FOUNDATION UNDERPINNING DESIGN (NOT FOR CONSTRUCTION)

DESIGN DATA *[taken from BS EN1997-1, BS8002:1994, BS8110, BS648]* **:**

Grade of basement to be designed: **Grade 3 - Domestic**

Typical material weights:

Concrete [normal reinforced] - (unit load) : $\rho_{conc} := 24\ kN \cdot m^{-3}$

Soil [Firm clays / Dense Gravel] - (unit load) : $\rho_{soil} := 18\ kN \cdot m^{-3}$

Water - (Bulk density) : $\rho_{water} := 9.81\ kN \cdot m^{-3}$

Concrete and Reinforcement specifications:

Characteristic tensile strength of reinforcement: $f_y := 500\ N \cdot mm^{-2}$

Characteristic compressive cube strength of concrete : $f_{cu} := 35\ N \cdot mm^{-2}$

Cover to reinforcement: $C_{cov} := 50\ mm$

Assumed diameter of reinforcing bars: $\phi := 20\ mm$

Soil characteristics:

Soil Type (1=Clay 2=Granular) - $S_{typ} := 1$

Angle of friction -

Granular Soils - [BS8002, 2.2.4 - A & B taken as 0, worst case] $\varphi'_{gravel} = 30\ ° + A + B$

$\varphi'_{gravel} := 30\ °$

Clay Soils - [BS8002 - Table 2, Based on plasticity Index of 30% (London clay)] $\varphi'_{clay} := 21\ °$

Cohesion -

Granular soil types taken as - $C_{gravel} := 0\ kN \cdot m^{-2}$

Clay soil types-

$C_{clay} := 20\ kN \cdot m^{-2}$

[Taken from Geotechdata.info, for inorganic clay of high plasticity (London clay) - 15-25kN/m²]

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Soil charicteristics continued:

Earth Pressure:
The calculation below for the coefficient of earth pressure is designed to take in to account both 'active' and 'at rest' pressure influences. The value taken accounts for the stem not being infinitely stiff but also in the permanent case resisting lateral pressure with little deflection. Therefore an intermediate median value between Ka and Ko is used. (An additional value for any inclination of the ground level is allowed for with the addition of the angle beta.)

Incline of top surface to horizontal - (assumed nominal 5°) : $\beta := 5\ °$

Internal angle of friction : $\Phi = 21\ °$

Rankine's coefficient of active lateral earth pressure:

$$k_a := \frac{\cos(\beta) - \left(\left(\cos(\beta)\right)^2 - \left(\cos(\Phi)\right)^2\right)^{\frac{1}{2}}}{\cos(\beta) + \left(\left(\cos(\beta)\right)^2 - \left(\cos(\Phi)\right)^2\right)^{\frac{1}{2}}} \qquad k_a = 0.48$$

$$k_0 := \left(1 - \sin(\Phi)\right) \cdot \left(1 + \sin(\beta)\right) \qquad k_0 = 0.698$$

Median coefficient:

$$k_m := k_a + \left(\frac{k_0 - k_a}{2}\right) \qquad k_m = 0.59$$

Rankine's coefficient of passive lateral earth pressure:

$$k_p := \frac{\cos(\beta) + \left(\left(\cos(\beta)\right)^2 - \left(\cos(\Phi)\right)^2\right)^{\frac{1}{2}}}{\cos(\beta) - \left(\left(\cos(\beta)\right)^2 - \left(\cos(\Phi)\right)^2\right)^{\frac{1}{2}}} \qquad k_p = 2.07$$

Angle of base friction : $\delta_b := 18.6\ °$

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Underpinning Conditions:

(A) CASE A

NOTES / ASSUMPTIONS:

1. The basement slab is 300mm thick and will be screeded for domestic use.
2. The basement walls are supporting the building over supported on the substrata beneath.
3. Soil type is taken as London Clay as confirmed by site investigations.
4. Water - Allow for 9.81kN/m² at ground level.
5. Passive pressures generated due soil present in front of base are ignored due to excavations for slab installation.
6. The following design does not check against rotational side failure, it is assumed pins will be fully propped/shored to contractor's designs at all times.
7. The following design does not include deflection checks as these are assumed to be negligible.
8. The calculation does not include SLS checks for either cracking or shrinkage.
9. The calculation does not allow for the effect of ground water seepage beneath the wall.

SEE FOLLOWING PAGES FOR RETAINING WALL CALULCATIONS.

