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Project: Retaining wall Analysis & Design, In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the recommended values.				Job Ref.	
Section: Civil & Geotechnical Engineering				Sheet no./rev. 1	
Calc. by: Dr. C. Sachpazis	Date: 04/04/2014	Chk'd by	Date	App'd by	Date

RETAINING WALL ANALYSIS (EN1997-1:2004)

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

Retaining wall details

Stem type;	Cantilever with inclined front face
Stem height;	h_{stem} = **4000** mm
Stem thickness;	t_{stem} = **450** mm
Slope length to front of stem;	l_{slf} = **100** mm
Angle to rear face of stem;	α = **90** deg
Angle to front face of stem;	α_f = **88.6** deg
Stem density;	γ_{stem} = **25** kN/m^3
Toe length;	l_{toe} = **1000** mm
Heel length;	l_{heel} = **4000** mm
Base thickness;	t_{base} = **450** mm
Base density;	γ_{base} = **25** kN/m^3
Height of retained soil;	h_{ret} = **3000** mm
Angle of soil surface;	β = **15** deg
Depth of cover;	d_{cover} = **500** mm
Height of water;	h_{water} = **300** mm
Water density;	γ_w = **9.8** kN/m^3

Retained soil properties

Soil type;	Medium dense well graded sand and gravel
Moist density;	γ_{mr} = **20** kN/m^3
Saturated density;	γ_{sr} = **22.3** kN/m^3
Characteristic effective shear resistance angle;	$\phi'_{r.k}$ = **25** deg
Characteristic wall friction angle;	$\delta_{r.k}$ = **16** deg

Base soil properties

Moist density;	γ_{mb} = **20** kN/m^3
Characteristic cohesion;	$c'_{b.k}$ = **5** kN/m^2
Characteristic adhesion;	$a_{b.k}$ = **5** kN/m^2
Characteristic effective shear resistance angle;	$\phi'_{b.k}$ = **25** deg
Characteristic wall friction angle;	$\delta_{b.k}$ = **20** deg
Characteristic base friction angle;	$\delta_{bb.k}$ = **25** deg

Loading details

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

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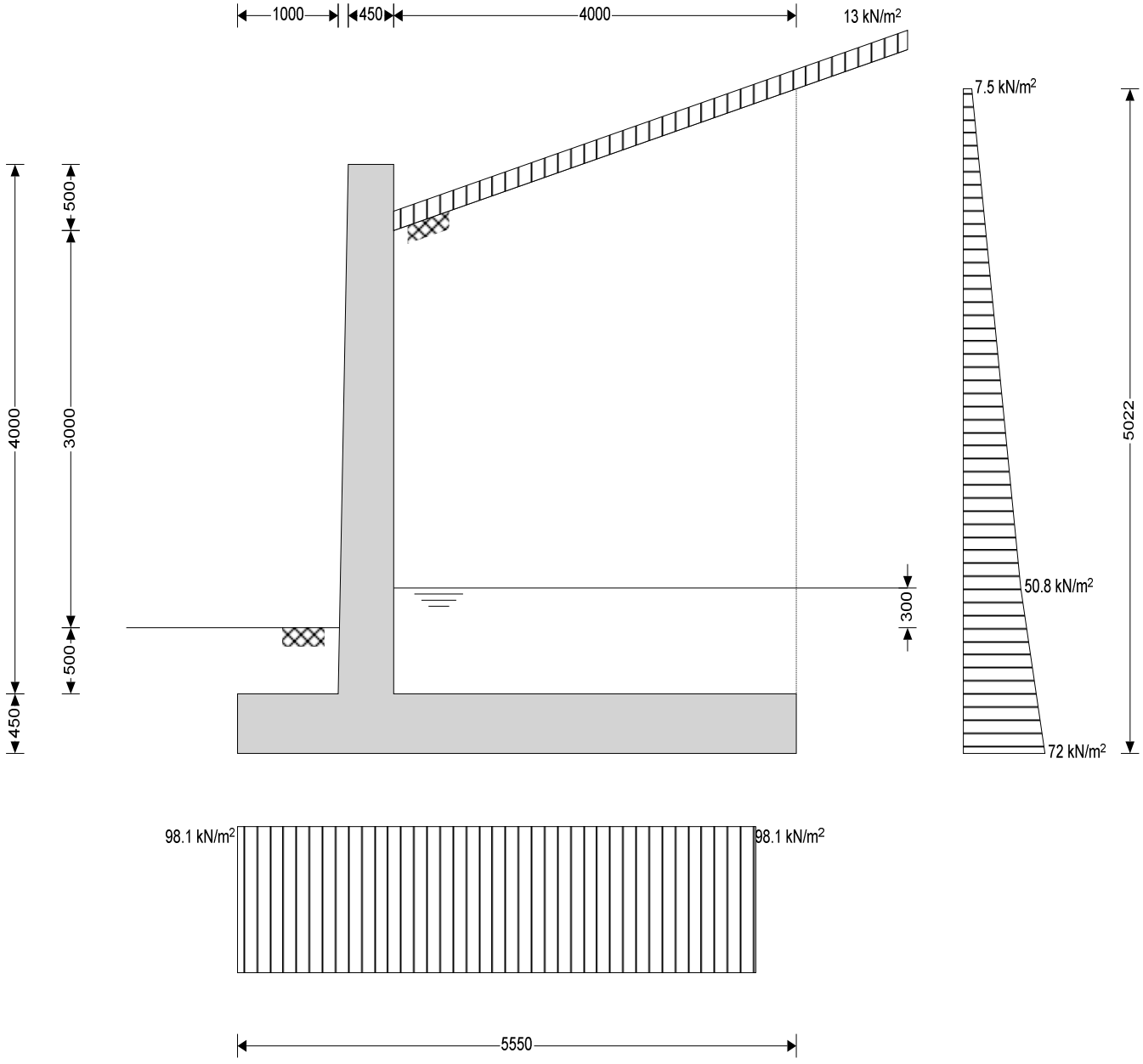

