CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 1	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Material Properties

Characteristic strength of concrete, f_{cu} ($\leq$ 60N/mm^2; HSC N/A)	40	N/mm^2	OK
Yield strength of longitudinal steel, f_y	460	N/mm^2	
Yield strength of shear link steel, f_{yv}	460	N/mm^2	
Type of concrete and density, ρ_c — Normal Weight	24	kN/m^3	
Concrete modulus of elasticity, E_c — Cracked Long Term (Creep)	7000	N/mm^2	
Steel sheet pile steel grade	S270GP		
Steel sheet pile design strength, p_y	270	N/mm^2	
Steel sheet pile modulus of elasticity, E_s	205000	N/mm^2	

Factor of Safety

Factor of safety method — FOS on Overall Effect			
Factor of safety (soil strength), FOS_1 = {$FOS_{c'}$, $FOS_{\tan\phi'}$, FOS_{Su}, $FOS_{\tan\delta'}$}			
Factor of safety, $FOS_{c'}$ = 1.2		1.0	*BS8002*
Factor of safety, $FOS_{\tan\phi'}$ = 1.2		1.0	*BS8002*
Factor of safety, FOS_{Su} = 1.5		1.0	*BS8002*
Factor of safety, $FOS_{\tan\delta'}$ = 1.2		1.0	*BS8002*
Factor of safety (overall net (effective) bearing), FOS_2 (	2.5	2.5	
Factor of safety (overall sliding resistance), FOS_3 (usual	1.4	1.4	
Factor of safety (overall uplift resistance), FOS_4 (usually	1.0	1.0	
Factor of safety (overall overturning resistance for conc	1.4	1.4	
Factor of safety (base heave instability), FOS_6 (usually	1.2	1.2	*Kohsaka & Ishiz*
Loading factor, K (between 1.20 and 1.40)		1.40	*BS8110*

Note loading factor K multiplies SLS loads for ULS loads for section (reinforcement) design; *cl. 2.4.3.1.1*

Soil Description

Water unit weight, γ_w = 9.81kN/m^3	9.8	kN/m^3	
Soil name — User Defined			
Dry bulk unit weight, γ_{dry}	18.0	kN/m^3	
Saturated bulk unit weight, γ_{sat}	20.0	kN/m^3	
Undrained shear strength limit to adopt ? — Lower Limit			
Undrained shear strength (lower limit) (factored), $S_{u,ll}$ / FOS_{Su}	50.0	kPa	
Undrained shear strength (upper limit) (factored), $S_{u,ul}$ / FOS_{Su}	50.0	kPa	
Undrained shear strength limit adopted (factored), S_u / FOS_{Su} = {$S_{u,ll}/FOS_{Su}$, (	50.0	kPa	
Note that S_u can be obtained from SPT (Stroud) values;			*Tomlinson*
Ignore effective cohesion (factored), c' / $FOS_{c'}$? — Exclude	0.0	kPa	
Effective angle of shear resistance (factored), $\tan^{-1}$ ($\tan\phi'$ / $FOS_{\tan\phi'}$)	30.0	degrees	
Note that ϕ' can be obtained from SPT (Peck) or CPT (Durgunoglu and Mitchell) values;			*Tomlinson*
Effective angle of friction on — 0.66ø' (Insitu Concrete Active Zone - Soil Interface)	19.8	degrees	
Effective angle of friction on — 0.50ø' (Insitu Concrete Passive Zone - Soil Interface)	15.0	degrees	
Effective angle of friction on — 1.00ø' (Cast in Place Concrete - Soil Interface)	30.0	degrees	

Note that for Coulomb (but not Rankine) theory, δ' reduces K_a and increases K_p, conservatively ignored;

Note that for both Coulomb and Rankine theories, δ' considered on active wall, passive wall and base;

Undrained, Drained or Empirical Overall (Effective) Bearing Capacity

Gross (effective) bearing capacity, q_f or q_f'	250	kPa

Note that the gross (effective) bearing capacity above is unfactored;

Analysis Method

Undrained or drained analysis ?	Drained Analysis		
For clays, perform undrained and drained analyses;			
For sands / gravels, perform drained analysis;			
For rocks, perform drained analysis;			
Rankine or Coulomb theory for K_a and K_p (for drained analysis only	Coulomb Theory		
At Rest or Active K_a (for drained analysis only) ?	Active		
Evaluate overall uplift resistance ?	Yes		

Note that overall uplift resistance (mid third) is conservative to overturning, thus may in certain instances be deemed to be overconservative and subsequently ignored;

Retaining Wall Dimensions

Retaining wall type	Concrete Cantilever Retaining Wall		
Depth of retained soil (active earth pressure), d_a	3.900	m	
Depth of resisting soil (passive earth pressure), d_p	1.200	m	
Note that d_p should be specified in anticipation of possible unplanned excavation to the minimum of the larger of 0.5m and 0.10d_a;			*BS8002*
Dry or saturated soil bulk unit weight ?	Saturated Soil		
Depth of water table from surface of retained soil, d_{aw}	2.400	m	**OK**
Depth of water table from surface of resisting soil, d_{pw}	0.000	m	**OK**
Note that d_{aw} and d_{pw} are required to be positive downwards; Underwater retaining wall not catered for;			
Angle of soil slope from horizontal, β (<= 90°)	0.0	degrees	**OK**

Retaining Wall Reinforcement

Cover to all (wall internal face) reinforcement, $cover_1$ (usually MAX(25, ϕ))	25	mm	
Cover to all (wall external face) reinforcement, $cover_2$ (usually 40 exposed; 5(	50	mm	
Cover to all (base bottom and side) reinforcement, $cover_3$ (usually 75)	50	mm	
Cover to all (base top) reinforcement, $cover_4$ (usually MAX(25, ϕ) internal; 40	50	mm	

Retaining Wall SLS Loading

Surcharge at surface (on active side), $p_{s,a}$ (minimum 10kPa)	10	kPa	*BS8002*
Surcharge at surface (on passive side), $p_{s,p}$	0	kPa	*cl. 3.3.4.1*

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.: jXXX	Sheet No.: 3	Rev.
		Member/Location	
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.	
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Executive Summary

Overall net (effective) bearing capacity	**15%**	**OK**
Overall sliding resistance capacity	**97%**	**OK**
Overall uplift resistance capacity	**96%**	**OK**
Overall overturning resistance capacity	**80%**	**OK**

Concrete Gravity Retaining Wall

Note concrete gravity retaining wall reinforcement design not required since there is no axial, shear or bending effects;

Concrete Cantilever Retaining Wall

Bending moment in stem	**56%**	**OK**
% Min longitudinal reinforcement in stem	**25%**	**OK**
Ultimate shear stress in stem	**7%**	**OK**
Shear design capacity in stem	**49%**	**OK**
Bending moment in heel	**0%**	**OK**
% Min longitudinal reinforcement in heel	**58%**	**OK**
Ultimate shear stress in heel	**0%**	**OK**
Shear design capacity in heel	**0%**	**OK**
Bending moment in toe	**81%**	**OK**
% Min longitudinal reinforcement in toe	**58%**	**OK**
Ultimate shear stress in toe	**2%**	**OK**
Shear design capacity in toe	**26%**	**OK**
Deflection requirements in stem	**133%**	**NOT OK**
Detailing requirements	**OK**	

Concrete or Steel Cantilever Embedded Retaining Wall

Iteration for moment equilibrium calculation	**N/A**	
Bending moment in wall	**N/A**	**N/A**
% Min longitudinal reinforcement in wall	**N/A**	**N/A**
Ultimate shear stress in wall	**N/A**	**N/A**
Shear design capacity in wall	**N/A**	**N/A**
Deflection requirements in wall (first principles)	**N/A**	**N/A**
Deflection requirements in wall (BS8110 method)	**N/A**	**N/A**
Detailing requirements	**N/A**	

Concrete Propped (Basement) Retaining Wall

Bending moment in stem	**N/A**	**N/A**
% Min longitudinal reinforcement in stem	**N/A**	**N/A**
Ultimate shear stress in stem	**N/A**	**N/A**
Shear design capacity in stem	**N/A**	**N/A**
Deflection requirements in stem	**N/A**	**N/A**
Detailing requirements	**N/A**	

Concrete or Steel Propped (Basement) Embedded Retaining Wall

Iteration for moment equilibrium calculation	**N/A**	
Bending moment in wall	**N/A**	**N/A**
% Min longitudinal reinforcement in wall	**N/A**	**N/A**
Ultimate shear stress in wall	**N/A**	**N/A**
Shear design capacity in wall	**N/A**	**N/A**
Deflection requirements in wall (first principles)	**N/A**	**N/A**
Deflection requirements in wall (BS8110 method)	**N/A**	**N/A**
Detailing requirements	**N/A**	

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.		Rev.
		jXXX	4		
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.	

Overall utilisation summary		133%	
% Sagging reinforcement in stem		0.52	%
% Sagging reinforcement in heel		0.22	%
% Sagging reinforcement in toe		0.22	%
% Vertical reinforcement in pile / wall		N/A	%
Estimated steel reinforcement quantity		38	kg/m^3
[Note that steel quantity in kg/m^3 can be obtained from 78.5 x % rebar];			
Material cost: concrete, c	250 $units/m^3$	steel, s 3500	units/tonne
Reinforced concrete material cost = c+(est. rebar quant).s		383	$units/m^3$
Design total length of embedded retaining wall, L_T		N/A	m

Note that further to the above, the susceptibility of the retaining wall to the following should also be investigated: -

(i) base heave instability

(ii) piping instability

(iii) slope instability

(iv) water pressure on sheet piled excavations in clay

Factor of Safety Method for Retaining Walls

Two approaches to the application of factor of safety are adopted in the calculations herein, i.e.

FOS on soil strength, or

FOS on overall effect;

Note that FOS on soil strength in lieu of FOS on overall effect effectively results in a double counting of FOS / load factor for ULS member design since the ULS design is subject to the loading factor, K. Although conservative, should economy be required, FOS on overall effect should be employed in lieu of FOS on soil strength for ULS member design, although both approaches should be investigated for the overall stability effects;

The former method i.e. the FOS on soil strength is described as the strength factor method, F_s; Tomlinson

Method 2 is referred to as the factor of safety on shear strength (F_s) method and is applied to embedded walls.

The strength factor method represents the Eurocode 7 approach where the value of F_s corresponds to the partial factors for materials (γ_m). The characteristic soil strength could be taken as corresponding to the values in design approach A where the CIRIA F_s values are much the same as the partial factors in Eurocode 7 (see Table 2.2).

Table 2.2 Partial factors on material properties for conventional design situations for ultimate limit states

Material property	Partial factor γ_m
Tan ϕ	(1.2–1.25)
c', C_u	(1.5–1.8)

For the cantilever condition (Fig. 5.25(*a*)) the depth d_o must satisfy the equation

$$P_P L_P + P_{WP} L_{WP} = P_A L_A + P_{WA} L_{WA}. \qquad (5.1)$$

When the wall is acting as a cantilever (Fig. 5.25(*a*)) a concentrated force *R* is applied at the toe to represent the passive resistance mobilized at the rear due to fixity at the toe (the method is also known as the fixed earth support method as given in the British Steel handbook for the design of sheet pile walls.

Design depth $d = d_o$ (5.2)

Then d is increased further by 20 per cent to allow for the simplifying assumption of the force R.

The latter method i.e. the FOS on overall effect is described as the factor on moments method, F_p; Tomlinson

Method 3 is applicable to embedded and free-standing walls (Fig. 5.26). It is known as the factor of safety on moments (F_p) method, and also as the CP2 method, the latter referring to the Institution of Structural Engineers' Code of Practice: *Earth-retaining Structures*. This was published in 1951, but its revision was long delayed because of lack of agreement on the many controversial aspects of retaining wall design.*

The depth of embedment or the proportions of the wall stem and base are calculated, when taking moments about the toe to satisfy the equation

$$F_p = \frac{\text{Restoring moments}}{\text{Overturning moments}} \qquad (5.3)$$

Usually only net water pressures are included for overturning moments so that for embedded walls

$$F_p = \frac{P_P L_P}{P_A L_A + P_{WA} L_{WA} - P_W L_W}. \qquad (5.4)$$

The design embedment $d = d_o$ is increased by 20 per cent for cantilevered walls but not for propped walls.

For free-standing walls

$$F_p = \frac{P_P L_P + Wb}{P_A L_A + P_{WA} L_{WA} - P_{WP} L_{WP}}. \qquad (5.5)$$

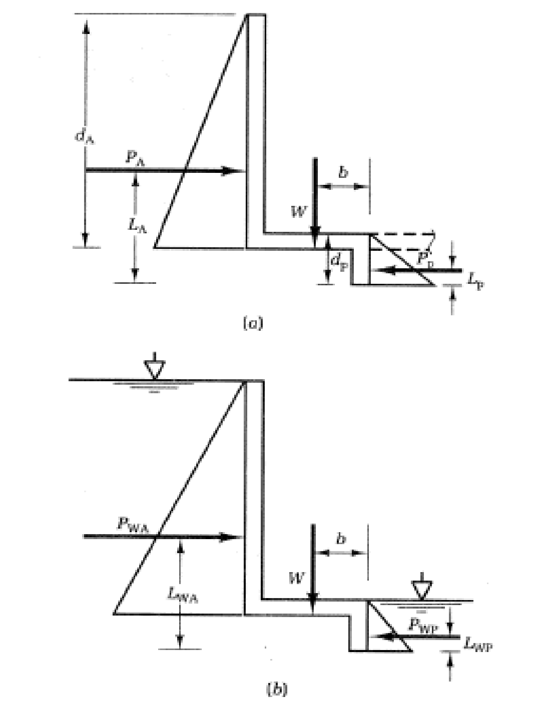


Fig. 5.26 Assumed soil and water pressure distribution on free-standing retaining walls. (*a*) Effective soil pressures. (*b*) Water pressure (no seepage).

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 6	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

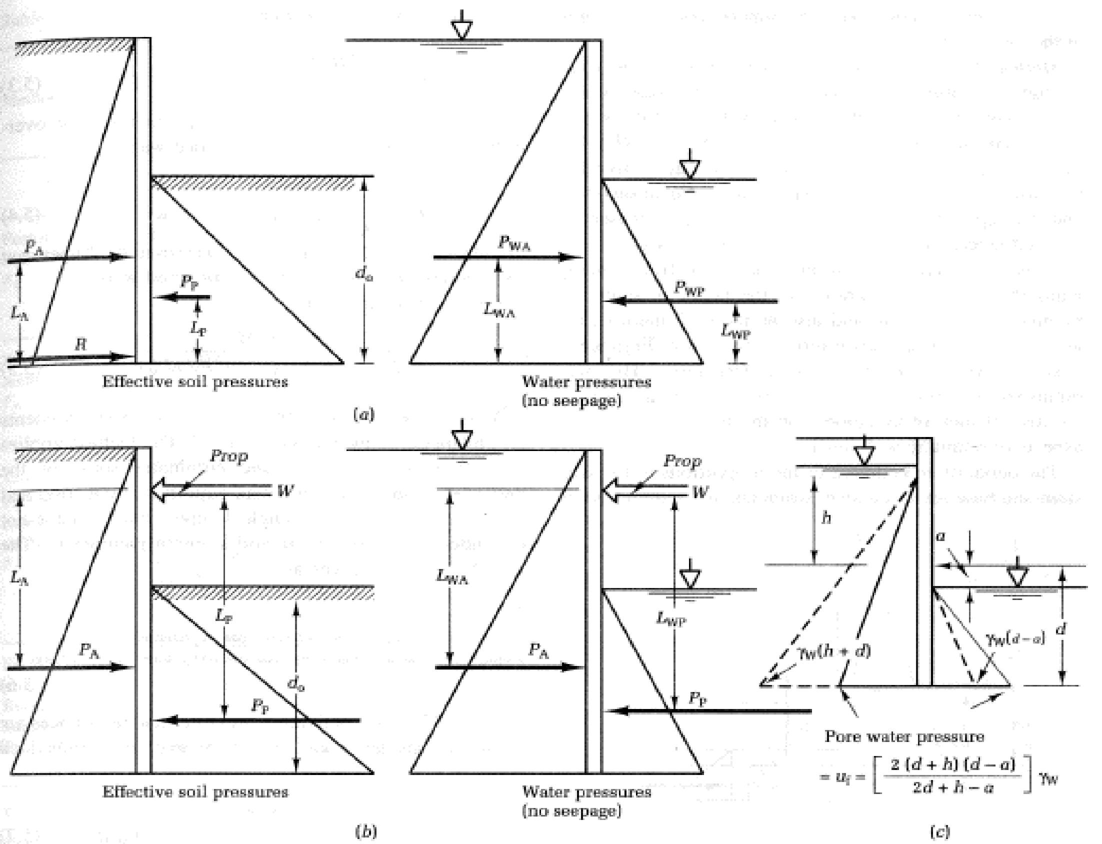


Fig. 5.25 Assumed soil and water pressure distribution on embedded retaining walls. (*a*) Cantilevered. (*b*) Propped. (*c*) Pore-water pressure distribution for seepage below toe of wall.

Table 5.2 Recommended factors of safety for determining a stable wall geometry in stiff clays (after Padfield and Mair[5.18])

Method		Design approach A: Recommended range for moderately conservative parameters (c', ϕ', or c_u)		Design approach B: Recommended minimum values for worst credible parameters ($c' = 0$, ϕ')		Comments
		Temporary works	Permanent works	Temporary works	Permanent works	
Factor on embedment F_d	Effective stress	1.1–1.2 (usually 1.2)	1.2–1.6 (usually 1.5)	Not recommended	1.2	This method is empirical. It should always be checked against one of the other methods
	Total stress†	2.0	—		—	
Strength factor method F_s	Effective stress	1.1–1.2 (usually 1.2 except for ϕ' >30° when lower value may be used)	1.2–1.5 (usually 1.5 except for ϕ' >30° when lower value may be used)	1.0	1.2	The mobilized angle of wall friction δ_m, and wall adhesion, C_{wm}, should also be reduced (see Section 7.3.2)‡
	Total stress†	1.5	—	—	—	
Factor on moments: CP2 method F_p	Effective stress	1.2–1.5	1.5–2.0	1.0	1.2–1.5	These recommended F_p values vary with ϕ' to be generally consistent with usual values of F_s and F_r
	$\phi' \geq 30°$	1.5	2.0	1.0	1.5	
	$\phi' = 20–30°$	1.2–1.5	1.5–2.0	1.0	1.2–1.5	
	$\phi' \leq 20°$	1.2	1.5	1.0	1.2	
	Total stress†	2.0	—	—	—	
Factor on moments: Burland–Potts method F_r	Effective stress	1.3–1.5 (usually 1.5)	1.5–2.0 (usually 2.0)	1.0	1.5	Not yet tested for cantilevers. A relatively new method with which little design experience has been obtained
	Total stress†	2.0	—	—	—	

† Total stress factors are speculative, and they should be treated with caution. ‡ of CIRIA report 104.

Notes
(1) In any situation where significant uncertainty exists, whether design approach A or B is adopted, a sensitivity study is always recommended, so that an appreciation of the importance of various parameters can be gained.
(2) Only a few of the factors of safety recommended in Table 5.1 are based on extensive practical experience, and even this experience is recent. At present, there is no well-documented evidence of the long-term performance of walls constructed in stiff clays, particularly in relation to serviceability and movements. However, the factors recommended in the table are based on the present framework of current knowledge and good practice.
(3) Of the four factors of safety recommended, only F_p depends on the value of ϕ'.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	7	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Scheme Design

Preliminary sizing of retaining walls

Gravity retaining walls – Typically have a base width of about 60–80 per cent of the retained height.

Propped embedded retaining walls – There are 16 methods for the design of these walls depending on whether they are considered flexible (sheet piling) or rigid (concrete diaphragm). A reasonable approach is to use BS 8002 Free Earth Support Method which takes moments about the prop position, followed by the Burland & Potts Method as a check. Any tension crack height is limited to the position of the prop.

Embedded retaining walls – Must be designed for fixed earth support where passive pressures are generated on the rear of the wall, at the toe. An approximate design method is to design the wall with free earth support by the same method as the propped wall but with moments taken at the foot of the embedded wall, before adding 20 per cent extra depth as an estimate of the extra depth required for the fixed earth condition.

Retaining walls

Rankine's theory on lateral earth pressure is most commonly used for retaining wall design, but Coulomb's theory is easier to apply for complex loading conditions. The most difficult part of Rankine's theory is the appropriate selection of the coefficient of lateral earth pressure, which depends on whether the wall is able to move. Typically where sufficient movement of a retaining wall is likely and acceptable, 'active' and 'passive' pressures can be assumed, but where movement is unlikely or unacceptable, the earth pressures should be considered 'at rest'. Active pressure will be mobilized if the wall moves 0.25–1 per cent of the wall height, while passive pressure will require movements of 2–4 per cent in dense sand or 10–15 per cent in loose sand. As it is normally difficult to assume that passive pressure will be mobilized, unless it is absolutely necessary for stability (e.g. embedded walls), the restraining effects of passive pressures are often ignored in analysis. The main implications of Rankine's theory are that the engineer must predict the deflected shape, to be able to predict the forces which will be applied to the wall.

Rankine's theory assumes that movement occurs, that the wall has a smooth back, that the retained ground surface is horizontal and that the soil is conhesionless, so that: $\sigma_h = k\sigma_v$

For soil at rest, $k = k_o$, for active pressure, $k = k_a$ and for passive pressure, $k = k_p$.

$$k_o \approx 1 - \sin\phi \qquad k_a = \frac{(1-\sin\phi)}{(1+\sin\phi)} \qquad k_p = \frac{1}{k_a} = \frac{(1+\sin\phi)}{(1-\sin\phi)}$$

For cohesive soil, k_o should be factored by the overconsolidation ratio, $OCR = \sqrt{\frac{\text{pre-consolidation pressure}}{\text{effective overburden pressure}}}$.

Typical k_o values are 0.35 for dense sand, 0.6 for loose sand, 0.5 to 0.6 for normally consolidated clay and 1.0 to 2.8 for overconsolidated clays such as London clay. The value of k_o depends on the geological history of the soil and should be obtained from a geotechnical engineer.

Rankine's theory can be adapted for cohesive soils, which can shrink away from the wall and reduce active pressures at the top of the wall as a tension 'crack' forms. Theoretically the soil pressures over the height of the tension crack can be omitted from the design, but in practice the crack is likely to fill with water, rehydrate the clay and remobilize the lateral pressure of the soil. The height of crack is $h_c = 2c'/(\gamma\sqrt{k_a})$ for drained conditions and $h_c = 2C_u/\gamma$ for undrained conditions.

Earth pressures greater than active

It is not normal to design the wall for stability for earth pressures exceeding active values (with factors of safety). In granular soils, the rotation needed to reduce earth pressures from K_0 to active is only about 10^{-3} radians (1mm per metre height) and it would be difficult to make a wall/foundation combination that will prevent this unless the wall is well propped.

Some walls may therefore be designed on the basis of active pressures only. However, earth pressures may creep up due to vibratory loads such as traffic and in these cases it is sensible to use K_0 in the calculation of earth pressures for structural design. The Department of Transport require the wall stem to be designed for K_0, *and apply a further load factor* for ULS design. This seems rather 'over the top'.

If the fill is to be compacted behind the wall, the wall structure must be designed for compaction pressures, though it is again likely that rotation or flexure of the wall will, in reality, reduce these to some extent. If very heavy compaction is to be applied close to the wall, and displacement must be minimal, higher earth pressures should be used in the stability calculation, or a detailed displacement analysis should be carried out.

