



Vale Consultancy
CONSULTING CIVIL & STRUCTURAL ENGINEERS

Title: Structural Calculations for RC Retaining Wall

Project: Park Avenue, Glynneath

Client: Manning Construction

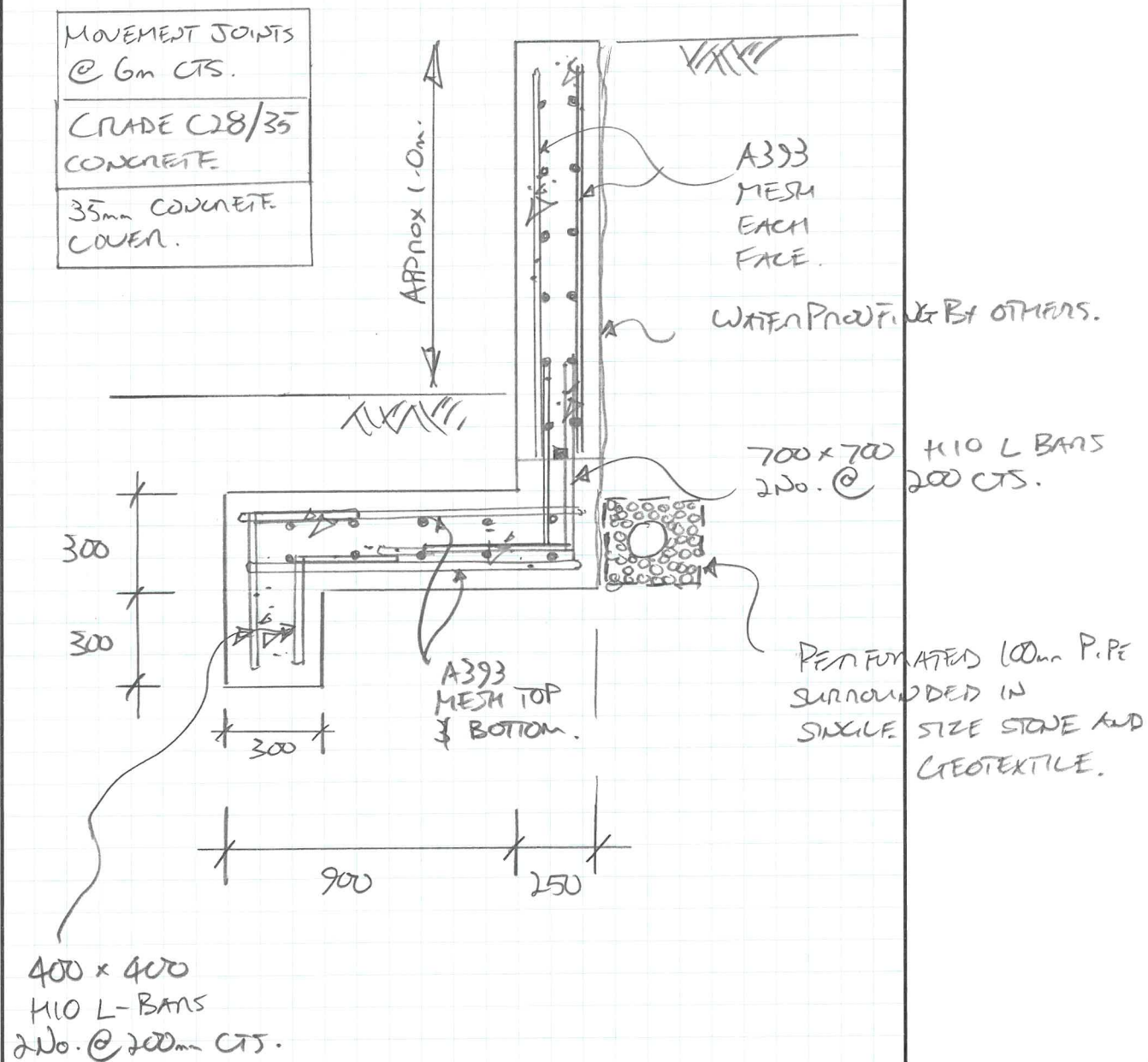
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Prepared By: MNJ
Checked By: JHM