Calculate retaining wall geometry

Base length; $l_{base} = l_{toe} + l_{slf} + t_{stem} + l_{heel} = \mathbf{5550}$ mm

Saturated soil height; $h_{sat} = h_{water} + d_{cover} = \mathbf{800}$ mm

Moist soil height; $h_{moist} = h_{ret} - h_{water} = \mathbf{2700}$ mm

Length of surcharge load; $l_{sur} = l_{heel} = \mathbf{4000}$ mm

- Distance to vertical component; $x_{sur\_v} = l_{base} - l_{heel} / 2 =$ **3550** mm

Effective height of wall; $h_{eff} = h_{base} + d_{cover} + h_{ret} + l_{sur} \times \tan(\beta) =$ **5022** mm

- Distance to horizontal component; $x_{sur\_h} = h_{eff} / 2 =$ **2511** mm

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

- Distance to vertical component; $x_{stem} = (h_{stem} \times t_{stem} \times (l_{toe} + l_{slf} + t_{stem} / 2) + h_{stem} \times l_{slf} / 2 \times (l_{toe} + 2 \times l_{slf} / 3)) / A_{stem} =$ **1299** mm

Area of wall base; $A_{base} = l_{base} \times t_{base} =$ **2.498** m^2

- Distance to vertical component; $x_{base} = l_{base} / 2 =$ **2775** mm

Area of saturated soil; $A_{sat} = h_{sat} \times l_{heel} =$ **3.2** m^2

- Distance to vertical component; $x_{sat\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat} =$ **3550** mm

- Distance to horizontal component; $x_{sat\_h} = (h_{sat} + h_{base}) / 3 =$ **417** mm

Area of water; $A_{water} = h_{sat} \times l_{heel} =$ **3.2** m^2

- Distance to vertical component; $x_{water\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat} =$ **3550** mm

- Distance to horizontal component; $x_{water\_h} = (h_{sat} + h_{base}) / 3 =$ **417** mm

Area of moist soil; $A_{moist} = h_{moist} \times l_{heel} + \tan(\beta) \times l_{heel}^2 / 2 =$ **12.944** m^2

- Distance to vertical component; $x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2 + \tan(\beta) \times l_{heel}^3 / 6) / A_{moist} =$ **3660** mm

- Distance to horizontal component; $x_{moist\_h} = ((h_{eff} - h_{sat} - h_{base}) \times (t_{base} + h_{sat} + (h_{eff} - h_{sat} - h_{base}) / 3) / 2 + (h_{sat} + t_{base})^2/2) / (h_{sat} + t_{base} + (h_{eff} - h_{sat} - h_{base}) / 2) =$ **1757** mm

