REINFORCED MASONRY 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 stepped rear face
Stem height;	h_{stem} = **2350** mm
Number of steps;	N_{steps} = **3**
Height of step 1;	h_{s1} = **750** mm
Thickness of step 1;	t_{s1} = **750** mm
Height of step 2;	h_{s2} = **800** mm
Thickness of step 2;	t_{s2} = **500** mm
Height of step 3;	h_{s3} = **800** mm
Thickness of step 3;	t_{s3} = **250** mm
Angle to rear face of stem;	α = **90** deg
Stem density;	γ_{stem} = **25** kN/m^3
Toe length;	l_{toe} = **600** mm
Heel length;	l_{heel} = **600** mm
Base thickness;	t_{base} = **400** mm
Key position;	p_{key} = **1700** mm
Key depth;	d_{key} = **400** mm
Key thickness;	t_{key} = **250** mm
Base density;	γ_{base} = **25** kN/m^3
Height of retained soil;	h_{ret} = **1950** mm
Angle of soil surface;	β = **15** deg
Depth of cover;	d_{cover} = **350** mm
Depth of excavation;	d_{exc} = **250** mm

Retained soil properties

Soil type; Dense well graded sand

Moist density; γ_{mr} = **20.3** kN/m^3

Saturated density; γ_{sr} = **22** kN/m^3

Characteristic effective shear resistance angle; $\phi'_{r.k}$ = **36** deg

Characteristic wall friction angle; $\delta_{r.k}$ = **18** deg

Base soil properties

Soil type; Dense well graded sand

Moist density; γ_{mb} = **20.3** kN/m^3

Characteristic cohesion; $c'_{b.k}$ = **0** kN/m^2

Characteristic effective shear resistance angle; $\phi'_{b.k}$ = **36** deg

Characteristic wall friction angle; $\delta_{b.k}$ = **18** deg

Characteristic base friction angle; $\delta_{bb.k}$ = **24** deg

Loading details

Permanent surcharge load; $Surcharge_G$ = **1** kN/m^2

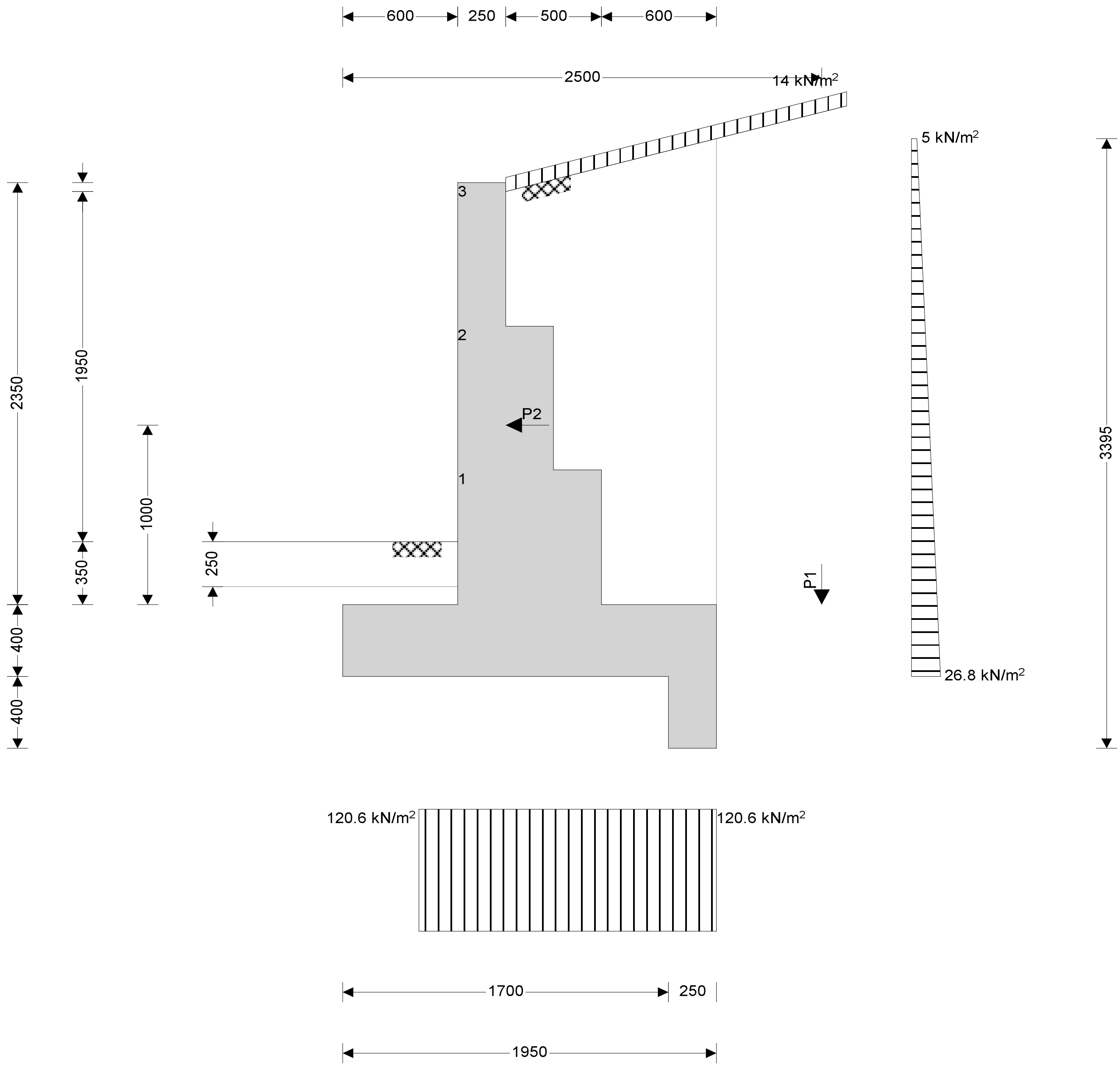
Variable surcharge load; $Surcharge_Q$ = **10** kN/m^2

