RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the recommended values

Retaining wall details

Stem type;	Cantilever
Stem height;	h_{stem} = **1800** mm
Stem thickness;	t_{stem} = **215** mm
Angle to rear face of stem;	α = **90** deg
Stem density;	γ_{stem} = **25** kN/m^3
Toe length;	l_{toe} = **350** mm
Heel length;	l_{heel} = **650** mm
Base thickness;	t_{base} = **250** mm
Base density;	γ_{base} = **25** kN/m^3
Height of retained soil;	h_{ret} = **900** mm
Angle of soil surface;	β = **0** deg
Depth of cover;	d_{cover} = **0** mm

Retained soil properties

Soil type;	Medium dense well graded sand
Moist density;	γ_{mr} = **21** kN/m^3
Saturated density;	γ_{sr} = **23** kN/m^3
Characteristic effective shear resistance angle;	$\phi'_{r.k}$ = **30** deg
Characteristic wall friction angle;	$\delta_{r.k}$ = **0** deg

Base soil properties

Soil type;	Medium dense well graded sand
Moist density;	γ_{mb} = **18** kN/m^3
Characteristic cohesion;	$c'_{b.k}$ = **0** kN/m^2
Characteristic effective shear resistance angle;	$\phi'_{b.k}$ = **30** deg
Characteristic wall friction angle;	$\delta_{b.k}$ = **15** deg
Characteristic base friction angle;	$\delta_{bb.k}$ = **30** deg

Loading details

Variable surcharge load;	$Surcharge_Q$ = **10** kN/m^2

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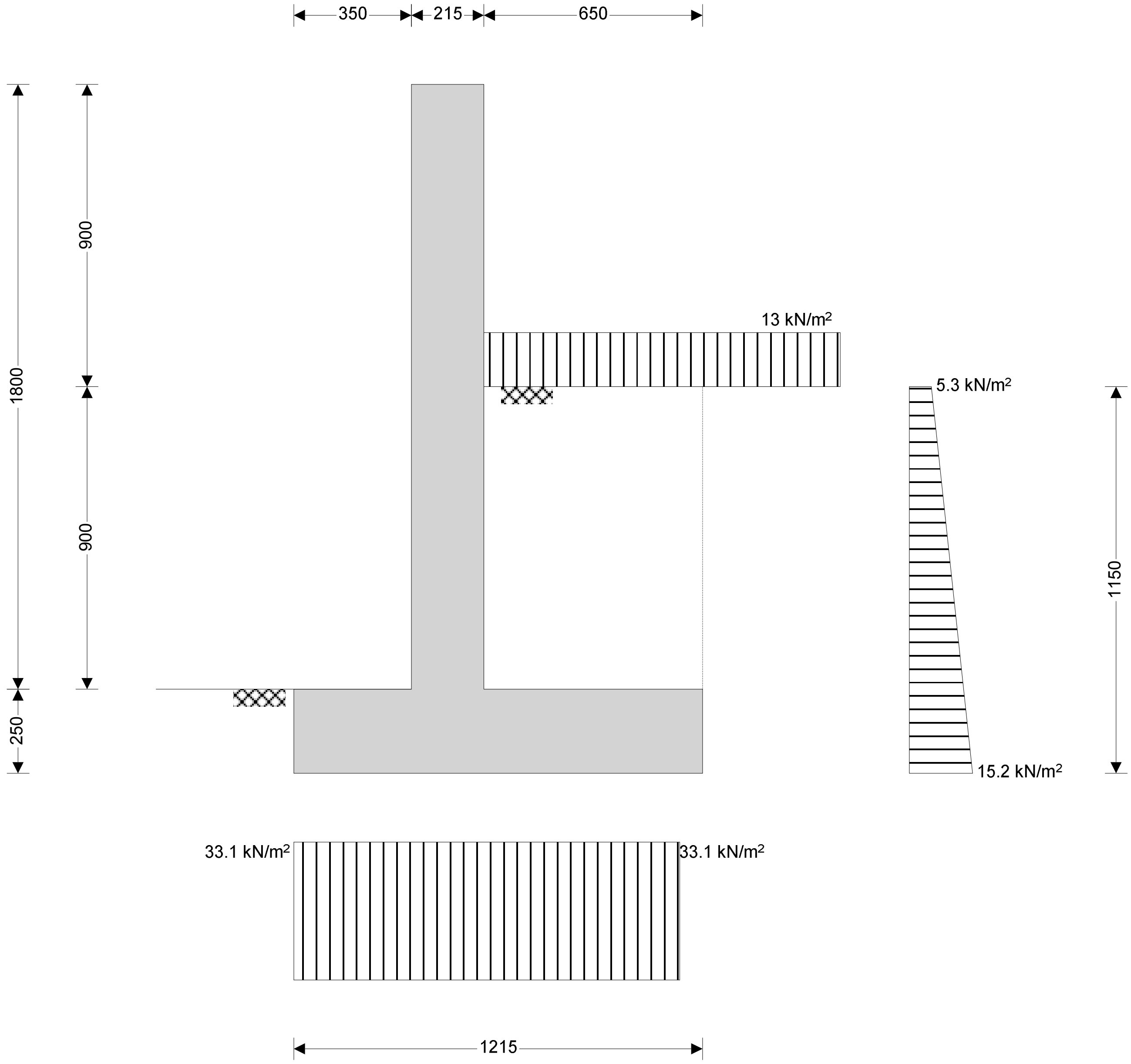


