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STRUCTURAL CALCULATIONS

For

EXTERNAL RETAINING WALLS

at

**RESIDENTIAL DEVELOPMENT
LAND OPPOSITE 5 AND 7
HEOL-Y-BRYNIAU
PANT
MERTHYR TYDFIL**

Project No: 22040

Date: July 2022

 FAR Structures Ltd Wayside, 30 Brynfield Road, Langland, Swansea, SA3 4SX t: +44 (0)7703 043 608 e:andrew@farstructures.uk	Project				Job no.	
	Land Opposite 5-7 Heol-Y-Bryniau, Pant				22040	
	Calcs for				Start page no./Revision	
	Driveway Retaining Walls				3	
	Calcs by	Calcs date	Checked by	Checked date	Approved by	Approved date
	AR	19/07/2022	AR	19/07/2022		

Length of toe $l_{toe} = 150 \text{ mm}$

Base thickness $t_b = 150 \text{ mm}$

Length of base $l_{o_a} = l_{toe} + t_w + l_{heel} = 850 \text{ mm}$

Height of active soil (at back of stem and heel)

Height of wall stem $h_{stem} = h - t_b = 990 \text{ mm}$

$h_{soil} = h + l_{heel} \times \tan(\theta) = 1140 \text{ mm}$

Load factors

Dead Load Factor $\gamma_{f_d} = 1.40$

Imposed Load Factor $\gamma_{f_i} = 1.60$

Coefficients using Rankine

Active coefficient (Sloping Surface) - no friction

$$k_{a_s} = (\cos(\theta) - \sqrt{((\cos(\theta))^2 - (\cos(\phi))^2)}) / (\cos(\theta) + \sqrt{((\cos(\theta))^2 - (\cos(\phi))^2)}) = 0.249$$

Active coefficient (level surface)

$$k_a = (1 - \sin(\phi)) / (1 + \sin(\phi)) = 0.249$$

Passive coefficient (level surface)

$$k_p = (1 + \sin(\phi)) / (1 - \sin(\phi)) = 4.023$$

At - rest coefficient

$$k_o = (1 - \sin(\phi)) = 0.398$$

For a one metre width - (Horizontal Components - Active Earth Pressures)

At the virtual back of the wall (back of heel)

Surcharge

pressure $p_s = k_{a_s} \times w_s = 0.6 \text{ kN/m}^2$

force – horizontal $F_s = (p_s \times h_{soil}) \times (\cos(\theta))^2 = 0.7 \text{ kN/m}$

overturning moment about toe $M_s = F_s \times h_{soil} / 2 = 0.4 \text{ kNm/m}$

Backfill

pressure $p_a = k_{a_s} \times \gamma_s \times h_{soil} = 5.4 \text{ kN/m}^2$

force – horizontal $F_a = (p_a \times h_{soil} / 2) \times (\cos(\theta))^2 = 3.1 \text{ kN/m}$

overturning moment about the toe $M_a = F_a \times h_{soil} / 3 = 1.2 \text{ kNm/m}$

Total horizontal force (unfactored)

$$F_t = F_s + F_a = 3.8 \text{ kN/m}$$

Total horizontal force (factored)

$$F_{t_ult} = \gamma_{f_i} \times F_s + \gamma_{f_d} \times F_a = 5.4 \text{ kN/m}$$

Total overturning moment (unfactored)

$$M_t = M_s + M_a = 1.6 \text{ kNm/m}$$

Total overturning moment (factored)

$$M_{t_ult} = \gamma_{f_i} \times M_s + \gamma_{f_d} \times M_a = 2.3 \text{ kNm/m}$$

Average load factor

$$\gamma_{f_av} = M_{t_ult} / M_t = 1.45$$

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STABILITY CHECKS

(Unfactored Loads - Active Soil Pressures)

1) SLIDING

Coefficient of friction $\mu = \tan(\phi) \times \text{factor} = 0.565$ factor = **0.75**

Passive pressures in front of wall

Top of base $pp_1 = k_p \times t_c \times \gamma_s = 15.3 \text{ kN/m}^2$

Underside of base $pp_2 = k_p \times (t_c + t_b) \times \gamma_s = 26.8 \text{ kN/m}^2$

Total resistance

Base $PP_{\text{base}} = (pp_1 + pp_2) \times t_b / 2 = 3.2 \text{ kN/m}$

Passive resistance **Soil in front of wall assumed to resist sliding**

$P = PP_{\text{base}} \times \text{soil_resists} = 3.2 \text{ kN/m}$

Factor of safety against sliding

Factor of safety required $FOS_{\text{reqd sliding}} = 2.00$

Length of heel provided $l_{\text{heel}} = 150 \text{ mm}$

Conservatively, it is assumed that the surcharge load does not provide downward pressure on the heel in the sliding calculation.

$FOS_{\text{sliding}} = (((l_{\text{heel}} \times (\gamma_s \times (h_{\text{stem}} + l_{\text{heel}} \times \tan(\theta)/2) + \gamma_b \times t_b)) + l_{\text{toe}} \times \gamma_b \times t_b + W_v + (t_w \times (\gamma_w \times h_{\text{stem}} + \gamma_b \times t_b))) \times \mu) + P) / F_t$

$FOS_{\text{sliding}} = 3.255$

Factor of safety against sliding = 3.3 i.e. > 2.0 - OK

2) OVERTURNING

Factor of safety against overturning

Factor of safety required $FOS_{\text{reqd o_turn}} = 2.00$

Length of toe provided $l_{\text{toe}} = 150 \text{ mm}$

Conservatively, it is assumed that the surcharge load does not provide downward pressure on the heel in the overturning calculation.

Taking Moments about front of the toe

$M_{r1} = (W_v + h_{\text{stem}} \times t_w \times \gamma_w) \times (l_{\text{toe}} + t_w / 2) = 4.4 \text{ kNm/m}$

$M_{r2} = l_{\text{heel}} \times h_{\text{stem}} \times \gamma_s \times (l_{\text{toe}} + t_w + l_{\text{heel}} / 2) = 2.2 \text{ kNm/m}$

$M_{r3} = (l_{\text{toe}} + t_w + l_{\text{heel}})^2 \times t_b \times \gamma_b / 2 = 1.3 \text{ kNm/m}$

$M_{r4} = l_{\text{heel}} \times l_{\text{heel}} \times \tan(\theta) / 2 \times \gamma_s \times (l_{\text{toe}} + t_w + l_{\text{heel}} \times 2/3) = 0.0 \text{ kNm/m}$

Resisting moment $M_r = M_{r1} + M_{r2} + M_{r3} + M_{r4} = 7.9 \text{ kNm/m}$

Factor of safety against overturning $FOS_{\text{o_turn}} = M_r / \text{abs}(M_t) = 5.01$

Factor of safety against overturning = 5.0 i.e. > 2.0 - OK

Overall length of base $l_{\text{o_a}} = l_{\text{toe}} + t_w + l_{\text{heel}} = 0.850 \text{ m}$

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3) BEARING PRESSURE (INCLUDING LIVE LOADS AND TOE COVER)

Total overturning moment for bearing calculation $M_t = 1.6 \text{ kNm/m}$

Total resisting moment for bearing calculation $M_r = 7.9 \text{ kNm/m}$

Total vertical load on base

$$N = t_w \times h_{\text{stem}} \times \gamma_w + (h_{\text{stem}} + l_{\text{heel}} \times \tan(\theta)/2) \times l_{\text{heel}} \times \gamma_s + t_c \times l_{\text{toe}} \times \gamma_s + l_{o_a} \times t_b \times \gamma_b + W_v + w_s \times l_{\text{heel}} + W_l$$

$$N = 17.1 \text{ kN/m}$$

Eccentricity of vertical load

$$e_1 = (M_r - \text{abs}(M_t) + t_c \times l_{\text{toe}}^2 \times \gamma_s/2 + w_s \times l_{\text{heel}} \times (l_{\text{toe}} + t_w + l_{\text{heel}}/2) + W_l \times (l_{\text{toe}} + t_w/2)) / N = 0.387 \text{ m}$$

$$e = l_{o_a} / 2 - e_1 = 0.038 \text{ m}$$

Resultant lies inside middle third

Maximum bearing pressure $p_{\text{max}} = \text{if}(\text{abs}(e) < (l_{o_a}/6), \sigma_{\text{max}2}, \sigma_{\text{max}1}) = 25.5 \text{ kN/m}^2$

Permissible bearing pressure $p_{\text{bearing}} = 75 \text{ kN/m}^2$

Maximum bearing pressure is 26 kN/m² i.e. < Allowable - OK

DESIGN BASE PRESSURES BASED UPON AT REST EARTH PRESSURES

For a one metre width - (Horizontal Components - At Rest Earth Pressures)

Surcharge

pressure $p_{s0} = k_o \times w_s = 1.0 \text{ kN/m}^2$

force $F_{s0} = p_{s0} \times h = 1.1 \text{ kN/m}$

moment $M_{s0} = F_{s0} \times h / 2 = 0.6 \text{ kNm/m}$

Backfill

pressure $p_o = k_o \times \gamma_s \times h = 8.6 \text{ kN/m}^2$

force $F_o = p_o \times h / 2 = 4.9 \text{ kN/m}$

moment $M_o = F_o \times h / 3 = 1.9 \text{ kNm/m}$

Total horizontal force (unfactored) $F_{t_o} = F_{s0} + F_o = 6.1 \text{ kN/m}$

Total horizontal force (factored) $F_{t_ult_o} = \gamma_{f_i} \times F_{s0} + \gamma_{f_d} \times F_o = 8.7 \text{ kN/m}$

Total moment (unfactored) $M_{t_o} = M_{s0} + M_o = 2.5 \text{ kNm/m}$

Total horizontal force (factored) $M_{t_ult_o} = \gamma_{f_i} \times M_{s0} + \gamma_{f_d} \times M_o = 3.7 \text{ kNm/m}$

Average load factor $\gamma_{f_av} = M_{t_ult_o} / M_{t_o} = 1.45$

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Total vertical load on base

$$N = t_w \times h_{\text{stem}} \times \gamma_w + (h_{\text{stem}} + l_{\text{heel}} \times \tan(\theta) / 2) \times l_{\text{heel}} \times \gamma_s + t_c \times l_{\text{toe}} \times \gamma_s + l_{o_a} \times t_b \times \gamma_b + W_v + w_s \times l_{\text{heel}} + W_i$$

$$N = 17.1 \text{ kN/m}$$

Total resistance moment (no live loads included or toe cover)

$$M_r = 7.862 \text{ kNm/m}$$

Eccentricity of vertical load

$$e_1 = (M_r - M_{t_o} + t_c \times l_{\text{toe}}^2 \times \gamma_s / 2 + w_s \times l_{\text{heel}} \times (l_{\text{toe}} + t_w + l_{\text{heel}} / 2) + W_i \times (l_{\text{toe}} + t_w / 2)) / N = 0.332 \text{ m}$$

$$e = l_{o_a} / 2 - e_1 = 0.093 \text{ m}$$

Resultant lies inside middle third

1) Resultant outside middle third **This Section is Invalid as Resultant is within Middle Third**

$$\sigma_{\text{max}1} = (2 \times N) / (3 \times (l_{o_a} / 2 - \text{abs}(e))) = 34 \text{ kN/m}^2$$

$$l_{b1} = (N \times 2 / \sigma_{\text{max}1}) = 0.995 \text{ m}$$

2) Resultant inside middle third

$$\sigma_{\text{max}2} = N / l_{o_a} + 6 \times N \times \text{abs}(e) / l_{o_a}^2 = 33 \text{ kN/m}^2$$

$$\sigma_{\text{min}2} = N / l_{o_a} - 6 \times N \times \text{abs}(e) / l_{o_a}^2 = 7 \text{ kN/m}^2$$

$$l_{b2} = l_{o_a} = 0.850 \text{ m}$$

Pressures under the base

$$\sigma_{\text{max}} = \text{if}(\text{abs}(e) < l_{o_a} / 6, \sigma_{\text{max}2}, \sigma_{\text{max}1}) = 33.4 \text{ kN/m}^2$$

$$\sigma_{\text{min}} = \text{if}(\text{abs}(e) < l_{o_a} / 6, \sigma_{\text{min}2}, 0 \text{ kN/m}^2) = 6.9 \text{ kN/m}^2$$

$$\text{Bearing length } l_p = \text{if}(\text{abs}(e) < (l_{o_a} / 6), l_{b2}, l_{b1}) = 0.850 \text{ m}$$

Pressures under the heel/stem interface

$$l_{p_heel} = l_p - l_{\text{toe}} - t_w = 0.150 \text{ m}$$

$$\sigma_{\text{heel}} = \max(((\sigma_{\text{max}} - \sigma_{\text{min}}) \times l_{p_heel} / l_p) + \sigma_{\text{min}}, 0 \text{ kN/m}^2) = 11.6 \text{ kN/m}^2$$