Vertical line load at 2500 mm; P_{G1} = **25** kN/m

P_{Q1} = **10** kN/m

Horizontal line load at 1000 mm; P_{G2} = **5** kN/m

P_{Q2} = **8** kN/m



Calculate retaining wall geometry

Base length; $l_{base} = l_{toe} + t_{s1} + l_{heel}$ = **1950** mm

Base height; $h_{base} = t_{base} + d_{key}$ = **800** mm

Moist soil height; $h_{moist} = h_{soil} = \mathbf{2300}$ mm

Length of surcharge load; $l_{sur} = (l_{heel} + t_{s1} - t_{s3}) = \mathbf{1100}$ mm

- Distance to vertical component; $x_{sur\_v} = l_{base} - (l_{heel} + t_{s1} - t_{s3}) / 2 = \mathbf{1400}$ mm

Effective height of wall; $h_{eff} = h_{base} + d_{cover} + h_{ret} + l_{sur} \times \tan(\beta) = \mathbf{3395}$ mm

- Distance to horizontal component; $x_{sur\_h} = h_{eff} / 2 - d_{key} = \mathbf{1297}$ mm

- Distance to horizontal component above key; $x_{sur\_h\_a} = (h_{eff} - d_{key}) / 2 = \mathbf{1497}$ mm

Area of wall stem; $A_{stem} = h_{s1} \times t_{s1} + h_{s2} \times t_{s2} + h_{s3} \times t_{s3} = \mathbf{1.163}$ m^2

- Distance to vertical component; $x_{stem} = l_{base} - (h_{s1} \times t_{s1} \times (l_{heel} + t_{s1} - t_{s1} / 2) + h_{s2} \times t_{s2} \times (l_{heel} + t_{s1} - t_{s2} / 2) + h_{s3} \times t_{s3} \times (l_{heel} + t_{s1} - t_{s3} / 2)) / A_{stem} = \mathbf{889}$ mm

Area of wall base; $A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key} = \mathbf{0.88}$ m^2

- Distance to vertical component; $x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base} = \mathbf{1072}$ mm

Area of moist soil; $A_{moist} = l_{heel} \times h_{s1} + (l_{heel} + t_{s1} - t_{s2}) \times h_{s2} + (l_{heel} + t_{s1} - t_{s3}) \times (h_{soil} - h_{s1} + h_{s2}) + \tan(\beta) \times (l_{heel} + t_{s1} - t_{s3})^2 / 2 = \mathbf{3.877}$ m^2

