Design Investigation into a Retaining Wall at St Peter's Marina, Newcastle

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Abstract: This study presents a comprehensive design investigation of a retaining wall for St Peter's Marina, Newcastle. It involves a detailed assessment of geological conditions, historical data analysis, and advanced engineering methodologies to develop an optimal wall design. Historical maps and recent site surveys provide insights into past site usage and existing conditions. Design considerations include integration with existing structures, aesthetic alignment, and the ability to withstand hydrostatic pressures and environmental conditions. Various wall types are evaluated, with an embedded steel sheet pile wall emerging as the most suitable. The construction methodology addresses site preparation, driving of sheet piles, anchoring, and quality assurance, ensuring the wall's functionality and longevity. Safety considerations are emphasized, outlining strategies for risk management and emergency response during construction. The study concludes with the implementation of the proposed design, signifying a significant contribution to the marina's infrastructure and resilience.

[AOD = Above Ordnance Datum]

I. Introduction

St Peters Marina is located on the north side of the river Tyne in Newcastle and functions as a small residential marina. The existing retaining wall on the river facing side of the marina is to be redesigned for the following parameters:

- Design Quay level: +3.45m AOD
- Dredge level: -5.45m AOD
- Mean High Water level: +2.70m AOD
- Mean Low Water level: -1.80m AOD

The ground is initially comprised of made ground, silt and siltstone and the wall is to be designed for a surcharge of 10kN to facilitate a light load bearing capacity. The wall site can be seen in Figure 1 with a projected length of 110m with the wall site being 8m away from a residential block.

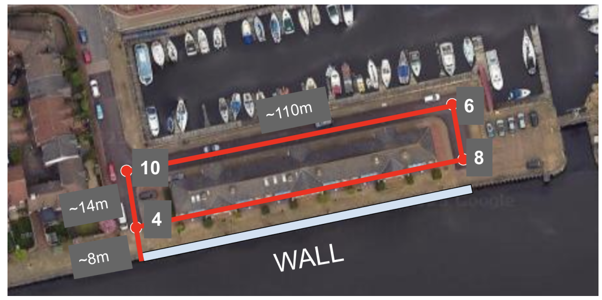


Figure 1: Satellite image of St Peters Marina with wall site marked in bold and approximate dimensions annotated. Four boreholes are marked and numbered 4; 6; 8; 10 (credit: Google).

II. Desk Study

A. Historical Data

- St Peters Dock in the 1860s-80s: Chemical works can be spotted near the project site which indicates possible historic contamination in soil - see Figure 2
- There is a sandy beach (when at low tide) seen in the 1880s and is seen to have disappeared by the 1890s: The site might be vulnerable to tidal actions, storm surges, or river current changes - see Figures 2 and 2
- Cranes can be seen at site location in the 1890s suggesting there may be heavy metal remnants in the soil
- From the 1890s to 1991 the site was called St Peters Works and operated as a ship building site [7] - see Figure 2
- Industrial area with railway lines running where the marina is currently: The presence of old railway lines may mean buried infrastructure or remnants that could interfere with construction - see Figure 2
- St Peters Marina was built in 1991 and the existing retaining wall can be seen in Figure 4

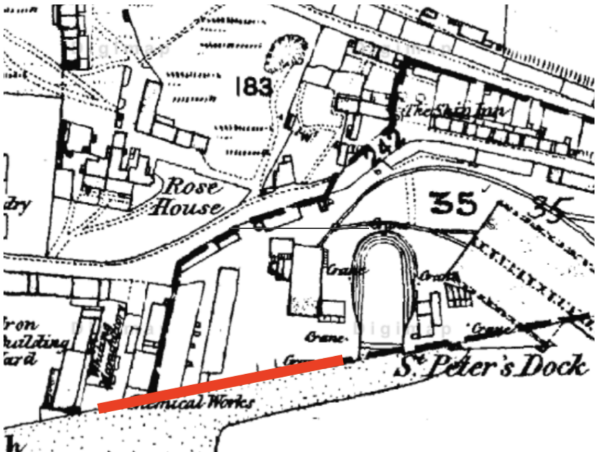


Figure 2: Historical map of the site from the 1860s to the 1880s (credit: Digimaps). Wall site marked in bold.

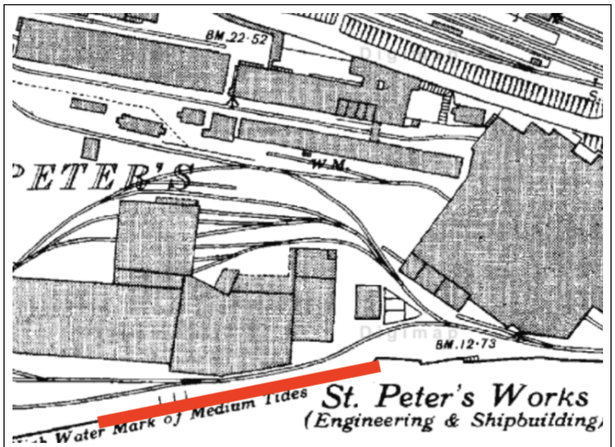


Figure 3: Historical map of the site from the 1890s (credit: Digimaps). Wall site marked in bold.

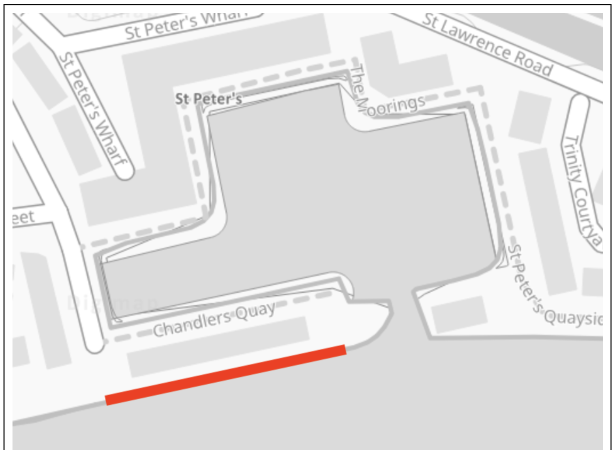


Figure 4: Historical map of the site from the 1990s (credit: Digimaps). Wall site marked in bold.

B. Borehole Records

There are four suitable borehole records that are analysed in this report (see Appendix **??** They encompass 150mm casing *cable percussion* boring to establish the ground conditions down to bedrock, along with Standard Penetration Test (SPT) values for each measured depth. These are used to create the ground model later in this report.

C. Constraints

1) On Design:

- Integration with the Existing Wall: If the new wall integrates with or replaces a portion of an existing structure, the design must accommodate the existing wall's foundations and structural integrity.
- Aesthetics: The new wall should harmoniously blend with the surrounding area [1]
- Access: The design should consider how construction will impact local traffic (both on water, into the marina, and land) and what provisions should be made to maintain access routes during construction.
- Soil Analysis: Detailed geotechnical investigations are critical due to the ground conditions stated (6m of fill material overlaying silts and sands, with bedrock at about 20m - boreholes provide this detailed information).
- Hydrostatic Pressure: Being next to a river, the design must consider the hydrostatic pressure exerted by the River Tyne, which will vary with the tide, weather conditions, and potential flooding scenarios.
- Structural Integrity: Engineering calculations must ensure the wall can withstand not just the surcharge but also additional stress from environmental conditions (e.g., wind, water currents) and accidental impacts (e.g., from boats).
- Maintenance: Design with an eye for long-term durability and ease of maintenance, considering the local climate and potential for weather-related damage.
- Climate Change Resilience: Consider future-proofing the structure against rising sea levels and potential changes in weather patterns due to climate change.

2) On Construction:

- Construction Methodology: Given the sensitive location, the construction methods employed should minimize disruption to the river and its surroundings. This consideration includes noise, physical barriers within the water, and potential pollution.
- Safety: Works must adhere to health and safety regulations to protect construction workers, marina staff, local residents, and wildlife.
- Ground contamination and unexploded ordance: The ground should be surveyed and analysed for historic chemical contamination and checked for unexploded ordnance due to the nature of the area being a ship building site during the major conflict of the 1940s.
- Timing: Construction might be restricted to certain times of the year to minimize environmental impact or avoid conflicting with peak marina usage.
- Planning Permission: Because the retaining wall is along a riverfront, specific local council regulations and national environmental laws in the UK must be adhered to. These might concern flood defense measures, riverbank ecosystem protection, aesthetics, and heritage preservation (if applicable).
- Building Regulations: The wall must meet the UK Building Regulations' requirements, especially regarding structures' safety and strength.
- Environmental Considerations: Assessments and mitigation for potential environmental impacts, including local flora and fauna, water quality, and ecological balance, might be necessary.

III. Ground Model

The ground model is constructed from the four borehole records located in the aforementioned Figure 1 and are more clearly laid out in Figure 5. Boreholes 4 and 10 alongside 8 and 6 were used to produce a conservative ground model of the ground projected forward to the wall site. The two sets of boreholes span the designated 120m of the wall site. Table III shows the range of values used for the unit weights and the angles of shear resistances for the three strata groups: made ground; silt; siltstone. To create an appropriate ground model the wall is placed on the site of the existing retaining wall, 8 metres away from the residential blocks (as seen in Figure 5. The ground below the dredge level on the river facing side of the wall creates *passive* pressures and acts against the *active* pressures pushing the wall towards the river. The unit weights need to satisfy the the upper bounds of these ranges fort he active side and the lower bounds for the passive side. To find the maximum active earth pressure coefficient, the lower bound of the angle of shearing resistance should be used, whilst the upper bound should be used for the passive earth pressure coefficient. The ground models for the projected wall points at the east and west sides of the wall are seen in Figures 6 and 7.

Strata	Unit Weight	Angle of Shearing Resistance
Made Ground	14kN - 18kN	29.5º - 31.0º
Silt	18kN - 21kN	29.5º - 30.0º
Siltstone	22kN - 28kN	27.0º - 34.0º

Table I: Value ranges of unit weights and angles of shearing resistance for the three strata groups shown in figures 6 and 7 [9]&[5]

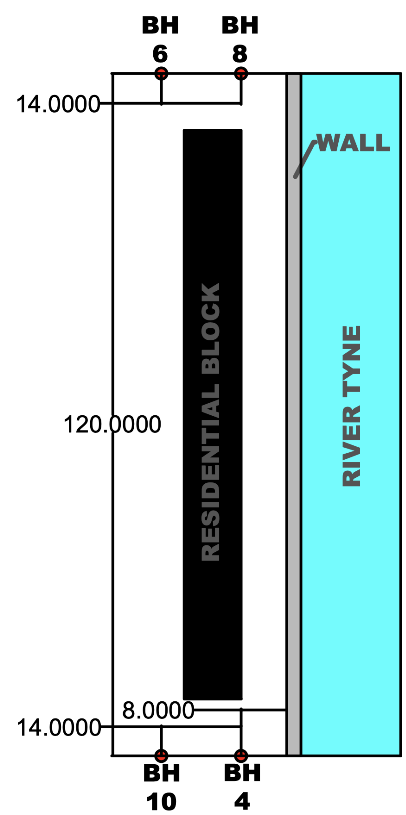


Figure 5: Simple plan view for conceptual ground model, showing borehole locations in reference to the wall and residential block [lengths in metres]