Pressures under the toe/stem interface

$$\sigma_{\text{toe}} = ((\sigma_{\text{max}} - \sigma_{\text{min}}) \times (l_{p_heel} + t_w) / l_p) + \sigma_{\text{min}} = 28.7 \text{ kN/m}^2$$

BASE DESIGN - HEEL

Shears and Moments

$$\text{Vertical load downward } w_{\text{ult_heel}} = (h_{\text{stem}} \times \gamma_s + \gamma_b \times t_b) \times \gamma_{t_d} + w_s \times \gamma_{t_i} = 35.3 \text{ kN/m}^2$$

$$w_{\text{ult_heel}1} = (l_{\text{heel}} \times \tan(\theta) / 2 \times \gamma_s) \times \gamma_{t_d} = 0.0 \text{ kN/m}^2$$

Ultimate Shear (at wall face)

$$\text{downward } V_{\text{ult_pos_heel}} = (w_{\text{ult_heel}} + w_{\text{ult_heel}1}) \times l_{\text{heel}} = 5.3 \text{ kN/m}$$

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upward

$$V_{ult_neg_heel} = (\sigma_{min} \times \max(l_{p_heel}, 0 \text{ mm}) + (\sigma_{heel} - \sigma_{min}) \times (\max(l_{p_heel}, 0 \text{ mm}))^2 / (2 \times l_{p_heel})) \times \gamma_{f_av}$$

$$V_{ult_neg_heel} = \mathbf{2.0 \text{ kN/m}}$$

Nett Ultimate Shear

$$V_{ult_heel} = \text{abs}(V_{ult_pos_heel} - V_{ult_neg_heel}) = \mathbf{3.3 \text{ kN/m}}$$

Ultimate Moment (at centre of wall)

$$\text{clockwise } M_{ult_pos_heel} = w_{ult_heel} \times l_{heel} \times (l_{heel} + t_w) / 2 + w_{ult_heel1} \times l_{heel} \times (2 \times l_{heel} / 3 + t_w / 2) = \mathbf{1.9 \text{ kNm/m}}$$

anticlockwise

$$M_{ult_neg_heel} = ((\sigma_{min} \times l_{p_heel} \times (l_{p_heel} + t_w) / 2) + (\sigma_{heel} - \sigma_{min}) / 2 \times l_{p_heel} \times (l_{p_heel} / 3 + t_w / 2)) \times \gamma_{f_av}$$

$$M_{ult_neg_heel} = \mathbf{0.7 \text{ kNm/m}}$$

Nett Ultimate Moment

$$M_{ult_heel} = \text{abs}(M_{ult_pos_heel} - M_{ult_neg_heel}) = \mathbf{1.2 \text{ kNm/m}}$$

HEEL REINFORCEMENT - MESH

Tension Reinforcement

Cover to bars in the top of the heel

$$C_{r_heel} = \mathbf{35 \text{ mm}}$$

Effective depth to bars

$$d_{heel} = t_b - C_{r_heel} - (6\text{mm}) = \mathbf{109 \text{ mm}}$$

Assume the base is a cantilevered slab

Characteristic strength of reinforcement

$$f_y = \mathbf{460 \text{ N/mm}^2}$$

Characteristic strength of concrete

$$f_{cu} = \mathbf{35 \text{ N/mm}^2}$$

Area of reinforcement required

$$K_{heel} = \text{abs}(M_{ult_heel}) / (d_{heel}^2 \times f_{cu}) = \mathbf{0.003} \quad K' = 0.156$$

Compression steel not required

Lever arm

$$z_{heel} = \min ((0.95 \times d_{heel}), (d_{heel} \times (0.5 + \sqrt{ (0.25 - K_{heel} / 0.9) }))) = \mathbf{104 \text{ mm}}$$

Reinforcement required

$$A_{s_heel} = \text{abs}(M_{ult_heel}) / (1 / \gamma_{ms} \times f_y \times z_{heel}) = \mathbf{26 \text{ mm}^2/\text{m}}$$

Minimum reinforcement $A_{s_min_heel} = \text{if}(f_y == 460 \text{ N/mm}^2, 0.0013 \times t_b, 0.0024 \times t_b) = \mathbf{195 \text{ mm}^2/\text{m}}$

$$A_{s_req_heel} = \max(A_{s_heel}, A_{s_min_heel}) = \mathbf{195 \text{ mm}^2/\text{m}}$$

Tension steel provided

$$\text{Use A252 Mesh } A_{s_prov_heel} = A_{sl_heel} = \mathbf{252 \text{ mm}^2/\text{m}}$$

Area of main tension steel provided in heel sufficient

Heel - Check min and max areas of steel

Total area of concrete

$$A_c = t_b = \mathbf{150000 \text{ mm}^2/\text{m}}$$

Minimum percentage area of reinforcement $k = \mathbf{0.13 \%}$

Minimum area of steel required

$$A_{s_min} = k \times A_c = \mathbf{195 \text{ mm}^2/\text{m}}$$

Maximum area of steel allowed

$$A_{s_max} = 4 \% \times A_c = \mathbf{6000 \text{ mm}^2/\text{m}}$$

Area of main steel provided OK

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Heel Distribution Steel

Minimum percentage of distribution reinforcement $k_1 = 0.13 \%$

Minimum Area Required $A_{s_dist_req} = k_1 \times A_c = 195 \text{ mm}^2/\text{m}$

Area Provided $A_{s_dist_base} = A_{st_heel} = 252 \text{ mm}^2/\text{m}$

Area of distribution steel provided OK

CHECK OF NOMINAL COVER

Cover to outer tension reinforcement

$$C_{heel} = t_b - d_{heel} - d_{sl_heel} / 2 = 37.0 \text{ mm}$$

Permissible minimum nominal cover to all reinforcement (Table 3.4)

$$C_{min_heel} = 35 \text{ mm}$$

Cover over outer steel OK (top of heel)

HEEL SHEAR RESISTANCE – AT WALL FACE

Applied shear stress at wall face

$$v_{heel} = V_{ult_heel} / d_{heel} = 0.03 \text{ N/mm}^2$$

Check shear stress to clause 3.4.5.2 (BS8110:Pt 1)

$$V_{allowable} = \min ((0.8 \text{ N}^{1/2}/\text{mm}) \times \sqrt{f_{cu}}, 5 \text{ N/mm}^2) = 4.73 \text{ N/mm}^2$$

Shear stress < maximum - OK

Shear stresses to clause 3.4.5.4 (BS8110:Pt1)

Allowable shear stress

$$V_c_{heel} = 0.60 \text{ N/mm}^2$$

No shear reinforcement required

BASE DESIGN - TOE

Shears and Moments

Conservatively all soil overburden on the toe is ignored

Ultimate Shear (conservatively - at face of wall)

$$V_{ult_toe} = ((\sigma_{toe} \times l_{toe}) + (((\sigma_{max} - \sigma_{toe}) / 2) \times l_{toe})) \times \gamma_{f_av} - l_{toe} \times t_b \times \gamma_b \times \gamma_{f_d} = 6.0 \text{ kN/m}$$

Ultimate Moment (at centre of wall)

$$M_{ult_toe} = ((\sigma_{toe} \times l_{toe} \times (l_{toe} + t_w)/2) + ((\sigma_{max} - \sigma_{toe})/2 \times l_{toe} \times (2 \times l_{toe}/3 + t_w/2))) \times \gamma_{f_av} - l_{toe} \times t_b \times \gamma_b \times \gamma_{f_d} \times (l_{toe}/2 + t_w/2)$$

$$M_{ult_toe} = 2.1 \text{ kNm/m}$$

TOE REINFORCEMENT - MESH

Tension Reinforcement

Cover to bars in the bottom of the toe $C_{r_toe} = 35 \text{ mm}$

Effective depth to bars $d_{toe} = t_b - C_{r_toe} - (6\text{mm}) = 109 \text{ mm}$

Assume the base is a cantilevered slab

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Characteristic strength of reinforcement $f_y = 460 \text{ N/mm}^2$

Characteristic strength of concrete $f_{cu} = 35 \text{ N/mm}^2$

Area of reinforcement required

$$K_{toe} = \text{abs}(M_{ult_toe}) / (d_{toe}^2 \times f_{cu}) = 0.005 \quad K' = 0.156$$

Compression steel not required

Lever arm $z_{toe} = \min((0.95 \times d_{toe}), (d_{toe} \times (0.5 + \sqrt{(0.25 - K_{toe}/0.9)}))) = 104 \text{ mm}$

Reinforcement required $A_{s_toe} = \text{abs}(M_{ult_toe}) / (1/\gamma_{ms} \times f_y \times z_{toe}) = 47 \text{ mm}^2/\text{m}$

Minimum reinforcement $A_{s_min_toe} = \text{if}(f_y == 460 \text{ N/mm}^2, 0.0013 \times t_b, 0.0024 \times t_b) = 195 \text{ mm}^2/\text{m}$

$A_{s_req_toe} = \max(A_{s_toe}, A_{s_min_toe}) = 195 \text{ mm}^2/\text{m}$

Tension steel provided

Use A252 Mesh $A_{s_prov_toe} = A_{s_toe} = 252 \text{ mm}^2/\text{m}$

Area of main tension steel provided in toe sufficient

Toe - Check min and max areas of steel

Total area of concrete $A_c = t_b = 150000 \text{ mm}^2/\text{m}$

Minimum percentage area of reinforcement $k = 0.13 \%$

Minimum area of steel required $A_{s_min} = k \times A_c = 195 \text{ mm}^2/\text{m}$

Maximum area of steel allowed $A_{s_max} = 4 \% \times A_c = 6000 \text{ mm}^2/\text{m}$

Area of main steel provided OK

Toe Distribution Steel

Minimum percentage of distribution reinforcement $k_1 = 0.13 \%$

Minimum Area Required $A_{s_dist_req} = k_1 \times A_c = 195 \text{ mm}^2/\text{m}$

Area Provided $A_{s_dist_base} = A_{s_toe} = 252 \text{ mm}^2/\text{m}$

Area of distribution steel provided OK

CHECK OF NOMINAL COVER

Cover to outer tension reinforcement

$$c_{toe} = t_b - d_{toe} - d_{sl_toe} / 2 = 37.0 \text{ mm}$$

Permissible minimum nominal cover to all reinforcement (Table 3.4)

$$c_{min_toe} = 35 \text{ mm}$$

Cover over outer steel OK (bottom of toe)

TOE SHEAR RESISTANCE

Applied shear stress

$$V_{toe} = V_{ult_toe} / d_{toe} = 0.06 \text{ N/mm}^2$$

Check shear stress to clause 3.4.5.2 (BS8110:Pt 1)

$$V_{allowable} = \min((0.8 \text{ N}^{1/2}/\text{mm}) \times \sqrt{f_{cu}}, 5 \text{ N/mm}^2) = 4.73 \text{ N/mm}^2$$

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Shear stress < maximum - OK

Shear stresses to clause 3.4.5.4 (BS8110:Pt 1)

Allowable shear stress

$$V_{c_toe} = 0.60 \text{ N/mm}^2$$

No shear reinforcement required

STEM DESIGN

Width of base of wall $t_w = 550.0 \text{ mm}$

Height of stem of wall $h_{stem} = 990 \text{ mm}$

DESIGN OF WALL SECTION 1 (AT REST PRESSURES)

Wall base section thickness $t_w = 550.0 \text{ mm}$

Depth from top of wall to base

$h_{stem} = 990 \text{ mm}$ **Warning the height of the wall is not a complete number of bricks**

Applied moment at base of section

$$M_{base} = (k_o \times w_s \times h_{stem}^2 / 2) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{stem}^3 / 6) \times \gamma_{f_d} = 2.5 \text{ kNm/m}$$

Applied shear force at base of section

$$F_{base} = (k_o \times w_s \times h_{stem}) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{stem}^2 / 2) \times \gamma_{f_d} = 6.8 \text{ kN/m}$$

CHECK RESISTANCE TO MOMENT WITHOUT FLEXURAL STRENGTH (BS5628:PT 1:CL 36.5.3)

Compressive strength (Table 2) $f_k = 6.40 \text{ N/mm}^2$

Design vertical load per unit length of wall $n_{w_base} = \gamma_{fd} \times (W_v + t_w \times h_{stem} \times \gamma_w) = 9.3 \text{ kN/m}$

Moment of resistance $M_{RC_base} = (n_{w_base} / 2) \times (t_w - (n_{w_base} \times \gamma_m / f_k)) = 2.5 \text{ kNm/m}$

Wall bending - OK

STEM SHEAR (BS5628:PT 1:CL 33)

