

Structural Design Check
for
2.4m / 1.2m Retaining Walls
at
Former Clun Primary School
Neath
SA11 4BW

Chris Meredith Designs
8 Beech Grove
Ebbw Vale
NP23 8WQ

(Tel: 07792798247 E.mail chrismdesigns@aol.com)

FORMER CLUN PRIMARY SCHOOL, NEATH, SA11 4BW

PROJECT GARDEN WALLS

PREPARED BY CM

DATE OCT 19

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CALCULATIONS

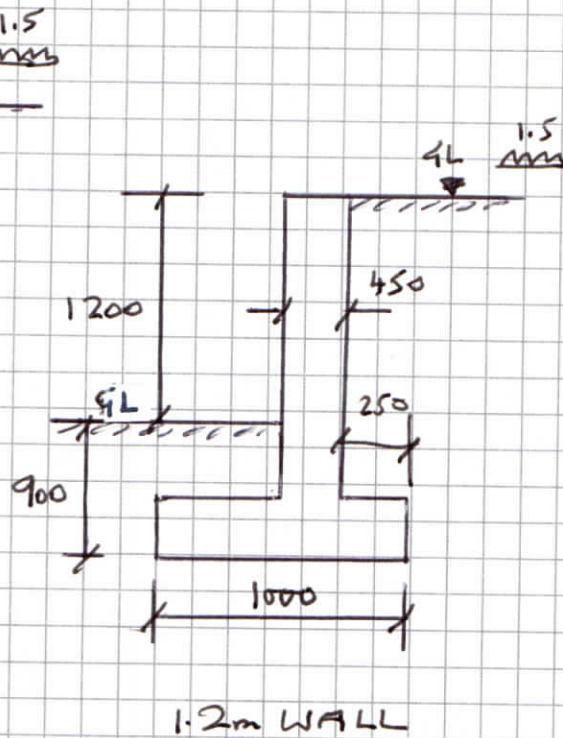
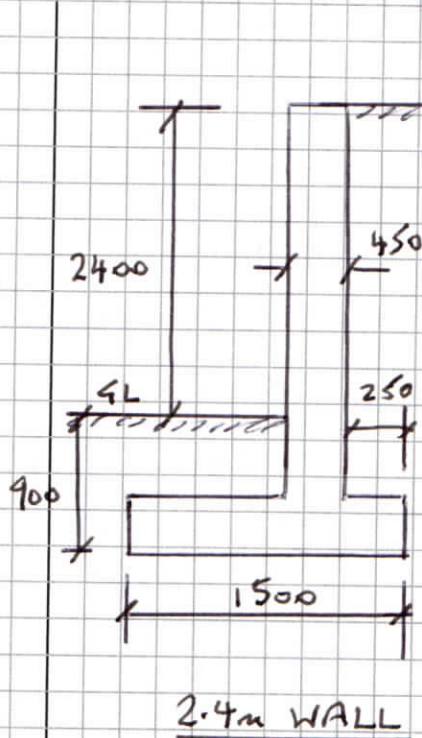
BS 8002 DESIGN

BS 5628 Check reinforced blockwork retaining walls to domestic garden areas. Surcharge 1.5 kN/m^2 to gardens.

BS 8110

(1) STABILITY ANALYSIS

Use 'Scale' software package to analyse the walls stability and check shear/bending of wall base and stem.



$$\phi = 35^\circ \text{ (granular fill)}$$

$$K_a = 0.27$$

$$\gamma_{\text{wall}} = 24 \text{ kN/m}^3$$

$$\gamma_{\text{soil}} = 18 \text{ kN/m}^3$$

$$\text{Block} = 7 \text{ N/m}^2 \quad \text{Mortar} = 1:4$$

$$\text{Bearing capacity} = 120 \text{ kN/m}^2 \text{ (clay)}$$

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CALCULATIONS

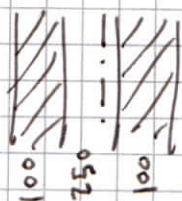
From 'SCALE' ANALYSIS FOR 2.4m WALL

$$FOS_{OT} = \underline{2.31} > 2$$

$$FOS_{shear} = \underline{2.59} > 2$$

$$\text{Bearing Pressure (max)} = 78.56 \text{ k/m}^2 < 120$$

PASS

(2) WALL STEM DESIGN

$$d_{eff} = 450 - 100 - 40 - \frac{16}{2} = \underline{302 \text{ mm}}$$

$$M_A = 20.87 \times 1.5 = \underline{31.2 \text{ kNm/m}} \text{ (ULS)}$$

$$M_R = \phi b d^2 \text{ gives } \phi = \frac{31.2 \times 10^6}{10^3 \times (302)^2} = \underline{0.34 \text{ N/mm}^2}$$

BS5628 for $f_k = 6.4$ $\gamma_m = 2.00$ $\gamma_m = 1.15$

$$f_k / \gamma_m = 6.4 / 2 = \underline{3.2 \text{ N/mm}^2} \text{ refer to BS5628 design chart}$$

4.2.4.2.1 gives $C = \underline{0.93}$ $f_y = 460$ $f_{cu} = 35$ $Z \leq 0.95d$

$$A_s \text{ required} = \frac{(31.2 \times 10^6) \times 1.15}{460 \times 0.93 \times 302} = \underline{278 \text{ mm}^2/\text{m}}$$

* PROVIDE 1 x A393 MESH REINFORCEMENT TO BOTH FACES OF WALL TO RESIST MOMENT ($A_s = 393$)

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CALCULATIONS

Shear $V = 20.34 \times 1.5 = \underline{30.51 \text{ kN/m (ULS)}}$

$A_s = \underline{503 \text{ mm}^2/\text{m}} \text{ (T16 @ 400)}$

$\rho = \frac{A_s}{bd} = \frac{503}{10^3 \times 302} = \underline{0.00166 \text{ N/mm}^2}$

$f_v = 0.35 + 17.5(\rho) = \underline{0.38 \text{ N/mm}^2}$

$v = \frac{30.51 \times 10^3}{10^3 \times 302} = \underline{0.10 \text{ N/mm}^2}$ $\frac{f_v}{\gamma_{sw} \frac{z}{2}} = \frac{0.38}{2} = \underline{0.19} > 0.10$

NO ADDITIONAL SHEAR REINFORCEMENT REQUIRED

(3) BASE DESIGN

$M_A = 15.43 \times 1.5 = \underline{23.15 \text{ kNm}}$ $V_A = 33.62 \times 1.5 = \underline{50.43 \text{ kN}}$

$d_{eff} = 300 - 40 - \frac{12}{2} = \underline{254 \text{ mm}}$

$K = \frac{23.15 \times 10^6}{35 \times 10^3 \times (254)^2} = \underline{0.01}$ $K' = 0.156$ $Z \leq 0.95d$

$A_s = \frac{23.15 \times 10^6}{0.87 \times 460 \times (0.95 \times 254)} = \underline{240 \text{ mm}^2/\text{m}}$

* PROVIDE 1 x A393 WITH REINFORCEMENT (TOP/BOTTOM)

Shear $V = \underline{50.43 \text{ kN/m}}$

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CALCULATIONS

$$V = 50.43 \text{ kN/m}$$

$$d = 254$$

$$v = \frac{50.43 \times 10^3}{10^3 \times 254} = 0.2 \text{ N/mm}^2 < v_c$$

$$\frac{100 A_s}{b d} = 0.15$$

$$f_y = 460$$

$$v_c = 0.38$$

NO ADDITIONAL SHEAR REINFORCEMENT REQUIRED

FROM 'SCALE' ANALYSIS FOR 1.2m WALL

$$FOS_{OT} = 2.94 > 2$$

$$FOS_{shear} = 4.89 > 2$$

$$\text{Bearing Pressure (max)} = 67.55 \text{ kN/m}^2 < 120$$

PASS.