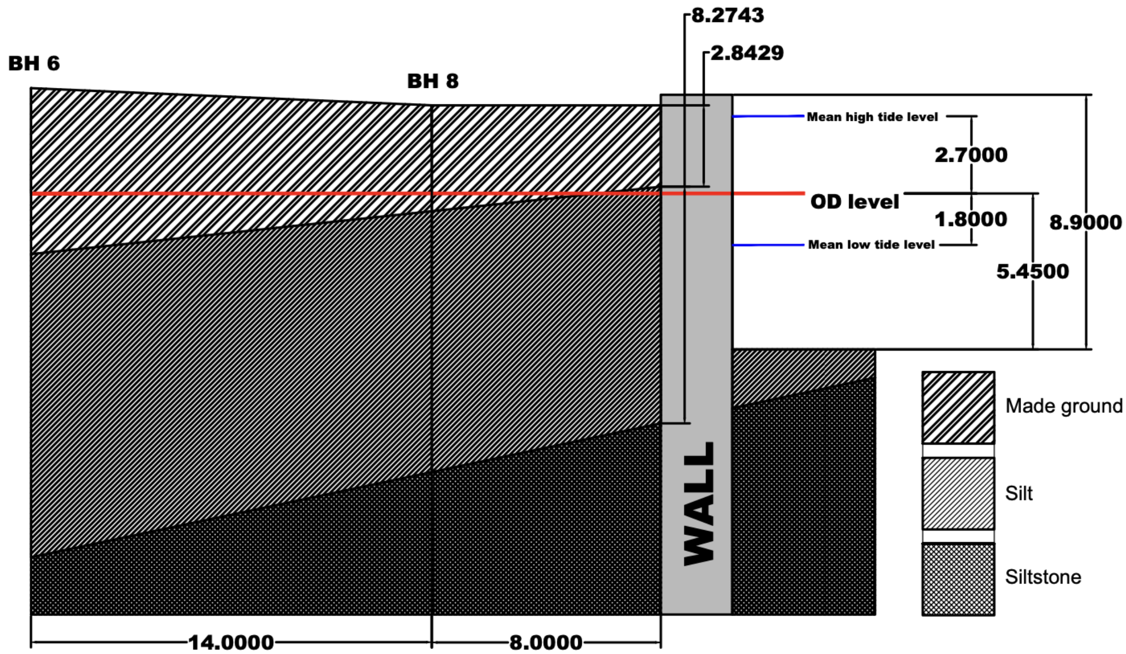


Figure 6: Section view of the Conceptual ground model showing strata for the active and passive sides of the wall using records and locations for boreholes 6 and 8 projected to east end of the wall site (legend for strata types can also be seen) [lengths in metres]

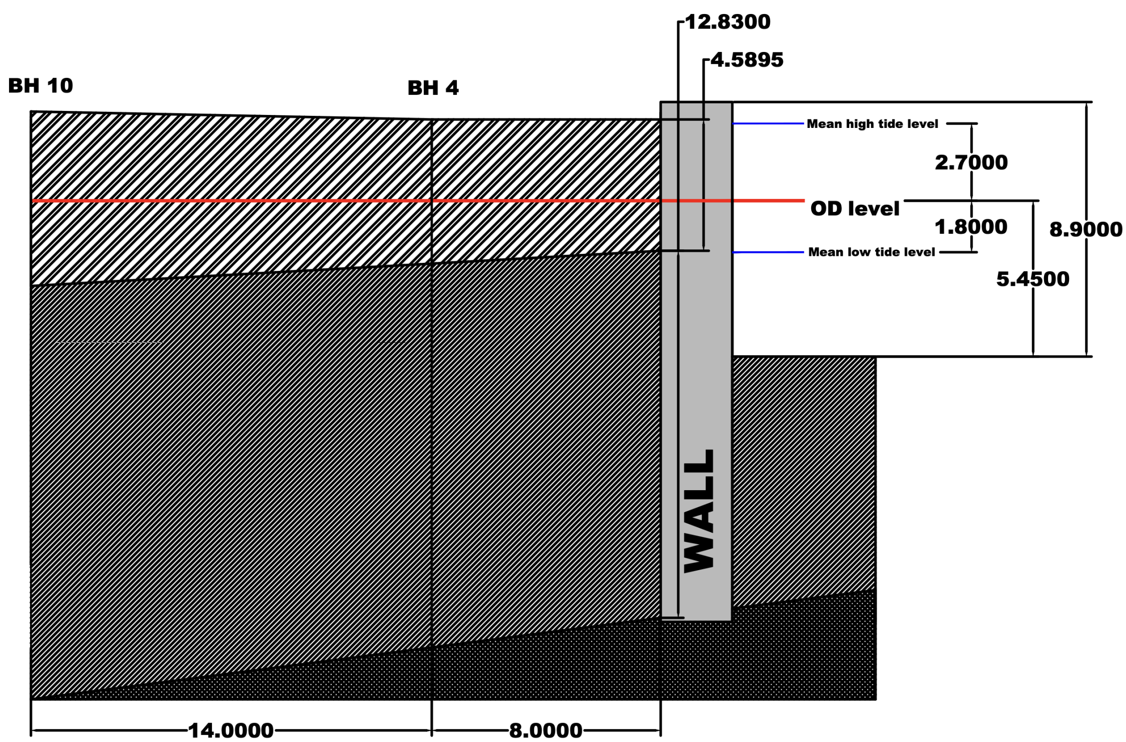


Figure 7: Section view of the Conceptual ground model showing strata for the active and passive sides of the wall using records and locations for boreholes 10 and 4 projected to the west end of wall site [lengths in metres]

IV. Wall Designs Considered

Based on the ground model portrayed at both ends of the 120 metre wall site by Figures 6 and 7, the different types of walls are considered to determine the most suitable wall type.

The criterion upon how the wall design types were analysed are as follow in descending order of importance:

1) Safety of construction for site
2) Height suitability
3) Structural integrity and loading capacity
4) Longevity and durability
5) Cost effectiveness of construction
6) Environmental friendliness
7) Speed of construction
8) Cost effectiveness of maintenance
9) Ease of construction
10) Aesthetics

Gravity wall types - basic block wall; cantilever wall; caisson wall; gabion wall; counterfort wall; crib-retaining wall - and embedded wall types - diaphragm wall; sheet pile wall; secant pile wall; soldier pile wall; contiguous pile wall - were considered.

The detailed comparison matrix for all eleven wall types considered can be seen in **Appendix A2**.

Ultimately an embedded wall was deemed to be much more suitable than any gravity type wall due to the relatively deep nature of the dredge deppth (8.9m), meaning any gravity wall would have to span at least this height, inducing both unreasonable material and economic costs. An embedded wall suitability fits the site location, with an embedment depth at some distance below the 8.9m dredge.

For these reasons an **embdedded steel sheet pile wall** was selected as the most suitable wall type for the 120m long site at St Peters marina.

V. Design Process

A. Design steps

The design process to fit the sheet pile wall *must* establish the following:

- The approximated ground and hydro-static pressures acting on the wall from the active and passive ground and water forces
- The moments about the wall that would lead to critical overturning and the assumed need for the an anchorage system
- The depth at which the anchorage system(s) should be employed
- The required embedment depth of each pile to counter the critical moment of overturning with aid from the anchorage system
- The class, material and width of each pile

All of these design steps must include appropriate factors of safety for the following parameters and values:

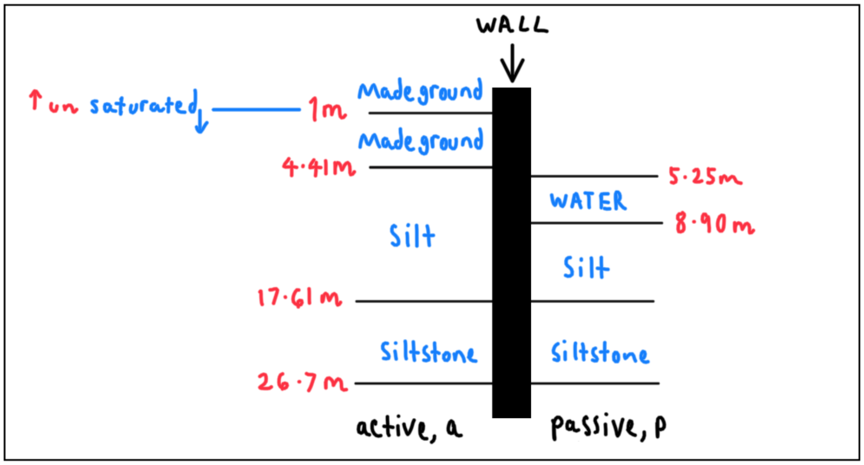
- Angles of shearing resistance: factor of safety of 1.25
- The 10kN Surcharge applied: factor of safety 1.50

Firstly the handwritten calculations are presented without any safety factors applied, and followed by computed results with the safety factors applied.

VI. Handwritten Calculations:

The handwritten calculations are shown from page 6 through 21 and depict the initial calculation methodology. Please note that the computational calculations following these handwritten notes vary in some ways where more appropriate design considerations are taken into account. The outputted values in the handwritten notes are simply for demonstrative purposes only whilst the computational outputs are conclusive.

An embedment depth of thrice the dredge depth is chosen:
$3 \times 8 \cdot 9 = 26 \cdot 7\,m$



Figure

Strata	γ (kN) p		γ (kN) a	K_a	K_p
Made ground	14	–	18	·345	3·124
Silt	18	–	21	·345	3·0
Siltstone	22	–	28	·376	3·537

Table

Total vertical pressure (kPa) = unit weight × depth,

$$\sigma_v = \gamma \cdot d \qquad (1)$$

Pore water pressure (kPa) = 10 × depth,

$$u = 10 \cdot d \text{ (if saturated)} \qquad (2)$$

Effective vertical pressure (kPa) = Total vertical pressure − pore water pressure,

$$\sigma_v' = \sigma_v - u \qquad (3)$$

For the active case:

d (m)	σ_v (kPa)	u (kPa)	σ_v' (kPa)
0	0	0	0
1	18 x 1 = 18	0 (unsaturated)	18 − 0 = 18
4·41	18 x 4·41 = 79·38	10 x 3·41 = 34·1	79·38 − 34·1 = 45·28
17·61	79·38 + 21 (17·61 − 4·41) = 356·58	10 x 16·61 = 166·1	356·58 − 166·1 = 190·48
26·7	356·58 + 28 (26·7 − 17·61) = 611·1	10 x 25·7 = 257	611·1 − 257 = 354·1

Table

For the passive case:

d (m)	σ_v (kPa)	u (kPa)	σ_v' (kPa)
0	0	0	0
5·25	0	0	0
8·9	10 x (8·9 − 5·25) = 36·5	10 x (8·9 − 5·25) = 36·5	36·5 − 36·5 = 0
17·61	36·5 + 18 x (17·61 − 8·9) = 193·28	10 x (17·61 − 5·25) = 123·6	193·28 − 123·6 = 69·68
26·7	193·28 + 22 x (26·7 − 17·61) = 393·26	10 x (26·7 − 5·25) = 214·5	393·26 − 214·5 = 178·76