Mortar designation Mortar = "iii"

Design dead load at the base of the wall $V_{base} = W_v + t_w \times h_{stem} \times \gamma_w = 10.35 \text{ kN/m}$

Design vertical dead load per unit area $g_{A_base} = V_{base} \times \gamma_{fd} / t_w = 0.02 \text{ N/mm}^2$

Characteristic shear strength of masonry

$$f_{v_i} = \min(1.75 \text{ N/mm}^2, 0.35 \text{ N/mm}^2 + (0.6 \times g_{A_base})) = 0.36 \text{ N/mm}^2$$

$$f_{v_iii} = \min(1.4 \text{ N/mm}^2, 0.15 \text{ N/mm}^2 + (0.6 \times g_{A_base})) = 0.16 \text{ N/mm}^2$$

$$f_v = \text{if}((\text{Mortar} == "i") || (\text{Mortar} == "ii"), f_{v_i}, f_{v_iii}) = 0.16 \text{ N/mm}^2$$

Ref BS 5628 Pt 1: Clause 25

Shear stress $V_{base} = F_{base} / t_w = 0.01 \text{ N/mm}^2$

Partial safety factor for shear $\gamma_{mv} = 2.5$

Wall base shear OK

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DESIGN OF WALL SECTION 2 (AT REST PRESSURES)

Wall section thickness $t_{wall_2} = 327.5$ mm

Depth from top of wall to base of section

$h_{wall_2} = 440$ mm **Warning the height of the section is not a complete number of bricks**

Applied moment at base of section

$$M_{wall_2} = (k_o \times w_s \times h_{wall_2}^2 / 2) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{wall_2}^3 / 6) \times \gamma_{f_d} = 0.3 \text{ kNm/m}$$

Applied shear force at base of section

$$F_{wall_2} = (k_o \times w_s \times h_{wall_2}) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{wall_2}^2 / 2) \times \gamma_{f_d} = 1.7 \text{ kN/m}$$

CHECK RESISTANCE TO MOMENT WITHOUT FLEXURAL STRENGTH (BS5628:PT 1:CL 36.5.3)

Compressive strength (Table 2) $f_k = 6.40$ N/mm²

Design vertical load per unit length of wall $n_{w_wall_2} = \gamma_{fd} \times (W_v + t_{wall_2} \times h_{wall_2} \times \gamma_w) = 2.5$ kN/m

Moment of resistance $M_{RC_wall_2} = (n_{w_wall_2} / 2) \times (t_{wall_2} - (n_{w_wall_2} \times \gamma_m / f_k)) = 0.4$ kNm/m

Wall bending - OK

STEM SHEAR (BS5628:PT 1:CL 33)

Mortar designation Mortar = "iii"

Design dead load at the base of the wall $V_{wall_2} = W_v + t_{wall_2} \times h_{wall_2} \times \gamma_w = 2.74$ kN/m

Design vertical dead load per unit area $g_{A_wall_2} = V_{wall_2} \times \gamma_{fd} / t_{wall_2} = 0.01$ N/mm²

Characteristic shear strength of masonry

$$f_{v_i} = \min(1.75 \text{ N/mm}^2, 0.35 \text{ N/mm}^2 + (0.6 \times g_{A_wall_2})) = 0.35 \text{ N/mm}^2$$

$$f_{v_iii} = \min(1.4 \text{ N/mm}^2, 0.15 \text{ N/mm}^2 + (0.6 \times g_{A_wall_2})) = 0.15 \text{ N/mm}^2$$

$$f_v = \text{if}((\text{Mortar} == "i") || (\text{Mortar} == "ii"), f_{v_i}, f_{v_iii}) = 0.15 \text{ N/mm}^2$$

Ref BS 5628 Pt 1: Clause 25

Shear stress

$$v_{wall_2} = F_{wall_2} / t_{wall_2} = 0.01 \text{ N/mm}^2$$

Partial safety factor for shear

$$\gamma_{mv} = 2.5$$

Wall section base shear OK

SUMMARY OF RESULTS

Wall Dimensions

Masonry Compressive Strength **Masonry Compressive Strength - 6.4 N/mm²**

Stem Base section **550mm thick and 990mm from base to the top of the wall**

Section 2 **328mm thick and 440mm from base of section 2 to the top of the wall**

Base Top Reinforcement - Mesh

Heel (Top) Reinforcement **Provide A252 Mesh (Top)**

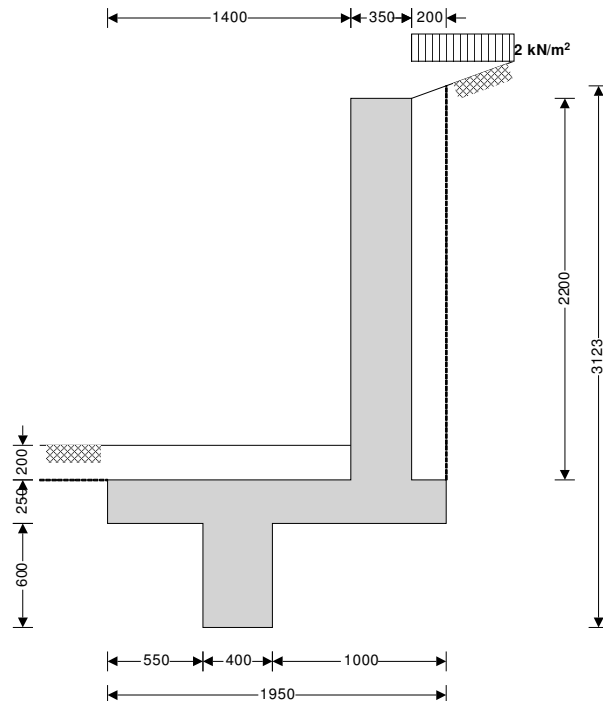
Base Bottom Reinforcement - Mesh

Toe (Bottom) Reinforcement **Provide A252 Mesh (Bottom)**

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RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type
Height of retaining wall stem
Thickness of wall stem
Length of toe
Length of heel
Overall length of base
Thickness of base
Depth of downstand
Position of downstand
Thickness of downstand
Height of retaining wall
Depth of cover in front of wall
Depth of unplanned excavation
Height of ground water behind wall
Height of saturated fill above base
Density of wall construction
Density of base construction
Angle of rear face of wall
Angle of soil surface behind wall
Effective height at virtual back of wall

Unpropped cantilever

$h_{\text{stem}} = 2200$ mm
 $t_{\text{wall}} = 350$ mm
 $l_{\text{toe}} = 1400$ mm
 $l_{\text{heel}} = 200$ mm
 $l_{\text{base}} = l_{\text{toe}} + l_{\text{heel}} + t_{\text{wall}} = 1950$ mm
 $t_{\text{base}} = 250$ mm
 $d_{\text{ds}} = 600$ mm
 $l_{\text{ds}} = 550$ mm
 $t_{\text{ds}} = 400$ mm
 $h_{\text{wall}} = h_{\text{stem}} + t_{\text{base}} + d_{\text{ds}} = 3050$ mm
 $d_{\text{cover}} = 200$ mm
 $d_{\text{exc}} = 200$ mm
 $h_{\text{water}} = 0$ mm
 $h_{\text{sat}} = \max(h_{\text{water}} - t_{\text{base}} - d_{\text{ds}}, 0 \text{ mm}) = 0$ mm
 $\gamma_{\text{wall}} = 23.6$ kN/m³
 $\gamma_{\text{base}} = 23.6$ kN/m³
 $\alpha = 90.0$ deg
 $\beta = 20.0$ deg
 $h_{\text{eff}} = h_{\text{wall}} + l_{\text{heel}} \times \tan(\beta) = 3123$ mm

Retained material details

Mobilisation factor
Moist density of retained material

$M = 1.5$
 $\gamma_m = 18.0$ kN/m³

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Saturated density of retained material $\gamma_s = 21.0 \text{ kN/m}^3$

Design shear strength $\phi' = 25.8 \text{ deg}$

Angle of wall friction $\delta = 19.9 \text{ deg}$

Base material details

Moist density $\gamma_{mb} = 18.0 \text{ kN/m}^3$

Design shear strength $\phi'_b = 25.8 \text{ deg}$

Design base friction $\delta_b = 19.9 \text{ deg}$

Allowable bearing pressure $P_{\text{bearing}} = 100 \text{ kN/m}^2$

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))})]^2) = 0.521$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))})]^2) = 4.785$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi') = 0.565$

Loading details

Surcharge load on plan Surcharge = **1.5 kN/m²**

Applied vertical dead load on wall $W_{\text{dead}} = 0.0 \text{ kN/m}$

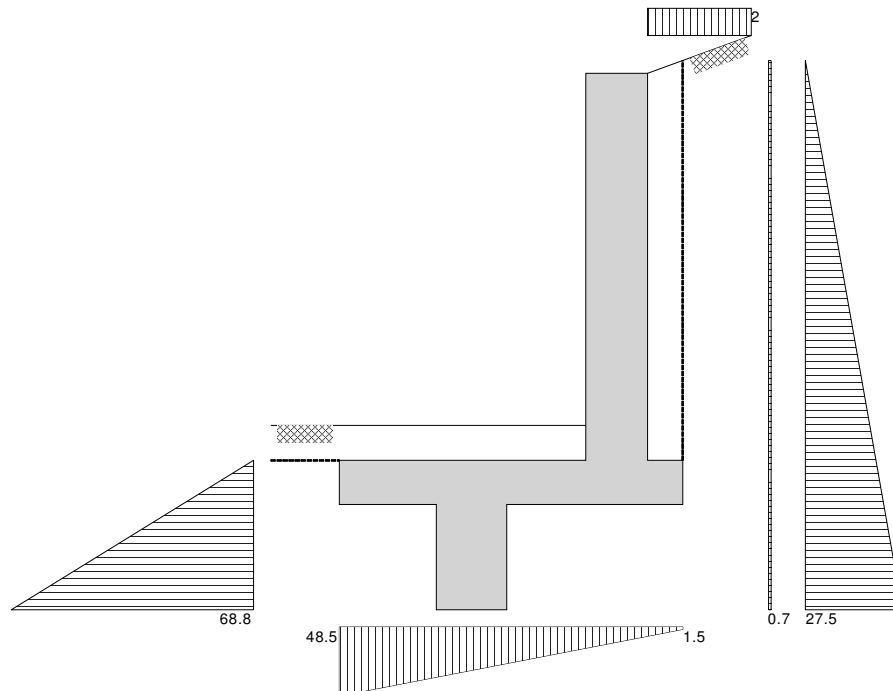
Applied vertical live load on wall $W_{\text{live}} = 0.0 \text{ kN/m}$

Position of applied vertical load on wall $l_{\text{load}} = 0 \text{ mm}$

Applied horizontal dead load on wall $F_{\text{dead}} = 0.0 \text{ kN/m}$

Applied horizontal live load on wall $F_{\text{live}} = 0.0 \text{ kN/m}$

Height of applied horizontal load on wall $h_{\text{load}} = 0 \text{ mm}$



Loads shown in kN/m, pressures shown in kN/m²

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Vertical forces on wall

Wall stem	$w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall} = 18.2 \text{ kN/m}$
Wall base	$w_{base} = l_{base} \times t_{base} \times \gamma_{base} = 11.5 \text{ kN/m}$
Wall downstand	$w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base} = 5.7 \text{ kN/m}$
Surcharge	$w_{sur} = \text{Surcharge} \times l_{heel} = 0.3 \text{ kN/m}$
Moist backfill to top of wall	$w_{m_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 7.9 \text{ kN/m}$
Moist backfill above top of wall	$w_{m_s} = 0.5 \times l_{heel}^2 \times \tan(\beta) \times \gamma_m = 0.1 \text{ kN/m}$
Soil in front of wall	$w_p = l_{toe} \times d_{cover} \times \gamma_{mb} = 5 \text{ kN/m}$
Total vertical load	$W_{total} = w_{wall} + w_{base} + w_{ds} + w_{sur} + w_{m_w} + w_{m_s} + w_p = 48.7 \text{ kN/m}$

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff} = 2.3 \text{ kN/m}$
Moist backfill above water table	$F_{m_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2 = 43 \text{ kN/m}$
Total horizontal load	$F_{total} = F_{sur} + F_{m_a} = 45.3 \text{ kN/m}$

Calculate stability against sliding

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 29.3 \text{ kN/m}$
Resistance to sliding	$F_{res} = F_p + W_{total} \times \tan(\delta_b) = 46.9 \text{ kN/m}$

