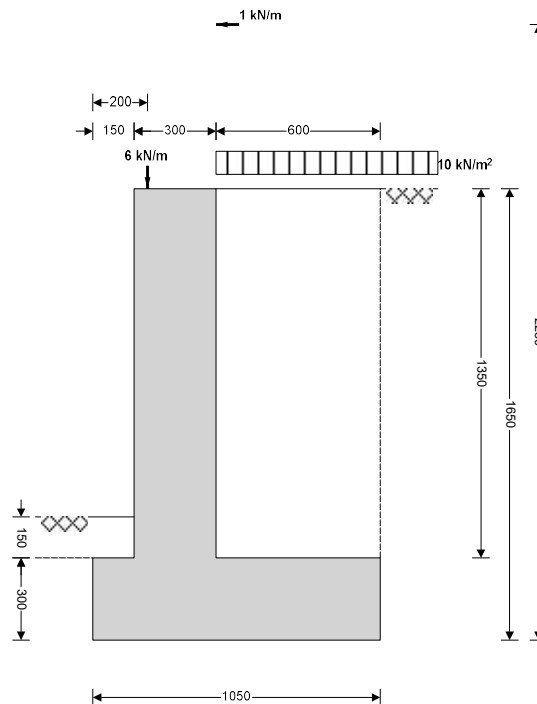


INTRODUCTION

Solutions to Structures Ltd. have been instructed to design the retaining wall to the side of the proposed parking area. The wall has been checked with allowance for the proposed stone parapet wall 900mm high.

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.09



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

$h_{\text{stem}} = 1350 \text{ mm}$
 $t_{\text{wall}} = 300 \text{ mm}$
 $l_{\text{toe}} = 150 \text{ mm}$
 $l_{\text{heel}} = 600 \text{ mm}$
 $l_{\text{base}} = l_{\text{toe}} + l_{\text{heel}} + t_{\text{wall}} = 1050 \text{ mm}$
 $t_{\text{base}} = 300 \text{ mm}$
 $d_{\text{ds}} = 0 \text{ mm}$
 $l_{\text{ds}} = 750 \text{ mm}$
 $t_{\text{ds}} = 300 \text{ mm}$
 $h_{\text{wall}} = h_{\text{stem}} + t_{\text{base}} + d_{\text{ds}} = 1650 \text{ mm}$
 $d_{\text{cover}} = 150 \text{ mm}$
 $d_{\text{exc}} = 150 \text{ mm}$
 $h_{\text{water}} = 0 \text{ mm}$
 $h_{\text{sat}} = \max(h_{\text{water}} - t_{\text{base}} - d_{\text{ds}}, 0 \text{ mm}) = 0 \text{ mm}$
 $\gamma_{\text{wall}} = 23.6 \text{ kN/m}^3$
 $\gamma_{\text{base}} = 23.6 \text{ kN/m}^3$
 $\alpha = 90.0 \text{ deg}$
 $\beta = 0.0 \text{ deg}$
 $h_{\text{eff}} = h_{\text{wall}} + l_{\text{heel}} \times \tan(\beta) = 1650 \text{ mm}$

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Retained material details

Mobilisation factor;	$M = 1.5$
Moist density of retained material;	$\gamma_m = 18.0 \text{ kN/m}^3$
Saturated density of retained material;	$\gamma_s = 21.0 \text{ kN/m}^3$
Design shear strength;	$\phi' = 24.2 \text{ deg}$
Angle of wall friction;	$\delta = 0.0 \text{ deg}$

Base material details

Moist density;	$\gamma_{mb} = 18.0 \text{ kN/m}^3$
Design shear strength;	$\phi'_b = 24.2 \text{ deg}$
Design base friction;	$\delta_b = 18.6 \text{ deg}$
Allowable bearing pressure;	$P_{\text{bearing}} = 150 \text{ kN/m}^2$

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))})^2) = 0.419$$

Passive pressure coefficient for base material

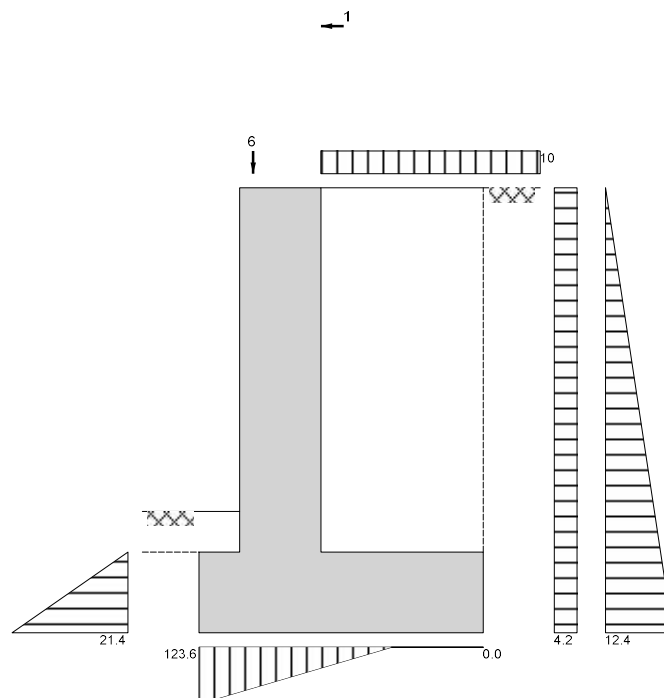
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))})^2) = 4.187$$

At-rest pressure

At-rest pressure for retained material;	$K_0 = 1 - \sin(\phi') = 0.590$
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Loading details

Surcharge load on plan;	Surcharge = 10.0 kN/m^2
Applied vertical dead load on wall;	$W_{\text{dead}} = 6.0 \text{ kN/m}$
Applied vertical live load on wall;	$W_{\text{live}} = 0.0 \text{ kN/m}$
Position of applied vertical load on wall;	$l_{\text{load}} = 200 \text{ mm}$
Applied horizontal dead load on wall;	$F_{\text{dead}} = 0.0 \text{ kN/m}$
Applied horizontal live load on wall;	$F_{\text{live}} = 0.7 \text{ kN/m}$
Height of applied horizontal load on wall;	$h_{\text{load}} = 2250 \text{ mm}$



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

Vertical forces on wall

Wall stem;

$$W_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall} = \mathbf{9.6 \text{ kN/m}}$$

Wall base;

$$W_{base} = l_{base} \times t_{base} \times \gamma_{base} = \mathbf{7.4 \text{ kN/m}}$$

Surcharge;

$$W_{sur} = \text{Surcharge} \times l_{heel} = \mathbf{6 \text{ kN/m}}$$

Moist backfill to top of wall;

$$W_{m_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = \mathbf{14.6 \text{ kN/m}}$$

Soil in front of wall;

$$W_p = l_{toe} \times d_{cover} \times \gamma_{mb} = \mathbf{0.4 \text{ kN/m}}$$

Applied vertical load;

$$W_v = W_{dead} + W_{live} = \mathbf{6 \text{ kN/m}}$$

Total vertical load;

$$W_{total} = W_{wall} + W_{base} + W_{sur} + W_{m_w} + W_p + W_v = \mathbf{44 \text{ kN/m}}$$

Horizontal forces on wall

Surcharge;

$$F_{sur} = K_a \times \text{Surcharge} \times h_{eff} = \mathbf{6.9 \text{ kN/m}}$$

Moist backfill above water table;

$$F_{m_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2 = \mathbf{10.3 \text{ kN/m}}$$

Applied horizontal load;

$$F_h = F_{dead} + F_{live} = \mathbf{0.7 \text{ kN/m}}$$

Total horizontal load;

$$F_{total} = F_{sur} + F_{m_a} + F_h = \mathbf{17.9 \text{ kN/m}}$$

Calculate stability against sliding

Passive resistance of soil in front of wall;

$$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = \mathbf{3.2 \text{ kN/m}}$$

Resistance to sliding;

$$F_{res} = F_p + W_{total} \times \tan(\delta_b) = \mathbf{18.0 \text{ kN/m}}$$

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge;

$$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 = \mathbf{5.7 \text{ kNm/m}}$$

Moist backfill above water table;

$$M_{m_a} = F_{m_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = \mathbf{5.6 \text{ kNm/m}}$$

Applied horizontal load;

$$M_{hor} = F_h \times h_{load} = \mathbf{1.7 \text{ kNm/m}}$$

Total overturning moment;

$$M_{ot} = M_{sur} + M_{m_a} + M_{hor} = \mathbf{13 \text{ kNm/m}}$$

Restoring moments

Wall stem;

$$M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2) = \mathbf{2.9 \text{ kNm/m}}$$