(4) WALL STEM DESIGN

Refer to previous analysis but using 1.2m wall data

$$M_A = 4.74 \times 1.5 = 7.11 \text{ kNm}$$

$$d_{eff} = 302 \text{ mm}$$

$$V_A = 7.58 \times 1.5 = 11.37 \text{ kN}$$

$$\phi = 0.95$$

$$A_s = \frac{7.11 \times 10^6 \times 1.15}{460 \times 0.95 \times 302} = 62 \text{ mm}^2/\text{m}$$

* PROVIDE 1 x A193 MESH REINFORCEMENT TO BOTH FACES

Shear $V = 11.37 \text{ kN/m}$ $A_s = 503$ $\rho = 0.02$

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CALCULATIONS

$$\text{given } f_c = \underline{0.38 \text{ N/mm}^2} \quad u = \frac{11.37 \times 10^3}{10^3 \times 302} = \underline{0.04} < f_u$$

NO ADDITIONAL SHEAR REINFORCEMENT REQUIRED.

(S) BASE DESIGN

$$M_A = 1.97 \times 1.5 = \underline{2.96 \text{ Km}} \quad V_A = 12.34 \times 1.5 = \underline{18.51 \text{ K}}$$

$$d = \underline{254 \text{ mm}} \quad k = \underline{0.001} \quad k' = 0.156 \quad z \leq 0.95d$$

$$A_s = \frac{2.96 \times 10^6}{0.87 \times 460 \times (0.95 \times 254)} = \underline{30.7 \text{ mm}^2/\text{m}}$$

* PROVIDE 1 x A393 MESH REINFORCEMENT (TOP/BOTTOM)

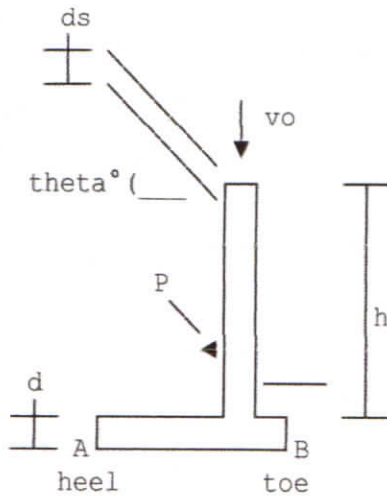
$$\text{Shear } V = \underline{18.51 \text{ K/m}}$$

$$U_c = \underline{0.38}$$

$$u = \frac{18.51 \times 10^3}{10^3 \times 254} = \underline{0.07} < U_c$$

NO ADDITIONAL SHEAR REINFORCEMENT REQUIRED

Location: 2.4m Retaining Wall



RC retaining wall to BS8002

Using either Rankine or Coulomb theory, the following assumptions are made:

- surface of rupture is a plane
- point of resultant pressure P on back back of wall is at one third of the distance up from the base of the wall.

Both Rankine and Coulomb give formula for resultant earth pressure on back of wall as $P = C_e \cdot w \cdot h^2 / 2$ where C_e is a pressure coefficient.
Weight/unit vol. of retained soil $w = 18 \text{ kN/m}^3$
Height of wall $h = 3 \text{ m}$
Pressure due to surcharge $\text{press} = 1.5 \text{ kN/m}^2$
Equivalent depth of surcharge $ds = \text{press}/w = 1.5/18 = 0.083333 \text{ m}$
Load above wall supported on stem $vo = 0 \text{ kN/m}$
Angle of slope of soil (if any) $\theta = 0^\circ$
Internal friction angle of soil $\phi = 38^\circ$
Angle of wall-to-soil friction $\delta = 25.333^\circ$
Friction factor on underside base $fb = 0.5$
Thickness of wall $t = 0.45 \text{ m}$
Density of wall (stem) $dt = 24 \text{ kN/m}^3$

Pressure from retained soil

Cosine of surcharge angle (θ) $ct = \cos(\text{RAD}(\theta)) = 1$
Sine of friction angle (ϕ) $sp = \sin(\text{RAD}(\phi)) = 0.61566$
Cosine of friction angle (ϕ) $cp = \cos(\text{RAD}(\phi)) = 0.78801$
Cosine of wall-soil friction (δ) $cd = \cos(\text{RAD}(\delta)) = 0.90384$
Sine of ($\phi + \delta$) $ss1 = \sin(\text{RAD}(\phi) + \text{RAD}(\delta))$
 $= \sin(\text{RAD}(38) + \text{RAD}(25.333))$
 $= 0.89363$
Sine of ($\phi - \theta$) $ss2 = \sin(\text{RAD}(\phi) - \text{RAD}(\theta))$
 $= \sin(\text{RAD}(38) - \text{RAD}(0))$
 $= 0.61566$
Coulomb theory:
Factor $f = cd \cdot (1 + \text{SQR}(ss1 \cdot ss2 / (cd \cdot ct)))^2$
 $= 0.90384 \cdot (1 + \text{SQR}(0.89363 \cdot 0.61566 / (0.90384 \cdot 1)))^2$
 $= 2.8644$
Pressure coefficient $Cec = cp^2 / f = 0.78801^2 / 2.8644$
 $= 0.21679$
Rankine theory:
Factor $f = \text{SQR}(ct^2 - cp^2) = \text{SQR}(1^2 - 0.78801^2)$
 $= 0.61566$
Pressure coefficient $Cer = ct \cdot (ct - f) / (ct + f)$
 $= 1 \cdot (1 - 0.61566) / (1 + 0.61566)$
 $= 0.23788$

Rankine pressure coefficient is chosen.

Resultant earth force (active) $P = C_e * w * h^2 / 2 = 0.23788 * 18 * 3^2 / 2$
 $= 19.269 \text{ kN/m run}$

Horiz.component of this force $P_h = P * \cos(\text{RAD}(\theta))$
 $= 19.269 * \cos(\text{RAD}(0))$
 $= 19.269 \text{ kN/m run}$

Vertical component of this force $P_v = P * \sin(\text{RAD}(\theta))$
 $= 19.269 * \sin(\text{RAD}(0))$
 $= 0 \text{ kN/m run}$

Pressure coefficient (surcharge) $C_a = (1 - s_p) / (1 + s_p)$
 $= (1 - 0.61566) / (1 + 0.61566)$
 $= 0.23788$

Resultant earth force (surcharge) $P_s = C_a * w * d_s * h = 0.23788 * 18 * 0.083333 * 3$
 $= 1.0705 \text{ kN/m run}$

Horiz.component of this force $P_{sh} = P_s * \cos(\text{RAD}(\theta))$
 $= 1.0705 * \cos(\text{RAD}(0))$
 $= 1.0705 \text{ kN/m run}$

Vertical component of this force $P_{sv} = P_s * \sin(\text{RAD}(\theta))$
 $= 1.0705 * \sin(\text{RAD}(0))$
 $= 0 \text{ kN/m run}$

