RETAINING WALL ANALYSIS & DESIGN

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

Retaining wall details

Stem type;	Cantilever with inclined rear face
Stem height;	h_{stem} = **6000** mm
Stem thickness;	t_{stem} = **350** mm
Slope length to rear of stem;	l_{slr} = **500** mm
Angle to rear face of stem;	$\alpha = \text{atan}(h_{stem} / l_{slr})$ = **85.2** deg
Stem density;	γ_{stem} = **25** kN/m^3
Toe length;	l_{toe} = **2500** mm
Heel length;	l_{heel} = **2500** mm
Base thickness;	t_{base} = **550** mm
Key position;	p_{key} = **5400** mm
Key depth;	d_{key} = **1000** mm
Key thickness;	t_{key} = **450** mm
Base density;	γ_{base} = **25** kN/m^3
Height of retained soil;	h_{ret} = **5000** mm
Angle of soil surface;	β = **5** deg
Depth of cover;	d_{cover} = **1000** mm
Depth of excavation;	d_{exc} = **1000** mm
Height of water;	h_{water} = **750** mm
Water density;	γ_w = **9.8** kN/m^3

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;	$\phi'_{r.k}$ = **36** deg
Characteristic wall friction angle;	$\delta_{r.k}$ = **10** deg

Base soil properties

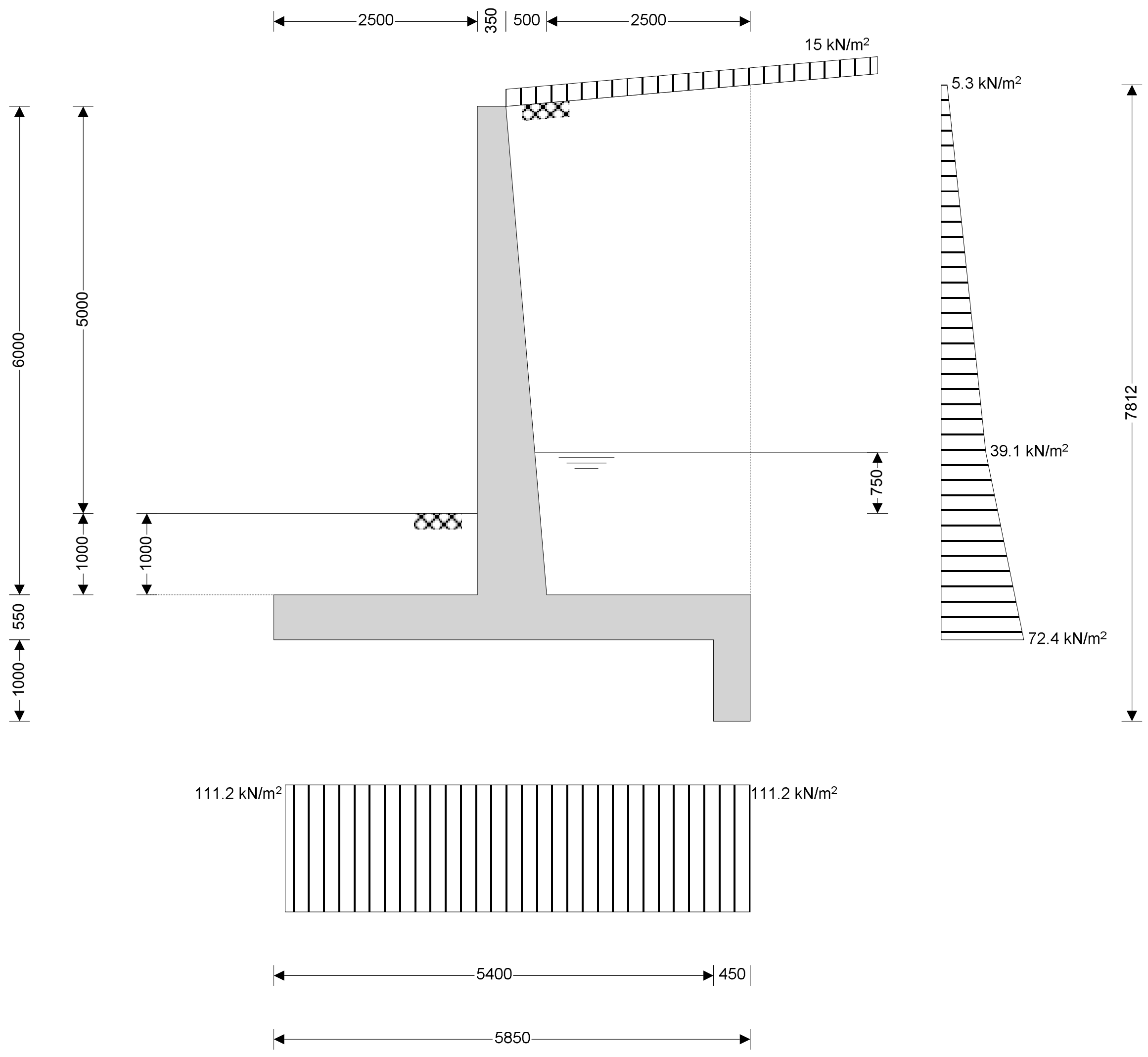
Soil type;	Medium dense well graded sand
Moist density;	γ_{mb} = **18** kN/m^3
Characteristic cohesion;	$c'_{b.k}$ = **0** kN/m^2
Characteristic effective shear resistance angle;	$\phi'_{b.k}$ = **32** deg
Characteristic wall friction angle;	$\delta_{b.k}$ = **18** deg