Wall base;

$$M_{base} = W_{base} \times l_{base} / 2 = \mathbf{3.9 \text{ kNm/m}}$$

Surcharge;

$$M_{sur_r} = W_{sur} \times (l_{base} - l_{heel} / 2) = \mathbf{4.5 \text{ kNm/m}}$$

Moist backfill;

$$M_{m_r} = (W_{m_w} \times (l_{base} - l_{heel} / 2) + W_{m_s} \times (l_{base} - l_{heel} / 3)) = \mathbf{10.9 \text{ kNm/m}}$$

Soil in front of wall;

$$M_{p_r} = W_p \times l_{toe} / 2 = \mathbf{0 \text{ kNm/m}}$$

Design vertical load;

$$M_v = W_v \times l_{load} = \mathbf{1.2 \text{ kNm/m}}$$

Total restoring moment;

$$M_{rest} = M_{wall} + M_{base} + M_{sur_r} + M_{m_r} + M_{p_r} + M_v = \mathbf{23.4 \text{ kNm/m}}$$

Check stability against overturning

Total overturning moment;

$$M_{ot} = \mathbf{13.0 \text{ kNm/m}}$$

Total restoring moment;

$$M_{rest} = \mathbf{23.4 \text{ kNm/m}}$$

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Total moment for bearing;

$$M_{total} = M_{rest} - M_{ot} = \mathbf{10.4 \text{ kNm/m}}$$

Total vertical reaction;

$$R = W_{total} = \mathbf{44.0 \text{ kN/m}}$$

Distance to reaction;

$$x_{bar} = M_{total} / R = \mathbf{237 \text{ mm}}$$

Eccentricity of reaction;

$$e = \text{abs}((l_{base} / 2) - x_{bar}) = \mathbf{288 \text{ mm}}$$

Reaction acts outside middle third of base

Bearing pressure at toe;

$$p_{toe} = R / (1.5 \times x_{bar}) = \mathbf{123.6 \text{ kN/m}^2}$$

Bearing pressure at heel;

$$p_{heel} = 0 \text{ kN/m}^2 = \mathbf{0 \text{ kN/m}^2}$$

PASS - Maximum bearing pressure is less than allowable bearing pressure

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RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.09

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; $W_{wall_f} = \gamma_{f_d} \times h_{stem} \times t_{wall} \times \gamma_{wall} = 13.4 \text{ kN/m}$
Wall base; $W_{base_f} = \gamma_{f_d} \times l_{base} \times t_{base} \times \gamma_{base} = 10.4 \text{ kN/m}$
Surcharge; $W_{sur_f} = \gamma_{f_l} \times \text{Surcharge} \times l_{heel} = 9.6 \text{ kN/m}$
Moist backfill to top of wall; $W_{m_w_f} = \gamma_{f_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 20.4 \text{ kN/m}$
Soil in front of wall; $W_{p_f} = \gamma_{f_d} \times l_{toe} \times d_{cover} \times \gamma_{mb} = 0.6 \text{ kN/m}$
Applied vertical load; $W_{v_f} = \gamma_{f_d} \times W_{dead} + \gamma_{f_l} \times W_{live} = 8.4 \text{ kN/m}$
Total vertical load; $W_{total_f} = W_{wall_f} + W_{base_f} + W_{sur_f} + W_{m_w_f} + W_{p_f} + W_{v_f} = 62.8 \text{ kN/m}$

Factored horizontal at-rest forces on wall

Surcharge; $F_{sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times h_{eff} = 15.6 \text{ kN/m}$
Moist backfill above water table; $F_{m_a_f} = \gamma_{f_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2 = 20.2 \text{ kN/m}$
Applied horizontal load; $F_{h_f} = \gamma_{f_e} \times F_{dead} + \gamma_{f_l} \times F_{live} = 1.2 \text{ kN/m}$
Total horizontal load; $F_{total_f} = F_{sur_f} + F_{m_a_f} + F_{h_f} = 37 \text{ kN/m}$
Passive resistance of soil in front of wall; $F_{p_f} = \gamma_{f_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 4.5 \text{ kN/m}$

Factored overturning moments

Surcharge; $M_{sur_f} = F_{sur_f} \times (h_{eff} - 2 \times d_{ds}) / 2 = 12.9 \text{ kNm/m}$
Moist backfill above water table; $M_{m_a_f} = F_{m_a_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 11.1 \text{ kNm/m}$
Applied horizontal load; $M_{hor_f} = F_{h_f} \times h_{load} = 2.7 \text{ kNm/m}$
Total overturning moment; $M_{ot_f} = M_{sur_f} + M_{m_a_f} + M_{hor_f} = 26.6 \text{ kNm/m}$

Restoring moments

Wall stem; $M_{wall_f} = W_{wall_f} \times (l_{toe} + t_{wall} / 2) = 4 \text{ kNm/m}$
Wall base; $M_{base_f} = W_{base_f} \times l_{base} / 2 = 5.5 \text{ kNm/m}$
Surcharge; $M_{sur_r_f} = W_{sur_f} \times (l_{base} - l_{heel} / 2) = 7.2 \text{ kNm/m}$
Moist backfill; $M_{m_r_f} = (W_{m_w_f} \times (l_{base} - l_{heel} / 2) + W_{m_s_f} \times (l_{base} - l_{heel} / 3)) = 15.3 \text{ kNm/m}$
Soil in front of wall; $M_{p_r_f} = W_{p_f} \times l_{toe} / 2 = 0 \text{ kNm/m}$
Design vertical load; $M_{v_f} = W_{v_f} \times l_{load} = 1.7 \text{ kNm/m}$
Total restoring moment; $M_{rest_f} = M_{wall_f} + M_{base_f} + M_{sur_r_f} + M_{m_r_f} + M_{p_r_f} + M_{v_f} = 33.7 \text{ kNm/m}$

Factored bearing pressure

Total moment for bearing; $M_{total_f} = M_{rest_f} - M_{ot_f} = 7.1 \text{ kNm/m}$
Total vertical reaction; $R_f = W_{total_f} = 62.8 \text{ kN/m}$
Distance to reaction; $X_{bar_f} = M_{total_f} / R_f = 112 \text{ mm}$
Eccentricity of reaction; $e_f = \text{abs}((l_{base} / 2) - X_{bar_f}) = 413 \text{ mm}$

Reaction acts outside middle third of base

Bearing pressure at toe; $p_{toe_f} = R_f / (1.5 \times X_{bar_f}) = 372 \text{ kN/m}^2$
Bearing pressure at heel; $p_{heel_f} = 0 \text{ kN/m}^2 = 0 \text{ kN/m}^2$
Rate of change of base reaction; $\text{rate} = p_{toe_f} / (3 \times X_{bar_f}) = 1102.19 \text{ kN/m}^2/\text{m}$
Bearing pressure at stem / toe; $p_{stem_toe_f} = \text{max}(p_{toe_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2) = 206.6 \text{ kN/m}^2$

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Bearing pressure at mid stem;

$$p_{\text{stem_mid_f}} = \max(p_{\text{toe_f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}} / 2)), 0 \text{ kN/m}^2) = \mathbf{41.3 \text{ kN/m}^2}$$

Bearing pressure at stem / heel;

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

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

Material properties

Characteristic strength of concrete;

$$f_{\text{cu}} = \mathbf{40 \text{ N/mm}^2}$$

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;

$$V_{\text{toe_bear}} = (p_{\text{toe_f}} + p_{\text{stem_toe_f}}) \times l_{\text{toe}} / 2 = \mathbf{43.4 \text{ kN/m}}$$

Shear from weight of base;

$$V_{\text{toe_wt_base}} = \gamma_{\text{f_d}} \times \gamma_{\text{base}} \times l_{\text{toe}} \times t_{\text{base}} = \mathbf{1.5 \text{ kN/m}}$$

Total shear for toe design;

$$V_{\text{toe}} = V_{\text{toe_bear}} - V_{\text{toe_wt_base}} = \mathbf{41.9 \text{ kN/m}}$$

Calculate moment for toe design

Moment from bearing pressure;

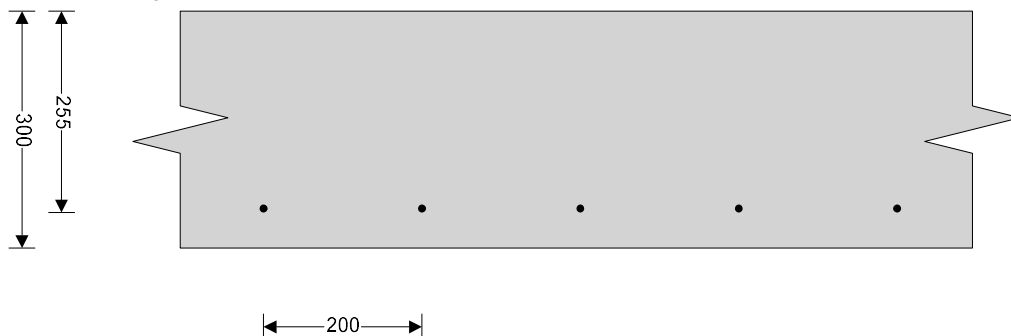
$$M_{\text{toe_bear}} = (2 \times p_{\text{toe_f}} + p_{\text{stem_mid_f}}) \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = \mathbf{11.8 \text{ kNm/m}}$$