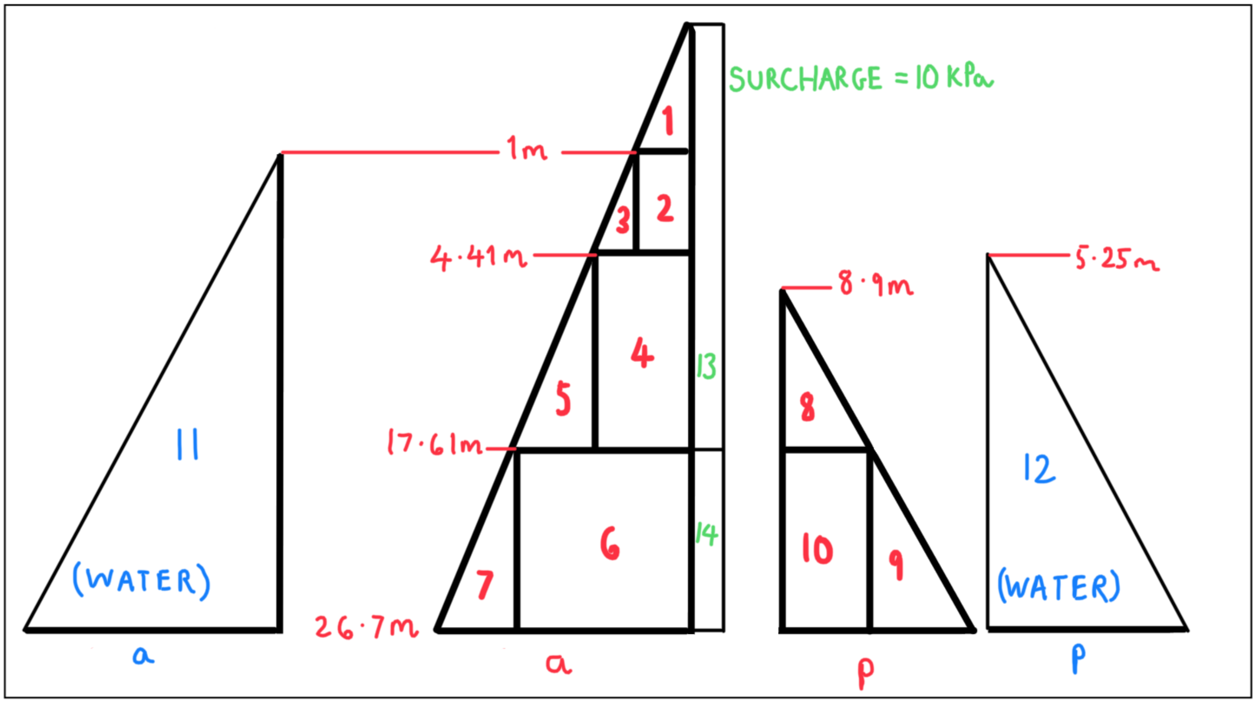
Table

Horizontal thrust (triangular) (kN) $= \frac{1}{2} \times$ Earth pressure coefficient $\times$ change in effective vertical pressure $\times$ change in depth,

$$T_\Delta = \frac{1}{2} K \times \Delta \sigma_v' \times \Delta d \qquad (4)$$

Horizontal thrust (rectangular) (kN) = Earth pressure coefficient $\times$ previous effective vertical pressure $\times$ change in depth,

$$T_\square = K \times \sigma_v'(n-1) \times \Delta d \qquad (5)$$



Figure

$$T_1 = \frac{1}{2} \times 0.345 \times 18 \times 1 = 6.21\text{ kN}$$

$$T_2 = 0.345 \times 18 \times 3.41 = 21.18\text{ kN}$$

$$T_3 = \frac{1}{2} \times 0.345 \times (45.28 - 18) \times 3.41 = 16.05\text{ kN}$$

$$T_4 = 0.345 \times 45.28 \times 13.2 = 206.21\text{ kN}$$

$$T_5 = \frac{1}{2} \times 0.345 \times (190.48 - 45.28) \times 13.2 = 330.62\text{ kN}$$

$$T_6 = 0.376 \times 190.48 \times 9.09 = 651.03\text{ kN}$$

$$T_7 = \frac{1}{2} \times 0.376 \times (354.1 - 190.48) \times 9.09 = 279.61\text{ kN}$$

$$T_8 = \frac{1}{2} \times 3 \times 69.68 \times 9.61 = 1004.44\text{ kN}$$

$$T_9 = \frac{1}{2} \times 3.537 \times (178.76 - 69.68) \times 9.09 = 1753.53\text{ kN}$$

$$T_{10} = 3.537 \times 69.68 \times 9.09 = 2240.30\text{ kN}$$

$$T_{11} = \frac{1}{2} \times 1 \times (10 \times 25.7) \times 25.7 = 3302.45\text{ kN}$$

$$T_{12} = \frac{1}{2} \times 1 \times (10 \times 21.45) \times 21.45 = 2300.51\text{ kN}$$

$$T_{13} = 10 \times 17.61 \times 0.345 = 60.75\text{ kN}$$

$$T_{14} = 10 \times 9.09 \times 0.376 = 34.18\text{ kN}$$

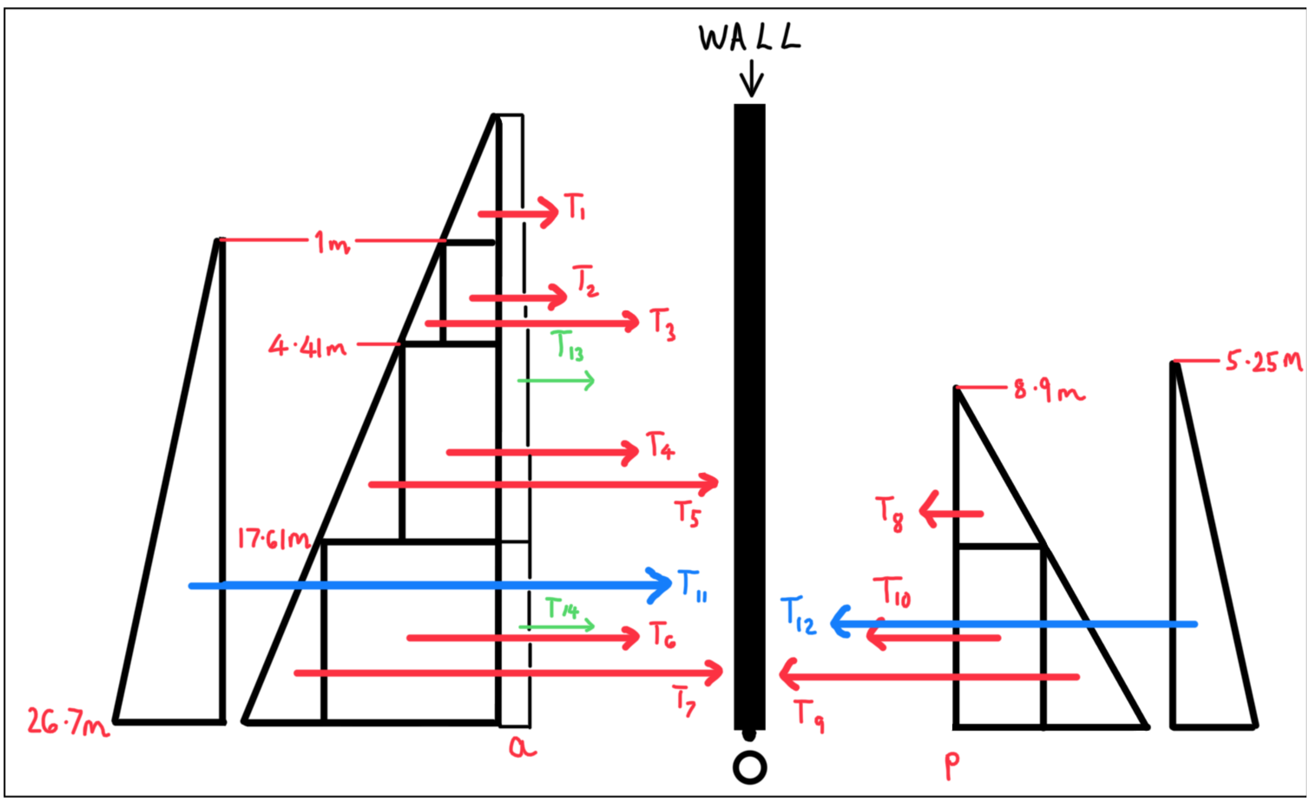
Bending Moments (about O) = Thrust x perpendicular distance

(kNm) $M = T \times y$ (6)

Note the centre of force of T_Δ acts $\frac{1}{3}$ from the base of the depth

AND

the centre of force of $T_\square$ acts $\frac{1}{2}$ from the base of the depth



Figure

Moments about O:

M_a ↻ :

1	$6 \cdot 21 \times 26 \cdot 03 = 161 \cdot 64$ kNm
2	$21 \cdot 18 \times 24 \cdot 00 = 508 \cdot 32$ kNm
3	$16 \cdot 05 \times 23 \cdot 43 = 376 \cdot 05$ kNm
4	$206 \cdot 21 \times 15 \cdot 69 = 3235 \cdot 43$ kNm
5	$330 \cdot 62 \times 13 \cdot 49 = 4460 \cdot 06$ kNm
6	$651 \cdot 03 \times 4 \cdot 55 = 2962 \cdot 19$ kNm
7	$279 \cdot 61 \times 3 \cdot 03 = 847 \cdot 22$ kNm
11	$3302 \cdot 45 \times 8 \cdot 57 = 28302 \cdot 00$ kNm
13	$60 \cdot 75 \times 17 \cdot 90 = 1087 \cdot 43$ kNm
14	$34 \cdot 18 \times 4 \cdot 55 = 155 \cdot 52$ kNm

$$\sum M_a = 42095 \cdot 86 \text{ kNm}$$

M_p ↺ :

8	$2008 \cdot 87 \times 14 \cdot 64 = 14704 \cdot 93$ kNm
9	$1753 \cdot 53 \times 3 \cdot 03 = 5313 \cdot 20$ kNm
10	$2240 \cdot 3 \times 4 \cdot 55 = 10193 \cdot 37$ kNm
12	$2300 \cdot 51 \times 7 \cdot 15 = 16448 \cdot 65$ kNm

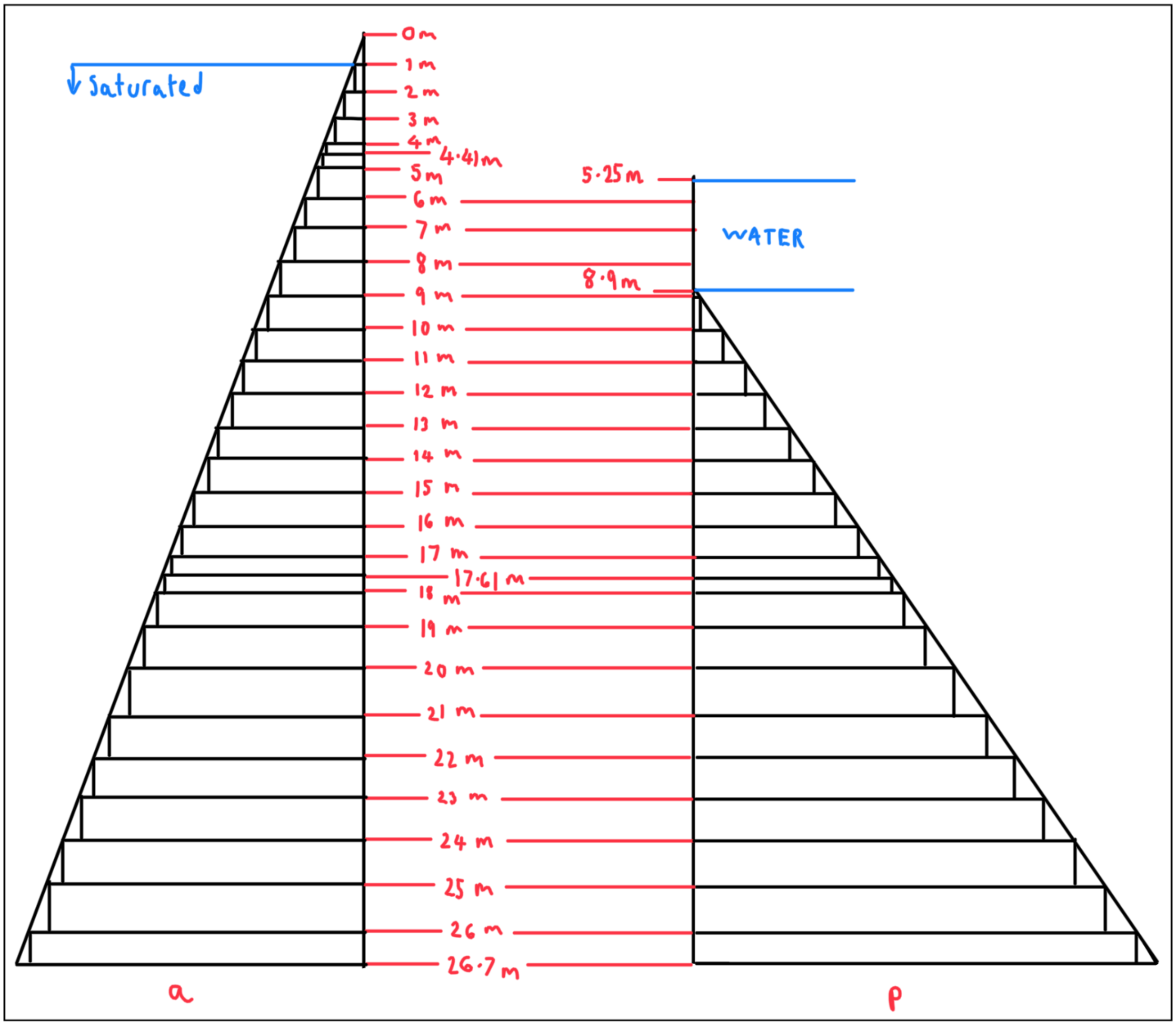
$$\sum M_p = 46659 \cdot 07 \text{ kNm}$$