Characteristic base friction angle; $\delta_{bb.k}$ = **30** deg

Loading details

Permanent surcharge load; $Surcharge_G$ = **2** kN/m^2

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



Calculate retaining wall geometry

Base length; $l_{base} = l_{toe} + t_{stem} + l_{slr} + l_{heel}$ = **5850** mm

Base height; $h_{base} = t_{base} + d_{key}$ = **1550** mm

Saturated soil height; $h_{sat} = h_{water} + d_{cover} = \mathbf{1750}$ mm

Moist soil height; $h_{moist} = h_{ret} - h_{water} = \mathbf{4250}$ mm

Length of surcharge load; $l_{sur} = (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) = \mathbf{3000}$ mm

- Distance to vertical component; $x_{sur\_v} = l_{base} - (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) / 2 = \mathbf{4350}$ mm

Effective height of wall; $h_{eff} = h_{base} + d_{cover} + h_{ret} + l_{sur} \times \tan(\beta) = \mathbf{7812}$ mm

- Distance to horizontal component; $x_{sur\_h} = h_{eff} / 2 - d_{key} = \mathbf{2906}$ mm

- Distance to horizontal component above key; $x_{sur\_h\_a} = (h_{eff} - d_{key}) / 2 = \mathbf{3406}$ mm

Area of wall stem; $A_{stem} = h_{stem} \times (t_{stem} + l_{slr} / 2) = \mathbf{3.6}$ m^2

- Distance to vertical component; $x_{stem} = (h_{stem} \times t_{stem} \times (l_{toe} + t_{stem} / 2) + h_{stem} \times l_{slr} / 2 \times (l_{toe} + t_{stem} + l_{slr} / 3)) / A_{stem} = \mathbf{2817}$ mm

Area of wall base; $A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key} = \mathbf{3.668}$ m^2

- Distance to vertical component; $x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base} = \mathbf{3256}$ mm

Area of saturated soil; $A_{sat} = h_{sat} \times (l_{heel} + l_{slr} \times h_{sat} / (2 \times h_{stem})) = \mathbf{4.503}$ m^2

- Distance to vertical component; $x_{sat\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2 + l_{slr} \times h_{sat}^2 / (2 \times h_{stem}) \times (l_{heel} + l_{slr} \times h_{sat} / (3 \times h_{stem}))) / A_{sat} = \mathbf{4563}$ mm

- Distance to horizontal component; $x_{sat\_h} = (h_{sat} + h_{base}) / 3 - d_{key} = \mathbf{100}$ mm

