} = \gamma_{s,d2} - \gamma_w = 10.2$ kN/m³
Active pressure using Coulomb theory $K_{a2} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))))^2} = 0.358$
Passive pressure using Coulomb theory $K_{p2} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))]^2} = 5.106$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 2023 Design Check			Start page no./Revision 2023 7 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Design soil properties - soil 3

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{23.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d3} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d3} = \gamma_s / \gamma_r = \mathbf{18.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d3} = \gamma_{s.d3} - \gamma_w = \mathbf{8.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a3} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

$$K_{p3} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.106}$$

Design soil properties - soil 4

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{23.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d4} = \gamma_m / \gamma_r = \mathbf{15.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d4} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d4} = \gamma_{s.d4} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a4} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

$$K_{p4} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.106}$$

Design soil properties - soil 5

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{20.5 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d5} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d5} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d5} = \gamma_{s.d5} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a5} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.360}$$

Passive pressure using Coulomb theory

$$K_{p5} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{4.622}$$

Design soil properties - soil 6

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d6} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d6} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d6} = \gamma_{s.d6} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

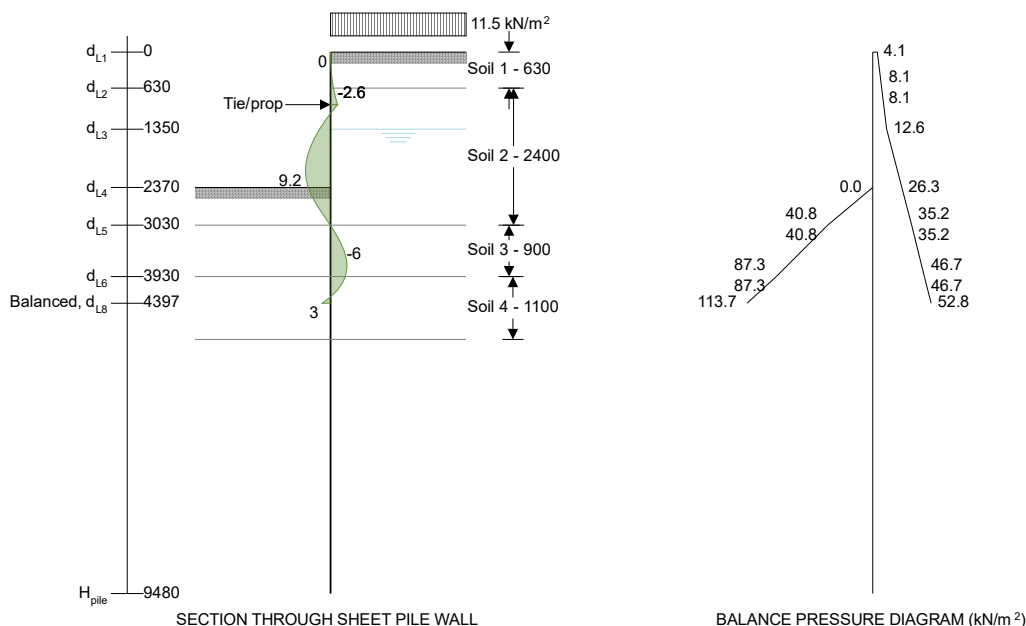
$$K_{a6} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

$$K_{p6} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.480}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2023 Design Check				Start page no./Revision 2023 8 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date



Overburden on active side

Overburden at 0 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 2
 Overburden at 1350 mm below GL in soil 2
 Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 4
 Overburden at 4397 mm below GL in soil 4

$$\begin{aligned} OB'_{a11} &= (p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q) = \mathbf{11.5 \text{ kN/m}^2} \\ OB'_{a21} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = \mathbf{22.5 \text{ kN/m}^2} \\ OB'_{a22} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = \mathbf{22.5 \text{ kN/m}^2} \\ OB'_{a31} &= \gamma_G \times \gamma_{m,d2} \times h_{a2} + OB'_{a22} = \mathbf{35.1 \text{ kN/m}^2} \\ OB'_{a41} &= \gamma_G \times \gamma_{d,d2} \times h_{a3} + OB'_{a31} = \mathbf{45.5 \text{ kN/m}^2} \\ OB'_{a51} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = \mathbf{52.2 \text{ kN/m}^2} \\ OB'_{a52} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = \mathbf{52.2 \text{ kN/m}^2} \\ OB'_{a61} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = \mathbf{59.6 \text{ kN/m}^2} \\ OB'_{a62} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = \mathbf{59.6 \text{ kN/m}^2} \\ OB'_{a71} &= \gamma_G \times \gamma_{d,d4} \times h_{a6} + OB'_{a62} = \mathbf{63.9 \text{ kN/m}^2} \end{aligned}$$

Overburden on passive side

Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 4
 Overburden at 4397 mm below GL in soil 4

$$\begin{aligned} OB'_{p41} &= 0 \text{ kN/m}^2 = \mathbf{0.0 \text{ kN/m}^2} \\ OB'_{p51} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = \mathbf{6.7 \text{ kN/m}^2} \\ OB'_{p52} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = \mathbf{6.7 \text{ kN/m}^2} \\ OB'_{p61} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = \mathbf{14.1 \text{ kN/m}^2} \\ OB'_{p62} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = \mathbf{14.1 \text{ kN/m}^2} \\ OB'_{p71} &= \gamma_{G,f} \times \gamma_{d,d4} \times h_{p6} + OB'_{p62} = \mathbf{18.4 \text{ kN/m}^2} \end{aligned}$$

Pressure on active side

Active at 0 mm below GL in soil 1
 Active at 630 mm below GL in soil 1
 Active at 630 mm below GL in soil 2
 Active at 1350 mm below GL in soil 2
 Active at 2370 mm below GL in soil 2
 Active at 3030 mm below GL in soil 2
 Active at 3030 mm below GL in soil 3
 Active at 3930 mm below GL in soil 3

$$\begin{aligned} p'_{a11} &= K_{a1} \times OB'_{a11} = \mathbf{4.1 \text{ kN/m}^2} \\ p'_{a21} &= K_{a1} \times OB'_{a21} = \mathbf{8.1 \text{ kN/m}^2} \\ p'_{a22} &= K_{a2} \times OB'_{a22} = \mathbf{8.1 \text{ kN/m}^2} \\ p'_{a31} &= K_{a2} \times OB'_{a31} = \mathbf{12.6 \text{ kN/m}^2} \\ p'_{a41} &= K_{a2} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = \mathbf{26.3 \text{ kN/m}^2} \\ p'_{a51} &= K_{a2} \times OB'_{a51} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = \mathbf{35.2 \text{ kN/m}^2} \\ p'_{a52} &= K_{a3} \times OB'_{a52} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = \mathbf{35.2 \text{ kN/m}^2} \\ p'_{a61} &= K_{a3} \times OB'_{a61} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = \mathbf{46.7 \text{ kN/m}^2} \end{aligned}$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 2023 Design Check			Start page no./Revision 2023 9 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Active at 3930 mm below GL in soil 4

$$p'_{a62} = K_{a4} \times OB'_{a62} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = \mathbf{46.7 \text{ kN/m}^2}$$

