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 2.9.20

Analysis summary

Design summary

Overall design utilisation 0.868

Overall design status Pass

Description	Unit	Capacity	Applied	F o S	Result
Bearing pressure	kN/m^2	125	108.5	1.152	PASS

Design summary

Description	Unit	Provided	Required	Utilisation	Result
Shear resistance	kN/m	15.6	167.1	0.093	PASS
Stem p0 - Shear resistance	kN/m	108.6	42.5	0.391	PASS
Stem p1 front face - Flexural reinforcement	mm^2/m	754.0	301.9	0.400	PASS
Stem p1 - Shear resistance	kN/m	108.6	4.8	0.044	PASS
Base bottom face - Flexural reinforcement	mm^2/m	754.0	580.2	0.769	PASS
Base - Shear resistance	kN/m	167.1	30.4	0.182	PASS
Key - Flexural reinforcement	mm^2/m	754.0	580.2	0.770	PASS
Key - Shear resistance	kN/m	167.1	15.6	0.093	PASS
Min. transverse stem reinf.	mm^2/m	754.0	250.0	0.332	PASS
Min. transverse base reinf.	mm^2/m	754.0	150.8	0.200	PASS

Retaining wall details

Stem type Propped cantilever

Stem height h_{stem} = **2950** mm

Prop height h_{prop} = **2850** mm

Stem thickness t_{stem} = **250** mm

Angle to rear face of stem α = **90** deg

Stem density γ_{stem} = **25** kN/m^3

Toe length l_{toe} = **850** mm

Base thickness t_{base} = **450** mm

Key position p_{key} = **0** mm

Key depth d_{key} = **450** mm

Key thickness t_{key} = **450** mm

Base density γ_{base} = **25** kN/m^3

Height of retained soil h_{ret} = **2700** mm

Angle of soil surface β = **0** deg

Depth of cover d_{cover} = **0** mm

Height of water h_{water} = **1700** mm

Water density γ_w = **9.8** kN/m^3

Retained soil properties

Soil type Firm silty clay

Moist density γ_{mr} = **18** kN/m^3

Saturated density γ_{sr} = **18** kN/m^3

Characteristic effective shear resistance angle $\phi'_{r.k}$ = **22** deg

Characteristic wall friction angle $\delta_{r.k}$ = **11** deg

Base soil properties

Soil type — Firm clay

Soil density — γ_b = **20** kN/m^3

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

Presumed bearing capacity — $P_{bearing}$ = **125** kN/m^2

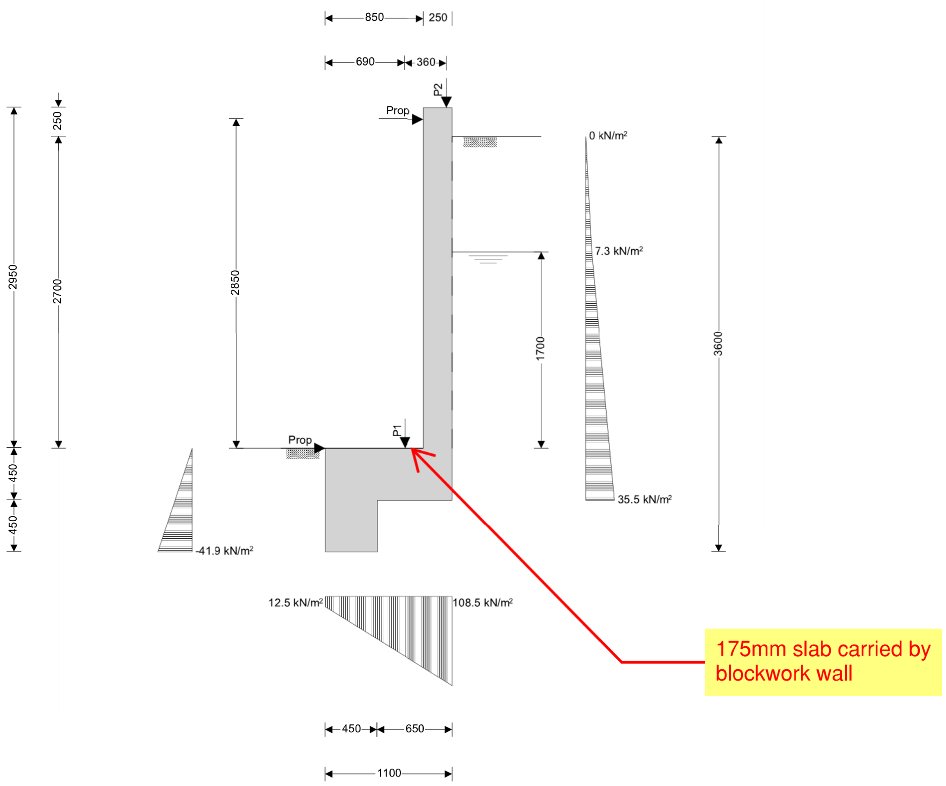
Loading details

Vertical line load at 690 mm — P_{G1} = **14.7** kN/m

P_{Q1} = **5.3** kN/m

Vertical line load at 1050 mm — P_{G2} = **7.7** kN/m

P_{Q2} = **3** kN/m



General arrangement - sketch pressures relate to bearing check

Calculate retaining wall geometry

Base length — $l_{base} = l_{toe} + t_{stem}$ = **1100** mm

Base height — $h_{base} = t_{base} + d_{key}$ = **900** mm

Saturated soil height — $h_{sat} = h_{water} + d_{cover}$ = **1700** mm

Moist soil height — $h_{moist} = h_{ret} - h_{water}$ = **1000** mm

Retained surface length — $l_{sur} = l_{heel}$ = **0** mm

Effective height of wall — $h_{eff} = h_{base} + d_{cover} + h_{ret}$ = **3600** mm

Area of wall stem — $A_{stem} = h_{stem} \times t_{stem}$ = **0.738** m^2