- Distance to horizontal component above key; $x_{sat\_h\_a} = (h_{sat} + t_{base}) / 3 = \mathbf{767}$ mm

Area of water; $A_{water} = h_{sat} \times (l_{heel} + l_{slr} \times h_{sat} / (2 \times h_{stem})) = \mathbf{4.503}$ m^2

- Distance to vertical component; $x_{water\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2 + l_{slr} \times h_{sat}^2 / (2 \times h_{stem}) \times (l_{heel} + l_{slr} \times h_{sat} / (3 \times h_{stem}))) / A_{sat} = \mathbf{4563}$ mm

- Distance to horizontal component; $x_{water\_h} = (h_{sat} + h_{base}) / 3 - d_{key} = \mathbf{100}$ mm

- Distance to horizontal component above key; $x_{water\_h\_a} = (h_{sat} + t_{base}) / 3 = \mathbf{767}$ mm

Area of moist soil; $A_{moist} = (h_{ret} - h_{water}) \times (l_{heel} + l_{slr} \times (h_{moist} + 2 \times h_{sat}) / (2 \times h_{stem})) + \tan(\beta) \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem})^2 / 2 = \mathbf{12.391}$ m^2

- Distance to vertical component; $x_{moist\_v} = l_{base} - (h_{moist} \times (l_{heel} + l_{slr} \times h_{sat} / h_{stem})^2 / 2 + l_{slr} \times h_{moist}^2 / (2 \times h_{stem}) \times ((l_{heel} + l_{slr} \times h_{sat} / h_{stem}) + l_{slr} \times h_{moist} / (3 \times h_{stem})) + \tan(\beta) \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem})^3 / 6) / A_{moist} = \mathbf{4450}$ mm

- Distance to horizontal component; $x_{moist\_h} = ((h_{eff} - h_{sat} - h_{base}) \times (t_{base} + h_{sat} + (h_{eff} - h_{sat} - h_{base}) / 3) / 2 + (h_{sat} + h_{base}) \times ((h_{sat} + h_{base})/2 - d_{key})) / (h_{sat} + h_{base} + (h_{eff} - h_{sat} - h_{base}) / 2) = \mathbf{1931}$ mm

- Distance to horizontal component above key; $x_{moist\_h\_a} = ((h_{eff} - h_{sat} - h_{base}) \times (t_{base} + h_{sat} + (h_{eff} - h_{sat} - h_{base}) / 3) / 2 + (h_{sat} + t_{base})^2/2) / (h_{sat} + t_{base} + (h_{eff} - h_{sat} - h_{base}) / 2) = \mathbf{2464}$ mm

Area of base soil; $A_{pass} = d_{cover} \times l_{toe} = \mathbf{2.5}$ m^2

- Distance to vertical component; $x_{pass\_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} =$ **1250** mm

- Distance to horizontal component; $x_{pass\_h} = (d_{cover} + h_{base}) / 3 - d_{key} =$ **-150** mm

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

Permanent unfavourable action; γ_G = **1.35**

Permanent favourable action; γ_{Gf} = **1.00**

Variable unfavourable action; γ_Q = **1.50**

Variable favourable action; γ_{Qf} = **0.00**

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

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

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

Weight density; γ_γ = **1.00**

Retained soil properties

Design effective shear resistance angle; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **36** deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **10** deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **32** deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **18** deg

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

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

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2)$ = **0.290**

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2)$ = **6.292**

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **90** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **91.7** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w)$ = **59.4** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w$ = **44.2** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **260.2** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{water\_v}$ = **545.5** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **38.8** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2$ = **27.2** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **72.1** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base}))$ = **199.6** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h}$ = **337.8** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **129.4** kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d})$ = **314.9** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction}$ = **444.3** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h}$ = **1.315**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **90** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **91.7** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w)$ = **59.4** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w$ = **44.2** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **260.2** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{water\_v}$ = **545.5** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key})$ = **33.9** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + t_{base})^2 / 2$ = **13.2** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + t_{base})^2 / 2$ = **35** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) =$ **163.7** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 =$ **-129.4** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h} =$ **116.4** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h\_a} =$ **115.4** kNm/m

