

Project 3 Fernfield, Baglan				Job no. 23-030	
Calcs for Driveway Retaining Walls				Start page no./Revision 1	
Calcs by JD	Calcs date 27/04/2023	Checked by	Checked date	Approved by	Approved date

INTRODUCTION

Following the collapse of a section of the existing retaining wall between the property and the section of road below emergency works were undertaken to reinstate the wall.

Four separate designs have been used in the wall sections as set out below:

Section 1	Gabion Basket wall max height 2m
Section 2	Reinforced Masonry max height 2m
Section 3	Reinforced Masonry max height 3m
Section 4	Inclined Masonry max height 3m

Sections 1 – 3 have a surcharge load of 10kN/m² allowed, this has been reduced to 2.5kN/m² for Section 4 where the ground above is a garden only accessible on foot.

SECTION 1

GABION RETAINING WALL ANALYSIS & DESIGN

In accordance with BS8002:2015 - Code of Practice for Earth Retaining Structures and the UK National Annex

Tedds calculation version 2.0.02

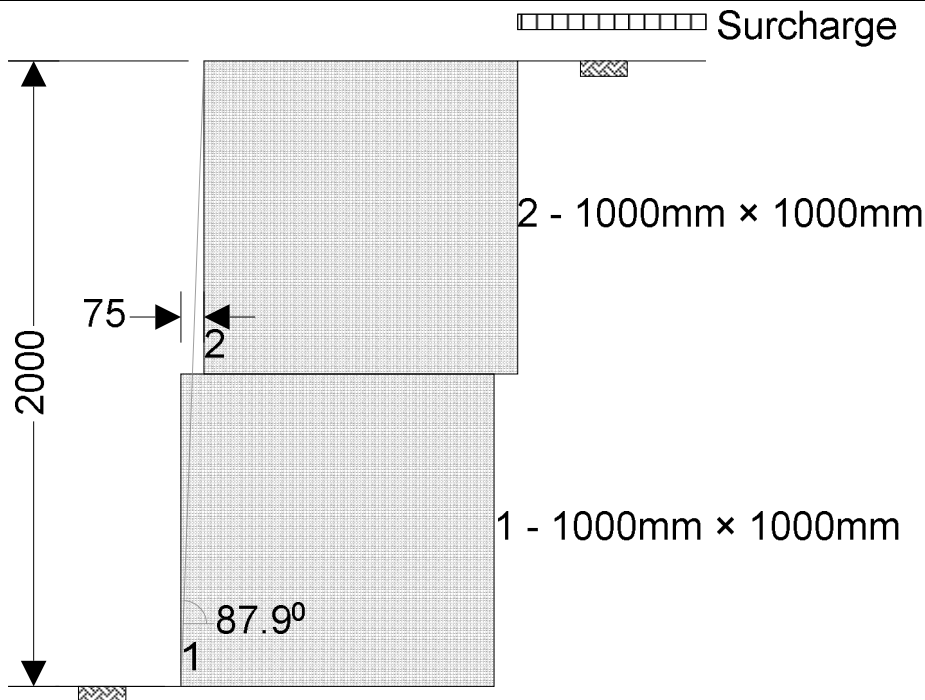
Design summary

Combination 1

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning, sliding and bearing at base level					
Overturning (kNm/m)	23.9	15.5	1.536	1.000	PASS
Sliding (kN/m)	27.2	19.9	1.370	1.000	PASS
Bearing (kN/m²)	150.0	76.8	1.954	1.000	PASS
Eccentricity (mm)	Reaction acts within the middle third of base				PASS
Overturning and sliding between courses 1 and 2					
Overturning (kNm/m)	9.5	2.7	3.541	1.000	PASS
Sliding (kN/m)	12.3	6.4	1.914	1.000	PASS

Combination 2

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning, sliding and bearing at base level					
Overturning (kNm/m)	24.1	15.9	1.521	1.000	PASS
Sliding (kN/m)	21.9	20.0	1.097	1.000	PASS
Bearing (kN/m ²)	150.0	76.8	1.954	1.000	PASS
Eccentricity (mm)	Reaction acts within the middle third of base				PASS
Overturning and sliding between courses 1 and 2					
Overturning (kNm/m)	9.5	2.8	3.366	1.000	PASS
Sliding (kN/m)	9.8	6.7	1.474	1.000	PASS



Wall geometry

Width of gabion 1;

$$w_1 = 1000 \text{ mm}$$

Height of gabion 1;

$$h_1 = 1000 \text{ mm}$$

Width of gabion 2;

$$w_2 = 1000 \text{ mm}$$

Height of gabion 2;

$$h_2 = 1000 \text{ mm}$$

Step to front face between courses 1 and 2;

$$s_2 = 75 \text{ mm}$$

Wall inclination;

$$\varepsilon = 0 \text{ deg}$$

Gabion properties

Unit weight of fill;

$$\gamma_d = 16.0 \text{ kN/m}^3$$

Friction between gabions;

$$\delta_{bg,k} = 35.0 \text{ deg}$$

Loading

Variable surcharge;

$$p_{o,Q} = 10 \text{ kN/m}^2$$

Soil properties

Slope of retained soil;

$$\beta = 0.0 \text{ deg}$$

Characteristic peak shearing resistance angle;

$$\phi'_{pk,k} = 35.0 \text{ deg}$$

Characteristic saturated density of retained soil;

$$\gamma_{sr} = 21.0 \text{ kN/m}^3$$

Coefficient for wall friction;

$$k_{membrane} = 0.75$$

Wall friction angle;

$$\delta_{r,k} = 26.3 \text{ deg}$$

Characteristic base friction angle;

$$\delta_{bb,k} = 35.0 \text{ deg}$$

Bearing capacity of founding soil;

$$q = 150 \text{ kN/m}^2$$

Wall geometry

Horizontal distance to centre of gravity gabion 1;

$$x_{g1} = w_1 / 2 = 500 \text{ mm}$$

Vertical distance to centre of gravity gabion 1;

$$y_{g1} = h_1 / 2 = 500 \text{ mm}$$

Weight of gabion 1;

$$W_{g1} = \gamma_d \times w_1 \times h_1 = 16.0 \text{ kN/m}$$

Horizontal distance to centre of gravity gabion 2;

$$x_{g2} = w_2 / 2 + s_2 = 575 \text{ mm}$$

Vertical distance to centre of gravity gabion 2;

$$y_{g2} = h_2 / 2 + h_1 = 1500 \text{ mm}$$

Weight of gabion 2;

$$W_{g2} = \gamma_d \times w_2 \times h_2 = \mathbf{16.0 \text{ kN/m}}$$

Weight of entire gabion;

$$W_g = W_{g1} + W_{g2} = \mathbf{32.0 \text{ kN/m}}$$

Horiz distance to centre of gravity entire gabion;

$$x_g = ((W_{g1} \times x_{g1}) + (W_{g2} \times x_{g2})) / W_g = \mathbf{538 \text{ mm}}$$

Vert distance to centre of gravity entire gabion;

$$y_g = ((W_{g1} \times y_{g1}) + (W_{g2} \times y_{g2})) / W_g = \mathbf{1000 \text{ mm}}$$

Correcting for wall inclination horiz dist;

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = \mathbf{538 \text{ mm}}$$

Vertical change in height due to wall inclination;

$$H_f = y_{g2} + h_2/2 - ((y_{g2} + h_2/2) \times \cos(\epsilon) - (x_{g2} + w_2/2) \times \sin(\epsilon)) = \mathbf{0 \text{ mm}}$$

Design dimensions

Effective angle of rear plane of wall;

$$\alpha = \text{Atan}((w_1 - (x_{g2} + (w_2 / 2))) / (y_{g2} + h_2 / 2)) + 90 \text{ deg} + \epsilon = \mathbf{87.9 \text{ deg}}$$

Effective face angle;

$$\theta = \text{Atan}((y_{g2} + (h_2 / 2)) / ((x_{g2} - (w_2 / 2)))) - \epsilon = \mathbf{87.9 \text{ deg}}$$

Effective height of wall;

$$H = (y_{g2} + h_2 / 2) + (w_1 \times \sin(\epsilon)) - H_f = \mathbf{2000 \text{ mm}}$$

Height of wall from toe to front edge of top gabion;

$$H_{incl} = ((y_{g2} + h_2 / 2) \times \cos(\epsilon) - (x_{g2} - (w_2 / 2)) \times \sin(\epsilon)) = \mathbf{2000 \text{ mm}}$$

Active pressure using Coulomb theory;

$$K_a = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k}) \times (1 + \sqrt{(\sin(\phi'_{r,k} + \delta_{r,k}) \times \sin(\phi'_{r,k} - \beta) / (\sin(\alpha - \delta_{r,k}) \times \sin(\alpha + \beta))}))^2 = \mathbf{0.260}$$

Active thrust due to soil;

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{sr} \times H^2 = \mathbf{10.9 \text{ kN/m}}$$

Minimum surcharge (cl.4.6.3.2);

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = \mathbf{6.7 \text{ kN/m}^2}$$

Pressure at base

Horizontal forces

Retained soil;

$$F_{soil,h,q} = P_{a,soil} \times \cos(90 - \alpha + \delta_{r,k}) = \mathbf{9.6 \text{ kN/m}}$$

Height of soil thrust resolved vertically;

$$d_{h,soil} = H / 3 - w_1 \times \sin(\epsilon) = \mathbf{667 \text{ mm}}$$

Surcharge;

$$F_{surch,h,q} = \max(p_{o,Q}, p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,k}) = \mathbf{4.6 \text{ kN/m}}$$

Height of surcharge thrust resolved vertically;

$$d_{h,surch} = H / 2 - w_1 \times \sin(\epsilon) = \mathbf{1000 \text{ mm}}$$

Vertical forces

Gabion weight;

$$F_{gabion,v,q} = W_g = \mathbf{32.0 \text{ kN/m}}$$

Retained soil;

$$F_{soil,v,q} = P_{a,soil} \times \sin(90 - \alpha + \delta_{r,k}) = \mathbf{5.2 \text{ kN/m}}$$

Horizontal dist to where soil thrust acts;

$$b_{v,soil} = w_1 \times \cos(\epsilon) - (H / 3) / \tan(\alpha) = \mathbf{975 \text{ mm}}$$

Surcharge;

$$F_{surch,v,q} = \max(p_{o,Q}, p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,k}) = \mathbf{2.5 \text{ kN/m}}$$

Horizontal dist to where surcharge thrust acts;

$$b_{v,surch} = w_1 \times \cos(\epsilon) - (H / 2) / \tan(\alpha) = \mathbf{963 \text{ mm}}$$

Total horizontal unfactored force;

$$T_q = F_{soil,h,q} + F_{surch,h,q} = \mathbf{14.2 \text{ kN/m}}$$

Total vertical unfactored force;

$$N_q = F_{gabion,v,q} + F_{soil,v,q} + F_{surch,v,q} = \mathbf{39.7 \text{ kN/m}}$$

Force normal to base;

$$N_s = N_q \times \cos(\epsilon) + T_q \times \sin(\epsilon) = \mathbf{39.7 \text{ kN/m}}$$

Total unfactored overturning force;

$$M_{o,q} = F_{soil,h,q} \times d_{h,soil} + F_{surch,h,q} \times d_{h,surch} = \mathbf{11.0 \text{ kNm/m}}$$