Moment from weight of base;

$$M_{\text{toe_wt_base}} = (\gamma_{\text{f_d}} \times \gamma_{\text{base}} \times t_{\text{base}} \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2) = \mathbf{0.4 \text{ kNm/m}}$$

Total moment for toe design;

$$M_{\text{toe}} = M_{\text{toe_bear}} - M_{\text{toe_wt_base}} = \mathbf{11.3 \text{ kNm/m}}$$



Check toe in bending

Width of toe;

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

Depth of reinforcement;

$$d_{\text{toe}} = t_{\text{base}} - c_{\text{toe}} - (\phi_{\text{toe}} / 2) = \mathbf{255.0 \text{ mm}}$$

Constant;

$$K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_{\text{cu}}) = \mathbf{0.004}$$

Compression reinforcement is not required

Lever arm;

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

$$z_{\text{toe}} = \mathbf{242 \text{ mm}}$$

Area of tension reinforcement required;

$$A_{\text{s_toe_des}} = M_{\text{toe}} / (0.87 \times f_y \times z_{\text{toe}}) = \mathbf{108 \text{ mm}^2/\text{m}}$$

Minimum area of tension reinforcement;

$$A_{\text{s_toe_min}} = k \times b \times t_{\text{base}} = \mathbf{390 \text{ mm}^2/\text{m}}$$

Area of tension reinforcement required;

$$A_{\text{s_toe_req}} = \text{Max}(A_{\text{s_toe_des}}, A_{\text{s_toe_min}}) = \mathbf{390 \text{ mm}^2/\text{m}}$$

Reinforcement provided;

$$\mathbf{A393 \text{ mesh}}$$

Area of reinforcement provided;

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

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress;

$$v_{\text{toe}} = V_{\text{toe}} / (b \times d_{\text{toe}}) = \mathbf{0.164 \text{ N/mm}^2}$$

Allowable shear stress;

$$v_{\text{adm}} = \min(0.8 \times \sqrt{f_{\text{cu}} / 1 \text{ N/mm}^2}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000 \text{ N/mm}^2}$$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

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Design concrete shear stress;

$$V_{c_toe} = 0.443 \text{ N/mm}^2$$

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

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

Material properties

Characteristic strength of concrete;

$$f_{cu} = 40 \text{ N/mm}^2$$

Characteristic strength of reinforcement;

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

Base details

Minimum area of reinforcement;

$$k = 0.13 \%$$

Cover to reinforcement in heel;

$$C_{heel} = 40 \text{ mm}$$

Calculate shear for heel design

Shear from weight of base;

$$V_{heel_wt_base} = \gamma_{f_d} \times \gamma_{base} \times l_{heel} \times t_{base} = 5.9 \text{ kN/m}$$

Shear from weight of moist backfill;

$$V_{heel_wt_m} = W_{m_w_f} = 20.4 \text{ kN/m}$$

Shear from surcharge;

$$V_{heel_sur} = W_{sur_f} = 9.6 \text{ kN/m}$$

Total shear for heel design;

$$V_{heel} = V_{heel_wt_base} + V_{heel_wt_m} + V_{heel_sur} = 36 \text{ kN/m}$$

Calculate moment for heel design

Moment from weight of base;

$$M_{heel_wt_base} = (\gamma_{f_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) = 2.8 \text{ kNm/m}$$

Moment from weight of moist backfill;

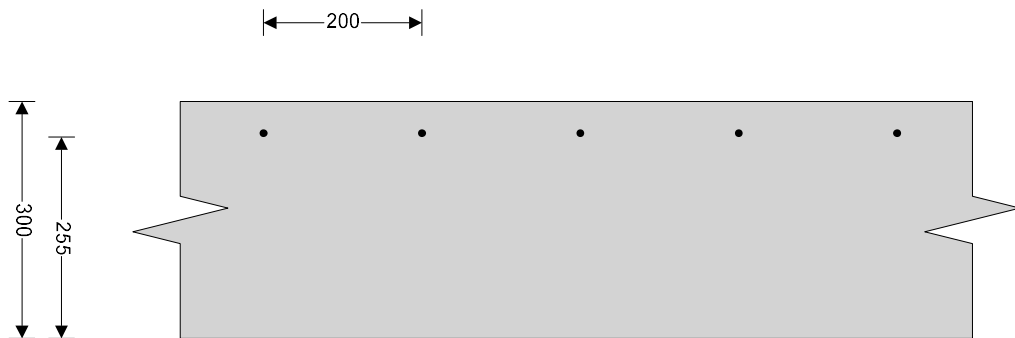
$$M_{heel_wt_m} = W_{m_w_f} \times (l_{heel} + t_{wall}) / 2 = 9.2 \text{ kNm/m}$$

Moment from surcharge;

$$M_{heel_sur} = W_{sur_f} \times (l_{heel} + t_{wall}) / 2 = 4.3 \text{ kNm/m}$$

Total moment for heel design;

$$M_{heel} = M_{heel_wt_base} + M_{heel_wt_m} + M_{heel_sur} = 16.3 \text{ kNm/m}$$



Check heel in bending

Width of heel;

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

Depth of reinforcement;

$$d_{heel} = t_{base} - C_{heel} - (\phi_{heel} / 2) = 255.0 \text{ mm}$$

Constant;

$$K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu}) = 0.006$$

Compression reinforcement is not required

Lever arm;

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

$$Z_{heel} = 242 \text{ mm}$$

Area of tension reinforcement required;

$$A_{s_heel_des} = M_{heel} / (0.87 \times f_y \times Z_{heel}) = 155 \text{ mm}^2/\text{m}$$

Minimum area of tension reinforcement;

$$A_{s_heel_min} = k \times b \times t_{base} = 390 \text{ mm}^2/\text{m}$$

Area of tension reinforcement required;

$$A_{s_heel_req} = \text{Max}(A_{s_heel_des}, A_{s_heel_min}) = 390 \text{ mm}^2/\text{m}$$

Reinforcement provided;

$$\text{A393 mesh}$$

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;

$$V_{heel} = V_{heel} / (b \times d_{heel}) = 0.141 \text{ N/mm}^2$$

Allowable shear stress;

$$V_{adm} = \min(0.8 \times \sqrt{f_{cu}} / 1 \text{ N/mm}^2, 5) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2$$

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PASS - Design shear stress is less than maximum shear stress

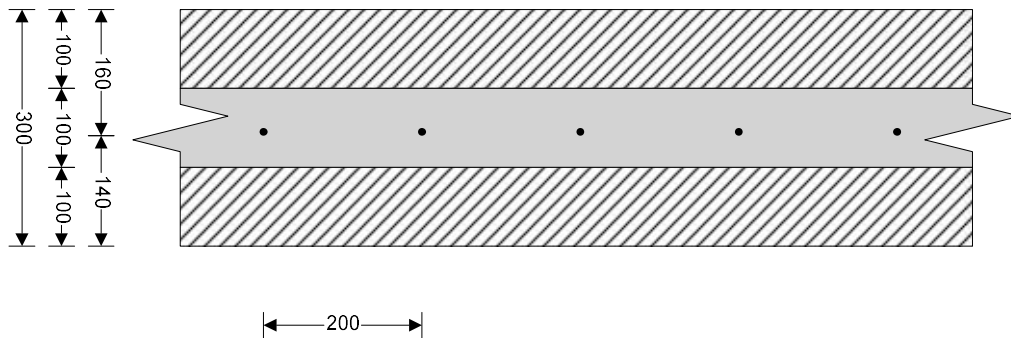
From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress;

$$V_{c_heel} = 0.443 \text{ N/mm}^2$$

$V_{heel} < V_{c_heel}$ - 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;

$$t_{cavity} = t_{wall} - t_{outer} - t_{inner} = 100 \text{ mm}$$

Depth of stem reinforcement;

$$d_{stem} = 160 \text{ mm}$$

Masonry details

Masonry type;

Aggregate concrete blocks no voids

Compressive strength of units;

$$p_{unit} = 10.0 \text{ N/mm}^2$$

Mortar designation;

(ii)

Category of manufacturing control of units;

Normal

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;

$$f_k = 8.1 \text{ N/mm}^2$$

Factored horizontal at-rest forces on stem

Surcharge;

$$F_{s_sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = 12.7 \text{ kN/m}$$