Calculate retaining wall geometry

Base length; $l_{base} = l_{toe} + t_{stem} + l_{heel}$ = **1215** mm

Moist soil height; $h_{moist} = h_{soil}$ = **900** mm

Length of surcharge load; $l_{sur} = l_{heel}$ = **650** mm

- Distance to vertical component; $x_{sur\_v} = l_{base} - l_{heel} / 2$ = **890** mm

Effective height of wall; $h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{1150}$ mm

- Distance to horizontal component; $x_{sur\_h} = h_{eff} / 2 = \mathbf{575}$ mm

Area of wall stem; $A_{stem} = h_{stem} \times t_{stem} = \mathbf{0.387}$ m^2

- Distance to vertical component; $x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{457}$ mm

Area of wall base; $A_{base} = l_{base} \times t_{base} = \mathbf{0.304}$ m^2

- Distance to vertical component; $x_{base} = l_{base} / 2 = \mathbf{607}$ mm

Area of moist soil; $A_{moist} = h_{moist} \times l_{heel} = \mathbf{0.585}$ m^2

- Distance to vertical component; $x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist} = \mathbf{890}$ mm

- Distance to horizontal component; $x_{moist\_h} = h_{eff} / 3 = \mathbf{383}$ mm

Partial factors on actions - Table A.3 - Combination 1

Permanent unfavourable action; $\gamma_G = \mathbf{1.35}$

Permanent favourable action; $\gamma_{Gf} = \mathbf{1.00}$

Variable unfavourable action; $\gamma_Q = \mathbf{1.50}$

Variable favourable action; $\gamma_{Qf} = \mathbf{0.00}$

Partial factors for soil parameters – Table A.4 - Combination 1

Angle of shearing resistance; $\gamma_{\phi'} = \mathbf{1.00}$

Effective cohesion; $\gamma_{c'} = \mathbf{1.00}$

Weight density; $\gamma_{\gamma} = \mathbf{1.00}$

Retained soil properties

Design effective shear resistance angle; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{30}$ deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{0}$ deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{30}$ deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{15}$ deg

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{30}$ deg

Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'} = \mathbf{0}$ kN/m^2

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.333}$

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2) = \mathbf{4.977}$

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{9.7}$ kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{7.6}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} = \mathbf{12.3}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} =$ **29.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **5.8** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \gamma_{mr} \times h_{eff}^2 / 2 =$ **6.2** kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{sur\_h} =$ **12** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$

= **2.7** kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d}) =$ **17.1** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} =$ **19.8** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} =$ **1.647**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **9.7** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **7.6** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} =$ **12.3** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} =$ **29.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **5.8** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \gamma_{mr} \times h_{eff}^2 / 2 =$ **6.2** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 =$ **-2.7** kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h} =$ **9.3** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **3.3** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} =$ **2.4** kNm/m