Area of base soil; $A_{pass} = d_{cover} \times (l_{toe} + l_{slf} \times d_{cover} / (2 \times h_{stem})) =$ **0.503** m^2

- Distance to vertical component; $x_{pass\_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2) + l_{slf} \times d_{cover}^2 / (2 \times h_{stem}) \times (l_{base} - l_{toe} - l_{slf} \times d_{cover} / (3 \times h_{stem}))) / A_{pass} =$ **503** mm

- Distance to horizontal component; $x_{pass\_h} = (d_{cover} + h_{base}) / 3 =$ **317** mm

Area of excavated base soil; $A_{exc} = h_{pass} \times (l_{toe} + l_{slf} \times h_{pass} / (2 \times h_{stem})) =$ **0.503** m^2

- Distance to vertical component; $x_{exc\_v} = l_{base} - (h_{pass} \times l_{toe} \times (l_{base} - l_{toe} / 2) + l_{slf} \times h_{pass}^2 / (2 \times h_{stem}) \times (l_{base} - l_{toe} - l_{slf} \times h_{pass} / (3 \times h_{stem}))) / A_{exc} =$ **503** mm

- Distance to horizontal component; $x_{exc\_h} = (h_{pass} + h_{base}) / 3 =$ **317** mm

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

Permanent unfavourable action; $\gamma_G =$ **1.35**

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

Variable unfavourable action; $\gamma_Q =$ **1.50**

Variable favourable action; $\gamma_{Qf} =$ **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; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) =$ **25** deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) =$ **16** deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) =$ **25** deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) =$ **20** deg

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) =$ **25** deg

Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'} =$ **5** kN/m^2

Design adhesion; $a_{b.d} = a_{b.k} / \gamma_{c'} =$ **5** kN/m^2

Using Coulomb theory

Active pressure coefficient;

$$K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2}) = \mathbf{0.469}$$

Passive pressure coefficient;

$$K_P = \sin(\alpha_f - \phi'_{b.d})^2 / (\sin(\alpha_f)^2 \times \sin(\alpha_f + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(\alpha_f + \delta_{b.d}) \times \sin(\alpha_f))]]^2}) = \mathbf{4.403}$$

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **50** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **62.4** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **39.8** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w =$ **31.4** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} =$ **258.9** kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb} =$ **10.1** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{exc\_v} + F_{water\_v} =$ **452.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} =$ **33.9** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **5.9** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **10.3** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **143.9** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h} =$ **194.1** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **37.3** kN/m

Base friction; $F_{friction} = a_{b.d} \times b + F_{total\_v} \times \tan(\delta_{bb.d}) =$ **216** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} =$ **253.4** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} =$ **1.306**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **50** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **62.4** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **39.8** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w =$ **31.4** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} =$ **258.9** kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb} =$ **10.1** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{exc\_v} + F_{water\_v} =$ **452.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **33.9** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **5.9** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **10.3** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **143.9** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 =$ **-37.3** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h} =$ **156.7** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **85.2** kNm/m

Saturated retained soil; $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h} = \mathbf{2.5}$ kNm/m

Water; $M_{water\_OT} = F_{water\_h} \times x_{water\_h} = \mathbf{4.3}$ kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} = \mathbf{252.8}$ kNm/m

Total; $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{water\_OT} + M_{sur\_OT} = \mathbf{344.8}$ kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} = \mathbf{65}$ kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} = \mathbf{173.3}$ kNm/m

Saturated retained soil; $M_{sat\_R} = F_{sat\_v} \times x_{sat\_v} = \mathbf{141.3}$ kNm/m

Water; $M_{water\_R} = F_{water\_v} \times x_{water\_v} = \mathbf{111.4}$ kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} = \mathbf{947.6}$ kNm/m

Base soil; $M_{exc\_R} = F_{exc\_v} \times x_{exc\_v} - F_{exc\_h} \times x_{exc\_h} = \mathbf{16.9}$ kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{sat\_R} + M_{moist\_R} + M_{exc\_R} + M_{water\_R} = \mathbf{1455.4}$ kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{4.222}$

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{67.5}$ kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{84.3}$ kN/m

Surcharge load; $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel} = \mathbf{60}$ kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_G \times A_{sat} \times (\gamma_{sr} - \gamma_w) = \mathbf{53.7}$ kN/m