RULES OF THUMB

Minimum thickness

Preferred minimum thickness of walls and slabs: 300mm
Where thicker consider surface zones of 200mm each face for reinforcement to control shrinkage/thermal cracking.

Reinforcement

Typically for water resistant walls: T16 @ 200 c/c in both faces and in both directions
or T12 @ 150 c/c in both faces and in both directions

Standard cover

Assumed concrete grade 35 (This should be a minimum)
Put the horizontal reinforcement furthest from earth face.

Face	Cover (mm)
Earth face of walls where shuttered	50
Earth face of walls (cast against earth)	75
External exposed faces of walls	40
Bottom and sides to base	75
Internal faces	Greater of 25 or bar diameter

Waterstops / waterbars

- Required by BS 8102 for grade 1 basements with concrete design to BS 8110
- Give extra "comfort" at construction joints, otherwise total reliance on workmanship
- Not essential but often desirable
- Use external waterstop for basements (preferred)
- Can use centrestop in vertical construction if necessary (e.g. swimming pool), must be carefully supported/kept in place.

3.2.2 Cover (BS 8110, Cl.3.3 - Tables 3.2 and 3.3; EC2, Cl.4.1)

Horizontal bars are placed further from the earth face. Cover is measured to the outer layer of reinforcement.

Earth face: 50mm) See Model Detail MRW1
External exposed face: 40mm)
Note: There may be particular requirements for concrete grade / mix in contaminated ground.

Internal face: 25mm or bar diameter, whichever is greater.
Note: This may be modified by particular internal environment.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	9	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

BARE ESSENTIALS RANKINE EXAM ORIENTED

- discontinuous σ_a'/σ_p' diagrams
- water pressure forces if drained analysis.
- factor passive resistance

(A) Continuous σ_v' diagram

$\sigma_v' = \sigma_v - u$ (drained) or $\sigma_v' = \sigma_v$ (undrained)

(B) Discontinuous σ_a'/σ_p' diagram computing above and below each interface

$\sigma_a' = K_a \sigma_v' - 2c'\sqrt{K_a}$ (drained) or $\sigma_a = \sigma_v - 2S_u$ (undrained)

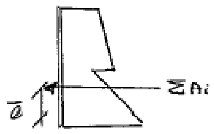
$\sigma_p' = K_p \sigma_v' + 2c'\sqrt{K_p}$ (drained) or $\sigma_p = \sigma_v + 2S_u$ (undrained)

where $K_a = \dfrac{1-\sin\phi'}{1+\sin\phi'}$

$K_p = \dfrac{1+\sin\phi'}{1-\sin\phi'} = \dfrac{1}{K_a}$

remember $K_p > K_a$ always

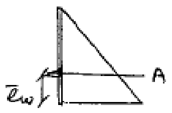
(C) Obtain earth force normal to wall from area under σ_a'/σ_p' diagram



Force normal to wall $= \sum A_i$

Line of action $\bar{e} = \left(\sum A_i e_i\right) / \sum A_i$

(D) Obtain force normal to wall due to water pressure u (for drained case only)

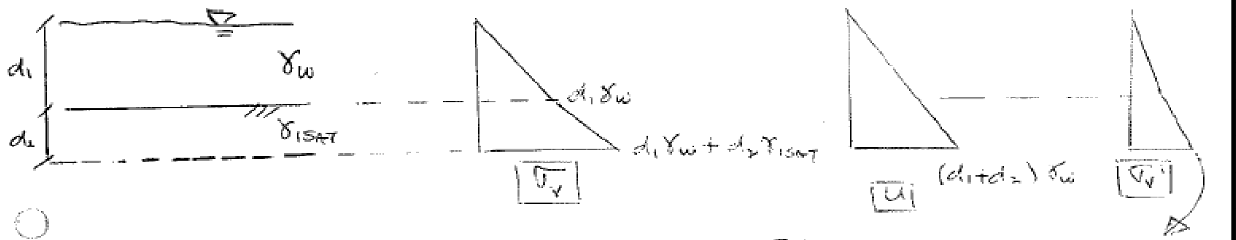


Force normal to wall = A

Line of action $\bar{e}_w = \frac{1}{3}$ from base.

Notes on computing $\sigma_v' = \sigma_v - u$

It may be better to compute σ_v' by drawing σ_v then subtracting u. Consider



$\sigma_v' = \sigma_v - u$

$= d_1\gamma_w + d_2\gamma_{SAT} - (d_1+d_2)\gamma_w$

Whereas if we had used

$\sigma_v' = d_1\gamma_w + d_2(\gamma_{SAT} - \gamma_w)$ method, it is incorrect.

This occurs when the water table is above all soil. The separation method is also more general in the case of seepage as $\frac{du}{dz} \neq \gamma_w$ anymore.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	10	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

BARE ESSENTIALS COULOMB OR CAQUOT-KERISEL EXAM ORIENTED

- discontinuous σ_a' / σ_p' diagram
- water pressure forces if drained only
- factor passive resistance
- modify K_a and K_p by $(\sin\alpha \cos\delta)^{-1}$

(A) Continuous σ_v' diagram

$\sigma_v' = \sigma_v - u$ (drained) or $\sigma_v' = \sigma_v$ (undrained)

(B) Discontinuous σ_a' / σ_p' diagram computing above and below each interface

$$\sigma_a' = \frac{K_a}{\sin\alpha \cos\delta} \sigma_v' \text{ (drained)} \quad \text{or} \quad \sigma_a = \sigma_v - 2S_u \text{ (undrained)}$$

$$\sigma_p' = \frac{K_p}{\sin\alpha \cos\delta} \sigma_v' \text{ (drained)} \quad \text{or} \quad \sigma_p = \sigma_v + 2S_u \text{ (undrained)}$$

Note :- Cohesion c' in drained case has been ignored $c' = 0$.

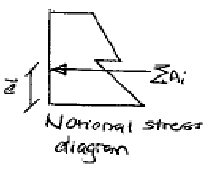
:- Values of K_a and K_p quoted from lecture notes or past year papers differ from that of standard text books but are related by

$$(K_a \text{ or } K_p)_{\text{standard books}} = \frac{(K_a \text{ or } K_p)_{\text{lecturer}}}{\sin\alpha \cos\delta}$$

Obtain K_a, K_p from tables or equation in notes.

(C) Obtain earth force at δ to normal of wall from area under σ_a' / σ_p' diagram

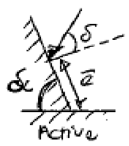
(i) Magnitude :

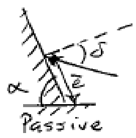


Force normal to wall $= \Sigma A_i$

Line of action $\bar{e} = (\Sigma A_i e_i) / \Sigma A_i$ along wall along wall

(ii) Inclination :

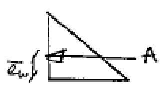




At δ to normal to wall.

(D) Obtain force normal to wall due to water pressure u (for drained case only)

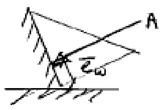
(i) Magnitude :



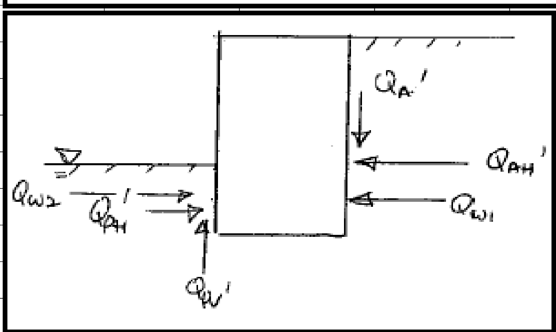
Force normal to wall $= A$

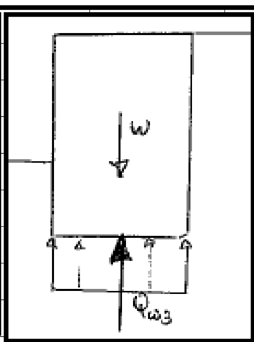
Line of action along wall $\bar{e}_w = \frac{1}{3}$ from base along wall

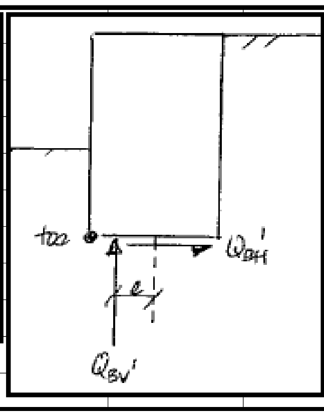
(ii) Inclination :



Normal to wall.







Relevant Retaining Wall Parameters

Relevant retaining wall type: **Concrete Cantilever Retaining Wall**

	ateral Earth Pressur	
	Angle, α (°)	Angle, γ (°)
Concrete Gravity Retaining Wall	N/A	N/A
Concrete Cantilever Retaining Wall	90.0	90.0
Concrete or Steel Cantilever Embedded Retaining Wall	N/A	N/A
Concrete Propped (Basement) Retaining Wall	N/A	N/A
Concrete or Steel Propped (Basement) Embedded Retaining Wall	N/A	N/A
	90.0	**90.0**

Gross working pressure, q_w **28** kPa

	Overall Sliding Resistance Capacity				
	$B_{width,base}'$ (m)	Vertical Load	(kN/m)	Horizontal Load	(kN/m)
Concrete Gravity Retaining Wa	N/A	$F_{concrete,gravity,v}'$	N/A	$F_{concrete,gravity,h}$	N/A
Concrete Cantilever Retaining	2.786	$F_{concrete,cantilever,v}'-W_4$	48	$F_{concrete,cantilever,h}$	19
Concrete or Steel Cantilever E	N/A	N/A	N/A	N/A	N/A
Concrete Propped (Basement)	N/A	N/A	N/A	N/A	N/A
Concrete or Steel Propped (Ba	N/A	N/A	N/A	N/A	N/A
	2.786	F_v'	**48**	F_h	**19**

Note for concrete cantilever retaining wall, surcharge not included in calculation of vertical (downward) load as it cannot be guaranteed;

Note negative F_h is effectively the additional passive resistance capacity over the active force;

	Overall Uplift Resistance Capacity	
	e_{eff} (m)	$e_{eff,limit}$ (m)
Concrete Gravity Retaining Wall	N/A	N/A
Concrete Cantilever Retaining Wall	0.657	0.683
Concrete or Steel Cantilever Embedded Retaining Wall	N/A	N/A
Concrete Propped (Basement) Retaining Wall	N/A	N/A
Concrete or Steel Propped (Basement) Embedded Retaining Wall	N/A	N/A
	0.657	**0.683**

	Overall Overturning Resistance	
	M_{ot} (kNm/m)	M_{rt} (kNm/m)
Concrete Gravity Retaining Wall	N/A	N/A
Concrete Cantilever Retaining Wall	89	111
Concrete or Steel Cantilever Embedded Retaining Wall	N/A	N/A
Concrete Propped (Basement) Retaining Wall	N/A	N/A
Concrete or Steel Propped (Basement) Embedded Retaining Wall	N/A	N/A
	89	**111**

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 12	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Undrained Lateral Earth Pressure

Bulk unit weight, $\gamma = \gamma_{dry}$ or γ_{sat}		N/A	kN/m^3	

Lateral (Active) Pressures of Retained Soil	**At Surface**	**At Base**		
Vertical total stress, $\sigma_{va} = p_{s,a}$ to $\sigma_{va} = p_{s,a} + \gamma.d_a$	N/A	N/A	kN/m^2	
Active pressure, $\sigma_{ha} = MAX(0.0 \text{ to } 4.8d_a, \sigma_{va} - 2S_u)$	N/A	N/A	kN/m^2	*BS5975*
				cl. 4.5.5.1
Active force, $F_a = 0.5 . (\sigma_{ha,surface}+\sigma_{ha,base}) . d_a$		**N/A**	kN/m	
Note earth pressure acts normal to retaining face, angle β ignored;				
Horizontal component of F_a, $F_{ah} = F_a . \sin\alpha$		**N/A**	kN/m	
Vertical (downward) component of F_a, $F_{av} = F_a . \cos\alpha$		**N/A**	kN/m	
Centroid of F_a, $e_a = d_a . (2\sigma_{ha,surface}+\sigma_{ha,base}) / [3.(\sigma_{ha,surface}+\sigma_{ha,base})]$		N/A	m	
Note the centroid e_a is measured from the base of the retained soil;				

Lateral (Passive) Pressures of Resisting Soil	**At Surface**	**At Base**	
Vertical total stress, $\sigma_{vp} = p_{s,p}$ to $\sigma_{vp} = p_{s,p} + \gamma.d_p$	N/A	N/A	kN/m^2
Passive pressure, $\sigma_{hp} = \sigma_{vp} + 2S_u$	N/A	N/A	kN/m^2
Passive force, $F_p = 0.5 . (\sigma_{hp,surface}+\sigma_{hp,base}) . d_p$		**N/A**	kN/m
Note earth pressure acts normal to resisting face, angle β ignored;			
Horizontal component of F_p, $F_{ph} = F_p . \sin\gamma$		**N/A**	kN/m
Vertical (downward) component of F_p, $F_{pv} = F_p . \cos\gamma$		**N/A**	kN/m
Centroid of F_p, $e_p = d_p . (2\sigma_{hp,surface}+\sigma_{hp,base}) / [3.(\sigma_{hp,surface}+\sigma_{hp,base})]$		N/A	m
Note the centroid e_p is measured from the base of the resisting soil;			

Calculated pressures will only be mobilized where equivalent strains occur and these will be dependent upon the elastic modulus of the soil and of the structural element as interacting members. Thus the restraining effect of struts, ground anchors or tie-backs may create higher active pressures than those from the basic active condition formulae, possibly locally approaching those from the passive condition formulae.

Drained Lateral Earth Pressure

Bulk unit weight, $\gamma = \gamma_{dry}$ or γ_{sat} 20.0 kN/m^3

Lateral (Active) Pressures of Retained Soil	At Surface	At WT	At Base	
Vertical total stress, $\sigma_{va} = p_{s,a}$ to $\sigma_{va} = p_{s,a} + \gamma.d_a$	10.0	58.0	88.0	kN/m^2
Hydrostatic pressure, u_a = 0.0 to 0.0 + γ_w.MAX(0.0, d_a-	0.0	0.0	14.7	kN/m^2
Vertical effective stress, $\sigma_{va}' = \sigma_{va} - u_a$	10.0	58.0	73.3	kN/m^2
Active earth pressure coefficient, K_a	0.30	0.30	0.30	
At Rest				
$K_a = (1-\sin\phi')$	0.50	0.50	0.50	
Rankine Theory				
Note Rankine theory assumes $\delta = 0°$, $\beta = 0°$ and $\alpha = 90°$;				
$K_a = (1-\sin\phi') / (1+\sin\phi')$	0.33	0.33	0.33	
Coulomb Theory				
K_a	0.30	0.30	0.30	

$$K_a = \frac{\sin^2(\alpha+\varphi')}{\sin^2\alpha \sin(\alpha-\delta')\left[1+\sqrt{\frac{\sin(\varphi'+\delta')\sin(\varphi'-\beta)}{\sin(\alpha-\delta')\sin(\alpha+\beta)}}\right]^2}$$

Active effective pressure, $\sigma_{ha}' = K_a.\sigma_{va}' - 2c'\sqrt{K_a}$	3.0	17.3	21.8	kN/m^2

Active force, F_a' **54** kN/m

Note if $d_{aw} < d_a$, $F_a' = 0.5 . (\sigma_{ha,surface}' + \sigma_{ha,wt}') . d_{aw} + 0.5 . (\sigma_{ha,wt}' + \sigma_{ha,base}') . (d_a - d_{aw})$;

Note if $d_{aw} \geq d_a$, $F_a' = 0.5 . (\sigma_{ha,surface}' + \sigma_{ha,base}') . d_a$;

Note earth pressure acts normal to retaining face (Rankine theory), angle β ignored;

Note earth pressure acts at δ' to normal to retaining face (Coulomb theory), angle β ignored;

Horizontal component of F_a', $F_{ah}' = F_a' . \cos(90°-\alpha+\delta')$ **50** kN/m

Vertical (downward) component of F_a', $F_{av}' = F_a' . \sin(90°-\alpha+\delta')$ **18** kN/m

Centroid of F_a', e_a 1.490 m

Note if $d_{aw} < d_a$, $e_a = \{[d_{aw} . (2\sigma_{ha,surface}' + \sigma_{ha,wt}') / [3.(\sigma_{ha,surface}' + \sigma_{ha,wt}')] + d_a - d_{aw}] . [0.5 . (\sigma_{ha,surface}'$-
$+ [(d_a - d_{aw}) . (2\sigma_{ha,wt}' + \sigma_{ha,base}') / [3.(\sigma_{ha,wt}' + \sigma_{ha,base}')]] . [0.5 . (\sigma_{ha,wt}' + \sigma_{ha,base}') . (d_a - d_{aw})]\} / F_a'$;

Note if $d_{aw} \geq d_a$, $e_a = d_a . (2\sigma_{ha,surface}' + \sigma_{ha,base}') / [3.(\sigma_{ha,surface}' + \sigma_{ha,base}')]$;

Hydrostatic force, $F_{ua} = 0.5 . (u_{a,surface} + u_{a,base}) . (d_a - d_{aw})$ **11** kN/m

Note hydrostatic pressure acts normal to retaining face;

Horizontal component of F_{ua}, $F_{uah} = F_{ua} . \sin\alpha$ **11** kN/m

Vertical (downward) component of F_{ua}, $F_{uav} = F_{ua} . \cos\alpha$ **0** kN/m

Centroid of F_{ua}, $e_{ua} = (d_a - d_{aw}) . (2u_{a,surface} + u_{a,base}) / [3.(u_{a,surface} + u_{a,base})]$ 0.500 m

Lateral (Passive) Pressures of Retained Soil	At Surface	At WT	At Base	
Vertical total stress, $\sigma_{vp} = p_{s,p}$ to $\sigma_{vp} = p_{s,p} + \gamma.d_p$	0.0	0.0	24.0	kN/m^2
Hydrostatic pressure, u_p = 0.0 to 0.0 + γ_w.MAX(0.0, d_p-	0.0	0.0	11.8	kN/m^2
Vertical effective stress, $\sigma_{vp}' = \sigma_{vp} - u_p$	0.0	0.0	12.2	kN/m^2
Passive earth pressure coefficient, K_p	4.98	4.98	4.98	

Rankine Theory

Note Rankine theory assumes δ = 0°, β = 0° and α = 90°;

$K_p = (1+\sin\phi') / (1-\sin\phi')$	3.00	3.00	3.00	

Coulomb Theory

K_p	4.98	4.98	4.98	

$$\boxed{K_p = \frac{\sin^2(\alpha-\varphi')}{\sin^2\alpha\sin(\alpha+\delta')\left[1-\sqrt{\frac{\sin(\varphi'+\delta')\sin(\varphi'+\beta)}{\sin(\alpha+\delta')\sin(\alpha+\beta)}}\right]^2}}$$

Note that K_P only accurate if δ' <= ϕ'/3; Thus consider adopting zero δ' for K_p above;

Passive effective pressure, $\sigma_{hp}' = K_p.\sigma_{vp}' + 2c'\sqrt{K_p}$	0.0	0.0	60.9	kN/m^2

Passive force, F_p'	37	kN/m

Note if d_{pw} < d_p, F_p' = 0.5 . ($\sigma_{hp,surface}$'+ $\sigma_{hp,wt}$') . d_{pw} + 0.5 . ($\sigma_{hp,wt}$'+ $\sigma_{hp,base}$') . (d_p-d_{pw});

Note if d_{pw} ≥ d_p, F_p' = 0.5 . ($\sigma_{hp,surface}$'+ $\sigma_{hp,base}$') . d_p;

Note earth pressure acts normal to resisting face (Rankine theory), angle β ignored;

Note earth pressure acts at δ' to normal to resisting face (Coulomb theory), angle β ignored;

Horizontal component of F_p', $F_{ph}' = F_p'$. cos(90°-γ-δ')	35	kN/m
Vertical (downward) component of F_p', $F_{pv}' = F_p'$. sin(90°-γ-δ')	-9	kN/m
Centroid of F_p', e_p	0.400	m

Note if d_{pw} < d_p, e_p = {[d_{pw} . (2 $\sigma_{hp,surface}$'+ $\sigma_{hp,wt}$') / [3.($\sigma_{hp,surface}$'+ $\sigma_{hp,wt}$')] + d_p - d_{pw}] . [0.5 . ($\sigma_{hp,surface}$'
+ [(d_p-d_{pw}) . (2 $\sigma_{hp,wt}$'+ $\sigma_{hp,base}$') / [3.($\sigma_{hp,wt}$'+ $\sigma_{hp,base}$')]] . [0.5 . ($\sigma_{hp,wt}$'+ $\sigma_{hp,base}$') . (d_p-d_{pw})]} / F_p';

Note if d_{pw} ≥ d_p, e_p = d_p . (2 $\sigma_{hp,surface}$'+ $\sigma_{hp,base}$') / [3.($\sigma_{hp,surface}$'+ $\sigma_{hp,base}$')];

Hydrostatic force, F_{up} = 0.5 . ($u_{p,surface}$+$u_{p,base}$) . (d_p-d_{pw})	7	kN/m

Note hydrostatic pressure acts normal to resisting face;

Horizontal component of F_{up}, $F_{uph} = F_{up}$. sinγ	7	kN/m
Vertical (downward) component of F_{up}, $F_{upv} = F_{up}$. cosγ	0	kN/m
Centroid of F_{up}, e_{up} = (d_p-d_{pw}) . (2$u_{p,surface}$+$u_{p,base}$) / [3.($u_{p,surface}$+$u_{p,base}$)]	0.400	m

Overall Net (Effective) Bearing Capacity

Note this section is applicable only for concrete gravity and concrete cantilever retaining walls;

(Effective) surcharge above founding level, p_0 or p_0'	63	kPa	
Case when soil is dry	***Invalid***		
$p_0 = p_{s,p}+\gamma_{dry}.d_a$ or $p_0' = p_{s,p}+\gamma_{dry}.d_a-\gamma_w.MAX(0.0, d_a-d_{aw})$	N/A	kPa	
Case when soil is saturated	***Valid***		
$p_0 = p_{s,p}+\gamma_{sat}.d_a$ or $p_0' = p_{s,p}+\gamma_{sat}.d_a-\gamma_w.MAX(0.0, d_a-d_{aw})$	63	kPa	
Net (effective) bearing capacity, $q_{fnet} = q_f - (p_0=0)$ or $q_{fnet}' = q_f' - (p_0'=0)$	250	kPa	
Gross (effective) bearing capacity, q_f or q_f'	250	kPa	

Note that for retaining walls, the (effective) surcharge above the founding level, p_0 or p_0' is taken as 0 for both the gross and net (effective) bearing capacity calculations in view of the fact that it is only on one side of the retaining wall that the overburden pressure above the founding level exists;

Net (effective) working pressure, $q_{wnet} = q_w - (p_0=0)$ or $q_{wnet}' = q_w' - (p_0'=0)$	15	kPa	
Gross working pressure, q_w	28	kPa	
Water pressure at founding level (active side), $u_a = \gamma_w.MAX(0.0, d_a$	15	kPa	
Water pressure at founding level (passive side), $u_p = \gamma_w.MAX(0.0,$	12	kPa	
Water pressure at founding level, $u = AVERAGE(u_a, u_p)$	13	kPa	
Gross (effective) working pressure, q_w or $q_w' = q_w - u$	15	kPa	

Note that for retaining walls, the (effective) surcharge above the founding level, p_0 or p_0' is taken as 0 for the net (effective) working pressure calculation in view of the fact that the retained soil may be formed by building up instead of by excavation;

Overall net (effective) bearing capacity (factored), $(q_{fnet}$ or $q_{fnet}') / FOS_2$	100	kPa	
Overall net (effective) bearing capacity utilisation = $(q_{wnet}$ or $q_{wnet}') / ((q_{fnet}$ or	15%		OK

In addition to the above, the susceptibility of the retaining wall to base heave instability in the case of excavations need to be carried out;

$+ \sigma_{hp,wt}') . d_{pw}]$

Overall Sliding Resistance Capacity

Note this section is applicable only for concrete gravity and concrete cantilever retaining walls;

Dead load component of SLS vertical (downward) load, $k_{SLStoDL}$		1.00		
Note that the dead load component is applied to reduce the SLS vertical (downward) load to the dead vertical (downward) load, this required as the live load component cannot be guaranteed;				
Total retaining wall dead vertical load, $k_{SLStoDL}.F_v'$		**48**	kN/m	
Total retaining wall SLS horizontal load, F_h		**19**	kN/m	
Overall sliding resistance capacity (factored), $F_{s,cap}$		**20**	kN/m	
Undrained Analysis	$F_{s,cap} = B_{width,base}'.S_u / FOS_3$	N/A	kN/m	*Tomlinson*
Drained Analysis	$F_{s,cap} = k_{SLStoDL}.F_v'.\tan\delta' / FOS_3$	20	kN/m	*Tomlinson*
Overall sliding resistance capacity utilisation = $F_h / F_{s,cap}$		**97%**		**OK**

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 17	Rev.
		Member/Location	
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.	
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Overall Uplift Resistance Capacity

Note this section is applicable only for concrete gravity and concrete cantilever retaining walls;

Overall uplift resistance capacity utilisation = e_{eff} / $e_{eff,limit}$	**96%**	**OK**

Overall Overturning Resistance Capacity

Note this section is applicable only for concrete gravity and concrete cantilever retaining walls;

Overall overturning resistance capacity utilisation = M_{ot} / M_{rt}	**80%**	**OK**

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 19	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	21	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Cell References									
concrete grade								**4**	
25									
30									
35									
40									
45									
50									
55									
60									
65									
70									
75									
80									
85									
90									
95									
100									
105									
110									
115									
120									
longitudinal reinforcement steel grade								**2**	
250									
460									
shear link reinforcement steel grade								**2**	
250									
460									
type of concrete								**1**	
Normal Weight									
Light Weight									
concrete elastic modulus								**3**	
Uncracked								28000	
Cracked								14000	
Cracked Long Term (Creep)								7000	
steel sheet pile steel grade								**2**	
S240GP								240	
S270GP								270	
S320GP								320	
S355GP								355	
S390GP								390	
S430GP								430	
factor of safety method								**2**	
FOS on Soil Strength									
FOS on Overall Effect									
soil name								**48**	

[Blank Page]

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	27	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Concrete Gravity Retaining Wall Dimensions

5.2.3 Gravity walls

The stability of gravity retaining walls is illustrated in Figure 5.1. Active pressures are assessed and applied to the retaining wall and, if appropriate, passive pressures are assumed in front of the wall. Water pressures are added commensurate with the drainage and seepage regime around the wall. The resulting force *R* is then calculated and stability is achieved if *R* can be resisted by the soil beneath the toe. The ability of the soil to resist the force is calculated using conventional bearing capacity considerations.

