RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Tedds calculation version 2.6.04

Retaining wall details

Stem type	Propped cantilever
Stem height	h_{stem} = **3200** mm
Prop height	h_{prop} = **3200** mm
Stem thickness	t_{stem} = **350** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **1000** mm
Heel length	l_{heel} = **50** mm
Base thickness	t_{base} = **350** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **3200** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm

Retained soil properties

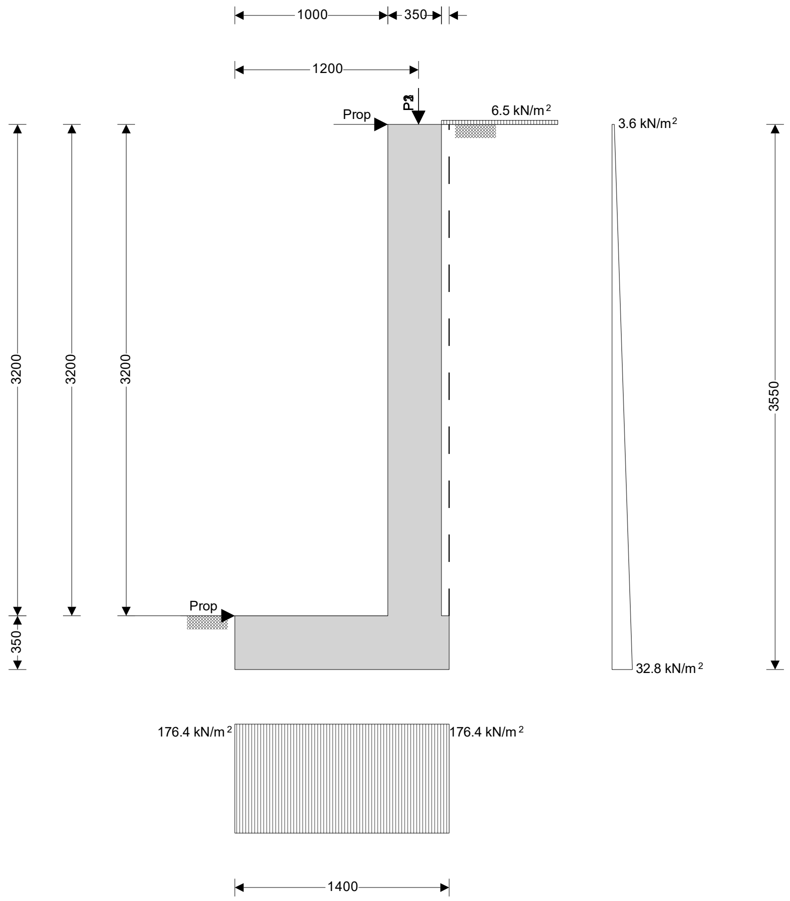
Soil type	Organic clay
Moist density	γ_{mr} = **15** kN/m^3
Saturated density	γ_{sr} = **15** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **18** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **9** deg

Base soil properties

Soil type	Organic clay
Moist density	γ_{mb} = **15** kN/m^3
Characteristic cohesion	$c'_{b.k}$ = **33** kN/m^2
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **18** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **9** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **12** deg

Loading details

Variable surcharge load	$Surcharge_Q$ = **5** kN/m^2
Vertical line load at 1200 mm	P_{G1} = **8** kN/m
Vertical line load at 1200 mm	P_{G2} = **8** kN/m
Vertical line load at 1200 mm	P_{G3} = **110** kN/m
	P_{Q3} = **60** kN/m



Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} + l_{heel}$ = **1400** mm
Moist soil height	$h_{moist} = h_{soil}$ = **3200** mm
Length of surcharge load	$l_{sur} = l_{heel}$ = **50** mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2$ = **1375** mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret}$ = **3550** mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2$ = **1775** mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem}$ = **1.12** m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2$ = **1175** mm
Area of wall base	$A_{base} = l_{base} \times t_{base}$ = **0.49** m^2
- Distance to vertical component	$x_{base} = l_{base} / 2$ = **700** mm
Area of moist soil	$A_{moist} = h_{moist} \times l_{heel}$ = **0.16** m^2
- Distance to vertical component	$x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist}$ = **1375** mm
- Distance to horizontal component	$x_{moist\_h} = h_{eff} / 3$ = **1183** 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 $\phi'_{r.d} = atan(tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **18** deg

Design wall friction angle $\delta_{r.d} = atan(tan(\delta_{r.k}) / \gamma_{\phi'})$ = **9** deg

Base soil properties

Design effective shear resistance angle $\phi'_{b.d} = atan(tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **18** deg

Design wall friction angle $\delta_{b.d} = atan(tan(\delta_{b.k}) / \gamma_{\phi'})$ = **9** deg

Design base friction angle $\delta_{bb.d} = atan(tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **12** deg

Design effective cohesion $c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **33** kN/m^2

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[}\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2)$ = **0.483**

Passive pressure coefficient $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[}\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2)$ = **2.359**

Bearing pressure check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem}$ = **37.8** kN/m

Wall base $F_{base} = \gamma_G \times A_{base} \times \gamma_{base}$ = **16.5** kN/m

Surcharge load $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel}$ = **0.4** kN/m

Line loads $F_{P\_v} = \gamma_G \times P_{G1} + \gamma_G \times P_{G2} + \gamma_G \times P_{G3} + \gamma_Q \times P_{Q3}$ = **260.1** kN/m

Moist retained soil $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr}$ = **3.2** kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v} + F_{P\_v}$ = **318.1** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff}$ = **12.7** kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times h_{eff}^2 / 2$ = **60.9** kN/m

Base soil $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2$ = **-2.1** kN/m

Total $F_{total\_h} = F_{moist\_h} + F_{pass\_h} + F_{sur\_h}$ = **71.4** kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem}$ = **44.4** kNm/m

Wall base $M_{base} = F_{base} \times x_{base}$ = **11.6** kNm/m

Surcharge load $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h}$ = **-22** kNm/m

Line loads $M_P = \gamma_G \times P_{G1} \times p_1 + \gamma_G \times P_{G2} \times p_2 + (\gamma_G \times P_{G3} + \gamma_Q \times P_{Q3}) \times p_3$ = **312.1** kNm/m

Moist retained soil $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h}$ = **-67.6** kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{sur} + M_P$ = **278.5** kNm/m

Check bearing pressure

Propping force to stem — $F_{prop\_stem} = \min((F_{total\_v} \times l_{base} / 2 - M_{total}) / (h_{prop} + t_{base}), F_{total\_h})$ = **-15.7** kN/m

Propping force to base — $F_{prop\_base} = F_{total\_h} - F_{prop\_stem}$ = **87.2** kN/m

Moment from propping force — $M_{prop} = F_{prop\_stem} \times (h_{prop} + t_{base})$ = **-55.9** kNm/m

Distance to reaction — $\bar{x} = l_{base} / 2$ = **700** mm

Eccentricity of reaction — $e = \bar{x} - l_{base} / 2$ = **0** mm

Loaded length of base — $l_{load} = l_{base}$ = **1400** mm

Bearing pressure at toe — $q_{toe} = F_{total\_v} / l_{base}$ = **227.2** kN/m^2

Bearing pressure at heel — $q_{heel} = F_{total\_v} / l_{base}$ = **227.2** kN/m^2

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

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

Bearing resistance factors — $N_q = \text{Exp}(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2$ = **5.258**

$N_c = (N_q - 1) \times \cot(\phi'_{b.d})$ = **13.104**

$N_{\gamma} = 2 \times (N_q - 1) \times \tan(\phi'_{b.d})$ = **2.767**

Foundation shape factors — $s_q = 1$

$s_{\gamma} = 1$

$s_c = 1$

Load inclination factors — $H = F_{sur\_h} + F_{moist\_h} + F_{pass\_h} - F_{prop\_stem} - F_{prop\_base}$ = **0** kN/m