Forces and moments on wall

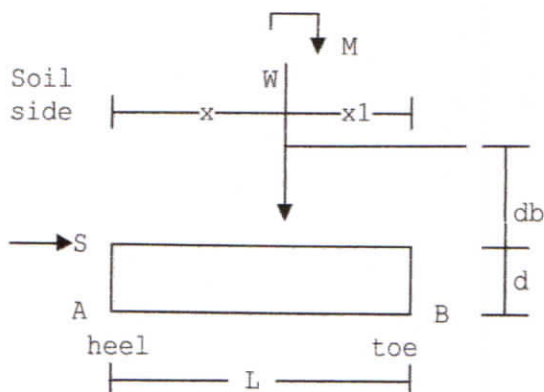
Maximum B.M. at base of stem $M = P_h * h / 3 + P_{sh} * h / 2$
 $= 19.269 * 3 / 3 + 1.0705 * 3 / 2$
 $= 20.874 \text{ kNm/m}$

Maximum S.F. at base of stem $S = P_h + P_{sh} = 19.269 + 1.0705 = 20.339 \text{ kN/m}$

Weight of wall $w = h * t * d_t = 3 * 0.45 * 24 = 32.4 \text{ kN/m run}$

Weight of wall plus load over $v = w + v_o = 32.4 + 0 = 32.4 \text{ kN/m run}$

Base



Thickness of base $d = 0.3 \text{ m}$

Length of base $L = 1.50 \text{ m}$

Distance from A to centre of stem $x = 0.475 \text{ m}$

Depth of soil over base at toe $d_b = 0.6 \text{ m}$

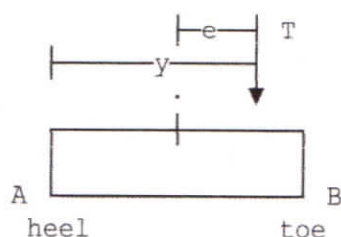
Depth of soil for passive resist. $d_p = 0.9 \text{ m}$

For simplicity, the relatively-trivial effects of the self-weight and location of any key on the pressures, etc beneath the base are ignored.

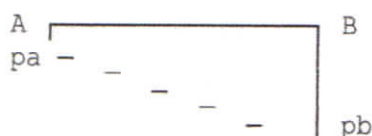
Distance from stem to front toe $x_1 = L - x = 1.5 - 0.475 = 1.025 \text{ m}$

Allowable ground pressure $p = 120 \text{ kN/m}^2$

Self-weight of foundation	$Sw = L \cdot d \cdot dt = 1.5 \cdot 0.3 \cdot 24 = 10.8 \text{ kN/m run}$
Wt. of soil behind wall (earth)	$wbe = (h + ds) \cdot (x - t/2) \cdot w$ $= (3 + 0.083333) \cdot (0.475 - 0.45/2) \cdot 18$ $= 13.875 \text{ kN/m run}$
Wt. of soil behind wall (slope)	$wbs = w \cdot (x - t/2)^2 \cdot \tan(\text{RAD}(\theta)) / 2$ $= 18 \cdot (0.475 - 0.45/2)^2 \cdot \tan(\text{RAD}(0)) / 2$ $= 0 \text{ kN/m run}$
Total weight of soil behind wall	$wb = wbe + wbs = 13.875 + 0 = 13.875 \text{ kN/m run}$
Weight of soil at front of wall	$wf = db \cdot (x1 - t/2) \cdot w$ $= 0.6 \cdot (1.025 - 0.45/2) \cdot 18$ $= 8.64 \text{ kN/m run}$
Total earth pressure (active)	$Pab = Ce \cdot ct \cdot w \cdot (h + d)^2 / 2$ $= 0.23788 \cdot 1 \cdot 18 \cdot (3 + 0.3)^2 / 2$ $= 23.315 \text{ kN/m run}$
Horiz.component of this force	$Pabh = Pab \cdot \cos(\text{RAD}(\theta))$ $= 23.315 \cdot \cos(\text{RAD}(0))$ $= 23.315 \text{ kN/m run}$
Vertical component of this force	$Pabv = Pab \cdot \sin(\text{RAD}(\theta))$ $= 23.315 \cdot \sin(\text{RAD}(0))$ $= 0 \text{ kN/m run}$
Total earth pressure (surcharge)	$Psb = Ca \cdot w \cdot ds \cdot (h + d)$ $= 0.23788 \cdot 18 \cdot 0.083333 \cdot (3 + 0.3)$ $= 1.1775 \text{ kN/m run}$
Horiz.component of this force	$Psbh = Psb \cdot \cos(\text{RAD}(\theta))$ $= 1.1775 \cdot \cos(\text{RAD}(0))$ $= 1.1775 \text{ kN/m run}$
Vertical component of this force	$Psbv = Psb \cdot \sin(\text{RAD}(\theta))$ $= 1.1775 \cdot \sin(\text{RAD}(0))$ $= 0 \text{ kN/m run}$
Total load on soil beneath base	$T = v + Sw + wb + wf + Pabv + Psbv$ $= 32.4 + 10.8 + 13.875 + 8.64 + 0 + 0$ $= 65.715 \text{ kN/m run}$
Overturning moment due to earth pressure	$Mt = Pabh \cdot (h + d) / 3 + Psbh \cdot (h + d) / 2$ $= 23.315 \cdot (3 + 0.3) / 3 + 1.1775 \cdot (3 + 0.3) / 2$ $= 27.589 \text{ kNm/m run}$
Force u/s base (earth pressure)	$St = Pabh + Psbh = 23.315 + 1.1775$ $= 24.492 \text{ kN/m run}$
Clockwise moments about A due to weight of soil behind wall	$Mcb = (3 \cdot wbe + 2 \cdot wbs) \cdot (x - t/2) / 6$ $= (3 \cdot 13.875 + 2 \cdot 0) \cdot (0.475 - 0.45/2) / 6$ $= 1.7344 \text{ kNm/m}$
Clockwise moments about A due to vert.component of earth pressure	$Mcbv = (Pabv + Psbv) \cdot (x - t/2)$ $= (0 + 0) \cdot (0.475 - 0.45/2)$ $= 0 \text{ kNm/m}$
Total clockwise moments about A:	$Mc = v \cdot x + Mt + Sw \cdot L / 2 + Mcb + Mcbv + wf \cdot (L - (x1 - t/2) / 2)$ $= 32.4 \cdot 0.475 + 27.589 + 10.8 \cdot 1.5 / 2 + 1.7344 + 0 + 8.64 \cdot (1.5 - (1.025 - 0.45/2) / 2)$ $= 62.318 \text{ kNm/m}$
Distance to centroid of load	$y = Mc / T = 62.318 / 65.715 = 0.9483 \text{ m}$



Eccentricity $e = y - L/2 = 0.9483 - 1.5/2 = 0.1983 \text{ m}$
Centroid of load lies within middle third. Pressure varies from p_a at A to p_b at B.



Base area modulus

$$\begin{aligned} z &= 1 \cdot L^2 / 6 \\ &= 1 \cdot 1.5^2 / 6 \\ &= 0.375 \text{ cu.m per metre run} \end{aligned}$$

Pressure at A

$$\begin{aligned} p_a &= T / (L \cdot 1) - T \cdot e / z \\ &= 65.715 / (1.5 \cdot 1) - 65.715 \cdot 0.1983 / 0.375 \\ &= 9.0595 \text{ kN/m}^2 \end{aligned}$$

Pressure at B

$$\begin{aligned} p_b &= T / (L \cdot 1) + T \cdot e / z \\ &= 65.715 / (1.5 \cdot 1) + 65.715 \cdot 0.1983 / 0.375 \\ &= 78.561 \text{ kN/m}^2 \end{aligned}$$

Maximum pressure is at B

$$p_{\max} = p_b = 78.561 \text{ kN/m}^2$$

As $p_{\max}$ does not exceed p ($78.561 \text{ kN/m}^2 \leq 120 \text{ kN/m}^2$),
pressure beneath base is within specified limit.