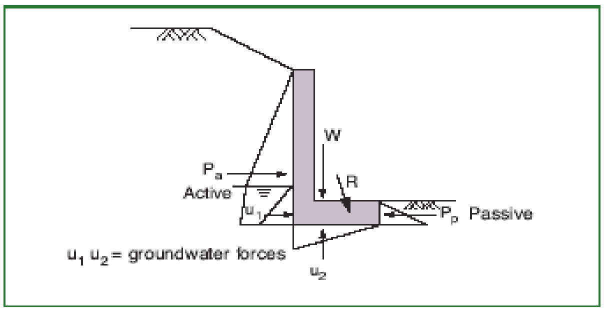


Fig 5.1 Typical gravity retaining wall

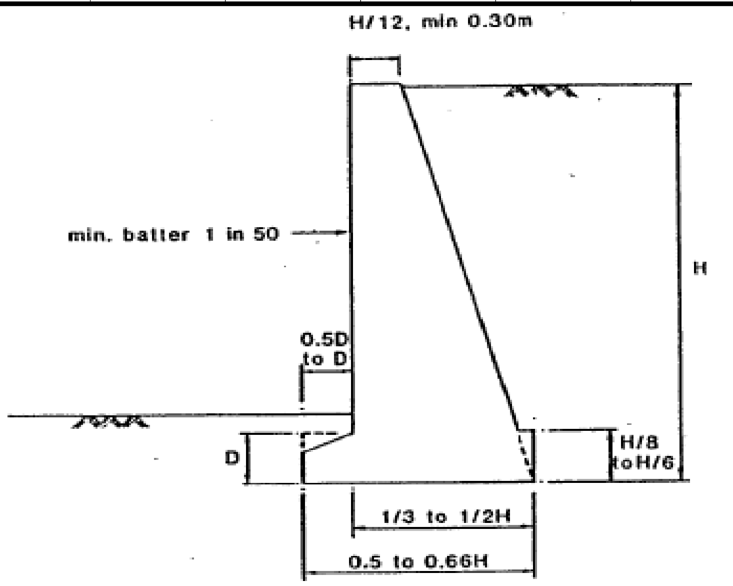
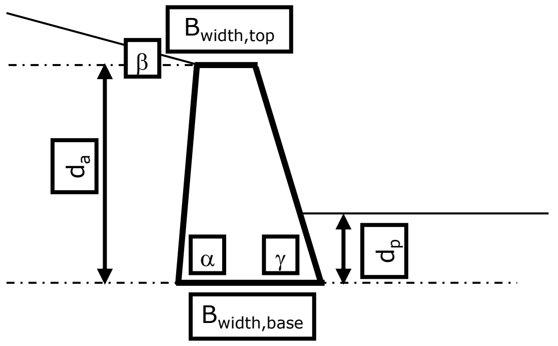


Figure 8.5 Preliminary dimensions for mass concrete walls.



Angle of retaining face from horizontal, α (<= 90°)	90.0	degrees	N/A
Angle of exposed face from horizontal, γ (<= 90°)	80.0	degrees	N/A
Width of base, $B_{width,base}$ (usually ≈ 0.60 to 0.80d_a)	3.120	m	
Width of top, $B_{width,top}$ = $B_{width,base}$ - d_a/tanα - d_a/tanγ	N/A	m	N/A

Concrete Gravity Retaining Wall Reinforcement

Note no reinforcement other than for crack control required;

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	28	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Concrete Gravity Retaining Wall SLS Loading

Retaining wall wall weight (left triangular portion), $W_1 = 0.5.(d_a/\tan\alpha).d_a.\rho_c$	N/A	kN/m
Retaining wall wall weight (rectangular portion), $W_2 = B_{width,top}.d_a.\rho_c$	N/A	kN/m
Retaining wall wall weight (right triangular portion), $W_3 = 0.5.(d_a/\tan\gamma).d_a.\rho_c$	N/A	kN/m
Water pressure at founding level (active side), $u_a = \gamma_w.\text{MAX}(0.0,\ d_a\text{-}d_{aw})$	N/A	kPa
Water pressure at founding level (passive side), $u_p = \gamma_w.\text{MAX}(0.0,\ d_p\text{-}d_{pw})$	N/A	kPa
Water pressure at founding level, $u = \text{AVERAGE}(u_a, u_p)$	N/A	kPa
Water uplift force at founding level, $F_{water} = u.B_{width,base}$	N/A	kN/m

Horizontal Load			Eccentricity from Base		
F_{ah} (F_{ah}')	N/A	kN/m	e_a	N/A	m
F_{uah}	N/A	kN/m	e_{ua}	N/A	m
F_{ph} (F_{ph}')	N/A	kN/m	e_p	N/A	m
F_{uph}	N/A	kN/m	e_{up}	N/A	m
Vertical (Downward) Load			**Eccentricity from Base Centroid**		
W_1	N/A	kN/m	$d_a/\tan\alpha)/3\text{-}B_{width,base}/2$	N/A	m
W_2	N/A	kN/m	$\text{-}B_{width,top}/2\text{-}B_{width,base}/2$	N/A	m
W_3	N/A	kN/m	$_{idth,base}/2\text{-}2.(d_a/\tan\gamma)/3$	N/A	m
F_{av} (F_{av}')	N/A	kN/m	$= e_a/\tan\alpha\text{-}B_{width,base}/2$	N/A	m
F_{uav}	N/A	kN/m	$= e_{ua}/\tan\alpha\text{-}B_{width,base}/2$	N/A	m
F_{pv} (F_{pv}')	N/A	kN/m	$= B_{width,base}/2\text{-}e_p/\tan\gamma$	N/A	m
F_{upv}	N/A	kN/m	$= B_{width,base}/2\text{-}e_{up}/\tan\gamma$	N/A	m
$\text{-}F_{water}$	N/A	kN/m	$).B_{width,base}/[3.(u_a+u_p)]$	N/A	m

Total retaining wall SLS vertical (downward) load, $F_{concrete,gravity,v}$	N/A	kN/m
Note $F_{concrete,gravity,v} = W_1+W_2+W_3+F_{av}(F_{av}')+0(F_{uav})+F_{pv}(F_{pv}')+0(F_{upv})$;		
Total retaining wall SLS effective vertical (downward) load, $F_{concrete,gravity,v}$'	N/A	kN/m
Note $F_{concrete,gravity,v}' = F_{concrete,gravity,v}\text{-}F_{water}$;		
Total retaining wall SLS horizontal load, $F_{concrete,gravity,h}$	N/A	kN/m
Note $F_{concrete,gravity,h} = F_{ah}(F_{ah}')+0(F_{uah})\text{-}F_{ph}(F_{ph}')\text{-}0(F_{uph})$;		
Note $F_{concrete,gravity,h}$ *is set to 0 if the sliding resistance capacity exceeds the sliding force;*		
Total retaining wall SLS moment about base centroid, $M_{concrete,gravity}$	N/A	kNm/m
Note $M_{concrete,gravity} = F_{ah}(F_{ah}').e_a+0(F_{uah}).e_{ua}\text{-}F_{ph}(F_{ph}').e_p\text{-}0(F_{uph}).e_{up}+W_1.e_{w1}+W_2.e_{w2}+W_3.e_{w3}$		
$+F_{av}(F_{av}').e_{av}+0(F_{uav}).e_{uav}+F_{pv}(F_{pv}').e_{pv}+0(F_{upv}).e_{upv}\text{-}F_{water}.e_{water}$;		
Note $M_{concrete,gravity}$ *is set to 0 if the restoring moment capacity exceeds the overturning moment;*		
Equivalent eccentricity, $e_{eff} = \text{MAX}(0, M_{concrete,gravity}) / F_{concrete,gravity,v}'$	N/A	m
Limiting eccentricity for no overall uplift (factored), $e_{eff,limit} = (B_{width,base} / 6)$ / F	N/A	m
Total retaining wall SLS overturning moment, $M_{concrete,gravity,ot}$	N/A	kNm/m
Note $M_{concrete,gravity,ot} = F_{ah}(F_{ah}').e_a+0(F_{uah}).e_{ua}\text{-}F_{av}(F_{av}').(B_{width,base}/2\text{-}e_{av})$		
$\text{-}0(F_{uav}).(B_{width,base}/2\text{-}e_{uav})+F_{water}.(B_{width,base}/2\text{-}e_{water})$;		
Total retaining wall SLS restoring moment, $M_{concrete,gravity,rt}$	N/A	kNm/m
Note $M_{concrete,gravity,rt} = [F_{ph}(F_{ph}').e_p+0(F_{uph}).e_{up}+W_1.(B_{width,base}/2\text{-}e_{w1})+W_2.(B_{width,base}/2\text{-}e_{w2})$		
$+W_3.(B_{width,base}/2\text{-}e_{w3})+F_{pv}(F_{pv}').(B_{width,base}/2\text{-}e_{pv})+0(F_{upv}).(B_{width,base}/2\text{-}e_{upv})]$ / FC		
Note surcharge not included in calculation of restoring moment as it cannot be guaranteed;		
Maximum gross working pressure, $q_{w1} = F_{concrete,gravity,v}/B_{width,base} + 6.M_{concrete,gr}$	N/A	kPa
Minimum gross working pressure, $q_{w2} = F_{concrete,gravity,v}/B_{width,base} - 6.M_{concrete,grav}$	N/A	kPa
Equivalent width, $B_{width,base}' = B_{width,base} - 2e_{eff}$	N/A	m
Gross working pressure, $q_w = F_{concrete,gravity,v} / B_{width,base}'$	N/A	kPa

Concrete Gravity Retaining Wall ULS Loading

Note ULS loading not applicable since reinforcement design not required;

S_5;

Concrete Gravity Retaining Wall Reinforcement Design

Note concrete gravity retaining wall reinforcement design not required since there is no axial, shear or bending effects;

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 37	Rev.
		Member/Location	
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.	
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	40	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 42		Rev.
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**		Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 45		Rev.
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**		Chd.

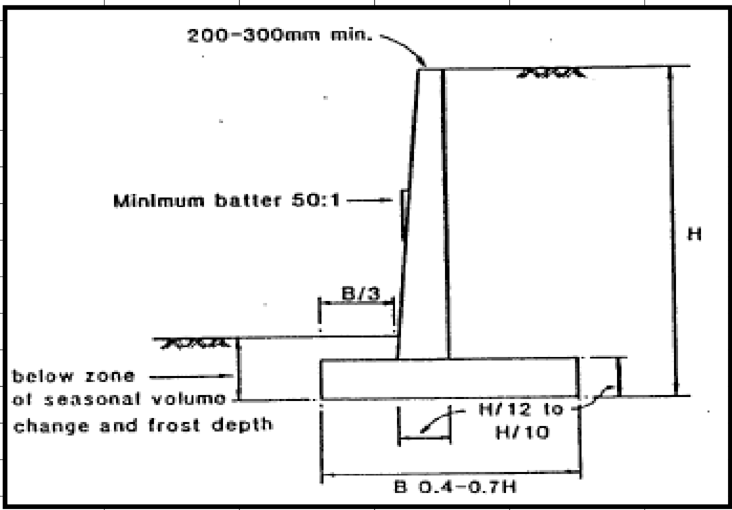
CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 49		Rev.
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**		Chd.

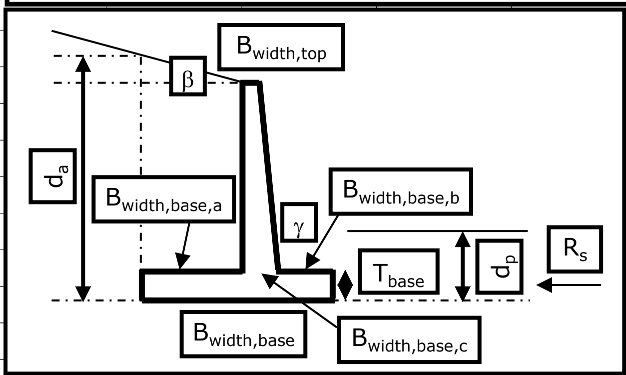
undrained shear strength limit to adopt								**1**	
Lower Limit									
Middle Limit									
Upper Limit									
ignore effective cohesion								**2**	
Include									
Exclude									
effective angle of friction						**1**	**7**	**5**	
1.00ø' (Cast in Place Concrete - Soil Interface)								1.00	
0.90ø' (Precast Concrete - Soil Interface)								0.90	
0.85ø' (Timber - Soil Interface)								0.85	
0.80ø' (Rough Corrugated Steel - Soil Interface)								0.80	
0.66ø' (Insitu Concrete Active Zone - Soil Interface)								0.66	
0.60ø' (Smooth Coated Steel - Soil Interface)								0.60	
0.50ø' (Insitu Concrete Passive Zone - Soil Interface)								0.50	
0.40ø'								0.40	
0.30ø'								0.30	
0.20ø'								0.20	
0.10ø'								0.10	
0.00ø' (No Friction Interface)								0.00	
method of analysis								**2**	
Undrained Analysis									
Drained Analysis									
Active or At Rest K_a (for drained analysis only)								**2**	
At Rest									
Active									
Rankine or Coulomb theory for K_a and K_p (for drained analysis only)								**2**	
Rankine Theory									
Coulomb Theory									
evaluate overall uplift resistance								**1**	
Yes									
No									
retaining wall type								**2**	
Concrete Gravity Retaining Wall									
Concrete Cantilever Retaining Wall									
Concrete or Steel Cantilever Embedded Retaining Wall									
Concrete Propped (Basement) Retaining Wall									
Concrete or Steel Propped (Basement) Embedded Retaining Wall									
cantilever retaining wall position of application of d_p								**2**	
Above Founding Level (as Drawn)									
Below Founding Level (i.e. on Shear Key)									
dry or saturated soil bulk unit weight ?								**2**	
Dry Soil									
Saturated Soil									

[Blank Page]

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	51	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Concrete Cantilever Retaining Wall Dimensions





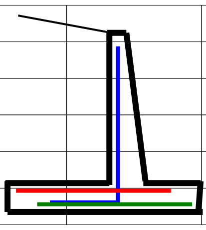
Note that for the concrete cantilever retaining wall, the toe may be used to provide the overall uplift resistance stability in lieu of the heel, however the overall sliding resistance stability must then be provided by an external sliding resistance passive reaction force, R_s;

Note that for the concrete cantilever retaining wall, the depth of retained soil, d_a is measured at the "virtual back" as indicated herein;

Angle of retaining face from horizontal, α = 90°	90.0	degrees	
Angle of exposed face from horizontal, γ (<= 90°)	90.0	degrees	OK
Thickness of base, T_{base}	450	mm	
Width of base, $B_{width,base,a}$	0.000	m	
Width of base, $B_{width,base,b}$	3.800	m	
Width of base, $B_{width,base,c}$	300	mm	
Width of base, $B_{width,base} = B_{width,base,a} + B_{width,base,b} + B_{width,base,c}$	4.100	m	
Width of top, $B_{width,top} = B_{width,base,c} - (d_a - B_{width,base,a}.\tan\beta - T_{base})/\tan\gamma$	300	mm	OK
External sliding resistance passive reaction force, R_s	0	kN/m	
Position of application of d_p	Below Founding Level (i.e. on Shear Key)		

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 52	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Concrete Cantilever Retaining Wall Reinforcement



Stem reinforcement

Heel reinforcement

Toe reinforcement

Longitudinal steel reinforcement diameter in stem, ϕ_{stem}	20	mm
Longitudinal steel reinforcement pitch in stem, p_{stem}	200	mm
Longitudinal steel area provided in stem, $A_{s,prov,stem} = (\pi.\phi_{stem}{}^2/4)/p_{stem}$	**1571**	mm^2/m
Longitudinal steel reinforcement diameter in heel, ϕ_{heel}	16	mm
Longitudinal steel reinforcement pitch in heel, p_{heel}	200	mm
Longitudinal steel area provided in heel, $A_{s,prov,heel} = (\pi.\phi_{heel}{}^2/4)/p_{heel}$	**1005**	mm^2/m
Longitudinal steel reinforcement diameter in toe, ϕ_{toe}	16	mm
Longitudinal steel reinforcement pitch in toe, p_{toe}	200	mm
Longitudinal steel area provided in toe, $A_{s,prov,toe} = (\pi.\phi_{toe}{}^2/4)/p_{toe}$	**1005**	mm^2/m
Shear link diameter in stem, $\phi_{link,stem}$	None	mm
Number of links per metre in stem, $n_{link,stem}$	5	/m
Area provided by all links per metre in stem, $A_{sv,prov,stem} = n_{link,stem}.\pi.\phi_{link,stem}{}^2/4$	**0**	mm^2/m
Pitch of links in stem, S_{stem}	200	mm
Shear link diameter in heel, $\phi_{link,heel}$	None	mm
Number of links per metre in heel, $n_{link,heel}$	5	/m
Area provided by all links per metre in heel, $A_{sv,prov,heel} = n_{link,heel}.\pi.\phi_{link,heel}{}^2/4$	**0**	mm^2/m
Pitch of links in heel, S_{heel}	200	mm
Shear link diameter in toe, $\phi_{link,toe}$	None	mm
Number of links per metre in toe, $n_{link,toe}$	5	/m
Area provided by all links per metre in toe, $A_{sv,prov,toe} = n_{link,toe}.\pi.\phi_{link,toe}{}^2/4$	**0**	mm^2/m
Pitch of links in toe, S_{toe}	200	mm
Effective depth to longitudinal steel in stem, $d_{stem} = B_{width,base,c}$ - $cover_2$ - $\phi_{link,st}$	240	mm
Effective depth to longitudinal steel in heel, $d_{heel} = T_{base}$ - $cover_4$ - $\phi_{link,heel}$ - ϕ_{hee}	392	mm
Effective depth to longitudinal steel in toe, $d_{toe} = T_{base}$ - $cover_3$ - $\phi_{link,heel}$ - $\phi_{toe}/$	392	mm
Estimated steel reinforcement quantity	**38**	kg/m^3
stem *[7.850 . ($A_{s,prov,stem}$) / ($B_{width,top}$ + $B_{width,base,c}$)/2];*	41	kg/m^3
base *[7.850 . ($A_{s,prov,heel}$ + $A_{s,prov,toe}$) / T_{base}];*	35	kg/m^3

No curtailment; No laps; Links ignored; Distribution steel ignored;

Concrete Cantilever Retaining Wall SLS Loading

Bulk unit weight, $\gamma = \gamma_{dry}$ or γ_{sat}	20.0	kN/m^3
Retaining wall base weight, $W_1 = B_{width,base}.T_{base}.\rho_c$	44	kN/m
Retaining wall wall weight (rectangular portion), $W_2 = B_{width,top}.(d_a\text{-}B_{width,base,a}.t$	25	kN/m
Retaining wall wall weight (triangular portion), $W_3 = 0.5.(B_{width,base,c}\text{-}B_{width,top}).($	0	kN/m
Retaining wall surcharge, $W_4 = p_{s,a}.B_{width,base,a}$	0	kN/m
Retaining wall earth backfill, $W_5 = B_{width,base,a}.(d_a\text{-}(B_{width,base,a}.\tan\beta)/2\text{-}T_{base}).\gamma$	0	kN/m

Note weight of earth in front of wall over toe ignored, conservative for overall sliding resistance capacity;

Water pressure at founding level (active side), $u_a = \gamma_w.MAX(0.0, d_a\text{-}d_{aw})$	15	kPa
Water pressure at founding level (passive side), $u_p = \gamma_w.MAX(0.0, d_p\text{-}d_{pw})$	0	kPa
Water pressure at founding level, $u = AVERAGE(u_a, u_p)$	7	kPa
Water uplift force at founding level, $F_{water} = u.B_{width,base}$	30	kN/m