Total unfactored restoring force;

$$M_{R,q} = F_{gabion,v,q} \times X_g + F_{soil,v,q} \times b_{v,soil} + F_{surch,v,q} \times b_{v,surch} = \mathbf{24.7 \text{ kNm/m}}$$

Eccentricity;

$$e = w_1 / 2 - (M_{R,q} - M_{o,q}) / N_s = \mathbf{156 \text{ mm}}$$

Reaction acts within middle third of base

Pressure at toe;

$$\sigma_{toe} = N_s / w_1 \times (1 + (6 \times e / w_1)) = \mathbf{76.8 \text{ kN/m}^2}$$

Pressure at heel;

$$\sigma_{heel} = N_s / w_1 \times (1 - (6 \times e / w_1)) = \mathbf{2.6 \text{ kN/m}^2}$$

Factor of safety;

$$FoS_Q = q / \max(\sigma_{toe}, \sigma_{heel}) = \mathbf{1.954}$$

Allowable factor of safety;

$$FoS_{Q,allow} = \mathbf{1.000}$$

PASS - Design FoS for allowable bearing pressure exceeds min allowable pressure to base

Design approach 1

Partial factors on actions - Section A.3.1 - Combination 1

Permanent unfavourable action;

$$\gamma_G = \mathbf{1.35}$$

Permanent favourable action;

$$\gamma_{G,f} = \mathbf{1.00}$$

Variable unfavourable action;

$$\gamma_Q = \mathbf{1.50}$$

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Variable favourable action;

$$\gamma_{Q,f} = 0.00$$

Partial factors for soil parameters - Section A.3.2 - Combination 1

Angle of shearing resistance;

$$\gamma_{\phi'} = 1.00$$

Weight density;

$$\gamma_{\gamma} = 1.00$$

Design soil properties

Design effective shearing resistance angle;

$$\phi'_{r,d} = \text{Atan}(\tan(\phi'_{pk,k}) / \gamma_{\phi'}) = 35.0 \text{ deg}$$

Design saturated density of retained soil;

$$\gamma_{s,d} = \gamma_{sr} / \gamma_{\gamma} = 21.0 \text{ kN/m}^3$$

Design wall friction angle (cl.5.4.2.1);

$$\delta_{r,d} = \min(\text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}), \phi'_{r,d} \times k_{\text{membrane}}) = 26.3 \text{ deg}$$

Design base friction angle;

$$\delta_{bb,d} = \text{Atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = 35.0 \text{ deg}$$

Design friction between gabions;

$$\delta_{bg,d} = \text{Atan}(\tan(\delta_{bg,k}) / \gamma_{\phi'}) = 35.0 \text{ deg}$$

Active pressure using Coulomb theory;

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta)))})^2) = 0.260$$

Active thrust due to soil;

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 10.9 \text{ kN/m}$$

Minimum surcharge (cl.4.6.3.2);

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 6.7 \text{ kN/m}^2$$

Horizontal forces

Retained soil;

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 13.0 \text{ kN/m}$$

Surcharge;

$$F_{surch,h} = \max(p_{o,Q} \times \gamma_Q, p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 6.9 \text{ kN/m}$$

Vertical forces

Gabion weight;

$$F_{gabion,v,f} = \gamma_{G,f} \times W_g = 32.0 \text{ kN/m}$$

Retained soil;

$$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 5.2 \text{ kN/m}$$

Surcharge;

$$F_{surch,v,f} = \max(p_{o,Q} \times \gamma_Q, p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 1.7 \text{ kN/m}$$

Overtuning stability - take moments about the toe

Overtuning moment;

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 15.5 \text{ kNm/m}$$

Restoring moment;

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times b_{v,soil} + F_{surch,v,f} \times b_{v,surch} = 23.9 \text{ kNm/m}$$

Factor of safety;

$$FoSM = M_R / M_o = 1.536$$

Allowable factor of safety;

$$FoSM_{allow} = 1.000$$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force;

$$T = F_{soil,h} + F_{surch,h} = 19.9 \text{ kN/m}$$

Total vertical force;

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 38.9 \text{ kN/m}$$

Sliding force;

$$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 19.9 \text{ kN/m}$$

Sliding resistance;

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bb,d}) = 27.2 \text{ kN/m}$$

Factor of safety;

$$FoSS = F_R / F_f = 1.370$$

Allowable factor of safety;

$$FoSS_{allow} = 1.000$$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Check overturning and sliding between courses 1 and 2

Wall geometry

Horizontal distance to centre of gravity gabion 2;

$$x_{g2} = w_2 / 2 = 500 \text{ mm}$$

Vertical distance to centre of gravity gabion 2;

$$y_{g2} = h_2 / 2 = 500 \text{ mm}$$

Weight of gabion 2;

$$W_{g2} = \gamma_d \times w_2 \times h_2 = 16.0 \text{ kN/m}$$

Weight of entire gabion;

$$W_g = W_{g2} = 16.0 \text{ kN/m}$$

Horiz distance to centre of gravity entire gabion;

$$x_g = ((W_{g2} \times x_{g2})) / W_g = 500 \text{ mm}$$

Vert distance to centre of gravity entire gabion;

$$y_g = ((W_{g2} \times y_{g2})) / W_g = 500 \text{ mm}$$

Correcting for wall inclination horiz dist;

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 500 \text{ mm}$$

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Vertical change in height due to wall inclination; $H_f = y_{g2} + h_2/2 - ((y_{g2} + h_2/2) \times \cos(\epsilon) - (x_{g2} + w_2/2) \times \sin(\epsilon)) = 0 \text{ mm}$

Design dimensions

Effective angle of rear plane of wall;

$$\alpha = 90 \text{ deg} + \epsilon = 90.0 \text{ deg}$$

Effective face angle;

$$\theta = 90 \text{ deg} - \epsilon = 90.0 \text{ deg}$$

Effective height of wall;

$$H = (y_{g2} + h_2 / 2) + (w_2 \times \sin(\epsilon)) - H_f = 1000 \text{ mm}$$

Height of wall from toe to front edge of top gabion;

$$H_{incl} = ((y_{g2} + h_2 / 2) \times \cos(\epsilon) - (x_{g2} - (w_2 / 2)) \times \sin(\epsilon)) = 1000 \text{ mm}$$

Active pressure using Coulomb theory;

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta)))^2}) = 0.245$$

Active thrust due to soil;

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 2.6 \text{ kN/m}$$

Minimum surcharge (cl.4.6.3.2);

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 3.3 \text{ kN/m}^2$$

Horizontal forces

Retained soil;

$$F_{soil_h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 3.1 \text{ kN/m}$$

Surcharge;

$$F_{surch_h} = \max(p_{o,Q} \times \gamma_Q, p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 3.3 \text{ kN/m}$$

Vertical forces

Gabion weight;

$$F_{gabion_v,f} = \gamma_{G,f} \times W_g = 16.0 \text{ kN/m}$$

Retained soil;

$$F_{soil_v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 1.1 \text{ kN/m}$$

Surcharge;

$$F_{surch_v,f} = \max(p_{o,Q} \times \gamma_{Q,f}, p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 0.4 \text{ kN/m}$$

Overturning stability - take moments about the toe

Overturning moment;

$$M_o = F_{soil_h} \times d_{h,soil} + F_{surch_h} \times d_{h,surch} = 2.7 \text{ kNm/m}$$

Restoring moment;

$$M_R = F_{gabion_v,f} \times X_g + F_{soil_v,f} \times b_{v,soil} + F_{surch_v,f} \times b_{v,surch} = 9.5 \text{ kNm/m}$$

Factor of safety;

$$FoSM = M_R / M_o = 3.541$$

Allowable factor of safety;

$$FoSM_{allow} = 1.000$$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force;

$$T = F_{soil_h} + F_{surch_h} = 6.4 \text{ kN/m}$$

Total vertical force;

$$N = F_{gabion_v,f} + F_{soil_v,f} + F_{surch_v,f} = 17.5 \text{ kN/m}$$

Sliding force;

$$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 6.4 \text{ kN/m}$$

Sliding resistance;

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 12.3 \text{ kN/m}$$

Factor of safety;

$$FoSS = F_R / F_f = 1.914$$

Allowable factor of safety;

$$FoSS_{allow} = 1.000$$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Design approach 1

Partial factors on actions - Section A.3.1 - Combination 2

Permanent unfavourable action;

$$\gamma_G = 1.00$$

Permanent favourable action;

$$\gamma_{G,f} = 1.00$$

Variable unfavourable action;

$$\gamma_Q = 1.30$$

Variable favourable action;

$$\gamma_{Q,f} = 0.00$$

Partial factors for soil parameters - Section A.3.2 - Combination 2

Angle of shearing resistance;

$$\gamma_{\phi} = 1.25$$

Weight density;

$$\gamma_{\gamma} = 1.00$$

Design soil properties

Design effective shearing resistance angle;

$$\phi'_{r,d} = \text{Atan}(\tan(\phi'_{pk,k}) / \gamma_{\phi}) = 29.3 \text{ deg}$$

Design saturated density of retained soil;

$$\gamma_{s,d} = \gamma_{sr} / \gamma_{\gamma} = 21.0 \text{ kN/m}^3$$

Design wall friction angle (cl.5.4.2.1);

$$\delta_{r,d} = \min(\text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi}), \phi'_{r,d} \times k_{\text{membrane}}) = 21.5 \text{ deg}$$

Design base friction angle;

$$\delta_{bb,d} = \text{Atan}(\tan(\delta_{bb,k}) / \gamma_{\phi}) = \mathbf{29.3 \text{ deg}}$$

Design friction between gabions;

$$\delta_{bg,d} = \text{Atan}(\tan(\delta_{bg,k}) / \gamma_{\phi}) = \mathbf{29.3 \text{ deg}}$$

Wall geometry

Horizontal distance to centre of gravity gabion 1;

$$x_{g1} = w_1 / 2 = \mathbf{500 \text{ mm}}$$

Vertical distance to centre of gravity gabion 1;

$$y_{g1} = h_1 / 2 = \mathbf{500 \text{ mm}}$$

Weight of gabion 1;

$$W_{g1} = \gamma_d \times w_1 \times h_1 = \mathbf{16.0 \text{ kN/m}}$$

Horizontal distance to centre of gravity gabion 2;

$$x_{g2} = w_2 / 2 + s_2 = \mathbf{575 \text{ mm}}$$

Vertical distance to centre of gravity gabion 2;

$$y_{g2} = h_2 / 2 + h_1 = \mathbf{1500 \text{ mm}}$$

Weight of gabion 2;

$$W_{g2} = \gamma_d \times w_2 \times h_2 = \mathbf{16.0 \text{ kN/m}}$$

Weight of entire gabion;

$$W_g = W_{g1} + W_{g2} = \mathbf{32.0 \text{ kN/m}}$$

Horiz distance to centre of gravity entire gabion;

$$x_g = ((W_{g1} \times x_{g1}) + (W_{g2} \times x_{g2})) / W_g = \mathbf{538 \text{ mm}}$$

Vert distance to centre of gravity entire gabion;

$$y_g = ((W_{g1} \times y_{g1}) + (W_{g2} \times y_{g2})) / W_g = \mathbf{1000 \text{ mm}}$$

Correcting for wall inclination horiz dist;

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = \mathbf{538 \text{ mm}}$$

Vertical change in height due to wall inclination;

$$H_f = y_{g2} + h_2/2 - ((y_{g2} + h_2/2) \times \cos(\epsilon) - (x_{g2} + w_2/2) \times \sin(\epsilon)) = \mathbf{0 \text{ mm}}$$