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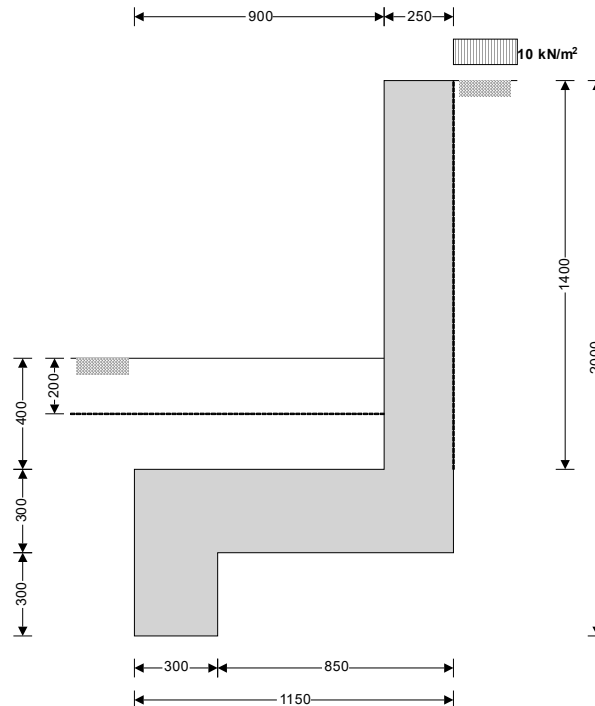
PARK AVENUE, GLYNNEATH.

R.C. RETAINING WALL SECTION



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

 $h_{\text{stem}} = 1400 \text{ mm}$
 $t_{\text{wall}} = 250 \text{ mm}$
 $l_{\text{toe}} = 900 \text{ mm}$
 $l_{\text{heel}} = 0 \text{ mm}$
 $l_{\text{base}} = l_{\text{toe}} + l_{\text{heel}} + t_{\text{wall}} = 1150 \text{ mm}$
 $t_{\text{base}} = 300 \text{ mm}$
 $d_{\text{ds}} = 300 \text{ mm}$
 $l_{\text{ds}} = 0 \text{ mm}$
 $t_{\text{ds}} = 300 \text{ mm}$
 $h_{\text{wall}} = h_{\text{stem}} + t_{\text{base}} + d_{\text{ds}} = 2000 \text{ mm}$
 $d_{\text{cover}} = 400 \text{ mm}$
 $d_{\text{exc}} = 200 \text{ mm}$
 $h_{\text{water}} = 0 \text{ mm}$
 $h_{\text{sat}} = \max(h_{\text{water}} - t_{\text{base}} - d_{\text{ds}}, 0 \text{ mm}) = 0 \text{ mm}$
 $\gamma_{\text{wall}} = 23.6 \text{ kN/m}^3$
 $\gamma_{\text{base}} = 23.6 \text{ kN/m}^3$
 $\alpha = 90.0 \text{ deg}$
 $\beta = 0.0 \text{ deg}$
 $h_{\text{eff}} = h_{\text{wall}} + l_{\text{heel}} \times \tan(\beta) = 2000 \text{ mm}$