Shear forces and bending moments on base

Pressure under back of wall

$$\begin{aligned} p_{wa} &= p_a + (p_b - p_a) \cdot (x - t/2) / L \\ &= 9.0595 + (78.561 - 9.0595) \cdot (0.475 - 0.45/2) / 1.5 \\ &= 20.643 \text{ kN/m}^2 \end{aligned}$$

Pressure under front of wall

$$\begin{aligned} p_{wb} &= p_a + (p_b - p_a) \cdot (x + t/2) / L \\ &= 9.0595 + (78.561 - 9.0595) \cdot (0.475 + 0.45/2) / 1.5 \\ &= 41.493 \text{ kN/m}^2 \end{aligned}$$

Downward S.F. on heel

$$\begin{aligned} S_{ad} &= dt \cdot d \cdot (x - t/2) + w_b \\ &= 24 \cdot 0.3 \cdot (0.475 - 0.45/2) + 13.875 \\ &= 15.675 \text{ kN/m} \end{aligned}$$

Upward S.F. on heel

$$\begin{aligned} S_{au} &= (p_a + p_{wa}) \cdot (x - t/2) / 2 \\ &= (9.0595 + 20.643) \cdot (0.475 - 0.45/2) / 2 \\ &= 3.7128 \text{ kN/m} \end{aligned}$$

Downward B.M. on toe

$$\begin{aligned} M_{bd} &= (dt \cdot d \cdot (x_1 - t/2) + wf) \cdot (x_1 - t/2) / 2 \\ &= (24 \cdot 0.3 \cdot (1.025 - 0.45/2) + 8.64) \\ &\quad \cdot (1.025 - 0.45/2) / 2 \\ &= 5.76 \text{ kNm/m} \end{aligned}$$

Downward B.M. on heel

$$\begin{aligned} M_{ad} &= (3 \cdot w_{be} + 4 \cdot w_{bs} + 3 \cdot dt \cdot d \cdot (x - t/2)) \cdot (x - t/2) / 6 \\ &= (3 \cdot 13.875 + 4 \cdot 0 + 3 \cdot 24 \cdot 0.3 \cdot (0.475 - 0.45/2)) \\ &\quad \cdot (0.475 - 0.45/2) / 6 \\ &= 1.9594 \text{ kNm/m} \end{aligned}$$

Total S.F. on toe (plus is up)

$$\begin{aligned} S_{wb} &= ((p_{wb} + p_b) / 2 - dt \cdot d) \cdot (x_1 - t/2) - wf \\ &= ((41.493 + 78.561) / 2 - 24 \cdot 0.3) \\ &\quad \cdot (1.025 - 0.45/2) - 8.64 \end{aligned}$$

$$\begin{aligned}
 &= 33.622 \text{ kN/m} \\
 \text{Total S.F. on heel (plus is up)} & S_wa = S_{au} - S_{ad} = 3.7128 - 15.675 \\
 &= -11.962 \text{ kN/m} \\
 \text{Total B.M. on toe (plus is up)} & M_{wb} = (2 \cdot p_b + p_{wb}) \cdot (x_1 - t/2)^2 / 6 - M_{bd} \\
 &= (2 \cdot 78.561 + 41.493) \cdot (1.025 - 0.45 \\
 &\quad / 2)^2 / 6 - 5.76 \\
 &= 15.426 \text{ kNm/m} \\
 \text{Total B.M. on heel (plus is up)} & M_{wa} = (2 \cdot p_a + p_{wa}) \cdot (x - t/2)^2 / 6 - M_{ad} \\
 &= (2 \cdot 9.0595 + 20.643) \cdot (0.475 - 0.45 \\
 &\quad / 2)^2 / 6 - 1.9594 \\
 &= -1.5556 \text{ kNm/m}
 \end{aligned}$$

Resistance to sliding

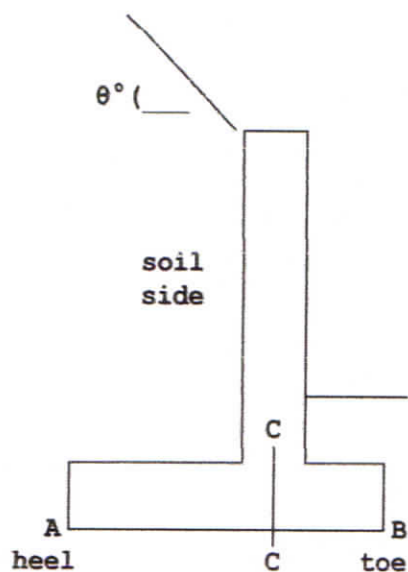
$$\begin{aligned}
 \text{Frictional resistance} & F = f_b \cdot T = 0.5 \cdot 65.715 = 32.858 \text{ kN/m run} \\
 \text{Rankine coeff. of passive pressure} & K_p = (\tan(\text{RAD}(45) + \text{RAD}(\phi/2)))^2 \\
 &= (\tan(\text{RAD}(45) + \text{RAD}(38/2)))^2 \\
 &= 4.2037 \\
 \text{Passive resistance} & R = 0.5 \cdot K_p \cdot w \cdot d_p^2 = 0.5 \cdot 4.2037 \cdot 18 \cdot 0.9^2 \\
 &= 30.645 \text{ kN/m} \\
 \text{FoS sliding (frict. resist. only)} & FOSF = F / S_t = 32.858 / 24.492 \\
 &= 1.3415 \\
 \text{FoS sliding (friction/cohesion + passive)} & FOSF2 = (F + R) / S_t \\
 &= (32.858 + 30.645) / 24.492 \\
 &= 2.5928
 \end{aligned}$$

Resistance to overturning

Rotation assumed to occur about lowest forward edge of base (i.e. toe).
Restraining moments:

$$\begin{aligned}
 \text{Due to soil behind wall} & M_{re} = w_{be} \cdot (L - (x - t/2)/2) + w_{bs} \cdot (L - (x - t/2) \\
 &\quad / 3) \\
 &= 13.875 \cdot (1.5 - (0.475 - 0.45/2)/2) + 0 \\
 &\quad \cdot (1.5 - (0.475 - 0.45/2)/3) \\
 &= 19.078 \text{ kNm/m} \\
 \text{Due to base, wall and soil on toe} & M_{rw} = v \cdot x_1 + S_w \cdot L/2 + w_f \cdot (x_1 - t/2)/2 \\
 &= 32.4 \cdot 1.025 + 10.8 \cdot 1.5/2 + 8.64 \\
 &\quad \cdot (1.025 - 0.45/2)/2 \\
 &= 44.766 \text{ kNm/m} \\
 \text{Due to vert. comp. of earth pres.} & M_{rv} = (P_{abv} + P_{sbv}) \cdot (x_1 + t/2) \\
 &= (0 + 0) \cdot (1.025 + 0.45/2) \\
 &= 0 \text{ kNm/m}
 \end{aligned}$$

$$\begin{aligned}
 \text{Total restraining mt. (with } M_{rv}) & M_{r1} = M_{re} + M_{rw} + M_{rv} = 19.078 + 44.766 + 0 \\
 &= 63.844 \text{ kNm/m} \\
 \text{ditto (without } M_{rv}) & M_{r2} = M_{re} + M_{rw} = 19.078 + 44.766 \\
 &= 63.844 \text{ kNm/m} \\
 \text{Total overturning moment} & M_{ot} = M_t = 27.589 \text{ kNm/m} \\
 \text{Safety factors against overturning:} & \\
 \text{Including vert. comp. of pressure} & FOSOT1 = M_{r1} / M_{ot} = 63.844 / 27.589 \\
 &= 2.3141 \\
 \text{Ignoring vert. comp. of pressure} & FOSOT2 = M_{r2} / M_{ot} = 63.844 / 27.589 \\
 &= 2.3141
 \end{aligned}$$