Active at 4397 mm below GL in soil 4

$$p'_{a71} = K_{a4} \times OB'_{a71} + \gamma_G \times \gamma_w \times (d_{L7} - d_w) = \mathbf{52.8 \text{ kN/m}^2}$$

Pressure on passive side

Passive at 2370 mm below GL in soil 2

$$p'_{p41} = K_{p2} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = \mathbf{0.0 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 2

$$p'_{p51} = K_{p2} \times OB'_{p51} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{40.8 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 3

$$p'_{p52} = K_{p3} \times OB'_{p52} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{40.8 \text{ kN/m}^2}$$

Passive at 3930 mm below GL in soil 3

$$p'_{p61} = K_{p3} \times OB'_{p61} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{87.3 \text{ kN/m}^2}$$

Passive at 3930 mm below GL in soil 4

$$p'_{p62} = K_{p4} \times OB'_{p62} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{87.3 \text{ kN/m}^2}$$

Passive at 4397 mm below GL in soil 4

$$p'_{p71} = K_{p4} \times OB'_{p71} + \gamma_{G,f} \times \gamma_w \times (d_{L7} - \max(d_s, d_w)) = \mathbf{113.8 \text{ kN/m}^2}$$

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2914 \text{ mm}}$$

Sum of active moments about contraflexure point

$$\Sigma M_{ac} = \mathbf{47.9 \text{ kNm/m}}$$

Sum of passive moments about contraflexure point

$$\Sigma M_{pc} = \mathbf{1.7 \text{ kNm/m}}$$

Force in tie

$$T = (\Sigma M_{ac} - \Sigma M_{pc}) / (d_{\text{contra}} - d_t) = \mathbf{23.2 \text{ kN/m}}$$

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 4397 mm as follows:-

Active moment about 4397 mm

Moment level 1

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = \mathbf{5.4 \text{ kNm/m}}$$

Moment level 1

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = \mathbf{10.1 \text{ kNm/m}}$$

Moment level 2

$$M_{a21} = 0.5 \times p'_{a22} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = \mathbf{10.2 \text{ kNm/m}}$$

Moment level 2

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = \mathbf{14.9 \text{ kNm/m}}$$

Moment level 3

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = \mathbf{17.4 \text{ kNm/m}}$$

Moment level 3

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = \mathbf{31.8 \text{ kNm/m}}$$

Moment level 4

$$M_{a41} = 0.5 \times p'_{a41} \times h_{a4} \times ((H - d_{L5}) + 2/3 \times h_{a4}) = \mathbf{15.7 \text{ kNm/m}}$$

Moment level 4

$$M_{a42} = 0.5 \times p'_{a51} \times h_{a4} \times ((H - d_{L5}) + 1/3 \times h_{a4}) = \mathbf{18.4 \text{ kNm/m}}$$

Moment level 5

$$M_{a51} = 0.5 \times p'_{a52} \times h_{a5} \times ((H - d_{L6}) + 2/3 \times h_{a5}) = \mathbf{16.9 \text{ kNm/m}}$$

Moment level 5

$$M_{a52} = 0.5 \times p'_{a61} \times h_{a5} \times ((H - d_{L6}) + 1/3 \times h_{a5}) = \mathbf{16.1 \text{ kNm/m}}$$

Moment level 6

$$M_{a61} = 0.5 \times p'_{a62} \times h_{a6} \times ((H - d_{L7}) + 2/3 \times h_{a6}) = \mathbf{3.4 \text{ kNm/m}}$$

Moment level 6

$$M_{a62} = 0.5 \times p'_{a71} \times h_{a6} \times ((H - d_{L7}) + 1/3 \times h_{a6}) = \mathbf{1.9 \text{ kNm/m}}$$

Passive moment about 4397 mm

Moment level 4

$$M_{p41} = 0.5 \times p'_{p41} \times h_{p4} \times ((H - d_{L5}) + 2/3 \times h_{p4}) = \mathbf{0.0 \text{ kNm/m}}$$

Moment level 4

$$M_{p42} = 0.5 \times p'_{p51} \times h_{p4} \times ((H - d_{L5}) + 1/3 \times h_{p4}) = \mathbf{21.4 \text{ kNm/m}}$$

Moment level 5

$$M_{p51} = 0.5 \times p'_{p52} \times h_{p5} \times ((H - d_{L6}) + 2/3 \times h_{p5}) = \mathbf{19.6 \text{ kNm/m}}$$

Moment level 5

$$M_{p52} = 0.5 \times p'_{p61} \times h_{p5} \times ((H - d_{L6}) + 1/3 \times h_{p5}) = \mathbf{30.1 \text{ kNm/m}}$$

Moment level 6

$$M_{p61} = 0.5 \times p'_{p62} \times h_{p6} \times ((H - d_{L7}) + 2/3 \times h_{p6}) = \mathbf{6.3 \text{ kNm/m}}$$

Moment level 6

$$M_{p62} = 0.5 \times p'_{p71} \times h_{p6} \times ((H - d_{L7}) + 1/3 \times h_{p6}) = \mathbf{4.1 \text{ kNm/m}}$$

Moment about toe for tie/prop

$$M_{pt} = T \times (H - d_t) = \mathbf{80.7 \text{ kNm/m}}$$

Total moments about 4397 mm

Total active moment

$$\Sigma M_a = \mathbf{162.2 \text{ kNm/m}}$$

Total passive moment

$$\Sigma M_p = \mathbf{162.2 \text{ kNm/m}}$$

Required pile length

Length of pile required to balance moments

$$H = \mathbf{4397 \text{ mm}}$$

	Project PCC Retaining Flood Wall Check				Job no.	
	Calcs for 2023 Design Check				Start page no./Revision 2023 10 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Depth to point of contraflexure

$$d_{\text{contra}} = 2914 \text{ mm}$$

Add 20% below this point

$$d_{\text{e_add}} = 1.2 \times (H - d_{\text{contra}}) = 1780 \text{ mm}$$

Minimum required pile length

$$H_{\text{total}} = d_{\text{contra}} + d_{\text{e_add}} = 4694 \text{ mm}$$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis)

$$M_{\text{pile}} = \max(\text{abs}(M_{\text{min}}), \text{abs}(M_{\text{max}})) / 1\text{m} = 9.2 \text{ kNm/m}$$