Design dimensions

Effective angle of rear plane of wall;

$$\alpha = \text{Atan}((w_1 - (x_{g2} + (w_2 / 2))) / (y_{g2} + h_2 / 2)) + 90 \text{ deg} + \epsilon = \mathbf{87.9 \text{ deg}}$$

Effective face angle;

$$\theta = \text{Atan}((y_{g2} + (h_2 / 2)) / ((x_{g2} - (w_2 / 2)))) - \epsilon = \mathbf{87.9 \text{ deg}}$$

Effective height of wall;

$$H = (y_{g2} + h_2 / 2) + (w_1 \times \sin(\epsilon)) - H_f = \mathbf{2000 \text{ mm}}$$

Height of wall from toe to front edge of top gabion;

$$H_{incl} = ((y_{g2} + h_2 / 2) \times \cos(\epsilon) - (x_{g2} - (w_2 / 2)) \times \sin(\epsilon)) = \mathbf{2000 \text{ mm}}$$

Active pressure using Coulomb theory;

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))}))^2 = \mathbf{0.321}$$

Active thrust due to soil;

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{13.5 \text{ kN/m}}$$

Minimum surcharge (cl.4.6.3.2);

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = \mathbf{6.7 \text{ kN/m}^2}$$

Horizontal forces

Retained soil;

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{12.3 \text{ kN/m}}$$

Surcharge;

$$F_{surch,h} = \max(p_{o,Q} \times \gamma_Q, p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{7.6 \text{ kN/m}}$$

Vertical forces

Gabion weight;

$$F_{gabion,v,f} = \gamma_{G,f} \times W_g = \mathbf{32.0 \text{ kN/m}}$$

Retained soil;

$$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{5.4 \text{ kN/m}}$$

Surcharge;

$$F_{surch,v,f} = \max(p_{o,Q} \times \gamma_{Q,f}, p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{1.7 \text{ kN/m}}$$

Overturning stability - take moments about the toe

Overturning moment;

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = \mathbf{15.9 \text{ kNm/m}}$$

Restoring moment;

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times b_{v,soil} + F_{surch,v,f} \times b_{v,surch} = \mathbf{24.1 \text{ kNm/m}}$$

Factor of safety;

$$FoS_M = M_R / M_o = \mathbf{1.521}$$

Allowable factor of safety;

$$FoS_{M_allow} = \mathbf{1.000}$$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force;

$$T = F_{soil,h} + F_{surch,h} = \mathbf{20.0 \text{ kN/m}}$$

Total vertical force;

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = \mathbf{39.1 \text{ kN/m}}$$

Sliding force;

$$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = \mathbf{20.0 \text{ kN/m}}$$

Sliding resistance;

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bb,d}) = \mathbf{21.9 \text{ kN/m}}$$

Factor of safety;

$$FoS_S = F_R / F_f = \mathbf{1.097}$$

Allowable factor of safety;

$$FoS_{S_allow} = \mathbf{1.000}$$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Project 3 Fernfield, Baglan				Job no. 23-030	
Calcs for Driveway Retaining Walls				Start page no./Revision 7	
Calcs by JD	Calcs date 27/04/2023	Checked by	Checked date	Approved by	Approved date

Check overturning and sliding between courses 1 and 2

Wall geometry

Horizontal distance to centre of gravity gabion 2;	$x_{g2} = w_2 / 2 = 500 \text{ mm}$
Vertical distance to centre of gravity gabion 2;	$y_{g2} = h_2 / 2 = 500 \text{ mm}$
Weight of gabion 2;	$W_{g2} = \gamma_d \times w_2 \times h_2 = 16.0 \text{ kN/m}$
Weight of entire gabion;	$W_g = W_{g2} = 16.0 \text{ kN/m}$
Horiz distance to centre of gravity entire gabion;	$x_g = ((W_{g2} \times x_{g2})) / W_g = 500 \text{ mm}$
Vert distance to centre of gravity entire gabion;	$y_g = ((W_{g2} \times y_{g2})) / W_g = 500 \text{ mm}$
Correcting for wall inclination horiz dist;	$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 500 \text{ mm}$
Vertical change in height due to wall inclination;	$H_f = y_{g2} + h_2/2 - ((y_{g2} + h_2/2) \times \cos(\epsilon) - (x_{g2} + w_2/2) \times \sin(\epsilon)) = 0 \text{ mm}$

Design dimensions

Effective angle of rear plane of wall;	$\alpha = 90 \text{ deg} + \epsilon = 90.0 \text{ deg}$
Effective face angle;	$\theta = 90 \text{ deg} - \epsilon = 90.0 \text{ deg}$
Effective height of wall;	$H = (y_{g2} + h_2 / 2) + (w_2 \times \sin(\epsilon)) - H_f = 1000 \text{ mm}$
Height of wall from toe to front edge of top gabion;	$H_{incl} = ((y_{g2} + h_2 / 2) \times \cos(\epsilon) - (x_{g2} - (w_2 / 2)) \times \sin(\epsilon)) = 1000 \text{ mm}$
Active pressure using Coulomb theory;	$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta)))})^2) = 0.305$
Active thrust due to soil;	$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 3.2 \text{ kN/m}$
Minimum surcharge (cl.4.6.3.2);	$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 3.3 \text{ kN/m}^2$

Horizontal forces

Retained soil;	$F_{soil_h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 3.0 \text{ kN/m}$
Surcharge;	$F_{surch_h} = \max(p_{o,Q} \times \gamma_Q, p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 3.7 \text{ kN/m}$

Vertical forces

Gabion weight;	$F_{gabion_v,f} = \gamma_{G,f} \times W_g = 16.0 \text{ kN/m}$
Retained soil;	$F_{soil_v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 1.2 \text{ kN/m}$
Surcharge;	$F_{surch_v,f} = \max(p_{o,Q} \times \gamma_{Q,f}, p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 0.4 \text{ kN/m}$

Overturning stability - take moments about the toe

Overturning moment;	$M_o = F_{soil_h} \times d_{h,soil} + F_{surch_h} \times d_{h,surch} = 2.8 \text{ kNm/m}$
Restoring moment;	$M_R = F_{gabion_v,f} \times X_g + F_{soil_v,f} \times b_{v,soil} + F_{surch_v,f} \times b_{v,surch} = 9.5 \text{ kNm/m}$
Factor of safety;	$FoS_M = M_R / M_o = 3.366$
Allowable factor of safety;	$FoS_{M_allow} = 1.000$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force;	$T = F_{soil_h} + F_{surch_h} = 6.7 \text{ kN/m}$
Total vertical force;	$N = F_{gabion_v,f} + F_{soil_v,f} + F_{surch_v,f} = 17.5 \text{ kN/m}$
Sliding force;	$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 6.7 \text{ kN/m}$
Sliding resistance;	$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 9.8 \text{ kN/m}$
Factor of safety;	$FoS_S = F_R / F_f = 1.474$
Allowable factor of safety;	$FoS_{S_allow} = 1.000$

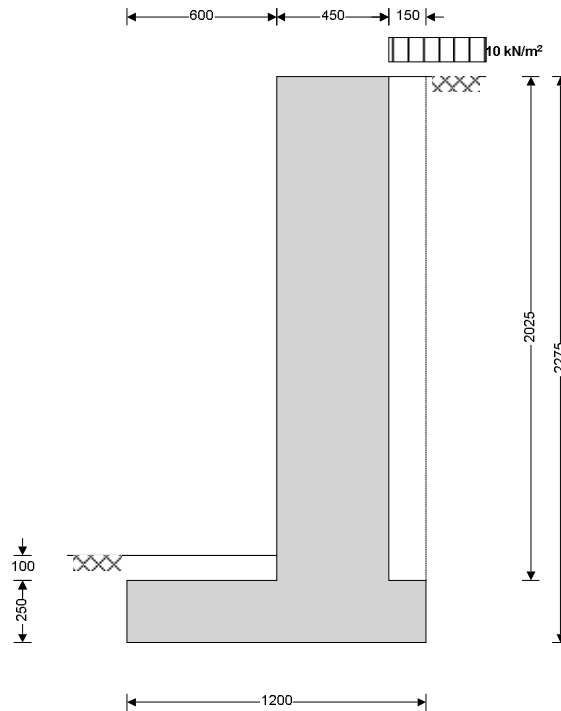
PASS - Design FOS for sliding exceeds min allowable FOS for sliding

;

SECTION 2

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

$h_{\text{stem}} = 2025 \text{ mm}$
 $t_{\text{wall}} = 450 \text{ mm}$
 $l_{\text{toe}} = 600 \text{ mm}$
 $l_{\text{heel}} = 150 \text{ mm}$
 $l_{\text{base}} = l_{\text{toe}} + l_{\text{heel}} + t_{\text{wall}} = 1200 \text{ mm}$
 $t_{\text{base}} = 250 \text{ mm}$
 $d_{\text{ds}} = 0 \text{ mm}$
 $l_{\text{ds}} = 950 \text{ mm}$
 $t_{\text{ds}} = 250 \text{ mm}$
 $h_{\text{wall}} = h_{\text{stem}} + t_{\text{base}} + d_{\text{ds}} = 2275 \text{ mm}$
 $d_{\text{cover}} = 100 \text{ mm}$
 $d_{\text{exc}} = 0 \text{ mm}$
 $h_{\text{water}} = 0 \text{ mm}$
 $h_{\text{sat}} = \max(h_{\text{water}} - t_{\text{base}} - d_{\text{ds}}, 0 \text{ mm}) = 0 \text{ mm}$
 $\gamma_{\text{wall}} = 19.0 \text{ kN/m}^3$
 $\gamma_{\text{base}} = 24.0 \text{ kN/m}^3$
 $\alpha = 90.0 \text{ deg}$
 $\beta = 0.0 \text{ deg}$
 $h_{\text{eff}} = h_{\text{wall}} + l_{\text{heel}} \times \tan(\beta) = 2275 \text{ mm}$

Retained material details

Mobilisation factor;
Moist density of retained material;

$M = 1.2$
 $\gamma_m = 21.0 \text{ kN/m}^3$

Saturated density of retained material;

$$\gamma_s = 23.0 \text{ kN/m}^3$$

Design shear strength;

$$\phi' = 30.3 \text{ deg}$$

Angle of wall friction;

$$\delta = 23.7 \text{ deg}$$

Base material details

Moist density;

$$\gamma_{mb} = 21.0 \text{ kN/m}^3$$

Design shear strength;

$$\phi'_b = 30.3 \text{ deg}$$

Design base friction;

$$\delta_b = 23.7 \text{ deg}$$

Allowable bearing pressure;

$$P_{\text{bearing}} = 150 \text{ kN/m}^2$$

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))})^2] = 0.293$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))})^2] = 7.371$$

At-rest pressure

At-rest pressure for retained material;

$$K_0 = 1 - \sin(\phi') = 0.495$$

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;