Design Summary

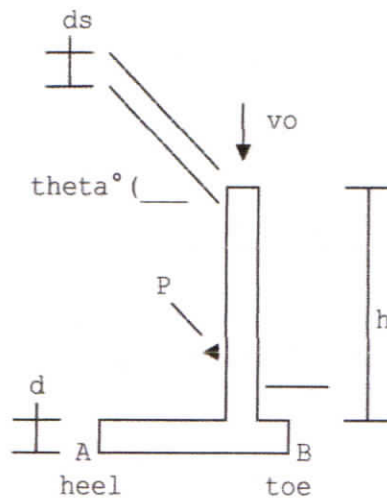
Moment at base of stem	20.874 kNm
Shear at base of stem	20.339 kN
Moment at c-c (toe)	15.426 kNm
Shear at c-c (toe)	33.622 kN
Moment at c-c (heel)	-1.5556 kNm
Shear at c-c (heel)	-11.962 kN

FoS for Overturning	
(1) With vertical component of earth pressure considered	2.3141
(2) Ignoring vertical component of earth pressure	2.3141

FoS for Sliding	
(1) Friction only	1.3415
(2) Friction+passive	2.5928

Pressure at A	9.0595 kN/m ²
Pressure at B	78.561 kN/m ²
Allowable GBP	120 kN/m ²

Location: 1.20m Retaining Wall



RC retaining wall to BS8002

Using either Rankine or Coulomb theory, the following assumptions are made:

- surface of rupture is a plane
- point of resultant pressure P on back of wall is at one third of the distance up from the base of the wall.

Both Rankine and Coulomb give formula for resultant earth pressure on back of wall as $P = C_e \cdot w \cdot h^2 / 2$ where C_e is a pressure coefficient.
Weight/unit vol. of retained soil $w = 18 \text{ kN/m}^3$
Height of wall $h = 1.80 \text{ m}$
Pressure due to surcharge $\text{press} = 1.5 \text{ kN/m}^2$
Equivalent depth of surcharge $ds = \text{press}/w = 1.5/18 = 0.083333 \text{ m}$
Load above wall supported on stem $vo = 0 \text{ kN/m}$
Angle of slope of soil (if any) $\theta = 0^\circ$
Internal friction angle of soil $\phi = 38^\circ$
Angle of wall-to-soil friction $\delta = 25.333^\circ$
Friction factor on underside base $fb = 0.5$
Thickness of wall $t = 0.45 \text{ m}$
Density of wall (stem) $dt = 24 \text{ kN/m}^3$

Pressure from retained soil

Cosine of surcharge angle (θ) $ct = \cos(\text{RAD}(\theta)) = 1$
Sine of friction angle (ϕ) $sp = \sin(\text{RAD}(\phi)) = 0.61566$
Cosine of friction angle (ϕ) $cp = \cos(\text{RAD}(\phi)) = 0.78801$
Cosine of wall-soil friction (δ) $cd = \cos(\text{RAD}(\delta)) = 0.90384$
Sine of ($\phi + \delta$) $ss1 = \sin(\text{RAD}(\phi) + \text{RAD}(\delta))$
 $= \sin(\text{RAD}(38) + \text{RAD}(25.333))$
 $= 0.89363$
Sine of ($\phi - \theta$) $ss2 = \sin(\text{RAD}(\phi) - \text{RAD}(\theta))$
 $= \sin(\text{RAD}(38) - \text{RAD}(0))$
 $= 0.61566$
Coulomb theory:
Factor $f = cd * (1 + \text{SQR}(ss1 * ss2 / (cd * ct)))^2$
 $= 0.90384 * (1 + \text{SQR}(0.89363 * 0.61566 / (0.90384 * 1)))^2$
 $= 2.8644$
Pressure coefficient $Cec = cp^2 / f = 0.78801^2 / 2.8644$
 $= 0.21679$
Rankine theory:
Factor $f = \text{SQR}(ct^2 - cp^2) = \text{SQR}(1^2 - 0.78801^2)$
 $= 0.61566$
Pressure coefficient $Cer = ct * (ct - f) / (ct + f)$
 $= 1 * (1 - 0.61566) / (1 + 0.61566)$
 $= 0.23788$

Rankine pressure coefficient is chosen.

Resultant earth force (active) $P = C_e * w * h^2 / 2 = 0.23788 * 18 * 1.8^2 / 2$
= 6.9367 kN/m run

Horiz.component of this force $P_h = P * \cos(\text{RAD}(\theta))$
= 6.9367 * $\cos(\text{RAD}(0))$
= 6.9367 kN/m run

Vertical component of this force $P_v = P * \sin(\text{RAD}(\theta))$
= 6.9367 * $\sin(\text{RAD}(0))$
= 0 kN/m run

Pressure coefficient (surcharge) $C_a = (1 - s_p) / (1 + s_p)$
= (1 - 0.61566) / (1 + 0.61566)
= 0.23788

Resultant earth force (surcharge) $P_s = C_a * w * d_s * h = 0.23788 * 18 * 0.083333 * 1.8$
= 0.64228 kN/m run

Horiz.component of this force $P_{sh} = P_s * \cos(\text{RAD}(\theta))$
= 0.64228 * $\cos(\text{RAD}(0))$
= 0.64228 kN/m run

Vertical component of this force $P_{sv} = P_s * \sin(\text{RAD}(\theta))$
= 0.64228 * $\sin(\text{RAD}(0))$
= 0 kN/m run

Forces and moments on wall

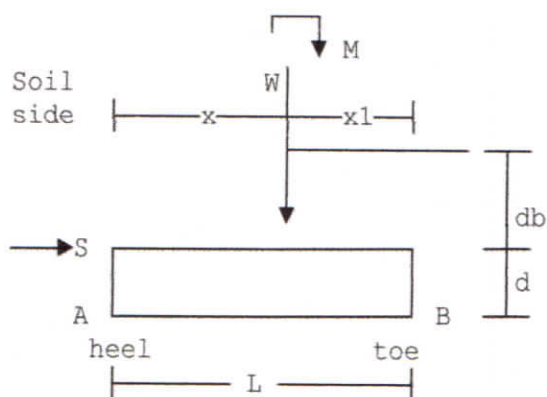
Maximum B.M. at base of stem $M = P_h * h / 3 + P_{sh} * h / 2$
= 6.9367 * 1.8 / 3 + 0.64228 * 1.8 / 2
= 4.7401 kNm/m

Maximum S.F. at base of stem $S = P_h + P_{sh} = 6.9367 + 0.64228$
= 7.579 kN/m

Weight of wall $v = h * t * d_t = 1.8 * 0.45 * 24 = 19.44$ kN/m run

Weight of wall plus load over $v = v + v_o = 19.44 + 0 = 19.44$ kN/m run

Base



Thickness of base $d = 0.3$ m

Length of base $L = 1.00$ m

Distance from A to centre of stem $x = 0.475$ m

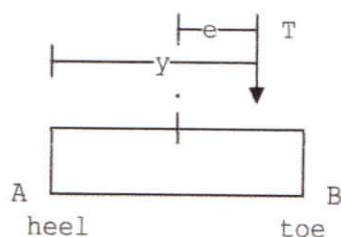
Depth of soil over base at toe $db = 0.6$ m

Depth of soil for passive resist. $dp = 0.9$ m

For simplicity, the relatively-trivial effects of the self-weight and location of any key on the pressures, etc beneath the base are ignored.