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

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

Using Coulomb theory

Active pressure coefficient for retained material

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

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

$$K_0 = 1 - \sin(\phi') = 0.590$$

Loading details

Surcharge load on plan

$$\text{Surcharge} = 10.0 \text{ kN/m}^2$$

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

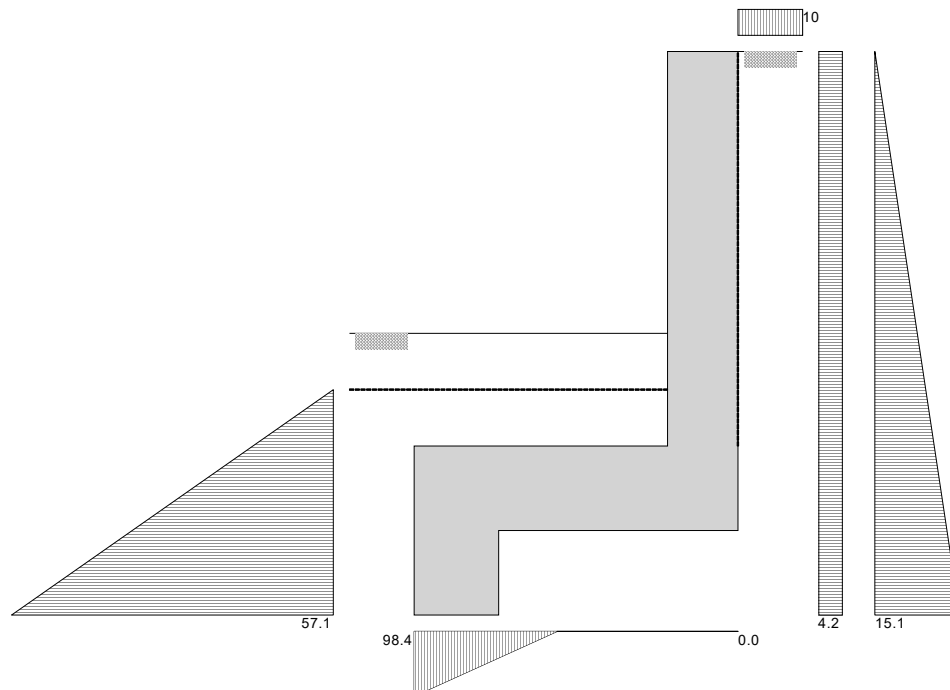
$$F_{\text{dead}} = 0.0 \text{ kN/m}$$

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	$W_{wall} = h_{stem} * t_{wall} * \gamma_{wall} = 8.3 \text{ kN/m}$
Wall base	$W_{base} = l_{base} * t_{base} * \gamma_{base} = 8.1 \text{ kN/m}$
Wall downstand	$W_{ds} = d_{ds} * t_{ds} * \gamma_{base} = 2.1 \text{ kN/m}$
Soil in front of wall	$W_p = l_{toe} * d_{cover} * \gamma_{mb} = 6.5 \text{ kN/m}$
Total vertical load	$W_{total} = W_{wall} + W_{base} + W_{ds} + W_p = 25 \text{ kN/m}$

Horizontal forces on wall

Surcharge	$F_{sur} = K_a * \text{Surcharge} * h_{eff} = 8.4 \text{ kN/m}$
Moist backfill above water table	$F_{m_a} = 0.5 * K_a * \gamma_m * (h_{eff} - h_{water})^2 = 15.1 \text{ kN/m}$
Total horizontal load	$F_{total} = F_{sur} + F_{m_a} = 23.4 \text{ kN/m}$

Calculate stability against sliding

Passive resistance of soil in front of wall	$F_p = 0.5 * K_p * \cos(\delta_b) * (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 * \gamma_{mb} = 22.9 \text{ kN/m}$
Resistance to sliding	$F_{res} = F_p + (W_{total} - w_p) * \tan(\delta_b) = 29.1 \text{ kN/m}$

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge	$M_{sur} = F_{sur} * (h_{eff} - 2 * d_{ds}) / 2 = 5.9 \text{ kNm/m}$
Moist backfill above water table	$M_{m_a} = F_{m_a} * (h_{eff} + 2 * h_{water} - 3 * d_{ds}) / 3 = 5.5 \text{ kNm/m}$
Soil in front of wall	$M_{p_o} = F_p * [2 * d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3 = 0.8 \text{ kNm/m}$
Total overturning moment	$M_{ot} = M_{sur} + M_{m_a} + M_{p_o} = 12.1 \text{ kNm/m}$

Restoring moments

Wall stem	$M_{wall} = W_{wall} * (l_{toe} + t_{wall} / 2) = 8.5 \text{ kNm/m}$
Wall base	$M_{base} = W_{base} * l_{base} / 2 = 4.7 \text{ kNm/m}$
Wall downstand	$M_{ds} = W_{ds} * (l_{ds} + t_{ds} / 2) = 0.3 \text{ kNm/m}$
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{ds} = 13.5 \text{ kNm/m}$

Check stability against overturning

Total overturning moment	$M_{ot} = 12.1 \text{ kNm/m}$
Total restoring moment	$M_{rest} = 13.5 \text{ kNm/m}$

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Soil in front of wall	$M_{p_r} = w_p * l_{toe} / 2 = 2.9 \text{ kNm/m}$
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{p_r} = 4.2 \text{ kNm/m}$
Total vertical reaction	$R = W_{total} = 25.0 \text{ kN/m}$
Distance to reaction	$x_{bar} = M_{total} / R = 169 \text{ mm}$
Eccentricity of reaction	$e = \text{abs}((l_{base} / 2) - x_{bar}) = 406 \text{ mm}$