Moist backfill above water table;

$$F_{s_m_a_f} = 0.5 \times \gamma_{f_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = 13.6 \text{ kN/m}$$

Applied horizontal load;

$$F_{s_h_f} = \gamma_{f_d} \times F_{dead} + \gamma_{f_l} \times F_{live} = 1.2 \text{ kN/m}$$

Calculate shear for stem design

Shear at base of stem;

$$V_{stem} = F_{s_sur_f} + F_{s_m_a_f} + F_{s_h_f} = 27.5 \text{ kN/m}$$

Calculate moment for stem design

Surcharge;

$$M_{s_sur} = F_{s_sur_f} \times (h_{stem} + t_{base}) / 2 = 10.5 \text{ kNm/m}$$

Moist backfill above water table;

$$M_{s_m_a} = F_{s_m_a_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = 8.1 \text{ kNm/m}$$

Applied horizontal load;

$$M_{s_hor} = F_{s_h_f} \times (h_{load} - t_{base} / 2) = 2.5 \text{ kNm/m}$$

Total moment for stem design;

$$M_{stem} = M_{s_sur} + M_{s_m_a} + M_{s_hor} = 21.1 \text{ kNm/m}$$

Check maximum design moment for wall stem

Width of wall;

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

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Maximum design moment;

$$M_{d_stem} = 0.4 \times f_k \times b \times d_{stem}^2 / \gamma_{mm} = \mathbf{36.2 \text{ kNm/m}}$$

PASS - Applied moment is less than maximum design moment

Check wall stem in bending

Moment of resistance factor;

$$Q = M_{stem} / d_{stem}^2 = \mathbf{0.825 \text{ N/mm}^2}$$

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

$$c = \mathbf{0.865}$$

Lever arm factor;

Lever arm;

$$Z_{stem} = \min(0.95, c) \times d_{stem} = \mathbf{138.4 \text{ mm}}$$

Area of tension reinforcement required;

$$A_{s_stem_des} = M_{stem} \times \gamma_{ms} / (f_y \times Z_{stem}) = \mathbf{351 \text{ mm}^2/\text{m}}$$

Minimum area of tension reinforcement;

$$A_{s_stem_min} = k \times b \times t_{wall} = \mathbf{390 \text{ mm}^2/\text{m}}$$

Area of tension reinforcement required;

$$A_{s_stem_req} = \text{Max}(A_{s_stem_des}, A_{s_stem_min}) = \mathbf{390 \text{ mm}^2/\text{m}}$$

Reinforcement provided;

A393 mesh

Area of reinforcement provided;

$$A_{s_stem_prov} = \pi \times \phi_{stem}^2 / (4 \times s_{stem}) = \mathbf{393 \text{ mm}^2/\text{m}}$$

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress;

$$V_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.172 \text{ N/mm}^2}$$

Basic characteristic shear strength of masonry;

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

$$f_{vbas} = \mathbf{0.393 \text{ N/mm}^2}$$

Shear span;

$$a = M_{stem} / V_{stem} = \mathbf{769.0 \text{ mm}}$$

Characteristic shear strength of masonry;

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

$$f_v = \mathbf{0.510 \text{ N/mm}^2}$$

Allowable shear stress;

$$V_{adm} = f_v / \gamma_{mv} = \mathbf{0.255 \text{ N/mm}^2}$$

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;

$$\text{ratio}_{act} = (h_{stem} + d_{stem} / 2) / d_{stem} = \mathbf{8.94}$$

PASS - Span to depth ratio is acceptable

Axial load check

Factored axial load on wall;

$$N_{wall} = ([t_{wall} \times h_{stem} \times \gamma_{wall} + W_{dead}] \times \gamma_{f_d}) + (W_{live} \times \gamma_{f_l}) = \mathbf{21.8 \text{ kN/m}}$$

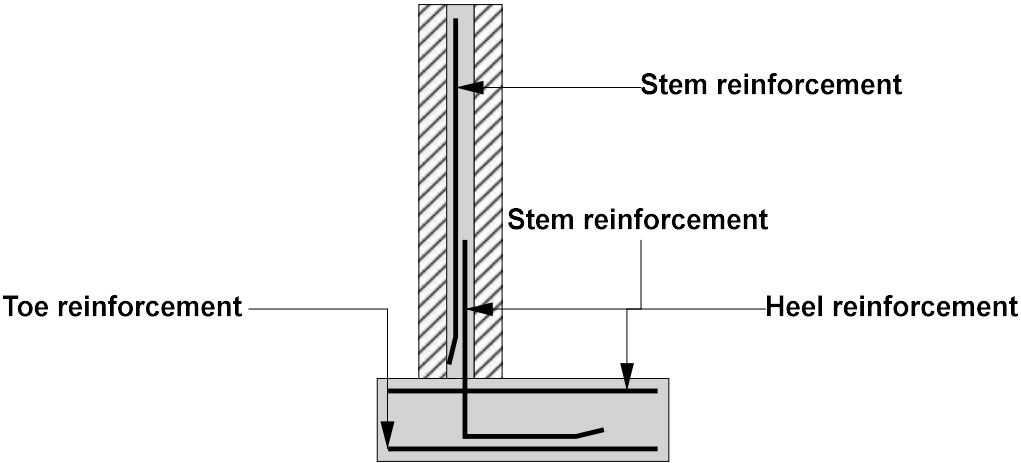
Limiting axial load;

$$N_{limit} = 0.1 \times f_k \times t_{wall} = \mathbf{244.3 \text{ kN/m}}$$

Applied axial load may be ignored - calculations valid

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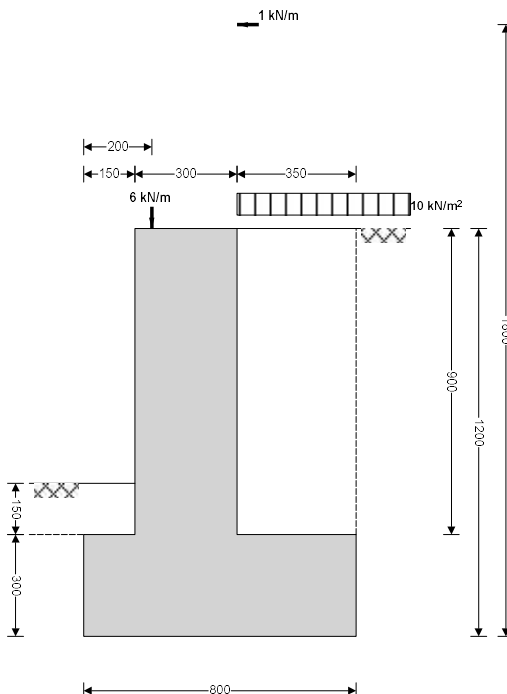
Indicative retaining wall reinforcement diagram



Toe mesh - A393 - (393 mm²/m)
Heel mesh - A393 - (393 mm²/m)
Stem mesh - A393 - (393 mm²/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.09



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

$h_{\text{stem}} = 900 \text{ mm}$
 $t_{\text{wall}} = 300 \text{ mm}$
 $l_{\text{toe}} = 150 \text{ mm}$
 $l_{\text{heel}} = 350 \text{ mm}$
 $l_{\text{base}} = l_{\text{toe}} + l_{\text{heel}} + t_{\text{wall}} = 800 \text{ mm}$
 $t_{\text{base}} = 300 \text{ mm}$
 $d_{\text{ds}} = 0 \text{ mm}$
 $l_{\text{ds}} = 500 \text{ mm}$
 $t_{\text{ds}} = 300 \text{ mm}$
 $h_{\text{wall}} = h_{\text{stem}} + t_{\text{base}} + d_{\text{ds}} = 1200 \text{ mm}$
 $d_{\text{cover}} = 150 \text{ mm}$
 $d_{\text{exc}} = 150 \text{ mm}$
 $h_{\text{water}} = 0 \text{ mm}$
 $h_{\text{sat}} = \max(h_{\text{water}} - t_{\text{base}} - d_{\text{ds}}, 0 \text{ mm}) = 0 \text{ mm}$
 $\gamma_{\text{wall}} = 23.6 \text{ kN/m}^3$
 $\gamma_{\text{base}} = 23.6 \text{ kN/m}^3$
 $\alpha = 90.0 \text{ deg}$
 $\beta = 0.0 \text{ deg}$
 $h_{\text{eff}} = h_{\text{wall}} + l_{\text{heel}} \times \tan(\beta) = 1200 \text{ mm}$

Retained material details

Mobilisation factor;
Moist density of retained material;
Saturated density of retained material;

$M = 1.5$
 $\gamma_{\text{m}} = 18.0 \text{ kN/m}^3$
 $\gamma_{\text{s}} = 21.0 \text{ kN/m}^3$