$$\frac{M_p}{M_a} = \text{Factor of Safety for overturning}$$

$$\frac{46659 \cdot 07}{42095 \cdot 86} = 1 \cdot 11 \quad \text{Factor of safety}$$

Determining the maximum bending moment:

The depth of the wall is split up in to 1m intervals, accounting for the strata/water layer changes to find an approximation of the maximum bending moment acting on the wall and the depth at which it acts (to the closest metre)

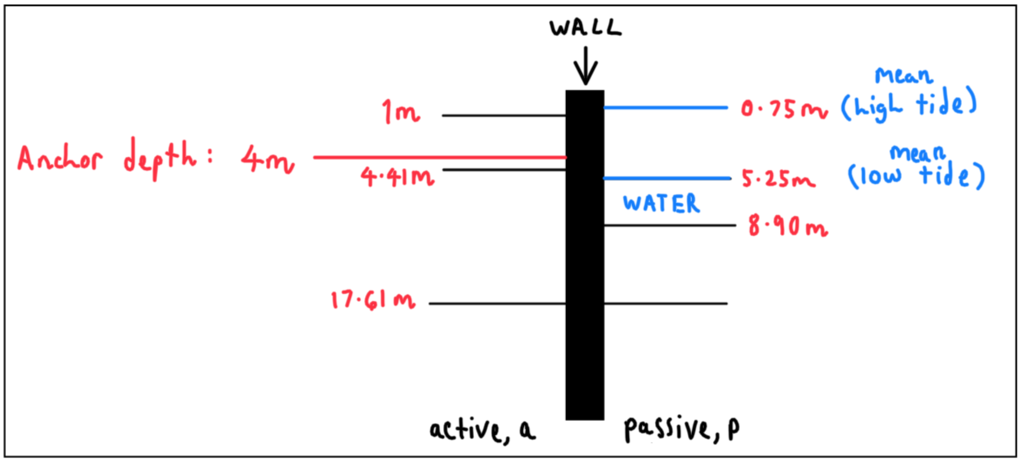


Figure

A maximum moment of 6074.81 KNm has been calculated at a depth of 19.62m

Finding the anchorage force

A suitable anchor depth is chosen at 4m as to allow for dry installation during a period of low tide



Figure

Moments are taken about the anchor depth of 4m to determine a suitable embedment depth :

M me t (about 4m) = Thrust x perpendicular distance
(kNm)

$$M = T \times (D - 4) \qquad (7)$$

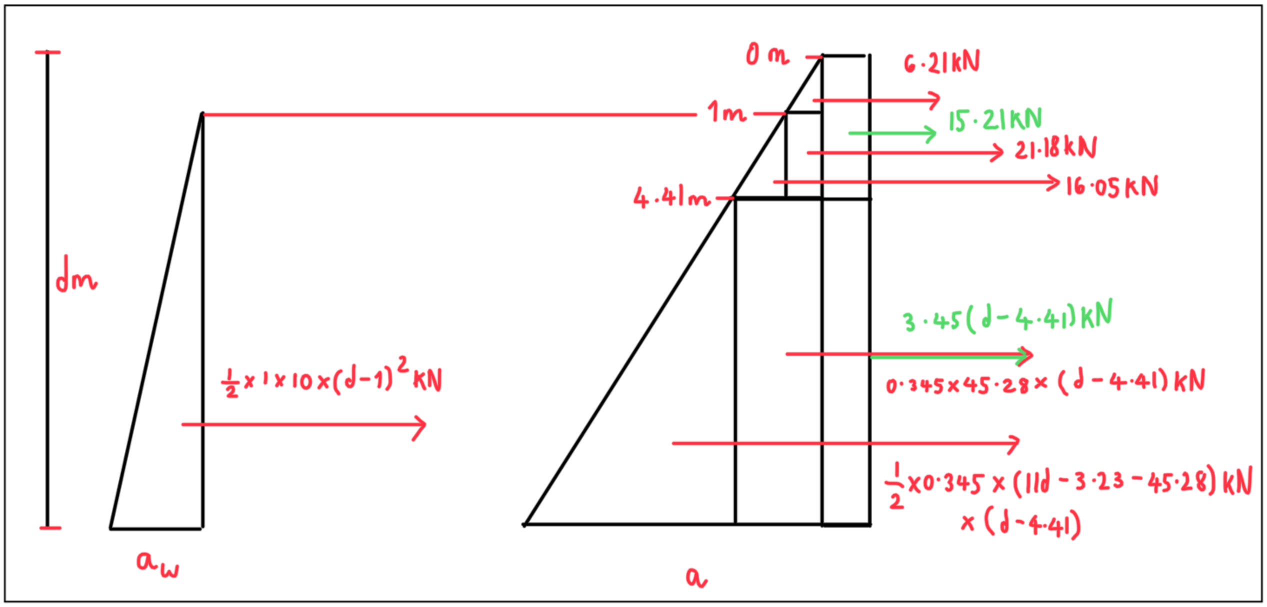
Sum of passive moments (about 4m) = Sum of (Passive thrust x Perpendicular distance)
(kNm)

$$\sum_i M_p = \sum_{D=0:d} (T_p \times (y_D - 4)) \qquad (8)$$

Sum of active moments (about 4m) = Sum of (active) thrust x Perpendicular distance)
(kNm)

$$\sum_i \; a = \sum_{D=0:d} (T_a \times (y_D - 4)) \qquad (9)$$

where d must satisfy $\dfrac{\overset{\curvearrowright}{M_4}}{\overset{\curvearrowleft}{M_4}} \geqslant 1$



Figure

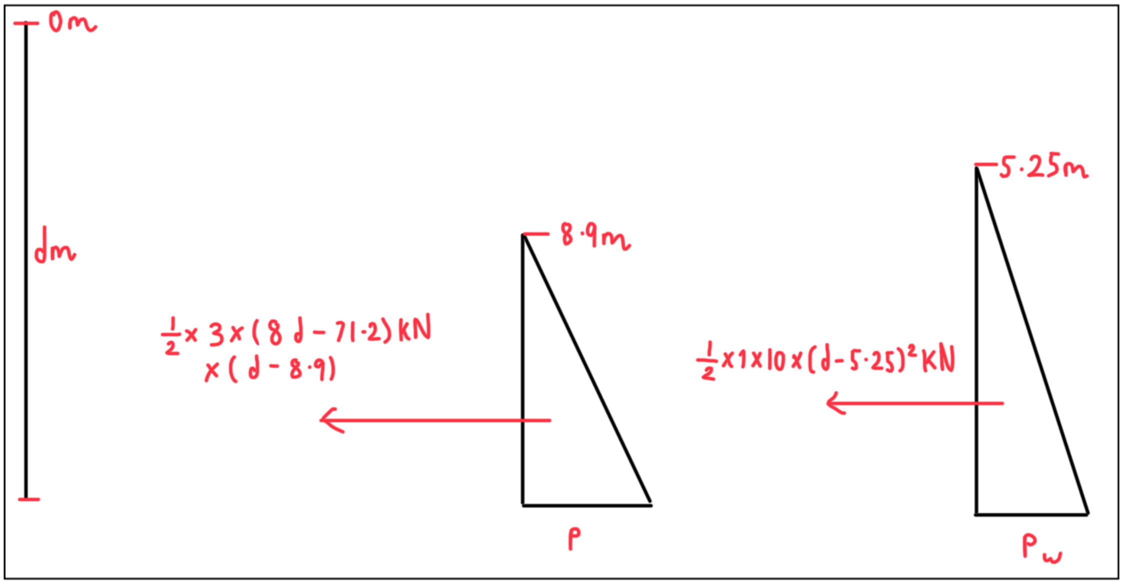
d	σ_{v_a}	u_a	σ'_{v_a}
d	$79.38 + 21(d - 4.41) = 21d - 13.23$	$10 \times (d-1) = 10d - 10$	$21d - 13.23 - 10d + 10$ $= 11d - 3.23$

Table

Active
Moments about 4m:

$$\overset{\curvearrowright}{M}_{a_4} = 6.21 \times 3\tfrac{1}{3} + 15.21 \times 1.80 + 21.18 \times 1.30 + 16.05 \times 0.726$$
$$+ (3.45d - 15.21) \times \left(4 - \frac{d-4.41}{2} - 4.41\right) + (15.62d - 68.89)\left(4 - \frac{d-4.41}{2} - 4.41\right)$$
$$+ \left(1.90d - 8.37\right) \times \left(4 - \tfrac{2}{3}(d-4.41) - 4.41\right) + 5(d-1)^2\left(4 - \tfrac{2}{3}(d-1) - 1\right)$$

$$= 76.11 + (3.45d - 15.21)(1.80 - d/2) + (15.62d - 68.89)(1.80 - d/2)$$
$$+ (1.9d - 8.37)(2.53 - 2d/3)(d - 4.41) + 5(d-1)^2(3.67 - 2d/3)$$



Figure

d	σ_{v_p}	u_p	σ_{v_p}'
d	$36.5 + 18 \times (d - 8.9)$ $= 18d - 123.7$	$10 \times (d - 5.25)$ $= 10d - 52.5$	$36.5d - 123.7 - 10d + 52.5$ $= 8d - 71.2$

Table

Passive
Moments about 4m:

$$M_{p_4} = (12d - 106.8) \times \left(4 - \frac{2}{3}(d - 8.9) - 8.9\right) + 5(d - 5.25)^2 \times \left(4 - \frac{2}{3}(d - 5.25) - 5.25\right)$$

$$= (12d - 10.8\ (1.03 - 2d/3)(d - 8.9) + 5(d - 5.25)^2(2.25 - 2d/3)$$

$$\text{Let } \overset{\curvearrowright}{M_{a_4}} = \overset{\curvearrowleft}{M_{p_4}}$$

$$76.11 + (3.45d - 15.21)(1.80 - d/2) + (15.62d - 68.89)(1.80 - d/2)$$
$$+ (1.9d - 8.37)(2.53 - 2d/3) + 5(d - 7)^2(3.67 - 2d/3)$$

$$=$$

$$(12d - 106.8)\left(1.03 - \frac{2d}{3}\right) + 5(d - 5.25)^2\left(2.25 - \frac{2d}{3}\right)$$

$$\boxed{\text{where} \quad 8.9 < d < 17.61}$$

Solving for d, $d = 1.63,\ 7.49,\ 14.90$

$\therefore\ d = 14.90$

Total embedment depth

Equilibrium of Forces

To achieve an equilibrium of forces the anchor must achieve a horizontal force that makes the:

Active horizontal forces = Passive horizontal forces

$$\text{i.e.}\quad T_p - T_{anchor} = T_p \qquad (10)$$

Therefore forces must be summed to the calculated embedment depth, $d \rightarrow 14.90m$

Taking the forces in Figure B6 and inputting $d = 14.9$, the resulting active forces on the wall are as follow:

6.21 kN, 15.21 kN, 21.18 kN, 16.05 kN,

$3.45(14.9 - 4.41) = 36.19\text{ kN},$

$0.345 \times 45.28 \times (14.9 - 4.41) = 163.87\text{ kN},$

$0.5 \times 0.345 \times (11 \times 14.9 - 3.23 - 45.28) \times (14.9 - 4.41) = 208.84\text{ kN},$

$0.5 \times 1 \times 10 \times (14.9 - 1)^2 = 966.05\text{ kN}$

and the passive forces on the wall are as follow:

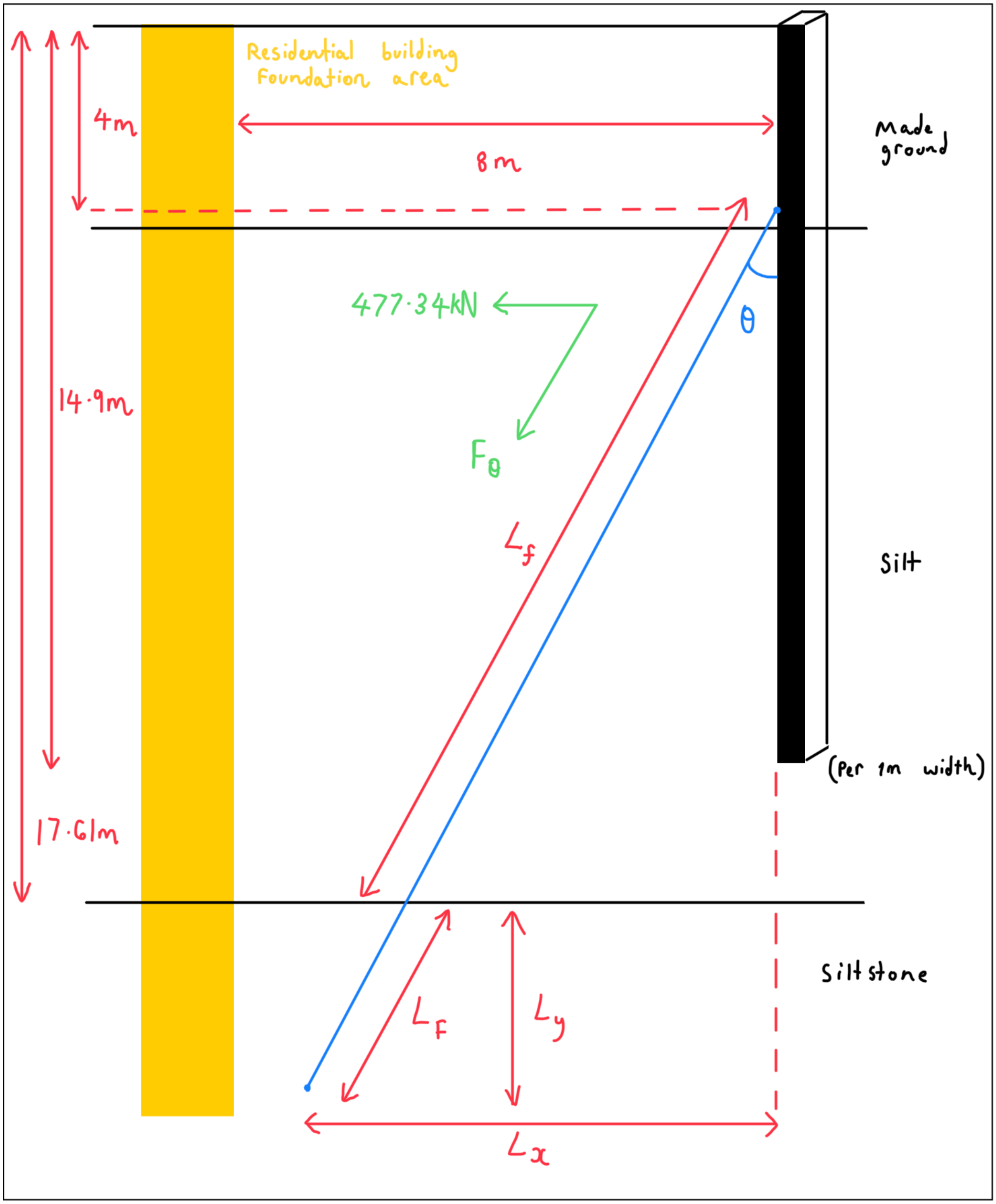
$0.5 \times 3 \times (8 \times 14.9 - 71.2) \times (14.9 - 8.9) = 432.00\text{ kN},$

$0.5 \times 1 \times 10 (14.9 - 5.25)^2 = 465.61\text{ kN}$

Using equation A10:

$$36.19 + 163.87 + 208.84 + 966.05 - T_{anchor} = 432 + 465.61$$

$$T_{anchor} = 477.34\text{ kN}$$



Figure

To find the angular force, F_θ, of the anchor the anchor angle must be

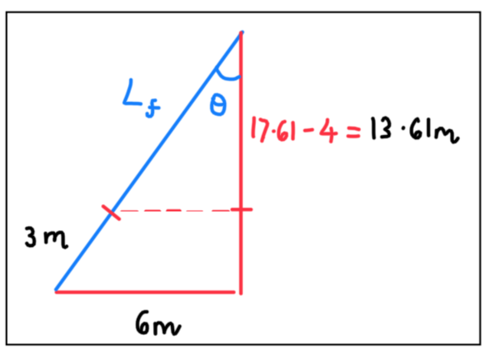
Found. To find the angle, the site and ground must be considered:

- The area under the residential building must be avoided by the anchor as to avoid any interference with foundations in the ground

  An L_x of 6m is chosen

- The anchor must have a suitable fixed length, L_F, so that sufficient bonding to the bedrock occurs

  An L_F of 3m is chosen



Figure

$$\sin\theta = \frac{6}{3 + L_f}$$

$$\cos\theta = \frac{13.61}{L_f}$$

$$L_f = \frac{13.61}{\cos\theta}$$

$$\sin\theta\left(3 + \frac{1.61}{\cos\theta}\right) = 6$$

$$3\sin\theta + 13.61\frac{\sin\theta}{\cos\theta} = 6$$

$$3\sin\theta\cos\theta + 13.61\sin\theta - 6\cos\theta = 0$$

Let $x = \sin\theta$; $\cos\theta = \sqrt{1-x^2}$

$(\cos^2\theta + \sin^2\theta = 1)$

$$\therefore\ 3x\sqrt{1-x} + 13.61x - 6\sqrt{1-x^2} = 0$$

Computationally Solved polynomial

$$x = 0.34306 = \sin\theta,$$

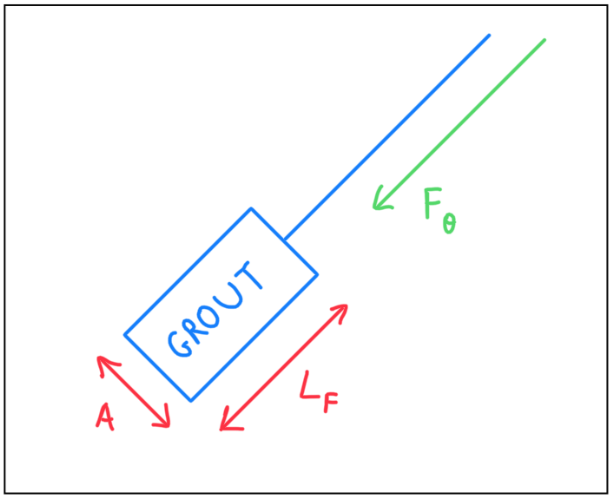
$$\theta = 20.06^\circ$$

$$L_f = 14.49\text{m}$$

So the total length of the anchor, $L_f + L_F$:

$$14.49 + 3 = 17.49\text{m}$$

and $$F_\theta = \frac{477.34}{\sin(20.06°)} = 1391.65\ \text{kN}$$



Figure

Ultimate bond force, $F_\theta = 1.392$ MN

Ultimate bond stress, $\sigma_\theta = 120 - 200$ psi

$= 0.827 - 1.379$ MPa

$$\text{Bond area} = \frac{\text{Ultimate bond force}}{\text{Ultimate bond stress}},$$

$$A = \frac{F_\theta}{\sigma_\theta} \tag{11}$$

The lower estimation of σ_θ will be used: 0.827 MPa:

$$A = \frac{1.392}{0.827} = 1.683\ m^2$$

Calculations for permanent waling behind wall

$$\text{Section modulus} = \frac{\text{Maximum moment}}{\text{yield stress}},$$

$$S = \frac{M_{max}}{\sigma_Y}$$

VII. Computational Calculations:

A. Nomenclature

D_{total}	Total depth
D_{sat}	Depth of saturation
D_{anchor}	Depth of anchor
S	Surcharge
σ_v	Total vertical pressure
u_{water}	Water vertical pressure
σ'_v	Effective vertical pressure
c'	Cohesion
ϕ_a, ϕ_p	Angles of shearing resistance for active and passive sides
u_a, u_p	Unit weights for active/passive sides
k_a, k_p	Earth pressure coefficients for active/passive sides
T_{tri_a}, T_{tri_p}	Triangular thrusts for active/passive sides
T_{rec_a}, T_{rec_p}	Rectangular thrusts for active/passive sides
M_a	Bending moment for active side
M_p	Bending moment for passive side
M	Net bending moment
γ_S	Safety factor for surcharge
γ_ϕ	Safety factor for angle of shearing resistance
γ_c	Safety factor for cohesion

B. Factors of Safety

Factors of safety are applied to all the computational calculations and values seen in the ground model (see Figure 7 on page 4) are used to establish conservative estimates of the ground unit soil depths. All factors of safety follow **Eurocode 7 guidelines** [4].

$$\tan \phi_f = \frac{\tan \phi}{\gamma_\phi} \quad (1)$$

$$c_f = \frac{c'}{\gamma_c} \quad (2)$$

$$S_f = S \times \gamma_S \quad (3)$$

where f represents the factored value

The advised factor of safety for unit weight is 1, so no factors are hence applied to the unit weights:

The angles of shearing Resistance are found from equation 1 where the factor of safety for the shearing Resistance, γ_ϕ, is set to 1.25:

Depth of layer (from top of pile), D	Unit Weight, u_p-u_a	Angle of Shearing Resistance, ϕ_a-ϕ_p	Factored Angle of Shearing Resistance, ϕ_{af}-ϕ_{pf}
0.61m - 5.20m	14kN - 18kN	29.5º - 31.0º	24.4º - 25.7º
5.20m - 18.03m	18kN - 21kN	29.5º - 30.0º	24.4º - 24.8º
18.03m -	22kN - 28kN	27.0º - 34.0º	22.2º - 28.4º