Total; $M_{total\_OT} = M_{moist\_OT} + M_{sur\_OT} =$ **5.7** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} =$ **4.4** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} =$ **4.6** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} =$ **10.9** kNm/m

Base soil; $M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h} =$ **0.2** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R} =$ **20.2** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **3.543**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem}$ = **13.1** kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base}$ = **10.3** kN/m

Surcharge load; $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel}$ = **9.8** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr}$ = **16.6** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v}$ = **49.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \gamma_Q \times Surcharge_Q \times h_{eff}$ = **5.8** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \gamma_{mr} \times h_{eff}^2 / 2$ = **6.2** kN/m

Total; $F_{total\_h} = \max(F_{moist\_h} + F_{pass\_h} + F_{sur\_h} - F_{total\_v} \times \tan(\delta_{bb.d}), 0 \text{ kN/m})$ = **0** kN/m

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem}$ = **6** kNm/m

Wall base; $M_{base} = F_{base} \times x_{base}$ = **6.2** kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h}$ = **5.4** kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h}$ = **12.4** kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{sur}$ = **29.9** kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v}$ = **603** mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2$ = **-4** mm

Loaded length of base; $l_{load} = 2 \times \bar{x}$ = **1206** mm

Bearing pressure at toe; $q_{toe} = F_{total\_v} / l_{load}$ = **41.2** kN/m^2

Bearing pressure at heel; q_{heel} = **0** kN/m^2

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb}$ = **4.5** kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma$ = **4.5** kN/m^2

Bearing resistance factors; $N_q = \text{Exp}(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2$ = **18.401**

$N_c = (N_q - 1) \times \cot(\phi'_{b.d})$ = **30.14**

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d})$ = **20.093**

Foundation shape factors; $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

Load inclination factors; $H = F_{total\_h}$ = **0** kN/m

$V = F_{total\_v}$ = **49.6** kN/m

$m = 2$

$i_q = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^m = \mathbf{1}$

$i_\gamma = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^{(m + 1)} = \mathbf{1}$

$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b.d})) = \mathbf{1}$

Net ultimate bearing capacity; $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{300.9}$ kN/m^2

Factor of safety; $FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{7.31}$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Partial factors on actions - Table A.3 - Combination 2

Permanent unfavourable action; $\gamma_G = \mathbf{1.00}$

Permanent favourable action; $\gamma_{Gf} = \mathbf{1.00}$

Variable unfavourable action; $\gamma_Q = \mathbf{1.30}$

Variable favourable action; $\gamma_{Qf} = \mathbf{0.00}$

Partial factors for soil parameters – Table A.4 - Combination 2

Angle of shearing resistance; $\gamma_{\phi'} = \mathbf{1.25}$

Effective cohesion; $\gamma_{c'} = \mathbf{1.25}$

Weight density; $\gamma_\gamma = \mathbf{1.00}$

Retained soil properties

Design effective shear resistance angle; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{24.8}$ deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{0}$ deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{24.8}$ deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{12.1}$ deg

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{24.8}$ deg

Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'} = \mathbf{0}$ kN/m^2

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.409}$

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2) = \mathbf{3.473}$

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{9.7}$ kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{7.6}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} = \mathbf{12.3}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} = \mathbf{29.6}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \gamma_Q \times Surcharge_Q \times h_{eff}$ = **6.1** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \gamma_{mr} \times h_{eff}^2 / 2$ = **5.7** kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{sur\_h}$ = **11.8** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$

= **1.9** kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d})$ = **13.7** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction}$ = **15.6** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h}$ = **1.319**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **9.7** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **7.6** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **12.3** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **29.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \gamma_Q \times Surcharge_Q \times h_{eff}$ = **6.1** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \gamma_{mr} \times h_{eff}^2 / 2$ = **5.7** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **-1.9** kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h}$ = **9.9** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h}$ = **3.5** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h}$ = **2.2** kNm/m