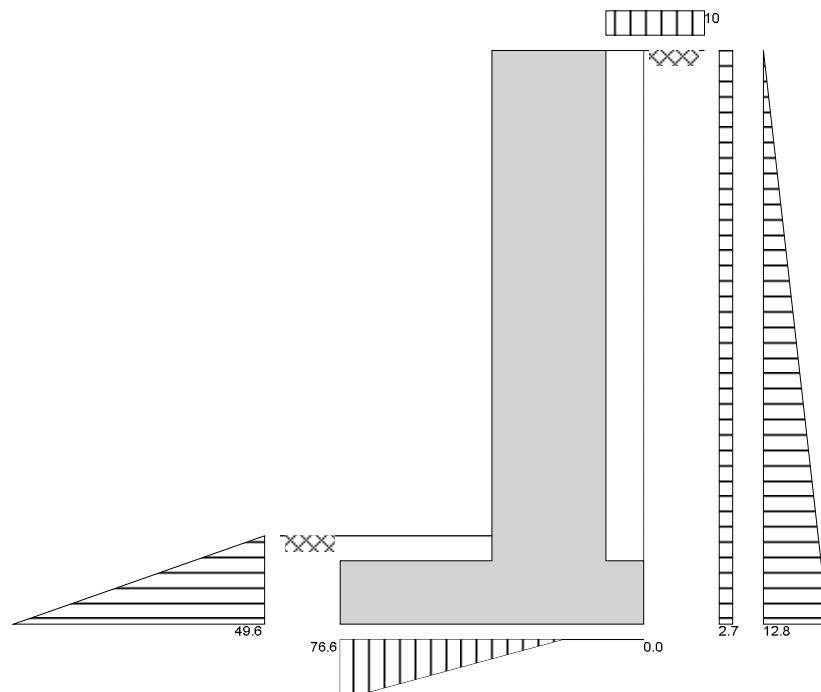
$$F_{\text{dead}} = 0.0 \text{ kN/m}$$

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

Vertical forces on wall

Wall stem;

$$w_{\text{wall}} = h_{\text{stem}} \times t_{\text{wall}} \times \gamma_{\text{wall}} = 17.3 \text{ kN/m}$$

Wall base;

$$W_{base} = l_{base} \times t_{base} \times \gamma_{base} = 7.2 \text{ kN/m}$$

Surcharge;

$$W_{sur} = \text{Surcharge} \times l_{heel} = 1.5 \text{ kN/m}$$

Moist backfill to top of wall;

$$W_{m_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 6.4 \text{ kN/m}$$

Soil in front of wall;

$$W_p = l_{toe} \times d_{cover} \times \gamma_{mb} = 1.3 \text{ kN/m}$$

Total vertical load;

$$W_{total} = W_{wall} + W_{base} + W_{sur} + W_{m_w} + W_p = 33.7 \text{ kN/m}$$

Horizontal forces on wall

Surcharge;

$$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff} = 6.1 \text{ kN/m}$$

Moist backfill above water table;

$$F_{m_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2 = 14.6 \text{ kN/m}$$

Total horizontal load;

$$F_{total} = F_{sur} + F_{m_a} = 20.7 \text{ kN/m}$$

Calculate stability against sliding

Passive resistance of soil in front of wall;

$$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 8.7 \text{ kN/m}$$

Resistance to sliding;

$$F_{res} = F_p + (W_{total} - W_{sur} - W_p) \times \tan(\delta_b) = 22.2 \text{ kN/m}$$

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge;

$$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 = 6.9 \text{ kNm/m}$$

Moist backfill above water table;

$$M_{m_a} = F_{m_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 11 \text{ kNm/m}$$

Total overturning moment;

$$M_{ot} = M_{sur} + M_{m_a} = 18 \text{ kNm/m}$$

Restoring moments

Wall stem;

$$M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2) = 14.3 \text{ kNm/m}$$

Wall base;

$$M_{base} = W_{base} \times l_{base} / 2 = 4.3 \text{ kNm/m}$$

Moist backfill;

$$M_{m_r} = (W_{m_w} \times (l_{base} - l_{heel} / 2) + W_{m_s} \times (l_{base} - l_{heel} / 3)) = 7.2 \text{ kNm/m}$$

Total restoring moment;

$$M_{rest} = M_{wall} + M_{base} + M_{m_r} = 25.8 \text{ kNm/m}$$

Check stability against overturning

Total overturning moment;

$$M_{ot} = 18.0 \text{ kNm/m}$$

Total restoring moment;

$$M_{rest} = 25.8 \text{ kNm/m}$$

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge;

$$M_{sur_r} = W_{sur} \times (l_{base} - l_{heel} / 2) = 1.7 \text{ kNm/m}$$

Soil in front of wall;

$$M_{p_r} = W_p \times l_{toe} / 2 = 0.4 \text{ kNm/m}$$

Total moment for bearing;

$$M_{total} = M_{rest} - M_{ot} + M_{sur_r} + M_{p_r} = 9.9 \text{ kNm/m}$$

Total vertical reaction;

$$R = W_{total} = 33.7 \text{ kN/m}$$

Distance to reaction;

$$x_{bar} = M_{total} / R = 293 \text{ mm}$$

Eccentricity of reaction;

$$e = \text{abs}((l_{base} / 2) - x_{bar}) = 307 \text{ mm}$$

Reaction acts outside middle third of base

Bearing pressure at toe;

$$p_{toe} = R / (1.5 \times x_{bar}) = 76.6 \text{ kN/m}^2$$

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

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;

$$W_{wall_f} = \gamma_{f_d} \times h_{stem} \times t_{wall} \times \gamma_{wall} = 24.2 \text{ kN/m}$$

Wall base;

$$W_{base_f} = \gamma_{f_d} \times l_{base} \times t_{base} \times \gamma_{base} = 10.1 \text{ kN/m}$$

Surcharge;

$$W_{sur_f} = \gamma_{f_l} \times \text{Surcharge} \times l_{heel} = 2.4 \text{ kN/m}$$

Moist backfill to top of wall;

$$W_{m_w_f} = \gamma_{f_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 8.9 \text{ kN/m}$$

Soil in front of wall;

$$W_{p_f} = \gamma_{f_d} \times l_{toe} \times d_{cover} \times \gamma_{mb} = 1.8 \text{ kN/m}$$

Total vertical load;

$$W_{total_f} = W_{wall_f} + W_{base_f} + W_{sur_f} + W_{m_w_f} + W_{p_f} = 47.4 \text{ kN/m}$$

Factored horizontal active forces on wall

Surcharge;

$$F_{sur_f} = \gamma_{f_l} \times K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff} = 9.8 \text{ kN/m}$$

Moist backfill above water table;

$$F_{m_a_f} = \gamma_{f_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2 = 20.4 \text{ kN/m}$$

Total horizontal load;

$$F_{total_f} = F_{sur_f} + F_{m_a_f} = 30.2 \text{ kN/m}$$

Passive resistance of soil in front of wall;
kN/m

$$F_{p_f} = \gamma_{f_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 12.2$$

Factored overturning moments

Surcharge;

$$M_{sur_f} = F_{sur_f} \times (h_{eff} - 2 \times d_{ds}) / 2 = 11.1 \text{ kNm/m}$$

Moist backfill above water table;

$$M_{m_a_f} = F_{m_a_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 15.5 \text{ kNm/m}$$

Total overturning moment;

$$M_{ot_f} = M_{sur_f} + M_{m_a_f} = 26.6 \text{ kNm/m}$$

Restoring moments

Wall stem;

$$M_{wall_f} = W_{wall_f} \times (l_{toe} + t_{wall} / 2) = 20 \text{ kNm/m}$$

Wall base;

$$M_{base_f} = W_{base_f} \times l_{base} / 2 = 6 \text{ kNm/m}$$

Surcharge;

$$M_{sur_r_f} = W_{sur_f} \times (l_{base} - l_{heel} / 2) = 2.7 \text{ kNm/m}$$

Moist backfill;

$$M_{m_r_f} = (W_{m_w_f} \times (l_{base} - l_{heel} / 2) + W_{m_s_f} \times (l_{base} - l_{heel} / 3)) = 10 \text{ kNm/m}$$

Soil in front of wall;

$$M_{p_r_f} = W_{p_f} \times l_{toe} / 2 = 0.5 \text{ kNm/m}$$

Total restoring moment;

$$M_{rest_f} = M_{wall_f} + M_{base_f} + M_{sur_r_f} + M_{m_r_f} + M_{p_r_f} = 39.3 \text{ kNm/m}$$

Factored bearing pressure

Total moment for bearing;

$$M_{total_f} = M_{rest_f} - M_{ot_f} = 12.8 \text{ kNm/m}$$

Total vertical reaction;

$$R_f = W_{total_f} = 47.4 \text{ kN/m}$$

Distance to reaction;

$$x_{bar_f} = M_{total_f} / R_f = 269 \text{ mm}$$

Eccentricity of reaction;

$$e_f = \text{abs}((l_{base} / 2) - x_{bar_f}) = 331 \text{ mm}$$

Reaction acts outside middle third of base

Bearing pressure at toe;

$$p_{toe_f} = R_f / (1.5 \times x_{bar_f}) = 117.5 \text{ kN/m}^2$$

Bearing pressure at heel;

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

Rate of change of base reaction;

$$\text{rate} = p_{toe_f} / (3 \times x_{bar_f}) = 145.52 \text{ kN/m}^2/\text{m}$$

Bearing pressure at stem / toe;

$$p_{stem_toe_f} = \text{max}(p_{toe_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2) = 30.2 \text{ kN/m}^2$$

Bearing pressure at mid stem;

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

Bearing pressure at stem / heel;

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

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

Material properties

Characteristic strength of concrete;

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

Project 3 Fernfield, Baglan				Job no. 23-030	
Calcs for Driveway Retaining Walls				Start page no./Revision 12	
Calcs by JD	Calcs date 27/04/2023	Checked by	Checked date	Approved by	Approved date

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;

$$c_{toe} = 30 \text{ mm}$$

Calculate shear for toe design

Shear from bearing pressure;

$$V_{toe_bear} = (p_{toe_f} + p_{stem_toe_f}) \times l_{toe} / 2 = 44.3 \text{ kN/m}$$

Shear from weight of base;

$$V_{toe_wt_base} = \gamma_{f_d} \times \gamma_{base} \times l_{toe} \times t_{base} = 5 \text{ kN/m}$$

Shear from weight of soil;

$$V_{toe_wt_soil} = w_{p_f} - (\gamma_{f_d} \times \gamma_m \times l_{toe} \times d_{exc}) = 1.8 \text{ kN/m}$$

Total shear for toe design;

$$V_{toe} = V_{toe_bear} - V_{toe_wt_base} - V_{toe_wt_soil} = 37.5 \text{ kN/m}$$

Calculate moment for toe design

Moment from bearing pressure;

$$M_{toe_bear} = (2 \times p_{toe_f} + p_{stem_mid_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = 26.7 \text{ kNm/m}$$

Moment from weight of base;

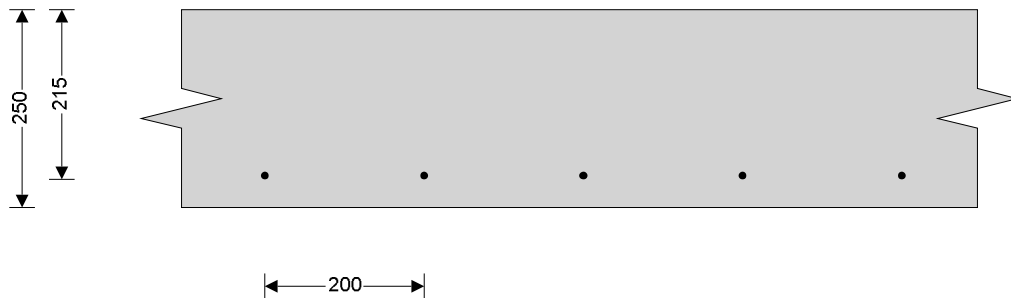
$$M_{toe_wt_base} = (\gamma_{f_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = 2.9 \text{ kNm/m}$$