$V = F_{total\_v}$ = **318.1** 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 — $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_{\gamma} \times s_{\gamma} \times i_{\gamma}$ = **489.1** kN/m^2

Factor of safety — $FoS_{bp} = n_f / \max(q_{toe}, q_{heel})$ = **2.153**

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 — $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **14.6** deg

Design wall friction angle — $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **7.2** deg

Base soil properties

Design effective shear resistance angle — $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **14.6** deg

Design wall friction angle — $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{7.2}$ deg

Design base friction angle — $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{9.7}$ deg

Design effective cohesion — $c'_{b.d} = c'_{b.k} / \gamma_{c'} = \mathbf{26.4}$ kN/m^2

Using Coulomb theory

Active pressure coefficient — $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[}\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2) = \mathbf{0.553}$

Passive pressure coefficient — $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[}\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2) = \mathbf{1.965}$

Bearing pressure check

Vertical forces on wall

Wall stem — $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{28}$ kN/m

Wall base — $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{12.3}$ kN/m

Surcharge load — $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel} = \mathbf{0.3}$ kN/m

Line loads — $F_{P\_v} = \gamma_G \times P_{G1} + \gamma_G \times P_{G2} + \gamma_G \times P_{G3} + \gamma_Q \times P_{Q3} = \mathbf{204}$ kN/m

Moist retained soil — $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{2.4}$ kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v} + F_{P\_v} = \mathbf{247}$ kN/m

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{12.7}$ kN/m

Moist retained soil — $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times h_{eff}^2 / 2 = \mathbf{51.8}$ kN/m

Base soil — $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-1.8}$ kN/m

Total — $F_{total\_h} = F_{moist\_h} + F_{pass\_h} + F_{sur\_h} = \mathbf{62.7}$ kN/m

Moments on wall

Wall stem — $M_{stem} = F_{stem} \times x_{stem} = \mathbf{32.9}$ kNm/m

Wall base — $M_{base} = F_{base} \times x_{base} = \mathbf{8.6}$ kNm/m

Surcharge load — $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} = \mathbf{-22}$ kNm/m

Line loads — $M_P = \gamma_G \times P_{G1} \times p_1 + \gamma_G \times P_{G2} \times p_2 + (\gamma_G \times P_{G3} + \gamma_Q \times P_{Q3}) \times p_3 = \mathbf{244.8}$ kNm/m

Moist retained soil — $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} = \mathbf{-58}$ kNm/m

Total — $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{sur} + M_P = \mathbf{206.2}$ kNm/m

Check bearing pressure

Propping force to stem — $F_{prop\_stem} = \min((F_{total\_v} \times l_{base} / 2 - M_{total}) / (h_{prop} + t_{base}), F_{total\_h}) = \mathbf{-9.4}$ kN/m

Propping force to base — $F_{prop\_base} = F_{total\_h} - F_{prop\_stem} = \mathbf{72.1}$ kN/m

Moment from propping force — $M_{prop} = F_{prop\_stem} \times (h_{prop} + t_{base}) = \mathbf{-33.3}$ kNm/m

Distance to reaction — $\bar{x} = l_{base} / 2 = \mathbf{700}$ mm

Eccentricity of reaction — $e = \bar{x} - l_{base} / 2 = \mathbf{0}$ mm

Loaded length of base — $l_{load} = l_{base} = \mathbf{1400}$ mm

Bearing pressure at toe — $q_{toe} = F_{total\_v} / l_{base} = \mathbf{176.4}$ kN/m^2

Bearing pressure at heel — $q_{heel} = F_{total\_v} / l_{base} = \mathbf{176.4}$ kN/m^2

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

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

Bearing resistance factors $N_q = Exp(\pi \times tan(\phi'_{b.d})) \times (tan(45 deg + \phi'_{b.d} / 2))^2 = \mathbf{3.784}$