Table II: Value ranges of unit weights and factored angles of shearing resistance for the three strata groups [9]&[5]

The cohesion values are taken from the laboratory tests carried out on samples from borehole 4 **(see Appendix 1B)**. A value of 1.4 for γ_c and equation 2 is used to find the factored effective cohesions:

Depth of layer (from top of pile), D	Effective Cohesion, c'	Factored Effective Cohesion c'_f
0.61m - 5.20m	0 kN/m^2	0 kN/m^2
5.20m - 18.03m	0 kN/m^2	0 kN/m^2
18.03m -	8 kN/m^2	6.4 kN/m^2

Table III: Value ranges of unit weights and factored angles of shearing resistance for the three strata groups [9]&[5]

The surcharge of 10kN is simply inputted into equation 3 to find the factored surcharge value. A γ_S of 1.4 is used:

$$S_f = 10 \times 1.4 = 14kN$$

C. Earth Pressure Coefficients

The earth pressure coefficients for active (k_a) and passive (k_p) sides:

$$k_a = \frac{1 - \sin(\phi_{af})}{1 + \sin(\phi_{af})} \quad (4)$$

$$k_p = \frac{1 + \sin(\phi_{pf})}{1 - \sin(\phi_{pf})} \quad (5)$$

The earth pressure coefficients for both the active and passive cases are found using the respective equations 4 and 5 and the angles of shearing resistance seen in Table IV:

Depth of layer (from top of pile), D	Factored Angle of Shearing Resistance, ϕ_{af}-ϕ_{pf}	Active Earth Pressure Coefficient, k_a	Passive Earth Pressure Coefficient, k_p
0.61 - 5.20	24.4º - 25.7º	0.415	2.455*
5.20 - 18.03	24.4º - 24.8º	0.415	2.445*
18.03 -	22.2º - 28.4º	0.452	2.814

Table IV: Angles of Shearing Resistance and corresponding Active and Passive Earth Pressure Coefficients at Various Depths. *There is no strata on the passive side until depth is 8.9m

To calculate the following pressures and subsequent forces, the pile depth is split up uniformly into sections along the total depth - i *represents each section from 0 to the total depth*.

D. Total Vertical Pressure

The total vertical pressure for active ($\sigma_{v,a}$) and passive ($\sigma_{v,p}$) sides are calculated as:

$$\sigma_{v,a}(i) = \Delta D \cdot u_a + \sigma_{v,a}(i-1) \tag{6}$$

$$\sigma_{v,p}(i) = \Delta D \cdot u_p + \sigma_{v,p}(i-1) \tag{7}$$

E. Pore Water Pressure

The pore water pressure for both active and passive sides are calculated as:

$$u_{water}(i) = \begin{cases} \Delta D \cdot 10 + u_{water}(i-1), \text{ if saturated} \\ \text{otherwise, } 0 \end{cases}$$

(8)

(9)

F. Effective Vertical Pressure

The effective vertical pressure for active ($\sigma'_{v,a}$) and passive ($\sigma'_{v,p}$) sides:

$$\sigma'_{v,a}(i) = \sigma_{v,a}(i) - u_{water,a}(i) \tag{10}$$

$$\sigma'_{v,p}(i) = \sigma_{v,p}(i) - u_{water,p}(i) \tag{11}$$

The effective vertical pressures are calculated as a result of the subtraction of the pore water pressure from the total pressure using equations 1 and 2 to find the total vertical pressures, equation 3 to find the pore water pressure, and equations 5 and 6 to find the effective vertical pressure, respectively for the active (see table V and passive (see table XII) cases:

Depth, D (m)	Pore Water Pressure, u_w (kPa)	Total Vertical Pressure, σ_v (kPa)	Effective Vertical Pressure, σ'_v (kPa)
0.00	0.0000	14.0000	0.0000
1.00	0.0000	32.0000	32.0000
2.00	10.0000	50.0000	40.0000
3.00	20.0000	68.0000	48.0000
4.00	30.0000	86.0000	56.0000
5.00	40.0000	104.0000	64.0000
6.00	50.0000	124.4300	74.4300
7.00	60.0000	145.4300	85.4300
8.00	70.0000	166.4300	96.4300
9.00	80.0000	187.4300	107.4300
10.00	90.0000	208.4300	118.4300
11.00	100.0000	229.4300	129.4300
12.00	110.0000	250.4300	140.4300
13.00	120.0000	271.4300	151.4300
14.00	130.0000	292.4300	162.4300
15.00	140.0000	313.4300	173.4300
16.00	150.0000	334.4300	184.4300
17.00	160.0000	355.4300	195.4300
18.00	170.0000	376.4300	206.4300
19.00	180.0000	404.2900	224.2900
20.00	190.0000	432.2900	242.2900
21.00	200.0000	460.2900	260.2900
22.00	210.0000	488.2900	278.2900
23.00	220.0000	516.2900	296.2900
24.00	230.0000	544.2900	314.2900
25.00	240.0000	572.2900	332.2900
26.00	250.0000	600.2900	350.2900
26.70	257.0000	619.8900	362.8900

Table V: Active Vertical Pressures at Various Depths

Depth, D (m)	Pore Water Pressure, u_w (kPa)	Total Vertical Pressure, σ_v (kPa)	Effective Vertical Pressure, σ'_v (kPa)
0.00	0.0000	0.0000	0.0000
1.00	0.0000	0.0000	0.0000
2.00	0.0000	0.0000	0.0000
3.00	0.0000	0.0000	0.0000
4.00	0.0000	0.0000	0.0000
5.00	0.0000	0.0000	0.0000
6.00	7.5000	7.6000	0.1000
7.00	17.5000	17.6000	0.1000
8.00	27.5000	27.6000	0.1000
9.00	37.5000	38.4800	0.9800
10.00	47.5000	56.4800	8.9800
11.00	57.5000	74.4800	16.9800
12.00	67.5000	92.4800	24.9800
13.00	77.5000	110.4800	32.9800
14.00	87.5000	128.4800	40.9800
15.00	97.5000	146.4800	48.9800
16.00	107.5000	164.4800	56.9800
17.00	117.5000	182.4800	64.9800
18.00	127.5000	200.4800	72.9800
19.00	137.5000	222.4000	84.9000
20.00	147.5000	244.4000	96.9000
21.00	157.5000	266.4000	108.9000
22.00	167.5000	288.4000	120.9000
23.00	177.5000	310.4000	132.9000
24.00	187.5000	332.4000	144.9000
25.00	197.5000	354.4000	156.9000
26.00	207.5000	376.4000	168.9000
26.70	214.5000	391.8000	177.3000

Table VI: Passive Vertical Pressures at Various Depths

G. Calculating cohesion

The cohesion is calculated by:

$$c_a = c' \cdot \sqrt{K_a} \tag{12}$$

$$c_p = c' \cdot \sqrt{K_p} \tag{13}$$

H. Total Horizontal Thrust for Active and Passive Cases including Cohesion

The total horizontal thrust for the active and passive cases can be split into triangular and rectangular components.

Figure 8 shows an novel diagram of the initial triangular and rectangular forces acting on the wall from the active side where the depths are integrated at 0.1m intervals. The triangular forces can be seen acting 1/3 of the triangular height from their base and the rectangular forces acting 1/2 of the height from their base.

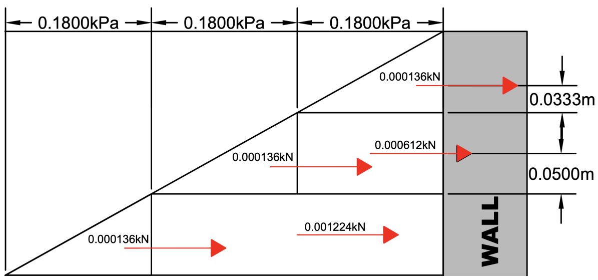


Figure 8: Diagram of the passive forces (arrows) acting on the embedded wall (note that the surcharge thrust is not shown in this diagram)

The thrusts are found by integrating the pressure between depths. This is done by treating the area as trapezoidal, or for clarity, triangles and rectangles: For the active case (a):

$$\begin{aligned} T_{tri,a}(i) = 0.5 \times ((\sigma'_{v,a}(i) \times k_a - c_a) \\ - (\sigma'_{v,a}(i-1) \times k_a - c_a)) \times \Delta D \end{aligned} \tag{14}$$

$$T_{rec,a}(i) = (\sigma'_{v,a}(i-1) \times k_a - c_a) \times \Delta D \tag{15}$$

For the passive case (p):

$$\begin{aligned} T_{tri,p}(i) = 0.5 \times ((\sigma'_{v,p}(i) \times k_p + c_p) \\ - (\sigma'_{v,p}(i-1) \times k_a + c_p)) \times \Delta D \end{aligned} \tag{16}$$

$$T_{rec,p}(i) = (\sigma'_{v,p}(i-1) \times k_p + c_p) \times \Delta D \tag{17}$$

I. Maximum Bending Moment Calculation

For each depth D_i, the bending moments are calculated as follows:

The active and passive moments due to earth pressure:

$$\begin{aligned} M_a(i) = \sum_{j=1}^{i} \Big[T_{tri_a}(j) \times \left(D_i - D_j - \frac{1}{3}\Delta D \right) \\ + T_{rec_a}(j) \times \left(D_i - D_j - \frac{1}{2}\Delta D \right) \Big] \end{aligned} \tag{18}$$

$$\begin{aligned} M_p(i) = \sum_{j=1}^{i} \Big[T_{tri_p}(j) \times \left(D_i - D_j - \frac{1}{3}\Delta D \right) \\ + T_{rec_p}(j) \times \left(D_i - D_j - \frac{1}{2}\Delta D \right) \Big] \end{aligned} \tag{19}$$

The active and passive moments due to water saturation:

$$water_a[i] = \begin{cases} 0.5 \times 10 \times (D_i - 1)^2 \times \frac{(D_i - 1)}{3}, \\ \quad \text{if } D_i > 1 \\ \text{otherwise}, 0 \end{cases} \tag{20}$$

$$water_p[i] = \begin{cases} 0.5 \times 10 \times (D_i - 5.25)^2 \times \frac{(D_i - 5.25)}{3}, \\ \quad \text{if } D_i > 5.25 \\ \text{otherwise}, 0 \end{cases} \tag{21}$$

The sum of moments at a given depth:

$$M(i) = M_a(i) - M_p(i) + water_a[i] - water_p[i] \tag{22}$$

Depth, D (m)	Triangular Thrust, T_{tri_a} (kN)	Rectangular Thrust, T_{rec_a} (kN)	Bending Moments, M_a (kNm)
0.00	0.0000	0.0000	0.0000
1.00	0.0004	0.1324	4.1311
2.00	0.0002	0.1661	22.5505
3.00	0.0002	0.1994	67.6131
4.00	0.0002	0.2327	152.6477
5.00	0.0002	0.2660	290.9830
6.00	0.0002	0.3092	496.0579
7.00	0.0002	0.3550	782.1033
8.00	0.0002	0.4008	1163.6947
9.00	0.0002	0.4465	1655.4088
10.00	0.0002	0.4923	2271.8227
11.00	0.0002	0.5381	3027.5131
12.00	0.0002	0.5838	3937.0571
13.00	0.0002	0.6296	5015.0316
14.00	0.0002	0.6754	6276.0134
15.00	0.0002	0.7212	7734.5794
16.00	0.0002	0.7669	9405.3066
17.00	0.0002	0.8127	11302.7718
18.00	0.0002	0.8585	13441.5520
19.00	0.0004	0.9698	15838.2743
20.00	0.0004	1.0512	18512.0595
21.00	0.0004	1.1325	21481.0431
22.00	0.0004	1.2139	24763.3601
23.00	0.0004	1.2952	28377.1453
24.00	0.0004	1.3766	32340.5338
25.00	0.0004	1.4579	36671.6604
26.00	0.0004	1.5393	41388.6602
26.70	0.0004	1.5962	44929.8658