Moment from weight of soil;

$$M_{toe_wt_soil} = (w_{p_f} - (\gamma_{f_d} \times \gamma_m \times l_{toe} \times d_{exc})) \times (l_{toe} + t_{wall}) / 2 = 0.9 \text{ kNm/m}$$

Total moment for toe design;

$$M_{toe} = M_{toe_bear} - M_{toe_wt_base} - M_{toe_wt_soil} = 22.9 \text{ kNm/m}$$



Check toe in bending

Width of toe;

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

Depth of reinforcement;

$$d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = 215.0 \text{ mm}$$

Constant;

$$K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = 0.014$$

Compression reinforcement is not required

Lever arm;

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

$$z_{toe} = 204 \text{ mm}$$

Area of tension reinforcement required;

$$A_{s_toe_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = 257 \text{ mm}^2/\text{m}$$

Minimum area of tension reinforcement;

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

Area of tension reinforcement required;

$$A_{s_toe_req} = \text{Max}(A_{s_toe_des}, A_{s_toe_min}) = 325 \text{ mm}^2/\text{m}$$

Reinforcement provided;

A393 mesh

Area of reinforcement provided;

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

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress;

$$v_{toe} = V_{toe} / (b \times d_{toe}) = 0.174 \text{ N/mm}^2$$

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;

$$v_{c_toe} = 0.468 \text{ N/mm}^2$$

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

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Design of reinforced concrete retaining wall heel (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

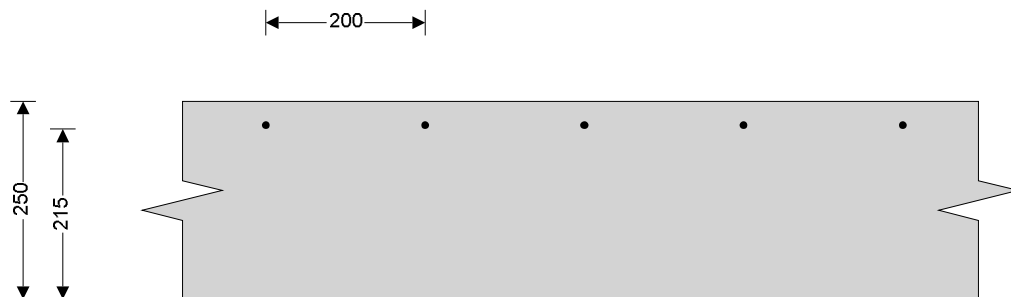
Minimum area of reinforcement; $k = 0.13 \%$
Cover to reinforcement in heel; $C_{heel} = 30 \text{ mm}$

Calculate shear for heel design

Shear from weight of base; $V_{heel_wt_base} = \gamma_{fd} \times \gamma_{base} \times l_{heel} \times t_{base} = 1.3 \text{ kN/m}$
Shear from weight of moist backfill; $V_{heel_wt_m} = w_{m_w_f} = 8.9 \text{ kN/m}$
Shear from surcharge; $V_{heel_sur} = w_{sur_f} = 2.4 \text{ kN/m}$
Total shear for heel design; $V_{heel} = V_{heel_wt_base} + V_{heel_wt_m} + V_{heel_sur} = 12.6 \text{ kN/m}$

Calculate moment for heel design

Moment from weight of base; $M_{heel_wt_base} = (\gamma_{fd} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) = 0.6 \text{ kNm/m}$
Moment from weight of moist backfill; $M_{heel_wt_m} = w_{m_w_f} \times (l_{heel} + t_{wall}) / 2 = 2.7 \text{ kNm/m}$
Moment from surcharge; $M_{heel_sur} = w_{sur_f} \times (l_{heel} + t_{wall}) / 2 = 0.7 \text{ kNm/m}$
Total moment for heel design; $M_{heel} = M_{heel_wt_base} + M_{heel_wt_m} + M_{heel_sur} = 4 \text{ kNm/m}$



Check heel in bending

Width of heel; $b = 1000 \text{ mm/m}$
Depth of reinforcement; $d_{heel} = t_{base} - C_{heel} - (\phi_{heel} / 2) = 215.0 \text{ mm}$
Constant; $K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu}) = 0.002$

Compression reinforcement is not required

Lever arm; $Z_{heel} = \min(0.5 + \sqrt{(0.25 - (\min(K_{heel}, 0.225) / 0.9))}, 0.95) \times d_{heel}$
 $Z_{heel} = 204 \text{ mm}$

Area of tension reinforcement required; $A_{s_heel_des} = M_{heel} / (0.87 \times f_y \times Z_{heel}) = 45 \text{ mm}^2/\text{m}$
Minimum area of tension reinforcement; $A_{s_heel_min} = k \times b \times t_{base} = 325 \text{ mm}^2/\text{m}$
Area of tension reinforcement required; $A_{s_heel_req} = \max(A_{s_heel_des}, A_{s_heel_min}) = 325 \text{ mm}^2/\text{m}$
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; $v_{heel} = V_{heel} / (b \times d_{heel}) = 0.059 \text{ N/mm}^2$
Allowable shear stress; $v_{adm} = \min(0.8 \times \sqrt{f_{cu}}, 5) \times 1 \text{ N/mm}^2 = 4.733 \text{ N/mm}^2$
PASS - Design shear stress is less than maximum shear stress

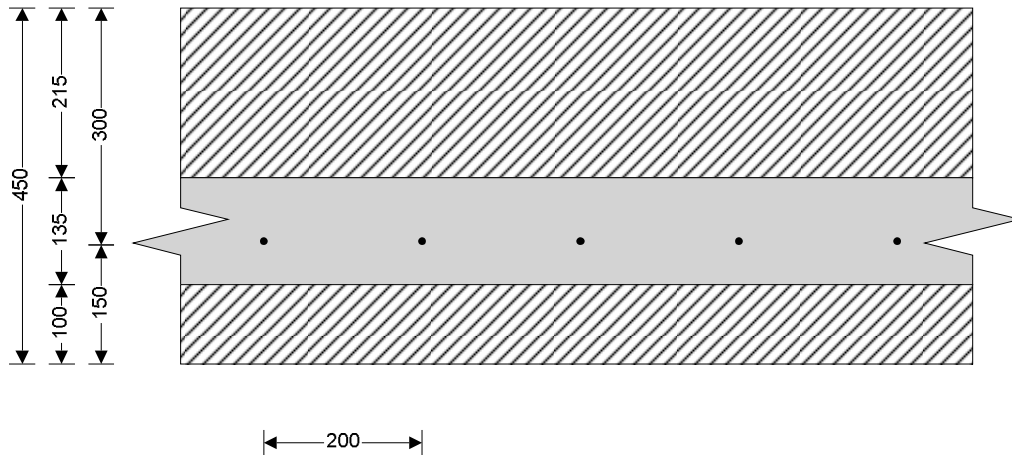
From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress; $v_{c_heel} = 0.468 \text{ N/mm}^2$

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

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



Wall details

Thickness of outer leaf of wall;
Thickness of inner leaf of wall;
Thickness of reinforced cavity;
Depth of stem reinforcement;

$t_{outer} = 215 \text{ mm}$
 $t_{inner} = 100 \text{ mm}$
 $t_{cavity} = t_{wall} - t_{outer} - t_{inner} = 135 \text{ mm}$
 $d_{stem} = 300 \text{ mm}$

Masonry details

Masonry type;
Compressive strength of units;
Mortar designation;
Category of manufacturing control of units;
Partial safety factor for material strength;

Aggregate concrete blocks no voids
 $p_{unit} = 10.0 \text{ N/mm}^2$
(ii)
Normal
 $\gamma_{mm} = 2.3$

Characteristic compressive strength of masonry

Least horizontal dimension of masonry units;
Height of masonry units;
Ratio of height to least horizontal dimension;

$b_{unit} = 100.0 \text{ mm}$
 $h_{unit} = 215.0 \text{ mm}$
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 active forces on stem

Surcharge;
kN/m

$F_{s_sur_f} = \gamma_{f_l} \times K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = 8.7$

Moist backfill above water table;
16.2 kN/m

$F_{s_m_a_f} = 0.5 \times \gamma_{f_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 =$

Calculate shear for stem design

Shear at base of stem;

$V_{stem} = F_{s_sur_f} + F_{s_m_a_f} = 24.8 \text{ kN/m}$

Calculate moment for stem design

Surcharge;
Moist backfill above water table;
Total moment for stem design;

$M_{s_sur} = F_{s_sur_f} \times (h_{stem} + t_{base}) / 2 = 9.9 \text{ kNm/m}$
 $M_{s_m_a} = F_{s_m_a_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = 12.9 \text{ kNm/m}$
 $M_{stem} = M_{s_sur} + M_{s_m_a} = 22.8 \text{ kNm/m}$

Check maximum design moment for wall stem

Width of wall;

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

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Maximum design moment;

$$M_{d_stem} = 0.4 \times f_k \times b \times d_{stem}^2 / \gamma_{mm} = \mathbf{127.4 \text{ kNm/m}}$$

PASS - Applied moment is less than maximum design moment

Check wall stem in bending

Moment of resistance factor;

$$Q = M_{stem} / d_{stem}^2 = \mathbf{0.253 \text{ N/mm}^2}$$

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

Lever arm factor;

$$c = \mathbf{0.963}$$

Lever arm;

$$z_{stem} = \min(0.95, c) \times d_{stem} = \mathbf{285.0 \text{ mm}}$$

Area of tension reinforcement required;

$$A_{s_stem_des} = M_{stem} \times \gamma_{ms} / (f_y \times z_{stem}) = \mathbf{184 \text{ mm}^2/\text{m}}$$

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;

$$v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.083 \text{ N/mm}^2}$$

Basic characteristic shear strength of masonry;

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

$$f_{vbas} = \mathbf{0.373 \text{ N/mm}^2}$$

Shear span;

$$a = M_{stem} / V_{stem} = \mathbf{918.0 \text{ mm}}$$

Characteristic shear strength of masonry;

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

$$f_v = \mathbf{0.647 \text{ N/mm}^2}$$

Allowable shear stress;

$$v_{adm} = f_v / \gamma_{mv} = \mathbf{0.323 \text{ N/mm}^2}$$

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;

$$\text{ratio}_{act} = (h_{stem} + d_{stem} / 2) / d_{stem} = \mathbf{7.25}$$

PASS - Span to depth ratio is acceptable

Axial load check

Factored axial load on wall;