- Distance to vertical component; $x_{moist\_v} = l_{base} - (l_{heel} \times h_{s1} \times l_{heel} / 2 + (l_{heel} + t_{s1} - t_{s2}) \times h_{s2} \times (l_{heel} + t_{s1} - t_{s2}) / 2 + (l_{heel} + t_{s1} - t_{s3}) \times (h_{soil} - h_{s1} + h_{s2}) \times (l_{heel} + t_{s1} - t_{s3}) / 2 + \tan(\beta) \times (l_{heel} + t_{s1} - t_{s3})^3 / 6) / A_{moist} = \mathbf{1459}$ mm

- Distance to horizontal component; $x_{moist\_h} = h_{eff} / 3 - d_{key} = \mathbf{732}$ mm

- Distance to horizontal component above key; $x_{moist\_h\_a} = (h_{eff} - d_{key}) / 3 = \mathbf{998}$ mm

Area of base soil; $A_{pass} = d_{cover} \times l_{toe} = \mathbf{0.21}$ m^2

- Distance to vertical component; $x_{pass\_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} = \mathbf{300}$ mm

- Distance to horizontal component; $x_{pass\_h} = (d_{cover} + h_{base}) / 3 - d_{key} = \mathbf{-17}$ mm

Area of excavated base soil; $A_{exc} = h_{pass} \times l_{toe} = \mathbf{0.06}$ m^2

- Distance to vertical component; $x_{exc\_v} = l_{base} - (h_{pass} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{exc} = \mathbf{300}$ mm

- Distance to horizontal component; $x_{exc\_h} = (h_{pass} + h_{base}) / 3 - d_{key} = \mathbf{-100}$ 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; 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; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **18** deg

Base soil properties

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

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

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **24** deg

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

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[}\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2)$ = **0.282**

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[}\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2)$ = **8.022**

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **29.1** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **22** kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1}$ = **25** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **78.5** kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb}$ = **1.2** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{exc\_v} + F_{P\_v}$ = **155.8** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **14.9** kN/m

Line loads; $F_{P\_h} = \gamma_G \times P_{G2} + \gamma_Q \times P_{Q2}$ = **18.8** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times h_{eff}^2 / 2$ = **42.3** kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{sur\_h} + F_{P\_h}$ = **75.9** kN/m

Check stability against sliding

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

= **62.6** kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d})$ = **69.4** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction}$ = **131.9** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h}$ = **1.738**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **29.1** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **22** kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1}$ = **25** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **78.5** kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb}$ = **1.2** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{exc\_v} + F_{P\_v}$ = **155.8** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key})$ = **13.1** kN/m

Line loads; $F_{P\_h} = \gamma_G \times P_{G2} + \gamma_Q \times P_{Q2}$ = **18.8** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2$ = **32.9** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **-62.6** kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h} + F_{P\_h}$ = **2.2** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h\_a}$ = **19.7** kNm/m

Line loads; $M_{P\_OT} = (\text{abs}(\gamma_G \times P_{G2} + \gamma_Q \times P_{Q2})) \times (p_2 + t_{base})$ = **26.3** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h\_a}$ = **32.8** kNm/m

Base soil; $M_{exc\_OT} = F_{exc\_v} \times x_{exc\_v}$ = **0.4** kNm/m

Total; $M_{total\_OT} = M_{moist\_OT} + M_{exc\_OT} + M_{sur\_OT} + M_{P\_OT}$ = **79.1** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem}$ = **25.8** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base}$ = **23.6** kNm/m

Line loads; $M_{P\_R} = (\text{abs}(\gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1})) \times p_1$ = **62.5** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **114.5** kNm/m

Base soil; $M_{exc\_R} = F_{exc\_v} \times x_{exc\_v}$ = **0.4** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R} + M_{P\_R}$ = **226.8** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{2.866}$

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{39.2}$ kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{29.7}$ kN/m

Surcharge load; $F_{sur\_v} = (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (l_{heel} + t_{s1} - t_{s3}) = \mathbf{18}$ kN/m

Line loads; $F_{P\_v} = \gamma_G \times P_{G1} + \gamma_Q \times P_{Q1} = \mathbf{48.8}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{106}$ kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} = \mathbf{5.7}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{pass\_v} + F_{sur\_v} + F_{P\_v} = \mathbf{247.4}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key}) = \mathbf{13.1}$ kN/m

Line loads; $F_{P\_h} = \gamma_G \times P_{G2} + \gamma_Q \times P_{Q2} = \mathbf{18.8}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2 = \mathbf{32.9}$ kN/m

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

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} = \mathbf{34.9}$ kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} = \mathbf{31.8}$ kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h\_a} = \mathbf{5.5}$ kNm/m