- Distance to vertical component — $x_{stem} = l_{toe} + t_{stem} / 2$ = **975** mm

Area of wall base $A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key} = \mathbf{0.698}$ m^2

- Distance to vertical component $x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base} = \mathbf{456}$ mm

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.k}) \times [1 + \sqrt{[\sin(\phi'_{r.k} + \delta_{r.k}) \times \sin(\phi'_{r.k} - \beta) / (\sin(\alpha - \delta_{r.k}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.413}$

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

Bearing pressure check

Vertical forces on wall

Wall stem $F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{18.4}$ kN/m

Wall base $F_{base} = A_{base} \times \gamma_{base} = \mathbf{17.4}$ kN/m

Line loads $F_{P\_v} = P_{G1} + P_{Q1} + P_{G2} + P_{Q2} = \mathbf{30.7}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{P\_v} + F_{water\_v} = \mathbf{66.6}$ kN/m

Horizontal forces on wall

Saturated retained soil $F_{sat\_h} = K_A \times \cos(\delta_{r.k}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + t_{base})^2 / 2 = \mathbf{7.7}$ kN/m

Water $F_{water\_h} = \gamma_w \times (h_{water} + d_{cover} + t_{base})^2 / 2 = \mathbf{22.7}$ kN/m

Moist retained soil $F_{moist\_h} = K_A \times \cos(\delta_{r.k}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) = \mathbf{19.3}$ kN/m

Base soil $F_{pass\_h} = -K_P \times \cos(\delta_{b.k}) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-18.9}$ kN/m

Total $F_{total\_h} = F_{sat\_h} + F_{water\_h} + F_{moist\_h} + F_{pass\_h} = \mathbf{30.8}$ kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem} = \mathbf{18}$ kNm/m

Wall base $M_{base} = F_{base} \times x_{base} = \mathbf{7.9}$ kNm/m

Line loads $M_P = (P_{G1} + P_{Q1}) \times p_1 + (P_{G2} + P_{Q2}) \times p_2 = \mathbf{25}$ kNm/m

Saturated retained soil $M_{sat} = -F_{sat\_h} \times x_{sat\_h} = \mathbf{-3.2}$ kNm/m

Water $M_{water} = -F_{water\_h} \times x_{water\_h} = \mathbf{-9.4}$ kNm/m

Moist retained soil $M_{moist} = -F_{moist\_h} \times x_{moist\_h} = \mathbf{-21.5}$ kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_P + M_{sat} + M_{water} + M_{moist} = \mathbf{16.8}$ kNm/m

Check bearing pressure

Propping force to stem $F_{prop\_stem} = \mathbf{8.9}$ kN/m

Propping force to base $F_{prop\_base} = F_{total\_h} - F_{prop\_stem} = \mathbf{21.9}$ kN/m

Moment from propping force $M_{prop} = F_{prop\_stem} \times (h_{prop} + t_{base}) = \mathbf{29.5}$ kNm/m

Distance to reaction $\bar{x} = (M_{total} + M_{prop}) / F_{total\_v} = \mathbf{695}$ mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{145}$ mm

Loaded length of base $l_{load} = l_{base} = \mathbf{1100}$ mm

Bearing pressure at toe $q_{toe} = F_{total\_v} / l_{base} \times (1 - 6 \times e / l_{base}) = \mathbf{12.5}$ kN/m^2