$N_c = (N_q - 1) \times cot(\phi'_{b.d}) = \mathbf{10.711}$

$N_\gamma = 2 \times (N_q - 1) \times tan(\phi'_{b.d}) = \mathbf{1.447}$

Foundation shape factors $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

Load inclination factors $H = F_{sur\_h} + F_{moist\_h} + F_{pass\_h} - F_{prop\_stem} - F_{prop\_base} = \mathbf{0}$ kN/m

$V = F_{total\_v} = \mathbf{247}$ 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 $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma =$ **317.8** kN/m^2

Factor of safety $FoS_{bp} = n_f / max(q_{toe}, q_{heel}) = \mathbf{1.802}$

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 UK National Annex incorporating National Amendment No.1

Tedds calculation version 2.6.04

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

Concrete strength class C30/37

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

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

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

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

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

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

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

Compressive strength coefficient - cl.3.1.6(1) $\alpha_{cc} = \mathbf{0.85}$

Design compressive concrete strength - exp.3.15 $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = \mathbf{17.0}$ 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 1642 mm

Depth of section — $h = \mathbf{350}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — $M = \mathbf{11.9}$ kNm/m

Depth to tension reinforcement — $d = h - c_{sf} - \phi_{sx} - \phi_{sfM} / 2 = \mathbf{294}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.005}$

$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{279}$ mm

Depth of neutral axis — $x = 2.5 \times (d – z) = \mathbf{37}$ mm

Area of tension reinforcement required — $A_{sfM.req} = M / (f_{yd} \times z) = \mathbf{98}$ mm^2/m

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

Area of tension reinforcement provided — $A_{sfM.prov} = \pi \times \phi_{sfM}^2 / (4 \times s_{sfM}) = \mathbf{565}$ mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{sfM.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{443}$ mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{sfM.max} = 0.04 \times h = \mathbf{14000}$ mm^2/m

$\max(A_{sfM.req}, A_{sfM.min}) / A_{sfM.prov} = \mathbf{0.783}$

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

Deflection control - Section 7.4

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

Required tension reinforcement ratio — $\rho = A_{sfM.req} / d = \mathbf{0.000}$

Required compression reinforcement ratio — $\rho' = A_{sfM.2.req} / d_2 = \mathbf{0.000}$

Structural system factor - Table 7.4N — $K_b = \mathbf{1}$

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

Limiting span to depth ratio - exp.7.16.a — $K_s \times K_b \times [11 + 1.5 \times \sqrt{}(f_{ck} / 1 \text{ N/mm}^2) \times \rho_0 / \rho + 3.2 \times \sqrt{}(f_{ck} / 1 \text{ N/mm}^2) \times (\rho_0 / \rho - 1)^{3/2}] = \mathbf{1803.8}$

Actual span to depth ratio — $h_{prop} / d = \mathbf{10.9}$

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

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 — $M_{sls} = \mathbf{8}$ kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{sfM.prov} \times z) = \mathbf{50.6}$ N/mm^2

Load duration — Long term

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

Effective area of concrete in tension — $A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2) = \mathbf{104417}$ mm^2/m

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

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

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

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

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

$k_3 = \mathbf{3.4}$

$k_4 = \mathbf{0.425}$

Maximum crack spacing - exp.7.11	$s_{r.max} = k_3 \times c_{sf} + k_1 \times k_2 \times k_4 \times \phi_{sfM} / \rho_{p.eff}$ = **513** 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

Check stem design at base of stem

Depth of section	h = **350** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	M = **25.7** kNm/m
Depth to tension reinforcement	$d = h - c_{sr} - \phi_{sr} / 2$ = **294** mm
	$K = M / (d^2 \times f_{ck})$ = **0.010**
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **279** mm
Depth of neutral axis	$x = 2.5 \times (d - z)$ = **37** mm
Area of tension reinforcement required	$A_{sr.req} = M / (f_{yd} \times z)$ = **212** mm²/m
Tension reinforcement provided	12 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **565** mm²/m
Minimum area of reinforcement - exp.9.1N	$A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **443** mm²/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{sr.max} = 0.04 \times h$ = **14000** mm²/m
	$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.783**