Line loads; $M_P = (\gamma_G \times P_{G1} + \gamma_Q \times P_{Q1}) \times p_1 - (\gamma_{Gf} \times P_{G2} + \gamma_{Qf} \times P_{Q2}) \times (p_2 + t_{base}) = \mathbf{114.9}$ kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h\_a} = \mathbf{121.8}$ kNm/m

Base soil; $M_{pass} = F_{pass\_v} \times x_{pass\_v} = \mathbf{1.7}$ kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{pass} + M_{sur} + M_P = \mathbf{310.6}$ kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} = \mathbf{1255}$ mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 = \mathbf{280}$ mm

Loaded length of base; $l_{load} = 2 \times (l_{base} - \bar{x}) = \mathbf{1389}$ mm

Bearing pressure at toe;	q_{toe} = **0** kN/m^2
Bearing pressure at heel;	$q_{heel} = F_{total\_v} / l_{load}$ = **178.1** kN/m^2
Effective overburden pressure;	$q = (t_{base} + d_{cover}) \times \gamma_{mb}$ = **15.2** kN/m^2
Design effective overburden pressure;	$q' = q / \gamma_{\gamma}$ = **15.2** kN/m^2
Bearing resistance factors;	$N_q = \text{Exp}(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2$ = **37.752**
	$N_c = (N_q - 1) \times \cot(\phi'_{b.d})$ = **50.585**
	$N_{\gamma} = 2 \times (N_q - 1) \times \tan(\phi'_{b.d})$ = **53.405**
Foundation shape factors;	$s_q = 1$
	$s_{\gamma} = 1$
	$s_c = 1$
Load inclination factors;	$H = F_{total\_h}$ = **0** kN/m
	$V = F_{total\_v}$ = **247.4** 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;	$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_{\gamma} \times s_{\gamma} \times i_{\gamma}$ = **1324.6** kN/m^2
Factor of safety;	$FoS_{bp} = n_f / \max(q_{toe}, q_{heel})$ = **7.439**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

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

Permanent unfavourable action;	γ_G = **1.00**
Permanent favourable action;	γ_{Gf} = **1.00**
Variable unfavourable action;	γ_Q = **1.30**
Variable favourable action;	γ_{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;	γ_{γ} = **1.00**

Retained soil properties

Design effective shear resistance angle;	$\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **30.2** deg
Design wall friction angle;	$\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **14.6** deg

Base soil properties

Design effective shear resistance angle;	$\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **30.2** deg
Design wall friction angle;	$\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **14.6** deg
Design base friction angle;	$\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **19.6** deg

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

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.370}$

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2) = \mathbf{4.938}$

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{29.1}$ kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{22}$ kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1} = \mathbf{25}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} = \mathbf{78.5}$ kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb} = \mathbf{1.2}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{exc\_v} + F_{P\_v} = \mathbf{155.8}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff} = \mathbf{17}$ kN/m

Line loads; $F_{P\_h} = \gamma_G \times P_{G2} + \gamma_Q \times P_{Q2} = \mathbf{15.4}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times h_{eff}^2 / 2 = \mathbf{41.8}$ kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{sur\_h} + F_{P\_h} = \mathbf{74.3}$ kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 = \mathbf{39.2}$ kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d}) = \mathbf{55.5}$ kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} = \mathbf{94.7}$ kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} = \mathbf{1.275}$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{29.1}$ kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{22}$ kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1} = \mathbf{25}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} = \mathbf{78.5}$ kN/m

Base soil; $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_{mb} = \mathbf{1.2}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{exc\_v} + F_{P\_v} =$ **155.8** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key}) =$ **15** kN/m

Line loads; $F_{P\_h} = \gamma_G \times P_{G2} + \gamma_Q \times P_{Q2} =$ **15.4** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2 =$ **32.6** kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 =$ **-39.2** kN/m

Total; $F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h} + F_{P\_h} =$ **23.8** kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h\_a} =$ **22.5** kNm/m

Line loads; $M_{P\_OT} = (abs(\gamma_G \times P_{G2} + \gamma_Q \times P_{Q2})) \times (p_2 + t_{base}) =$ **21.6** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h\_a} =$ **32.5** kNm/m

Base soil; $M_{exc\_OT} = F_{exc\_v} \times x_{exc\_v} =$ **0.4** kNm/m

Total; $M_{total\_OT} = M_{moist\_OT} + M_{exc\_OT} + M_{sur\_OT} + M_{P\_OT} =$ **76.9** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} =$ **25.8** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} =$ **23.6** kNm/m