Total; $M_{total\_OT} = M_{moist\_OT} + M_{sur\_OT}$ = **5.7** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem}$ = **4.4** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base}$ = **4.6** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **10.9** kNm/m

Base soil; $M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h}$ = **0.2** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R}$ = **20.1** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT}$ = **3.535**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{9.7}$ kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{7.6}$ kN/m

Surcharge load; $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel} = \mathbf{8.5}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{12.3}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v} = \mathbf{38}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{6.1}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \gamma_{mr} \times h_{eff}^2 / 2 = \mathbf{5.7}$ kN/m

Total; $F_{total\_h} = \max(F_{moist\_h} + F_{pass\_h} + F_{sur\_h} - F_{total\_v} \times \tan(\delta_{bb.d}), 0 \text{ kN/m}) = \mathbf{0}$ kN/m

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} = \mathbf{4.4}$ kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} = \mathbf{4.6}$ kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} = \mathbf{4}$ kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} = \mathbf{8.8}$ kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{sur} = \mathbf{21.8}$ kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} = \mathbf{574}$ mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 = \mathbf{-34}$ mm

Loaded length of base; $l_{load} = 2 \times \bar{x} = \mathbf{1147}$ mm

Bearing pressure at toe; $q_{toe} = F_{total\_v} / l_{load} = \mathbf{33.1}$ kN/m^2

Bearing pressure at heel; $q_{heel} = \mathbf{0}$ kN/m^2

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb} = \mathbf{4.5}$ kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma = \mathbf{4.5}$ kN/m^2

Bearing resistance factors; $N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 = \mathbf{10.431}$

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{20.418}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) = \mathbf{8.712}$

Foundation shape factors; $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

Load inclination factors; $H = F_{total\_h} = \mathbf{0}$ kN/m

$V = F_{total\_v} = \mathbf{38}$ kN/m

$m = 2$

$i_q = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^m = \mathbf{1}$

$i_\gamma = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^{(m + 1)} = \mathbf{1}$

$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b.d})) = \mathbf{1}$

Net ultimate bearing capacity; $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{136.9}$ kN/m^2

Factor of safety; $FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{4.132}$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum dated January 2008 and the recommended values and EN1996-1-1:2005 incorporating Corrigenda dated February 2006 and July 2009 and the recommended values

Concrete details - Table 3.1 - Strength and deformation characteristics for concrete

Concrete strength class; C30/37

Characteristic compressive cylinder strength; $f_{ck} = \mathbf{30}$ N/mm^2

Characteristic compressive cube strength; $f_{ck,cube} = \mathbf{37}$ N/mm^2

Mean value of compressive cylinder strength; $f_{cm} = f_{ck} + 8$ N/mm^2 = **38** N/mm^2

Mean value of axial tensile strength; $f_{ctm} = 0.3$ N/mm$^2 \times (f_{ck} / 1$ N/mm$^2)^{2/3}$ = **2.9** N/mm^2

5% fractile of axial tensile strength; $f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.0}$ N/mm^2

Secant modulus of elasticity of concrete; $E_{cm} = 22$ kN/mm$^2 \times (f_{cm} / 10$ N/mm$^2)^{0.3}$ = **32837** N/mm^2

Partial factor for concrete - Table 2.1N; $\gamma_C = \mathbf{1.50}$

Compressive strength coefficient - cl.3.1.6(1); $\alpha_{cc} = \mathbf{1.00}$

Design compressive concrete strength - exp.3.15; $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = \mathbf{20.0}$ N/mm^2

Maximum aggregate size; $h_{agg} = \mathbf{20}$ mm

Reinforcement details

Characteristic yield strength of reinforcement; $f_{yk} = \mathbf{500}$ N/mm^2

Modulus of elasticity of reinforcement; $E_s = \mathbf{200000}$ N/mm^2

Partial factor for reinforcing steel - Table 2.1N; $\gamma_S = \mathbf{1.15}$

Design yield strength of reinforcement; $f_{yd} = f_{yk} / \gamma_S = \mathbf{435}$ N/mm^2