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 = 2.2 \text{ kNm/m}$
Moist backfill above water table	$M_{m_a} = F_{m_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 19 \text{ kNm/m}$
Soil in front of wall	$M_{p_o} = F_p \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3 = 9.3 \text{ kNm/m}$
Total overturning moment	$M_{ot} = M_{sur} + M_{m_a} + M_{p_o} = 30.4 \text{ kNm/m}$

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2) = 28.6 \text{ kNm/m}$
Wall base	$M_{base} = w_{base} \times l_{base} / 2 = 11.2 \text{ kNm/m}$
Wall downstand	$M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2) = 4.2 \text{ kNm/m}$
Surcharge	$M_{sur_r} = w_{sur} \times (l_{base} - l_{heel} / 2) = 0.6 \text{ kNm/m}$
Moist backfill	$M_{m_r} = (w_{m_w} \times (l_{base} - l_{heel} / 2) + w_{m_s} \times (l_{base} - l_{heel} / 3)) = 14.9 \text{ kNm/m}$
Soil in front of wall	$M_{p_r} = w_p \times l_{toe} / 2 = 3.5 \text{ kNm/m}$
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{ds} + M_{sur_r} + M_{m_r} + M_{p_r} = 63.1 \text{ kNm/m}$

Check stability against overturning

Total overturning moment	$M_{ot} = 30.4 \text{ kNm/m}$
Total restoring moment	$M_{rest} = 63.1 \text{ kNm/m}$

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Total moment for bearing	$M_{total} = M_{rest} - M_{ot} = 32.6 \text{ kNm/m}$
Total vertical reaction	$R = W_{total} = 48.7 \text{ kN/m}$
Distance to reaction	$x_{bar} = M_{total} / R = 670 \text{ mm}$
Eccentricity of reaction	$e = \text{abs}((l_{base} / 2) - x_{bar}) = 305 \text{ mm}$

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) = 48.5 \text{ kN/m}^2$
Bearing pressure at heel	$p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = 1.5 \text{ kN/m}^2$

PASS - Maximum bearing pressure is less than allowable bearing pressure

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RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.08

Ultimate limit state load factors

Dead load factor	$\gamma_{f_d} = 1.4$
Live load factor	$\gamma_{f_l} = 1.6$
Earth and water pressure factor	$\gamma_{f_e} = 1.4$

Factored vertical forces on wall

Wall stem	$W_{wall_f} = \gamma_{f_d} \times h_{stem} \times t_{wall} \times \gamma_{wall} = 25.4 \text{ kN/m}$
Wall base	$W_{base_f} = \gamma_{f_d} \times l_{base} \times t_{base} \times \gamma_{base} = 16.1 \text{ kN/m}$
Wall downstand	$W_{ds_f} = \gamma_{f_d} \times d_{ds} \times t_{ds} \times \gamma_{base} = 7.9 \text{ kN/m}$
Surcharge	$W_{sur_f} = \gamma_{f_l} \times \text{Surcharge} \times l_{heel} = 0.5 \text{ kN/m}$
Moist backfill to top of wall	$W_{m_w_f} = \gamma_{f_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 11.1 \text{ kN/m}$
Moist backfill above top of wall	$W_{m_s_f} = \gamma_{f_d} \times 0.5 \times l_{heel}^2 \times \tan(\beta) \times \gamma_m = 0.2 \text{ kN/m}$
Soil in front of wall	$W_{p_f} = \gamma_{f_d} \times l_{toe} \times d_{cover} \times \gamma_{mb} = 7.1 \text{ kN/m}$
Total vertical load kN/m	$W_{total_f} = W_{wall_f} + W_{base_f} + W_{ds_f} + W_{sur_f} + W_{m_w_f} + W_{m_s_f} + W_{p_f} = 68.3$

Factored horizontal at-rest forces on wall

Surcharge	$F_{sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times h_{eff} = 4.2 \text{ kN/m}$
Moist backfill above water table	$F_{m_a_f} = \gamma_{f_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2 = 69.4 \text{ kN/m}$
Total horizontal load	$F_{total_f} = F_{sur_f} + F_{m_a_f} = 73.6 \text{ kN/m}$
Passive resistance of soil in front of wall kN/m	$F_{p_f} = \gamma_{f_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 41$

Factored overturning moments

Surcharge	$M_{sur_f} = F_{sur_f} \times (h_{eff} - 2 \times d_{ds}) / 2 = 4.1 \text{ kNm/m}$
Moist backfill above water table	$M_{m_a_f} = F_{m_a_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 30.6 \text{ kNm/m}$
Soil in front of wall	$M_{p_o_f} = F_{p_f} \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3 = 13 \text{ kNm/m}$
Total overturning moment	$M_{ot_f} = M_{sur_f} + M_{m_a_f} + M_{p_o_f} = 47.6 \text{ kNm/m}$

Restoring moments

Wall stem	$M_{wall_f} = W_{wall_f} \times (l_{toe} + t_{wall} / 2) = 40.1 \text{ kNm/m}$
Wall base	$M_{base_f} = W_{base_f} \times l_{base} / 2 = 15.7 \text{ kNm/m}$
Wall downstand	$M_{ds_f} = W_{ds_f} \times (l_{ds} + t_{ds} / 2) = 5.9 \text{ kNm/m}$
Surcharge	$M_{sur_r_f} = W_{sur_f} \times (l_{base} - l_{heel} / 2) = 0.9 \text{ kNm/m}$
Moist backfill	$M_{m_r_f} = (W_{m_w_f} \times (l_{base} - l_{heel} / 2) + W_{m_s_f} \times (l_{base} - l_{heel} / 3)) = 20.9 \text{ kNm/m}$
Soil in front of wall	$M_{p_r_f} = W_{p_f} \times l_{toe} / 2 = 4.9 \text{ kNm/m}$
Total restoring moment	$M_{rest_f} = M_{wall_f} + M_{base_f} + M_{ds_f} + M_{sur_r_f} + M_{m_r_f} + M_{p_r_f} = 88.4 \text{ kNm/m}$

Factored bearing pressure

Total moment for bearing	$M_{total_f} = M_{rest_f} - M_{ot_f} = 40.8 \text{ kNm/m}$
Total vertical reaction	$R_f = W_{total_f} = 68.3 \text{ kN/m}$
Distance to reaction	$x_{bar_f} = M_{total_f} / R_f = 597 \text{ mm}$
Eccentricity of reaction	$e_f = \text{abs}((l_{base} / 2) - x_{bar_f}) = 378 \text{ mm}$
Reaction acts outside middle third of base	
Bearing pressure at toe	$p_{toe_f} = R_f / (1.5 \times x_{bar_f}) = 76.3 \text{ kN/m}^2$
Bearing pressure at heel	$p_{heel_f} = 0 \text{ kN/m}^2 = 0 \text{ kN/m}^2$
Rate of change of base reaction	$\text{rate} = p_{toe_f} / (3 \times x_{bar_f}) = 42.57 \text{ kN/m}^2/\text{m}$

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Bearing pressure at stem / toe

$$p_{\text{stem_toe_f}} = \max(p_{\text{toe_f}} - (\text{rate} \times l_{\text{toe}}), 0 \text{ kN/m}^2) = \mathbf{16.6 \text{ kN/m}^2}$$

Bearing pressure at mid stem

$$p_{\text{stem_mid_f}} = \max(p_{\text{toe_f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}} / 2)), 0 \text{ kN/m}^2) = \mathbf{9.2 \text{ kN/m}^2}$$

Bearing pressure at stem / heel

$$p_{\text{stem_heel_f}} = \max(p_{\text{toe_f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}})), 0 \text{ kN/m}^2) = \mathbf{1.7 \text{ kN/m}^2}$$

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete

$$f_{\text{cu}} = \mathbf{35 \text{ N/mm}^2}$$

Characteristic strength of reinforcement

$$f_y = \mathbf{500 \text{ N/mm}^2}$$

Base details

Minimum area of reinforcement

$$k = \mathbf{0.13 \%}$$

Cover to reinforcement in toe

$$c_{\text{toe}} = \mathbf{40 \text{ mm}}$$

Calculate shear for toe design

Shear from bearing pressure

$$V_{\text{toe_bear}} = (p_{\text{toe_f}} + p_{\text{stem_toe_f}}) \times l_{\text{toe}} / 2 = \mathbf{65 \text{ kN/m}}$$

Shear from weight of base

$$V_{\text{toe_wt_base}} = \gamma_{\text{f_d}} \times \gamma_{\text{base}} \times l_{\text{toe}} \times t_{\text{base}} = \mathbf{11.6 \text{ kN/m}}$$

Shear from weight of downstand

$$V_{\text{toe_wt_ds}} = \gamma_{\text{f_d}} \times \gamma_{\text{base}} \times d_{\text{ds}} \times t_{\text{ds}} = \mathbf{7.9 \text{ kN/m}}$$

Total shear for toe design

$$V_{\text{toe}} = V_{\text{toe_bear}} - V_{\text{toe_wt_base}} - V_{\text{toe_wt_ds}} = \mathbf{45.5 \text{ kN/m}}$$

Calculate moment for toe design

Moment from bearing pressure

$$M_{\text{toe_bear}} = (2 \times p_{\text{toe_f}} + p_{\text{stem_mid_f}}) \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = \mathbf{66.9 \text{ kNm/m}}$$

Moment from weight of base

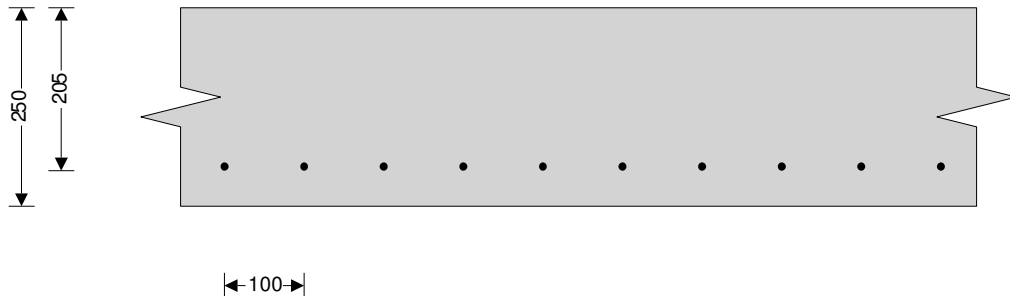
$$M_{\text{toe_wt_base}} = (\gamma_{\text{f_d}} \times \gamma_{\text{base}} \times t_{\text{base}} \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2) = \mathbf{10.2 \text{ kNm/m}}$$

Moment from weight of downstand

$$M_{\text{toe_wt_ds}} = \gamma_{\text{f_d}} \times \gamma_{\text{base}} \times d_{\text{ds}} \times t_{\text{ds}} \times (l_{\text{toe}} - l_{\text{ds}} + (t_{\text{wall}} - t_{\text{ds}}) / 2) = \mathbf{6.5 \text{ kNm/m}}$$

Total moment for toe design

$$M_{\text{toe}} = M_{\text{toe_bear}} - M_{\text{toe_wt_base}} - M_{\text{toe_wt_ds}} = \mathbf{50.1 \text{ kNm/m}}$$



Check toe in bending

Width of toe

$$b = \mathbf{1000 \text{ mm/m}}$$

Depth of reinforcement

$$d_{\text{toe}} = t_{\text{base}} - c_{\text{toe}} - (\phi_{\text{toe}} / 2) = \mathbf{205.0 \text{ mm}}$$

Constant

$$K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_{\text{cu}}) = \mathbf{0.034}$$

Compression reinforcement is not required

Lever arm

$$z_{\text{toe}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{toe}}, 0.225) / 0.9))}, 0.95) \times d_{\text{toe}}$$

$$z_{\text{toe}} = \mathbf{195 \text{ mm}}$$

Area of tension reinforcement required

$$A_{\text{s_toe_des}} = M_{\text{toe}} / (0.87 \times f_y \times z_{\text{toe}}) = \mathbf{591 \text{ mm}^2/\text{m}}$$

Minimum area of tension reinforcement

$$A_{\text{s_toe_min}} = k \times b \times t_{\text{base}} = \mathbf{325 \text{ mm}^2/\text{m}}$$

Area of tension reinforcement required

$$A_{\text{s_toe_req}} = \text{Max}(A_{\text{s_toe_des}}, A_{\text{s_toe_min}}) = \mathbf{591 \text{ mm}^2/\text{m}}$$

Reinforcement provided

B785 mesh

Area of reinforcement provided

$$A_{\text{s_toe_prov}} = \mathbf{785 \text{ mm}^2/\text{m}}$$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress

$$v_{\text{toe}} = V_{\text{toe}} / (b \times d_{\text{toe}}) = \mathbf{0.222 \text{ N/mm}^2}$$