Maximum shear force in pile (from analysis)

$$V_{\text{pile}} = 30.7 \text{ kN/m}$$

Nominal yield strength of pile

$$f_{y_pile} = 240 \text{ N/mm}^2$$

User defined section

Plastic modulus of pile

$$W_{\text{pl,y}} = 2330 \text{ cm}^3/\text{m}$$

Thickness of web

$$s = 7.3 \text{ mm}$$

Thickness of flange

$$t = 13.4 \text{ mm}$$

Overall height

$$h = 371 \text{ mm}$$

Section width

$$b = 400 \text{ mm}$$

Web incline angle

$$\alpha_{\text{pile}} = 67.0 \text{ deg}$$

Shear buckling of web (cl.5.2.2(6))

Width of section

$$c = (h - t) / \sin(\alpha_{\text{pile}}) = 388 \text{ mm}$$

Thickness of web

$$t_w = s = 7.3 \text{ mm}$$

$$\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y_pile})} = 0.990$$

$$c / t_w = 53.2 = 53.8 \times \varepsilon \leq 72 \times \varepsilon$$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2)

$$\beta_B = 0.8$$

Design bending resistance (eqn.5.2)

$$M_{c,Rd} = W_{\text{pl,y}} \times f_{y_pile} \times \beta_B / \gamma_{M0} = 447.4 \text{ kNm/m}$$

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6)

$$A_v = s \times (h - t) = 2610 \text{ mm}^2$$

Design shear resistance (eqn.5.5)

$$V_{\text{pl,Rd}} = A_v \times f_{y_pile} / (\sqrt{3} \times \gamma_{M0}) / b = 904.3 \text{ kN/m}$$

PASS - Shear capacity exceeds shear in pile



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2045 Design Check				Start page no./Revision 2045 1 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

STEEL SHEET PILING ANALYSIS & DESIGN

In accordance with BS EN1997-1:2004 - Code of Practice for Geotechnical design and the UK National Annex

Tedds calculation version 2.0.07

Design summary

Combination 1

Description	Unit	Provided	Required	Utilisation	Result
Total length required	mm	9480	4117	2.303	PASS
Moment capacity	kNm/m	385.9	8.2	46.818	PASS
Shear capacity	kN/m	779.3	32.7	23.807	PASS

Force in tie/prop 24.0 kN/m

Combination 2

Description	Unit	Provided	Required	Utilisation	Result
Total length required	mm	9480	4694	2.020	PASS
Moment capacity	kNm/m	385.9	9.2	42.155	PASS
Shear capacity	kN/m	779.3	30.7	25.421	PASS

Force in tie/prop 23.2 kN/m

Geometry

Design method	Fixed earth support
Total length of sheet pile provided	$H_{pile} = 9480$ mm
Number of different types of soil	$N_s = 6$
Retained height	$d_{ret} = 1870$ mm
Depth of unplanned excavation	$d_{ex} = 500$ mm
Total retained height	$d_s = 2370$ mm
Angle of retained slope	$\beta = 0.0$ deg
Depth from ground level to tie	$d_t = 920$ mm
Depth from GL to top of water table retained side	$d_w = 1350$ mm
Depth from GL to top of water table retaining side	$d_{wp} = 2370$ mm

Loading

Permanent surcharge	$p_{o,G} = 5.0$ kN/m ²
Variable surcharge	$p_{o,Q} = 5.0$ kN/m ²

Soil layer 1

Characteristic shearing resistance angle	$\phi'_{k_s1} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s1} = 28.0$ deg
Moist density of soil	$\gamma_{m_s1} = 17.5$ kN/m ³
Characteristic saturated density of retained soil	$\gamma_{s_s1} = 21.0$ kN/m ³
Height of soil 1	$h_1 = 630$ mm

Soil layer 2

Characteristic shearing resistance angle	$\phi'_{k_s2} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s2} = 28.0$ deg
Moist density of soil	$\gamma_{m_s2} = 17.5$ kN/m ³
Characteristic saturated density of retained soil	$\gamma_{s_s2} = 20.0$ kN/m ³
Height of soil 2	$h_2 = 2400$ mm

Soil layer 3

Characteristic shearing resistance angle	$\phi'_{k_s3} = 30.0$ deg
Characteristic wall friction angle	$\delta_{k_s3} = 28.0$ deg
Moist density of soil	$\gamma_{m_s3} = 14.0$ kN/m ³

	Project PCC Retaining Flood Wall Check				Job no.	
	Calcs for 2045 Design Check				Start page no./Revision 2045 2 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Characteristic saturated density of retained soil
Height of soil 3

$$\gamma_{s_s3} = 18.0 \text{ kN/m}^3$$

$$h_3 = 900 \text{ mm}$$

Soil layer 4

Characteristic shearing resistance angle
Characteristic wall friction angle

$$\phi'_{k_s4} = 30.0 \text{ deg}$$

$$\delta_{k_s4} = 28.0 \text{ deg}$$

Moist density of soil

$$\gamma_{m_s4} = 15.0 \text{ kN/m}^3$$

Characteristic saturated density of retained soil
Height of soil 4

$$\gamma_{s_s4} = 19.0 \text{ kN/m}^3$$

$$h_4 = 1100 \text{ mm}$$

Soil layer 5

Characteristic shearing resistance angle
Characteristic wall friction angle

$$\phi'_{k_s5} = 30.0 \text{ deg}$$

$$\delta_{k_s5} = 25.0 \text{ deg}$$

Moist density of soil

$$\gamma_{m_s5} = 14.0 \text{ kN/m}^3$$

Characteristic saturated density of retained soil
Height of soil 5

$$\gamma_{s_s5} = 19.0 \text{ kN/m}^3$$

$$h_5 = 1100 \text{ mm}$$

Soil layer 6

Characteristic shearing resistance angle
Characteristic wall friction angle

$$\phi'_{k_s6} = 30.0 \text{ deg}$$

$$\delta_{k_s6} = 30.0 \text{ deg}$$

Moist density of soil

$$\gamma_{m_s6} = 14.0 \text{ kN/m}^3$$

Characteristic saturated density of retained soil
Height of soil 6

$$\gamma_{s_s6} = 19.0 \text{ kN/m}^3$$

$$h_6 = 5700 \text{ mm}$$

Partial factors on actions - Section A.3.1 - Combination 1

Permanent unfavourable action

$$\gamma_G = 1.35$$

Permanent favourable action

$$\gamma_{G,f} = 1.00$$

Variable unfavourable action

$$\gamma_Q = 1.50$$

Angle of shearing resistance

$$\gamma_{\phi'} = 1.00$$

Weight density

$$\gamma_\gamma = 1.00$$

Design soil properties - soil 1

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 30.0 \text{ deg}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 28.0 \text{ deg}$$