Saturated retained soil; $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h\_a} =$ **10.1** kNm/m

Water; $M_{water\_OT} = F_{water\_h} \times x_{water\_h\_a} =$ **26.9** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h\_a} =$ **403.4** kNm/m

Base soil; $M_{exc\_OT} = F_{exc\_h} \times x_{exc\_h} =$ **62.5** kNm/m

Total; $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{exc\_OT} + M_{water\_OT} + M_{sur\_OT} =$ **618.3** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} =$ **253.6** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} =$ **298.6** kNm/m

Saturated retained soil; $M_{sat\_R} = F_{sat\_v} \times x_{sat\_v} =$ **271** kNm/m

Water; $M_{water\_R} = F_{water\_v} \times x_{water\_v} =$ **201.6** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} =$ **1157.9** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{sat\_R} + M_{moist\_R} + M_{water\_R} =$ **2182.6** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **3.53**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} =$ **121.5** kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} =$ **123.8** kN/m

Surcharge load; $F_{sur\_v} = (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) =$ **53.1** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_G \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **80.2** kN/m

Water; $F_{water\_v} = \gamma_G \times A_{water} \times \gamma_w =$ **59.6** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} =$ **351.3** kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} =$ **60.8** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{pass\_v} + F_{water\_v} + F_{sur\_v} = \mathbf{850.2}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key}) = \mathbf{33.9}$ kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + t_{base})^2 / 2 = \mathbf{13.2}$ kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + t_{base})^2 / 2 = \mathbf{35}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) = \mathbf{163.7}$ kN/m

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

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} = \mathbf{342.3}$ kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} = \mathbf{403.1}$ kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h\_a} = \mathbf{115.6}$ kNm/m

Saturated retained soil; $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h\_a} = \mathbf{355.7}$ kNm/m

Water; $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h\_a} = \mathbf{245.2}$ kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h\_a} = \mathbf{1159.7}$ kNm/m

Base soil; $M_{pass} = F_{pass\_v} \times x_{pass\_v} = \mathbf{75.9}$ kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur} = \mathbf{2697.6}$ kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} = \mathbf{3173}$ mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 = \mathbf{248}$ mm

Loaded length of base; $l_{load} = 2 \times (l_{base} - \bar{x}) = \mathbf{5354}$ mm

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

Bearing pressure at heel; $q_{heel} = F_{total\_v} / l_{load} = \mathbf{158.8}$ kN/m^2

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb} - (t_{base} + d_{cover} + h_{water}) \times \gamma_w = \mathbf{5.3}$ kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma = \mathbf{5.3}$ kN/m^2

Bearing resistance factors; $N_q = \mathrm{Exp}(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 = \mathbf{23.177}$

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{35.49}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) = \mathbf{27.715}$

Foundation shape factors; $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

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

$V = F_{total\_v} = \mathbf{850.2}$ 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; $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{731.4}$ kN/m^2

Factor of safety; $FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{4.606}$

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; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{30.2}$ deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{8}$ deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{26.6}$ deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{14.6}$ 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; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \surd[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2) = \mathbf{0.365}$

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \surd[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2) = \mathbf{4.105}$

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **90** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **91.7** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w)$ = **59.4** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w$ = **44.2** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **260.2** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{water\_v}$ = **545.5** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **41.7** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2$ = **25.6** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **53.4** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base}))$ = **187.4** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h}$ = **308.1** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **85.9** kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d})$ = **251.9** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction}$ = **337.8** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h}$ = **1.096**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **90** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **91.7** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w)$ = **59.4** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w$ = **44.2** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **260.2** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{water\_v}$ = **545.5** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key})$ = **36.4** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + t_{base})^2 / 2$ = **12.4** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + t_{base})^2 / 2$ = **25.9** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base}))$ = **153.7** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **-85.9** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h}$ = **142.5** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h\_a}$ = **123.9** kNm/m

Saturated retained soil; $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h\_a}$ = **9.5** kNm/m