Bearing pressure at heel $q_{heel} = F_{total\_v} / l_{base} \times (1 + 6 \times e / l_{base}) = \mathbf{108.5}$ kN/m^2

Factor of safety $FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) = \mathbf{1.152}$

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 2.9.20

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

Concrete strength class	C32/40
Characteristic compressive cylinder strength	f_{ck} = **32** N/mm^2
Characteristic compressive cube strength	$f_{ck,cube}$ = **40** N/mm^2
Mean value of compressive cylinder strength	f_{cm} = f_{ck} + 8 N/mm^2 = **40** N/mm^2
Mean value of axial tensile strength	f_{ctm} = 0.3 N/mm^2 × (f_{ck} / 1 N/mm^2)$^{2/3}$ = **3.0** N/mm^2
5% fractile of axial tensile strength	$f_{ctk,0.05}$ = 0.7 × f_{ctm} = **2.1** N/mm^2
Secant modulus of elasticity of concrete	E_{cm} = 22 kN/mm^2 × (f_{cm} / 10 N/mm^2)$^{0.3}$ = **33346** N/mm^2
Partial factor for concrete - Table 2.1N	γ_C = **1.50**
Compressive strength coefficient - cl.3.1.6(1)	α_{cc} = **0.85**
Design compressive concrete strength - exp.3.15	f_{cd} = α_{cc} × f_{ck} / γ_C = **18.1** N/mm^2
Maximum aggregate size	h_{agg} = **20** mm
Ultimate strain - Table 3.1	ε_{cu2} = **0.0035**
Shortening strain - Table 3.1	ε_{cu3} = **0.0035**
Effective compression zone height factor	λ = **0.80**
Effective strength factor	η = **1.00**
Bending coefficient k_1	K_1 = **0.40**
Bending coefficient k_2	K_2 = 1.00 × (0.6 + 0.0014/ε_{cu2}) = **1.00**
Bending coefficient k_3	K_3 =**0.40**
Bending coefficient k_4	K_4 = 1.00 × (0.6 + 0.0014/ε_{cu2}) =**1.00**

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} / γ_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

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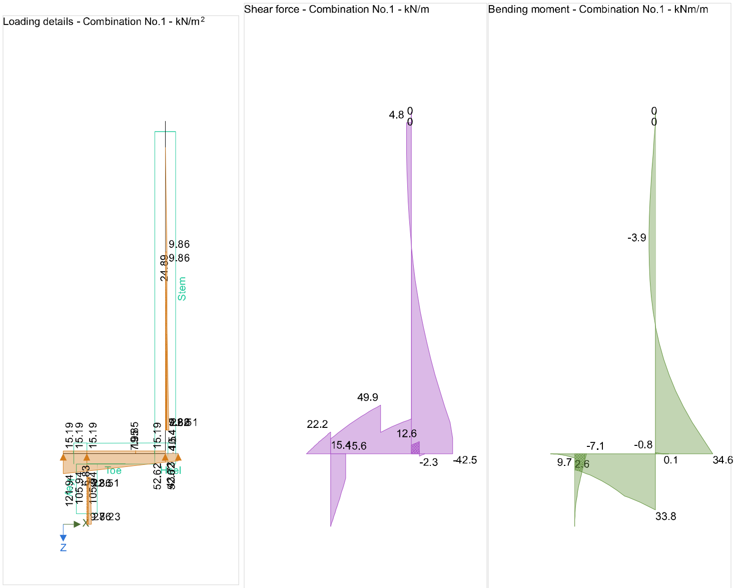
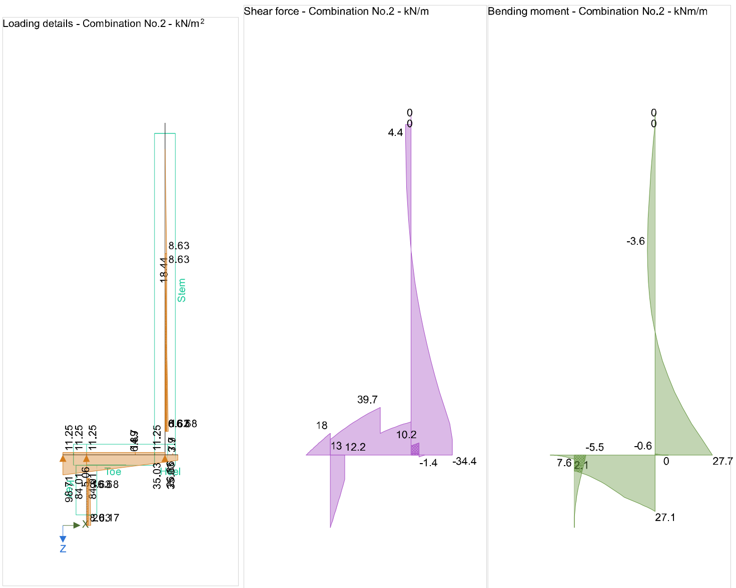