Design moist density of retained soil

$$\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.5 \text{ kN/m}^3$$

Design saturated density of retained soil

$$\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 21.0 \text{ kN/m}^3$$

Design buoyant density of retained soil

$$\gamma_{d,d1} = \gamma_{s,d1} - \gamma_w = 11.2 \text{ kN/m}^3$$

Active pressure using Coulomb theory

$$K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.296$$

Passive pressure using Coulomb theory

$$K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = 9.012$$

Design soil properties - soil 2

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 30.0 \text{ deg}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 28.0 \text{ deg}$$

Design moist density of retained soil

$$\gamma_{m,d2} = \gamma_m / \gamma_\gamma = 17.5 \text{ kN/m}^3$$

Design saturated density of retained soil

$$\gamma_{s,d2} = \gamma_s / \gamma_\gamma = 20.0 \text{ kN/m}^3$$

Design buoyant density of retained soil

$$\gamma_{d,d2} = \gamma_{s,d2} - \gamma_w = 10.2 \text{ kN/m}^3$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 2045 Design Check			Start page no./Revision 2045 3 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Active pressure using Coulomb theory

$$K_{a2} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p2} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 3

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{28.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d3} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d3} = \gamma_s / \gamma_r = \mathbf{18.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d3} = \gamma_{s.d3} - \gamma_w = \mathbf{8.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a3} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p3} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 4

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{28.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d4} = \gamma_m / \gamma_r = \mathbf{15.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d4} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d4} = \gamma_{s.d4} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a4} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p4} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{9.012}$$

Design soil properties - soil 5

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{25.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d5} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d5} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d5} = \gamma_{s.d5} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a5} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.296}$$

Passive pressure using Coulomb theory

$$K_{p5} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = \mathbf{7.704}$$

Design soil properties - soil 6

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d6} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d6} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d6} = \gamma_{s.d6} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

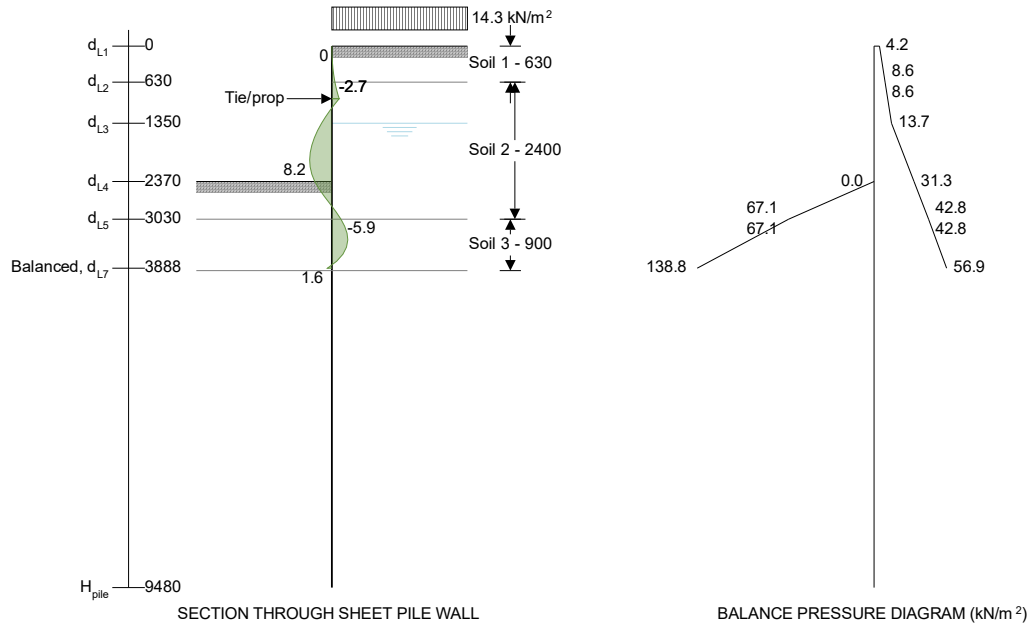
$$K_{a6} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))}))^2) = \mathbf{0.297}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2045 Design Check				Start page no./Revision 2045 4 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Passive pressure using Coulomb theory

$$K_{p6} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))}]^2) = 10.095$$



Overburden on active side

Overburden at 0 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 2
 Overburden at 1350 mm below GL in soil 2
 Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3888 mm below GL in soil 3

$$\begin{aligned} OB'_{a11} &= (p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q) = 14.3 \text{ kN/m}^2 \\ OB'_{a21} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 29.1 \text{ kN/m}^2 \\ OB'_{a22} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 29.1 \text{ kN/m}^2 \\ OB'_{a31} &= \gamma_G \times \gamma_{m,d2} \times h_{a2} + OB'_{a22} = 46.1 \text{ kN/m}^2 \\ OB'_{a41} &= \gamma_G \times \gamma_{d,d2} \times h_{a3} + OB'_{a31} = 60.2 \text{ kN/m}^2 \\ OB'_{a51} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = 69.3 \text{ kN/m}^2 \\ OB'_{a52} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = 69.3 \text{ kN/m}^2 \\ OB'_{a61} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = 78.7 \text{ kN/m}^2 \end{aligned}$$

Overburden on passive side

Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3888 mm below GL in soil 3

$$\begin{aligned} OB'_{p41} &= 0 \text{ kN/m}^2 = 0.0 \text{ kN/m}^2 \\ OB'_{p51} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = 6.7 \text{ kN/m}^2 \\ OB'_{p52} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = 6.7 \text{ kN/m}^2 \\ OB'_{p61} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = 13.8 \text{ kN/m}^2 \end{aligned}$$