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$$w_{\text{base}} = l_{\text{base}} \times t_{\text{base}} \times \gamma_{\text{base}} = \mathbf{5.7 \text{ kN/m}}$$

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Surcharge;

$$w_{sur} = \text{Surcharge} \times l_{heel} = \mathbf{3.5 \text{ kN/m}}$$

Moist backfill to top of wall;

$$w_{m_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = \mathbf{5.7 \text{ kN/m}}$$

Soil in front of wall;

$$w_p = l_{toe} \times d_{cover} \times \gamma_{mb} = \mathbf{0.4 \text{ kN/m}}$$

Applied vertical load;

$$W_v = W_{dead} + W_{live} = \mathbf{6 \text{ kN/m}}$$

Total vertical load;

$$W_{total} = W_{wall} + W_{base} + W_{sur} + W_{m_w} + w_p + W_v = \mathbf{27.6 \text{ kN/m}}$$

Horizontal forces on wall

Surcharge;

$$F_{sur} = K_a \times \text{Surcharge} \times h_{eff} = \mathbf{5 \text{ kN/m}}$$

Moist backfill above water table;

$$F_{m_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2 = \mathbf{5.4 \text{ kN/m}}$$

Applied horizontal load;

$$F_h = F_{dead} + F_{live} = \mathbf{0.7 \text{ kN/m}}$$

Total horizontal load;

$$F_{total} = F_{sur} + F_{m_a} + F_h = \mathbf{11.2 \text{ kN/m}}$$

Calculate stability against sliding

Passive resistance of soil in front of wall;

$$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = \mathbf{3.2 \text{ kN/m}}$$

Resistance to sliding;

$$F_{res} = F_p + W_{total} \times \tan(\delta_b) = \mathbf{12.5 \text{ kN/m}}$$

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge;

$$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 = \mathbf{3 \text{ kNm/m}}$$

Moist backfill above water table;

$$M_{m_a} = F_{m_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = \mathbf{2.2 \text{ kNm/m}}$$

Applied horizontal load;

$$M_{hor} = F_h \times h_{load} = \mathbf{1.3 \text{ kNm/m}}$$

Total overturning moment;

$$M_{ot} = M_{sur} + M_{m_a} + M_{hor} = \mathbf{6.5 \text{ kNm/m}}$$

Restoring moments

Wall stem;

$$M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2) = \mathbf{1.9 \text{ kNm/m}}$$

Wall base;

$$M_{base} = W_{base} \times l_{base} / 2 = \mathbf{2.3 \text{ kNm/m}}$$

Surcharge;

$$M_{sur_r} = W_{sur} \times (l_{base} - l_{heel} / 2) = \mathbf{2.2 \text{ kNm/m}}$$

Moist backfill;

$$M_{m_r} = (w_{m_w} \times (l_{base} - l_{heel} / 2) + W_{m_s} \times (l_{base} - l_{heel} / 3)) = \mathbf{3.5 \text{ kNm/m}}$$

Soil in front of wall;

$$M_{p_r} = w_p \times l_{toe} / 2 = \mathbf{0 \text{ kNm/m}}$$

Design vertical load;

$$M_v = W_v \times l_{load} = \mathbf{1.2 \text{ kNm/m}}$$

Total restoring moment;

$$M_{rest} = M_{wall} + M_{base} + M_{sur_r} + M_{m_r} + M_{p_r} + M_v = \mathbf{11.1 \text{ kNm/m}}$$

Check stability against overturning

Total overturning moment;

$$M_{ot} = \mathbf{6.5 \text{ kNm/m}}$$

Total restoring moment;

$$M_{rest} = \mathbf{11.1 \text{ kNm/m}}$$

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Total moment for bearing;

$$M_{total} = M_{rest} - M_{ot} = \mathbf{4.6 \text{ kNm/m}}$$

Total vertical reaction;

$$R = W_{total} = \mathbf{27.6 \text{ kN/m}}$$

Distance to reaction;

$$x_{bar} = M_{total} / R = \mathbf{167 \text{ mm}}$$

Eccentricity of reaction;

$$e = \text{abs}((l_{base} / 2) - x_{bar}) = \mathbf{233 \text{ mm}}$$

Reaction acts outside middle third of base

Bearing pressure at toe;

$$p_{toe} = R / (1.5 \times x_{bar}) = \mathbf{109.9 \text{ kN/m}^2}$$

Bearing pressure at heel;

$$p_{heel} = 0 \text{ kN/m}^2 = \mathbf{0 \text{ kN/m}^2}$$

PASS - Maximum bearing pressure is less than allowable bearing pressure

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RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.09

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; $W_{wall_f} = \gamma_{f_d} \times h_{stem} \times t_{wall} \times \gamma_{wall} = 8.9 \text{ kN/m}$
Wall base; $W_{base_f} = \gamma_{f_d} \times l_{base} \times t_{base} \times \gamma_{base} = 7.9 \text{ kN/m}$
Surcharge; $W_{sur_f} = \gamma_{f_l} \times \text{Surcharge} \times l_{heel} = 5.6 \text{ kN/m}$
Moist backfill to top of wall; $W_{m_w_f} = \gamma_{f_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 7.9 \text{ kN/m}$
Soil in front of wall; $W_{p_f} = \gamma_{f_d} \times l_{toe} \times d_{cover} \times \gamma_{mb} = 0.6 \text{ kN/m}$
Applied vertical load; $W_{v_f} = \gamma_{f_d} \times W_{dead} + \gamma_{f_l} \times W_{live} = 8.4 \text{ kN/m}$
Total vertical load; $W_{total_f} = W_{wall_f} + W_{base_f} + W_{sur_f} + W_{m_w_f} + W_{p_f} + W_{v_f} = 39.4 \text{ kN/m}$

Factored horizontal at-rest forces on wall

Surcharge; $F_{sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times h_{eff} = 11.3 \text{ kN/m}$
Moist backfill above water table; $F_{m_a_f} = \gamma_{f_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2 = 10.7 \text{ kN/m}$
Applied horizontal load; $F_{h_f} = \gamma_{f_e} \times F_{dead} + \gamma_{f_l} \times F_{live} = 1.2 \text{ kN/m}$
Total horizontal load; $F_{total_f} = F_{sur_f} + F_{m_a_f} + F_{h_f} = 23.2 \text{ kN/m}$
Passive resistance of soil in front of wall; $F_{p_f} = \gamma_{f_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 4.5 \text{ kN/m}$

Factored overturning moments

Surcharge; $M_{sur_f} = F_{sur_f} \times (h_{eff} - 2 \times d_{ds}) / 2 = 6.8 \text{ kNm/m}$
Moist backfill above water table; $M_{m_a_f} = F_{m_a_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 4.3 \text{ kNm/m}$
Applied horizontal load; $M_{hor_f} = F_{h_f} \times h_{load} = 2.1 \text{ kNm/m}$
Total overturning moment; $M_{ot_f} = M_{sur_f} + M_{m_a_f} + M_{hor_f} = 13.2 \text{ kNm/m}$

Restoring moments

Wall stem; $M_{wall_f} = W_{wall_f} \times (l_{toe} + t_{wall} / 2) = 2.7 \text{ kNm/m}$
Wall base; $M_{base_f} = W_{base_f} \times l_{base} / 2 = 3.2 \text{ kNm/m}$
Surcharge; $M_{sur_f} = W_{sur_f} \times (l_{base} - l_{heel} / 2) = 3.5 \text{ kNm/m}$
Moist backfill; $M_{m_r_f} = (W_{m_w_f} \times (l_{base} - l_{heel} / 2) + W_{m_s_f} \times (l_{base} - l_{heel} / 3)) = 5 \text{ kNm/m}$
Soil in front of wall; $M_{p_r_f} = W_{p_f} \times l_{toe} / 2 = 0 \text{ kNm/m}$
Design vertical load; $M_{v_f} = W_{v_f} \times l_{load} = 1.7 \text{ kNm/m}$
Total restoring moment; $M_{rest_f} = M_{wall_f} + M_{base_f} + M_{sur_f} + M_{m_r_f} + M_{p_r_f} + M_{v_f} = 16 \text{ kNm/m}$

Factored bearing pressure

Total moment for bearing; $M_{total_f} = M_{rest_f} - M_{ot_f} = 2.8 \text{ kNm/m}$
Total vertical reaction; $R_f = W_{total_f} = 39.4 \text{ kN/m}$
Distance to reaction; $x_{bar_f} = M_{total_f} / R_f = 72 \text{ mm}$
Eccentricity of reaction; $e_f = \text{abs}((l_{base} / 2) - x_{bar_f}) = 328 \text{ mm}$