Horizontal Load			Eccentricity from Base		
F_{ah} (F_{ah}')	50	kN/m	e_a	1.490	m
F_{uah}	11	kN/m	e_{ua}	0.500	m
F_{ph} (F_{ph}')	35	kN/m	e_p	-0.800	m
F_{uph}	7	kN/m	e_{up}	-0.800	m
Vertical (Downward) Load			**Eccentricity from Base Centroid**		
W_1	44	kN/m	$e_{w1} = 0.000$	0.000	m
W_2	25	kN/m	$B_{width,base}/2+B_{width,top}/2$	-1.900	m
W_3	0	kN/m	$B_{width,top}+B_{width,base,c})/3$	-1.750	m
W_4	0	kN/m	$_{width,base,a}/2\text{-}B_{width,base}/2$	-2.050	m
W_5	0	kN/m	$_{width,base,a}/2\text{-}B_{width,base}/2$	-2.050	m
F_{av} (F_{av}')	18	kN/m	$B_{width,base,a}\text{-}B_{width,base}/2$	-2.050	m
F_{uav}	0	kN/m	$B_{width,base,a}\text{-}B_{width,base}/2$	-2.050	m
F_{pv} (F_{pv}')	-9	kN/m	$e_{pv} = B_{width,base}/2$	2.050	m
F_{upv}	0	kN/m	$e_{upv} = B_{width,base}/2$	2.050	m
$-F_{water}$	-30	kN/m	$).B_{width,base}/[3.(u_a+u_p)]$	-0.683	m

Note eccentricity of vertical load from base centroid based upon the simplification that the active pressure acts entirely on the stem (d_a-T_{base}) and that the passive pressure acts entirely on the base T_{base}, where the shear key (if employed) is assumed to also be;

Total retaining wall SLS vertical (downward) load, $F_{concrete,cantilever,v}$	78	kN/m

Note $F_{concrete,cantilever,v} = W_1+W_2+W_3+W_4+W_5+F_{av}(F_{av}')+0(F_{uav})+F_{pv}(F_{pv}')+0(F_{upv})$;

Total retaining wall SLS effective vertical (downward) load, $F_{concrete,cantilever,v}$'	48	kN/m

Note $F_{concrete,cantilever,v}' = F_{concrete,cantilever,v}\text{-}F_{water}$;

Total retaining wall SLS horizontal load, $F_{concrete,cantilever,h}$	19	kN/m

Note $F_{concrete,cantilever,h} = F_{ah}(F_{ah}')+0(F_{uah})\text{-}F_{ph}(F_{ph}')\text{-}0(F_{uph})\text{-}R_s$;

Note $F_{concrete,cantilever,h}$ is set to 0 if the sliding resistance capacity exceeds the sliding force;

Total retaining wall SLS moment about base centroid, $M_{concrete,cantilever}$	31	kNm/m

Note $M_{concrete,cantilever} = F_{ah}(F_{ah}').e_a+0(F_{uah}).e_{ua}\text{-}F_{ph}(F_{ph}').e_p\text{-}0(F_{uph}).e_{up}+W_1.e_{w1}+W_2.e_{w2}+W_3.e_{w3}$
$+W_5.e_{w5}+F_{av}(F_{av}').e_{av}+0(F_{uav}).e_{uav}+F_{pv}(F_{pv}').e_{pv}+0(F_{upv}).e_{upv}\text{-}F_{water}.e_{water}$;

Note surcharge not included in calculation of restoring moment as it cannot be guaranteed;

Note $M_{concrete,cantilever}$ is set to 0 if the restoring moment capacity exceeds the overturning moment;

Equivalent eccentricity, $e_{eff} = MAX(0, M_{concrete,cantilever}) / (F_{concrete,cantilever,v}'\text{-}W_4)$	0.657	m

Note surcharge not included in calculation of restoring vertical (downward) load as it cannot be guaranteed;

Limiting eccentricity for no overall uplift (factored), $e_{eff,limit} = (B_{width,base} / 6) / F$	0.683	m

Total retaining wall SLS overturning moment, $M_{concrete,cantilever,ot}$ 89 kNm/m

Note $M_{concrete,cantilever,ot} = F_{ah}(F_{ah}').e_a+0(F_{uah}).e_{ua}-F_{av}(F_{av}').(B_{width,base}/2-e_{av})$
$-0(F_{uav}).(B_{width,base}/2-e_{uav})+F_{water}.(B_{width,base}/2-e_{water})$;

Total retaining wall SLS restoring moment, $M_{concrete,cantilever,rt}$ 111 kNm/m

Note $M_{concrete,cantilever,rt} = [F_{ph}(F_{ph}').e_p+0(F_{uph}).e_{up}+W_1.(B_{width,base}/2-e_{w1})+W_2.(B_{width,base}/2-e_{w2})$
$+W_3.(B_{width,base}/2-e_{w3})+W_5.(B_{width,base}/2-e_{w5})$
$+F_{pv}(F_{pv}').(B_{width,base}/2-e_{pv})+0(F_{upv}).(B_{width,base}/2-e_{upv})] / FOS_5$;

Note surcharge not included in calculation of restoring moment as it cannot be guaranteed;

Maximum gross working pressure, $q_{w1} = F_{concrete,cantilever,v}/B_{width,base} + 6.M_{concrete,}$ 30 kPa

Minimum gross working pressure, $q_{w2} = F_{concrete,cantilever,v}/B_{width,base} - 6.M_{concrete,ca}$ 8 kPa

Equivalent width, $B_{width,base}' = B_{width,base} - 2e_{eff}$ **2.786** m

Gross working pressure, $q_w = F_{concrete,cantilever,v} / B_{width,base}'$ **28** kPa

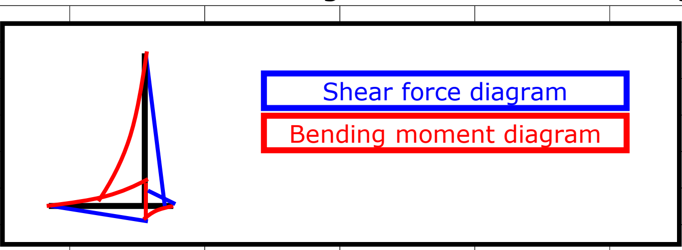
Concrete Cantilever Retaining Wall ULS Loading

	ULS Horizontal Load	
$K.F_{ah}$ $(K.F_{ah}')$	**71**	kN/m
$K.F_{uah}$	**15**	kN/m
$K.F_{ph}$ $(K.F_{ph}')$	**49**	kN/m
$K.F_{uph}$	**10**	kN/m

Note it is assumed that the ULS loads act at the same eccentricities as the SLS loads;

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 55	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Concrete Cantilever Retaining Wall Reinforcement Design



Bending Moment Design in Stem

Moment at stem base per metre, M	**87**	kNm/m	
Note $M = MAX\ [0,\ K.F_{ah}\,(K.F_{ah}').(e_a - T_{base} + B_{width,base,c}/2) + 0(K.F_{uah}).(e_{ua} - T_{base} + B_{width,base,c}/2)$ $-K.F_{ph}\,(K.F_{ph}').(e_p - T_{base} + B_{width,base,c}/2) - 0(K.F_{uph}).(e_{up} - T_{base} + B_{width,base,c}/2)];$			
Concrete moment capacity per metre, $M_u = 0.156f_{cu}.1000.d_{stem}^2$	**359**	kNm/m	
Bending stress, $[M/bd^2] = M / [(1000).d_{stem}^2]$	1.51	N/mm^2	
Bending stress ratio, $K = [M/bd^2] / f_{cu} <= 0.156$	0.038		**OK**
Lever arm, $z = d_{stem} . [0.5 + (0.25-K/0.9)^{0.5}] <= 0.95d_{stem}$	228	mm	
Area of tension steel required, $A_s = M / [(0.95f_y).z]$	**873**	mm^2/m	
Area of tensile steel reinforcement provided, $A_{s,prov,stem}$	1571	mm^2/m	
Bending moment in stem utilisation = $A_s / A_{s,prov,stem}$	**56%**		**OK**
% Min longitudinal reinforcement in stem (>= $0.0024.1000.B_{width,base,c}$ G250;	0.52	%	
% Min longitudinal reinforcement in stem utilisation	**25%**		**OK**

Shear Design in Stem

Shear force at stem base per metre, V_{ult} = MAX [0, $K.F_{ah}(K.F_{ah}')+0(K.F_{uah})-K.F$	**86**	kN/m	
Shear force at stem base per metre, V = MAX [0, $K.F_{ah}(K.F_{ah}')+0(K.F_{uah})-K.F_{ph}$	**86**	kN/m	
Ultimate shear stress in stem, $v_{ult}=V_{ult}/(1000.d_{stem})$ (< $0.8f_{cu}^{0.5}$ & $5N/mm^2$)	**0.36**	N/mm^2	
Ultimate shear stress in stem utilisation	**7%**		**OK**
Design shear stress in stem, $v_d=V/(1000.d_{stem})$	**0.36**	N/mm^2	
(Conservatively, shear capacity enhancement by ***either*** *calculating v_d at d from support and comparing against unenhanced v_c as clause 3.4.5.10 BS8110* ***or*** *calculating v_d at support and comparing against enhanced v_c within 2d of the support as clause 3.4.5.8 BS8110 ignored;)*			
Area of tensile steel reinforcement provided, $A_{s,prov,stem}$	1571	mm^2/m	
$\rho_w = 100A_{s,prov,stem}/(1000.d_{stem})$	0.65	%	
$v_c = (0.79/1.25)(\rho_w f_{cu}/25)^{1/3}(400/d_{stem})^{1/4}$; $\rho_w<3$; $f_{cu}<40$; $(400/d_{stem})^{1/4}>0.67$	**0.73**	N/mm^2	
Check $v_d < v_c$ for no links	**VALID**		
Concrete shear capacity $v_c.(1000.d_{stem})$	**175**	kN/m	
Check $v_c < v_d < 0.4 + v_c$ for nominal links	**N/A**		
Provide nominal links such that $A_{sv} / S > 0.4.(1000)/(0.95f_{yv})$ i.e. A	**0.92**	$mm^2/mm/m$	
Concrete and nominal links shear capacity $(0.4 + v_c).(1000.d_{stem})$	**271**	kN/m	
Check $v_d > 0.4 + v_c$ for design links	**N/A**		
Provide shear links $A_{sv} / S > 1000.(v_d-v_c)/(0.95f_{yv})$ i.e. $A_{sv} / S >$	**0.92**	$mm^2/mm/m$	
Concrete and design links shear capacity $(A_{sv,prov,stem}/S_{stem}).(0.95f_{yv}$	**175**	kN/m	
Area provided by all links per metre, $A_{sv,prov,stem}$	0	mm^2/m	
Tried $A_{sv,prov,stem} / S_{stem}$ value	0.00	$mm^2/mm/m$	
Design shear resistance in stem utilisation	**49%**		**OK**

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	56	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Bending Moment Design in Heel

Moment in heel (at stem) per metre, M	0	kNm/m	
Note $M = K.W_1.(B_{width,base,a}/B_{width,base}).(B_{width,base,a}+B_{width,base,c})/2+K.W_4.(B_{width,base,a}+B_{width,base,c})/2$			
$+K.W_5.(B_{width,base,a}+B_{width,base,c})/2$			
$-K.[2.q_{w2}+(q_{w1}-q_{w2}).(B_{width,base,a}+B_{width,base,c}/2)/B_{width,base}].(B_{width,base,a}+B_{width,base,c}/2)/2$			
$.(B_{width,base,a}+B_{width,base,c}/2).(2q_{w2}+q_{w3})\ /\ [3.(q_{w2}+q_{w3})]$			
where $q_{w3} = q_{w2}+(q_{w1}-q_{w2}).(B_{width,base,a}+B_{width,base,c}/2)/B_{width,base}$;			
Concrete moment capacity per metre, $M_u = 0.156f_{cu}.1000.d_{heel}^2$	959	kNm/m	
Bending stress, $[M/bd^2] = M / [(1000).d_{heel}^2]$	0.00	N/mm^2	
Bending stress ratio, $K = [M/bd^2] / f_{cu} <= 0.156$	0.000		OK
Lever arm, $z = d_{heel} . [0.5 + (0.25\text{-}K/0.9)^{0.5}] <= 0.95d_{heel}$	372	mm	
Area of tension steel required, $A_s = M / [(0.95f_y).z]$	-1	mm^2/m	
Area of tensile steel reinforcement provided, $A_{s,prov,heel}$	1005	mm^2/m	
Bending moment in heel utilisation = $A_s / A_{s,prov,heel}$	0%		OK
% Min longitudinal reinforcement in heel (>= $0.0024.1000.T_{base}$ G250; >= 0.(	0.22	%	
% Min longitudinal reinforcement in heel utilisation	58%		OK

Shear Design in Heel

Shear force in heel (at stem) per metre, V_{ult}	0	kN/m	
Shear force in heel (at stem) per metre, V	0	kN/m	
Note V_{ult} *and* $V = K.W_1.B_{width,base,a}/B_{width,base}+K.W_4+K.W_5-K.[2.q_{w2}+(q_{w1}-q_{w2}).B_{width,base,a}$			
$/B_{width,base}].B_{width,base,a}/2$;			
Ultimate shear stress in heel, $v_{ult}=V_{ult}/(1000.d_{heel})$ (< $0.8f_{cu}^{0.5}$ & $5N/mm^2$)	0.00	N/mm^2	
Ultimate shear stress in heel utilisation	0%		OK
Design shear stress in heel, $v_d=V/(1000.d_{heel})$	0.00	N/mm^2	
(Conservatively, shear capacity enhancement by ***either*** *calculating* v_d *at d from support and*			
comparing against unenhanced v_c *as clause 3.4.5.10 BS8110* ***or*** *calculating* v_d *at support and*			
comparing against enhanced v_c *within 2d of the support as clause 3.4.5.8 BS8110 ignored;)*			
Area of tensile steel reinforcement provided, $A_{s,prov,heel}$	1005	mm^2/m	
$\rho_w = 100A_{s,prov,heel}/(1000.d_{heel})$	0.26	%	
$v_c = (0.79/1.25)(\rho_w f_{cu}/25)^{1/3}(400/d_{heel})^{1/4}$; $\rho_w<3$; $f_{cu}<40$; $(400/d_{heel})^{1/4}>0.67$	0.47	N/mm^2	
Check $v_d < v_c$ for no links	**VALID**		
Concrete shear capacity $v_c.(1000.d_{heel})$	185	kN/m	
Check $v_c < v_d < 0.4 + v_c$ for nominal links	**N/A**		
Provide nominal links such that $A_{sv} / S > 0.4.(1000)/(0.95f_{yv})$ i.e. A	0.92	$mm^2/mm/m$	
Concrete and nominal links shear capacity $(0.4 + v_c).(1000.d_{heel})$	342	kN/m	
Check $v_d > 0.4 + v_c$ for design links	**N/A**		
Provide shear links $A_{sv} / S > 1000.(v_d\text{-}v_c)/(0.95f_{yv})$ i.e. $A_{sv} / S >$	0.92	$mm^2/mm/m$	
Concrete and design links shear capacity $(A_{sv,prov,heel}/S_{heel}).(0.95f_{yv})$	185	kN/m	
Area provided by all links per metre, $A_{sv,prov,heel}$	0	mm^2/m	
Tried $A_{sv,prov,heel} / S_{heel}$ value	0.00	$mm^2/mm/m$	
Design shear resistance in heel utilisation	0%		OK

Bending Moment Design in Toe

Moment in toe (at stem) per metre, M	133	kNm/m	

Note $M = K.[2.q_{w1} - (q_{w1} - q_{w2}).(B_{width,base,b} + B_{width,base,c}/2)/B_{width,base}].(B_{width,base,b} + B_{width,base,c}/2)/2$

$.(B_{width,base,b} + B_{width,base,c}/2).(2q_{w1} + q_{w3}) / [3.(q_{w1} + q_{w3})]$

$-K.W_1.(B_{width,base,b}/B_{width,base}).(B_{width,base,b} + B_{width,base,c})/2$

where $q_{w3} = q_{w2} + (q_{w1} - q_{w2}).(B_{width,base,a} + B_{width,base,c}/2)/B_{width,base}$;

Note weight of earth in front of wall over toe conservatively ignored;

Concrete moment capacity per metre, $M_u = 0.156f_{cu}.1000.d_{toe}^2$	959	kNm/m	
Bending stress, $[M/bd^2] = M / [(1000).d_{toe}^2]$	0.87	N/mm^2	
Bending stress ratio, $K = [M/bd^2] / f_{cu} <= 0.156$	0.022		OK
Lever arm, $z = d_{toe} . [0.5 + (0.25-K/0.9)^{0.5}] <= 0.95d_{toe}$	372	mm	
Area of tension steel required, $A_s = M / [(0.95f_y).z]$	818	mm^2/m	
Area of tensile steel reinforcement provided, $A_{s,prov,toe}$	1005	mm^2/m	
Bending moment in toe utilisation = $A_s / A_{s,prov,toe}$	81%		OK
% Min longitudinal reinforcement in toe (>= $0.0024.1000.T_{base}$ G250; >= 0.0(	0.22	%	
% Min longitudinal reinforcement in toe utilisation	58%		OK

Shear Design in Toe

Shear force in toe (at stem) per metre, V_{ult}	48	kN/m	
Shear force in toe (at stem) per metre, V	48	kN/m	

Note V_{ult} and $V = K.[2.q_{w1} - (q_{w1} - q_{w2}).B_{width,base,b}/B_{width,base}].B_{width,base,b}/2 - K.W_1.B_{width,base,b}/B_{width,base}$;

Note weight of earth in front of wall over toe conservatively ignored;

Ultimate shear stress in toe, $v_{ult}=V_{ult}/(1000.d_{toe})$ (< $0.8f_{cu}^{0.5}$ & $5N/mm^2$)	0.12	N/mm^2	
Ultimate shear stress in toe utilisation	2%		OK
Design shear stress in toe, $v_d=V/(1000.d_{toe})$	0.12	N/mm^2	

*(Conservatively, shear capacity enhancement by **either** calculating v_d at d from support and comparing against unenhanced v_c as clause 3.4.5.10 BS8110 **or** calculating v_d at support and comparing against enhanced v_c within 2d of the support as clause 3.4.5.8 BS8110 ignored;)*

Area of tensile steel reinforcement provided, $A_{s,prov,toe}$	1005	mm^2/m	
$\rho_w = 100A_{s,prov,toe}/(1000.d_{toe})$	0.26	%	
$v_c = (0.79/1.25)(\rho_w f_{cu}/25)^{1/3}(400/d_{toe})^{1/4}$; $\rho_w<3$; $f_{cu}<40$; $(400/d_{toe})^{1/4}>0.67$	0.47	N/mm^2	
Check $v_d < v_c$ for no links	VALID		
Concrete shear capacity $v_c.(1000.d_{toe})$	185	kN/m	
Check $v_c < v_d < 0.4 + v_c$ for nominal links	N/A		
Provide nominal links such that A_{sv} / S > 0.4.(1000)/(0.95f_{yv}) i.e. A	0.92	$mm^2/mm/m$	
Concrete and nominal links shear capacity $(0.4 + v_c).(1000.d_{toe})$	342	kN/m	
Check $v_d > 0.4 + v_c$ for design links	N/A		
Provide shear links A_{sv} / S > 1000.(v_d-v_c)/(0.95f_{yv}) i.e. A_{sv} / S >	0.92	$mm^2/mm/m$	
Concrete and design links shear capacity $(A_{sv,prov,toe}/S_{toe}).(0.95f_{yv}).$c	185	kN/m	
Area provided by all links per metre, $A_{sv,prov,toe}$	0	mm^2/m	
Tried $A_{sv,prov,toe} / S_{toe}$ value	0.00	$mm^2/mm/m$	
Design shear resistance in toe utilisation	26%		OK

Detailing Requirements

All detailing requirements met ?	OK		
Max longitudinal steel reinforcement pitch in stem ($<3d_{stem}$, <750mm)	200	mm	OK
Max longitudinal steel reinforcement pitch in heel ($<3d_{heel}$, <750mm)	200	mm	OK
Max longitudinal steel reinforcement pitch in toe ($<3d_{toe}$, <750mm)	200	mm	OK

Maximum spacing: 0.5% Ast or less - 300mm
Between 0.5% and 1.0% - 225mm
1.0% Ast or greater - 175mm

Max longitudinal steel reinforcement pitch in stem	200	mm	OK
Max longitudinal steel reinforcement pitch in heel	200	mm	OK
Max longitudinal steel reinforcement pitch in toe	200	mm	OK
Min longitudinal steel reinforcement pitch in stem ($>75mm+\phi_{stem}$, $>100mm+\phi$	200	mm	OK
Min longitudinal steel reinforcement pitch in heel ($>75mm+\phi_{heel}$, $>100mm+\phi_{he}$	200	mm	OK
Min longitudinal steel reinforcement pitch in toe ($>75mm+\phi_{toe}$, $>100mm+\phi_{toe}$	200	mm	OK

Note an allowance has been made for laps in the min pitch by increasing the criteria by the bar diameter.