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Allowable shear stress

$$v_{adm} = \min(0.8 \times \sqrt{f_{cu} / 1 \text{ N/mm}^2}, 5) \times 1 \text{ N/mm}^2 = \mathbf{4.733 \text{ N/mm}^2}$$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress

$$v_{c_toe} = \mathbf{0.607 \text{ N/mm}^2}$$

$v_{toe} < v_{c_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall heel (BS 8002:1994)

Material properties

Characteristic strength of concrete

$$f_{cu} = \mathbf{35 \text{ N/mm}^2}$$

Characteristic strength of reinforcement

$$f_y = \mathbf{500 \text{ N/mm}^2}$$

Base details

Minimum area of reinforcement

$$k = \mathbf{0.13 \%}$$

Cover to reinforcement in heel

$$c_{heel} = \mathbf{40 \text{ mm}}$$

Calculate shear for heel design

Shear from bearing pressure

$$V_{heel_bear} = p_{stem_heel_f} \times ((3 \times x_{bar_f}) - l_{toe} - t_{wall}) / 2 = \mathbf{0 \text{ kN/m}}$$

Shear from weight of base

$$V_{heel_wt_base} = \gamma_{fd} \times \gamma_{base} \times l_{heel} \times t_{base} = \mathbf{1.7 \text{ kN/m}}$$

Shear from weight of moist backfill

$$V_{heel_wt_m} = w_{m_w_f} + w_{m_s_f} = \mathbf{11.3 \text{ kN/m}}$$

Shear from surcharge

$$V_{heel_sur} = w_{sur_f} = \mathbf{0.5 \text{ kN/m}}$$

Total shear for heel design

$$V_{heel} = -V_{heel_bear} + V_{heel_wt_base} + V_{heel_wt_m} + V_{heel_sur} = \mathbf{13.4 \text{ kN/m}}$$

Calculate moment for heel design

Moment from bearing pressure

$$M_{heel_bear} = p_{stem_mid_f} \times ((3 \times x_{bar_f}) - l_{toe} - t_{wall} / 2)^2 / 6 = \mathbf{0.1 \text{ kNm/m}}$$

Moment from weight of base

$$M_{heel_wt_base} = (\gamma_{fd} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) = \mathbf{0.6 \text{ kNm/m}}$$

Moment from weight of moist backfill
kNm/m

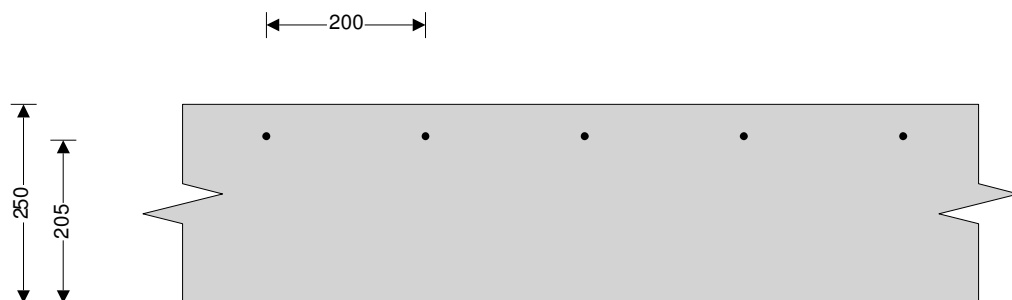
$$M_{heel_wt_m} = w_{m_w_f} \times (l_{heel} + t_{wall}) / 2 + w_{m_s_f} \times (2 \times l_{heel} / 3 + t_{wall} / 2) = \mathbf{3.1}$$

Moment from surcharge

$$M_{heel_sur} = w_{sur_f} \times (l_{heel} + t_{wall}) / 2 = \mathbf{0.1 \text{ kNm/m}}$$

Total moment for heel design

$$M_{heel} = -M_{heel_bear} + M_{heel_wt_base} + M_{heel_wt_m} + M_{heel_sur} = \mathbf{3.7 \text{ kNm/m}}$$



Check heel in bending

Width of heel

$$b = \mathbf{1000 \text{ mm/m}}$$

Depth of reinforcement

$$d_{heel} = t_{base} - c_{heel} - (\phi_{heel} / 2) = \mathbf{205.0 \text{ mm}}$$

Constant

$$K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu}) = \mathbf{0.003}$$

Compression reinforcement is not required

Lever arm

$$z_{heel} = \min(0.5 + \sqrt{(0.25 - (\min(K_{heel}, 0.225) / 0.9))}, 0.95) \times d_{heel}$$

$$z_{heel} = \mathbf{195 \text{ mm}}$$

Area of tension reinforcement required

$$A_{s_heel_des} = M_{heel} / (0.87 \times f_y \times z_{heel}) = \mathbf{44 \text{ mm}^2/\text{m}}$$

Minimum area of tension reinforcement

$$A_{s_heel_min} = k \times b \times t_{base} = \mathbf{325 \text{ mm}^2/\text{m}}$$

Area of tension reinforcement required

$$A_{s_heel_req} = \text{Max}(A_{s_heel_des}, A_{s_heel_min}) = \mathbf{325 \text{ mm}^2/\text{m}}$$

Reinforcement provided

A393 mesh

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Area of reinforcement provided

$$A_{s_heel_prov} = 393 \text{ mm}^2/\text{m}$$

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress

$$v_{heel} = V_{heel} / (b \times d_{heel}) = 0.065 \text{ N/mm}^2$$

Allowable shear stress

$$v_{adm} = \min(0.8 \times \sqrt{f_{cu}} / 1 \text{ N/mm}^2, 5) \times 1 \text{ N/mm}^2 = 4.733 \text{ N/mm}^2$$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress

$$v_{c_heel} = 0.482 \text{ N/mm}^2$$

$v_{heel} < v_{c_heel}$ - No shear reinforcement required

Design of reinforced concrete retaining wall downstand (BS 8002:1994)

Material properties

Characteristic strength of concrete

$$f_{cu} = 35 \text{ N/mm}^2$$

Characteristic strength of reinforcement

$$f_y = 500 \text{ N/mm}^2$$

Base details

Minimum area of reinforcement

$$k = 0.13 \%$$

Cover to reinforcement in downstand

$$c_{ds} = 40 \text{ mm}$$

Calculate shear for downstand design

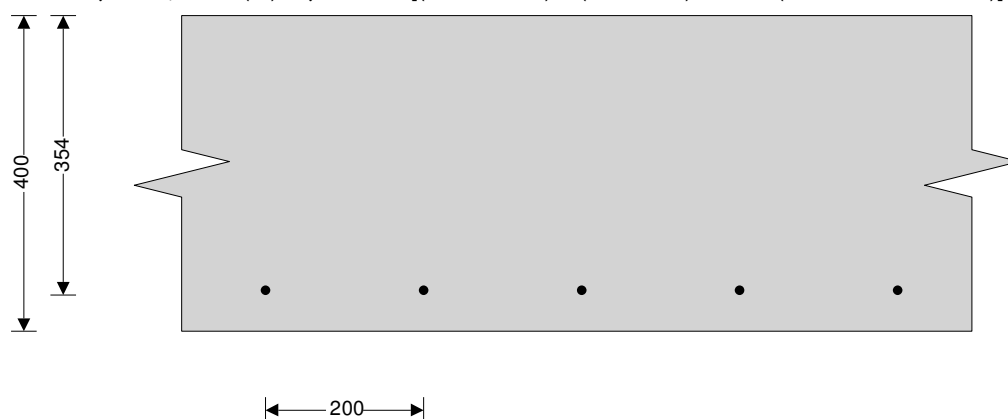
Total shear for downstand design

$$V_{down} = \gamma_{t_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times (d_{cover} + t_{base} + d_{ds} / 2) = 51 \text{ kN/m}$$

Calculate moment for downstand design

Total moment for downstand design

$$M_{down} = \gamma_{t_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times [(d_{cover} + t_{base}) \times (t_{base} + d_{ds}) + d_{ds} \times (t_{base} / 2 + 2 \times d_{ds} / 3)] / 2 = 23.7 \text{ kNm/m}$$



Check downstand in bending

Width of downstand

$$b = 1000 \text{ mm/m}$$

Depth of reinforcement

$$d_{down} = t_{ds} - c_{ds} - (\phi_{down} / 2) = 354.0 \text{ mm}$$

Constant

$$K_{down} = M_{down} / (b \times d_{down}^2 \times f_{cu}) = 0.005$$

Compression reinforcement is not required

Lever arm

$$z_{down} = \text{Min}(0.5 + \sqrt{(0.25 - (\min(K_{down}, 0.225) / 0.9))}, 0.95) \times d_{down}$$

$$z_{down} = 336 \text{ mm}$$

Area of tension reinforcement required

$$A_{s_down_des} = M_{down} / (0.87 \times f_y \times z_{down}) = 162 \text{ mm}^2/\text{m}$$

Minimum area of tension reinforcement

$$A_{s_down_min} = k \times b \times t_{ds} = 520 \text{ mm}^2/\text{m}$$

Area of tension reinforcement required

$$A_{s_down_req} = \text{Max}(A_{s_down_des}, A_{s_down_min}) = 520 \text{ mm}^2/\text{m}$$

Reinforcement provided

12 mm dia.bars @ 200 mm centres

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Area of reinforcement provided

$$A_{s_down_prov} = 565 \text{ mm}^2/\text{m}$$

PASS - Reinforcement provided at the retaining wall downstand is adequate

Check shear resistance at downstand

Design shear stress

$$v_{down} = V_{down} / (b \times d_{down}) = 0.144 \text{ N/mm}^2$$

Allowable shear stress

$$v_{adm} = \min(0.8 \times \sqrt{f_{cu}} / 1 \text{ N/mm}^2, 5) \times 1 \text{ N/mm}^2 = 4.733 \text{ N/mm}^2$$

PASS - Design shear stress is less than maximum shear stress

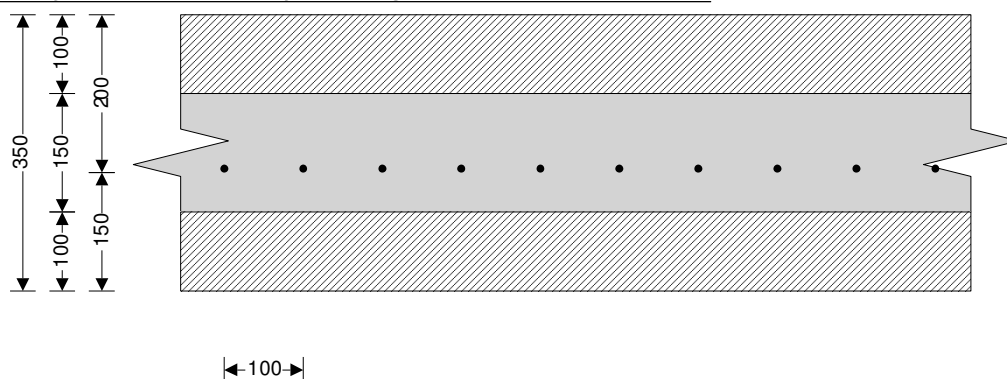
From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress

$$v_{c_down} = 0.396 \text{ N/mm}^2$$

$v_{down} < v_{c_down}$ - No shear reinforcement required

Design of cavity reinforced masonry retaining wall stem - BS5628-2:2000



Wall details

Thickness of outer leaf of wall

$$t_{outer} = 100 \text{ mm}$$

Thickness of inner leaf of wall

$$t_{inner} = 100 \text{ mm}$$

Thickness of reinforced cavity

$$t_{cavity} = t_{wall} - t_{outer} - t_{inner} = 150 \text{ mm}$$

Depth of stem reinforcement

$$d_{stem} = 200 \text{ mm}$$

Masonry details

Masonry type

Aggregate concrete blocks no voids

Compressive strength of units

$$p_{unit} = 7.3 \text{ N/mm}^2$$

Mortar designation

(ii)

Category of manufacturing control of units

Category II

Partial safety factor for material strength

$$\gamma_{mm} = 2.3$$

Characteristic compressive strength of masonry

Least horizontal dimension of masonry units

$$b_{unit} = 100.0 \text{ mm}$$

Height of masonry units

$$h_{unit} = 215.0 \text{ mm}$$

Ratio of height to least horizontal dimension

$$\text{ratio} = h_{unit} / b_{unit} = 2.2$$

From BS5628:2 Table 3d, mortar ii

Characteristic compressive strength

$$f_k = 6.4 \text{ N/mm}^2$$

Factored horizontal at-rest forces on stem

Surcharge

$$F_{s_sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = 3.1 \text{ kN/m}$$

Moist backfill above water table

$$F_{s_m_a_f} = 0.5 \times \gamma_{f_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = 36.8 \text{ kN/m}$$