Reaction acts outside middle third of base

Bearing pressure at toe; $p_{toe_f} = R_f / (1.5 \times x_{bar_f}) = 366.1 \text{ kN/m}^2$
Bearing pressure at heel; $p_{heel_f} = 0 \text{ kN/m}^2 = 0 \text{ kN/m}^2$
Rate of change of base reaction; $\text{rate} = p_{toe_f} / (3 \times x_{bar_f}) = 1702.83 \text{ kN/m}^2/\text{m}$
Bearing pressure at stem / toe; $p_{stem_toe_f} = \text{max}(p_{toe_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2) = 110.7 \text{ kN/m}^2$
Bearing pressure at mid stem; $p_{stem_mid_f} = \text{max}(p_{toe_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2) = 0 \text{ kN/m}^2$

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Bearing pressure at stem / heel;

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

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

Material properties

Characteristic strength of concrete;

$$f_{\text{cu}} = 40 \text{ N/mm}^2$$

Characteristic strength of reinforcement;

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

Base details

Minimum area of reinforcement;

$$k = 0.13 \%$$

Cover to reinforcement in toe;

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

Calculate shear for toe design

Shear from bearing pressure;

$$V_{\text{toe_bear}} = (p_{\text{toe_f}} + p_{\text{stem_toe_f}}) \times l_{\text{toe}} / 2 = 35.8 \text{ kN/m}$$

Shear from weight of base;

$$V_{\text{toe_wt_base}} = \gamma_{\text{f_d}} \times \gamma_{\text{base}} \times l_{\text{toe}} \times t_{\text{base}} = 1.5 \text{ kN/m}$$

Total shear for toe design;

$$V_{\text{toe}} = V_{\text{toe_bear}} - V_{\text{toe_wt_base}} = 34.3 \text{ kN/m}$$

Calculate moment for toe design

Moment from bearing pressure;

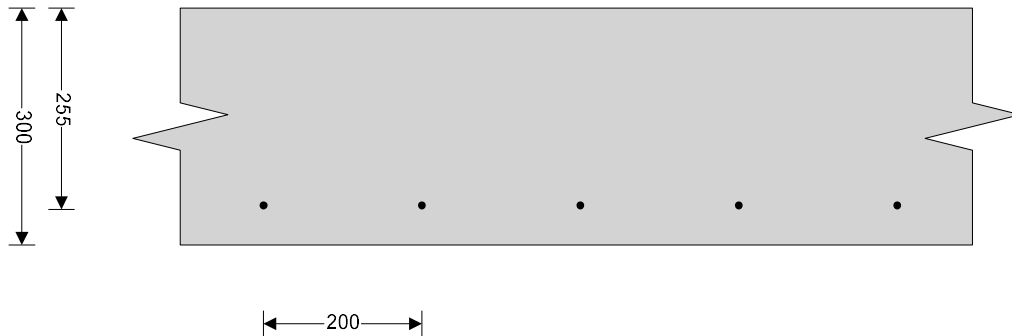
$$M_{\text{toe_bear}} = (2 \times p_{\text{toe_f}} + p_{\text{stem_mid_f}}) \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = 11 \text{ kNm/m}$$

Moment from weight of base;

$$M_{\text{toe_wt_base}} = (\gamma_{\text{f_d}} \times \gamma_{\text{base}} \times t_{\text{base}} \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2) = 0.4 \text{ kNm/m}$$

Total moment for toe design;

$$M_{\text{toe}} = M_{\text{toe_bear}} - M_{\text{toe_wt_base}} = 10.5 \text{ kNm/m}$$



Check toe in bending

Width of toe;

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

Depth of reinforcement;

$$d_{\text{toe}} = t_{\text{base}} - c_{\text{toe}} - (\phi_{\text{toe}} / 2) = 255.0 \text{ mm}$$

Constant;

$$K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_{\text{cu}}) = 0.004$$

Compression reinforcement is not required

Lever arm;

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

$$z_{\text{toe}} = 242 \text{ mm}$$

Area of tension reinforcement required;

$$A_{\text{s_toe_des}} = M_{\text{toe}} / (0.87 \times f_y \times z_{\text{toe}}) = 100 \text{ mm}^2/\text{m}$$

Minimum area of tension reinforcement;

$$A_{\text{s_toe_min}} = k \times b \times t_{\text{base}} = 390 \text{ mm}^2/\text{m}$$

Area of tension reinforcement required;

$$A_{\text{s_toe_req}} = \text{Max}(A_{\text{s_toe_des}}, A_{\text{s_toe_min}}) = 390 \text{ mm}^2/\text{m}$$

Reinforcement provided;

A393 mesh

Area of reinforcement provided;

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

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress;

$$v_{\text{toe}} = V_{\text{toe}} / (b \times d_{\text{toe}}) = 0.134 \text{ N/mm}^2$$

Allowable shear stress;

$$v_{\text{adm}} = \min(0.8 \times \sqrt{f_{\text{cu}} / 1 \text{ N/mm}^2}, 5) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2$$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress;

$$v_{\text{c_toe}} = 0.443 \text{ N/mm}^2$$

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

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

Material properties

Characteristic strength of concrete; $f_{cu} = 40 \text{ N/mm}^2$

Characteristic strength of reinforcement; $f_y = 500 \text{ N/mm}^2$

Base details

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

Cover to reinforcement in heel; $C_{heel} = 40 \text{ mm}$

Calculate shear for heel design

Shear from weight of base; $V_{heel_wt_base} = \gamma_{f_d} \times \gamma_{base} \times l_{heel} \times t_{base} = 3.5 \text{ kN/m}$

Shear from weight of moist backfill; $V_{heel_wt_m} = W_{m_w_f} = 7.9 \text{ kN/m}$

Shear from surcharge; $V_{heel_sur} = W_{sur_f} = 5.6 \text{ kN/m}$

Total shear for heel design; $V_{heel} = V_{heel_wt_base} + V_{heel_wt_m} + V_{heel_sur} = 17 \text{ kN/m}$

Calculate moment for heel design

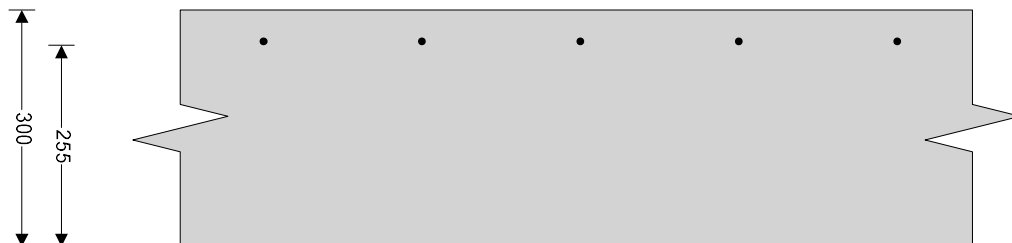
Moment from weight of base; $M_{heel_wt_base} = (\gamma_{f_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) = 1.2 \text{ kNm/m}$

Moment from weight of moist backfill; $M_{heel_wt_m} = W_{m_w_f} \times (l_{heel} + t_{wall}) / 2 = 2.6 \text{ kNm/m}$

Moment from surcharge; $M_{heel_sur} = W_{sur_f} \times (l_{heel} + t_{wall}) / 2 = 1.8 \text{ kNm/m}$

Total moment for heel design; $M_{heel} = M_{heel_wt_base} + M_{heel_wt_m} + M_{heel_sur} = 5.6 \text{ kNm/m}$

← 200 →



Check heel in bending

Width of heel; $b = 1000 \text{ mm/m}$

Depth of reinforcement; $d_{heel} = t_{base} - C_{heel} - (\phi_{heel} / 2) = 255.0 \text{ mm}$

Constant; $K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu}) = 0.002$

Compression reinforcement is not required

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

$Z_{heel} = 242 \text{ mm}$

Area of tension reinforcement required; $A_{s_heel_des} = M_{heel} / (0.87 \times f_y \times Z_{heel}) = 54 \text{ mm}^2/\text{m}$

Minimum area of tension reinforcement; $A_{s_heel_min} = k \times b \times t_{base} = 390 \text{ mm}^2/\text{m}$

Area of tension reinforcement required; $A_{s_heel_req} = \max(A_{s_heel_des}, A_{s_heel_min}) = 390 \text{ mm}^2/\text{m}$

Reinforcement provided;

A393 mesh

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;

$V_{heel} = V_{heel} / (b \times d_{heel}) = 0.067 \text{ N/mm}^2$

Allowable shear stress;

$V_{adm} = \min(0.8 \times \sqrt{f_{cu} / 1 \text{ N/mm}^2}, 5) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2$