Water; $F_{water\_v} = \gamma_G \times A_{water} \times \gamma_w = \mathbf{42.4}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{349.5}$ kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} = \mathbf{13.6}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{pass\_v} + F_{water\_v} + F_{sur\_v} = \mathbf{671}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{33.9}$ kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 = \mathbf{5.9}$ kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{10.3}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) = \mathbf{143.9}$ kN/m

Base soil; $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2 =$ **-37.3** kN/m

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

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} =$ **87.7** kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} =$ **233.9** kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} =$ **127.8** kNm/m

Saturated retained soil; $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h} =$ **188.3** kNm/m

Water; $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h} =$ **146.1** kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} =$ **1026.4** kNm/m

Base soil; $M_{pass} = F_{pass\_v} \times x_{pass\_v} - F_{pass\_h} \times x_{pass\_h} =$ **18.7** kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur} =$ **1829** kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} =$ **2726** mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 =$ **-49** mm

Loaded length of base; $l_{load} = 2 \times \bar{x} =$ **5452** mm

Bearing pressure at toe; $q_{toe} = F_{total\_v} / l_{load} =$ **123.1** kN/m^2

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

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb} - (t_{base} + d_{cover} + h_{water}) \times \gamma_w =$ **6.7** kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma =$ **6.7** kN/m^2

Bearing resistance factors; $N_q = \mathrm{Exp}(\pi \times \tan(\phi'_{b.d})) \times (\tan(45\ deg + \phi'_{b.d} / 2))^2 =$ **10.662**

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) =$ **20.721**

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) =$ **9.011**

Foundation shape factors; $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

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

$V = F_{total\_v} =$ **671** 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; $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma =$ **425.7** kN/m^2

Factor of safety; $FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) =$ **3.459**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

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

Permanent unfavourable action; $\gamma_G =$ **1.00**

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

Variable unfavourable action; $\gamma_Q =$ **1.30**

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

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

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

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

Weight density; $\gamma_\gamma =$ **1.00**

Retained soil properties

Design effective shear resistance angle; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) =$ **20.5** deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) =$ **12.9** deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) =$ **20.5** deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) =$ **16.2** deg

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) =$ **20.5** deg

Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'} =$ **4** kN/m^2

Design adhesion; $a_{b.d} = a_{b.k} / \gamma_{c'} =$ **4** kN/m^2

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2}) =$ **0.590**

Passive pressure coefficient; $K_P = \sin(\alpha_f - \phi'_{b.d})^2 / (\sin(\alpha_f)^2 \times \sin(\alpha_f + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(\alpha_f + \delta_{b.d}) \times \sin(\alpha_f))]]^2}) =$ **3.111**

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **50** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **62.4** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **39.8** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w =$ **31.4** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} =$ **258.9** kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb} =$ **10.1** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{exc\_v} + F_{water\_v} =$ **452.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **37.5** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **5.6** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **7.7** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **136** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h} =$ **186.8** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **27** kN/m

Base friction; $F_{friction} = a_{b.d} \times b + F_{total\_v} \times \tan(\delta_{bb.d}) =$ **172.8** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} =$ **199.8** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} =$ **1.07**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **50** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **62.4** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **39.8** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w =$ **31.4** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} =$ **258.9** kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb} =$ **10.1** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{exc\_v} + F_{water\_v} =$ **452.6** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **37.5** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **5.6** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **7.7** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **136** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 =$ **-27** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h} =$ **159.8** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **94.2** kNm/m

Saturated retained soil; $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h} =$ **2.3** kNm/m

Water; $M_{water\_OT} = F_{water\_h} \times x_{water\_h} =$ **3.2** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} =$ **238.9** kNm/m

Total; $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{water\_OT} + M_{sur\_OT} =$ **338.7** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} =$ **65** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} =$ **173.3** kNm/m

Saturated retained soil; $M_{sat\_R} = F_{sat\_v} \times x_{sat\_v} =$ **141.3** kNm/m

Water; $M_{water\_R} = F_{water\_v} \times x_{water\_v} =$ **111.4** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} =$ **947.6** kNm/m

Base soil; $M_{exc\_R} = F_{exc\_v} \times x_{exc\_v} - F_{exc\_h} \times x_{exc\_h} =$ **13.6** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{sat\_R} + M_{moist\_R} + M_{exc\_R} + M_{water\_R} =$ **1452.2** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **4.288**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} =$ **50** kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} =$ **62.4** kN/m