Reaction acts outside middle third of base

Bearing pressure at toe	$p_{toe} = R / (1.5 * x_{bar}) = 98.4 \text{ kN/m}^2$
Bearing pressure at heel	$p_{heel} = 0 \text{ kN/m}^2 = 0 \text{ kN/m}^2$

PASS - Maximum bearing pressure is less than allowable bearing pressure

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RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.08

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	$W_{wall_f} = \gamma_{f_d} * h_{stem} * t_{wall} * \gamma_{wall} = 11.6 \text{ kN/m}$
Wall base	$W_{base_f} = \gamma_{f_d} * l_{base} * t_{base} * \gamma_{base} = 11.4 \text{ kN/m}$
Wall downstand	$W_{ds_f} = \gamma_{f_d} * d_{ds} * t_{ds} * \gamma_{base} = 3 \text{ kN/m}$
Soil in front of wall	$W_{p_f} = \gamma_{f_d} * l_{toe} * d_{cover} * \gamma_{mb} = 9.1 \text{ kN/m}$
Total vertical load	$W_{total_f} = W_{wall_f} + W_{base_f} + W_{ds_f} + W_{p_f} = 35 \text{ kN/m}$

Factored horizontal at-rest forces on wall

Surcharge	$F_{sur_f} = \gamma_{f_l} * K_0 * \text{Surcharge} * h_{eff} = 18.9 \text{ kN/m}$
Moist backfill above water table	$F_{m_a_f} = \gamma_{f_e} * 0.5 * K_0 * \gamma_m * (h_{eff} - h_{water})^2 = 29.7 \text{ kN/m}$
Total horizontal load	$F_{total_f} = F_{sur_f} + F_{m_a_f} = 48.6 \text{ kN/m}$
Passive resistance of soil in front of wall	$F_{p_f} = \gamma_{f_e} * 0.5 * K_p * \cos(\delta_b) * (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 * \gamma_{mb} = 32 \text{ kN/m}$

Factored overturning moments

Surcharge	$M_{sur_f} = F_{sur_f} * (h_{eff} - 2 * d_{ds}) / 2 = 13.2 \text{ kNm/m}$
Moist backfill above water table	$M_{m_a_f} = F_{m_a_f} * (h_{eff} + 2 * h_{water} - 3 * d_{ds}) / 3 = 10.9 \text{ kNm/m}$
Soil in front of wall	$M_{p_o_f} = F_{p_f} * [2 * d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3 = 1.1 \text{ kNm/m}$
Total overturning moment	$M_{ot_f} = M_{sur_f} + M_{m_a_f} + M_{p_o_f} = 25.2 \text{ kNm/m}$

Restoring moments

Wall stem	$M_{wall_f} = W_{wall_f} * (l_{toe} + t_{wall} / 2) = 11.9 \text{ kNm/m}$
Wall base	$M_{base_f} = W_{base_f} * l_{base} / 2 = 6.6 \text{ kNm/m}$
Wall downstand	$M_{ds_f} = W_{ds_f} * (l_{ds} + t_{ds} / 2) = 0.4 \text{ kNm/m}$
Soil in front of wall	$M_{p_r_f} = W_{p_f} * l_{toe} / 2 = 4.1 \text{ kNm/m}$
Total restoring moment	$M_{rest_f} = M_{wall_f} + M_{base_f} + M_{ds_f} + M_{p_r_f} = 22.9 \text{ kNm/m}$

Factored bearing pressure

Total moment for bearing	$M_{total_f} = M_{rest_f} - M_{ot_f} = -2.3 \text{ kNm/m}$
Total vertical reaction	$R_f = W_{total_f} = 35.0 \text{ kN/m}$
Distance to reaction	$x_{bar_f} = M_{total_f} / R_f = -64 \text{ mm}$
Eccentricity of reaction	$e_f = \text{abs}((l_{base} / 2) - x_{bar_f}) = 639 \text{ mm}$