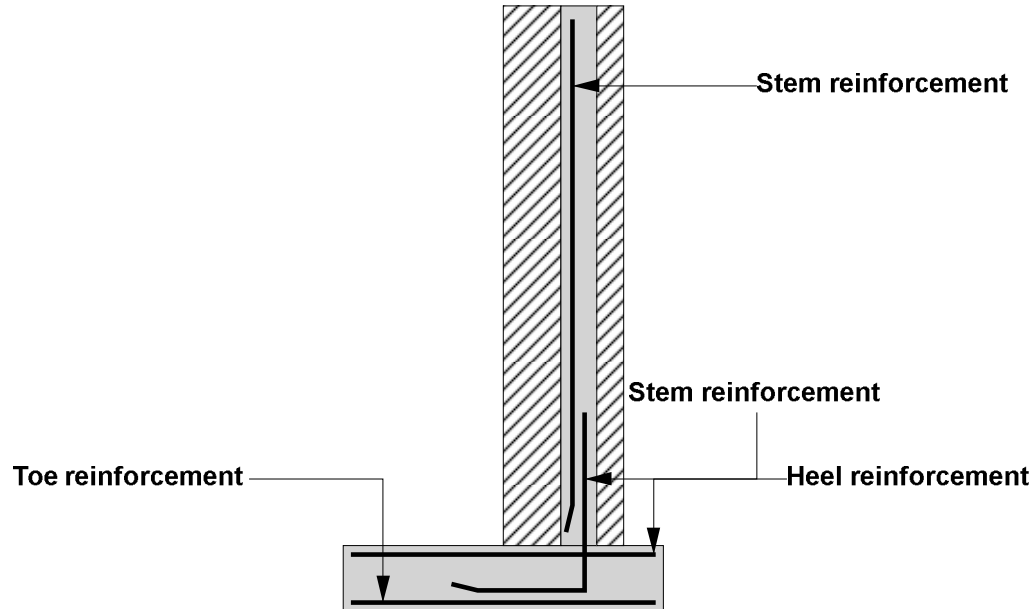
$$N_{wall} = ([t_{wall} \times h_{stem} \times \gamma_{wall} + W_{dead}] \times \gamma_{f_d}) + (W_{live} \times \gamma_{f_l}) = \mathbf{24.2 \text{ kN/m}}$$

Limiting axial load;

$$N_{limit} = 0.1 \times f_k \times t_{wall} = \mathbf{366.4 \text{ kN/m}}$$

Applied axial load may be ignored - calculations valid

Indicative retaining wall reinforcement diagram



Toe mesh - A393 - (393 mm²/m)

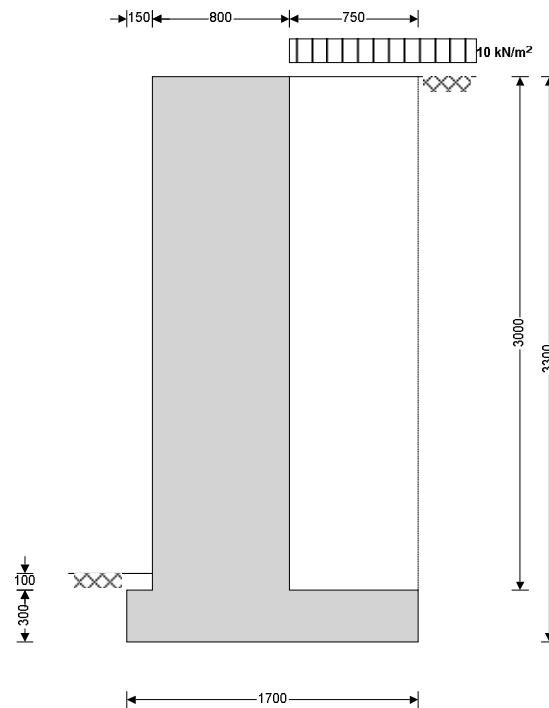
Heel mesh - A393 - (393 mm²/m)

Stem mesh - A393 - (393mm²/m)

SECTION 3

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

$h_{\text{stem}} = 3000 \text{ mm}$
 $t_{\text{wall}} = 800 \text{ mm}$
 $l_{\text{toe}} = 150 \text{ mm}$
 $l_{\text{heel}} = 750 \text{ mm}$
 $l_{\text{base}} = l_{\text{toe}} + l_{\text{heel}} + t_{\text{wall}} = 1700 \text{ mm}$
 $t_{\text{base}} = 300 \text{ mm}$
 $d_{\text{ds}} = 0 \text{ mm}$
 $l_{\text{ds}} = 1000 \text{ mm}$
 $t_{\text{ds}} = 300 \text{ mm}$
 $h_{\text{wall}} = h_{\text{stem}} + t_{\text{base}} + d_{\text{ds}} = 3300 \text{ mm}$
 $d_{\text{cover}} = 100 \text{ mm}$
 $d_{\text{exc}} = 0 \text{ mm}$
 $h_{\text{water}} = 0 \text{ mm}$
 $h_{\text{sat}} = \max(h_{\text{water}} - t_{\text{base}} - d_{\text{ds}}, 0 \text{ mm}) = 0 \text{ mm}$
 $\gamma_{\text{wall}} = 19.0 \text{ kN/m}^3$
 $\gamma_{\text{base}} = 24.0 \text{ kN/m}^3$
 $\alpha = 90.0 \text{ deg}$
 $\beta = 0.0 \text{ deg}$
 $h_{\text{eff}} = h_{\text{wall}} + l_{\text{heel}} \times \tan(\beta) = 3300 \text{ mm}$

Retained material details

Mobilisation factor;
Moist density of retained material;

$M = 1.2$
 $\gamma_m = 21.0 \text{ kN/m}^3$

Saturated density of retained material;

$$\gamma_s = 23.0 \text{ kN/m}^3$$

Design shear strength;

$$\phi' = 30.3 \text{ deg}$$

Angle of wall friction;

$$\delta = 23.7 \text{ deg}$$

Base material details

Moist density;

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

Design shear strength;

$$\phi'_b = 31.2 \text{ deg}$$

Design base friction;

$$\delta_b = 24.4 \text{ deg}$$

Allowable bearing pressure;

$$P_{\text{bearing}} = 150 \text{ kN/m}^2$$

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))})^2] = 0.293$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))})^2] = 8.102$$

At-rest pressure

At-rest pressure for retained material;

$$K_0 = 1 - \sin(\phi') = 0.495$$

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;

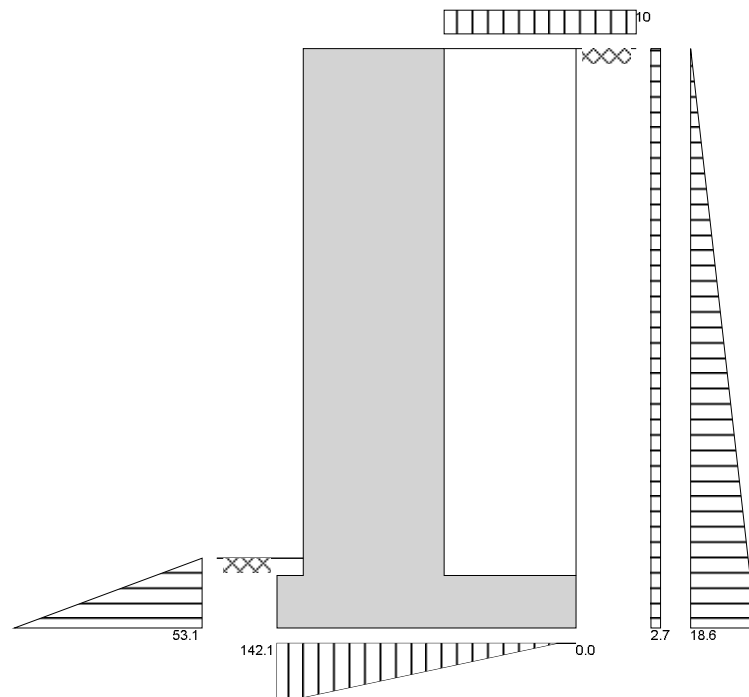
$$F_{\text{dead}} = 0.0 \text{ kN/m}$$

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

Vertical forces on wall

Wall stem;

$$w_{\text{wall}} = h_{\text{stem}} \times t_{\text{wall}} \times \gamma_{\text{wall}} = 45.6 \text{ kN/m}$$

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Wall base;

$$W_{base} = l_{base} \times t_{base} \times \gamma_{base} = 12.2 \text{ kN/m}$$

Surcharge;

$$W_{sur} = \text{Surcharge} \times l_{heel} = 7.5 \text{ kN/m}$$

Moist backfill to top of wall;

$$W_{m_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 47.3 \text{ kN/m}$$

Soil in front of wall;

$$W_p = l_{toe} \times d_{cover} \times \gamma_{mb} = 0.3 \text{ kN/m}$$

Total vertical load;

$$W_{total} = W_{wall} + W_{base} + W_{sur} + W_{m_w} + W_p = 112.9 \text{ kN/m}$$

Horizontal forces on wall

Surcharge;

$$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff} = 8.8 \text{ kN/m}$$

Moist backfill above water table;

$$F_{m_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2 = 30.6 \text{ kN/m}$$

Total horizontal load;

$$F_{total} = F_{sur} + F_{m_a} = 39.5 \text{ kN/m}$$

Calculate stability against sliding

Passive resistance of soil in front of wall;

$$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 10.6 \text{ kN/m}$$

Resistance to sliding;

$$F_{res} = F_p + W_{total} \times \tan(\delta_b) = 61.8 \text{ kN/m}$$

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge;

$$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 = 14.6 \text{ kNm/m}$$

Moist backfill above water table;

$$M_{m_a} = F_{m_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 33.7 \text{ kNm/m}$$

Total overturning moment;

$$M_{ot} = M_{sur} + M_{m_a} = 48.3 \text{ kNm/m}$$

Restoring moments

Wall stem;

$$M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2) = 25.1 \text{ kNm/m}$$

Wall base;

$$M_{base} = W_{base} \times l_{base} / 2 = 10.4 \text{ kNm/m}$$

Surcharge;

$$M_{sur_r} = W_{sur} \times (l_{base} - l_{heel} / 2) = 9.9 \text{ kNm/m}$$

Moist backfill;

$$M_{m_r} = (W_{m_w} \times (l_{base} - l_{heel} / 2) + W_{m_s} \times (l_{base} - l_{heel} / 3)) = 62.6 \text{ kNm/m}$$

Soil in front of wall;

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

Total restoring moment;

$$M_{rest} = M_{wall} + M_{base} + M_{sur_r} + M_{m_r} + M_{p_r} = 108 \text{ kNm/m}$$

Check stability against overturning

Total overturning moment;

$$M_{ot} = 48.3 \text{ kNm/m}$$

Total restoring moment;

$$M_{rest} = 108.0 \text{ kNm/m}$$

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Total moment for bearing;

$$M_{total} = M_{rest} - M_{ot} = 59.7 \text{ kNm/m}$$

Total vertical reaction;

$$R = W_{total} = 112.9 \text{ kN/m}$$

Distance to reaction;

$$x_{bar} = M_{total} / R = 529 \text{ mm}$$

Eccentricity of reaction;

$$e = \text{abs}((l_{base} / 2) - x_{bar}) = 321 \text{ mm}$$

Reaction acts outside middle third of base

Bearing pressure at toe;

$$p_{toe} = R / (1.5 \times x_{bar}) = 142.1 \text{ kN/m}^2$$

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

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;

$$W_{wall_f} = \gamma_{f_d} \times h_{stem} \times t_{wall} \times \gamma_{wall} = 63.8 \text{ kN/m}$$

Wall base;

$$W_{base_f} = \gamma_{f_d} \times l_{base} \times t_{base} \times \gamma_{base} = 17.1 \text{ kN/m}$$

Surcharge;

$$W_{sur_f} = \gamma_{f_l} \times \text{Surcharge} \times l_{heel} = 12 \text{ kN/m}$$

Moist backfill to top of wall;

$$W_{m_w_f} = \gamma_{f_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m = 66.1 \text{ kN/m}$$