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	$\rho = A_{sr.req} / d$ = **0.001**
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	$K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}]$ = **557.4**
Actual span to depth ratio	h_{prop} / d = **10.9**

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} = **17.5** kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **110.6** N/mm²
Load duration	Long term
Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **104417** mm²/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **2.9** N/mm²
Reinforcement ratio	$\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.005**

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

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

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

$k_3 = \mathbf{3.4}$

$k_4 = \mathbf{0.425}$

Maximum crack spacing - exp.7.11 $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff} = \mathbf{547}$ mm

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

$w_k = \mathbf{0.181}$ mm

$w_k / w_{max} = \mathbf{0.605}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force $V = \mathbf{46.7}$ kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.825}$

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.473}$ N/mm^2

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

$V_{Rd.c} = \mathbf{138.9}$ kN/m

$V / V_{Rd.c} = \mathbf{0.336}$

PASS - Design shear resistance exceeds design shear force

Check stem design at prop

Depth of section $h = \mathbf{350}$ mm

Rectangular section in shear - Section 6.2

Design shear force $V = \mathbf{14.2}$ kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.825}$

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.473}$ N/mm^2

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

$V_{Rd.c} = \mathbf{138.9}$ kN/m

$V / V_{Rd.c} = \mathbf{0.102}$

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) $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem}) = \mathbf{350}$ mm^2/m

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

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

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

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

Check base design at toe

Depth of section $h = \mathbf{350}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 $M = \mathbf{107.7}$ kNm/m

Depth to tension reinforcement $d = h - c_{bb} - \phi_{bb} / 2 = \mathbf{269}$ mm

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

$K' =$ **0.207**

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d =$ **256** mm

Depth of neutral axis — $x = 2.5 \times (d - z) =$ **34** mm

Area of tension reinforcement required — $A_{bb.req} = M / (f_{yd} \times z) =$ **969** mm²/m

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

Area of tension reinforcement provided — $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) =$ **565** mm²/m

Minimum area of reinforcement - exp.9.1N — $A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **405** mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{bb.max} = 0.04 \times h =$ **14000** mm²/m

$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} =$ **1.714**

FAIL - Area of reinforcement provided is less 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 — $\psi_2 =$ **0.6**

Serviceability bending moment — $M_{sls} =$ **77.4** kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{bb.prov} \times z) =$ **535.4** N/mm²

Load duration — Long term

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

Effective area of concrete in tension — $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) =$ **105458** mm²/m

Mean value of concrete tensile strength — $f_{ct.eff} = f_{ctm} =$ **2.9** N/mm²

Reinforcement ratio — $\rho_{p.eff} = A_{bb.prov} / A_{c.eff} =$ **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 — $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} =$ **635** mm

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

$w_k =$ **1.021** mm

$w_k / w_{max} =$ **3.402**

FAIL - Maximum crack width exceeds limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — $V =$ **215.4** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) =$ **1.862**

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} =$ **0.487** N/mm²

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

$V_{Rd.c} =$ **131.1** kN/m

$V / V_{Rd.c} =$ **1.643**

FAIL - Design shear resistance is less than design shear force

Rectangular section in shear - Section 6.2

Design shear force — V = **7.2** kN/m

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

$k = \min(1 + \sqrt{(200\ mm / d)}, 2) = \mathbf{1.862}$

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

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.487}\ N/mm^2$

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

$V_{Rd.c} = \mathbf{131.1}\ kN/m$

$V / V_{Rd.c} = \mathbf{0.055}$

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) — $A_{bx.req} = 0.2 \times A_{bb.prov} = \mathbf{113}\ mm^2/m$

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

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

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

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