Cover to reinforcement

Top face of base; $c_{bt} = \mathbf{50}$ mm

Bottom face of base; $c_{bb} = \mathbf{75}$ mm

Masonry details - Section 3.1

Masonry type; Aggregate concrete - Group 1

Normalised mean compressive strength; $f_b = \mathbf{10.4}$ N/mm^2

Characteristic flexural strength - cl.3.6.3(3); $f_{xk} = \mathbf{0.1}$ N/mm^2

Initial shear strength - Table 3.4; $f_{vko} = \mathbf{0.15}$ N/mm^2

Mortar details - Section 3.2

Mortar type; General purpose - M6, prescribed mix

Compressive strength of mortar; f_m = **6** N/mm^2

Ultimate limit states - cl.2.4.3(1)

Class of execution control; 1

Category of manufacture control; 1

Partial factor for direct or flexural compression; γ_{Mc} = **1.7**

Partial factor for flexural tension; γ_{Mt} = **1.7**

Partial factor for shear; γ_{Mv} = **1.7**

Characteristic strengths of concrete infill - Table 3.2

Concrete infill strength class; C25/30

Characteristic compressive strength; $f_{ck,infill}$ = **25** N/mm^2

Characteristic shear strength; $f_{cvk,infill}$ = **0.45** N/mm^2

Design shear strength; $f_{cvd,infill} = f_{cvk,infill} / \gamma_{Mv}$ = **0.265** N/mm^2

Check stem design at base of stem

Depth of section; t = **215** mm

Pocket wall details

Length of pocket; l_{pocket} = **200** mm

Depth of pocket; d_{pocket} = **200** mm

Masonry cover to front of pocket; p_{pocket} = **100** mm

Masonry cover to rear of pocket; c_{pocket} = **100** mm

Spacing of pockets; s_{pocket} = **1000** mm

Masonry characteristics

Compressive strength constants - Table 3.3; K = **0.55**

Characteristic compressive strength - cl.3.6.1.2(1); $f_k = K \times f_b^{0.7} \times f_m^{0.3}$ = **4.85** N/mm^2

Design compressive strength; $f_d = \min(f_k, f_{ck,infill}) / \gamma_{Mc}$ = **2.853** N/mm^2

Design flexural strength; $f_{xd} = f_{xk} / \gamma_{Mt}$ = **0.059** N/mm^2

Height of masonry; $h_{wt} = h_{stem}$ = **1800** mm

Compressive axial force combination 1; $F = \gamma_{Gf} \times \gamma_{stem} \times h_{wt} \times t$ = **9.7** kN/m

Eccentricity of axial load; e = **0** mm

Capacity reduction factor - exp.6.4; $\Phi = 1 - 2 \times e / t$ = **1**

Design vertical resistance - exp.6.2; $N_{Rd} = \Phi \times t \times f_d$ = **613.4** kN/m

Design vertical compressive stress; $\sigma_d = \min(F / t, 0.15 \times N_{Rd} / t)$ = **0.045** N/mm^2

Apparent design flexural strength - exp.6.16; $f_{xd,app} = f_{xd} + \sigma_d$ = **0.104** N/mm^2

Characteristic shear strength - exp.3.5; $f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, 0.065 \times f_b)$ = **0.168** N/mm^2

Design shear strength; $f_{vd} = f_{vk} / \gamma_{Mv}$ = **0.099** N/mm^2

Reinforced masonry members subjected to bending, bending and axial loading, or axial loading - Section 6.6

Design bending moment combination 1; M = **3.2** kNm/m

Tension reinforcement provided; 2 × 10 dia.bars @ 1000 c/c

Area of tension reinforcement provided; $A_{sr.prov} = 2 \times \pi \times \phi_{sr}^2 / (4 \times s_{pocket})$ = **157** mm^2/m

Depth to tension reinforcement; d = **250** mm

Flange thickness - cl.6.6.3(1); $t_{fl} = \min(t_{stem}, 0.5 \times d)$ = **125** mm