Distance from stem to front toe $x_1 = L - x = 1 - 0.475 = 0.525$ m

Allowable ground pressure	$p=120 \text{ kN/m}^2$
Self-weight of foundation	$Sw=L*d*dt=1*0.3*24=7.2 \text{ kN/m run}$
Wt. of soil behind wall (earth)	$wbe=(h+ds)*(x-t/2)*w$ $= (1.8+0.083333)*(0.475-0.45/2)*18$ $=8.475 \text{ kN/m run}$
Wt. of soil behind wall (slope)	$wbs=w*(x-t/2)^2*TAN(RAD(theta))/2$ $=18*(0.475-0.45/2)^2*TAN(RAD(0))/2$ $=0 \text{ kN/m run}$
Total weight of soil behind wall	$wb=wbe+wbs=8.475+0=8.475 \text{ kN/m run}$
Weight of soil at front of wall	$wf=db*(x1-t/2)*w$ $=0.6*(0.525-0.45/2)*18$ $=3.24 \text{ kN/m run}$
Total earth pressure (active)	$Pab=Ce*ct*w*(h+d)^2/2$ $=0.23788*1*18*(1.8+0.3)^2/2$ $=9.4416 \text{ kN/m run}$
Horiz.component of this force	$Pabh=Pab*COS(RAD(theta))$ $=9.4416*COS(RAD(0))$ $=9.4416 \text{ kN/m run}$
Vertical component of this force	$Pabv=Pab*SIN(RAD(theta))$ $=9.4416*SIN(RAD(0))$ $=0 \text{ kN/m run}$
Total earth pressure (surcharge)	$Psb=Ca*w*ds*(h+d)$ $=0.23788*18*0.083333*(1.8+0.3)$ $=0.74933 \text{ kN/m run}$
Horiz.component of this force	$Psbh=Psb*COS(RAD(theta))$ $=0.74933*COS(RAD(0))$ $=0.74933 \text{ kN/m run}$
Vertical component of this force	$Psbv=Psb*SIN(RAD(theta))$ $=0.74933*SIN(RAD(0))$ $=0 \text{ kN/m run}$
Total load on soil beneath base	$T=v+Sw+wb+wf+Pabv+Psbv$ $=19.44+7.2+8.475+3.24+0+0$ $=38.355 \text{ kN/m run}$
Overturning moment due to earth pressure	$Mt=Pabh*(h+d)/3+Psbh*(h+d)/2$ $=9.4416*(1.8+0.3)/3+0.74933*(1.8+0.3)/2$ $=7.3959 \text{ kNm/m run}$
Force u/s base (earth pressure)	$St=Pabh+Psbh=9.4416+0.74933$ $=10.191 \text{ kN/m run}$
Clockwise moments about A due to weight of soil behind wall	$Mcb=(3*wbe+2*wbs)*(x-t/2)/6$ $=(3*8.475+2*0)*(0.475-0.45/2)/6$ $=1.0594 \text{ kNm/m}$
Clockwise moments about A due to vert.component of earth pressure	$Mcbv=(Pabv+Psbv)*(x-t/2)$ $=(0+0)*(0.475-0.45/2)$ $=0 \text{ kNm/m}$
Total clockwise moments about A:	$Mc=v*x+Mt+Sw*L/2+Mcb+Mcbv+wf*(L-(x1-t/2)/2)$ $=19.44*0.475+7.3959+7.2*1/2+1.0594+0+3.24*(1-(0.525-0.45/2)/2)$ $=24.043 \text{ kNm/m}$
Distance to centroid of load	$y=Mc/T=24.043/38.355=0.62686 \text{ m}$



Eccentricity $e = y - L/2 = 0.62686 - 1/2 = 0.12686 \text{ m}$
Centroid of load lies within middle third. Pressure varies from p_a at A to p_b at B.



Base area modulus $z = 1 \cdot L^2 / 6$
 $= 1 \cdot 1^2 / 6$
 $= 0.16667 \text{ cu.m per metre run}$
Pressure at A $p_a = T / (L \cdot 1) - T \cdot e / z$
 $= 38.355 / (1 \cdot 1) - 38.355 \cdot 0.12686 / 0.16667$
 $= 9.1603 \text{ kN/m}^2$
Pressure at B $p_b = T / (L \cdot 1) + T \cdot e / z$
 $= 38.355 / (1 \cdot 1) + 38.355 \cdot 0.12686 / 0.16667$
 $= 67.55 \text{ kN/m}^2$
Maximum pressure is at B $p_{\max} = p_b = 67.55 \text{ kN/m}^2$
As $p_{\max}$ does not exceed p ($67.55 \text{ kN/m}^2 \leq 120 \text{ kN/m}^2$),
pressure beneath base is within specified limit.

Shear forces and bending moments on base

Pressure under back of wall $p_{wa} = p_a + (p_b - p_a) \cdot (x - t/2) / L$
 $= 9.1603 + (67.55 - 9.1603) \cdot (0.475 - 0.45/2) / 1$
 $= 23.758 \text{ kN/m}^2$
Pressure under front of wall $p_{wb} = p_a + (p_b - p_a) \cdot (x + t/2) / L$
 $= 9.1603 + (67.55 - 9.1603) \cdot (0.475 + 0.45/2) / 1$
 $= 50.033 \text{ kN/m}^2$
Downward S.F. on heel $S_{ad} = dt \cdot d \cdot (x - t/2) + w_b$
 $= 24 \cdot 0.3 \cdot (0.475 - 0.45/2) + 8.475$
 $= 10.275 \text{ kN/m}$
Upward S.F. on heel $S_{au} = (p_a + p_{wa}) \cdot (x - t/2) / 2$
 $= (9.1603 + 23.758) \cdot (0.475 - 0.45/2) / 2$
 $= 4.1147 \text{ kN/m}$
Downward B.M. on toe $M_{bd} = (dt \cdot d \cdot (x_1 - t/2) + w_f) \cdot (x_1 - t/2) / 2$
 $= (24 \cdot 0.3 \cdot (0.525 - 0.45/2) + 3.24) \cdot (0.525 - 0.45/2) / 2$
 $= 0.81 \text{ kNm/m}$
Downward B.M. on heel $M_{ad} = (3 \cdot w_{be} + 4 \cdot w_{bs} + 3 \cdot dt \cdot d \cdot (x - t/2)) \cdot (x - t/2) / 6$
 $= (3 \cdot 8.475 + 4 \cdot 0 + 3 \cdot 24 \cdot 0.3 \cdot (0.475 - 0.45/2)) \cdot (0.475 - 0.45/2) / 6$
 $= 1.2844 \text{ kNm/m}$
Total S.F. on toe (plus is up) $S_{wb} = ((p_{wb} + p_b) / 2 - dt \cdot d) \cdot (x_1 - t/2) - w_f$
 $= ((50.033 + 67.55) / 2 - 24 \cdot 0.3) \cdot (0.525 - 0.45/2) - 3.24$

$$\begin{aligned}
 &=12.237 \text{ kN/m} \\
 \text{Total S.F. on heel (plus is up)} & \quad S_{wa}=S_{au}-S_{ad}=4.1147-10.275 \\
 &=-6.1603 \text{ kN/m} \\
 \text{Total B.M. on toe (plus is up)} & \quad M_{wb}=(2 \cdot p_b+p_{wb}) \cdot (x_1-t/2)^2/6-M_{bd} \\
 &=(2 \cdot 67.55+50.033) \cdot (0.525-0.45 \\
 &\quad /2)^2/6-0.81 \\
 &=1.967 \text{ kNm/m} \\
 \text{Total B.M. on heel (plus is up)} & \quad M_{wa}=(2 \cdot p_a+p_{wa}) \cdot (x-t/2)^2/6-M_{ad} \\
 &=(2 \cdot 9.1603+23.758) \cdot (0.475-0.45 \\
 &\quad /2)^2/6-1.2844 \\
 &=-0.84606 \text{ kNm/m}
 \end{aligned}$$