Calculate shear for stem design

Shear at base of stem

$$V_{stem} = F_{s_sur_f} + F_{s_m_a_f} = 39.8 \text{ kN/m}$$

Calculate moment for stem design

Surcharge

$$M_{s_sur} = F_{s_sur_f} \times (h_{stem} + t_{base}) / 2 = 3.8 \text{ kNm/m}$$

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Moist backfill above water table

$$M_{s_m_a} = F_{s_m_a_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = \mathbf{32.4 \text{ kNm/m}}$$

Total moment for stem design

$$M_{stem} = M_{s_sur} + M_{s_m_a} = \mathbf{36.2 \text{ kNm/m}}$$

Check maximum design moment for wall stem

Width of wall

$$b = \mathbf{1000 \text{ mm/m}}$$

Maximum design moment

$$M_{d_stem} = 0.4 \times f_k \times b \times d_{stem}^2 / \gamma_{mm} = \mathbf{44.5 \text{ kNm/m}}$$

PASS - Applied moment is less than maximum design moment

Check wall stem in bending

Moment of resistance factor

$$Q = M_{stem} / d_{stem}^2 = \mathbf{0.905 \text{ N/mm}^2}$$

$$Q = 2 \times c \times (1 - c) \times f_k / \gamma_{mm}$$

Lever arm factor

$$c = \mathbf{0.795}$$

Lever arm

$$Z_{stem} = \min(0.95, c) \times d_{stem} = \mathbf{159.1 \text{ mm}}$$

Area of tension reinforcement required

$$A_{s_stem_des} = M_{stem} \times \gamma_{ms} / (f_y \times Z_{stem}) = \mathbf{524 \text{ mm}^2/\text{m}}$$

Minimum area of tension reinforcement

$$A_{s_stem_min} = k \times b \times t_{wall} = \mathbf{455 \text{ mm}^2/\text{m}}$$

Area of tension reinforcement required

$$A_{s_stem_req} = \text{Max}(A_{s_stem_des}, A_{s_stem_min}) = \mathbf{524 \text{ mm}^2/\text{m}}$$

Reinforcement provided

B785 mesh

Area of reinforcement provided

$$A_{s_stem_prov} = \pi \times \phi_{stem}^2 / (4 \times s_{stem}) = \mathbf{785 \text{ mm}^2/\text{m}}$$

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress

$$V_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.199 \text{ N/mm}^2}$$

Basic characteristic shear strength of masonry

$$f_{vbas} = \min[0.35 + (17.5 \times A_{s_stem_prov} / (b \times d_{stem})), 0.7] \times 1 \text{ N/mm}^2$$

$$f_{vbas} = \mathbf{0.419 \text{ N/mm}^2}$$

Shear span

$$a = M_{stem} / V_{stem} = \mathbf{909.1 \text{ mm}}$$

Characteristic shear strength of masonry

$$f_v = \text{Min}(f_{vbas} \times \max(2.5 - 0.25 \times (a / d_{stem}), 1), 1.75 \text{ N/mm}^2)$$

$$f_v = \mathbf{0.571 \text{ N/mm}^2}$$

Allowable shear stress

$$V_{adm} = f_v / \gamma_{mv} = \mathbf{0.285 \text{ N/mm}^2}$$

PASS - Design shear stress is less than maximum shear stress

Check limiting dimensions

Limiting span/effective depth ratio

$$\text{ratio}_{max} = \mathbf{18.00}$$

Actual span/effective depth ratio

$$\text{ratio}_{act} = (h_{stem} + d_{stem} / 2) / d_{stem} = \mathbf{11.50}$$

PASS - Span to depth ratio is acceptable

Axial load check

Factored axial load on wall

$$N_{wall} = ([t_{wall} \times h_{stem} \times \gamma_{wall} + W_{dead}] \times \gamma_{f_d}) + (W_{live} \times \gamma_{f_l}) = \mathbf{25.4 \text{ kN/m}}$$

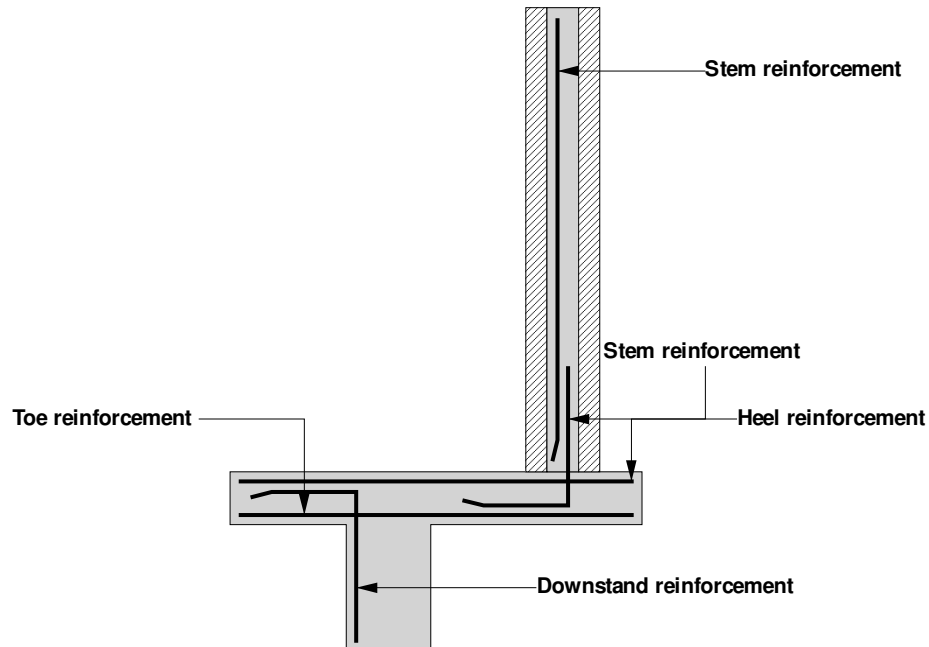
Limiting axial load

$$N_{limit} = 0.1 \times f_k \times t_{wall} = \mathbf{224.0 \text{ kN/m}}$$

Applied axial load may be ignored - calculations valid

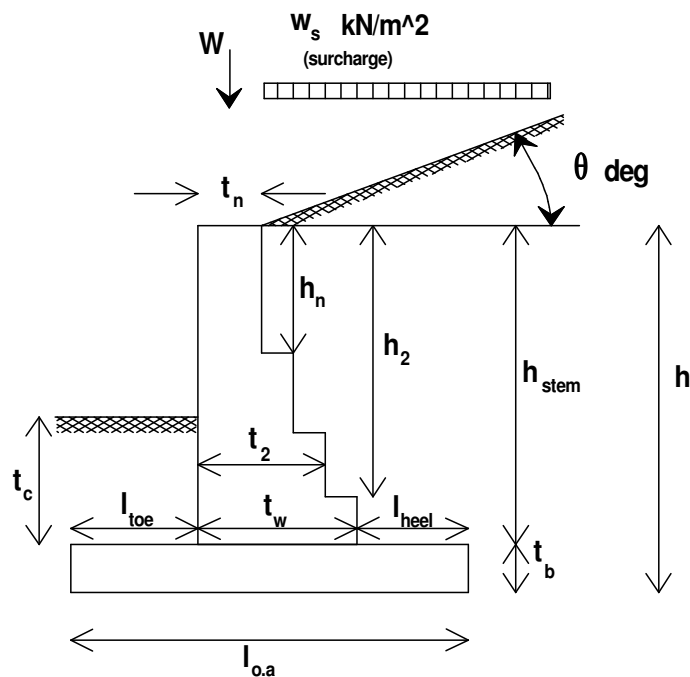
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Indicative retaining wall reinforcement diagram



Toe mesh - B785 - (785 mm²/m)
 Heel mesh - A393 - (393 mm²/m)
 Downstand bars - 12 mm dia.@ 200 mm centres - (565 mm²/m)
 Stem mesh - B785 - (785 mm²/m)

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CANTILEVER MASONRY RETAINING WALL DESIGN (BS8110&BS5628) MASONRY CANTILEVER RETAINING WALL DESIGN TO CP2 & BS5628 (PART 1)

RETAINING WALL PRESSURES - GRANULAR FILL - NO WALL FRICTION – ASSUMED FULLY DRAINED

General Soil Data

Density of retained soil	$\gamma_s = 19.0 \text{ kN/m}^3$
Angle of internal friction	$\phi = 37.0^\circ$
Angle of soil surface	$\theta = 0.0^\circ$
Ground cover over base at front of wall – if > 0mm, assumed permanent	$t_c = 200 \text{ mm}$

Loads on wall and ground

Surcharge load (horizontal plan area)	$w_s = 2.5 \text{ kN/m}^2$
Design vertical dead load on wall (unfactored)	$W_v = 0.00 \text{ kN/m}$
Design vertical live load on wall (unfactored)	$W_l = 0.00 \text{ kN/m}$

Stem details

Density of wall stem brickwork	$\gamma_w = 19.0 \text{ kN/m}^3$
Wall base section thickness	$t_w = 440.0 \text{ mm}$
Height retained	$h = 850 \text{ mm}$

Base details

Density of wall base	$\gamma_b = 23.6 \text{ kN/m}^3$
Length of heel	$l_{heel} = 150 \text{ mm}$

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Length of toe $l_{toe} = 150 \text{ mm}$

Base thickness $t_b = 150 \text{ mm}$

Length of base $l_{o_a} = l_{toe} + t_w + l_{heel} = 740 \text{ mm}$

Height of active soil (at back of stem and heel)

Height of wall stem $h_{stem} = h - t_b = 700 \text{ mm}$

$h_{soil} = h + l_{heel} \times \tan(\theta) = 850 \text{ mm}$

Load factors

Dead Load Factor $\gamma_{f_d} = 1.40$

Imposed Load Factor $\gamma_{f_i} = 1.60$

Coefficients using Rankine

Active coefficient (Sloping Surface) - no friction

$$k_{a_s} = (\cos(\theta) - \sqrt{((\cos(\theta))^2 - (\cos(\phi))^2)}) / (\cos(\theta) + \sqrt{((\cos(\theta))^2 - (\cos(\phi))^2)}) = 0.249$$

Active coefficient (level surface)

$$k_a = (1 - \sin(\phi)) / (1 + \sin(\phi)) = 0.249$$

Passive coefficient (level surface)

$$k_p = (1 + \sin(\phi)) / (1 - \sin(\phi)) = 4.023$$

At - rest coefficient

$$k_o = (1 - \sin(\phi)) = 0.398$$

For a one metre width - (Horizontal Components - Active Earth Pressures)

At the virtual back of the wall (back of heel)

Surcharge

pressure $p_s = k_{a_s} \times w_s = 0.6 \text{ kN/m}^2$

force – horizontal $F_s = (p_s \times h_{soil}) \times (\cos(\theta))^2 = 0.5 \text{ kN/m}$

overturning moment about toe $M_s = F_s \times h_{soil} / 2 = 0.2 \text{ kNm/m}$

Backfill

pressure $p_a = k_{a_s} \times \gamma_s \times h_{soil} = 4.0 \text{ kN/m}^2$

force – horizontal $F_a = (p_a \times h_{soil} / 2) \times (\cos(\theta))^2 = 1.7 \text{ kN/m}$

overturning moment about the toe $M_a = F_a \times h_{soil} / 3 = 0.5 \text{ kNm/m}$

Total horizontal force (unfactored)

$$F_t = F_s + F_a = 2.2 \text{ kN/m}$$

Total horizontal force (factored)

$$F_{t_ult} = \gamma_{f_i} \times F_s + \gamma_{f_d} \times F_a = 3.2 \text{ kN/m}$$

Total overturning moment (unfactored)

$$M_t = M_s + M_a = 0.7 \text{ kNm/m}$$

Total overturning moment (factored)

$$M_{t_ult} = \gamma_{f_i} \times M_s + \gamma_{f_d} \times M_a = 1.0 \text{ kNm/m}$$

Average load factor

$$\gamma_{f_av} = M_{t_ult} / M_t = 1.46$$

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STABILITY CHECKS

(Unfactored Loads - Active Soil Pressures)

1) SLIDING

Coefficient of friction $\mu = \tan(\phi) \times \text{factor} = 0.565$ factor = **0.75**

Passive pressures in front of wall

Top of base $pp_1 = k_p \times t_c \times \gamma_s = 15.3 \text{ kN/m}^2$

Underside of base $pp_2 = k_p \times (t_c + t_b) \times \gamma_s = 26.8 \text{ kN/m}^2$

Total resistance

Base $PP_{\text{base}} = (pp_1 + pp_2) \times t_b / 2 = 3.2 \text{ kN/m}$

Passive resistance **Soil in front of wall assumed to resist sliding**

$P = PP_{\text{base}} \times \text{soil_resists} = 3.2 \text{ kN/m}$

Factor of safety against sliding

Factor of safety required $FOS_{\text{reqd sliding}} = 2.00$

Length of heel provided $l_{\text{heel}} = 150 \text{ mm}$

Conservatively, it is assumed that the surcharge load does not provide downward pressure on the heel in the sliding calculation.