WARNING - Beyond scope of calculation

Bearing pressure at toe	$p_{toe_f} = R_f / (1.5 * x_{bar_f}) = -362.6 \text{ kN/m}^2$
Bearing pressure at heel	$p_{heel_f} = 0 \text{ kN/m}^2 = 0 \text{ kN/m}^2$
Rate of change of base reaction	$\text{rate} = p_{toe_f} / (3 * x_{bar_f}) = 1878.28 \text{ kN/m}^2/\text{m}$
Bearing pressure at stem / toe	$p_{stem_toe_f} = \text{max}(p_{toe_f} - (\text{rate} * l_{toe}), 0 \text{ kN/m}^2) = 0 \text{ kN/m}^2$
Bearing pressure at mid stem	$p_{stem_mid_f} = \text{max}(p_{toe_f} - (\text{rate} * (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2) = 0 \text{ kN/m}^2$
Bearing pressure at stem / heel	$p_{stem_heel_f} = \text{max}(p_{toe_f} - (\text{rate} * (l_{toe} + t_{wall})), 0 \text{ kN/m}^2) = 0 \text{ kN/m}^2$

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

Material properties

Characteristic strength of concrete	$f_{cu} = 40 \text{ N/mm}^2$
Characteristic strength of reinforcement	$f_y = 500 \text{ N/mm}^2$

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Base details

Minimum area of reinforcement $k = 0.13 \%$
Cover to reinforcement in toe $C_{toe} = 35 \text{ mm}$

Calculate shear for toe design

Shear from weight of base $V_{toe_wt_base} = \gamma_{f_d} * \gamma_{base} * l_{toe} * t_{base} = 8.9 \text{ kN/m}$
Shear from weight of downstand $V_{toe_wt_ds} = \gamma_{f_d} * \gamma_{base} * d_{ds} * t_{ds} = 3 \text{ kN/m}$
Shear from weight of soil $V_{toe_wt_soil} = w_{p_f} - (\gamma_{f_d} * \gamma_m * l_{toe} * d_{exc}) = 4.5 \text{ kN/m}$
Total shear for toe design $V_{toe} = V_{toe_wt_base} - V_{toe_wt_ds} - V_{toe_wt_soil} = 1.4 \text{ kN/m}$

Calculate moment for toe design

Moment from weight of base $M_{toe_wt_base} = (\gamma_{f_d} * \gamma_{base} * t_{base} * (l_{toe} + t_{wall} / 2)^2 / 2) = 5.2 \text{ kNm/m}$
Moment from weight of downstand $M_{toe_wt_ds} = \gamma_{f_d} * \gamma_{base} * d_{ds} * t_{ds} * (l_{toe} - l_{ds} + (t_{wall} - t_{ds}) / 2) = 2.6 \text{ kNm/m}$
Moment from weight of soil $M_{toe_wt_soil} = (w_{p_f} - (\gamma_{f_d} * \gamma_m * l_{toe} * d_{exc})) * (l_{toe} + t_{wall}) / 2 = 2.6 \text{ kNm/m}$
Total moment for toe design $M_{toe} = M_{toe_wt_base} - M_{toe_wt_ds} - M_{toe_wt_soil} = 0 \text{ kNm/m}$

As the moment is negative the design of the retaining wall toe is beyond the scope of this calculation

Design of reinforced concrete retaining wall downstand (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

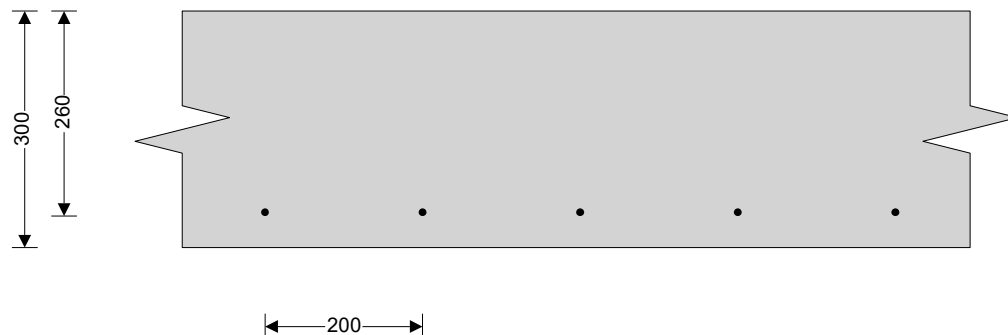
Minimum area of reinforcement $k = 0.13 \%$
Cover to reinforcement in downstand $C_{ds} = 35 \text{ mm}$