Resistance to sliding

$$\begin{aligned}
 \text{Frictional resistance} & \quad F=f_b \cdot T=0.5 \cdot 38.355=19.178 \text{ kN/m run} \\
 \text{Rankine coeff.of passive pressure} & \quad K_p=(\tan(\text{RAD}(45)+\text{RAD}(\phi/2)))^2 \\
 &=(\tan(\text{RAD}(45)+\text{RAD}(38/2)))^2 \\
 &=4.2037 \\
 \text{Passive resistance} & \quad R=0.5 \cdot K_p \cdot w \cdot d_p^2=0.5 \cdot 4.2037 \cdot 18 \cdot 0.9^2 \\
 &=30.645 \text{ kN/m} \\
 \text{FoS sliding (frict.resist.only)} & \quad FOSF=F/St=19.178/10.191 \\
 &=1.8818 \\
 \text{FoS sliding (friction/cohesion + passive)} & \quad FOSF2=(F+R)/St \\
 &=(19.178+30.645)/10.191 \\
 &=4.8889
 \end{aligned}$$

Resistance to overturning

Rotation assumed to occur about lowest forward edge of base (i.e. toe).
Restraining moments:

$$\begin{aligned}
 \text{Due to soil behind wall} & \quad M_{re}=w_{be} \cdot (L-(x-t/2)/2)+w_{bs} \cdot (L-(x-t/2) \\
 &\quad /3) \\
 &=8.475 \cdot (1-(0.475-0.45/2)/2)+0 \cdot (1 \\
 &\quad -(0.475-0.45/2)/3) \\
 &=7.4156 \text{ kNm/m} \\
 \text{Due to base,wall and soil on toe} & \quad M_{rw}=v \cdot x_1+S_w \cdot L/2+w_f \cdot (x_1-t/2)/2 \\
 &=19.44 \cdot 0.525+7.2 \cdot 1/2+3.24 \cdot (0.525 \\
 &\quad -0.45/2)/2 \\
 &=14.292 \text{ kNm/m} \\
 \text{Due to vert.comp.of earth pres.} & \quad M_{rv}=(p_{abv}+p_{sbv}) \cdot (x_1+t/2) \\
 &=(0+0) \cdot (0.525+0.45/2) \\
 &=0 \text{ kNm/m}
 \end{aligned}$$

$$\begin{aligned}
 \text{Total restraining mt.(with } M_{rv}) & \quad M_{r1}=M_{re}+M_{rw}+M_{rv}=7.4156+14.292+0 \\
 &=21.708 \text{ kNm/m}
 \end{aligned}$$

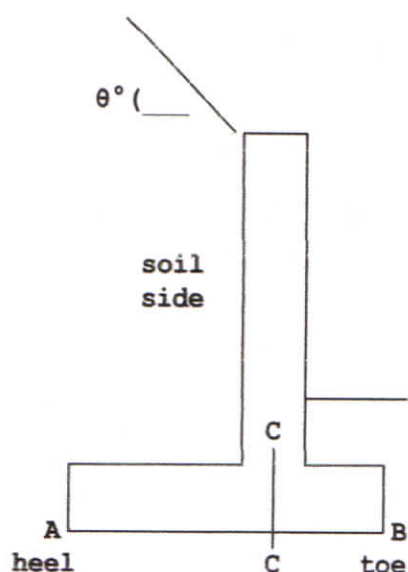
$$\begin{aligned}
 \text{ditto (without } M_{rv}) & \quad M_{r2}=M_{re}+M_{rw}=7.4156+14.292 \\
 &=21.708 \text{ kNm/m}
 \end{aligned}$$

$$\text{Total overturning moment} \quad M_{ot}=M_t=7.3959 \text{ kNm/m}$$

Safety factors against overturning:

$$\begin{aligned}
 \text{Including vert.comp.of pressure} & \quad FOSOT1=M_{r1}/M_{ot}=21.708/7.3959 \\
 &=2.9351
 \end{aligned}$$

$$\begin{aligned}
 \text{Ignoring vert.comp.of pressure} & \quad FOSOT2=M_{r2}/M_{ot}=21.708/7.3959 \\
 &=2.9351
 \end{aligned}$$



Design Summary

Moment at base of stem	4.7401 kNm
Shear at base of stem	7.579 kN
Moment at c-c (toe)	1.967 kNm
Shear at c-c (toe)	12.237 kN
Moment at c-c (heel)	-0.84606 kNm
Shear at c-c (heel)	-6.1603 kN

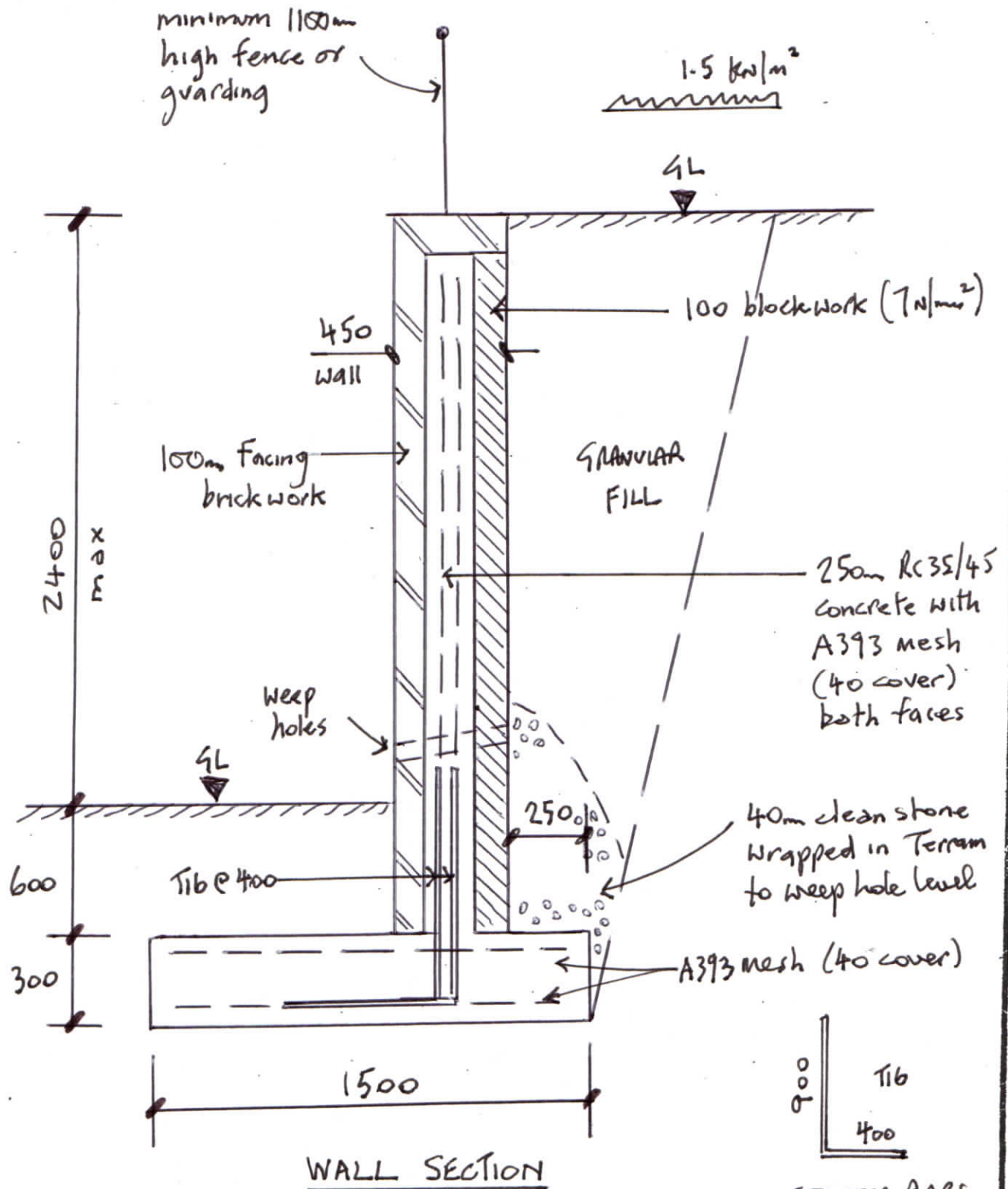
FoS for Overturning	
(1) With vertical component of earth pressure considered	2.9351
(2) Ignoring vertical component of earth pressure	2.9351