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CONDITION A

Length of conditon A - $L_w := 38\ m$
[Note: Forces calculated act on 1.0m of wall]

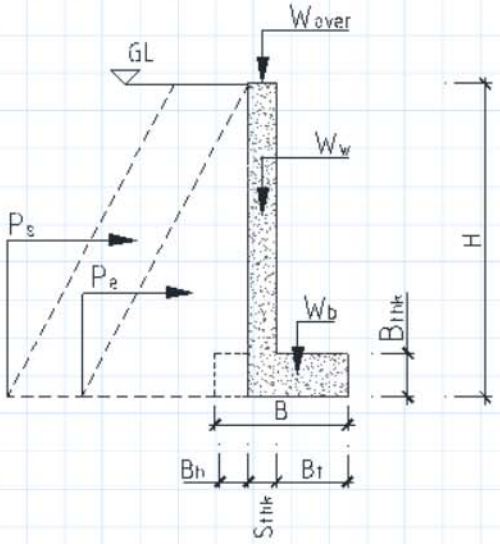

fig.1 - Retaining wall diagram

Wall Details:

Wall Height - $H := 3.5\ m$

Soil Height - $Hs := H$

Toe length - $B_t := 1.7\ m$

Heel length - $B_h := 0.2\ m$

Stem Thickenss - $S_{thk} := 0.3\ m$

Base Thickness - $B_{thk} := 0.45\ m$

Base length (inc. heel) - $B := B_t + S_{thk} + B_h = 2.2\ m$

Load eccentriciy - $e_L := \frac{B}{2} - B_h - \left(\frac{S_{thk}}{2}\right) = 0.75\ m$

Stem Height - $H_{stem} := H - B_{thk} = 3.05\ m$

Water Height - $H_{water} := H - B_{thk} = 3.05\ m$

Note:
Wall Height taken directly from architectural plans and sections + 450mm slab thickening.

Vertical Loads:

NOTE: All line loads are assumed to be acting centrally on wall stem.

Permanent line load on wall - $G_k := 35\ kN \cdot m^{-1}$

Imposed line load on wall - $Q_k := 6\ kN \cdot m^{-1}$

Total line load on wall - $l_{Tot.} := G_k + Q_k = 41\ kN \cdot m^{-1}$

Weight of retaining wall stem - $W_w := \rho_{conc} \cdot S_{thk} \cdot \left(H - B_{thk}\right) \cdot 1.0\ m = 21.96\ kN$

Total wall load - $N_{wall} := \left(l_{Tot.} \cdot 1.0\ m\right) + W_w = 62.96\ kN$

Weight of retaining wall base - $W_b := \rho_{conc} \cdot B \cdot B_{thk} \cdot 1.0\ m = 23.76\ kN$

Weight of soil over heel - $W_s := \rho_{soil} \cdot B_h \cdot \left(H - B_{thk}\right) \cdot 1.0\ m = 10.98\ kN$

Total vertical force - $N_{Tot.} := N_{wall} + W_b + W_s = 97.7\ kN$

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Foundation Design (A) continued:

Horizontal forces:

Active Pressure : NOTE: Temporary case consider drained only.

$P_a := \rho_{soil} \cdot Hs \cdot k_m = 37.18\ kN \cdot m^{-2}$

$P_e := 0.5 \cdot P_a \cdot Hs \cdot 1.0\ m = 65.06\ kN$

Surcharge magnitude - $F_s := 5.0\ kN \cdot m^{-2}$

$P_s := F_s \cdot Hs \cdot k_m \cdot 1.0\ m = 10.33\ kN$

CHECK OVERTURNING: Factor of safety: $\gamma_{ot} := 2.0$

$M_{ot} := \left(P_e \cdot \frac{Hs}{3}\right) + \left(P_s \cdot \frac{Hs}{2}\right) = 93.97\ kN \cdot m$

$M_{resist} := \left(\left(N_{wall}\right) \cdot \left(B - B_h - \left(\frac{S_{thk}}{2}\right)\right)\right) + \left(W_b \cdot \frac{B}{2}\right) + \left(W_s \cdot \left(B - \frac{B_h}{2}\right)\right) = 165.67\ kN \cdot m$

Check: $\frac{M_{res}}{M_{ot}} > \gamma_{ot}$; $Fos_{ovr} = 1.76$ RESULT = "FAIL!"

CHECK SLIDING: Factor of safety: $\gamma_{slide} := 1.5$

Angle of base friction : $\varphi' = 21\ °$ [See deisgn data]

Base adhesion: $Soil\_type =$ "Clay" $\therefore$ $C_b = 20\ kN \cdot m^{-2}$ [See deisgn data]

$\therefore$ $F_{resist} := \left(N_{Tot.} \cdot \tan\left(\varphi'\right)\right) + \left(C_b \cdot B^2\right) = 134.3\ kN$

$F_{slide} := P_e + P_s = 75.39\ kN$

Check: $\frac{F_{resist}}{F_{slide}} > \gamma_{slide}$; $Fos_{slide} = 1.78$ RESULT = "SO OK"