Pressure on active side

Active at 0 mm below GL in soil 1
 Active at 630 mm below GL in soil 1
 Active at 630 mm below GL in soil 2
 Active at 1350 mm below GL in soil 2
 Active at 2370 mm below GL in soil 2
 Active at 3030 mm below GL in soil 2
 Active at 3030 mm below GL in soil 3
 Active at 3888 mm below GL in soil 3

$$\begin{aligned} p'_{a11} &= K_{a1} \times OB'_{a11} = 4.2 \text{ kN/m}^2 \\ p'_{a21} &= K_{a1} \times OB'_{a21} = 8.6 \text{ kN/m}^2 \\ p'_{a22} &= K_{a2} \times OB'_{a22} = 8.6 \text{ kN/m}^2 \\ p'_{a31} &= K_{a2} \times OB'_{a31} = 13.7 \text{ kN/m}^2 \\ p'_{a41} &= K_{a2} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = 31.3 \text{ kN/m}^2 \\ p'_{a51} &= K_{a2} \times OB'_{a51} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = 42.8 \text{ kN/m}^2 \\ p'_{a52} &= K_{a3} \times OB'_{a52} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = 42.8 \text{ kN/m}^2 \\ p'_{a61} &= K_{a3} \times OB'_{a61} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = 56.9 \text{ kN/m}^2 \end{aligned}$$

Pressure on passive side

Passive at 2370 mm below GL in soil 2

$$p'_{p41} = K_{p2} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = 0.0 \text{ kN/m}^2$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2045 Design Check				Start page no./Revision 2045 5 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Passive at 3030 mm below GL in soil 2

$$p'_{p51} = K_{p2} \times OB'_{p51} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{67.1 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 3

$$p'_{p52} = K_{p3} \times OB'_{p52} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{67.1 \text{ kN/m}^2}$$

Passive at 3888 mm below GL in soil 3

$$p'_{p61} = K_{p3} \times OB'_{p61} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{138.8 \text{ kN/m}^2}$$

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2742 \text{ mm}}$$

Sum of active moments about contraflexure point

$$\Sigma M_{\text{ac}} = \mathbf{44.6 \text{ kNm/m}}$$

Sum of passive moments about contraflexure point

$$\Sigma M_{\text{pc}} = \mathbf{0.9 \text{ kNm/m}}$$

Force in tie

$$T = (\Sigma M_{\text{ac}} - \Sigma M_{\text{pc}}) / (d_{\text{contra}} - d_t) = \mathbf{24.0 \text{ kN/m}}$$

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 3888 mm as follows:-

Active moment about 3888 mm

Moment level 1

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = \mathbf{4.9 \text{ kNm/m}}$$

Moment level 1

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = \mathbf{9.4 \text{ kNm/m}}$$

Moment level 2

$$M_{a21} = 0.5 \times p'_{a22} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = \mathbf{9.4 \text{ kNm/m}}$$

Moment level 2

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = \mathbf{13.7 \text{ kNm/m}}$$

Moment level 3

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = \mathbf{15.3 \text{ kNm/m}}$$

Moment level 3

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = \mathbf{29.7 \text{ kNm/m}}$$

Moment level 4

$$M_{a41} = 0.5 \times p'_{a41} \times h_{a4} \times ((H - d_{L5}) + 2/3 \times h_{a4}) = \mathbf{13.4 \text{ kNm/m}}$$

Moment level 4

$$M_{a42} = 0.5 \times p'_{a51} \times h_{a4} \times ((H - d_{L5}) + 1/3 \times h_{a4}) = \mathbf{15.2 \text{ kNm/m}}$$

Moment level 5

$$M_{a51} = 0.5 \times p'_{a52} \times h_{a5} \times ((H - d_{L6}) + 2/3 \times h_{a5}) = \mathbf{10.5 \text{ kNm/m}}$$

Moment level 5

$$M_{a52} = 0.5 \times p'_{a61} \times h_{a5} \times ((H - d_{L6}) + 1/3 \times h_{a5}) = \mathbf{7.0 \text{ kNm/m}}$$

Passive moment about 3888 mm

Moment level 4

$$M_{p41} = 0.5 \times p'_{p41} \times h_{p4} \times ((H - d_{L5}) + 2/3 \times h_{p4}) = \mathbf{0.0 \text{ kNm/m}}$$

Moment level 4

$$M_{p42} = 0.5 \times p'_{p51} \times h_{p4} \times ((H - d_{L5}) + 1/3 \times h_{p4}) = \mathbf{23.9 \text{ kNm/m}}$$

Moment level 5

$$M_{p51} = 0.5 \times p'_{p52} \times h_{p5} \times ((H - d_{L6}) + 2/3 \times h_{p5}) = \mathbf{16.5 \text{ kNm/m}}$$

Moment level 5

$$M_{p52} = 0.5 \times p'_{p61} \times h_{p5} \times ((H - d_{L6}) + 1/3 \times h_{p5}) = \mathbf{17.0 \text{ kNm/m}}$$

Moment about toe for tie/prop

$$M_{\text{pt}} = T \times (H - d_t) = \mathbf{71.2 \text{ kNm/m}}$$

Total moments about 3888 mm

Total active moment

$$\Sigma M_a = \mathbf{128.5 \text{ kNm/m}}$$

Total passive moment

$$\Sigma M_p = \mathbf{128.6 \text{ kNm/m}}$$

Required pile length

Length of pile required to balance moments

$$H = \mathbf{3888 \text{ mm}}$$

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2742 \text{ mm}}$$

Add 20% below this point

$$d_{\text{e_add}} = 1.2 \times (H - d_{\text{contra}}) = \mathbf{1376 \text{ mm}}$$

Minimum required pile length

$$H_{\text{total}} = d_{\text{contra}} + d_{\text{e_add}} = \mathbf{4117 \text{ mm}}$$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis)

$$M_{\text{pile}} = \max(\text{abs}(M_{\text{min}}), \text{abs}(M_{\text{max}})) / 1\text{m} = \mathbf{8.2 \text{ kNm/m}}$$