Water; $M_{water\_OT} = F_{water\_h} \times x_{water\_h\_a}$ = **19.9** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h\_a}$ = **378.7** kNm/m

Base soil; $M_{exc\_OT} = F_{exc\_h} \times x_{exc\_h}$ = **41.5** kNm/m

Total; $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{exc\_OT} + M_{water\_OT} + M_{sur\_OT}$ = **573.6** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem}$ = **253.6** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base}$ = **298.6** kNm/m

Saturated retained soil; $M_{sat\_R} = F_{sat\_v} \times x_{sat\_v}$ = **271** kNm/m

Water; $M_{water\_R} = F_{water\_v} \times x_{water\_v}$ = **201.6** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **1157.9** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{sat\_R} + M_{moist\_R} + M_{water\_R}$ = **2182.6** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT}$ = **3.805**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem}$ = **90** kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base}$ = **91.7** kN/m

Surcharge load; $F_{sur\_v} = (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) = \mathbf{45}$ kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_G \times A_{sat} \times (\gamma_{sr} - \gamma_w) = \mathbf{59.4}$ kN/m

Water; $F_{water\_v} = \gamma_G \times A_{water} \times \gamma_w = \mathbf{44.2}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{260.2}$ kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} = \mathbf{45}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{pass\_v} + F_{water\_v} + F_{sur\_v} = \mathbf{635.5}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key}) = \mathbf{36.4}$ kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + t_{base})^2 / 2 = \mathbf{12.4}$ kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + t_{base})^2 / 2 = \mathbf{25.9}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) = \mathbf{153.7}$ kN/m

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

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} = \mathbf{253.6}$ kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} = \mathbf{298.6}$ kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h\_a} = \mathbf{71.8}$ kNm/m

Saturated retained soil; $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h\_a} = \mathbf{261.5}$ kNm/m

Water; $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h\_a} = \mathbf{181.7}$ kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h\_a} = \mathbf{779.2}$ kNm/m

Base soil; $M_{pass} = F_{pass\_v} \times x_{pass\_v} = \mathbf{56.3}$ kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur} = \mathbf{1902.5}$ kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} = \mathbf{2994}$ mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 = \mathbf{69}$ mm

Loaded length of base; $l_{load} = 2 \times (l_{base} - \bar{x}) = \mathbf{5712}$ mm

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

Bearing pressure at heel; $q_{heel} = F_{total\_v} / l_{load} = \mathbf{111.2}$ kN/m^2

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb} - (t_{base} + d_{cover} + h_{water}) \times \gamma_w =$ **5.3** kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma =$ **5.3** kN/m^2

Bearing resistance factors; $N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 =$ **12.588**

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) =$ **23.18**

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) =$ **11.585**

Foundation shape factors; $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

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

$V = F_{total\_v} =$ **635.5** kN/m

$m = 2$

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

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

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

Net ultimate bearing capacity; $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma =$ **338.2** kN/m^2

Factor of safety; $FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) =$ **3.04**

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

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

Concrete strength class; C40/50

Characteristic compressive cylinder strength; $f_{ck} =$ **40** N/mm^2

Characteristic compressive cube strength; $f_{ck,cube} =$ **50** N/mm^2

Mean value of compressive cylinder strength; $f_{cm} = f_{ck} + 8$ N/mm^2 = **48** N/mm^2

Mean value of axial tensile strength; $f_{ctm} = 0.3$ N/mm$^2 \times (f_{ck} / 1$ N/mm$^2)^{2/3}$ = **3.5** N/mm^2

5% fractile of axial tensile strength; $f_{ctk,0.05} = 0.7 \times f_{ctm} =$ **2.5** N/mm^2

Secant modulus of elasticity of concrete; $E_{cm} = 22$ kN/mm$^2 \times (f_{cm} / 10$ N/mm$^2)^{0.3}$ = **35220** N/mm^2

Partial factor for concrete - Table 2.1N; $\gamma_C =$ **1.50**

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

Design compressive concrete strength - exp.3.15; $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C$ = **26.7** N/mm^2