Rib thickness; $t_{rib} = l_{pocket} + 2 \times c_{pocket}$ = **400** mm

Effective flange width - cl.6.6.3; $b_{fl} = \min(t_{rib} + 12 \times t_{fl}, s_{pocket}, h_{stem} / 3)$ = **600** mm

Minimum area of reinforcement - cl.8.2.3(1); $A_{sr.min} = 0.0005 \times (t + t_{rib} \times (d - t) / s_{pocket})$ = **115** mm^2/m

Lever arm - exp.6.23; $z = d \times \min(1 - 0.5 \times A_{sr.prov} \times f_{yd} \times s_{pocket} / (b_{fl} \times d \times f_d), 0.95)$ = **230** mm

Moment of resistance - exp.6.22 and exp.6.28; $M_{Rd} = \min(A_{sr.prov} \times f_{yd} \times z, f_d \times b_{fl} \times t_{fl} \times (d - 0.5 \times t_{fl}) / s_{pocket})$

M_{Rd} = **15.7** kNm/m

M / M_{Rd} = **0.202**

PASS - Moment of resistance exceeds applied design moment

Reinforced masonry members subjected to shear loading - Section 6.7

Design shear force V = **8.327** kN/m

Design shear resistance - exp.6.40; $V_{Rd} = \min(f_{vd}, f_{cvd,infill}) \times t_{rib} \times d / s_{pocket}$ = **9.882** kN/m

V / V_{Rd} = **0.843**

PASS - Design shear resistance exceeds applied design shear force

Note - The capacity of the wall stem to span between reinforced pockets is currently beyond the scope of this calculation and should be verified independently.

Check base design at toe

Depth of section; h = **250** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **2** kNm/m

Depth to tension reinforcement; $d = h - c_{bb} - \phi_{bb} / 2$ = **170** mm

$K = M / (d^2 \times f_{ck})$ = **0.002**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 – 3.53 \times K)^{0.5}, 0.95) \times d$ = **161** mm

Depth of neutral axis; $x = 2.5 \times (d – z)$ = **21** mm

Area of tension reinforcement required; $A_{bb.req} = M / (f_{yd} \times z)$ = **29** mm^2/m

Tension reinforcement provided; 10 dia.bars @ 300 c/c

Area of tension reinforcement provided; $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **262** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{bb.min}$ = max(0.26 × f_{ctm} / f_{yk}, 0.0013) × d = **256** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{bb.max}$ = 0.04 × h = **10000** mm^2/m

max($A_{bb.req}$, $A_{bb.min}$) / $A_{bb.prov}$ = **0.978**

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Limiting crack width; w_{max} = **0.3** mm

Variable load factor - EN1990 – Table A1.1; ψ_2 = **0.6**

Serviceability bending moment; M_{sls} = **1.5** kNm/m

Tensile stress in reinforcement; σ_s = M_{sls} / ($A_{bb.prov}$ × z) = **34.5** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

Effective area of concrete in tension; $A_{c.eff}$ = min(2.5 × (h - d), (h – x) / 3, h / 2) = **76250** mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff}$ = f_{ctm} = **2.9** N/mm^2

Reinforcement ratio; $\rho_{p.eff}$ = $A_{bb.prov}$ / $A_{c.eff}$ = **0.003**

Modular ratio; α_e = E_s / E_{cm} = **6.091**

Bond property coefficient; k_1 = **0.8**

Strain distribution coefficient; k_2 = **0.5**

k_3 = **3.4**

k_4 = **0.425**

Maximum crack spacing - exp.7.11; $s_{r.max}$ = k_3 × c_{bb} + k_1 × k_2 × k_4 × ϕ_{bb} / $\rho_{p.eff}$ = **750** mm

Maximum crack width - exp.7.8; w_k = $s_{r.max}$ × max(σ_s – k_t × ($f_{ct.eff}$ / $\rho_{p.eff}$) × (1 + α_e × $\rho_{p.eff}$), 0.6 × σ_s) / E_s

w_k = **0.078** mm

w_k / w_{max} = **0.259**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **11.6** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **2.000**