Soil in front of wall;

$$W_{p_f} = \gamma_{f_d} \times l_{toe} \times d_{cover} \times \gamma_{mb} = 0.4 \text{ kN/m}$$

Total vertical load;

$$W_{total_f} = W_{wall_f} + W_{base_f} + W_{sur_f} + W_{m_w_f} + W_{p_f} = 159.5 \text{ kN/m}$$

Factored horizontal at-rest forces on wall

Surcharge;

$$F_{sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times h_{eff} = 26.2 \text{ kN/m}$$

Moist backfill above water table;

$$F_{m_a_f} = \gamma_{f_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2 = 79.3 \text{ kN/m}$$

Total horizontal load;

$$F_{total_f} = F_{sur_f} + F_{m_a_f} = 105.5 \text{ kN/m}$$

Passive resistance of soil in front of wall;
kN/m

$$F_{p_f} = \gamma_{f_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 14.9$$

Factored overturning moments

Surcharge;

$$M_{sur_f} = F_{sur_f} \times (h_{eff} - 2 \times d_{ds}) / 2 = 43.2 \text{ kNm/m}$$

Moist backfill above water table;

$$M_{m_a_f} = F_{m_a_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 87.2 \text{ kNm/m}$$

Total overturning moment;

$$M_{ot_f} = M_{sur_f} + M_{m_a_f} = 130.4 \text{ kNm/m}$$

Restoring moments

Wall stem;

$$M_{wall_f} = W_{wall_f} \times (l_{toe} + t_{wall} / 2) = 35.1 \text{ kNm/m}$$

Wall base;

$$M_{base_f} = W_{base_f} \times l_{base} / 2 = 14.6 \text{ kNm/m}$$

Surcharge;

$$M_{sur_r_f} = W_{sur_f} \times (l_{base} - l_{heel} / 2) = 15.9 \text{ kNm/m}$$

Moist backfill;

$$M_{m_r_f} = (W_{m_w_f} \times (l_{base} - l_{heel} / 2) + W_{m_s_f} \times (l_{base} - l_{heel} / 3)) = 87.6$$

kNm/m

Soil in front of wall;

$$M_{p_r_f} = W_{p_f} \times l_{toe} / 2 = 0 \text{ kNm/m}$$

Total restoring moment;

$$M_{rest_f} = M_{wall_f} + M_{base_f} + M_{sur_r_f} + M_{m_r_f} + M_{p_r_f} = 153.3 \text{ kNm/m}$$

Factored bearing pressure

Total moment for bearing;

$$M_{total_f} = M_{rest_f} - M_{ot_f} = 22.8 \text{ kNm/m}$$

Total vertical reaction;

$$R_f = W_{total_f} = 159.5 \text{ kN/m}$$

Distance to reaction;

$$x_{bar_f} = M_{total_f} / R_f = 143 \text{ mm}$$

Eccentricity of reaction;

$$e_f = \text{abs}((l_{base} / 2) - x_{bar_f}) = 707 \text{ mm}$$

Reaction acts outside middle third of base

Bearing pressure at toe;

$$p_{toe_f} = R_f / (1.5 \times x_{bar_f}) = 742.6 \text{ kN/m}^2$$

Bearing pressure at heel;

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

Rate of change of base reaction;

$$\text{rate} = p_{toe_f} / (3 \times x_{bar_f}) = 1728.54 \text{ kN/m}^2/\text{m}$$

Bearing pressure at stem / toe;

$$p_{stem_toe_f} = \max(p_{toe_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2) = 483.3 \text{ kN/m}^2$$

Bearing pressure at mid stem;

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

Bearing pressure at stem / heel;

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

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

Material properties

Characteristic strength of concrete;

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

Characteristic strength of reinforcement;

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

Base details

Minimum area of reinforcement;

$$k = 0.13 \%$$

Cover to reinforcement in toe;

$$c_{toe} = 30 \text{ mm}$$

Calculate shear for toe design

Shear from bearing pressure;

$$V_{toe_bear} = (p_{toe_f} + p_{stem_toe_f}) \times l_{toe} / 2 = 91.9 \text{ kN/m}$$

Shear from weight of base;

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

Shear from weight of soil;

$$V_{toe_wt_soil} = w_{p_f} - (\gamma_{f_d} \times \gamma_m \times l_{toe} \times d_{exc}) = 0.4 \text{ kN/m}$$

Total shear for toe design;

$$V_{toe} = V_{toe_bear} - V_{toe_wt_base} - V_{toe_wt_soil} = 90.1 \text{ kN/m}$$

Calculate moment for toe design

Moment from bearing pressure;

$$M_{toe_bear} = (2 \times p_{toe_f} + p_{stem_mid_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = 74.9 \text{ kNm/m}$$

Moment from weight of base;

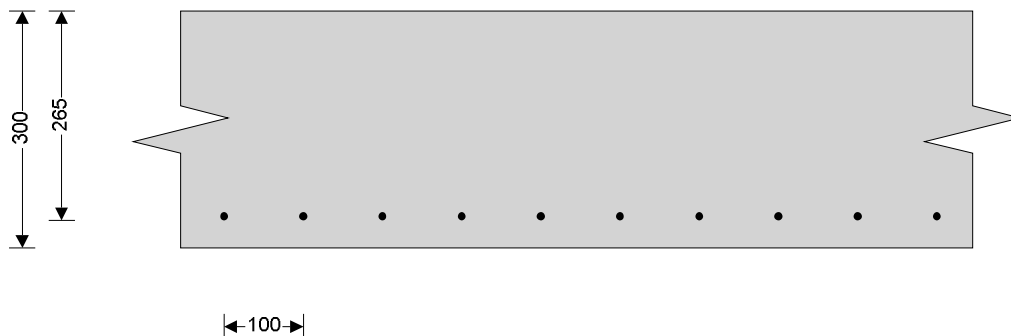
$$M_{toe_wt_base} = (\gamma_{f_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = 1.5 \text{ kNm/m}$$

Moment from weight of soil;

$$M_{toe_wt_soil} = (w_{p_f} - (\gamma_{f_d} \times \gamma_m \times l_{toe} \times d_{exc})) \times (l_{toe} + t_{wall}) / 2 = 0.2 \text{ kNm/m}$$

Total moment for toe design;

$$M_{toe} = M_{toe_bear} - M_{toe_wt_base} - M_{toe_wt_soil} = 73.2 \text{ kNm/m}$$



Check toe in bending

Width of toe;

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

Depth of reinforcement;

$$d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = 265.0 \text{ mm}$$

Constant;

$$K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = 0.030$$

Compression reinforcement is not required

Lever arm;

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

$$z_{toe} = 252 \text{ mm}$$

Area of tension reinforcement required;

$$A_{s_toe_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = 668 \text{ mm}^2/\text{m}$$

Minimum area of tension reinforcement;

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

Area of tension reinforcement required;

$$A_{s_toe_req} = \max(A_{s_toe_des}, A_{s_toe_min}) = 668 \text{ mm}^2/\text{m}$$

Reinforcement provided;

$$10 \text{ mm dia. bars @ } 100 \text{ mm centres}$$

Area of reinforcement provided;

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

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress;

$$v_{toe} = V_{toe} / (b \times d_{toe}) = 0.340 \text{ N/mm}^2$$

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

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Design concrete shear stress;

$$V_{c_toe} = 0.522 \text{ N/mm}^2$$

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

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

Material properties

Characteristic strength of concrete;

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

Characteristic strength of reinforcement;

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

Base details

Minimum area of reinforcement;

$$k = 0.13 \%$$

Cover to reinforcement in heel;

$$C_{heel} = 30 \text{ mm}$$

Calculate shear for heel design

Shear from weight of base;

$$V_{heel_wt_base} = \gamma_{fd} \times \gamma_{base} \times l_{heel} \times t_{base} = 7.6 \text{ kN/m}$$

Shear from weight of moist backfill;

$$V_{heel_wt_m} = w_{m_w_f} = 66.1 \text{ kN/m}$$

Shear from surcharge;

$$V_{heel_sur} = w_{sur_f} = 12 \text{ kN/m}$$

Total shear for heel design;

$$V_{heel} = V_{heel_wt_base} + V_{heel_wt_m} + V_{heel_sur} = 85.7 \text{ kN/m}$$

Calculate moment for heel design

Moment from weight of base;

$$M_{heel_wt_base} = (\gamma_{fd} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) = 6.7 \text{ kNm/m}$$

Moment from weight of moist backfill;

$$M_{heel_wt_m} = w_{m_w_f} \times (l_{heel} + t_{wall}) / 2 = 51.3 \text{ kNm/m}$$

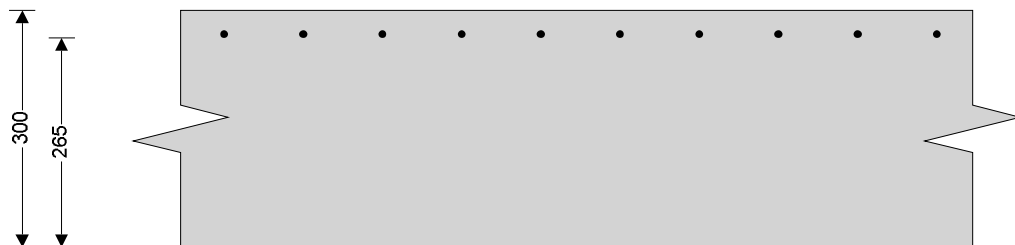
Moment from surcharge;

$$M_{heel_sur} = w_{sur_f} \times (l_{heel} + t_{wall}) / 2 = 9.3 \text{ kNm/m}$$

Total moment for heel design;

$$M_{heel} = M_{heel_wt_base} + M_{heel_wt_m} + M_{heel_sur} = 67.2 \text{ kNm/m}$$

← 100 →



Check heel in bending

Width of heel;

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

Depth of reinforcement;

$$d_{heel} = t_{base} - C_{heel} - (\phi_{heel} / 2) = 265.0 \text{ mm}$$

Constant;

$$K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu}) = 0.027$$

Compression reinforcement is not required

Lever arm;

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

$$Z_{heel} = 252 \text{ mm}$$

Area of tension reinforcement required;

$$A_{s_heel_des} = M_{heel} / (0.87 \times f_y \times Z_{heel}) = 614 \text{ mm}^2/\text{m}$$

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;

$$A_{s_heel_req} = \text{Max}(A_{s_heel_des}, A_{s_heel_min}) = 614 \text{ mm}^2/\text{m}$$

Reinforcement provided;

$$10 \text{ mm dia. bars @ } 100 \text{ mm centres}$$

Area of reinforcement provided;