Maximum shear force in pile (from analysis)

$$V_{\text{pile}} = \mathbf{32.7 \text{ kN/m}}$$

Nominal yield strength of pile

$$f_{y_pile} = \mathbf{240 \text{ N/mm}^2}$$

User defined section

Plastic modulus of pile

$$W_{\text{pl,y}} = \mathbf{2010 \text{ cm}^3/\text{m}}$$

Thickness of web

$$s = \mathbf{6.1 \text{ mm}}$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 2045 Design Check			Start page no./Revision 2045 6 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Thickness of flange $t = 12.2$ mm
Overall height $h = 381$ mm
Section width $b = 400$ mm
Web incline angle $\alpha_{pile} = 67.0$ deg

Shear buckling of web (cl.5.2.2(6))

Width of section $c = (h - t) / \sin(\alpha_{pile}) = 401$ mm
Thickness of web $t_w = s = 6.1$ mm
 $\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y_pile})} = 0.990$
 $c / t_w = 65.7 = 66.4 \times \varepsilon \leq 72 \times \varepsilon$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2) $\beta_B = 0.8$
Design bending resistance (eqn.5.2) $M_{c,Rd} = W_{pl,y} \times f_{y_pile} \times \beta_B / \gamma_{M0} = 385.9$ kNm/m

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6) $A_v = s \times (h - t) = 2250$ mm²
Design shear resistance (eqn.5.5) $V_{pl,Rd} = A_v \times f_{y_pile} / (\sqrt{3} \times \gamma_{M0}) / b = 779.3$ kN/m

PASS - Shear capacity exceeds shear in pile

Partial factors on actions - Section A.3.1 - Combination 2

Permanent unfavourable action $\gamma_G = 1.00$
Permanent favourable action $\gamma_{G,f} = 1.00$
Variable unfavourable action $\gamma_Q = 1.30$
Angle of shearing resistance $\gamma_{\phi'} = 1.25$
Weight density $\gamma_\gamma = 1.00$

Design soil properties - soil 1

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 24.8$ deg
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 23.0$ deg
Design moist density of retained soil $\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.5$ kN/m³
Design saturated density of retained soil $\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 21.0$ kN/m³
Design buoyant density of retained soil $\gamma_{d,d1} = \gamma_{s,d1} - \gamma_w = 11.2$ kN/m³
Active pressure using Coulomb theory $K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.358$
Passive pressure using Coulomb theory $K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = 5.106$

Design soil properties - soil 2

Design effective shearing resistance angle $\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = 24.8$ deg
Design wall friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = 23.0$ deg
Design moist density of retained soil $\gamma_{m,d2} = \gamma_m / \gamma_\gamma = 17.5$ kN/m³
Design saturated density of retained soil $\gamma_{s,d2} = \gamma_s / \gamma_\gamma = 20.0$ kN/m³
Design buoyant density of retained soil $\gamma_{d,d2} = \gamma_{s,d2} - \gamma_w = 10.2$ kN/m³
Active pressure using Coulomb theory $K_{a2} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.358$
Passive pressure using Coulomb theory $K_{p2} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = 5.106$

	Project PCC Retaining Flood Wall Check				Job no.	
	Calcs for 2045 Design Check				Start page no./Revision 2045 7 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Design soil properties - soil 3

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{23.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d3} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d3} = \gamma_s / \gamma_r = \mathbf{18.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d3} = \gamma_{s.d3} - \gamma_w = \mathbf{8.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a3} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

$$K_{p3} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.106}$$

Design soil properties - soil 4

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{23.0 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d4} = \gamma_m / \gamma_r = \mathbf{15.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d4} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d4} = \gamma_{s.d4} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a4} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

$$K_{p4} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.106}$$

Design soil properties - soil 5

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{20.5 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d5} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d5} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d5} = \gamma_{s.d5} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

$$K_{a5} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.360}$$

Passive pressure using Coulomb theory

$$K_{p5} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{4.622}$$

Design soil properties - soil 6

Design effective shearing resistance angle

$$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design wall friction angle

$$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$$

Design moist density of retained soil

$$\gamma_{m.d6} = \gamma_m / \gamma_r = \mathbf{14.0 \text{ kN/m}^3}$$

Design saturated density of retained soil

$$\gamma_{s.d6} = \gamma_s / \gamma_r = \mathbf{19.0 \text{ kN/m}^3}$$

Design buoyant density of retained soil

$$\gamma_{d.d6} = \gamma_{s.d6} - \gamma_w = \mathbf{9.2 \text{ kN/m}^3}$$

Active pressure using Coulomb theory

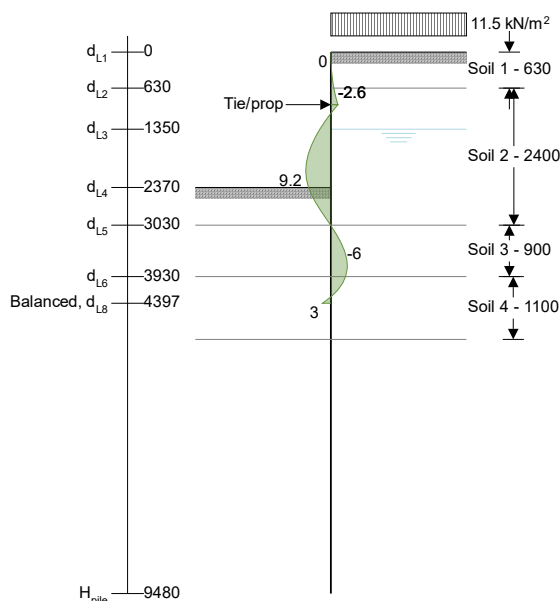
$$K_{a6} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = \mathbf{0.358}$$

Passive pressure using Coulomb theory

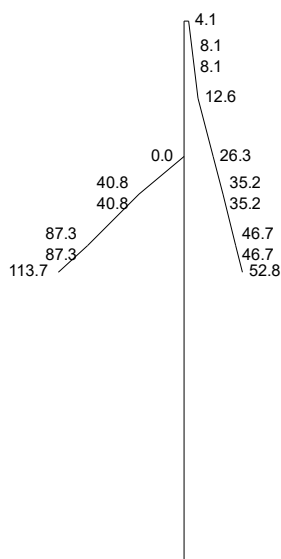
$$K_{p6} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))})^2] = \mathbf{5.480}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2045 Design Check				Start page no./Revision 2045 8 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date



SECTION THROUGH SHEET PILE WALL



BALANCE PRESSURE DIAGRAM (kN/m²)