Surcharge load; $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel} =$ **52** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_G \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **39.8** kN/m

Water; $F_{water\_v} = \gamma_G \times A_{water} \times \gamma_w =$ **31.4** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} =$ **258.9** kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} =$ **10.1** kN/m

Total;	$F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{pass\_v} + F_{water\_v} + F_{sur\_v}$ = **504.6** kN/m

Horizontal forces on wall

Surcharge load;	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff}$ = **37.5** kN/m
Saturated retained soil;	$F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2$ = **5.6** kN/m
Water;	$F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **7.7** kN/m
Moist retained soil;	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base}))$ = **136** kN/m
Base soil;	$F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2$ = **-27** kN/m
Total;	$F_{total\_h} = \max(F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h} - (a_{b.d} \times b + F_{total\_v} \times \tan(\delta_{bb.d})), 0$ kN/m) = **0** kN/m

Moments on wall

Wall stem;	$M_{stem} = F_{stem} \times x_{stem}$ = **65** kNm/m
Wall base;	$M_{base} = F_{base} \times x_{base}$ = **173.3** kNm/m
Surcharge load;	$M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h}$ = **90.4** kNm/m
Saturated retained soil;	$M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h}$ = **139** kNm/m
Water;	$M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h}$ = **108.2** kNm/m
Moist retained soil;	$M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h}$ = **708.7** kNm/m
Base soil;	$M_{pass} = F_{pass\_v} \times x_{pass\_v} - F_{pass\_h} \times x_{pass\_h}$ = **13.6** kNm/m
Total;	$M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur}$ = **1298.1** kNm/m

Check bearing pressure

Distance to reaction;	$\bar{x} = M_{total} / F_{total\_v}$ = **2573** mm
Eccentricity of reaction;	$e = \bar{x} - l_{base} / 2$ = **-202** mm
Loaded length of base;	$l_{load} = 2 \times \bar{x}$ = **5145** mm
Bearing pressure at toe;	$q_{toe} = F_{total\_v} / l_{load}$ = **98.1** kN/m^2
Bearing pressure at heel;	q_{heel} = **0** kN/m^2
Effective overburden pressure;	$q = (t_{base} + d_{cover}) \times \gamma_{mb} - (t_{base} + d_{cover} + h_{water}) \times \gamma_w$ = **6.7** kN/m^2
Design effective overburden pressure;	$q' = q / \gamma_\gamma$ = **6.7** kN/m^2

Bearing resistance factors;	$N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45\ deg + \phi'_{b.d} / 2))^2 =$ **6.698**
	$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) =$ **15.273**
	$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) =$ **4.251**
Foundation shape factors;	$s_q = 1$
	$s_\gamma = 1$
	$s_c = 1$
Load inclination factors;	$H = F_{total\_h} =$ **0** kN/m
	$V = F_{total\_v} =$ **504.6** 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;	$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma =$ **217.7** kN/m^2
Factor of safety;	$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) =$ **2.22**

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;	C20/25
Characteristic compressive cylinder strength;	$f_{ck} =$ **20** N/mm^2
Characteristic compressive cube strength;	$f_{ck,cube} =$ **25** N/mm^2
Mean value of compressive cylinder strength;	$f_{cm} = f_{ck} + 8$ N/mm^2 = **28** N/mm^2
Mean value of axial tensile strength;	$f_{ctm} = 0.3$ N/mm^2 $\times (f_{ck} / 1$ N/mm$^2)^{2/3} =$ **2.2** N/mm^2
5% fractile of axial tensile strength;	$f_{ctk,0.05} = 0.7 \times f_{ctm} =$ **1.5** N/mm^2
Secant modulus of elasticity of concrete;	$E_{cm} = 22$ kN/mm^2 $\times (f_{cm} / 10$ N/mm$^2)^{0.3} =$ **29962** 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;	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C =$ **13.3** 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 = **550** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **235.8** kNm/m

Depth to tension reinforcement; $d = h - c_{sr} - \phi_{sr} / 2$ = **488** mm

$K = M / (d^2 \times f_{ck})$ = **0.050**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **463** mm

Depth of neutral axis; $x = 2.5 \times (d - z)$ = **61** mm

Area of tension reinforcement required; $A_{sr.req} = M / (f_{yd} \times z)$ = **1171** mm^2/m