Check stem design at 1710 mm

Depth of section — h = **250** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **3.9** kNm/m

Depth to tension reinforcement — $d = h - c_{sf} - \phi_{sx} - \phi_{sfM} / 2 =$ **192** mm

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

$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$

$K' =$ **0.207**

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d =$ **182** mm

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

Area of tension reinforcement required — $A_{sfM.req} = M / (f_{yd} \times z) =$ **49** mm^2/m

Tension reinforcement provided	12 dia.bars @ 150 c/c
Area of tension reinforcement provided	$A_{sfM.prov} = \pi \times \phi_{sfM}^2 / (4 \times s_{sfM})$ = **754** mm^2/m
Minimum area of reinforcement - exp.9.1N	$A_{sfM.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **302** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{sfM.max} = 0.04 \times h$ = **10000** mm^2/m
	$\max(A_{sfM.req}, A_{sfM.min}) / A_{sfM.prov}$ = **0.4**

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

Library item: Rectangular single output

Deflection control - Section 7.4

Reference reinforcement ratio	$\rho_0 = \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} / 1000$ = **0.006**
Required tension reinforcement ratio	$\rho = A_{sfM.req} / d$ = **0.000**
Required compression reinforcement ratio	$\rho' = A_{sfM.2.req} / d_2$ = **0.000**
Structural system factor - Table 7.4N	K_b = **1**
Reinforcement factor - exp.7.17	$K_s = \min(500 \text{ N/mm}^2 / (f_{yk} \times A_{sfM.req} / A_{sfM.prov}), 1.5)$ = **1.5**
Limiting span to depth ratio - exp.7.16.a	$\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b)$ = **40**
Actual span to depth ratio	h_{prop} / d = **14.8**

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} = **3.5** kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{sfM.prov} \times z)$ = **25.2** N/mm^2
Load duration	Long term
Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$
	$A_{c.eff}$ = **75333** mm^2/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{sfM.prov} / A_{c.eff}$ = **0.010**
Modular ratio	$\alpha_e = E_s / E_{cm}$ = **5.998**
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	$s_{r.max} = k_3 \times c_{sf} + k_1 \times k_2 \times k_4 \times \phi_{sfM} / \rho_{p.eff}$ = **340** 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 = **0.026** mm
	w_k / w_{max} = **0.086**

PASS - Maximum crack width is less than limiting crack width

Check stem design at base of stem

Depth of section	h = **250** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	M = **25** kNm/m
Depth to tension reinforcement	$d = h - c_{sr} - \phi_{sr} / 2$ = **194** mm
	$K = M / (d^2 \times f_{ck})$ = **0.021**
	$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C) \times (1 - \lambda \times (\delta - K_1)/(2 \times K_2)) \times (\lambda \times (\delta - K_1)/(2 \times K_2))$
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d =$ **184** mm

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

Area of tension reinforcement required $A_{sr.req} = M / (f_{yd} \times z) =$ **312** mm^2/m

Tension reinforcement provided 12 dia.bars @ 150 c/c

Area of tension reinforcement provided $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) =$ **754** mm^2/m

Minimum area of reinforcement - exp.9.1N $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **305** mm^2/m

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

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov} =$ **0.414**

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

Library item: Rectangular single output

Deflection control - Section 7.4

Reference reinforcement ratio $\rho_0 = \sqrt{}(f_{ck} / 1 N/mm^2) / 1000 =$ **0.006**

Required tension reinforcement ratio $\rho = A_{sr.req} / d =$ **0.002**

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 $K_s = \min(500 N/mm^2 / (f_{yk} \times A_{sr.req} / A_{sr.prov}), 1.5) =$ **1.5**

Limiting span to depth ratio - exp.7.16.a $\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{}(f_{ck} / 1 N/mm^2) \times \rho_0 / \rho + 3.2 \times \sqrt{}(f_{ck} / 1 N/mm^2) \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b) =$ **40**

Actual span to depth ratio $h_{prop} / d =$ **14.7**

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 $\psi_2 =$ **0.6**

Serviceability bending moment $M_{sls} =$ **17.1** kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{sr.prov} \times z) =$ **123.4** N/mm^2