Overburden on active side

Overburden at 0 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 1
 Overburden at 630 mm below GL in soil 2
 Overburden at 1350 mm below GL in soil 2
 Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 4
 Overburden at 4397 mm below GL in soil 4

$$\begin{aligned} OB'_{a11} &= (p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q) = \mathbf{11.5 \text{ kN/m}^2} \\ OB'_{a21} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = \mathbf{22.5 \text{ kN/m}^2} \\ OB'_{a22} &= \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = \mathbf{22.5 \text{ kN/m}^2} \\ OB'_{a31} &= \gamma_G \times \gamma_{m,d2} \times h_{a2} + OB'_{a22} = \mathbf{35.1 \text{ kN/m}^2} \\ OB'_{a41} &= \gamma_G \times \gamma_{d,d2} \times h_{a3} + OB'_{a31} = \mathbf{45.5 \text{ kN/m}^2} \\ OB'_{a51} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = \mathbf{52.2 \text{ kN/m}^2} \\ OB'_{a52} &= \gamma_G \times \gamma_{d,d2} \times h_{a4} + OB'_{a41} = \mathbf{52.2 \text{ kN/m}^2} \\ OB'_{a61} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = \mathbf{59.6 \text{ kN/m}^2} \\ OB'_{a62} &= \gamma_G \times \gamma_{d,d3} \times h_{a5} + OB'_{a52} = \mathbf{59.6 \text{ kN/m}^2} \\ OB'_{a71} &= \gamma_G \times \gamma_{d,d4} \times h_{a6} + OB'_{a62} = \mathbf{63.9 \text{ kN/m}^2} \end{aligned}$$

Overburden on passive side

Overburden at 2370 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 2
 Overburden at 3030 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 3
 Overburden at 3930 mm below GL in soil 4
 Overburden at 4397 mm below GL in soil 4

$$\begin{aligned} OB'_{p41} &= 0 \text{ kN/m}^2 = \mathbf{0.0 \text{ kN/m}^2} \\ OB'_{p51} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = \mathbf{6.7 \text{ kN/m}^2} \\ OB'_{p52} &= \gamma_{G,f} \times \gamma_{d,d2} \times h_{p4} + OB'_{p41} = \mathbf{6.7 \text{ kN/m}^2} \\ OB'_{p61} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = \mathbf{14.1 \text{ kN/m}^2} \\ OB'_{p62} &= \gamma_{G,f} \times \gamma_{d,d3} \times h_{p5} + OB'_{p52} = \mathbf{14.1 \text{ kN/m}^2} \\ OB'_{p71} &= \gamma_{G,f} \times \gamma_{d,d4} \times h_{p6} + OB'_{p62} = \mathbf{18.4 \text{ kN/m}^2} \end{aligned}$$

Pressure on active side

Active at 0 mm below GL in soil 1
 Active at 630 mm below GL in soil 1
 Active at 630 mm below GL in soil 2
 Active at 1350 mm below GL in soil 2
 Active at 2370 mm below GL in soil 2
 Active at 3030 mm below GL in soil 2
 Active at 3030 mm below GL in soil 3
 Active at 3930 mm below GL in soil 3

$$\begin{aligned} p'_{a11} &= K_{a1} \times OB'_{a11} = \mathbf{4.1 \text{ kN/m}^2} \\ p'_{a21} &= K_{a1} \times OB'_{a21} = \mathbf{8.1 \text{ kN/m}^2} \\ p'_{a22} &= K_{a2} \times OB'_{a22} = \mathbf{8.1 \text{ kN/m}^2} \\ p'_{a31} &= K_{a2} \times OB'_{a31} = \mathbf{12.6 \text{ kN/m}^2} \\ p'_{a41} &= K_{a2} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = \mathbf{26.3 \text{ kN/m}^2} \\ p'_{a51} &= K_{a2} \times OB'_{a51} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = \mathbf{35.2 \text{ kN/m}^2} \\ p'_{a52} &= K_{a3} \times OB'_{a52} + \gamma_G \times \gamma_w \times (d_{L5} - d_w) = \mathbf{35.2 \text{ kN/m}^2} \\ p'_{a61} &= K_{a3} \times OB'_{a61} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = \mathbf{46.7 \text{ kN/m}^2} \end{aligned}$$

	Project PCC Retaining Flood Wall Check			Job no.	
	Calcs for 2045 Design Check			Start page no./Revision 2045 9 1	
	Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by Approved date

Active at 3930 mm below GL in soil 4

$$p'_{a62} = K_{a4} \times OB'_{a62} + \gamma_G \times \gamma_w \times (d_{L6} - d_w) = \mathbf{46.7 \text{ kN/m}^2}$$

Active at 4397 mm below GL in soil 4

$$p'_{a71} = K_{a4} \times OB'_{a71} + \gamma_G \times \gamma_w \times (d_{L7} - d_w) = \mathbf{52.8 \text{ kN/m}^2}$$

Pressure on passive side

Passive at 2370 mm below GL in soil 2

$$p'_{p41} = K_{p2} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = \mathbf{0.0 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 2

$$p'_{p51} = K_{p2} \times OB'_{p51} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{40.8 \text{ kN/m}^2}$$

Passive at 3030 mm below GL in soil 3

$$p'_{p52} = K_{p3} \times OB'_{p52} + \gamma_{G,f} \times \gamma_w \times (d_{L5} - \max(d_s, d_w)) = \mathbf{40.8 \text{ kN/m}^2}$$

Passive at 3930 mm below GL in soil 3

$$p'_{p61} = K_{p3} \times OB'_{p61} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{87.3 \text{ kN/m}^2}$$

Passive at 3930 mm below GL in soil 4

$$p'_{p62} = K_{p4} \times OB'_{p62} + \gamma_{G,f} \times \gamma_w \times (d_{L6} - \max(d_s, d_w)) = \mathbf{87.3 \text{ kN/m}^2}$$

Passive at 4397 mm below GL in soil 4

$$p'_{p71} = K_{p4} \times OB'_{p71} + \gamma_{G,f} \times \gamma_w \times (d_{L7} - \max(d_s, d_w)) = \mathbf{113.8 \text{ kN/m}^2}$$

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure

$$d_{\text{contra}} = \mathbf{2914 \text{ mm}}$$

Sum of active moments about contraflexure point

$$\Sigma M_{ac} = \mathbf{47.9 \text{ kNm/m}}$$

Sum of passive moments about contraflexure point

$$\Sigma M_{pc} = \mathbf{1.7 \text{ kNm/m}}$$

Force in tie

$$T = (\Sigma M_{ac} - \Sigma M_{pc}) / (d_{\text{contra}} - d_t) = \mathbf{23.2 \text{ kN/m}}$$