$\therefore$ **IN TEMPORARY CASE WALL TO BE PROPPED at a 1/3 AND MID HEIGHT TO RESIST BOTH OVERTURNING AND SLIDING. IN PERMANENT CASE CONSIDER STRUCTURE MONOLITHIC WITH BASE SLAB TO PROVIDE SIMILAR RESISTANCE.**

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Foundation Design (A) continued:

CHECK BEARING PRESSURE:

$GBP_{Allowable} = 100\ kN \cdot m^{-2}$ $Soil\_type =$ "Clay"

$M_{resist} := \left(\left\langle N_{wall} \right\rangle \cdot \left(\frac{B}{2} - \left(B_h + \frac{S_{thk}}{2} \right) \right) \right) + \left(W_s \cdot \left(\frac{B}{2} - \frac{B_h}{2} \right) \right) = 58.2\ kN \cdot m$

$M_{ot} = 93.97\ kN \cdot m$

$M_{net} := M_{ot} - M_{resist} = 35.77\ kN \cdot m$

Resultant eccentricity, *e*: $e := \left| \frac{M_{net}}{N_{Tot.}} \right| = 366.2\ mm$

Check within middle 3rd: $e < \frac{B}{6}$; $\frac{B}{6} = 366.67\ mm$ RESULT = "SO OK"

Max/ Min pressures:

Pressure @ heel: $q_{heel} := \frac{N_{Tot.}}{B \cdot 1\ m} \cdot \left(1 - \frac{6 \cdot e}{B} \right) = 0.06\ kN \cdot m^{-2}$

Pressure @ toe: $q_{toe} := \frac{N_{Tot.}}{B \cdot 1\ m} \cdot \left(1 + \frac{6 \cdot e}{B} \right) = 88.76\ kN \cdot m^{-2}$

Check: $GBP_{Max} < GBP_{Allowable}$ RESULT = "SO OK"

DESIGN REINFORCING FOR PERMANENT, UNDRAINED CONDITION:

Single pin width : $b := 1000\ mm$

Active Pressure :
(Permanent case case undrained)

$P_a := \rho_{soil} \cdot H_{stem} \cdot k_m \cdot 1.0\ m$

$P_a = 32.4\ kN \cdot m^{-1}$

Horizontal forces:

$P_e := 0.5 \cdot P_a \cdot H_{stem} = 49.4\ kN$

$P_s := F_s \cdot H_{stem} \cdot k_m \cdot 1.0\ m = 9\ kN$

$P_w := \rho_{water} \cdot \frac{\left(1.0 \cdot H_{water} \right)^2}{2} \cdot 1.0\ m = 45.63\ kN$

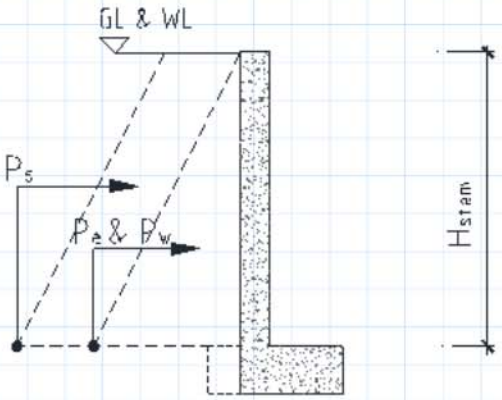

fig.2 - Retaining wall diagram.

Design moment at base of wall, M [Water table taken at full height of wall]

$M := 1.5 \cdot \left(\left(P_e \cdot \frac{H_{stem}}{3} \right) + \left(P_s \cdot \frac{H_{stem}}{2} \right) + \left(P_w \cdot \frac{H_{stem}}{3} \right) \right) = 165.51\ kN \cdot m$

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Foundation Design (A) continued:

Effective depth, d

$d := S_{thk} - C_{cov} - \frac{\phi}{2} = 240\ mm$

Ultimate moment of resistance, Mu

$M_u := 0.156 \cdot f_{cu} \cdot b \cdot d^2 = 314.5\ kN \cdot m$

Check: $M_u > M$ RESULT = "SO OK"

$\therefore$ **SO NO COMPRESSION REINFORCEMENT NEEDED.**

DESIGN WALL AS SINGLY REINFORCED BEAM:

$k := \frac{M}{f_{cu} \cdot b \cdot d^2} = 0.08$; $\mu_z := 0.5 + \left(\sqrt{0.25 - \frac{k}{0.9}}\right)$

Check: $\mu_z < 0.95$ $RESULT$ = "PASS" $\therefore$ $\mu_z = 0.9$

Lever arm, z : $z := \mu_z \cdot d$ $\therefore$ $z = 215.63\ mm$

So area of steel required is :