Table VII: Active Moments at Various Depths

Depth, D (m)	Triangular Thrust, T_{tri_a} (kN)	Rectangular Thrust, T_{rec_a} (kN)	Bending Moments, M_a (kNm)
0.00	0.0000	0.0000	0.0000
1.00	0.0000	0.0000	0.0000
2.00	0.0000	0.0000	0.0000
3.00	0.0000	0.0000	0.0000
4.00	0.0000	0.0000	0.0000
5.00	0.0000	0.0000	0.0000
6.00	0.0000	0.0010	0.7316
7.00	0.0000	0.0010	9.0863
8.00	0.0000	0.0010	35.0410
9.00	0.0010	0.0220	88.6007
10.00	0.0010	0.2175	184.2952
11.00	0.0010	0.4131	349.4386
12.00	0.0010	0.6086	613.5845
13.00	0.0010	0.8041	1006.2867
14.00	0.0010	0.9997	1557.0985
15.00	0.0010	1.1952	2295.5738
16.00	0.0010	1.3908	3251.2661
17.00	0.0010	1.5863	4453.7290
18.00	0.0010	1.7818	5932.5161
19.00	0.0017	2.2739	7727.0492
20.00	0.0017	2.6110	9886.8094
21.00	0.0017	2.9480	12455.5030
22.00	0.0017	3.2850	15476.8340
23.00	0.0017	3.6221	18994.5061
24.00	0.0017	3.9591	23052.2235
25.00	0.0017	4.2962	27693.6899
26.00	0.0017	4.6332	32962.6094
26.70	0.0017	4.8691	37047.5910

Table VIII: Passive Moments at Various Depths

J. Establishing the Embedment Depth and Anchorage System

The moments are taken about the point at which the anchor is inserted and attached to the pile. In this case the anchor should placed above the low mean tide level to ease the insertion method during a period where the tide is low, allowing the anchor to be inserted above the river level. For this reason an anchor depth, D_{anchor}, of 4m down the wall (-0.55m AOD) is suitable. The moments about the anchor point, D_{anchor}, are calculated as follow:

The bending moments due to the water pressure:

For the active case (a):

$$\text{water\_a}[i] = \begin{cases} -\frac{1}{2} \times 10 \times (D_i - 1)^3/3, \\ \text{if } D_i = \frac{D_{anchor}-1}{3} \\ \\ \frac{1}{2} \times 10 \times (D_i - 1)^3/3, \\ \text{if } D_i = \frac{D_{total}-1}{3} \\ \\ \text{otherwise}, 0 \end{cases} \tag{23}$$

(24)

For the passive case (p):

$$\text{water\_p}[i] = \begin{cases} -\frac{1}{2} \times 10 \times (D_i - 5.25)^3/3, \\ \text{if } D_i = \frac{D_{total}-5.25}{3} \\ \\ \text{otherwise}, 0 \end{cases} \tag{25}$$

Moments Calculation

$$\begin{aligned} M_a[i] =& T_{tri\_a}[i] \times \left(\frac{\Delta D}{3} + D_i - D_{anchor}\right) \\ &+ T_{rec\_a}[i] \times \left(\frac{\Delta D}{2} + D_i - D_{anchor}\right) \\ &+ \text{water\_a}[i] \end{aligned} \tag{26}$$

$$\begin{aligned} M_p[i] =& - T_{tri\_p}[i] \times \left(\frac{\Delta D}{3} + D_i - D_{anchor}\right) \\ &- T_{rec\_p}[i] \times \left(\frac{\Delta D}{2} + D_i - D_{anchor}\right) \\ &+ \text{water\_p}[i] \end{aligned} \tag{27}$$

$$M[i] = M_a[i] + M_p[i] + M[i-1] \tag{28}$$

The moments are taken about a D_{anchor} of 4m. The sum of moments are calculated until the total moments about 4m becomes zero and the factor of safety is, hence, equal to 1. That is to say:

$$\frac{M_{positive}[i]}{M_{negative}[i]} = 1 \tag{29}$$

Table IX shows the factors of safety at various depths with a suitable embedment depth found at 19.03m, closest to the nearest 0.01m.

Depth, D (m)	Factor of safety
7.00	0.1771
8.00	0.2052
9.00	0.2412
10.00	0.3105
11.00	0.4013
12.00	0.4938
13.00	0.5815
14.00	0.6625
15.00	0.7366
16.00	0.8041
17.00	0.8656
18.00	0.9217
19.00	0.9981
19.03	1.0003
20.00	1.0697
21.00	1.1358
22.00	1.1967
23.00	1.2527
24.00	1.3044
25.00	1.3520
26.00	1.3960
26.70	1.4248

Table IX: Factor of safety at Various Depths where Factor of safety is the overturning moments divided by the restoring moments about a depth of 4m

K. Net Horizontal Force Calculation

To determine the required anchor force, the forces acting on the pile must be calculated to the embedment depth. The net force acting at any depth is equal to:

$$\begin{aligned} Force_{Net}[i] = & \; T_{tri\_a}[i] + T_{rec\_a}[i] \\ & - T_{tri\_p}[i] - T_{rec\_p}[i] \\ & + water_a[i] + water_p[i] \\ & + Force_{Net}[i-1] \end{aligned} \tag{30}$$

To achieve equilibrium of forces:

$$Force_{Net} + Force_{Anchor} = 0 \tag{31}$$

The anchor force is found to be $537.97kN$. Note this is the horizontal force that the anchor must create in the direction of the active side, acting against the active forces, to create the equilibrium.

Accounting for this anchor force, the bending moments and the shear forces can be seen to be plotted against the depth in Figures 12 and 13 respectively.

L. Sheet Specification

Now the maximum absolute moment is 1143.10kN occurring at 9.72m as seen in Figure 12.

The maximum moment, M_{max}, is used to determine the yield stress, σ_{yield}, of the steel used for the sheet pile. The section modulus,S, of the sheet pile design is needed.

$$\sigma_{yield} = \frac{M_{max}}{S} \tag{32}$$

A hat-type Nippon steel sheet pile will be used [2].

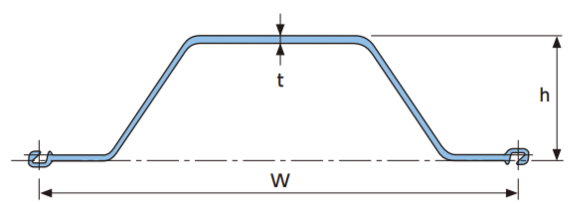


Figure 9: Nippon Steel Hat-type sheet cross section.

Moment of Inertia (cm^4/m)	Section Modulus (cm^4/m)	Unit Mass (kg/m^2)	Maximum Length (m)
45000	2450	163	15
Width, w (mm)	Height, h (mm)	Thickness, t (mm)	
900	368	15	

Table X: Material Properties for NS-SP-45H

Using equation with a section modulus of 2450(cm^4/m) and taking the maximum moment as 1143.10kN, the maximum yield stress that the wall will be subject to comes out to be 466.57MPa.

A suitable steel, SYW390, is used for the wall (https://www.china-steelpiling.com/steel-grade.html)

Material Grade	Minimum Yield Strength (kN)	Minimum Tensile Strength (kN)	Elongation $(\%)$
SYW390	490	540	15

Table XI: Material Properties for grade SYW390 steel [8]

It is essential that the steel used in the sheet piles maintain a minimum yield stress integrity of 466.57MPa to ensure no yielding and risk failure. SYW390 grade steel [8] can be used to satisfy this. A suitable grade such as, *S500GP*, could also be used as a European alternative [3].

M. Anchor Specification

A GEWI Threadbar is used with the following specification (dywidag)

Nominal Diameter (mm)	Steel Grade (N/mm^2)	Ultimate Strength (kN)	Yield Strength (kN)	Design Resistance (kN)	Weight (kg/m)
63.5	555/700	2217	1758	1529	20.38

Table XII: Material Proprties for GEWI anchor

The bond area is calculated from the ultimate bond stress for siltstone. An approximated value of 0.827MPa is chosen [6]. Given that the distance between each anchor will be 0.9m (one placed at each sheet trough, uniformly) and a partial factor of 3 is applied to the anchor force, a 50º anchor slope is chosen and the axial anchor value is determined by:

$$F_{\text{anchor}_{\text{axial}}} = 3 \times 0.9 \times \frac{F_{\text{anchor}_{\text{horizontal}}}}{\sin(50°)} \tag{33}$$

This outputs an axial force of 1896.13kN.

$$Area_{bond} = \frac{F_{anchor_{axial}}}{\sigma_{bond}} \tag{34}$$

This outputs a bond area of 2.29m^2.

To finally determine the diameter of the bonded/fixed end, the bond area can derive the diameter 0.1784m for a bond length of 4.0930m.

A Dwyidag bolt of diameter 0.1m will be used to affix each anchor to the meeting point of two hat-type sections. A capping beam will be positioned along the interior of the wall to hold the anchors in place and maintain structural integrity across the wall.

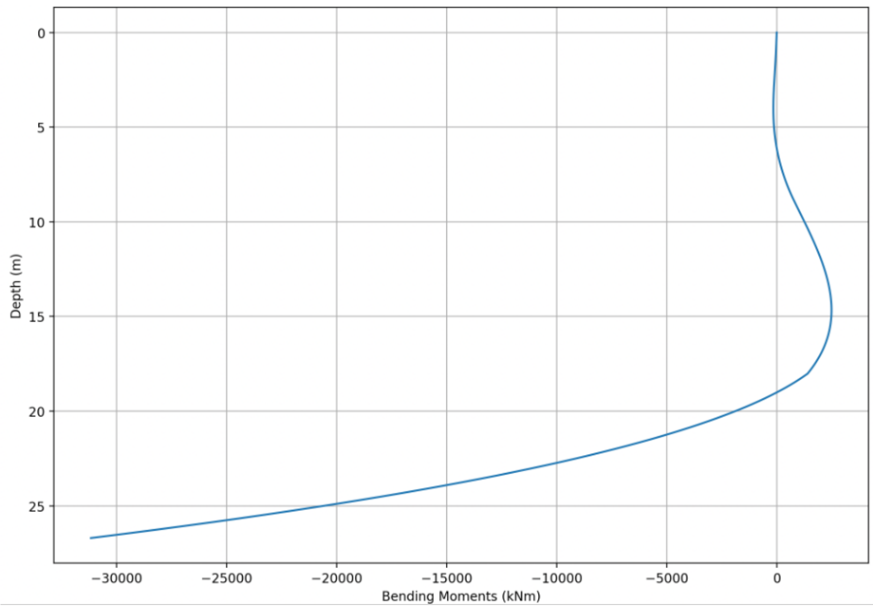


Figure 11: Graph showing the total moments about 4m (point of anchorage) considered at various depths, where the total moments are 0 at 19.03m

VIII. Construction Methodology

A. Introduction

In the construction of the sheet pile walls at St Peter's Marina, it is essential to employ a methodological approach. This section is dedicated to outlining a comprehensive construction methodology that emphasizes safety, efficiency, environmental sustainability, and structural integrity.

B. Pre-Construction Phase

1) Site Preparation and Setup: Before commencing the actual construction, the site must be prepared. This involves ensuring clear access routes for construction machinery and materials. A thorough site clearing is necessary to remove any debris, vegetation, or obstacles that could impede construction activities. Designating a staging area is crucial for organizing equipment, material storage, and on-site facilities, while ensuring that they do not disrupt marina operations. As a part of the preparation, implementing comprehensive safety measures such as signage, barriers, and restricted access zones is mandatory to secure the construction site.