Calculate shear for downstand design

Total shear for downstand design $V_{down} = \gamma_{f_e} * K_p * \cos(\delta_b) * \gamma_m * d_{ds} * (d_{cover} + t_{base} + d_{ds} / 2) = 25.5 \text{ kN/m}$

Calculate moment for downstand design

Total moment for downstand design $M_{down} = \gamma_{f_e} * K_p * \cos(\delta_b) * \gamma_m * d_{ds} * [(d_{cover} + t_{base}) * (t_{base} + d_{ds}) + d_{ds} * (t_{base} / 2 + 2 * d_{ds} / 3)] / 2 = 7.9 \text{ kNm/m}$



Check downstand in bending

Width of downstand $b = 1000 \text{ mm/m}$
Depth of reinforcement $d_{down} = t_{ds} - C_{ds} - (\phi_{down} / 2) = 260.0 \text{ mm}$
Constant $K_{down} = M_{down} / (b * d_{down}^2 * f_{cu}) = 0.003$

Compression reinforcement is not required

Lever arm $Z_{down} = \text{Min}(0.5 + \sqrt{(0.25 - (\text{min}(K_{down}, 0.225) / 0.9))}, 0.95) * d_{down}$
 $Z_{down} = 247 \text{ mm}$

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Area of tension reinforcement required
Minimum area of tension reinforcement
Area of tension reinforcement required
Reinforcement provided
Area of reinforcement provided

$$A_{s_down_des} = M_{down} / (0.87 \times f_y \times Z_{down}) = \mathbf{73 \text{ mm}^2/m}$$

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

$$A_{s_down_req} = \text{Max}(A_{s_down_des}, A_{s_down_min}) = \mathbf{390 \text{ mm}^2/m}$$

A393 mesh

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

PASS - Reinforcement provided at the retaining wall downstand is adequate

Check shear resistance at downstand

Design shear stress
Allowable shear stress

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

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress

$$V_{c_down} = \mathbf{0.438 \text{ N/mm}^2}$$

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

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

Material properties

Characteristic strength of concrete
Characteristic strength of reinforcement

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

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

Wall details

Minimum area of reinforcement
Cover to reinforcement in stem
Cover to reinforcement in wall

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

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

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

Factored horizontal at-rest forces on stem

Surcharge
Moist backfill above water table

$$F_{s_sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = \mathbf{13.2 \text{ kN/m}}$$

$$F_{s_m_a_f} = 0.5 \times \gamma_{f_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = \mathbf{14.6 \text{ kN/m}}$$

Calculate shear for stem design

Shear at base of stem

$$V_{stem} = F_{s_sur_f} + F_{s_m_a_f} = \mathbf{27.8 \text{ kN/m}}$$

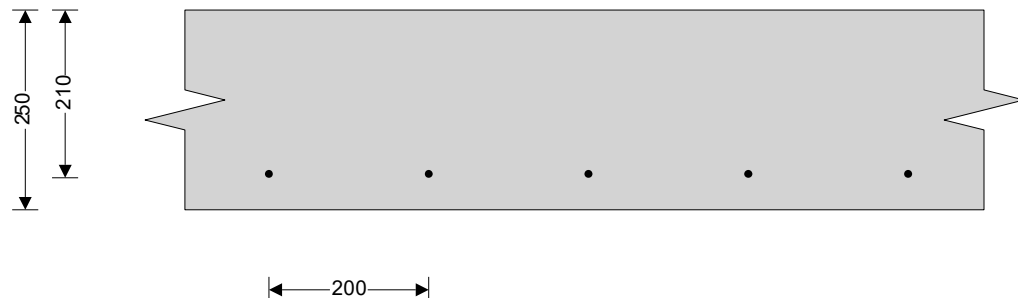
Calculate moment for stem design

Surcharge
Moist backfill above water table
Total moment for stem design

$$M_{s_sur} = F_{s_sur_f} \times (h_{stem} + t_{base}) / 2 = \mathbf{11.2 \text{ kNm/m}}$$

$$M_{s_m_a} = F_{s_m_a_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = \mathbf{9 \text{ kNm/m}}$$

$$M_{stem} = M_{s_sur} + M_{s_m_a} = \mathbf{20.2 \text{ kNm/m}}$$



Check wall stem in bending

Width of wall stem
Depth of reinforcement
Constant

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

$$d_{stem} = t_{wall} - C_{stem} - (\phi_{stem} / 2) = \mathbf{210.0 \text{ mm}}$$

$$K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = \mathbf{0.011}$$

Compression reinforcement is not required

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Lever arm

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

$$Z_{stem} = \mathbf{199 \text{ mm}}$$

Area of tension reinforcement required

$$A_{s_stem_des} = M_{stem} / (0.87 \times f_y \times Z_{stem}) = \mathbf{233 \text{ mm}^2/\text{m}}$$