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

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

Minimum area of reinforcement - exp.9.1N; $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **634** mm^2/m

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

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.477**

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} = **152.3** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **134** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **156250** mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff} = f_{ctm}$ = **2.2** N/mm^2

Reinforcement ratio; $\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.016**

Modular ratio; $\alpha_e = E_s / E_{cm}$ = **6.675**

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; $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **441** 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 = **0.177** mm

w_k / w_{max} = **0.59**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **153.5** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.641**

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.329** N/mm^2

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

$V_{Rd.c}$ = **207.2** kN/m

$V / V_{Rd.c}$ = **0.741**

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); $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times (t_{stem} + l_{slf}))$ = **614** 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 = **450** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **48.9** kNm/m

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

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

K' = **0.196**

K' > K - No compression reinforcement is required

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

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

Area of tension reinforcement required; $A_{bb.req} = M / (f_{yd} \times z)$ = **323** mm^2/m

Tension reinforcement provided;	16 dia.bars @ 200 c/c
Area of tension reinforcement provided;	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **1005** mm^2/m
Minimum area of reinforcement - exp.9.1N;	$A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **477** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3);	$A_{bb.max} = 0.04 \times h$ = **18000** mm^2/m
	$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov}$ = **0.475**

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} = **35.3** kNm/m
Tensile stress in reinforcement;	$\sigma_s = M_{sls} / (A_{bb.prov} \times z)$ = **100.8** N/mm^2
Load duration;	Long term
Load duration factor;	k_t = **0.4**
Effective area of concrete in tension;	$A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **134708** mm^2/m
Mean value of concrete tensile strength;	$f_{ct.eff} = f_{ctm}$ = **2.2** N/mm^2
Reinforcement ratio;	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff}$ = **0.007**
Modular ratio;	$\alpha_e = E_s / E_{cm}$ = **6.675**
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;	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff}$ = **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 = **0.187** mm
	w_k / w_{max} = **0.625**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force;	V = **97.4** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.738**
Longitudinal reinforcement ratio;	$\rho_l = \min(A_{bb.prov} / d, 0.02)$ = **0.003**
	$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.359** N/mm^2
Design shear resistance - exp.6.2a & 6.2b;	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **134.9** kN/m
	$V / V_{Rd.c}$ = **0.722**

PASS - Design shear resistance exceeds design shear force

Check base design at heel

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

Rectangular section in flexure - Section 6.1

Design bending moment combination 2; M = **238.1** kNm/m

Depth to tension reinforcement; $d = h - c_{bt} - \phi_{bt} / 2$ = **388** mm

$K = M / (d^2 \times f_{ck})$ = **0.079**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **358** mm

Depth of neutral axis; $x = 2.5 \times (d - z)$ = **73** mm

Area of tension reinforcement required; $A_{bt.req} = M / (f_{yd} \times z)$ = **1529** mm^2/m

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

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

Minimum area of reinforcement - exp.9.1N; $A_{bt.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **504** mm^2/m

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

$\max(A_{bt.req}, A_{bt.min}) / A_{bt.prov}$ = **0.623**

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} = **107.7** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{bt.prov} \times z)$ = **122.5** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **125559** mm^2/m

Mean value of concrete tensile strength; $f_{ct.eff} = f_{ctm}$ = **2.2** N/mm^2

Reinforcement ratio; $\rho_{p.eff} = A_{bt.prov} / A_{c.eff}$ = **0.020**

Modular ratio; $\alpha_e = E_s / E_{cm}$ = **6.675**

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; $s_{r.max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p.eff}$ = **387** 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 = **0.142** mm

w_k / w_{max} = **0.475**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **89.9** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.718**

Longitudinal reinforcement ratio; ρ_l = min($A_{bt.prov}$ / d, 0.02) = **0.006**

v_{min} = 0.035 $N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.353** 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}) × d

$V_{Rd.c}$ = **186.3** kN/m

V / $V_{Rd.c}$ = **0.483**

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 × $A_{bt.prov}$ = **491** mm^2/m

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

Transverse reinforcement provided; 16 dia.bars @ 300 c/c

Area of transverse reinforcement provided; $A_{bx.prov}$ = π × ϕ_{bx}^2 / (4 × s_{bx}) = **670** mm^2/m

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

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