Maximum aggregate size; h_{agg} = **20** mm

Reinforcement details

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

Modulus of elasticity of reinforcement; E_s = **200000** N/mm^2

Partial factor for reinforcing steel - Table 2.1N; γ_S = **1.15**

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

Cover to reinforcement

Front face of stem; c_{sf} = **40** mm

Rear face of stem; c_{sr} = **50** mm

Top face of base; c_{bt} = **50** mm

Bottom face of base; c_{bb} = **75** mm

Check stem design at base of stem

Depth of section; h = **850** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **358.8** kNm/m

Depth to tension reinforcement; $d = h - c_{sr} - \phi_{sr} / 2$ = **790** mm

$K = M / (d^2 \times f_{ck})$ = **0.014**

K' = **0.196**

K' > K - No compression reinforcement is required

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

Depth of neutral axis; $x = 2.5 \times (d – z)$ = **99** mm

Area of tension reinforcement required; $A_{sr.req} = M / (f_{yd} \times z)$ = **1100** mm^2/m

Tension reinforcement provided; 20 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **1571** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **1441**
mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{sr.max} = 0.04 \times h$ = **34000** mm^2/m

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.918**

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 = **0.3**

Serviceability bending moment; M_{sls} = **224.8** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **190.7** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) =$ **150000** mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff} = f_{ctm} =$ **3.5** N/mm^2

Reinforcement ratio; $\rho_{p.eff} = A_{sr.prov} / A_{c.eff} =$ **0.010**

Modular ratio; $\alpha_e = E_s / E_{cm} =$ **5.679**

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; $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff} =$ **495** mm

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

$w_k =$ **0.283** mm

$w_k / w_{max} =$ **0.943**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; $V =$ **161.4** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) =$ **1.503**

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} =$ **0.408** N/mm^2

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

$V_{Rd.c} =$ **322.3** kN/m

$V / V_{Rd.c} =$ **0.501**

PASS - Design shear resistance exceeds design shear force

Horizontal reinforcement parallel to face of stem - Section 9.6

Minimum area of reinforcement – cl.9.6.3(1); $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times (t_{stem} + l_{slr})) =$ **850** mm^2/m

Maximum spacing of reinforcement – cl.9.6.3(2); $s_{sx\_max} =$ **400** mm

Transverse reinforcement provided; 16 dia.bars @ 200 c/c

Area of transverse reinforcement provided; $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx}) =$ **1005** mm^2/m

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

Check base design at toe

Depth of section; $h =$ **550** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; $M =$ **237.7** kNm/m

Depth to tension reinforcement; $d = h - c_{bb} - \phi_{bb} / 2 =$ **463** mm

$K = M / (d^2 \times f_{ck}) =$ **0.028**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 – 3.53 \times K)^{0.5}, 0.95) \times d$ = **439** mm

Depth of neutral axis; $x = 2.5 \times (d – z)$ = **58** mm

Area of tension reinforcement required; $A_{bb.req} = M / (f_{yd} \times z)$ = **1244** mm^2/m

Tension reinforcement provided; 25 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **2454** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **844** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{bb.max} = 0.04 \times h$ = **22000** mm^2/m

$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov}$ = **0.507**

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 = **0.3**

Serviceability bending moment; M_{sls} = **134.1** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{bb.prov} \times z)$ = **124.4** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **164063** mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff} = f_{ctm}$ = **3.5** N/mm^2

Reinforcement ratio; $\rho_{p.eff} = A_{bb.prov} / A_{c.eff}$ = **0.015**

Modular ratio; $\alpha_e = E_s / E_{cm}$ = **5.679**

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; $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff}$ = **539** 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 = **0.201** mm

w_k / w_{max} = **0.67**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **203.3** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.658**

Longitudinal reinforcement ratio; $\rho_l = min(A_{bb.prov} / d, 0.02) =$ **0.005**

$v_{min} = 0.035 N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} =$ **0.472** N/mm^2