$FOS_{\text{sliding}} = (((l_{\text{heel}} \times (\gamma_s \times (h_{\text{stem}} + l_{\text{heel}} \times \tan(\theta)/2) + \gamma_b \times t_b)) + l_{\text{toe}} \times \gamma_b \times t_b + W_v + (t_w \times (\gamma_w \times h_{\text{stem}} + \gamma_b \times t_b))) \times \mu) + P) / F_t$

$FOS_{\text{sliding}} = 4.058$

Factor of safety against sliding = 4.1 i.e. > 2.0 - OK

2) OVERTURNING

Factor of safety against overturning

Factor of safety required $FOS_{\text{reqd o_turn}} = 2.00$

Length of toe provided $l_{\text{toe}} = 150 \text{ mm}$

Conservatively, it is assumed that the surcharge load does not provide downward pressure on the heel in the overturning calculation.

Taking Moments about front of the toe

$M_{r1} = (W_v + h_{\text{stem}} \times t_w \times \gamma_w) \times (l_{\text{toe}} + t_w / 2) = 2.2 \text{ kNm/m}$

$M_{r2} = l_{\text{heel}} \times h_{\text{stem}} \times \gamma_s \times (l_{\text{toe}} + t_w + l_{\text{heel}} / 2) = 1.3 \text{ kNm/m}$

$M_{r3} = (l_{\text{toe}} + t_w + l_{\text{heel}})^2 \times t_b \times \gamma_b / 2 = 1.0 \text{ kNm/m}$

$M_{r4} = l_{\text{heel}} \times l_{\text{heel}} \times \tan(\theta) / 2 \times \gamma_s \times (l_{\text{toe}} + t_w + l_{\text{heel}} \times 2/3) = 0.0 \text{ kNm/m}$

Resisting moment $M_r = M_{r1} + M_{r2} + M_{r3} + M_{r4} = 4.5 \text{ kNm/m}$

Factor of safety against overturning $FOS_{\text{o_turn}} = M_r / \text{abs}(M_t) = 6.30$

Factor of safety against overturning = 6.3 i.e. > 2.0 - OK

Overall length of base $l_{\text{o_a}} = l_{\text{toe}} + t_w + l_{\text{heel}} = 0.740 \text{ m}$

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3) BEARING PRESSURE (INCLUDING LIVE LOADS AND TOE COVER)

Total overturning moment for bearing calculation $M_t = 0.7 \text{ kNm/m}$

Total resisting moment for bearing calculation $M_r = 4.5 \text{ kNm/m}$

Total vertical load on base

$$N = t_w \times h_{\text{stem}} \times \gamma_w + (h_{\text{stem}} + l_{\text{heel}} \times \tan(\theta)/2) \times l_{\text{heel}} \times \gamma_s + t_c \times l_{\text{toe}} \times \gamma_s + l_{o_a} \times t_b \times \gamma_b + W_v + w_s \times l_{\text{heel}} + W_l$$

$$N = 11.4 \text{ kN/m}$$

Eccentricity of vertical load

$$e_1 = (M_r - \text{abs}(M_t) + t_c \times l_{\text{toe}}^2 \times \gamma_s/2 + w_s \times l_{\text{heel}} \times (l_{\text{toe}} + t_w + l_{\text{heel}}/2) + W_l \times (l_{\text{toe}} + t_w/2)) / N = 0.354 \text{ m}$$

$$e = l_{o_a} / 2 - e_1 = 0.016 \text{ m}$$

Resultant lies inside middle third

Maximum bearing pressure $p_{\text{max}} = \text{if}(\text{abs}(e) < (l_{o_a}/6), \sigma_{\text{max}2}, \sigma_{\text{max}1}) = 17.4 \text{ kN/m}^2$

Permissible bearing pressure $p_{\text{bearing}} = 75 \text{ kN/m}^2$

Maximum bearing pressure is 17 kN/m² i.e. < Allowable - OK

DESIGN BASE PRESSURES BASED UPON AT REST EARTH PRESSURES

For a one metre width - (Horizontal Components - At Rest Earth Pressures)

Surcharge

pressure $p_{s0} = k_o \times w_s = 1.0 \text{ kN/m}^2$

force $F_{s0} = p_{s0} \times h = 0.8 \text{ kN/m}$

moment $M_{s0} = F_{s0} \times h / 2 = 0.4 \text{ kNm/m}$

Backfill

pressure $p_o = k_o \times \gamma_s \times h = 6.4 \text{ kN/m}^2$

force $F_o = p_o \times h / 2 = 2.7 \text{ kN/m}$

moment $M_o = F_o \times h / 3 = 0.8 \text{ kNm/m}$

Total horizontal force (unfactored) $F_{t_o} = F_{s0} + F_o = 3.6 \text{ kN/m}$

Total horizontal force (factored) $F_{t_ult_o} = \gamma_{f_i} \times F_{s0} + \gamma_{f_d} \times F_o = 5.2 \text{ kN/m}$

Total moment (unfactored) $M_{t_o} = M_{s0} + M_o = 1.1 \text{ kNm/m}$

Total horizontal force (factored) $M_{t_ult_o} = \gamma_{f_i} \times M_{s0} + \gamma_{f_d} \times M_o = 1.7 \text{ kNm/m}$

Average load factor $\gamma_{f_av} = M_{t_ult_o} / M_{t_o} = 1.46$

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Total vertical load on base

$$N = t_w \times h_{\text{stem}} \times \gamma_w + (h_{\text{stem}} + l_{\text{heel}} \times \tan(\theta) / 2) \times l_{\text{heel}} \times \gamma_s + t_c \times l_{\text{toe}} \times \gamma_s + l_{o_a} \times t_b \times \gamma_b + W_v + W_s \times l_{\text{heel}} + W_l$$

$$N = 11.4 \text{ kN/m}$$

Total resistance moment (no live loads included or toe cover)

$$M_r = 4.461 \text{ kNm/m}$$

Eccentricity of vertical load

$$e_1 = (M_r - M_{t_o} + t_c \times l_{\text{toe}}^2 \times \gamma_s / 2 + W_s \times l_{\text{heel}} \times (l_{\text{toe}} + t_w + l_{\text{heel}} / 2) + W_l \times (l_{\text{toe}} + t_w / 2)) / N = 0.317 \text{ m}$$

$$e = l_{o_a} / 2 - e_1 = 0.053 \text{ m}$$

Resultant lies inside middle third

1) Resultant outside middle third **This Section is Invalid as Resultant is within Middle Third**

$$\sigma_{\text{max}1} = (2 \times N) / (3 \times (l_{o_a} / 2 - \text{abs}(e))) = 24 \text{ kN/m}^2$$

$$l_{b1} = (N \times 2 / \sigma_{\text{max}1}) = 0.951 \text{ m}$$

2) Resultant inside middle third

$$\sigma_{\text{max}2} = N / l_{o_a} + 6 \times N \times \text{abs}(e) / l_{o_a}^2 = 22 \text{ kN/m}^2$$

$$\sigma_{\text{min}2} = N / l_{o_a} - 6 \times N \times \text{abs}(e) / l_{o_a}^2 = 9 \text{ kN/m}^2$$

$$l_{b2} = l_{o_a} = 0.740 \text{ m}$$

Pressures under the base

$$\sigma_{\text{max}} = \text{if}(\text{abs}(e) < l_{o_a} / 6, \sigma_{\text{max}2}, \sigma_{\text{max}1}) = 22.0 \text{ kN/m}^2$$

$$\sigma_{\text{min}} = \text{if}(\text{abs}(e) < l_{o_a} / 6, \sigma_{\text{min}2}, 0 \text{ kN/m}^2) = 8.8 \text{ kN/m}^2$$

$$\text{Bearing length } l_p = \text{if}(\text{abs}(e) < (l_{o_a} / 6), l_{b2}, l_{b1}) = 0.740 \text{ m}$$

Pressures under the heel/stem interface

$$l_{p_heel} = l_p - l_{\text{toe}} - t_w = 0.150 \text{ m}$$

$$\sigma_{\text{heel}} = \max(((\sigma_{\text{max}} - \sigma_{\text{min}}) \times l_{p_heel} / l_p) + \sigma_{\text{min}}, 0 \text{ kN/m}^2) = 11.5 \text{ kN/m}^2$$

Pressures under the toe/stem interface

$$\sigma_{\text{toe}} = ((\sigma_{\text{max}} - \sigma_{\text{min}}) \times (l_{p_heel} + t_w) / l_p) + \sigma_{\text{min}} = 19.3 \text{ kN/m}^2$$

BASE DESIGN - HEEL

Shears and Moments

$$\text{Vertical load downward } W_{\text{ult_heel}} = (h_{\text{stem}} \times \gamma_s + \gamma_b \times t_b) \times \gamma_{t_d} + W_s \times \gamma_{t_i} = 27.6 \text{ kN/m}^2$$

$$W_{\text{ult_heel}1} = (l_{\text{heel}} \times \tan(\theta) / 2 \times \gamma_s) \times \gamma_{t_d} = 0.0 \text{ kN/m}^2$$

Ultimate Shear (at wall face)

$$\text{downward } V_{\text{ult_pos_heel}} = (W_{\text{ult_heel}} + W_{\text{ult_heel}1}) \times l_{\text{heel}} = 4.1 \text{ kN/m}$$

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upward

$$V_{ult_neg_heel} = (\sigma_{min} \times \max(l_{p_heel}, 0 \text{ mm}) + (\sigma_{heel} - \sigma_{min}) \times (\max(l_{p_heel}, 0 \text{ mm}))^2 / (2 \times l_{p_heel})) \times \gamma_{f_av}$$

$$V_{ult_neg_heel} = \mathbf{2.2 \text{ kN/m}}$$

Nett Ultimate Shear

$$V_{ult_heel} = \text{abs}(V_{ult_pos_heel} - V_{ult_neg_heel}) = \mathbf{1.9 \text{ kN/m}}$$

Ultimate Moment (at centre of wall)

$$\text{clockwise } M_{ult_pos_heel} = w_{ult_heel} \times l_{heel} \times (l_{heel} + t_w) / 2 + w_{ult_heel1} \times l_{heel} \times (2 \times l_{heel} / 3 + t_w / 2) = \mathbf{1.2 \text{ kNm/m}}$$

anticlockwise

$$M_{ult_neg_heel} = ((\sigma_{min} \times l_{p_heel} \times (l_{p_heel} + t_w) / 2) + (\sigma_{heel} - \sigma_{min}) / 2 \times l_{p_heel} \times (l_{p_heel} / 3 + t_w / 2)) \times \gamma_{f_av}$$

$$M_{ult_neg_heel} = \mathbf{0.7 \text{ kNm/m}}$$

Nett Ultimate Moment

$$M_{ult_heel} = \text{abs}(M_{ult_pos_heel} - M_{ult_neg_heel}) = \mathbf{0.6 \text{ kNm/m}}$$

HEEL REINFORCEMENT - MESH

Tension Reinforcement

Cover to bars in the top of the heel

$$C_{r_heel} = \mathbf{35 \text{ mm}}$$

Effective depth to bars

$$d_{heel} = t_b - C_{r_heel} - (6 \text{ mm}) = \mathbf{109 \text{ mm}}$$

Assume the base is a cantilevered slab

Characteristic strength of reinforcement

$$f_y = \mathbf{460 \text{ N/mm}^2}$$

Characteristic strength of concrete

$$f_{cu} = \mathbf{35 \text{ N/mm}^2}$$

Area of reinforcement required

$$K_{heel} = \text{abs}(M_{ult_heel}) / (d_{heel}^2 \times f_{cu}) = \mathbf{0.001} \quad K' = 0.156$$

Compression steel not required

Lever arm

$$z_{heel} = \min((0.95 \times d_{heel}), (d_{heel} \times (0.5 + \sqrt{(0.25 - K_{heel} / 0.9)}))) = \mathbf{104 \text{ mm}}$$

Reinforcement required

$$A_{s_heel} = \text{abs}(M_{ult_heel}) / (1 / \gamma_{ms} \times f_y \times z_{heel}) = \mathbf{13 \text{ mm}^2/\text{m}}$$

Minimum reinforcement $A_{s_min_heel} = \text{if}(f_y == 460 \text{ N/mm}^2, 0.0013 \times t_b, 0.0024 \times t_b) = \mathbf{195 \text{ mm}^2/\text{m}}$

$$A_{s_req_heel} = \max(A_{s_heel}, A_{s_min_heel}) = \mathbf{195 \text{ mm}^2/\text{m}}$$