2) Surveys, Markings, and Preparatory Studies: A thorough reassessment of the site's geotechnical characteristics; conducting additional borehole tests to confirm soil and subsoil conditions; ensuring the suitability of the chosen sheet piling technique. Furthermore; a detailed utility mapping is crucial to identify and mark the location of underground utilities; thereby preventing any accidental damage during the excavation and piling processes.

C. Construction Phase

1) Driving of Sheet Piles: The core of the construction phase is the driving of sheet piles into the ground. To initiate, a convoy of transportation vehicles will deliver the sheet piles to the site. Subsequent to the delivery, the deployment of piling rigs and cranes at their designated positions will take place. Utilizing either vibratory or impact hammers, the sheet piles will be driven into the soil to the predetermined depth in accordance with the layout plan. During this process, continuous monitoring of the piles' straightness and alignment is essential to ensure the integrity of the wall. In scenarios involving dense soil layers, the application of lubrication or water jetting may be required to facilitate the penetration of the piles.

2) Anchoring System Installation: The anchoring system plays a pivotal role in the stability of the sheet pile wall. Installation of GEWI Threadbar anchors will be carried out at a depth of approximately 4 meters. The anchors will be strategically placed at specified intervals to provide optimal support to the wall. Each anchor will undergo rigorous load tests to ensure compliance with design requirements. Once the anchors are successfully installed and tested, they will be connected to the sheet piles using

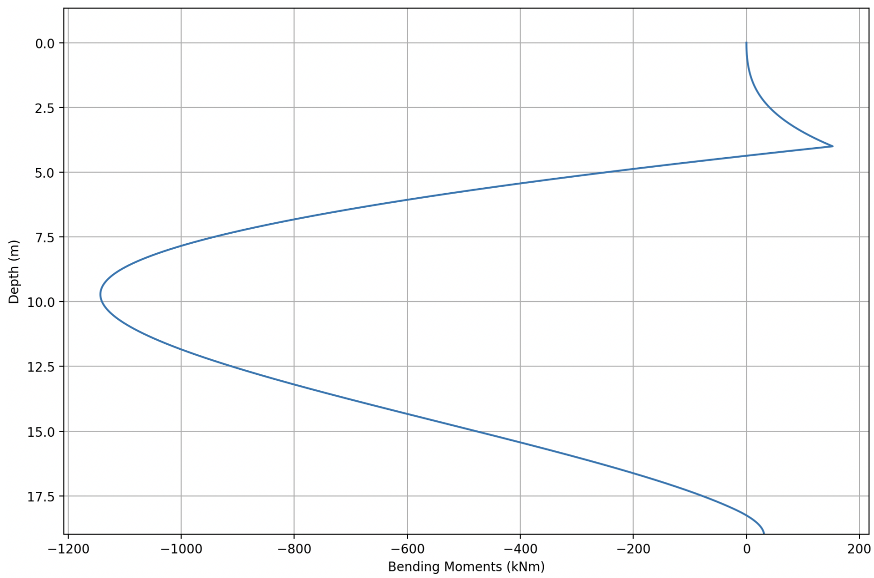


Figure 12: Graph showing the total moments about various depths for the anchored wall with a maximum absolute moment of 1143.10kN at 9.72m

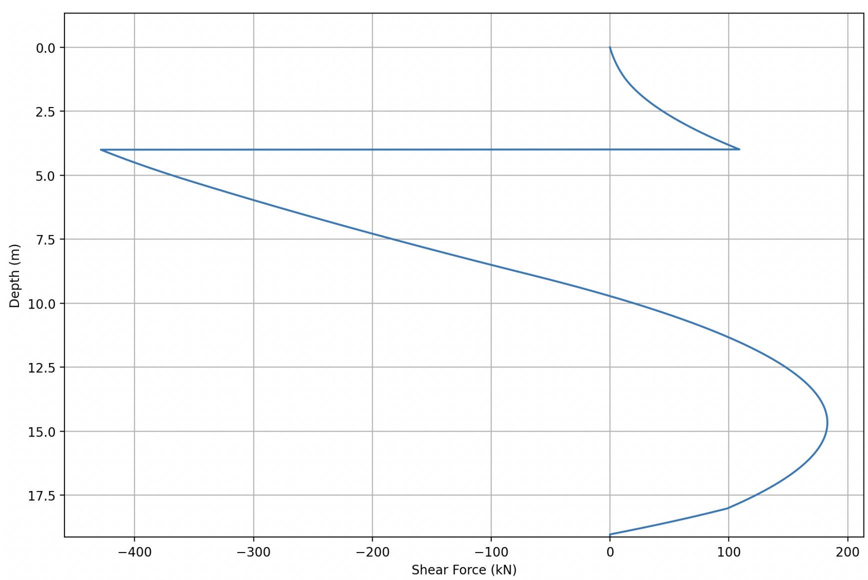


Figure 13: Graph showing the total shear force acting at various depths

appropriate tie rods and fastening mechanisms, thereby securing the wall against lateral pressures.

3) Quality Control and Assurance: Quality control is paramount throughout the construction phase. Regular use of surveying equipment to monitor any movement of the piles during installation is mandatory. The construction team will carry out routine inspections to detect any potential defects or misalignments in the sheet piles. Such vigilance is crucial to maintain the integrity of the structure and ensure that it adheres to the planned design specifications.

D. Post-Construction Phase

1) Backfilling and Compaction: Once the sheet piles are securely in place, backfilling of the excavated area behind the wall will commence. The backfill material will be selected based on its compatibility with the site conditions and its ability to provide adequate support to the wall. Proper compaction techniques will be employed to ensure that the backfill material is densely packed, thereby preventing future settlement issues.

2) Environmental Restoration and Monitoring: Post-construction environmental restoration and monitoring are crucial, especially given the marina's ecological sensitivity. The team will monitor the water quality within the marina to identify and address any contamination that might have occurred during the construction. Additionally, any impact on local flora and fauna will be thoroughly inspected and mitigated. Efforts will be made to restore the site to its original environmental state or better.

3) Final Inspection, Documentation, and Handover: The concluding phase involves a comprehensive inspection of the newly constructed wall. This includes a detailed review of the anchor systems, connections, and the overall structural integrity of the wall. Following the successful completion of the inspection, a detailed project report will be prepared, summarizing the construction process, methodologies employed, and any challenges encountered and overcome. This report, along with the fully inspected and approved sheet pile wall, will then be officially handed over to the marina authorities.

E. Conclusion

The construction methodology for the sheet pile walls at St Peter's Marina is a testament to the commitment to precision, safety, and environmental stewardship. This detailed methodology encompasses all critical phases from pre-construction to the final handover, ensuring the wall's longevity, functionality, and its ability to harmoniously coexist with the marina's natural environment. While tailored for St Peter's Marina, this methodology could potentially serve as a guideline for similar maritime construction projects.

IX. Safety Considerations in Construction of Sheet Pile Walls

A. Introduction

Safety is a paramount concern in the construction of sheet pile walls at St Peter's Marina. This section delves into the strategies and protocols implemented to ensure the safety of workers, visitors, and the surrounding environment during the construction process. Emphasizing risk assessment, preventive measures, and emergency response protocols, this section aligns with the overarching aim of maintaining the highest standards of safety throughout the project's duration.

B. Risk Assessment and Management

1) Hazard Identification: A comprehensive risk assessment will be conducted prior to the commencement of construction activities. This involves identifying potential hazards related to the sheet piling work, such as risks from heavy machinery operation, working near water, and handling large structural components.

2) Safety Planning: Based on the identified risks, a detailed safety plan will be developed. This plan will outline preventive measures, including safe work procedures, usage of protective gear, and regular safety training for all personnel.

C. Preventive Measures

1) Worker Safety:

- **Training and Awareness:** All personnel will undergo thorough training in safety procedures and emergency response. Regular safety drills and briefings will be conducted to ensure awareness and preparedness.
- **Personal Protective Equipment (PPE):** Mandatory use of PPE such as helmets, safety vests, gloves, and steel-toed boots will be enforced. Specialized equipment like life jackets will be provided for work near water.

2) Machinery and Equipment Safety:

- **Regular Inspections:** Construction machinery and equipment, including cranes and pile driving hammers, will be subjected to rigorous pre-use inspections to ensure they are in optimal working condition.
- **Operating Protocols:** Strict adherence to machinery operating protocols will be mandated to prevent accidents. This includes ensuring that only trained and authorized personnel operate heavy machinery.

3) Worksite Safety:

- **Barricades and Signage:** Clear signage and barricades will be installed to demarcate hazardous areas, guiding personnel and visitors to stay within safe zones.
- **Emergency Access:** The site layout will include designated emergency access routes to ensure prompt response in case of accidents.

D. Emergency Response Protocols

1) Medical Emergencies: A fully equipped first-aid station will be established on-site. In case of medical emergencies, trained first-aid personnel will provide immediate assistance, and arrangements with local hospitals will be made for emergency transport.
2) Environmental Spills and Containment: In the event of environmental spills or contaminations, especially into the marina waters, an immediate containment and remediation plan will be activated. This plan includes spill containment kits and protocols to minimize environmental impact.

E. Monitoring and Continuous Improvement

1) Safety Audits: Regular safety audits will be conducted to assess the effectiveness of safety measures. These audits will help identify areas for improvement and implement corrective actions promptly.
2) Feedback Mechanism: A feedback mechanism will be established for workers to report potential hazards or suggest safety improvements. This approach encourages a proactive safety culture where all team members contribute to a safer work environment.

X. Sustainability

A. Sustainable Design and Planning

- **Low-Impact Design:** The design of the retaining wall incorporates features that reduce environmental disturbance, such as minimal land excavation and the use of terrain-adaptive construction techniques.
- **Life Cycle Assessment:** A comprehensive life cycle assessment (LCA) will be conducted to evaluate the environmental impacts associated with the wall's materials and construction processes over its entire life span.

B. Material Selection and Use

- **Eco-friendly Materials:** Preference is given to materials with a lower environmental footprint, such as recycled steel for sheet piles and anchors.
- **Resource Efficiency:** Efficient use of materials is prioritized to minimize waste, with plans for recycling or reusing surplus or scrap materials.
- **Sourcing Locally:** Where possible, materials will be sourced from local suppliers to reduce transportation-related carbon emissions.

C. Construction Process

- **Reducing Carbon Footprint:** Utilizing construction equipment that is fuel-efficient or powered by alternative energy sources to minimize carbon emissions during construction.
- **Waste Management:** Implementing stringent waste management protocols to ensure that construction waste is properly sorted, recycled, or disposed of in an environmentally responsible manner.
- **Water Management:** Efficient water usage and management on site, including controlling sediment runoff into the marina waters.

D. Operational Sustainability

- **Longevity and Maintenance:** The wall is designed for durability and ease of maintenance, reducing the need for frequent repairs or replacements and hence minimizing environmental impact over its lifetime.
- **Environmental Monitoring:** Post-construction, ongoing monitoring will be implemented to observe the wall's impact on local ecosystems and take corrective actions if adverse effects are detected.

E. Community and Ecosystem Integration

- **Community Engagement:** Engaging with local communities to ensure that the project aligns with local environmental and social goals.
- **Ecosystem Protection:** Measures will be taken to protect the aquatic and terrestrial ecosystems around the marina, ensuring that the construction and presence of the wall do not disrupt local wildlife habitats.

Please refer to DRAWING No. ENGI-3351-VBCN68-1 and DRAWING No. ENGI-3351-VBCN68-2 alongisde this report.

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