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

$V_{Rd.c} =$ **254.7** kN/m

$V / V_{Rd.c} =$ **0.798**

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section; h = **550** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 2; M = **175.9** kNm/m

Depth to tension reinforcement; $d = h - c_{bt} - \phi_{bt} / 2 =$ **492** mm

$K = M / (d^2 \times f_{ck}) =$ **0.018**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d =$ **467** mm

Depth of neutral axis; $x = 2.5 \times (d - z) =$ **62** mm

Area of tension reinforcement required; $A_{bt.req} = M / (f_{yd} \times z) =$ **866** mm^2/m

Tension reinforcement provided; 16 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) =$ **1005** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{bt.min} = max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **898** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{bt.max} = 0.04 \times h =$ **22000** mm^2/m

$max(A_{bt.req}, A_{bt.min}) / A_{bt.prov} =$ **0.893**

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; $\psi_2 =$ **0.3**

Serviceability bending moment; $M_{sls} =$ **65.3** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{bt.prov} \times z) =$ **139.1** N/mm^2

Load duration; Long term

Load duration factor; $k_t =$ **0.4**

Effective area of concrete in tension; $A_{c.eff} = min(2.5 \times (h - d), (h - x) / 3, h / 2) =$ **145000** mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff} = f_{ctm} =$ **3.5** N/mm^2

Reinforcement ratio; $\rho_{p.eff} = A_{bt.prov} / A_{c.eff} =$ **0.007**

Modular ratio; $\alpha_e = E_s / E_{cm} =$ **5.679**

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; $s_{r.max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p.eff}$ = **562** 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 = **0.235** mm

w_k / w_{max} = **0.782**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **137.5** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.638**

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.464** N/mm^2

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

$V_{Rd.c}$ = **228.2** kN/m

$V / V_{Rd.c}$ = **0.603**

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section; h = **450** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **53.4** kNm/m

Depth to tension reinforcement; $d = h - c_{bb} - \phi_k / 2$ = **367** mm

$K = M / (d^2 \times f_{ck})$ = **0.010**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **349** mm

Depth of neutral axis; $x = 2.5 \times (d - z)$ = **46** mm

Area of tension reinforcement required; $A_{k.req} = M / (f_{yd} \times z)$ = **353** mm^2/m

Tension reinforcement provided; 16 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{k.prov} = \pi \times \phi_k^2 / (4 \times s_k)$ = **1005** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{k.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **670** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{k.max} = 0.04 \times h$ = **18000** mm^2/m

$\max(A_{k.req}, A_{k.min}) / A_{k.prov}$ = **0.666**

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 = **0.3**

Serviceability bending moment; M_{sls} = **40** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{k.prov} \times z)$ = **114.1** 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) = **134708** mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff} = f_{ctm}$ = **3.5** N/mm^2

Reinforcement ratio; $\rho_{p.eff} = A_{k.prov} / A_{c.eff}$ = **0.007**

Modular ratio; $\alpha_e = E_s / E_{cm}$ = **5.679**

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; $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p.eff}$ = **619** 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 = **0.212** mm

w_k / w_{max} = **0.707**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **95.8** kN/m

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

k = min(1 + √(200 mm / d), 2) = **1.738**

Longitudinal reinforcement ratio; $\rho_l = \min(A_{k.prov} / d, 0.02)$ = **0.003**