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

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress;

$$v_{heel} = V_{heel} / (b \times d_{heel}) = 0.323 \text{ N/mm}^2$$

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

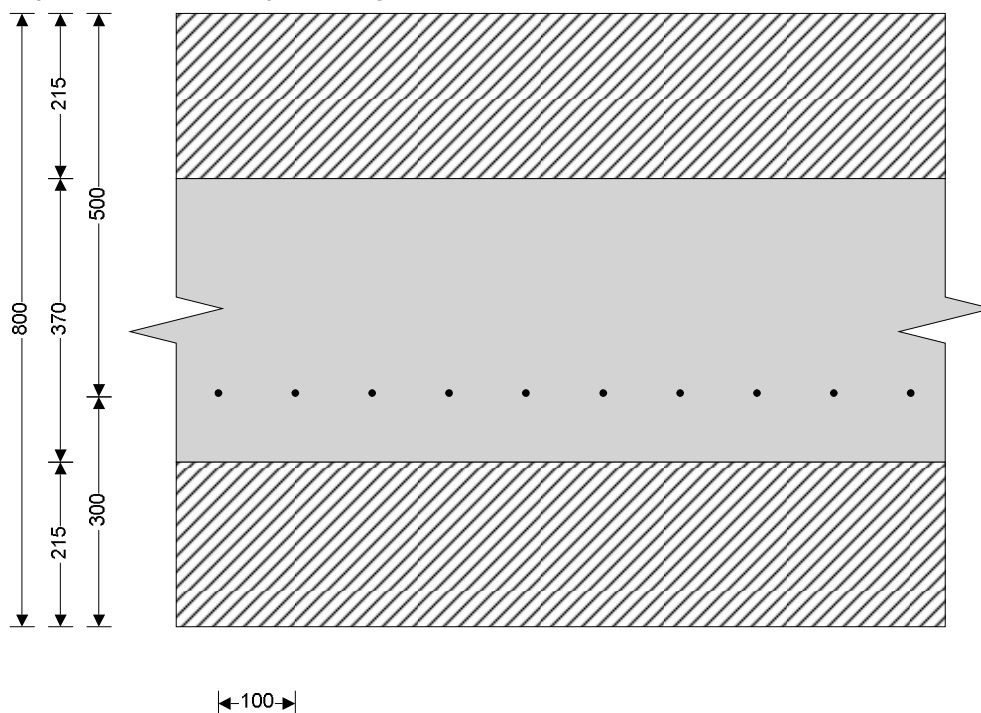
From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress;

$$v_{c_heel} = 0.522 \text{ N/mm}^2$$

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

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



Wall details

Thickness of outer leaf of wall;

$$t_{outer} = 215 \text{ mm}$$

Thickness of inner leaf of wall;

$$t_{inner} = 215 \text{ mm}$$

Thickness of reinforced cavity;

$$t_{cavity} = t_{wall} - t_{outer} - t_{inner} = 370 \text{ mm}$$

Depth of stem reinforcement;

$$d_{stem} = 500 \text{ mm}$$

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;

$$F_{s_sur_f} = \gamma_{f_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = 23.8 \text{ kN/m}$$

Moist backfill above water table;

$$F_{s_m_a_f} = 0.5 \times \gamma_{f_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = 65.6 \text{ kN/m}$$

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Calculate shear for stem design

Shear at base of stem;

$$V_{\text{stem}} = F_{s_sur_f} + F_{s_m_a_f} = \mathbf{89.3 \text{ kN/m}}$$

Calculate moment for stem design

Surcharge;

$$M_{s_sur} = F_{s_sur_f} \times (h_{\text{stem}} + t_{\text{base}}) / 2 = \mathbf{39.2 \text{ kNm/m}}$$

Moist backfill above water table;

$$M_{s_m_a} = F_{s_m_a_f} \times (2 \times h_{\text{sat}} + h_{\text{eff}} - d_{\text{ds}} + t_{\text{base}} / 2) / 3 = \mathbf{75.4 \text{ kNm/m}}$$

Total moment for stem design;

$$M_{\text{stem}} = M_{s_sur} + M_{s_m_a} = \mathbf{114.6 \text{ kNm/m}}$$

Check maximum design moment for wall stem

Width of wall;

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

Maximum design moment;

$$M_{d_stem} = 0.4 \times f_k \times b \times d_{\text{stem}}^2 / \gamma_{\text{mm}} = \mathbf{354.0 \text{ kNm/m}}$$

PASS - Applied moment is less than maximum design moment

Check wall stem in bending

Moment of resistance factor;

$$Q = M_{\text{stem}} / d_{\text{stem}}^2 = \mathbf{0.459 \text{ N/mm}^2}$$

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

Lever arm factor;

$$c = \mathbf{0.930}$$

Lever arm;

$$z_{\text{stem}} = \min(0.95, c) \times d_{\text{stem}} = \mathbf{465.2 \text{ mm}}$$

Area of tension reinforcement required;

$$A_{s_stem_des} = M_{\text{stem}} \times \gamma_{\text{ms}} / (f_y \times z_{\text{stem}}) = \mathbf{567 \text{ mm}^2/\text{m}}$$

Reinforcement provided;

$$\mathbf{10 \text{ mm dia. bars @ } 100 \text{ mm centres}}$$

Area of reinforcement provided;

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

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress;

$$v_{\text{stem}} = V_{\text{stem}} / (b \times d_{\text{stem}}) = \mathbf{0.179 \text{ N/mm}^2}$$

Basic characteristic shear strength of masonry;

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

$$f_{v\text{bas}} = \mathbf{0.377 \text{ N/mm}^2}$$

Shear span;

$$a = M_{\text{stem}} / V_{\text{stem}} = \mathbf{1283.1 \text{ mm}}$$

Characteristic shear strength of masonry;

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

$$f_v = \mathbf{0.702 \text{ N/mm}^2}$$

Allowable shear stress;

$$v_{\text{adm}} = f_v / \gamma_{\text{mv}} = \mathbf{0.351 \text{ N/mm}^2}$$

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;

$$\text{ratio}_{\text{act}} = (h_{\text{stem}} + d_{\text{stem}} / 2) / d_{\text{stem}} = \mathbf{6.50}$$

PASS - Span to depth ratio is acceptable

Axial load check

Factored axial load on wall;

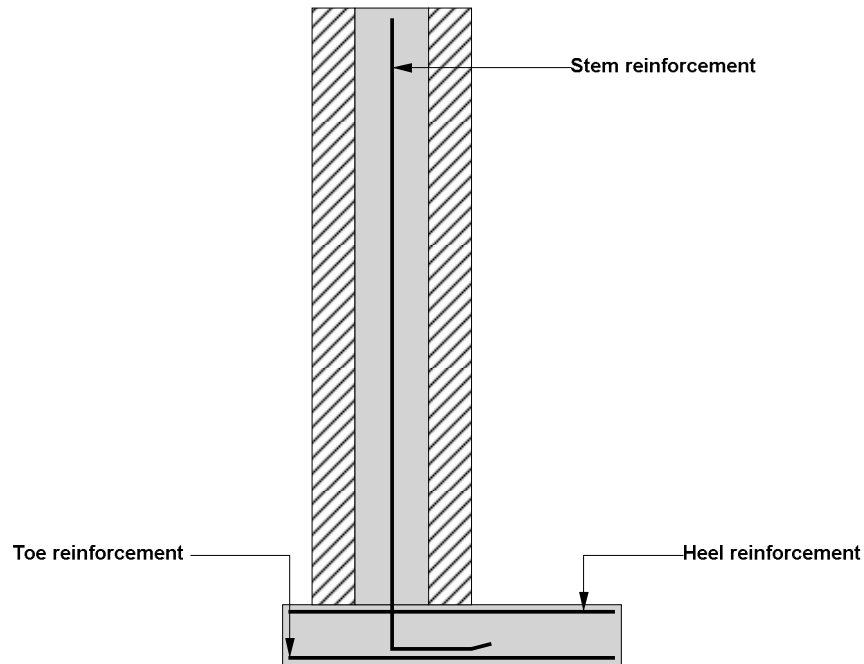
$$N_{\text{wall}} = ([t_{\text{wall}} \times h_{\text{stem}} \times \gamma_{\text{wall}} + W_{\text{dead}}] \times \gamma_{f_d}) + (W_{\text{live}} \times \gamma_{f_l}) = \mathbf{63.8 \text{ kN/m}}$$

Limiting axial load;

$$N_{\text{limit}} = 0.1 \times f_k \times t_{\text{wall}} = \mathbf{651.4 \text{ kN/m}}$$

Applied axial load may be ignored - calculations valid

Indicative retaining wall reinforcement diagram



Toe bars - 10 mm dia.@ 100 mm centres - (785 mm²/m)

Heel bars - 10 mm dia.@ 100 mm centres - (785 mm²/m)

Stem bars - 10 mm dia.@ 100 mm centres - (785 mm²/m)

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SECTION 4

INCLINED WALL BEHIND STEPS TO REAR GARDEN.

The wall is constructed at an incline of 13 degrees into the retained material and comprises a 440mm thick dense blockwork wall on a 750x300mm mass concrete base with a 150mm toe and heel.

As the area above the wall can only be accessed on foot as a level garden area the surcharge has been taken as 2.5kN/m²

Soil properties

Moist density;	$\gamma_{mb} = 18.0 \text{ kN/m}^3$
Wall Angle to vertical;	$\alpha = 77 \text{ deg}$
Slope of retained soil;	$\beta = 0.0 \text{ deg}$
Characteristic peak shearing resistance angle;	$\phi'_{pk,k} = 35.0 \text{ deg}$
Wall friction angle;	$\delta_{r,k} = 0 \text{ deg}$ (eggshell drainage sheet behind)
Design base friction angle;	$\delta_b = 26.0 \text{ deg}$
Bearing capacity of founding soil;	$q = 150 \text{ kN/m}^2$

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))}]^2) = 0.192$$

Horizontal load on wall	$P_a = 0.5 K_a \gamma_{mb} H$ $= 5.184 \text{ kN}$
Lever arm	$l_a = 0.333 \times 3.0$ $= 1.0 \text{ m}$
Moment due to soil	$M_s = 5.2 \text{ kNm/m}$
Surcharge load on plan;	Surcharge = 2.5 kN/m²
Horizontal load due to surcharge	$P_s = V K_a H$ $= 2.5 \times 0.192 \times 3$ $= 1.44 \text{ kN}$
Lever arm	$l_a = 0.5 \times 3.0$ $= 1.5 \text{ m}$
Moment due to surcharge	$M_s = 2.16 \text{ kNm/m}$
Total Overturning Moment	$M_o = 7.4 \text{ kN/m}$
Dead Load from wall	$R_v = 3 \times 0.44 \times 18$ $= 23.76 \text{ kN}$
Lever arm	$l_w = 1.5 \sin 13 + 0.22 + 0.15$ $= 0.708 \text{ m}$
Restoring Moment	$M_r = 23.76 \times 0.708$ $= 16.8 \text{ kNm/m}$
Factor of Safety Against overturning	$FOT = M_r / M_o$ $= 2.27 > 2$

Therefore O.K. for Overturning

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CHECK SLIDING

$$\begin{aligned}
 F_s &= RV \tan \delta_{bb,k} / RH \\
 &= 23.76 \tan 26 / 6.624 \\
 &= 1.749 > 1.5
 \end{aligned}$$

THEREFORE O.K. FOR SLIDING

CHECK BEARING CAPACITY

Lever arm to resultant

$$\begin{aligned}
 &= Mr - Mo / R_v \\
 &= 16.8 - 7.4 / 23.76 \\
 &= 0.396m
 \end{aligned}$$

Eccentricity

$$\begin{aligned}
 e &= 0.396 - (750/2) \\
 &= 21mm \text{ toward back of foundation.}
 \end{aligned}$$

Note: reaction lies within middle third of masonry thickness and masonry only transmits axial load

Max base pressure

$$\begin{aligned}
 &= (R_v/B) (1+6e/B) \\
 &= (23.76 / 0.75)(1+0.126/0.75) \\
 &= 38 \text{ kN/m}^2 < 150 \text{ kN/m}^2
 \end{aligned}$$

THEREFORE O.K. FOR BEARING