$As_{req} := \frac{M}{0.95 \cdot f_y \cdot (0.95 \cdot d)} = 1528.27\ mm^2$ [in per meter i.e. *mm²/m*]

Reinforcing bar dia. specified : $\phi_{vertF} := 20\ mm$ Spacing : $b_{sv} := 200\ mm$

$As_{actual} = 1570.8\ mm^2$ *[mm²/m]*

Check: $\mathrm{As_{actual}} > As_{req}$ RESULT = "SO OK"

So use - H20 bars @ 200 centres (1570 mm²/m) in FF [Far Face]

Provide reinforcement to NF as well, steel area required is minimum steel area:
[Definitions below taken from EC2 9.6.2(1) & 9.6.3(1)]

$As_{vmin} := 0.002 \cdot b \cdot S_{thk} = 600\ mm^2$ (half in each face so divide by 2 to get NF req.)

$As_{NFmin} := As_{vmin} \cdot 0.5 = 300\ mm^2$ $\phi_{vertN} := 12\ mm$ $b_{sv} = 200\ mm$ *[mm²/m]*

Check: $\mathrm{As_{actualN}} > As_{NFmin}$ RESULT = "SO OK"

So also use H12 bars @ 200 centres in NF [Near Face] to prevent excessive cracking

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Foundation Design (A) continued:

Distribution reinforcement, steel area required is minimum horiz. steel area:

[mm²/m]

$As_{hmin} := \max\left(0.001 \cdot b \cdot S_{thk}, 25\% \cdot As_{actual}\right) = 392.7\ mm^2$

Reinforcing bar dia. specified : $\phi_{horiz} := 10\ mm$ Spacing : $b_{sh} := 200\ mm$

[mm²/m]

$As_{actual} = 392.7\ mm^2$

Check: $\mathrm{As}_{\mathrm{actual}} > As_{hmin}$ $\mathrm{RESULT} = \text{“SO OK”}$

So use - H10 bars @ 200 centres (393 mm²/m) as horizontal reinforcement.

END OF CALCULATION

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Condition A - Detailing summary

Wall dimension summary

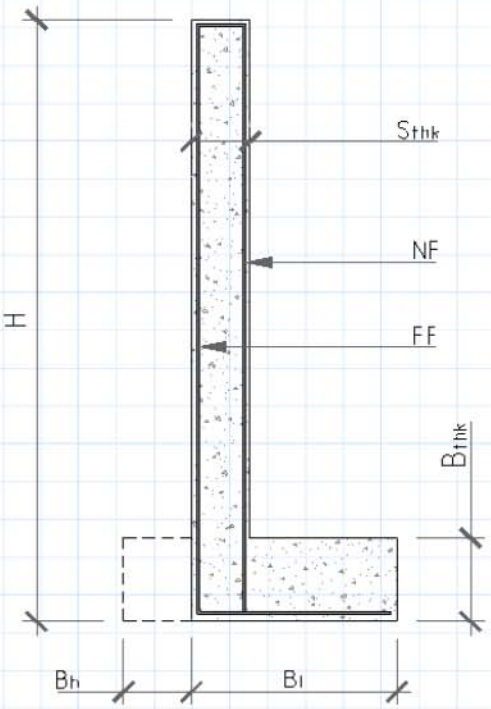
Wall Height - $H = 3500\ mm$

Stem Thickenss - $S_{thk} = 300\ mm$

Base length (not inc. heel) - $B_l = 2000\ mm$

Heel length - $B_h = 200\ mm$

Base Thickness - $B_{thk} = 450\ mm$



Reinforcement summary

Far face reinforceing bar diameter : $\phi_{vertF} = 20\ mm$ at $b_{sv} = 200\ mm$ c/c

Near face reinforceing bar diameter : $\phi_{vertN} = 12\ mm$ at $b_{sv} = 200\ mm$ c/c

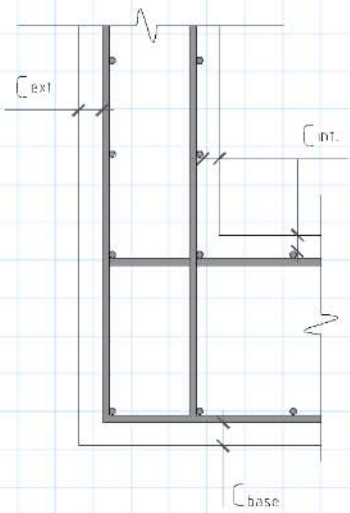
Horizontal distribution bar diameter : $\phi_{horiz} = 10\ mm$ at $b_{sh} = 200\ mm$ c/c

Concrete cover summary

Internal bar cover: $C_{int.} := 35\ mm$

External bar cover : $C_{ext.} := 50\ mm$

Underpin base cover : $C_{base} := 70\ mm$



END OF DETAIL SUMMARY

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