Minimum area of tension reinforcement

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

Area of tension reinforcement required

$$A_{s_stem_req} = \text{Max}(A_{s_stem_des}, A_{s_stem_min}) = \mathbf{325 \text{ mm}^2/\text{m}}$$

Reinforcement provided

A393 mesh

Area of reinforcement provided

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

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem
Design shear stress

$$V_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.132 \text{ N/mm}^2}$$

Allowable shear stress

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8
Design concrete shear stress

$$V_{c_stem} = \mathbf{0.497 \text{ N/mm}^2}$$

$V_{stem} < V_{c_stem}$ - No shear reinforcement required

Check retaining wall deflection
Basic span/effective depth ratio

$$\text{ratio}_{bas} = \mathbf{7}$$

Design service stress

$$f_s = 2 \times f_y \times A_{s_stem_req} / (3 \times A_{s_stem_prov}) = \mathbf{275.9 \text{ N/mm}^2}$$

Modification factor

$$\text{factor}_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s) / (120 \times (0.9 \text{ N/mm}^2 + (M_{stem} / (b \times d_{stem}^2)))), 2) = \mathbf{1.78}$$

Maximum span/effective depth ratio

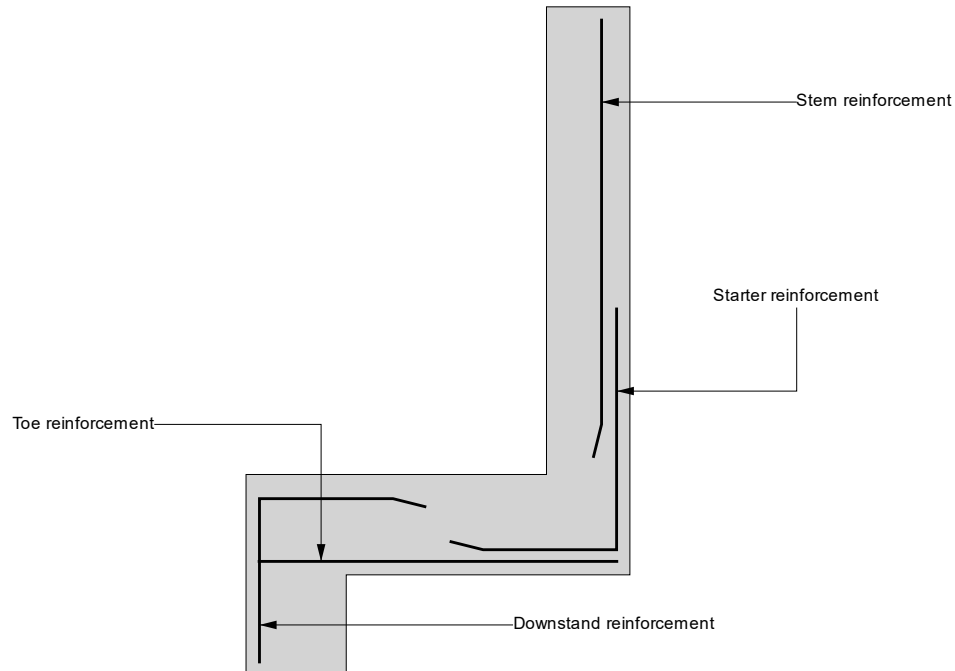
$$\text{ratio}_{max} = \text{ratio}_{bas} \times \text{factor}_{tens} = \mathbf{12.49}$$

Actual span/effective depth ratio

$$\text{ratio}_{act} = h_{stem} / d_{stem} = \mathbf{6.67}$$

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



The design of the retaining wall toe is beyond the scope of this calculation!

Downstand mesh - A393 - (393 mm²/m)

Stem mesh - A393 - (393 mm²/m)