Longitudinal reinforcement ratio; ρ_l = min($A_{bb.prov}$ / d, 0.02) = **0.002**

v_{min} = 0.035 N$^{1/2}$/mm × $k^{3/2}$ × $f_{ck}^{0.5}$ = **0.542** N/mm^2

Design shear resistance - exp.6.2a & 6.2b; $V_{Rd.c}$ = max($C_{Rd.c}$ × k × (100 N^2/mm^4 × ρ_l × f_{ck})$^{1/3}$, v_{min}) × d

$V_{Rd.c}$ = **92.2** kN/m

V / $V_{Rd.c}$ = **0.126**

PASS - Design shear resistance exceeds design shear force

Rectangular section in flexure - Section 6.1

Design bending moment combination 2; $M = \mathbf{2.2}$ kNm/m

Depth to tension reinforcement; $d = h - c_{bt} - \phi_{bt} / 2 = \mathbf{194}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.002}$

$K' = \mathbf{0.196}$

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d =$ **184** mm

Depth of neutral axis; $x = 2.5 \times (d - z) = \mathbf{24}$ mm

Area of tension reinforcement required; $A_{bt.req} = M / (f_{yd} \times z) = \mathbf{27}$ mm^2/m

Tension reinforcement provided; 12 dia.bars @ 300 c/c

Area of tension reinforcement provided; $A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) = \mathbf{377}$ mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{bt.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{292}$ mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{bt.max} = 0.04 \times h = \mathbf{10000}$ mm^2/m

$\max(A_{bt.req}, A_{bt.min}) / A_{bt.prov} = \mathbf{0.775}$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Limiting crack width; $w_{max} = \mathbf{0.3}$ mm

Variable load factor - EN1990 – Table A1.1; $\psi_2 = \mathbf{0.6}$

Serviceability bending moment; $M_{sls} = \mathbf{0.4}$ kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{bt.prov} \times z) = \mathbf{5.5}$ N/mm^2

Load duration; Long term

Load duration factor; $k_t = \mathbf{0.4}$

Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = \mathbf{75250}$ mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff} = f_{ctm} = \mathbf{2.9}$ N/mm^2

Reinforcement ratio; $\rho_{p.eff} = A_{bt.prov} / A_{c.eff} = \mathbf{0.005}$

Modular ratio; $\alpha_e = E_s / E_{cm} = \mathbf{6.091}$

Bond property coefficient; $k_1 = \mathbf{0.8}$

Strain distribution coefficient; $k_2 = \mathbf{0.5}$

$k_3 = \mathbf{3.4}$

$k_4 = \mathbf{0.425}$

Maximum crack spacing - exp.7.11; $s_{r.max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p.eff} = \mathbf{577}$ mm

Maximum crack width - exp.7.8; $w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$

$w_k = \mathbf{0.009}$ mm

$w_k / w_{max} = \mathbf{0.032}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; $V = \mathbf{6}$ kN/m

$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{2.000}$

Longitudinal reinforcement ratio; $\rho_l = \min(A_{bt.prov} / d, 0.02) = \mathbf{0.002}$

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.542} \text{ N/mm}^2$

Design shear resistance - exp.6.2a & 6.2b; $V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}$,