PASS - Design shear stress is less than maximum shear stress

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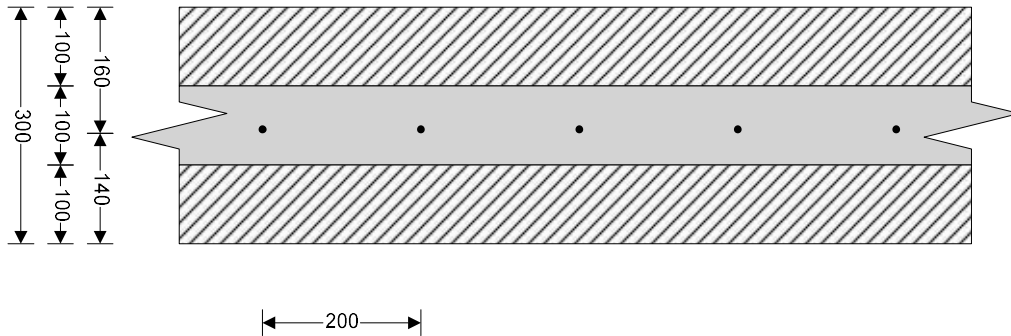
From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress;

$$V_{c_heel} = 0.443 \text{ N/mm}^2$$

$V_{heel} < V_{c_heel}$ - 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;

$$t_{cavity} = t_{wall} - t_{outer} - t_{inner} = 100 \text{ mm}$$

Depth of stem reinforcement;

$$d_{stem} = 160 \text{ mm}$$

Masonry details

Masonry type;

Aggregate concrete blocks no voids

Compressive strength of units;

$$p_{unit} = 10.0 \text{ N/mm}^2$$

Mortar designation;

(ii)

Category of manufacturing control of units;

Normal

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;

$$f_k = 8.1 \text{ N/mm}^2$$

Factored horizontal at-rest forces on stem

Surcharge;

$$F_{s_sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = 8.5 \text{ kN/m}$$

Moist backfill above water table;

$$F_{s_m_a_f} = 0.5 \times \gamma_{f_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = 6 \text{ kN/m}$$

Applied horizontal load;

$$F_{s_h_f} = \gamma_{f_d} \times F_{dead} + \gamma_{f_l} \times F_{live} = 1.2 \text{ kN/m}$$

Calculate shear for stem design

Shear at base of stem;

$$V_{stem} = F_{s_sur_f} + F_{s_m_a_f} + F_{s_h_f} = 15.7 \text{ kN/m}$$

Calculate moment for stem design

Surcharge;

$$M_{s_sur} = F_{s_sur_f} \times (h_{stem} + t_{base}) / 2 = 5.1 \text{ kNm/m}$$

Moist backfill above water table;

$$M_{s_m_a} = F_{s_m_a_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = 2.7 \text{ kNm/m}$$

Applied horizontal load;

$$M_{s_hor} = F_{s_h_f} \times (h_{load} - t_{base} / 2) = 2 \text{ kNm/m}$$

Total moment for stem design;

$$M_{stem} = M_{s_sur} + M_{s_m_a} + M_{s_hor} = 9.8 \text{ kNm/m}$$

Check maximum design moment for wall stem

Width of wall;

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

Maximum design moment;

$$M_{d_stem} = 0.4 \times f_k \times b \times d_{stem}^2 / \gamma_{mm} = 36.2 \text{ kNm/m}$$

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PASS - Applied moment is less than maximum design moment

Check wall stem in bending

Moment of resistance factor;

$$Q = M_{\text{stem}} / d_{\text{stem}}^2 = \mathbf{0.381 \text{ N/mm}^2}$$

Lever arm factor;

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

Lever arm;

$$c = \mathbf{0.943}$$

$$Z_{\text{stem}} = \min(0.95, c) \times d_{\text{stem}} = \mathbf{150.9 \text{ mm}}$$

Area of tension reinforcement required;

$$A_{s_stem_des} = M_{\text{stem}} \times \gamma_{\text{ms}} / (f_y \times Z_{\text{stem}}) = \mathbf{149 \text{ mm}^2/\text{m}}$$

Minimum area of tension reinforcement;

$$A_{s_stem_min} = k \times b \times t_{\text{wall}} = \mathbf{390 \text{ mm}^2/\text{m}}$$

Area of tension reinforcement required;

$$A_{s_stem_req} = \text{Max}(A_{s_stem_des}, A_{s_stem_min}) = \mathbf{390 \text{ mm}^2/\text{m}}$$

Reinforcement provided;

A393 mesh

Area of reinforcement provided;

$$A_{s_stem_prov} = \pi \times \phi_{\text{stem}}^2 / (4 \times s_{\text{stem}}) = \mathbf{393 \text{ mm}^2/\text{m}}$$

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress;

$$V_{\text{stem}} = V_{\text{stem}} / (b \times d_{\text{stem}}) = \mathbf{0.098 \text{ N/mm}^2}$$

Basic characteristic shear strength of masonry;

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

$$f_{v\text{bas}} = \mathbf{0.393 \text{ N/mm}^2}$$

Shear span;

$$a = M_{\text{stem}} / V_{\text{stem}} = \mathbf{621.6 \text{ mm}}$$

Characteristic shear strength of masonry;

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

$$f_v = \mathbf{0.601 \text{ N/mm}^2}$$

Allowable shear stress;

$$V_{\text{adm}} = f_v / \gamma_{\text{mv}} = \mathbf{0.300 \text{ N/mm}^2}$$

PASS - Design shear stress is less than maximum shear stress

Check limiting dimensions

Limiting span/effective depth ratio;

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

Actual span/effective depth ratio;

$$\text{ratio}_{\text{act}} = (h_{\text{stem}} + d_{\text{stem}} / 2) / d_{\text{stem}} = \mathbf{6.13}$$

PASS - Span to depth ratio is acceptable

Axial load check

Factored axial load on wall;

$$N_{\text{wall}} = ([t_{\text{wall}} \times h_{\text{stem}} \times \gamma_{\text{wall}} + W_{\text{dead}}] \times \gamma_{\text{f_d}}) + (W_{\text{live}} \times \gamma_{\text{f_l}}) = \mathbf{17.3 \text{ kN/m}}$$

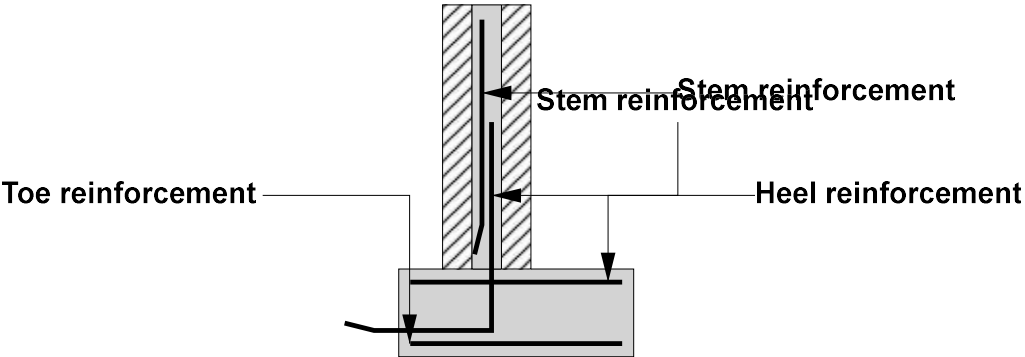
Limiting axial load;

$$N_{\text{limit}} = 0.1 \times f_k \times t_{\text{wall}} = \mathbf{244.3 \text{ kN/m}}$$

Applied axial load may be ignored - calculations valid

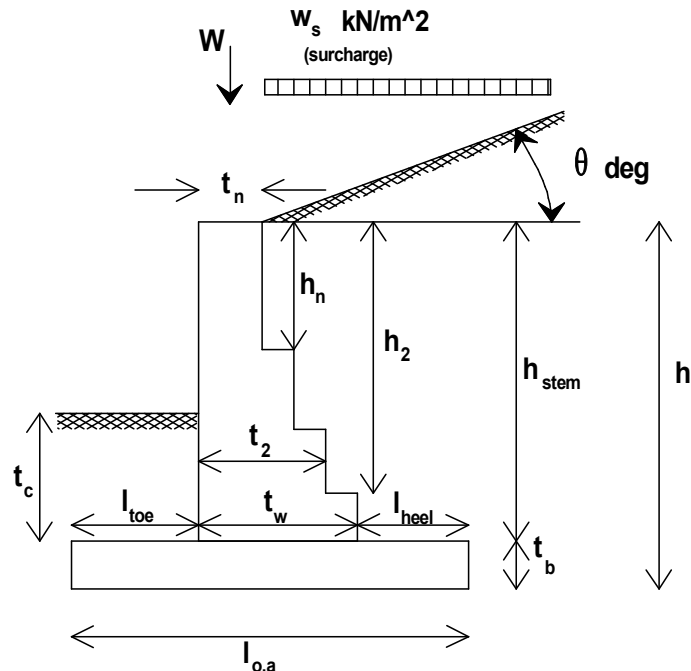
 Tekla® Tedds Solutions To Structures Ltd 44 Depot Road Cwmafan Port Talbot	Project				Job no.	
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Indicative retaining wall reinforcement diagram