FoS for Sliding	
(1) Friction only	1.8818
(2) Friction+passive	4.8889

Pressure at A	9.1603 kN/m ²
Pressure at B	67.55 kN/m ²
Allowable GBP	120 kN/m ²

DO NOT SCALE

CONCRETE RC35/45
(10mm aggregate)



NOTES

PROVIDE $\phi 64$ WEEP HOLES @ 1000 CRS.
POUR WALL IN MAX 900 HIGH SECTIONS
WITH MESH LAPPED 400mm, TEMPORARY
SUPPORT WHEN POURING WALL
REMOVE ANY SOFT SPOTS FROM FORMATION

Project Title

2.4m GARDEN RETAINING WALL
FORMER CLUN PRIMARY SCHOOL

Drawn CM

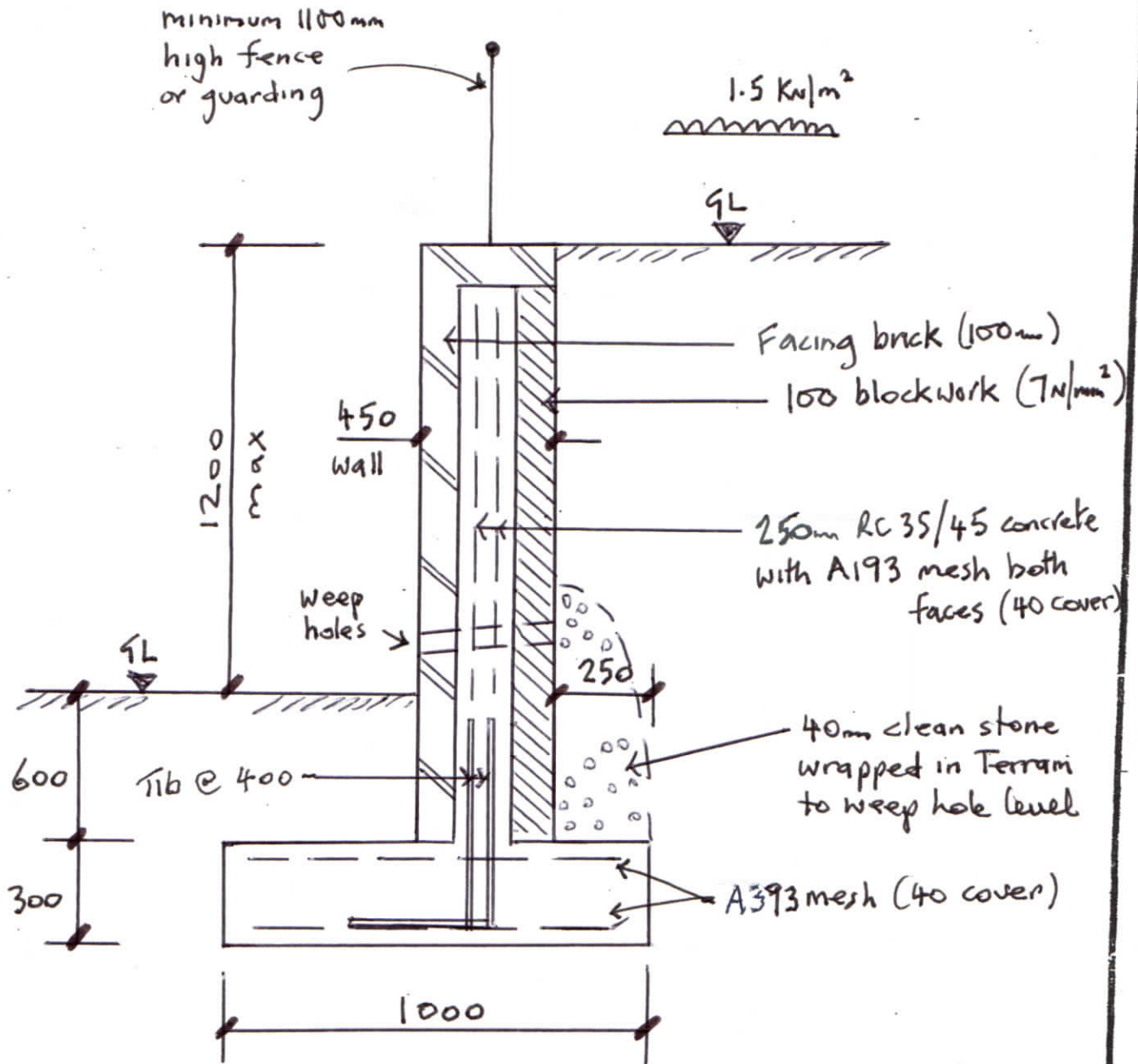
Date OCT 19

Drg.

JS/WALL/02

Rev.

DO NOT SCALE



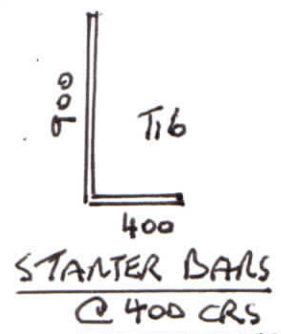
WALL SECTION

NOTES

PROVIDE $\phi 64$ WEEP HOLES AT 1000mm CRS TO WALL

POUR WALL IN MAXIMUM 900mm HIGH SECTIONS WITH MESH LAPPED AT JOINT MINIMUM 400mm, TEMPORARY SUPPORT WHEN POURING WALL

REMOVE ANY SOFT SPOTS FROM THE FORMATION AND REINSTATE FULLY



Project Title		
1.2m GARDEN RETAINING WALL		
FORMER CLUN PRIMARY SCHOOL		
Drawn	CM	Date OCT 19
Drg.	JS / WALL / 01	
		Rev.