Line loads; $M_{P\_R} = (abs(\gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1})) \times p_1 =$ **62.5** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} =$ **114.5** kNm/m

Base soil; $M_{exc\_R} = F_{exc\_v} \times x_{exc\_v} =$ **0.4** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R} + M_{P\_R} =$ **226.8** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **2.948**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} =$ **29.1** kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} =$ **22** kN/m

Surcharge load; $F_{sur\_v} = (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (l_{heel} + t_{s1} - t_{s3}) =$ **15.4** kN/m

Line loads; $F_{P\_v} = \gamma_G \times P_{G1} + \gamma_Q \times P_{Q1} = \mathbf{38}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{78.5}$ kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} = \mathbf{4.3}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{pass\_v} + F_{sur\_v} + F_{P\_v} = \mathbf{187.2}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times (h_{eff} - d_{key}) = \mathbf{15}$ kN/m

Line loads; $F_{P\_h} = \gamma_G \times P_{G2} + \gamma_Q \times P_{Q2} = \mathbf{15.4}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2 = \mathbf{32.6}$ kN/m

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

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} = \mathbf{25.8}$ kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} = \mathbf{23.6}$ kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h\_a} = \mathbf{-1}$ kNm/m

Line loads; $M_P = (\gamma_G \times P_{G1} + \gamma_Q \times P_{Q1}) \times p_1 - (\gamma_{Gf} \times P_{G2} + \gamma_{Qf} \times P_{Q2}) \times (p_2 + t_{base}) = \mathbf{88}$ kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h\_a} = \mathbf{82}$ kNm/m

Base soil; $M_{pass} = F_{pass\_v} \times x_{pass\_v} = \mathbf{1.3}$ kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{pass} + M_{sur} + M_P = \mathbf{219.8}$ kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} = \mathbf{1174}$ mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 = \mathbf{199}$ mm

Loaded length of base; $l_{load} = 2 \times (l_{base} - \bar{x}) = \mathbf{1553}$ mm

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

Bearing pressure at heel; $q_{heel} = F_{total\_v} / l_{load} = \mathbf{120.6}$ kN/m^2

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb} = \mathbf{15.2}$ kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma = \mathbf{15.2}$ kN/m^2

Bearing resistance factors; $N_q = \text{Exp}(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 = \mathbf{18.753}$

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{30.543}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) = \mathbf{20.637}$

Foundation shape factors; $s_q = 1$

$s_\gamma = 1$

	$s_c = 1$
Load inclination factors;	$H = F_{total\_h} = \mathbf{0}$ kN/m
	$V = F_{total\_v} = \mathbf{187.2}$ 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;	$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{609.2}$ kN/m^2
Factor of safety;	$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{5.052}$

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;	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 $= \mathbf{38}$ N/mm^2
Mean value of axial tensile strength;	$f_{ctm} = 0.3$ N/mm$^2 \times (f_{ck} / 1$ N/mm$^2)^{2/3} = \mathbf{2.9}$ 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$^2)^{0.3} = \mathbf{32837}$ 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

Front face of stem;	$c_{sf} = \mathbf{40}$ mm
Rear face of stem;	$c_{sr} = \mathbf{50}$ mm
Top face of base;	$c_{bt} = \mathbf{50}$ mm
Bottom face of base;	$c_{bb} = \mathbf{75}$ mm

Check stem design at base of stem

Depth of section; h = **750** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **51.7** kNm/m

Depth to tension reinforcement; $d = h - c_{sr} - \phi_{sr} / 2$ = **692** mm

$K = M / (d^2 \times f_{ck})$ = **0.004**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **657** mm

Depth of neutral axis; $x = 2.5 \times (d – z)$ = **87** mm

Area of tension reinforcement required; $A_{sr.req} = M / (f_{yd} \times z)$ = **181** mm^2/m

Tension reinforcement provided; 16 dia.bars @ 150 c/c

Area of tension reinforcement provided; $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **1340** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **1042** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{sr.max} = 0.04 \times h$ = **30000** mm^2/m

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.778**

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

Deflection control - Section 7.4

Reference reinforcement ratio; $\rho_0 = \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} / 1000$ = **0.005**

Required tension reinforcement ratio; $\rho = A_{sr.req} / d$ = **0.000**

Required compression reinforcement ratio; $\rho' = A_{sr.2.req} / d_2$ = **0.000**