Toe mesh - A393 - (393 mm²/m)
Heel mesh - A393 - (393 mm²/m)
Stem mesh - A393 - (393 mm²/m)

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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; $\gamma_s = 18.0 \text{ kN/m}^3$
- ; Angle of internal friction; $\phi = 30.0^\circ$
- ; Angle of soil surface; $\theta = 0.0^\circ$
- ; Ground cover over base at front of wall
– if > 0mm, assumed permanent; $t_c = 150 \text{ mm}$

Loads on wall and ground

- ; Surcharge load (horizontal plan area); $w_s = 10.0 \text{ kN/m}^2$
- ; Design vertical dead load on wall (unfactored); $W_v = 4.00 \text{ kN/m}$
- ; 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; $t_w = 375.0 \text{ mm}$
- ; Height retained; $h = 750 \text{ mm}$

Base details

- ; Density of wall base; $\gamma_b = 23.6 \text{ kN/m}^3$
- ; Length of heel; $l_{heel} = 150 \text{ mm}$
- ; Length of toe; $l_{toe} = 0 \text{ mm}$
- ; Base thickness; $t_b = 300 \text{ mm}$
- ; Length of base; $l_{o.a} = l_{toe} + t_w + l_{heel} = 525 \text{ mm}$

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

Height of wall stem;

$$h_{\text{stem}} = h - t_b = \mathbf{450 \text{ mm}}$$

$$h_{\text{soil}} = h + l_{\text{heel}} \times \tan(\theta) = \mathbf{750 \text{ mm}}$$

Load factors

; Dead Load Factor;

$$\gamma_{f_d} = \mathbf{1.40}$$

; Imposed Load Factor;

$$\gamma_{f_i} = \mathbf{1.60}$$

Coefficients using Rankine

Active coefficient (Sloping Surface) - no friction

$$k_{a_s} = (\cos(\theta) - \sqrt{((\cos(\theta))^2 - (\cos(\phi))^2)}) / (\cos(\theta) + \sqrt{((\cos(\theta))^2 - (\cos(\phi))^2)}) = \mathbf{0.333}$$

Active coefficient (level surface);

$$k_a = (1 - \sin(\phi)) / (1 + \sin(\phi)) = \mathbf{0.333}$$

Passive coefficient (level surface);

$$k_p = (1 + \sin(\phi)) / (1 - \sin(\phi)) = \mathbf{3.000}$$

At - rest coefficient;

$$k_o = (1 - \sin(\phi)) = \mathbf{0.500}$$

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

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

Surcharge

pressure;

$$p_s = k_{a_s} \times w_s = \mathbf{3.3 \text{ kN/m}^2}$$

force – horizontal;

$$F_s = (p_s \times h_{\text{soil}}) \times (\cos(\theta))^2 = \mathbf{2.5 \text{ kN/m}}$$

overturning moment about toe; $M_s = F_s \times h_{\text{soil}} / 2 = \mathbf{0.9 \text{ kNm/m}}$

Backfill

pressure;

$$p_a = k_{a_s} \times \gamma_s \times h_{\text{soil}} = \mathbf{4.5 \text{ kN/m}^2}$$

force – horizontal;

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

overturning moment about the toe;

$$M_a = F_a \times h_{\text{soil}} / 3 = \mathbf{0.4 \text{ kNm/m}}$$

Total horizontal force (unfactored);

$$F_t = F_s + F_a = \mathbf{4.2 \text{ kN/m}}$$

Total horizontal force (factored);

$$F_{t_{\text{ult}}} = \gamma_{f_i} \times F_s + \gamma_{f_d} \times F_a = \mathbf{6.4 \text{ kN/m}}$$

Total overturning moment (unfactored);

$$M_t = M_s + M_a = \mathbf{1.4 \text{ kNm/m}}$$

Total overturning moment (factored);

$$M_{t_{\text{ult}}} = \gamma_{f_i} \times M_s + \gamma_{f_d} \times M_a = \mathbf{2.1 \text{ kNm/m}}$$

Average load factor;

$$\gamma_{f_{\text{av}}} = M_{t_{\text{ult}}} / M_t = \mathbf{1.54}$$

STABILITY CHECKS

(Unfactored Loads - Active Soil Pressures)

1) SLIDING

; Coefficient of friction;

$$\mu = \tan(\phi) \times \text{factor} = \mathbf{0.433} ; \text{factor} = \mathbf{0.75}$$

Passive pressures in front of wall

Top of base;

$$pp_1 = k_p \times t_c \times \gamma_s = \mathbf{8.1 \text{ kN/m}^2}$$

Underside of base;

$$pp_2 = k_p \times (t_c + t_b) \times \gamma_s = \mathbf{24.3 \text{ kN/m}^2}$$

Total resistance

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Base; $PP_{base} = (pp_1 + pp_2) \times t_b / 2 = 4.9 \text{ kN/m}$

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

$$P = PP_{base} \times \text{soil_resists} = 4.9 \text{ kN/m}$$

Factor of safety against sliding

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

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

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

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

$$FOS_{sliding} = 2.416$$

Factor of safety against sliding = 2.4 i.e. > 2.0 - OK

2) OVERTURNING

Factor of safety against overturning

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

Length of toe provided; $l_{toe} = 0 \text{ mm}$

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

$$M_{r1} = (W_v + h_{stem} \times t_w \times \gamma_w) \times (l_{toe} + t_w / 2) = 1.4 \text{ kNm/m}$$

$$M_{r2} = l_{heel} \times h_{stem} \times \gamma_s \times (l_{toe} + t_w + l_{heel} / 2) = 0.5 \text{ kNm/m}$$

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

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

Resisting moment; $M_r = M_{r1} + M_{r2} + M_{r3} + M_{r4} = 2.9 \text{ kNm/m}$

Factor of safety against overturning; $FOS_{o_turn} = M_r / \text{abs}(M_t) = 2.11$

Factor of safety against overturning = 2.1 i.e. > 2.0 - OK

Overall length of base; $l_{o_a} = l_{toe} + t_w + l_{heel} = 0.525 \text{ m}$

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

Total overturning moment for bearing calculation; $M_t = 1.4 \text{ kNm/m}$

Total resisting moment for bearing calculation; $M_r = 2.9 \text{ kNm/m}$

Total vertical load on base

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

$$N = 13.6 \text{ kN/m}$$

Eccentricity of vertical load

$$e_1 = (M_r - \text{abs}(M_t) + t_c \times l_{toe}^2 \times \gamma_s / 2 + W_s \times l_{heel} \times (l_{toe} + t_w + l_{heel} / 2) + W_l \times (l_{toe} + t_w / 2)) / N = 0.161 \text{ m}$$

$$e = l_{o_a} / 2 - e_1 = 0.102 \text{ m}$$

Resultant lies outside middle third;

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Maximum bearing pressure; $p_{max} = \text{if}(\text{abs}(e) < (l_o / 6), \sigma_{max2}, \sigma_{max1}) = 56.6 \text{ kN/m}^2$

; Permissible bearing pressure; $p_{bearing} = 150 \text{ kN/m}^2$

Maximum bearing pressure is 57 kN/m² i.e. < Allowable - OK

STEM DESIGN

Width of base of wall; $t_w = 375.0 \text{ mm}$

Height of stem of wall; $h_{stem} = 450 \text{ mm}$

DESIGN OF WALL SECTION 1 (AT REST PRESSURES)

; Wall base section thickness; $t_w = 375.0 \text{ mm}$

Depth from top of wall to base

; $h_{stem} = 450 \text{ mm}$;

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

$$F_{base} = (k_o \times W_s \times h_{stem}) \times \gamma_{f_i} + (k_o \times \gamma_s \times h_{stem}^2 / 2) \times \gamma_{f_d} = 4.9 \text{ kN/m}$$

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

; Compressive strength (Table 2); $f_k = 7.30 \text{ N/mm}^2$

; Design vertical load per unit length of wall; $n_{w_base} = \gamma_{fd} \times (W_v + t_w \times h_{stem} \times \gamma_w) = 6.5 \text{ kN/m}$

; 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; $V_{base} = W_v + t_w \times h_{stem} \times \gamma_w = 7.21 \text{ kN/m}$

; 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

SUMMARY OF RESULTS

Wall Dimensions

Masonry Compressive Strength ; **Masonry Compressive Strength - 7.3 N/mm²**

Stem Base section ; **375mm thick and 450mm from base to the top of the wall**

Base mass concrete 525 x 300mm section, 150mm toe to receive masonry cladding.;