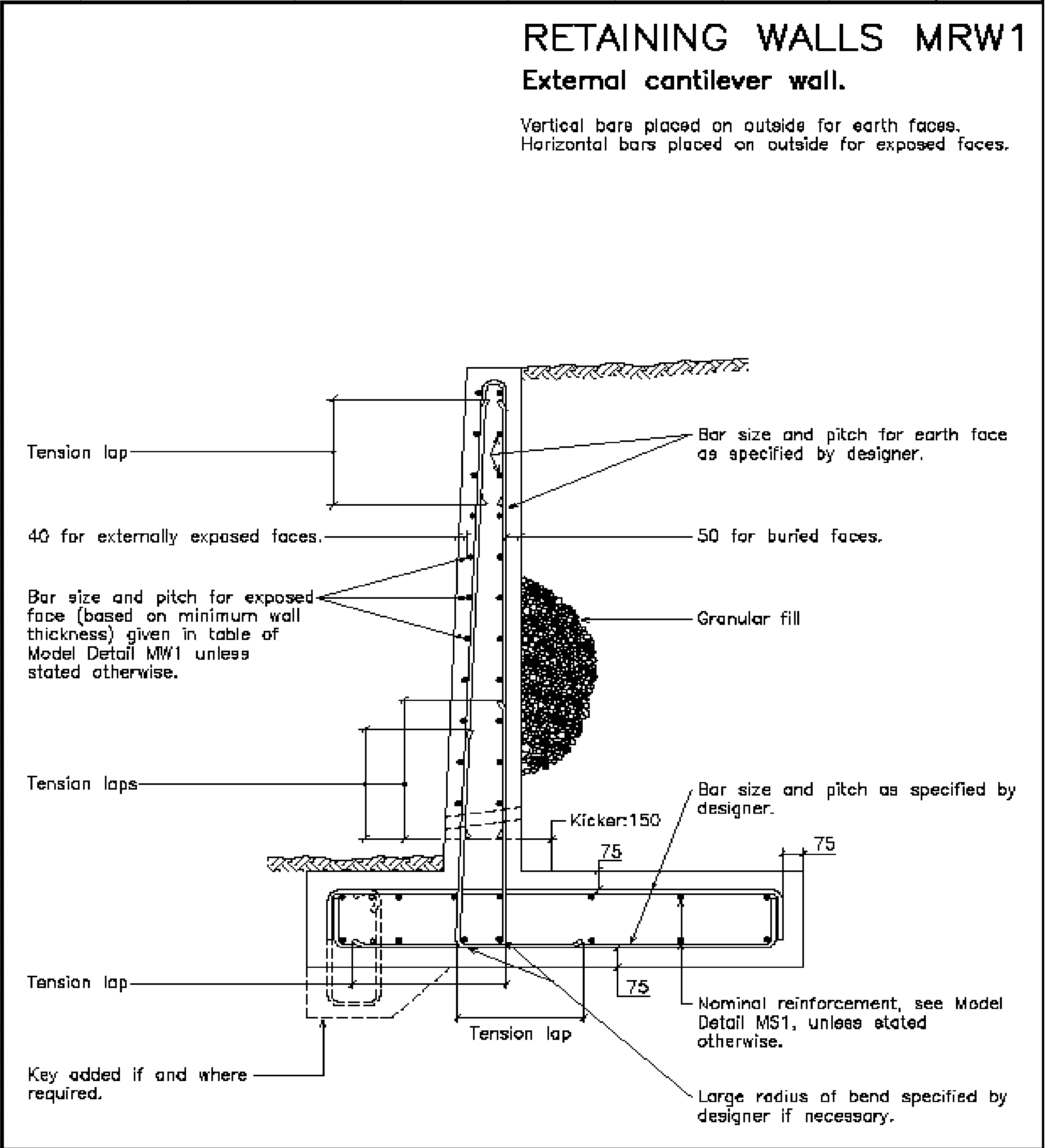
% Max longitudinal reinforcement in stem ($<= 0.04.1000.B_{width,base,c}$)	0.34	%	OK
% Max longitudinal reinforcement in heel ($<= 0.04.1000.T_{base}$)	0.22	%	OK
% Max longitudinal reinforcement in toe ($<= 0.04.1000.T_{base}$)	0.22	%	OK
Longitudinal steel reinforcement diameter in stem, ϕ_{stem} (>=12mm)	20	mm	OK
Longitudinal steel reinforcement diameter in heel, ϕ_{heel} (>=12mm)	16	mm	OK
Longitudinal steel reinforcement diameter in toe, ϕ_{toe} (>=12mm)	16	mm	OK

Deflection Criteria in Stem

Span, $l = d_a - T_{base} + B_{width,base,c}/2$	3.600	m	
Span, l / effective depth, d_{stem} ratio	15.0		
Basic span / effective depth ratio criteria (7 cantilever)	7.0		
Note multiplier $C_{1,span\ more\ or\ less\ than\ 10m}$ not applicable;			
Modification factor for tension C_2			
M/bd_{stem}^2	1.51	N/mm^2	
$f_s = \frac{2 f_y A_{s\ req}}{3 A_{s\ prov}} \times \frac{1}{\beta_b}$ *(β_b =1.0)*	171	N/mm^2	
Modification $0.55 + \frac{(477 - f_s)}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0$	1.61		
Modified span / effective depth ratio criteria	11.3		
Deflection in stem utilisation	133%		NOT OK

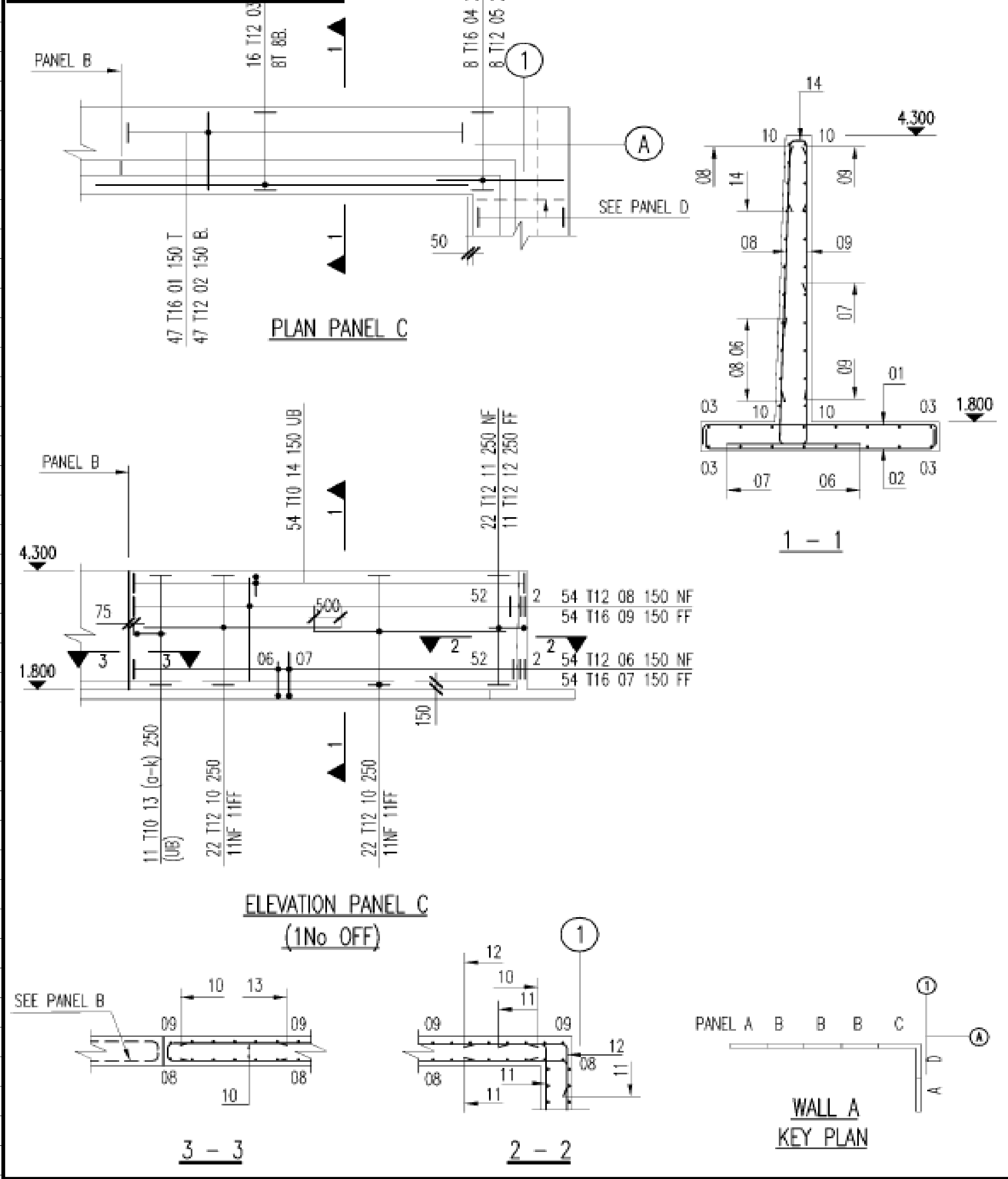
CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	59	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Standard Concrete Cantilever Retaining Wall Reinforcement Details



CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	60	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Free Standing Retaining Wall



CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	71	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	72	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

longitudinal rebar diameter				**8**	**8**	**5**	**5**	**6**	
						6	**7**	**6**	
6									
8									
10									
12									
16									
20									
25									
32									
40									
shear link diameter				**4**	**4**	**1**	**1**	**1**	
						3	**4**	**1**	
None									
6									
8									
10									
12									
16									
20									
25									
type of embedded retaining wall							**2**	**2**	
Concrete Contiguous / Interlocking / Secant Pile Wall									
Concrete Diaphragm Wall									
Steel Sheet Pile Wall									
contiguous / interlocking / secant pile shaft diameter							**7**	**5**	
300mm								300	
450mm								450	
600mm								600	
750mm								750	
900mm								900	
1050mm								1050	
1200mm								1200	
1350mm								1350	
1500mm								1500	
1650mm								1650	
1800mm								1800	
1950mm								1950	
2100mm								2100	
steel sheet pile section description							**48**	**121**	
shear case			**3**	**3**	**3**	**1**	**1**	**1**	
bending moment and shear design in embedded retaining walls									
relevant height of exposed face, H_R								N/A	
Point	**Depth, y**	**$F_{ah,y}$**	**$e_{a,y}$**	**$F_{ph,y}$**	**$e_{p,y}$**	**M**	**V**		
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
3	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
7	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
8	N/A	N/A	N/A	N/A	N/A	N/A	N/A		

Link Cells									
link 1								8.300	
link 2								N/A	
link 3								6.500	
link 4								N/A	
link 5								30.000	
link 6								30.000	

Concrete or Steel Cantilever Embedded Retaining Wall Dimensions and Reinforcement

5.2.4 Cantilever walls

The stability of cantilever walls is illustrated in Figure 5.2. The mode of failure of the wall is by rotation about a point near the toe and the resulting active and passive pressures are shown in the Figure. This is a statically determinate system and, for any given active and passive pressure limits, there is only one depth of wall where a solution can be found[5.2].

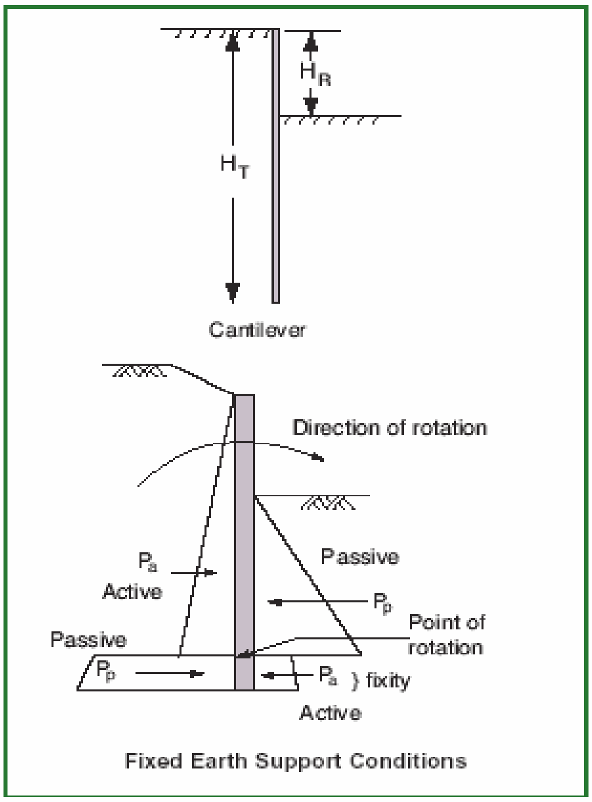
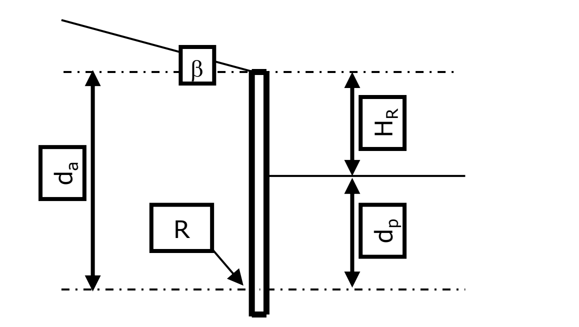


Fig 5.2 Cantilever wall stability



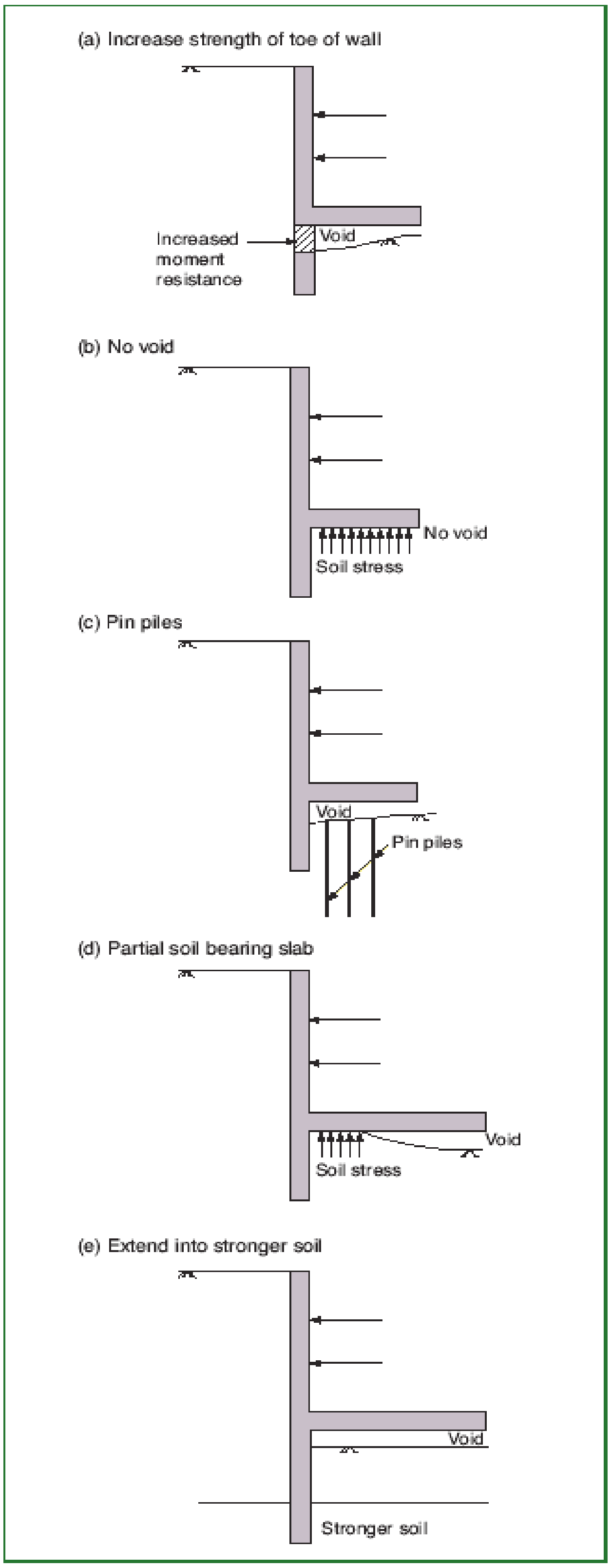


Fig 5.5 Methods for dealing with potential toe instability

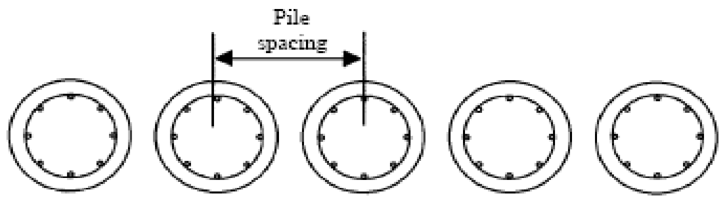


Figure A3.5 *Contiguous pile wall* (see Table A3.1)

Table A3.1 *Contiguous pile wall – typical diameters and spacing*

Diameter mm	Spacing mm	Diameter mm	Spacing mm	Diameter mm	Spacing mm
300	400	900	1000	1800	1900
450	550	1050	1150	2100	2200
600	700	1200	1300	2400	2500
750	850	1500	1600		

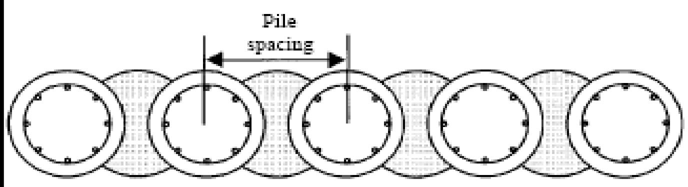


Figure A3.7 *Hard/soft secant pile wall* (see Table A3.2)

Table A3.2 *Hard/soft secant pile wall – typical diameters and spacing*

Diameter mm Male	Female	Spacing[1] mm	Diameter mm Male	Female	Spacing [1] mm
450	450	600	900	600	1100
600	600	800	1200	600	1400
750	750	1000	1200	750	1450

Note
1. The gap between the male piles should not exceed 40 per cent of the diameter of the soft piles.

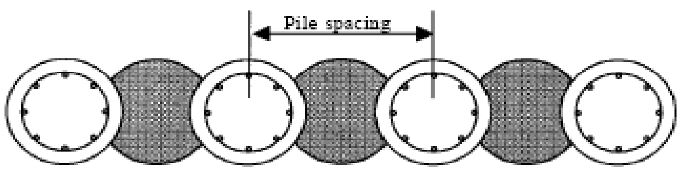


Figure A3.9 *Hard/firm secant pile wall* (see Table A3.3)

Table A3.3 *Hard/firm secant pile wall – typical diameters and spacing*

Diameter mm male and female	Spacing mm
600	900
750	1150

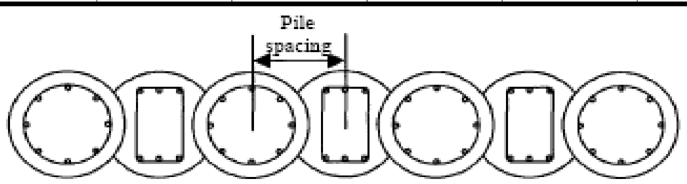


Figure A3.10 *Hard/hard secant pile wall (see page 289)*

Diameter mm Male and female	Spacing mm
750	650
880	760
1180	1025

Table A3.4 *Hard/hard secant pile wall – typical diameters and spac*

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.		Rev.
		jXXX	76		
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021		Chd.

Angle of retaining face from horizontal, α = 90°	90.0	degrees
Angle of exposed face from horizontal, γ = 90°	90.0	degrees
Height of exposed face, H_R (usually <= 5.000)	8.300	m

Note that H_R should be specified in anticipation of possible unplanned excavation to the minimum of the larger of 0.5m and 0.10 of the original retained height, this increasing the value of H_R;

Note that H_R should also be specified accounting for the fact that the prop location may not be at the very top of the wall, but instead stepped down, this decreasing the value of H_R by the step down;

Type of embedded retaining wall: Concrete Diaphragm Wall

Concrete Contiguous / Interlocking / Secant Pile Wall

Note that pile below refers to the hard reinforced pile;

Pile shaft diameter, D	900mm	N/A	mm
Pile clearance spacing, s (usually 50 to 75)		100	mm
Pile pitch, p = D+s		N/A	mm
Pile shaft second moment of area, I = $[\pi D^4/64]/p$		N/A	cm^4/m
Pile shaft cross sectional area, $A_{ps} = \pi D^2/4$		N/A	mm^2/pile
Longitudinal steel reinforcement diameter in pile, ϕ_{pile}	32		mm
Longitudinal steel reinforcement number in pile, n_{pile}		18	/pile
Longitudinal steel area provided in pile, $A_{s,prov,pile} = n_{pile}$.		N/A	mm^2/pile
Shear link diameter in pile, $\phi_{link,pile}$	10		mm
Number of links in a cross section in pile, i.e. number of		2	/pile
Area provided by all links in a cross-section in pile, $A_{sv,p}$		N/A	mm^2/pile
Pitch of links in pile, S_{pile}		150	mm
Ratio h_s/D = (D - 2.MAX($cover_1$, $cover_2$) - 2.$\phi_{link,pile}$ - ϕ_{pile}		N/A	
Estimated steel reinforcement quantity		N/A	kg/m^3

[7850 . $A_{s,prov,pile}$ / (π.D^2/4)]; No laps; Links ignored;

Concrete Diaphragm Wall

Wall thickness, t (usually 600 to 1500)		900	mm
Wall second moment of area, I = $100.t^3/12$		N/A	cm^4/m
Longitudinal steel reinforcement diameter in wall, ϕ_{wall}	32		mm
Longitudinal steel reinforcement pitch in wall, p_{wall}		150	mm
Longitudinal steel area provided in wall, $A_{s,prov,wall}$ = (π.ϕ		N/A	mm^2/m
Shear link diameter in wall, $\phi_{link,wall}$	10		mm
Number of links per metre in wall, $n_{link,wall}$		7	/m
Area provided by all links per metre in wall, $A_{sv,prov,wall}$ =		N/A	mm^2/m
Pitch of links in wall, S_{wall}		200	mm
Effective depth to longitudinal steel in wall, d_{wall} = t - cc		N/A	mm
Estimated steel reinforcement quantity		N/A	kg/m^3

[7.850 . ($A_{s,prov,wall}$) / t];

No curtailment; No laps; Links ignored; Distribution steel ignored;

Steel Sheet Pile Wall

Section description	High Mod Z-Type Frodingham 4N (762x267x173)		
Section mass, m		N/A	kg/m
Section mass, m		N/A	kg/m^2
Section depth, h		N/A	mm
Section second moment of area, I		N/A	cm^4/m
Section elastic modulus, Z		N/A	cm^3/m
Section shear area, h.t/b		N/A	cm^2/m

ing

Concrete or Steel Cantilever Embedded Retaining Wall SLS Loading

Horizontal Load			Eccentricity from Base		
F_{ah} (F_{ah}')	N/A	kN/m	e_a	N/A	m
F_{uah}	N/A	kN/m	e_{ua}	N/A	m
F_{ph} (F_{ph}')	N/A	kN/m	e_p	N/A	m
F_{uph}	N/A	kN/m	e_{up}	N/A	m

Total retaining wall SLS horizontal load, $F_{cantilever,h}$ N/A kN/m

Note $F_{cantilever,h} = F_{ah}(F_{ah}')+0(F_{uah})-F_{ph}(F_{ph}')/FOS_5-0(F_{uph})$;

Note negative $F_{cantilever,h}$ is effectively the additional passive resistance capacity over the active force;

Goal seek Mcantilever to 0.0 by changing da and dp (fixed earth method)
(click multiple times until convergence to the practical solution)

BS8002

Total retaining wall SLS moment about point of rotation, $M_{cantilever}$ N/A kNm/m N/A

Note $M_{cantilever} = F_{ah}(F_{ah}').e_a+0(F_{uah}).e_{ua}-F_{ph}(F_{ph}')/FOS_5.e_p-0(F_{uph}).e_{up}$;

Anticipated maximum value of d_a for commencement of iteration 30.000 m

Employ factor on embedment ? Yes, Factor 1.2

Note that the factor on embedment should be employed if the other FOS methods are not employed;

Design embedment of embedded retaining wall, L_0 = (1.2 or 1.0).d_p N/A m *Tomlinson*

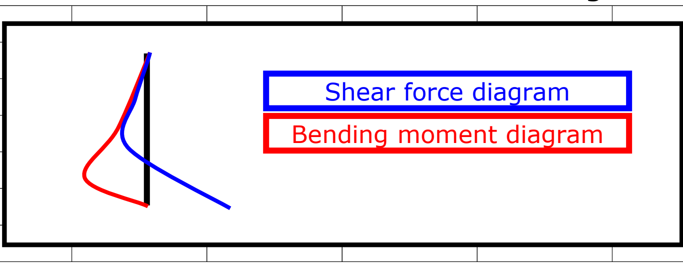
Design total length of embedded retaining wall, $L_T = L_0+H_R$ N/A m

Concrete or Steel Cantilever Embedded Retaining Wall ULS Loading

ULS Horizontal Load		
K.F_{ah} (K.F_{ah}')	N/A	kN/m
K.F_{uah}	N/A	kN/m
K.F_{ph} (K.F_{ph}')	N/A	kN/m
K.F_{uph}	N/A	kN/m

Note it is assumed that the ULS loads act at the same eccentricities as the SLS loads;

Concrete or Steel Cantilever Embedded Retaining Wall Section Design



Bending Moment Design in Wall, Shear Design in Wall and Detailing Requirements

Point	Depth, y (m)	Bending Moment in Wall, M (kNm/m)	Shear Force in Wall, V (kN/m)
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A
17	N/A	N/A	N/A
18	N/A	N/A	N/A
Σ		N/A	N/A

Note $M = K.F_{ah,y}(K.F_{ah,y}').e_{a,y} - K.F_{ph,y}(K.F_{ph,y}')/FOS_5.e_{p,y} + 0(K.F_{uah,y}).e_{ua,y} - 0(K.F_{uph,y}).e_{up,y}$;