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.507** N/mm^2

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

$V_{Rd.c}$ = **186.2** kN/m

$V / V_{Rd.c}$ = **0.514**

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

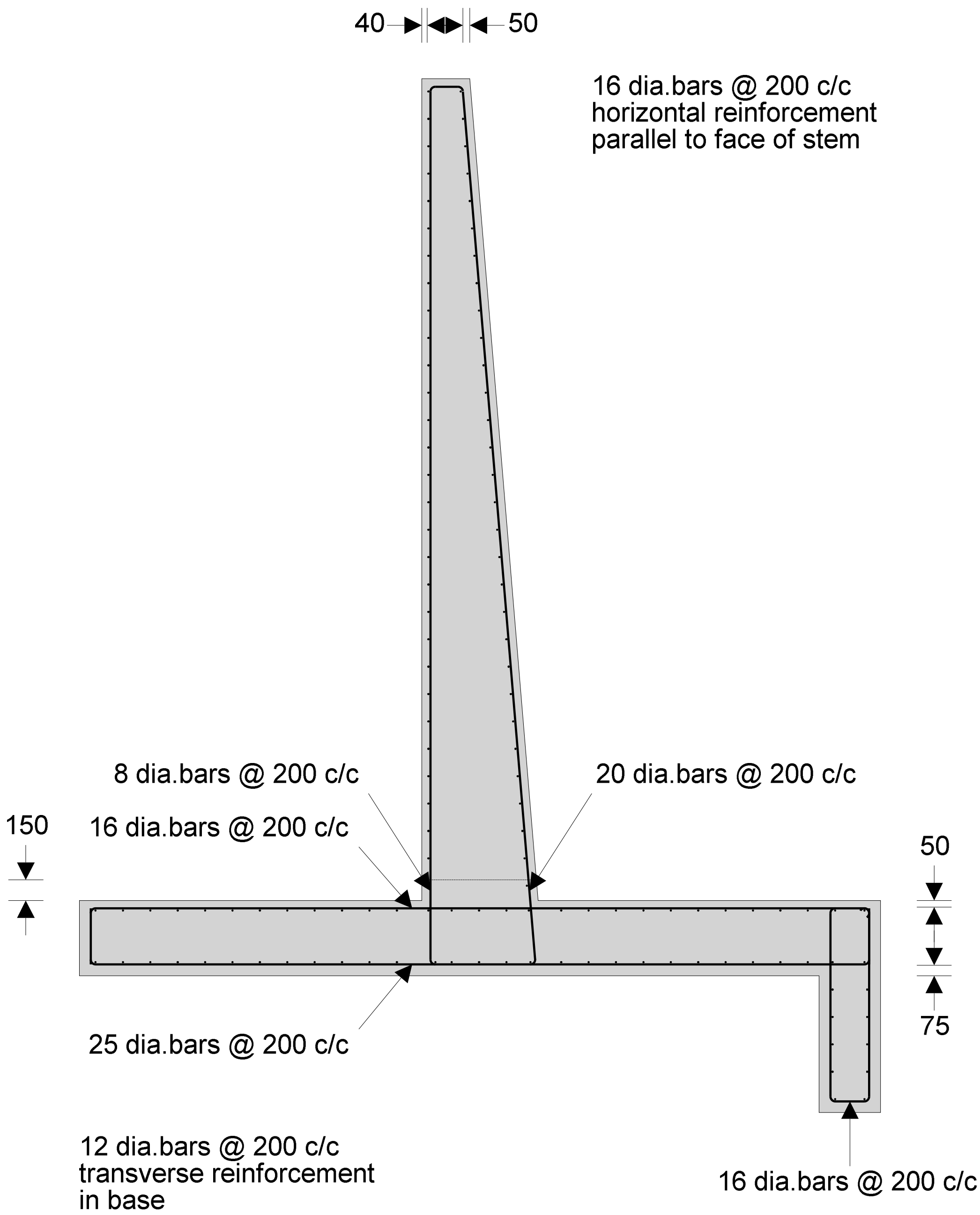
Minimum area of reinforcement – cl.9.3.1.1(2); $A_{bx.req} = 0.2 \times A_{bb.prov}$ = **491** mm^2/m

Maximum spacing of reinforcement – cl.9.3.1.1(3); s_{bx_max} = **450** mm

Transverse reinforcement provided; 12 dia.bars @ 200 c/c

Area of transverse reinforcement provided; $A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx})$ = **565** mm^2/m

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



40
50
16 dia.bars @ 200 c/c
horizontal reinforcement
parallel to face of stem
8 dia.bars @ 200 c/c
20 dia.bars @ 200 c/c
150
16 dia.bars @ 200 c/c
50
25 dia.bars @ 200 c/c
75
12 dia.bars @ 200 c/c
transverse reinforcement
in base
16 dia.bars @ 200 c/c