Structural system factor - Table 7.4N; K_b = **1**

Reinforcement factor - exp.7.17; $K_s = \min(500 \text{ N/mm}^2 / (f_{yk} \times A_{sr.req} / A_{sr.prov}), 1.5)$ = **1.5**

Limiting span to depth ratio - exp.7.16.a; $K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}]$ = **2617.3**

Actual span to depth ratio; h_{stem} / d = **3.4**

PASS - Span to depth ratio is less than deflection control limit

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} = **30.6** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **34.7** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

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

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

Reinforcement ratio; $\rho_{p.eff} = A_{sr.prov} / A_{c.eff} =$ **0.009**

Modular ratio; $\alpha_e = E_s / E_{cm} =$ **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; $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff} =$ **464** mm

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

$w_k =$ **0.048** mm

$w_k / w_{max} =$ **0.161**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; $V =$ **53.5** kN/m

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

$k = \min(1 + \sqrt{(200\ mm / d)}, 2) =$ **1.538**

Longitudinal reinforcement ratio; $\rho_l = \min(A_{sf.prov} / d, 0.02) =$ **0.001**

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} =$ **0.366** N/mm^2

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

$V_{Rd.c} =$ **252.9** kN/m

$V / V_{Rd.c} =$ **0.212**

PASS - Design shear resistance exceeds design shear force

Check stem design at 750 mm

Depth of section; $h =$ **500** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; $M =$ **17.6** kNm/m

Depth to tension reinforcement; $d = h - c_{sr} - \phi_{sr1} / 2 =$ **445** mm

$K = M / (d^2 \times f_{ck}) =$ **0.003**

$K' =$ **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d =$ **423** mm

Depth of neutral axis; $x = 2.5 \times (d - z) =$ **56** mm

Area of tension reinforcement required; $A_{sr1.req} = M / (f_{yd} \times z) =$ **96** mm^2/m

Tension reinforcement provided; 10 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{sr1.prov} = \pi \times \phi_{sr1}^2 / (4 \times s_{sr1})$ = **393** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{sr1.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **670** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{sr1.max} = 0.04 \times h$ = **20000** mm^2/m

$\max(A_{sr1.req}, A_{sr1.min}) / A_{sr1.prov}$ = **1.707**

FAIL - Area of reinforcement provided is less than minimum 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} = **10.4** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{sr1.prov} \times z)$ = **62.6** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **137500** mm^2/m

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

Reinforcement ratio; $\rho_{p.eff} = A_{sr1.prov} / A_{c.eff}$ = **0.003**

Modular ratio; $\alpha_e = E_s / E_{cm}$ = **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; $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr1} / \rho_{p.eff}$ = **765** 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 = **0.144** mm

w_k / w_{max} = **0.479**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **38** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.670**

Longitudinal reinforcement ratio; $\rho_l = \min(A_{sf1.prov} / d, 0.02)$ = **0.001**

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.414** N/mm^2

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

$V_{Rd.c}$ = **184.2** kN/m

$V / V_{Rd.c}$ = **0.207**

PASS - Design shear resistance exceeds design shear force

Check stem design at 1550 mm

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

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **2.6** kNm/m

Depth to tension reinforcement; $d = h - c_{sr} - \phi_{sr2} / 2$ = **195** mm

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

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **185** mm

Depth of neutral axis; $x = 2.5 \times (d – z)$ = **24** mm

Area of tension reinforcement required; $A_{sr2.req} = M / (f_{yd} \times z)$ = **33** mm^2/m

Tension reinforcement provided; 10 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{sr2.prov} = \pi \times \phi_{sr2}^2 / (4 \times s_{sr2})$ = **393** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{sr2.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **294** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{sr2.max} = 0.04 \times h$ = **10000** mm^2/m

$\max(A_{sr2.req}, A_{sr2.min}) / A_{sr2.prov}$ = **0.748**

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} = **1.6** kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{sr2.prov} \times z)$ = **21.5** N/mm^2

Load duration; Long term

Load duration factor; k_t = **0.4**

Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **75208** mm^2/m

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

Reinforcement ratio; $\rho_{p.eff} = A_{sr2.prov} / A_{c.eff}$ = **0.005**

Modular ratio; $\alpha_e = E_s / E_{cm}$ = **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; $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr2} / \rho_{p.eff}$ = **496** 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 = **0.032** mm

w_k / w_{max} = **0.106**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **7.3** kN/m