Note $V = K.F_{ah,y}(K.F_{ah,y}') - K.F_{ph,y}(K.F_{ph,y}')/FOS_5 + 0(K.F_{uah,y}) - 0(K.F_{uph,y})$;

where for undrained analysis

$\sigma_{va,surface} = p_{s,a}$

$\sigma_{va,y} = p_{s,a} + \gamma.y$

$\sigma_{ha,surface} = MAX(0, \sigma_{va,surface} - 2S_u)$

$\sigma_{ha,y} = MAX(4.8y, \sigma_{va,y} - 2S_u)$

$F_{ah,y} = 0.5.(\sigma_{ha,surface} + \sigma_{ha,y}).y.\sin\alpha$

$e_{a,y} = y.(2\sigma_{ha,surface} + \sigma_{ha,y})/[3.(\sigma_{ha,surface} + \sigma_{ha,y})]$

$\sigma_{vp,surface} = p_{s,p}$

$\sigma_{vp,y} = p_{s,p} + \gamma.(y - H_R)$

$\sigma_{hp,surface} = \sigma_{vp,surface} + 2S_u$

$\sigma_{hp,y} = \sigma_{vp,y} + 2S_u$

$F_{ph,y} = 0.5.(\sigma_{hp,surface} + \sigma_{hp,y}).MAX(0.0, y - H_R).\sin\gamma$

$e_{p,y} = (y - H_R).(2\sigma_{hp,surface} + \sigma_{hp,y})/[3.(\sigma_{hp,surface} + \sigma_{hp,y})$

and for drained analysis

$\sigma_{va,surface}' = p_{s,a} - 0.0$

$\sigma_{va,y}' = p_{s,a} + \gamma.y - \gamma_w.MAX(0.0, y - d_{aw})$

$\sigma_{ha,surface}' = K_a.\sigma_{va,surface}' - 2c'\sqrt{K_a}$

$\sigma_{ha,y}' = K_a.\sigma_{va,y}' - 2c'\sqrt{K_a}$

$F_{ah,y}' = 0.5.(\sigma_{ha,surface}' + \sigma_{ha,y}').y.\cos(90° - \alpha$

$e_{a,y} = y.(2\sigma_{ha,surface}' + \sigma_{ha,y}')/[3.(\sigma_{ha,surface}' +$

$u_{a,surface} = 0.0$

$u_{a,y} = 0.0 + \gamma_w.MAX(0.0, y - d_{aw})$

$F_{uah,y} = 0.5.(u_{a,surface} + u_{a,y}).MAX(0.0, y - d_{aw}$

$e_{ua,y} = (y - d_{aw}).(2u_{a,surface} + u_{a,y})/[3.(u_{a,surfac}$

$\sigma_{vp,surface}' = p_{s,p} - 0.0$

$\sigma_{vp,y}' = p_{s,p} + \gamma.MAX(0.0, y - H_R) - \gamma_w.MAX(0.$

$\sigma_{hp,surface}' = K_p.\sigma_{vp,surface}' + 2c'\sqrt{K_p}$

$\sigma_{hp,y}' = K_p.\sigma_{vp,y}' + 2c'\sqrt{K_p}$

$F_{ph,y}' = 0.5.(\sigma_{hp,surface}' + \sigma_{hp,y}').MAX(0.0, y-$

$e_{p,y} = MAX(0.0, y - H_R).(2\sigma_{hp,surface}' + \sigma_{hp,y}')/$

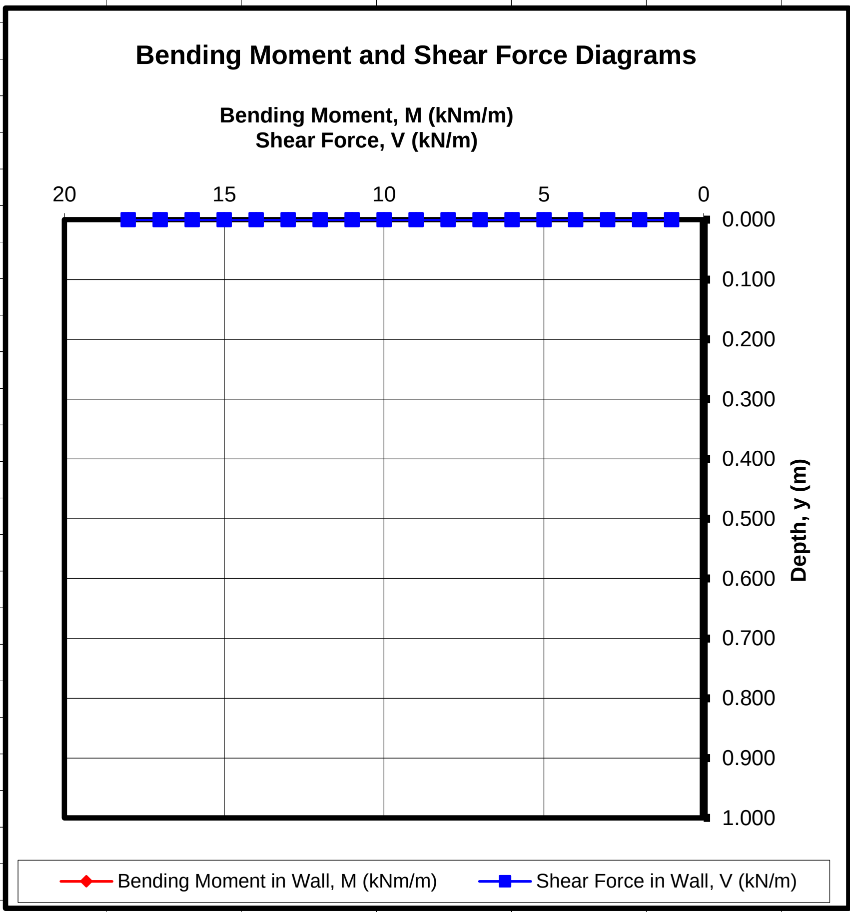
$u_{p,surface} = 0.0$

$u_{p,y} = 0.0 + \gamma_w.MAX(0.0, y - H_R - d_{pw})$

$F_{uph,y} = 0.5.(u_{p,surface} + u_{p,y}).MAX(0.0, y - H_R$

$e_{up,y} = (y - H_R - d_{pw}).(2u_{p,surface} + u_{p,y})/[3.(u_p$

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 79	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.



	Moment in wall per metre, M	N/A	kNm/m	
	Shear force in wall per metre, V_{ult} or V	N/A	kN/m	
	Concrete Contiguous / Interlocking / Secant Pile Wall			
	Ratio h_s/D	N/A		
	Bending stress, $M.p/D^3$	N/A	N/mm^2	
	From interaction charts, $100A_s/A_{ps}$	2.0	%	
	Area of tensile steel required, $A_s = (100A_s/A_{ps})/100.A_{ps}$	N/A	mm^2/pile	
	Area of tensile steel reinforcement provided, $A_{s,prov,pile}$	N/A	mm^2/pile	
$+\delta)$	Bending moment in wall utilisation = A_s / $A_{s,prov,pile}$	N/A		N/A
$\sigma_{ha,y}')]$				
	Note that pile shear design to be performed as per column design;			
$).\sin\alpha$	All detailing requirements met ?	N/A		
$_e+u_{a,y})]$				
	Min longitudinal steel reinforcement number, n_{pile} (>=6 circular)	N/A		N/A
$0, y-H_R-d_p$	Min longitudinal steel reinforcement diameter, ϕ_{pile} (>=12mm)	N/A	mm	N/A
	Percentage of reinforcement $A_{s,prov,pile}/A_{ps}$ x 100% (>0.4% and <6.	N/A	%	N/A
	Longitudinal steel reinforcement pitch (>=75mm but >=100mm fo	N/A	mm	N/A
$H_R).\cos(90°-\gamma-\delta)$	Circular pile bar pitch = $\pi(D-2.MAX(cover_1,cover_2)-\phi_{pile})/$	N/A	mm	
$/[3.(\sigma_{hp,surfa}$	Min link diameter, $\phi_{link,pile}$ (>=0.25ϕ_{pile}; >=8mm)	N/A	mm	N/A
	Max link pitch, S_{pile} (<=12ϕ_{pile}, <=300mm, <=D for circular)	N/A	mm	N/A
	Require an overall enclosing link.			
$-d_{pw}).\sin\gamma$				
$_{surface}+u_{p,y})]$				

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 80	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Concrete Diaphragm Wall

Concrete moment capacity per metre, $M_u = 0.156f_{cu}.1000.d_{wall}^2$	N/A	kNm/m	
Bending stress, $[M/bd^2] = M / [(1000).d_{wall}^2]$	N/A	N/mm^2	
Bending stress ratio, $K = [M/bd^2] / f_{cu}$	N/A		N/A
Lever arm, $z = d_{wall} . [0.5 + (0.25\text{-}K/0.9)^{0.5}] <= 0.95d_{wall}$	N/A	mm	
Area of tension steel required, $A_s = M / [(0.95f_y).z]$	N/A	mm^2/m	
Area of tensile steel reinforcement provided, $A_{s,prov,wall}$	N/A	mm^2/m	
Bending moment in wall utilisation = $A_s / A_{s,prov,wall}$	N/A		N/A
% Min longitudinal reinforcement in wall (>= 0.0024.1000.t G250;	N/A	%	
% Min longitudinal reinforcement in wall utilisation	N/A		N/A
Ultimate shear stress in wall, $v_{ult}=V_{ult}/(1000.d_{wall})$ (< $0.8f_{cu}^{0.5}$ & 5N/	N/A	N/mm^2	
Ultimate shear stress in wall utilisation	N/A		N/A
Design shear stress in wall, $v_d=V/(1000.d_{wall})$	N/A	N/mm^2	
*(Conservatively, shear capacity enhancement by **either** calculating v_d at d from support and comparing against unenhanced v_c as clause 3.4.5.10 BS8110 **or** calculating v_d at support and comparing against enhanced v_c within 2d of the support as clause 3.4.5.8 BS8110 ignored;)*			
Area of tensile steel reinforcement provided, $A_{s,prov,wall}$	N/A	mm^2/m	
$\rho_w = 100A_{s,prov,wall}/(1000.d_{wall})$	N/A	%	
$v_c = (0.79/1.25)(\rho_w f_{cu}/25)^{1/3}(400/d_{wall})^{1/4}$; $\rho_w<3$; $f_{cu}<40$; $(400/d_{wall}$	N/A	N/mm^2	
Check $v_d < v_c$ for no links	N/A		
Concrete shear capacity $v_c.(1000.d_{wall})$	N/A	kN/m	
Check $v_c < v_d < 0.4 + v_c$ for nominal links	N/A		
Provide nominal links such that $A_{sv} / S > 0.4.(1000)/(0.$	N/A	$mm^2/mm/m$	
Concrete and nominal links shear capacity $(0.4 + v_c).(1$	N/A	kN/m	
Check $v_d > 0.4 + v_c$ for design links	N/A		
Provide shear links $A_{sv} / S > 1000.(v_d\text{-}v_c)/(0.95f_{yv})$ i.e.	N/A	$mm^2/mm/m$	
Concrete and design links shear capacity $(A_{sv,prov,wall}/S_{wa}$	N/A	kN/m	
Area provided by all links per metre, $A_{sv,prov,wall}$	N/A	mm^2/m	
Tried $A_{sv,prov,wall} / S_{wall}$ value	N/A	$mm^2/mm/m$	
Design shear resistance in wall utilisation	N/A		N/A
All detailing requirements met ?	N/A		
Max longitudinal steel reinforcement pitch in wall (<$3d_{wall}$, <750mr	N/A	mm	N/A
Max longitudinal steel reinforcement pitch in wall	N/A	mm	N/A

Maximum spacing: 0.5% Ast or less - 300mm
Between 0.5% and 1.0% - 225mm
1.0% Ast or greater - 175mm

Min longitudinal steel reinforcement pitch in wall (>75mm+ϕ_{wall}, >1	N/A	mm	N/A
Note an allowance has been made for laps in the min pitch by increasing the criteria by the bar diam			
% Max longitudinal reinforcement in wall (<= 0.04.1000.t)	N/A	%	N/A
Longitudinal steel reinforcement diameter in wall, ϕ_{wall} (>=12mm)	N/A	mm	N/A

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 81	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Steel Sheet Pile Wall

Section (elastic) moment capacity per metre, $M_c = p_y.Z$	N/A	kNm/m	
Bending moment in wall utilisation = M / M_c	N/A		N/A
Section shear capacity per metre, $V_c = 0.6h.t.p_y$	N/A	kN/m	
Design shear resistance in wall utilisation = V / V_c	N/A		N/A

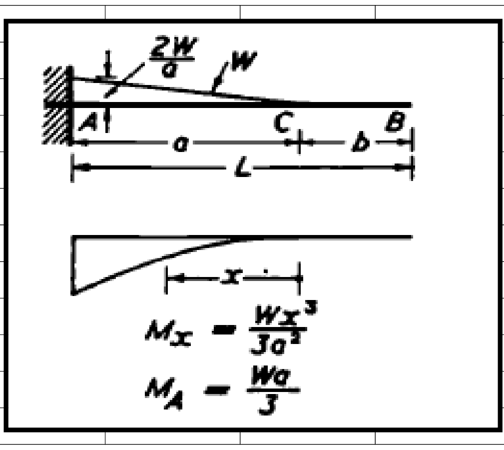
eter.

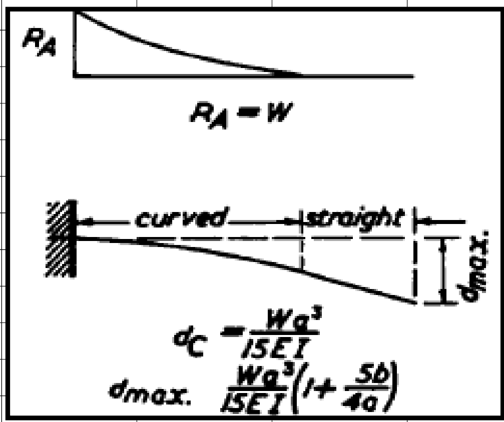
CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.		Rev.
		jXXX	82		
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.	

Deflection Criteria in Wall

Span, l = depth, y to zero shear force, V — N/A m

SLS moment in wall per metre, M_{SLS} = M/K — N/A kNm/m





Equivalent back-calculated triangular distributed loading, W = $3M_{SLS}/l$ — N/A kN/m

Concrete Contiguous / Interlocking / Secant Pile Wall

Maximum deflection in wall, $\delta_{max} = W.l^3/(15E_c.I)$	N/A	mm	
Deflection in wall (first principles) utilisation = $\delta_{max}/(l/250)$	N/A		N/A
Span, l / pile shaft diameter, D ratio	N/A		
Basic span / effective depth ratio criteria (7 cantilever)	N/A		
Note multiplier $C_{1,span\ more\ or\ less\ than\ 10m}$ not applicable;			
Modification factor for tension C_2			
$M.p/D^3$	N/A	N/mm^2	
$f_s = \frac{2f_y A_{s\ req}}{3A_{s\ prov}} \times \frac{1}{\beta_b}$ — *Note $A_{s,prov,pile}/2$ as circular section;* *(β_b =1.0)*	N/A	N/mm^2	
Modification $0.55 + \frac{(477-f_s)}{120\left(0.9+\frac{M}{bd^2}\right)} \leq 2.0$	N/A		
Modified span / effective depth ratio criteria	N/A		
Deflection in wall (BS8110 method) utilisation	N/A		N/A

Concrete Diaphragm Wall

Maximum deflection in wall, $\delta_{max} = W.l^3/(15E_c.I)$	N/A	mm	
Deflection in wall (first principles) utilisation = $\delta_{max}/(l/250)$	N/A		N/A
Span, l / effective depth, d_{wall} ratio	N/A		
Basic span / effective depth ratio criteria (7 cantilever)	N/A		
Note multiplier $C_{1,span\ more\ or\ less\ than\ 10m}$ not applicable;			
Modification factor for tension C_2			
M/bd_{wall}^2	N/A	N/mm^2	
$f_s = \frac{2f_y A_{s\ req}}{3A_{s\ prov}} \times \frac{1}{\beta_b}$ *(β_b =1.0)*	N/A	N/mm^2	
Modification $0.55 + \frac{(477-f_s)}{120\left(0.9+\frac{M}{bd^2}\right)} \leq 2.0$	N/A		
Modified span / effective depth ratio criteria	N/A		
Deflection in wall (BS8110 method) utilisation	N/A		N/A

Steel Sheet Pile Wall

Maximum deflection in wall, $\delta_{max} = W.l^3/(15E_s.I)$	N/A	mm	
Deflection in wall (first principles) utilisation = $\delta_{max}/(l/250)$	N/A		N/A

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 84	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	85	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 87		Rev.
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**		Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 89	Rev.
		Member/Location	
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.	
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 90	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	92	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

9	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
10	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
11	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
12	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
13	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
14	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
15	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
16	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
17	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A		

Point	**Depth, y**	$\sigma_{ha,surface}'$	$\sigma_{ha,WT}'$	$\sigma_{ha,base}'$	$F_{a,y}'$	$F_{ah,y}'$	$e_{a,y}$	$F_{uah,y}$	$e_{ua,y}$
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

		$\sigma_{hp,surface}'$	$\sigma_{hp,WT}'$	$\sigma_{hp,base}'$	$F_{p,y}'$	$F_{ph,y}'$	$e_{p,y}$	$F_{uph,y}$	$e_{up,y}$
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

deflection in cantilever embedded retaining wall

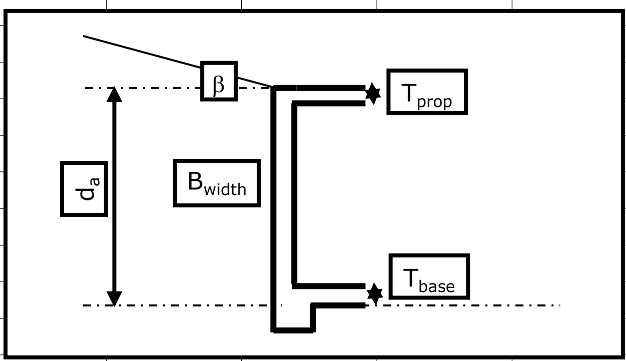
V	**ABS(V)**	**Depth, y**
N/A	N/A	N/A
N/A	N/A	N/A
N/A	N/A	N/A
N/A	N/A	N/A
N/A	N/A	N/A
N/A	N/A	N/A
N/A	N/A	N/A
N/A	N/A	N/A
N/A	N/A	N/A

M	**V**								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								
N/A	N/A								

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 97	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Concrete Propped (Basement) Retaining Wall Dimensions

Note should the retaining wall also be subject to axial compressive forces from the superstructure above as well as bending moments and shears calculated herein, a column design check should be undertaken over a metre strip of the retaining wall accounting for both axial and bending effects. Usually for retaining walls subject to low axial stresses (<= 5N/mm^2), this being the case for retaining walls supporting its self weight and a suspended deck, the axial compressive force only serves to reduce the steel area requirement. However for retaining walls subject to high axial stresses, this being the case for retaining walls supporting column loads from superstructure above or in the case of core walls, the axial compressive force will increase the steel area requirement. This phenomenon is apparent when the column interaction chart is studied. The base of the retaining wall should also be designed as for a strip or a pile foundation to resist this vertical load;

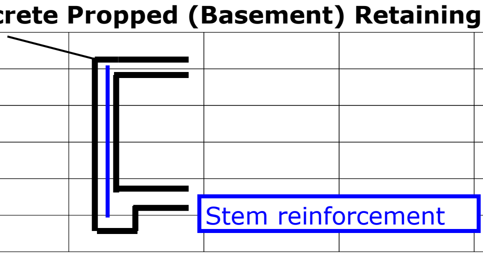


Angle of retaining face from horizontal, α = 90°	90.0	degrees	
Angle of exposed face from horizontal, γ = 90°	90.0	degrees	**N/A**
Thickness of prop, T_{prop}	250	mm	
Thickness of base, T_{base}	250	mm	

Note that the physical thickness of the prop and base has not been considered in effectively reducing the effective span of the simply supported retaining wall, instead the full defined depth dimension, d_a is adopted as the effective span;

Width, B_{width}	350	mm	**N/A**

Concrete Propped (Basement) Retaining Wall Reinforcement



Longitudinal steel reinforcement diameter in stem, ϕ_{stem}	20	mm
Longitudinal steel reinforcement pitch in stem, p_{stem}	200	mm
Longitudinal steel area provided in stem, $A_{s,prov,stem} = (\pi.\phi_{stem}{}^2/4)/p_{stem}$	**N/A**	mm^2/m
Shear link diameter in stem, $\phi_{link,stem}$	None	mm
Number of links per metre in stem, $n_{link,stem}$	5	/m
Area provided by all links per metre in stem, $A_{sv,prov,stem} = n_{link,stem}.\pi.\phi_{link,stem}{}^2/4$	**N/A**	mm^2/m
Pitch of links in stem, S_{stem}	200	mm
Effective depth to longitudinal steel in stem, $d_{stem} = B_{width} - cover_1 - \phi_{link,stem}$ - (	N/A	mm
Estimated steel reinforcement quantity	**N/A**	kg/m^3
stem *[7.850 . ($A_{s,prov,stem}$) / B_{width}];*	N/A	kg/m^3

No curtailment; No laps; Links ignored; Distribution steel ignored;

Concrete Propped (Basement) Retaining Wall SLS Loading

Horizontal Load			Eccentricity from Base		
F_{ah} (F_{ah}')	**N/A**	kN/m	e_a	**N/A**	m
$\sigma_{ha,surface}.\sin\alpha$ ($\sigma_{ha,surface}'.\cos(90°-\alpha+\delta)$)	N/A	kN/m^2			
$\sigma_{ha,base}.\sin\alpha$ ($\sigma_{ha,base}'.\cos(90°-\alpha+\delta)$)	N/A	kN/m^2			
F_{uah}	**N/A**	kN/m	e_{ua}	**N/A**	m
$u_{a,surface}.\sin\alpha$	N/A	kN/m^2			
$u_{a,base}.\sin\alpha$	N/A	kN/m^2			

Note that expressions above are simplified in that the change of slope on the vertical and horizontal effective stress diagrams due to the water table are unaccounted for;

Prop uniformly distributed SLS compression load, $F_{concrete,propped,h}$ **N/A** kN/m

Note $F_{concrete,propped,h} = (F_{ah}(F_{ah}')).e_a+0(F_{uah}).e_{ua})/d_a$;

Concrete Propped (Basement) Retaining Wall ULS Loading

ULS Horizontal Load		
$K.F_{ah}$ ($K.F_{ah}$')	**N/A**	kN/m
$K.\sigma_{ha,surface}.\sin\alpha$ ($K.\sigma_{ha,surface}'.\cos(90°-\alpha+\delta)$)	N/A	kN/m^2
$K.\sigma_{ha,base}.\sin\alpha$ ($K.\sigma_{ha,base}'.\cos(90°-\alpha+\delta)$)	N/A	kN/m^2
$K.F_{uah}$	**N/A**	kN/m
$K.u_{a,surface}.\sin\alpha$	N/A	kN/m^2
$K.u_{a,base}.\sin\alpha$	N/A	kN/m^2

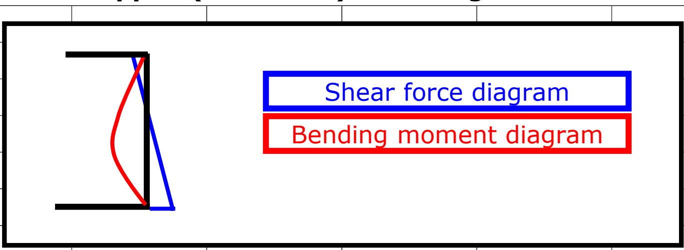
Note it is assumed that the ULS loads act at same eccentricities as the SLS loads;

Note that expressions above are simplified in that the change of slope on the vertical and horizontal effective stress diagrams due to the water table are unaccounted for;