$v_{min}) \times d$

$V_{Rd.c} = \mathbf{105.2}$ kN/m

$V / V_{Rd.c} = \mathbf{0.058}$

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

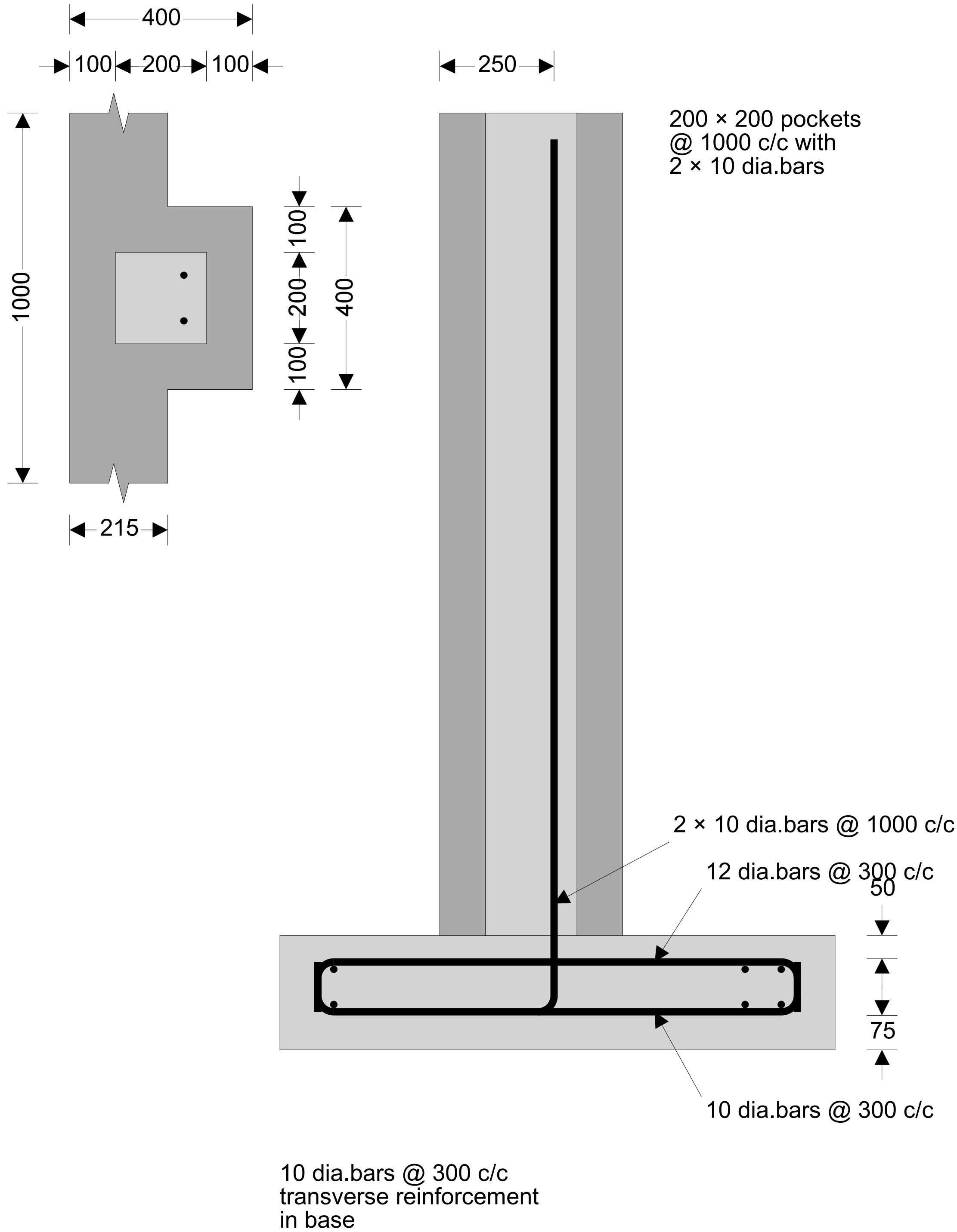
Minimum area of reinforcement – cl.9.3.1.1(2); $A_{bx.req} = 0.2 \times A_{bt.prov} = \mathbf{75} \text{ mm}^2/\text{m}$

Maximum spacing of reinforcement – cl.9.3.1.1(3); $s_{bx\_max} = \mathbf{450}$ mm

Transverse reinforcement provided; 10 dia.bars @ 300 c/c

Area of transverse reinforcement provided; $A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx}) = \mathbf{262} \text{ mm}^2/\text{m}$

PASS - Area of reinforcement provided is greater than area of reinforcement required



400
100
200
100
250
200 × 200 pockets
@ 1000 c/c with
2 × 10 dia.bars
1000
100
200
100
400
215
2 × 10 dia.bars @ 1000 c/c
12 dia.bars @ 300 c/c
50
75
10 dia.bars @ 300 c/c
10 dia.bars @ 300 c/c
transverse reinforcement
in base