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

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

Longitudinal reinforcement ratio; $\rho_l = \min(A_{sf2.prov} / d, 0.02)$ = **0.002**

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

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

$V_{Rd.c}$ = **105.7** kN/m

$V / V_{Rd.c}$ = **0.069**

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); $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{s1})$ = **750** mm^2/m

Maximum spacing of reinforcement – cl.9.6.3(2); s_{sx_max} = **400** mm

Transverse reinforcement provided; 10 dia.bars @ 200 c/c

Area of transverse reinforcement provided; $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **393** mm^2/m

FAIL - Area of reinforcement provided is less than area of reinforcement required

Check base design at toe

Depth of section; h = **400** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **19** kNm/m

Depth to tension reinforcement; $d = h - c_{bb} - \phi_{bb} / 2$ = **317** mm

$K = M / (d^2 \times f_{ck})$ = **0.006**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **301** mm

Depth of neutral axis; $x = 2.5 \times (d - z)$ = **40** mm

Area of tension reinforcement required; $A_{bb.req} = M / (f_{yd} \times z)$ = **145** mm^2/m

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

Area of tension reinforcement provided; $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **670** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{bb.min}$ = max(0.26 × f_{ctm} / f_{yk}, 0.0013) × d = **477** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{bb.max}$ = 0.04 × h = **16000** mm^2/m

max($A_{bb.req}$, $A_{bb.min}$) / $A_{bb.prov}$ = **0.712**

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} = **3.3** kNm/m

Tensile stress in reinforcement; σ_s = M_{sls} / ($A_{bb.prov}$ × z) = **16.3** 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) = **120125** mm^2/m

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

Reinforcement ratio; $\rho_{p.eff}$ = $A_{bb.prov}$ / $A_{c.eff}$ = **0.006**

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} / $\rho_{p.eff}$ = **743** 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 = **0.036** mm

w_k / w_{max} = **0.121**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **23** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.794**

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

v_{min} = 0.035 $N^{1/2}/mm$ × $k^{3/2}$ × $f_{ck}^{0.5}$ = **0.461** 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

$V_{Rd.c}$ = **146.1** kN/m

V / $V_{Rd.c}$ = **0.157**

PASS - Design shear resistance exceeds design shear force

Rectangular section in shear - Section 6.2

Design shear force; $V = \mathbf{59.1}$ kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.794}$

Longitudinal reinforcement ratio; $\rho_l = \min(A_{bt.prov} / d, 0.02) = \mathbf{0.001}$

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.461}$ N/mm^2

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

$V_{Rd.c} = \mathbf{146.1}$ kN/m

$V / V_{Rd.c} = \mathbf{0.404}$

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section; $h = \mathbf{250}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; $M = \mathbf{6.1}$ kNm/m

Depth to tension reinforcement; $d = h - c_{bb} - \phi_k / 2 = \mathbf{169}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.007}$

$K' = \mathbf{0.196}$

K' > K - No compression reinforcement is required

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

Depth of neutral axis; $x = 2.5 \times (d - z) = \mathbf{21}$ mm

Area of tension reinforcement required; $A_{k.req} = M / (f_{yd} \times z) = \mathbf{88}$ mm^2/m

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

Area of tension reinforcement provided; $A_{k.prov} = \pi \times \phi_k^2 / (4 \times s_k) = \mathbf{565}$ mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{k.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{255}$ mm^2/m

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

$\max(A_{k.req}, A_{k.min}) / A_{k.prov} = \mathbf{0.45}$

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; $M_{sls} = \mathbf{4.4}$ kNm/m

Tensile stress in reinforcement; $\sigma_s = M_{sls} / (A_{k.prov} \times z) = \mathbf{48.8}$ 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 × (h - d), (h – x) / 3, h / 2) = **76292** mm^2/m

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

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

Modular ratio; $\alpha_e = E_s / E_{cm}$ = **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; $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p.eff}$ = **530** 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 = **0.078** 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 = **28.2** kN/m