Prop uniformly distributed ULS compression load, $K.F_{concrete,propped,h}$ **N/A** kN/m

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 99	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Concrete Propped (Basement) Retaining Wall Reinforcement Design



Bending Moment Design in Stem

Moment in stem (near midspan) per metre, M	**N/A**	kNm/m	

Note M = [K. $\sigma_{ha,surface}$.sin α(K. $\sigma_{ha,surface}$'.cos(90°- α + δ))].0.125.d$_a{}^2$

+0.5.[K. $\sigma_{ha,base}$.sin α(K. $\sigma_{ha,base}$'.cos(90°- α + δ))-K. $\sigma_{ha,surface}$.sin α(K. $\sigma_{ha,surface}$'.cos(90°- α + δ))].0.12

+[0(K.u$_{a,surface}$.sin α)].0.125.d$_a{}^2$ +0.5.[0(K.u$_{a,base}$.sin α)-0(K.u$_{a,surface}$.sin α)].0.128.d$_a{}^2$;

Note for simplicity, the maximum bending moments from both the uniform and the triangular load distributions are added although they occur at slightly different locations;

Concrete moment capacity per metre, $M_u = 0.156f_{cu}.1000.d_{stem}{}^2$	**N/A**	kNm/m	
Bending stress, $[M/bd^2] = M / [(1000).d_{stem}{}^2]$	N/A	N/mm^2	
Bending stress ratio, $K = [M/bd^2] / f_{cu} <= 0.156$	N/A		**N/A**
Lever arm, $z = d_{stem}\ .\ [0.5 + (0.25\text{-}K/0.9)^{0.5}] <= 0.95d_{stem}$	N/A	mm	
Area of tension steel required, $A_s = M / [(0.95f_y).z]$	**N/A**	mm^2/m	
Area of tensile steel reinforcement provided, $A_{s,prov,stem}$	N/A	mm^2/m	
Bending moment in stem utilisation = $A_s / A_{s,prov,stem}$	**N/A**		**N/A**
% Min longitudinal reinforcement in stem (>= 0.0024.1000.B$_{width}$ G250; >= 0	N/A	%	
% Min longitudinal reinforcement in stem utilisation	**N/A**		**N/A**

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 100	Rev.
		Member/Location	
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.	
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Shear Design in Stem

Shear force at stem base per metre, V_{ult}	N/A	kN/m	
Shear force at stem base per metre, V	N/A	kN/m	
Note V_{ult} and V = [K. $\sigma_{ha,surface}$ .sin α(K. $\sigma_{ha,surface}$ '.cos(90°- $\alpha + \delta$))].d $_a$/2			
+0.5.[K. $\sigma_{ha,base}$ .sin α(K. $\sigma_{ha,base}$ '.cos(90°- $\alpha + \delta$))-K. $\sigma_{ha,surface}$ .sin α(K. $\sigma_{ha,surface}$ '.cos(90°- α +			
+[0(K.u $_{a,surface}$ .sin α)].d $_a$/2+0.5.[0(K.u $_{a,base}$ .sin α)-0(K.u $_{a,surface}$ .sin α)].2.d $_a$/3;			
Ultimate shear stress in stem, $v_{ult}=V_{ult}/(1000.d_{stem})$ (< $0.8f_{cu}^{0.5}$ & $5N/mm^2$)	N/A	N/mm^2	
Ultimate shear stress in stem utilisation	N/A		N/A
8.d $_a$ ^{2}			
Design shear stress in stem, $v_d=V/(1000.d_{stem})$	N/A	N/mm^2	
*(Conservatively, shear capacity enhancement by **either** calculating v_d at d from support and*			
*comparing against unenhanced v_c as clause 3.4.5.10 BS8110 **or** calculating v_d at support and*			
comparing against enhanced v_c within 2d of the support as clause 3.4.5.8 BS8110 ignored;)			
Area of tensile steel reinforcement provided, $A_{s,prov,stem}$	N/A	mm^2/m	
$\rho_w = 100A_{s,prov,stem}/(1000.d_{stem})$	N/A	%	
$v_c = (0.79/1.25)(\rho_w f_{cu}/25)^{1/3}(400/d_{stem})^{1/4}$; $\rho_w<3$; $f_{cu}<40$; $(400/d_{stem})^{1/4}>0.67$	N/A	N/mm^2	
Check $v_d < v_c$ for no links	N/A		
Concrete shear capacity $v_c.(1000.d_{stem})$	N/A	kN/m	
Check $v_c < v_d < 0.4 + v_c$ for nominal links	N/A		
Provide nominal links such that A_{sv} / S > 0.4.(1000)/(0.95f_{yv}) i.e. A	N/A	$mm^2/mm/m$	
Concrete and nominal links shear capacity $(0.4 + v_c).(1000.d_{stem})$	N/A	kN/m	
Check $v_d > 0.4 + v_c$ for design links	N/A		
Provide shear links A_{sv} / S > 1000.(v_d-v_c)/(0.95f_{yv}) i.e. A_{sv} / S >	N/A	$mm^2/mm/m$	
Concrete and design links shear capacity $(A_{sv,prov,stem}/S_{stem}).(0.95f_{yv}$	N/A	kN/m	
Area provided by all links per metre, $A_{sv,prov,stem}$	N/A	mm^2/m	
Tried $A_{sv,prov,stem}$ / S_{stem} value	N/A	$mm^2/mm/m$	
Design shear resistance in stem utilisation	N/A		N/A

Detailing Requirements

All detailing requirements met ?	N/A		
Max longitudinal steel reinforcement pitch in stem ($<3d_{stem}$, <750mm)	N/A	mm	N/A

))].2.d_/3

Maximum spacing: 0.5% Ast or less - 300mm
Between 0.5% and 1.0% - 225mm
1.0% Ast or greater - 175mm

Max longitudinal steel reinforcement pitch in stem	N/A	mm	N/A
Min longitudinal steel reinforcement pitch in stem (>75mm+ϕ_{stem}, >100mm+ϕ	N/A	mm	N/A

Note an allowance has been made for laps in the min pitch by increasing the criteria by the bar diameter.

% Max longitudinal reinforcement in stem (<= 0.04.1000.B_{width})	N/A	%	N/A
Longitudinal steel reinforcement diameter in stem, ϕ_{stem} (>=12mm)	N/A	mm	N/A

Deflection Criteria in Stem

Span, $l = d_a$	N/A	m	
Span, l / effective depth, d_{stem} ratio	N/A		
Basic span / effective depth ratio criteria (20 simply supported)	N/A		

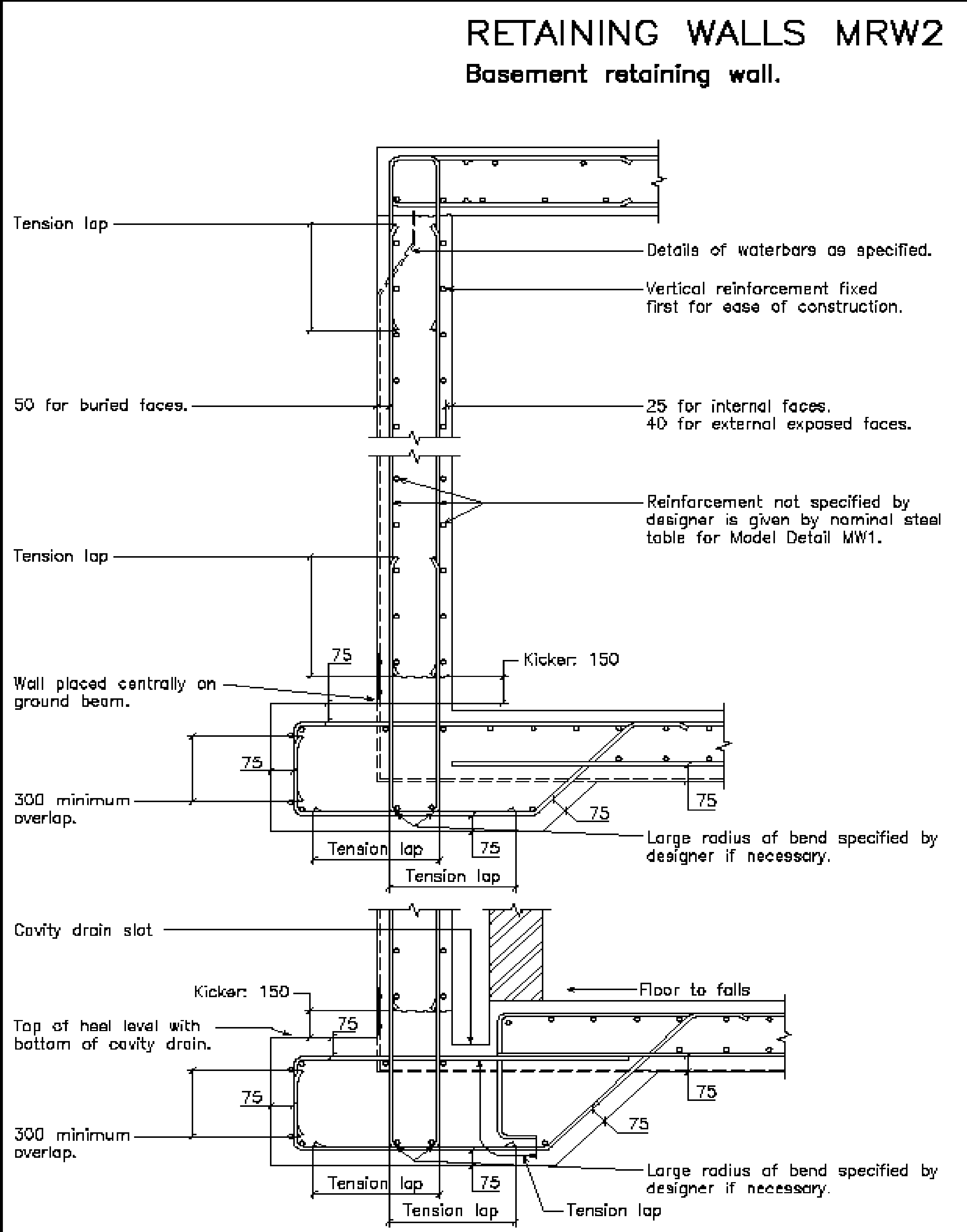
Note multiplier $C_{1,span\ more\ or\ less\ than\ 10m}$ not applicable;

Modification factor for tension C_2

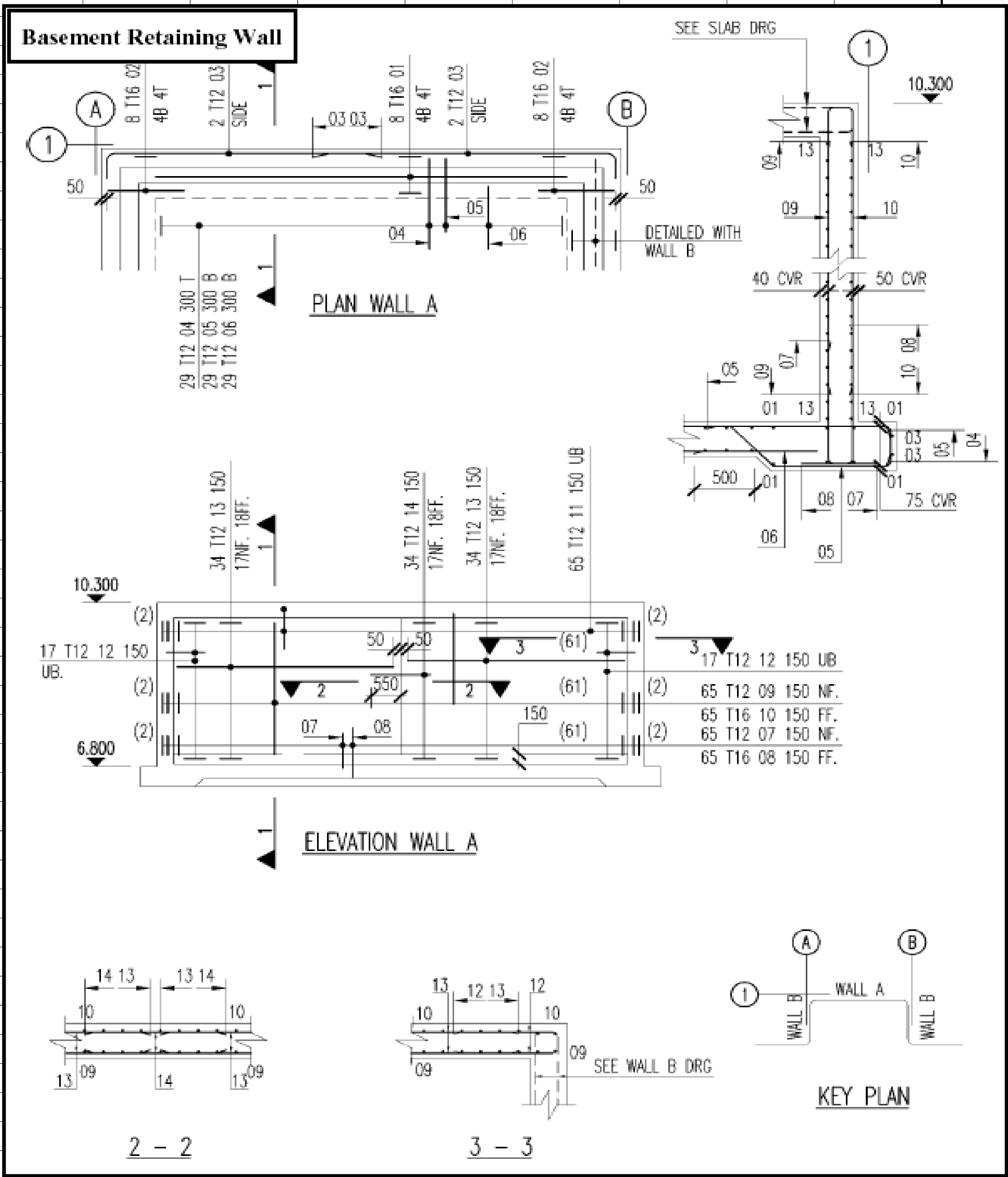
M/bd_{stem}^2	N/A	N/mm^2	
$f_s = \frac{2f_y A_{s\ req}}{3A_{s\ prov}} \times \frac{1}{\beta_b}$ (β_b=1.0)	N/A	N/mm^2	
Modification $0.55 + \frac{(477 - f_s)}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0$	N/A		
Modified span / effective depth ratio criteria	N/A		
Deflection in stem utilisation	N/A		N/A

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 102	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Standard Concrete Propped (Basement) Retaining Wall Reinforcement Details



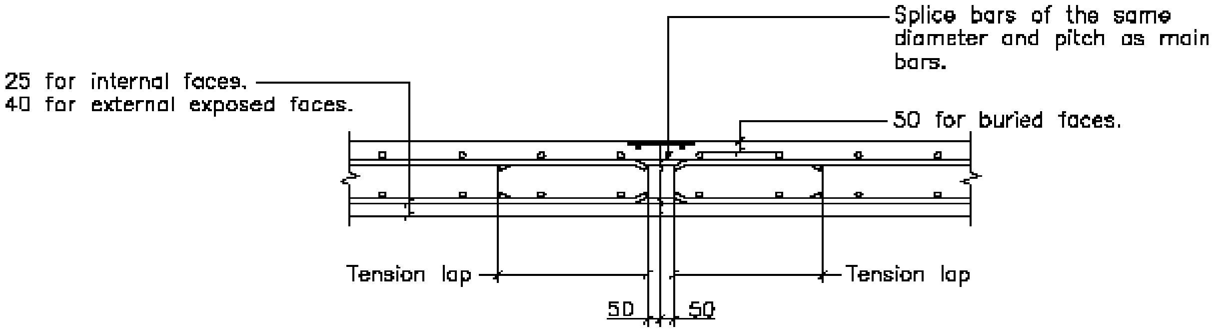
CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	103	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.



CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	104	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

RETAINING WALLS MRW3

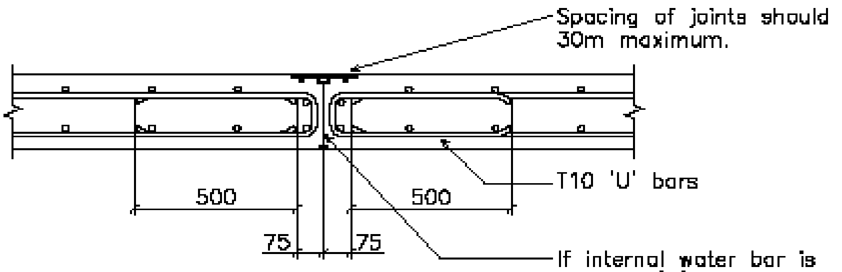
Vertical construction joints.



DETAIL 'A'

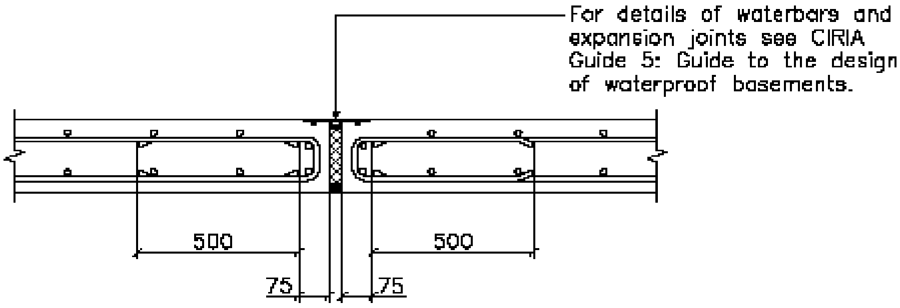
Simple construction joint

If dowel bar specified see Model Detail MF5 B.



DETAIL 'B'

Full contraction joint



DETAIL 'C'

Movement joint

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 109	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	111	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.		Rev.
		jXXX	113		
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date	21/11/2021	Chd.

N/A	N/A	N/A							
N/A	N/A	N/A							
N/A	N/A	N/A							
N/A	N/A	N/A							
N/A	N/A	N/A							
N/A	N/A	N/A							
N/A	N/A	N/A							
N/A	N/A	N/A							
N/A	N/A	N/A							
(V)) from	**N/A**								
employ factor on embedment ?							**1**	**1**	
Yes, Factor 1.2								1.2	
No, Factor 1.0								1.0	

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	120	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Concrete or Steel Propped (Basement) Embedded Retaining Wall Dimensions and Reinforcement

5.2.5 Singly-propped walls

The stability of singly-propped walls is similar to cantilever walls and is illustrated in Figure 5.3. Here the failure is by rotation of wall about the prop level. Again, this is a statically determinate problem[5.2].

5.2.6 Multi-propped walls

Instability of the wall can arise in the cases of cantilever and singly-propped walls. Overall instability is unlikely to arise in the cases of multi-propped/anchored walls because of the redundant nature of the structure. However, local instability may arise as the result of local overstressing and the formation of a hinge where, for example, the multi-propped/anchored wall terminates in clay and where a void is left at the bottom of the excavation (see Figure 5.4). The amount by which the toe of a wall extends below excavation level may be due to a temporary works stability requirement or to limit seepage; see Chapter 3. As the clay softens, movement will occur towards the excavation, with soil moving into the void. The toe of the wall will be pushed in this direction and, if sufficient strength is not provided, the toe could be overstressed. Although this is unlikely to result in general instability, it is highly undesirable as it could allow water ingress and is almost certain to promote movement in the soil at the sides of the excavation. This could have detrimental effects on the foundations of any adjacent structures or on nearby services. There are no generally accepted methods for analysing such failure by way of hand calculations.

Some of the approaches that are available to overcome such a problem are listed below;

- Increase the strength of the toe of the wall especially where it connects to the base slab. This may be expensive (see Figure 5.5a).
- Do away with the void under the base slab. This will result in a build-up of pressure on the base slab, which must be accounted for in the slab design (see Figure 5.5b).
- Increase the vertical effective stress in the soil immediately in front of the toe of the wall. This can be achieved by installing pin piles[5.7] or by using a partial soil-bearing base slab (see Figures 5.5c and 5.5d). Extend walls deeper into stronger soil if such soil is present (see Figure 5.5e).