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 4397 mm as follows:-

Active moment about 4397 mm

Moment level 1

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = \mathbf{5.4 \text{ kNm/m}}$$

Moment level 1

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = \mathbf{10.1 \text{ kNm/m}}$$

Moment level 2

$$M_{a21} = 0.5 \times p'_{a22} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = \mathbf{10.2 \text{ kNm/m}}$$

Moment level 2

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = \mathbf{14.9 \text{ kNm/m}}$$

Moment level 3

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = \mathbf{17.4 \text{ kNm/m}}$$

Moment level 3

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = \mathbf{31.8 \text{ kNm/m}}$$

Moment level 4

$$M_{a41} = 0.5 \times p'_{a41} \times h_{a4} \times ((H - d_{L5}) + 2/3 \times h_{a4}) = \mathbf{15.7 \text{ kNm/m}}$$

Moment level 4

$$M_{a42} = 0.5 \times p'_{a51} \times h_{a4} \times ((H - d_{L5}) + 1/3 \times h_{a4}) = \mathbf{18.4 \text{ kNm/m}}$$

Moment level 5

$$M_{a51} = 0.5 \times p'_{a52} \times h_{a5} \times ((H - d_{L6}) + 2/3 \times h_{a5}) = \mathbf{16.9 \text{ kNm/m}}$$

Moment level 5

$$M_{a52} = 0.5 \times p'_{a61} \times h_{a5} \times ((H - d_{L6}) + 1/3 \times h_{a5}) = \mathbf{16.1 \text{ kNm/m}}$$

Moment level 6

$$M_{a61} = 0.5 \times p'_{a62} \times h_{a6} \times ((H - d_{L7}) + 2/3 \times h_{a6}) = \mathbf{3.4 \text{ kNm/m}}$$

Moment level 6

$$M_{a62} = 0.5 \times p'_{a71} \times h_{a6} \times ((H - d_{L7}) + 1/3 \times h_{a6}) = \mathbf{1.9 \text{ kNm/m}}$$

Passive moment about 4397 mm

Moment level 4

$$M_{p41} = 0.5 \times p'_{p41} \times h_{p4} \times ((H - d_{L5}) + 2/3 \times h_{p4}) = \mathbf{0.0 \text{ kNm/m}}$$

Moment level 4

$$M_{p42} = 0.5 \times p'_{p51} \times h_{p4} \times ((H - d_{L5}) + 1/3 \times h_{p4}) = \mathbf{21.4 \text{ kNm/m}}$$

Moment level 5

$$M_{p51} = 0.5 \times p'_{p52} \times h_{p5} \times ((H - d_{L6}) + 2/3 \times h_{p5}) = \mathbf{19.6 \text{ kNm/m}}$$

Moment level 5

$$M_{p52} = 0.5 \times p'_{p61} \times h_{p5} \times ((H - d_{L6}) + 1/3 \times h_{p5}) = \mathbf{30.1 \text{ kNm/m}}$$

Moment level 6

$$M_{p61} = 0.5 \times p'_{p62} \times h_{p6} \times ((H - d_{L7}) + 2/3 \times h_{p6}) = \mathbf{6.3 \text{ kNm/m}}$$

Moment level 6

$$M_{p62} = 0.5 \times p'_{p71} \times h_{p6} \times ((H - d_{L7}) + 1/3 \times h_{p6}) = \mathbf{4.1 \text{ kNm/m}}$$

Moment about toe for tie/prop

$$M_{pt} = T \times (H - d_t) = \mathbf{80.7 \text{ kNm/m}}$$

Total moments about 4397 mm

Total active moment

$$\Sigma M_a = \mathbf{162.2 \text{ kNm/m}}$$

Total passive moment

$$\Sigma M_p = \mathbf{162.2 \text{ kNm/m}}$$

Required pile length

Length of pile required to balance moments

$$H = \mathbf{4397 \text{ mm}}$$



Project PCC Retaining Flood Wall Check				Job no.	
Calcs for 2045 Design Check				Start page no./Revision 2045 10 1	
Calcs by MC	Calcs date 27/03/2023	Checked by	Checked date	Approved by	Approved date

Depth to point of contraflexure

$$d_{\text{contra}} = 2914 \text{ mm}$$

Add 20% below this point

$$d_{\text{e_add}} = 1.2 \times (H - d_{\text{contra}}) = 1780 \text{ mm}$$

Minimum required pile length

$$H_{\text{total}} = d_{\text{contra}} + d_{\text{e_add}} = 4694 \text{ mm}$$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis)

$$M_{\text{pile}} = \max(\text{abs}(M_{\text{min}}), \text{abs}(M_{\text{max}})) / 1\text{m} = 9.2 \text{ kNm/m}$$

Maximum shear force in pile (from analysis)

$$V_{\text{pile}} = 30.7 \text{ kN/m}$$

Nominal yield strength of pile

$$f_{y_pile} = 240 \text{ N/mm}^2$$

User defined section

Plastic modulus of pile

$$W_{pl,y} = 2010 \text{ cm}^3/\text{m}$$

Thickness of web

$$s = 6.1 \text{ mm}$$

Thickness of flange

$$t = 12.2 \text{ mm}$$

Overall height

$$h = 381 \text{ mm}$$

Section width

$$b = 400 \text{ mm}$$

Web incline angle

$$\alpha_{\text{pile}} = 67.0 \text{ deg}$$

Shear buckling of web (cl.5.2.2(6))

Width of section

$$c = (h - t) / \sin(\alpha_{\text{pile}}) = 401 \text{ mm}$$

Thickness of web

$$t_w = s = 6.1 \text{ mm}$$

$$\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y_pile})} = 0.990$$

$$c / t_w = 65.7 = 66.4 \times \varepsilon \leq 72 \times \varepsilon$$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2)

$$\beta_B = 0.8$$

Design bending resistance (eqn.5.2)

$$M_{c,Rd} = W_{pl,y} \times f_{y_pile} \times \beta_B / \gamma_{M0} = 385.9 \text{ kNm/m}$$

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6)

$$A_v = s \times (h - t) = 2250 \text{ mm}^2$$

Design shear resistance (eqn.5.5)

$$V_{pl,Rd} = A_v \times f_{y_pile} / (\sqrt{3} \times \gamma_{M0}) / b = 779.3 \text{ kN/m}$$

PASS - Shear capacity exceeds shear in pile