Tension steel provided

$$\text{Use A252 Mesh } A_{s_prov_heel} = A_{sl_heel} = \mathbf{252 \text{ mm}^2/\text{m}}$$

Area of main tension steel provided in heel sufficient

Heel - Check min and max areas of steel

Total area of concrete

$$A_c = t_b = \mathbf{150000 \text{ mm}^2/\text{m}}$$

Minimum percentage area of reinforcement $k = \mathbf{0.13 \%}$

Minimum area of steel required

$$A_{s_min} = k \times A_c = \mathbf{195 \text{ mm}^2/\text{m}}$$

Maximum area of steel allowed

$$A_{s_max} = 4 \% \times A_c = \mathbf{6000 \text{ mm}^2/\text{m}}$$

Area of main steel provided OK

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Heel Distribution Steel

Minimum percentage of distribution reinforcement $k_1 = 0.13 \%$

Minimum Area Required $A_{s_dist_req} = k_1 \times A_c = 195 \text{ mm}^2/\text{m}$

Area Provided $A_{s_dist_base} = A_{st_heel} = 252 \text{ mm}^2/\text{m}$

Area of distribution steel provided OK

CHECK OF NOMINAL COVER

Cover to outer tension reinforcement

$$C_{heel} = t_b - d_{heel} - d_{sl_heel} / 2 = 37.0 \text{ mm}$$

Permissible minimum nominal cover to all reinforcement (Table 3.4)

$$C_{min_heel} = 35 \text{ mm}$$

Cover over outer steel OK (top of heel)

HEEL SHEAR RESISTANCE – AT WALL FACE

Applied shear stress at wall face

$$v_{heel} = V_{ult_heel} / d_{heel} = 0.02 \text{ N/mm}^2$$

Check shear stress to clause 3.4.5.2 (BS8110:Pt 1)

$$V_{allowable} = \min ((0.8 \text{ N}^{1/2}/\text{mm}) \times \sqrt{f_{cu}}, 5 \text{ N/mm}^2) = 4.73 \text{ N/mm}^2$$

Shear stress < maximum - OK

Shear stresses to clause 3.4.5.4 (BS8110:Pt1)

Allowable shear stress

$$V_c_{heel} = 0.60 \text{ N/mm}^2$$

No shear reinforcement required

BASE DESIGN - TOE

Shears and Moments

Conservatively all soil overburden on the toe is ignored

Ultimate Shear (conservatively - at face of wall)

$$V_{ult_toe} = ((\sigma_{toe} \times l_{toe}) + (((\sigma_{max} - \sigma_{toe}) / 2) \times l_{toe})) \times \gamma_{f_av} - l_{toe} \times t_b \times \gamma_b \times \gamma_{f_d} = 3.8 \text{ kN/m}$$

Ultimate Moment (at centre of wall)

$$M_{ult_toe} = ((\sigma_{toe} \times l_{toe} \times (l_{toe} + t_w)/2) + ((\sigma_{max} - \sigma_{toe})/2 \times l_{toe} \times (2 \times l_{toe}/3 + t_w/2))) \times \gamma_{f_av} - l_{toe} \times t_b \times \gamma_b \times \gamma_{f_d} \times (l_{toe}/2 + t_w/2)$$

$$M_{ult_toe} = 1.1 \text{ kNm/m}$$

TOE REINFORCEMENT - MESH

Tension Reinforcement

Cover to bars in the bottom of the toe $C_{r_toe} = 35 \text{ mm}$

Effective depth to bars $d_{toe} = t_b - C_{r_toe} - (6\text{mm}) = 109 \text{ mm}$

Assume the base is a cantilevered slab

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Characteristic strength of reinforcement $f_y = 460 \text{ N/mm}^2$

Characteristic strength of concrete $f_{cu} = 35 \text{ N/mm}^2$

Area of reinforcement required

$$K_{toe} = \text{abs}(M_{ult_toe}) / (d_{toe}^2 \times f_{cu}) = 0.003 \quad K' = 0.156$$

Compression steel not required

Lever arm $z_{toe} = \min((0.95 \times d_{toe}), (d_{toe} \times (0.5 + \sqrt{(0.25 - K_{toe}/0.9)}))) = 104 \text{ mm}$

Reinforcement required $A_{s_toe} = \text{abs}(M_{ult_toe}) / (1/\gamma_{ms} \times f_y \times z_{toe}) = 25 \text{ mm}^2/\text{m}$

Minimum reinforcement $A_{s_min_toe} = \text{if}(f_y == 460 \text{ N/mm}^2, 0.0013 \times t_b, 0.0024 \times t_b) = 195 \text{ mm}^2/\text{m}$

$A_{s_req_toe} = \max(A_{s_toe}, A_{s_min_toe}) = 195 \text{ mm}^2/\text{m}$

Tension steel provided

Use A252 Mesh $A_{s_prov_toe} = A_{sl_toe} = 252 \text{ mm}^2/\text{m}$

Area of main tension steel provided in toe sufficient

Toe - Check min and max areas of steel

Total area of concrete $A_c = t_b = 150000 \text{ mm}^2/\text{m}$

Minimum percentage area of reinforcement $k = 0.13 \%$

Minimum area of steel required $A_{s_min} = k \times A_c = 195 \text{ mm}^2/\text{m}$

Maximum area of steel allowed $A_{s_max} = 4 \% \times A_c = 6000 \text{ mm}^2/\text{m}$

Area of main steel provided OK

Toe Distribution Steel

Minimum percentage of distribution reinforcement $k_1 = 0.13 \%$

Minimum Area Required $A_{s_dist_req} = k_1 \times A_c = 195 \text{ mm}^2/\text{m}$

Area Provided $A_{s_dist_base} = A_{st_toe} = 252 \text{ mm}^2/\text{m}$

Area of distribution steel provided OK

CHECK OF NOMINAL COVER

Cover to outer tension reinforcement

$$c_{toe} = t_b - d_{toe} - d_{sl_toe} / 2 = 37.0 \text{ mm}$$

Permissible minimum nominal cover to all reinforcement (Table 3.4)

$$c_{min_toe} = 35 \text{ mm}$$

Cover over outer steel OK (bottom of toe)

TOE SHEAR RESISTANCE

Applied shear stress

$$V_{toe} = V_{ult_toe} / d_{toe} = 0.03 \text{ N/mm}^2$$

Check shear stress to clause 3.4.5.2 (BS8110:Pt 1)

$$V_{allowable} = \min((0.8 \text{ N}^{1/2}/\text{mm}) \times \sqrt{f_{cu}}, 5 \text{ N/mm}^2) = 4.73 \text{ N/mm}^2$$

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Shear stress < maximum - OK

Shear stresses to clause 3.4.5.4 (BS8110:Pt 1)

Allowable shear stress

$$V_{c_toe} = 0.60 \text{ N/mm}^2$$

No shear reinforcement required

STEM DESIGN

Width of base of wall $t_w = 440.0 \text{ mm}$

Height of stem of wall $h_{stem} = 700 \text{ mm}$

DESIGN OF WALL SECTION 1 (AT REST PRESSURES)

Wall base section thickness $t_w = 440.0 \text{ mm}$

Depth from top of wall to base

$h_{stem} = 700 \text{ mm}$ **Warning the height of the wall is not a complete number of bricks**

Applied moment at base of section

$$M_{base} = (k_o \times w_s \times h_{stem}^2 / 2) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{stem}^3 / 6) \times \gamma_{f_d} = 1.0 \text{ kNm/m}$$

Applied shear force at base of section

$$F_{base} = (k_o \times w_s \times h_{stem}) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{stem}^2 / 2) \times \gamma_{f_d} = 3.7 \text{ kN/m}$$

CHECK RESISTANCE TO MOMENT WITHOUT FLEXURAL STRENGTH (BS5628:PT 1:CL 36.5.3)

Compressive strength (Table 2) $f_k = 6.40 \text{ N/mm}^2$

Design vertical load per unit length of wall $n_{w_base} = \gamma_{fd} \times (W_v + t_w \times h_{stem} \times \gamma_w) = 5.3 \text{ kN/m}$

Moment of resistance $M_{RC_base} = (n_{w_base} / 2) \times (t_w - (n_{w_base} \times \gamma_m / f_k)) = 1.2 \text{ kNm/m}$

Wall bending - OK

STEM SHEAR (BS5628:PT 1:CL 33)

Mortar designation Mortar = "iii"

Design dead load at the base of the wall $V_{base} = W_v + t_w \times h_{stem} \times \gamma_w = 5.85 \text{ kN/m}$

Design vertical dead load per unit area $g_{A_base} = V_{base} \times \gamma_{fd} / t_w = 0.01 \text{ N/mm}^2$

Characteristic shear strength of masonry

$$f_{v_i} = \min(1.75 \text{ N/mm}^2, 0.35 \text{ N/mm}^2 + (0.6 \times g_{A_base})) = 0.36 \text{ N/mm}^2$$

$$f_{v_iii} = \min(1.4 \text{ N/mm}^2, 0.15 \text{ N/mm}^2 + (0.6 \times g_{A_base})) = 0.16 \text{ N/mm}^2$$

$$f_v = \text{if}((\text{Mortar} == "i") || (\text{Mortar} == "ii"), f_{v_i}, f_{v_iii}) = 0.16 \text{ N/mm}^2$$

Ref BS 5628 Pt 1: Clause 25

Shear stress $V_{base} = F_{base} / t_w = 0.01 \text{ N/mm}^2$

Partial safety factor for shear $\gamma_{mv} = 2.5$

Wall base shear OK

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DESIGN OF WALL SECTION 2 (AT REST PRESSURES)

Wall section thickness $t_{wall_2} = 327.5$ mm

Depth from top of wall to base of section

$h_{wall_2} = 440$ mm **Warning the height of the section is not a complete number of bricks**

Applied moment at base of section

$$M_{wall_2} = (k_o \times w_s \times h_{wall_2}^2 / 2) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{wall_2}^3 / 6) \times \gamma_{f_d} = 0.3 \text{ kNm/m}$$

Applied shear force at base of section

$$F_{wall_2} = (k_o \times w_s \times h_{wall_2}) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{wall_2}^2 / 2) \times \gamma_{f_d} = 1.7 \text{ kN/m}$$

CHECK RESISTANCE TO MOMENT WITHOUT FLEXURAL STRENGTH (BS5628:PT 1:CL 36.5.3)

Compressive strength (Table 2) $f_k = 6.40$ N/mm²

Design vertical load per unit length of wall $n_{w_wall_2} = \gamma_{fd} \times (W_v + t_{wall_2} \times h_{wall_2} \times \gamma_w) = 2.5$ kN/m

Moment of resistance $M_{RC_wall_2} = (n_{w_wall_2} / 2) \times (t_{wall_2} - (n_{w_wall_2} \times \gamma_m / f_k)) = 0.4$ kNm/m

Wall bending - OK

STEM SHEAR (BS5628:PT 1:CL 33)

Mortar designation Mortar = "iii"

Design dead load at the base of the wall $V_{wall_2} = W_v + t_{wall_2} \times h_{wall_2} \times \gamma_w = 2.74$ kN/m

Design vertical dead load per unit area $g_{A_wall_2} = V_{wall_2} \times \gamma_{fd} / t_{wall_2} = 0.01$ N/mm²

Characteristic shear strength of masonry

$$f_{v_i} = \min(1.75 \text{ N/mm}^2, 0.35 \text{ N/mm}^2 + (0.6 \times g_{A_wall_2})) = 0.35 \text{ N/mm}^2$$

$$f_{v_iii} = \min(1.4 \text{ N/mm}^2, 0.15 \text{ N/mm}^2 + (0.6 \times g_{A_wall_2})) = 0.15 \text{ N/mm}^2$$

$$f_v = \text{if}((\text{Mortar} == "i") || (\text{Mortar} == "ii"), f_{v_i}, f_{v_iii}) = 0.15 \text{ N/mm}^2$$

Ref BS 5628 Pt 1: Clause 25

Shear stress $v_{wall_2} = F_{wall_2} / t_{wall_2} = 0.01$ N/mm²

Partial safety factor for shear $\gamma_{mv} = 2.5$

Wall section base shear OK

SUMMARY OF RESULTS

Wall Dimensions

Masonry Compressive Strength **Masonry Compressive Strength - 6.4 N/mm²**

Stem Base section **440mm thick and 700mm from base to the top of the wall**

Section 2 **328mm thick and 440mm from base of section 2 to the top of the wall**

Base Top Reinforcement - Mesh

Heel (Top) Reinforcement **Provide A252 Mesh (Top)**

Base Bottom Reinforcement - Mesh

Toe (Bottom) Reinforcement **Provide A252 Mesh (Bottom)**