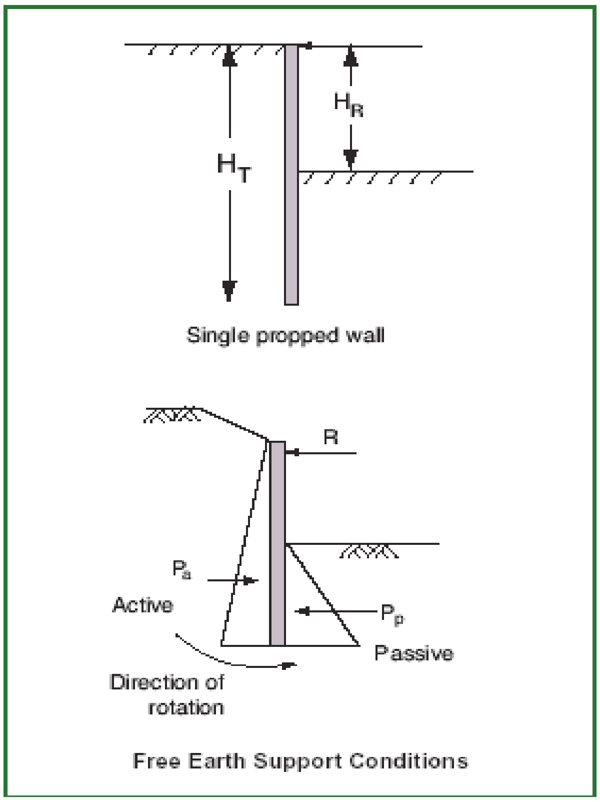


Fig 5.3 Stability of singly-propped walls

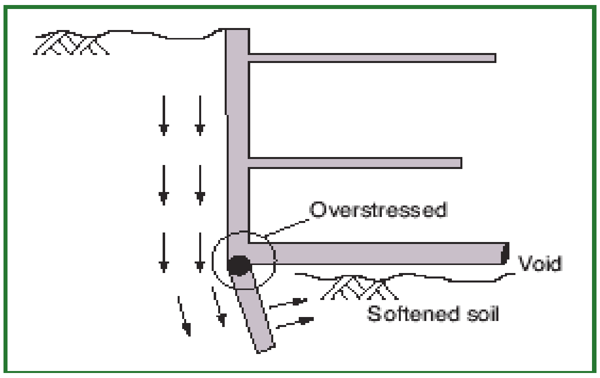
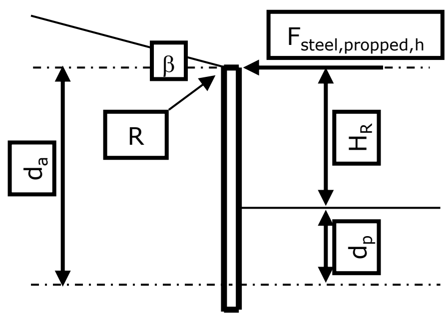


Fig 5.4 Multi-propped wall stability



CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 121	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Angle of retaining face from horizontal, α = 90°	90.0	degrees
Angle of exposed face from horizontal, γ = 90°	90.0	degrees
Height of exposed face, H_R	6.500	m

Note that H_R should be specified in anticipation of possible unplanned excavation to the minimum of the larger of 0.5m and 0.10 of the original retained height, this increasing the value of H_R;

Note that H_R should also be specified accounting for the fact that the prop location may not be at the very top of the wall, but instead stepped down, this decreasing the value of H_R by the step down;

Type of embedded retaining wall: Concrete Diaphragm Wall

Concrete Contiguous / Interlocking / Secant Pile Wall

Note that pile below refers to the hard reinforced pile;

Pile shaft diameter, D	1200mm	N/A	mm
Pile clearance spacing, s (usually 50 to 75)		50	mm
Pile pitch, p = D+s		N/A	mm
Pile shaft second moment of area, I = $[\pi D^4/64]/p$		N/A	cm^4/m
Pile shaft cross sectional area, $A_{ps} = \pi D^2/4$		N/A	mm^2/pile
Longitudinal steel reinforcement diameter in pile, ϕ_{pile}	25		mm
Longitudinal steel reinforcement number in pile, n_{pile}		21	/pile
Longitudinal steel area provided in pile, $A_{s,prov,pile} = n_{pile}$·		N/A	mm^2/pile
Shear link diameter in pile, $\phi_{link,pile}$	10		mm
Number of links in a cross section in pile, i.e. number of		2	/pile
Area provided by all links in a cross-section in pile, $A_{sv,p}$		N/A	mm^2/pile
Pitch of links in pile, S_{pile}		200	mm
Ratio h_s/D = (D - 2.MAX($cover_1$, $cover_2$) - 2.$\phi_{link,pile}$ - ϕ_{pile}		N/A	
Estimated steel reinforcement quantity		N/A	kg/m^3

[7850 . $A_{s,prov,pile}$ / ($\pi.D^2/4$)]; No laps; Links ignored;

Concrete Diaphragm Wall

Wall thickness, t (usually 600 to 1500)		1000	mm
Wall second moment of area, I = $100.t^3/12$		N/A	cm^4/m
Longitudinal steel reinforcement diameter in wall, ϕ_{wall}	20		mm
Longitudinal steel reinforcement pitch in wall, p_{wall}		200	mm
Longitudinal steel area provided in wall, $A_{s,prov,wall}$ = ($\pi.\phi$		N/A	mm^2/m
Shear link diameter in wall, $\phi_{link,wall}$	8		mm
Number of links per metre in wall, $n_{link,wall}$		5	/m
Area provided by all links per metre in wall, $A_{sv,prov,wall}$ =		N/A	mm^2/m
Pitch of links in wall, S_{wall}		200	mm
Effective depth to longitudinal steel in wall, d_{wall} = t - co		N/A	mm
Estimated steel reinforcement quantity		N/A	kg/m^3

[7.850 . ($A_{s,prov,wall}$) / t];

No curtailment; No laps; Links ignored; Distribution steel ignored;

Steel Sheet Pile Wall

Section description	Standard U-Type PU28+1		
Section mass, m		N/A	kg/m
Section mass, m		N/A	kg/m^2
Section depth, h		N/A	mm
Section second moment of area, I		N/A	cm^4/m
Section elastic modulus, Z		N/A	cm^3/m
Section shear area, h.t/b		N/A	cm^2/m

Concrete or Steel Propped (Basement) Embedded Retaining Wall SLS Loading

Horizontal Load			Eccentricity from Base		
F_{ah} (F_{ah}')	N/A	kN/m	e_a	N/A	m
F_{uah}	N/A	kN/m	e_{ua}	N/A	m
F_{ph} (F_{ph}')	N/A	kN/m	e_p	N/A	m
F_{uph}	N/A	kN/m	e_{up}	N/A	m

Total retaining wall SLS horizontal load, $F_{propped,h}$ **N/A** kN/m

Note $F_{propped,h}$ = F_{ah} (F_{ah}')+0(F_{uah})-F_{ph} (F_{ph}')/FOS_5 -0(F_{uph});

Note positive $F_{propped,h}$ is effectively the prop uniformly distributed SLS compression load;

Goal seek Mpropped to 0.0 by changing da and dp (free earth method)
(change initial da and click multiple times until convergence to the practical solution)

BS8002

Total retaining wall SLS moment about prop, $M_{propped}$ **N/A** kNm/m **N/A**

Note $M_{propped}$ = F_{ah} (F_{ah}').(d_a -e_a)+0(F_{uah}).(d_a -e_{ua})-F_{ph} (F_{ph}')/FOS_5.(d_a -e_p)-0(F_{uph}).(d_a -e_{up});

Anticipated maximum value of d_a for commencement of iteration 30.000 m

Employ factor on embedment ? Yes, Factor 1.2

Note that the factor on embedment should be employed if the other FOS methods are not employed;

Design embedment of embedded retaining wall, L_0 = (1.2 or 1.0).d_p **N/A** m *Tomlinson*

Design total length of embedded retaining wall, L_T = L_0+H_R **N/A** m

Concrete or Steel Propped (Basement) Embedded Retaining Wall ULS Loading

ULS Horizontal Load		
K.F_{ah} (K.F_{ah}')	N/A	kN/m
K.F_{uah}	N/A	kN/m
K.F_{ph} (K.F_{ph}')	N/A	kN/m
K.F_{uph}	N/A	kN/m

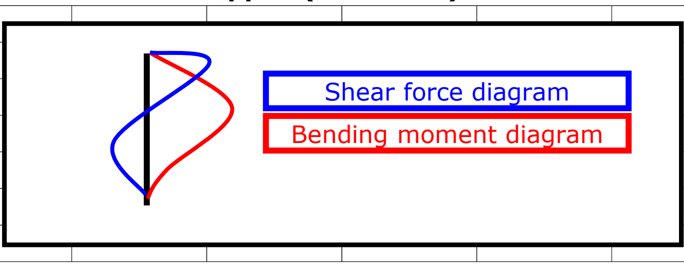
Note it is assumed that the ULS loads act at the same eccentricities as the SLS loads;

Total retaining wall ULS horizontal load, K.$F_{propped,h}$ **N/A** kN/m

Note positive K.$F_{propped,h}$ is effectively the prop uniformly distributed ULS compression load;

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	123	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

Concrete or Steel Propped (Basement) Embedded Retaining Wall Section Design



Bending Moment Design in Wall, Shear Design in Wall and Detailing Requirements

Point	Depth, y (m)	Bending Moment in Wall, M (kNm/m)	Shear Force in Wall, V (kN/m)
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A
17	N/A	N/A	N/A
18	N/A	N/A	N/A
Σ		N/A	N/A

Note $M = K.F_{ah,y}(K.F_{ah,y}').e_{a,y} - K.F_{ph,y}(K.F_{ph,y}')/FOS_5.e_{p,y} + 0(K.F_{uah,y}).e_{ua,y} - 0(K.F_{uph,y}).e_{up,y} - K.F_{pr}$

Note $V = K.F_{ah,y}(K.F_{ah,y}') - K.F_{ph,y}(K.F_{ph,y}')/FOS_5 + 0(K.F_{uah,y}) - 0(K.F_{uph,y}) - K.F_{propped,h}$;

where for undrained analysis

$\sigma_{va,surface} = p_{s,a}$

$\sigma_{va,y} = p_{s,a} + \gamma.y$

$\sigma_{ha,surface} = MAX(0, \sigma_{va,surface} - 2S_u)$

$\sigma_{ha,y} = MAX(4.8y, \sigma_{va,y} - 2S_u)$

$F_{ah,y} = 0.5.(\sigma_{ha,surface} + \sigma_{ha,y}).y.\sin\alpha$

$e_{a,y} = y.(2\sigma_{ha,surface} + \sigma_{ha,y})/[3.(\sigma_{ha,surface} + \sigma_{ha,y})]$

$\sigma_{vp,surface} = p_{s,p}$

$\sigma_{vp,y} = p_{s,p} + \gamma.(y - H_R)$

$\sigma_{hp,surface} = \sigma_{vp,surface} + 2S_u$

$\sigma_{hp,y} = \sigma_{vp,y} + 2S_u$

$F_{ph,y} = 0.5.(\sigma_{hp,surface} + \sigma_{hp,y}).MAX(0.0, y - H_R).\sin\gamma$

$e_{p,y} = (y - H_R).(2\sigma_{hp,surface} + \sigma_{hp,y})/[3.(\sigma_{hp,surface} + \sigma_{hp,y})$

and for drained analysis

$\sigma_{va,surface}' = p_{s,a} - 0.0$

$\sigma_{va,y}' = p_{s,a} + \gamma.y - \gamma_w.MAX(0.0, y - d_{aw})$

$\sigma_{ha,surface}' = K_a.\sigma_{va,surface}' - 2c'\sqrt{K_a}$

$\sigma_{ha,y}' = K_a.\sigma_{va,y}' - 2c'\sqrt{K_a}$

$F_{ah,y}' = 0.5.(\sigma_{ha,surface}' + \sigma_{ha,y}').y.\cos(90° - \alpha$

$e_{a,y} = y.(2\sigma_{ha,surface}' + \sigma_{ha,y}')/[3.(\sigma_{ha,surface}' +$

$u_{a,surface} = 0.0$

$u_{a,y} = 0.0 + \gamma_w.MAX(0.0, y - d_{aw})$

$F_{uah,y} = 0.5.(u_{a,surface} + u_{a,y}).MAX(0.0, y - d_{aw}$

$e_{ua,y} = (y - d_{aw}).(2u_{a,surface} + u_{a,y})/[3.(u_{a,surfac}$

$\sigma_{vp,surface}' = p_{s,p} - 0.0$

$\sigma_{vp,y}' = p_{s,p} + \gamma.MAX(0.0, y - H_R) - \gamma_w.MAX(0.$

$\sigma_{hp,surface}' = K_p.\sigma_{vp,surface}' + 2c'\sqrt{K_p}$

$\sigma_{hp,y}' = K_p.\sigma_{vp,y}' + 2c'\sqrt{K_p}$

$F_{ph,y}' = 0.5.(\sigma_{hp,surface}' + \sigma_{hp,y}').MAX(0.0, y-$

$e_{p,y} = MAX(0.0, y - H_R).(2\sigma_{hp,surface}' + \sigma_{hp,y}')/$

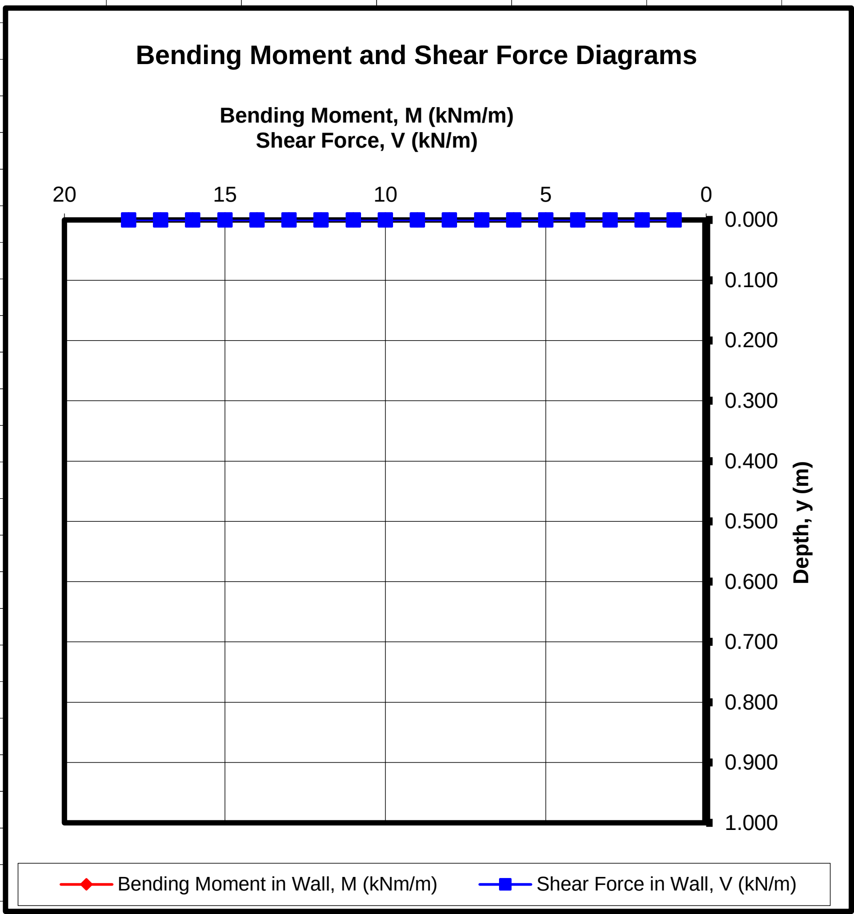
$u_{p,surface} = 0.0$

$u_{p,y} = 0.0 + \gamma_w.MAX(0.0, y - H_R - d_{pw})$

$F_{uph,y} = 0.5.(u_{p,surface} + u_{p,y}).MAX(0.0, y - H_R$

$e_{up,y} = (y - H_R - d_{pw}).(2u_{p,surface} + u_{p,y})/[3.(u_p$

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.		Rev.
		jXXX	124		
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021		Chd.



Moment in wall per metre, M	N/A	kNm/m	
Shear force in wall per metre, V_{ult} or V	N/A	kN/m	

Concrete Contiguous / Interlocking / Secant Pile Wall

opped,h ·y;

	Ratio h_s/D	N/A		
	Bending stress, $M.p/D^3$	N/A	N/mm^2	
	From interaction charts, $100A_s/A_c$	0.5	%	
	Area of tensile steel required, $A_s = (100A_s/A_{ps})/100.A_{ps}$	N/A	mm^2/pile	
	Area of tensile steel reinforcement provided, $A_{s,prov,pile}$	N/A	mm^2/pile	
+δ)	Bending moment in wall utilisation = A_s / $A_{s,prov,pile}$	N/A		N/A
σ ha,y ')]				

Note that pile shear design to be performed as per column design;

).sin α	All detailing requirements met ?	N/A		
e +u a,y)]				
	Min longitudinal steel reinforcement number, n_{pile} (>=6 circular)	N/A		N/A
0, y-H R -d p	Min longitudinal steel reinforcement diameter, ϕ_{pile} (>=12mm)	N/A	mm	N/A
	Percentage of reinforcement $A_{s,prov,pile}/A_{ps}$ x 100% (>0.4% and <6.	N/A	%	N/A
	Longitudinal steel reinforcement pitch (>=75mm but >=100mm fo	N/A	mm	N/A
H R).cos(90°-γ-δ)	Circular pile bar pitch = $\pi(D-2.MAX(cover_1,cover_2)-\phi_{pile})/$	N/A	mm	
/[3.(σ hp,surfa	Min link diameter, $\phi_{link,pile}$ (>=0.25ϕ_{pile}; >=8mm)	N/A	mm	N/A
	Max link pitch, S_{pile} (<=12ϕ_{pile}, <=300mm, <=D for circular)	N/A	mm	N/A

Require an overall enclosing link.

-d pw).sin γ

surface +u p,y)]

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 125	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Concrete Diaphragm Wall

Concrete moment capacity per metre, $M_u = 0.156f_{cu}.1000.d_{wall}^2$	**N/A**	kNm/m	
Bending stress, $[M/bd^2] = M / [(1000).d_{wall}^2]$	N/A	N/mm^2	
Bending stress ratio, $K = [M/bd^2] / f_{cu}$	N/A		**N/A**
Lever arm, $z = d_{wall} . [0.5 + (0.25\text{-}K/0.9)^{0.5}] <= 0.95d_{wall}$	N/A	mm	
Area of tension steel required, $A_s = M / [(0.95f_y).z]$	**N/A**	mm^2/m	
Area of tensile steel reinforcement provided, $A_{s,prov,wall}$	N/A	mm^2/m	
Bending moment in wall utilisation = $A_s / A_{s,prov,wall}$	**N/A**		**N/A**
% Min longitudinal reinforcement in wall (>= 0.0024.1000.t G250;	N/A	%	
% Min longitudinal reinforcement in wall utilisation	**N/A**		**N/A**
Ultimate shear stress in wall, $v_{ult}=V_{ult}/(1000.d_{wall})$ (< $0.8f_{cu}^{0.5}$ & 5N/	**N/A**	N/mm^2	
Ultimate shear stress in wall utilisation	**N/A**		**N/A**
Design shear stress in wall, $v_d=V/(1000.d_{wall})$	**N/A**	N/mm^2	
*(Conservatively, shear capacity enhancement by **either** calculating v_d at d from support and comparing against unenhanced v_c as clause 3.4.5.10 BS8110 **or** calculating v_d at support and comparing against enhanced v_c within 2d of the support as clause 3.4.5.8 BS8110 ignored;)*			
Area of tensile steel reinforcement provided, $A_{s,prov,wall}$	N/A	mm^2/m	
$\rho_w = 100A_{s,prov,wall}/(1000.d_{wall})$	N/A	%	
$v_c = (0.79/1.25)(\rho_w f_{cu}/25)^{1/3}(400/d_{wall})^{1/4}$; $\rho_w<3$; $f_{cu}<40$; $(400/d_{wall}$	**N/A**	N/mm^2	
Check $v_d < v_c$ for no links	**N/A**		
Concrete shear capacity $v_c.(1000.d_{wall})$	**N/A**	kN/m	
Check $v_c < v_d < 0.4 + v_c$ for nominal links	**N/A**		
Provide nominal links such that $A_{sv} / S > 0.4.(1000)/(0.$	**N/A**	$mm^2/mm/m$	
Concrete and nominal links shear capacity $(0.4 + v_c).(1$	**N/A**	kN/m	
Check $v_d > 0.4 + v_c$ for design links	**N/A**		
Provide shear links $A_{sv} / S > 1000.(v_d\text{-}v_c)/(0.95f_{yv})$ i.e.	**N/A**	$mm^2/mm/m$	
Concrete and design links shear capacity $(A_{sv,prov,wall}/S_{wa}$	**N/A**	kN/m	
Area provided by all links per metre, $A_{sv,prov,wall}$	N/A	mm^2/m	
Tried $A_{sv,prov,wall} / S_{wall}$ value	N/A	$mm^2/mm/m$	
Design shear resistance in wall utilisation	**N/A**		**N/A**
All detailing requirements met ?	**N/A**		
Max longitudinal steel reinforcement pitch in wall (<$3d_{wall}$, <750mr	N/A	mm	**N/A**
Max longitudinal steel reinforcement pitch in wall	N/A	mm	**N/A**

Maximum spacing:	0.5% Ast or less - 300mm
	Between 0.5% and 1.0% - 225mm
	1.0% Ast or greater - 175mm

Min longitudinal steel reinforcement pitch in wall (>75mm+ϕ_{wall}, >1	N/A	mm	**N/A**
Note an allowance has been made for laps in the min pitch by increasing the criteria by the bar diam			
% Max longitudinal reinforcement in wall (<= 0.04.1000.t)	N/A	%	**N/A**
Longitudinal steel reinforcement diameter in wall, ϕ_{wall} (>=12mm)	N/A	mm	**N/A**

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 126	Rev.
		Member/Location	
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.	
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Steel Sheet Pile Wall

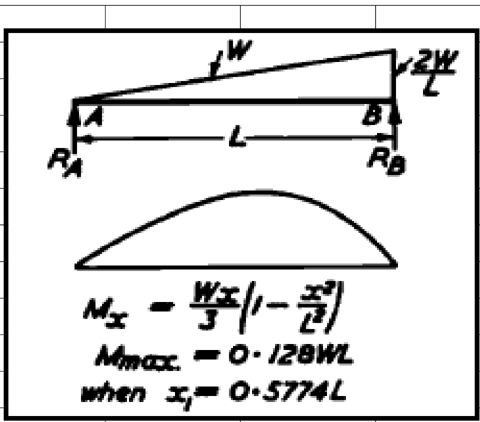
Section (elastic) moment capacity per metre, $M_c = p_y.Z$	**N/A**	kNm/m	
Bending moment in wall utilisation = M / M_c	**N/A**		**N/A**
Section shear capacity per metre, $V_c = 0.6h.t.p_y$	**N/A**	kN/m	
Design shear resistance in wall utilisation = V / V_c	**N/A**		**N/A**

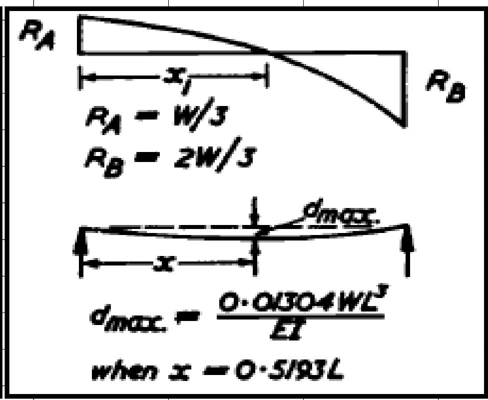
eter.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 127	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date **21/11/2021**	Chd.

Deflection Criteria in Wall

Span, $l = d_a$	N/A	m
SLS moment in wall per metre, $M_{SLS} = M/K$	N/A	kNm/m





Equivalent back-calculated triangular distributed loading, $W = M_{SLS}/(0.128.l)$	N/A	kN/m	
Concrete Contiguous / Interlocking / Secant Pile Wall			
Maximum deflection in wall, $\delta_{max} = 0.01304W.l^3/(E_c.I)$	**N/A**	mm	
Deflection in wall (first principles) utilisation = $\delta_{max}/(l/250)$	**N/A**		**N/A**
Span, l / pile shaft diameter, D ratio	**N/A**		
Basic span / effective depth ratio criteria (20 simply supported)	N/A		
Note multiplier $C_{1,span\ more\ or\ less\ than\ 10m}$ not applicable;			
Modification factor for tension C_2			
$M.p/D^3$	N/A	N/mm²	
$f_s = \frac{2 f_y A_{s\ req}}{3 A_{s\ prov}} \times \frac{1}{\beta_b}$ *Note $A_{s,prov,pile}/2$ as circular section; (β_b =1.0)*	N/A	N/mm²	
Modification $0.55 + \frac{(477 - f_s)}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0$	N/A		
Modified span / effective depth ratio criteria	**N/A**		
Deflection in wall (BS8110 method) utilisation	**N/A**		**N/A**
Concrete Diaphragm Wall			
Maximum deflection in wall, $\delta_{max} = 0.01304W.l^3/(E_c.I)$	**N/A**	mm	
Deflection in wall (first principles) utilisation = $\delta_{max}/(l/250)$	**N/A**		**N/A**
Span, l / effective depth, d_{wall} ratio	**N/A**		
Basic span / effective depth ratio criteria (20 simply supported)	N/A		
Note multiplier $C_{1,span\ more\ or\ less\ than\ 10m}$ not applicable;			
Modification factor for tension C_2			
M/bd_{wall}^2	N/A	N/mm²	
$f_s = \frac{2 f_y A_{s\ req}}{3 A_{s\ prov}} \times \frac{1}{\beta_b}$ *(β_b =1.0)*	N/A	N/mm²	
Modification $0.55 + \frac{(477 - f_s)}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0$	N/A		
Modified span / effective depth ratio criteria	**N/A**		
Deflection in wall (BS8110 method) utilisation	**N/A**		**N/A**
Steel Sheet Pile Wall			
Maximum deflection in wall, $\delta_{max} = 0.01304W.l^3/(E_s.I)$	**N/A**	mm	
Deflection in wall (first principles) utilisation = $\delta_{max}/(l/250)$	**N/A**		**N/A**

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No. jXXX	Sheet No. 128	Rev.
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.		Rev.
		jXXX	130		
		Member/Location			
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.			
Structure, Member Design - Geotechnics Retaining Walls		Made by **XX**	Date	**21/11/2021**	Chd.

CONSULTING ENGINEERS	Engineering Calculation Sheet Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	131	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Retaining Wall	Drg.		
Structure, Member Design - Geotechnics Retaining Walls		Made by XX	Date 21/11/2021	Chd.