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

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

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

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

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

$V_{Rd.c}$ = **91.6** kN/m

$V / V_{Rd.c}$ = **0.308**

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

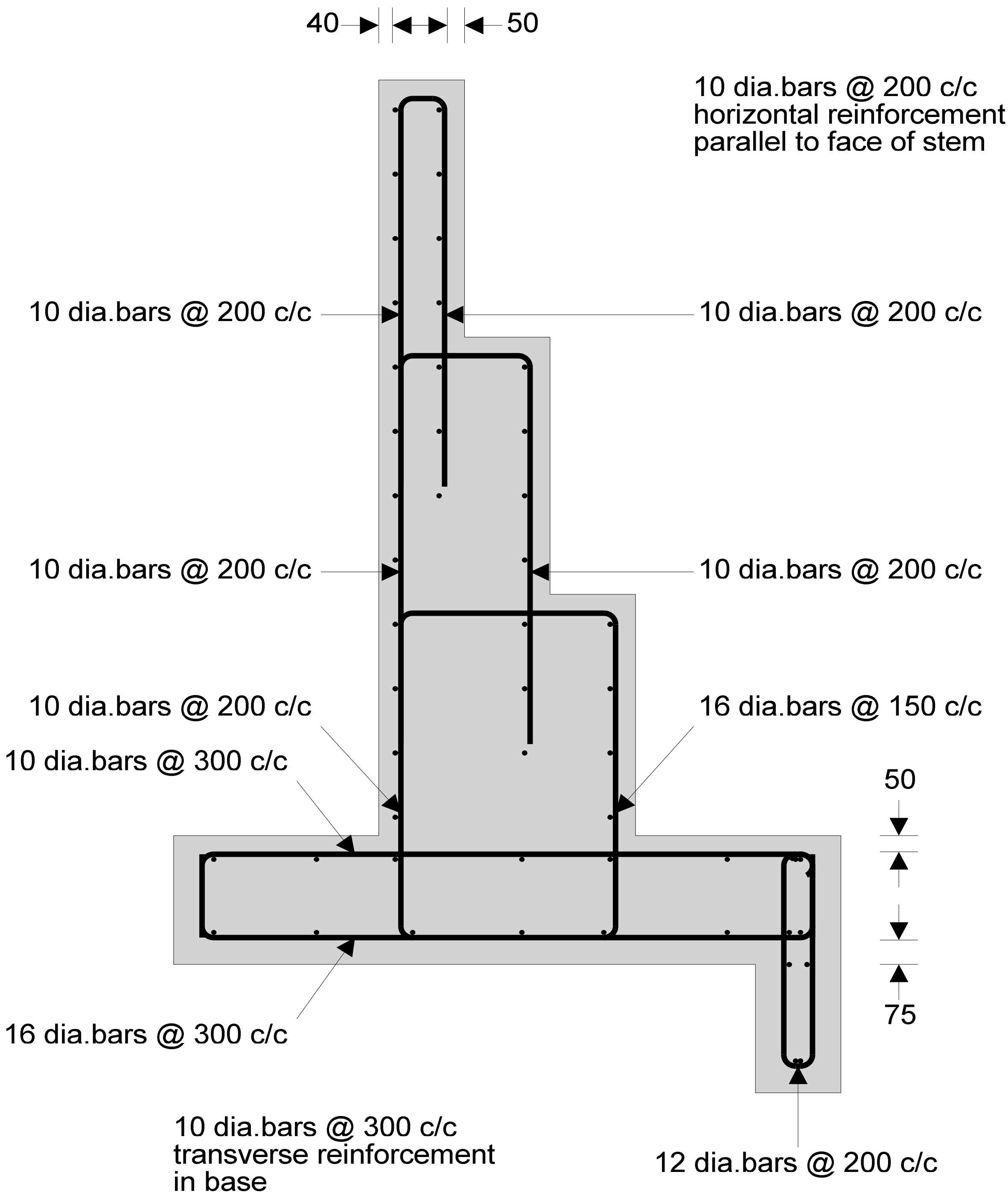
Minimum area of reinforcement – cl.9.3.1.1(2); $A_{bx.req} = 0.2 \times A_{bb.prov}$ = **134** mm^2/m

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

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

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

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



40
50
10 dia.bars @ 200 c/c
horizontal reinforcement
parallel to face of stem
10 dia.bars @ 200 c/c
10 dia.bars @ 200 c/c
10 dia.bars @ 200 c/c
10 dia.bars @ 200 c/c
10 dia.bars @ 200 c/c
16 dia.bars @ 150 c/c
10 dia.bars @ 300 c/c
50
75
16 dia.bars @ 300 c/c
10 dia.bars @ 300 c/c
transverse reinforcement
in base
12 dia.bars @ 200 c/c