Load duration Long term

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

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

$A_{c.eff} =$ **75250** mm^2/m

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm} =$ **3.0** N/mm^2

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

Modular ratio $\alpha_e = E_s / E_{cm} =$ **5.998**

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 $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff} =$ **374** mm

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

$w_k =$ **0.138** mm

$w_k / w_{max} =$ **0.461**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force $V =$ **42.5** kN/m

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

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

Longitudinal reinforcement ratio — $\rho_l = \min(A_{sr.prov} / d, 0.02) = \mathbf{0.004}$

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.560}\ N/mm^2$

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

$V_{Rd.c} = \mathbf{108.6}\ kN/m$

$V / V_{Rd.c} = \mathbf{0.391}$

PASS - Design shear resistance exceeds design shear force

Check stem design at prop

Depth of section — h = **250** mm

Rectangular section in shear - Section 6.2

Design shear force — V = **4.8** kN/m

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

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

Longitudinal reinforcement ratio — $\rho_l = \min(A_{sr1.prov} / d, 0.02) = \mathbf{0.004}$

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.560}\ N/mm^2$

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

$V_{Rd.c} = \mathbf{108.6}\ kN/m$

$V / V_{Rd.c} = \mathbf{0.044}$

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) — $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem}) = \mathbf{250}\ mm^2/m$

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

Transverse reinforcement provided — 12 dia.bars @ 150 c/c

Area of transverse reinforcement provided — $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx}) = \mathbf{754}\ mm^2/m$

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 = **29.7** kNm/m

Depth to tension reinforcement — $d = h - c_{bb} - \phi_{bb} / 2 = \mathbf{369}$ mm

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

$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$

$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d = \mathbf{351}$ mm

Depth of neutral axis — $x = 2.5 \times (d – z) = \mathbf{46}$ mm

Area of tension reinforcement required — $A_{bb.req} = M / (f_{yd} \times z) = \mathbf{195}\ mm^2/m$

Tension reinforcement provided — 12 dia.bars @ 150 c/c

Area of tension reinforcement provided — $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = \mathbf{754}\ mm^2/m$

Minimum area of reinforcement - exp.9.1N — $A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{580}\ mm^2/m$

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

$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} = \mathbf{0.77}$

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

Library item: Rectangular single output

Crack control - Section 7.3

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

Variable load factor - EN1990 – Table A1.1	ψ_2 = **0.6**
Serviceability bending moment	M_{sls} = **20.7** kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bb.prov} \times z)$ = **78.4** N/mm^2
Load duration	Long term
Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$
	$A_{c.eff}$ = **134625** mm^2/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff}$ = **0.006**
Modular ratio	$\alpha_e = E_s / E_{cm}$ = **5.998**
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 = **0.146** mm
	w_k / w_{max} = **0.486**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	V = **30.4** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.736**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb.prov} / d, 0.02)$ = **0.002**
	$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.453** N/mm^2
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **167.1** kN/m
	$V / V_{Rd.c}$ = **0.182**

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section	h = **450** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	M = **3.6** kNm/m
Depth to tension reinforcement	$d = h - c_{bb} - \phi_k / 2$ = **369** mm
	$K = M / (d^2 \times f_{ck})$ = **0.001**
	$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **351** mm
Depth of neutral axis	$x = 2.5 \times (d – z)$ = **46** mm
Area of tension reinforcement required	$A_{k.req} = M / (f_{yd} \times z)$ = **24** mm^2/m
Tension reinforcement provided	12 dia.bars @ 150 c/c
Area of tension reinforcement provided	$A_{k.prov} = \pi \times \phi_k^2 / (4 \times s_k)$ = **754** mm^2/m
Minimum area of reinforcement - exp.9.1N	$A_{k.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **580** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{k.max} = 0.04 \times h$ = **18000** mm^2/m

$\max(A_{k.req}, A_{k.min}) / A_{k.prov}$ = **0.77**

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

Library item: Rectangular single output

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} = **2.7** kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{k.prov} \times z)$ = **10.1** N/mm^2

Load duration Long term

Load duration factor k_t = **0.4**

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

$A_{c.eff}$ = **134625** mm^2/m

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2

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

Modular ratio $\alpha_e = E_s / E_{cm}$ = **5.998**

Bond property coefficient k_1 = **0.8**

Strain distribution coefficient k_2 = **0.5**

k_3 = **3.4**

k_4 = **0.425**

Maximum crack spacing - exp.7.11 $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p.eff}$ = **619** mm

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

w_k = **0.019** mm

w_k / w_{max} = **0.062**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force V = **15.6** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.736**

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.453** N/mm^2

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

$V_{Rd.c}$ = **167.1** kN/m

$V / V_{Rd.c}$ = **0.093**

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

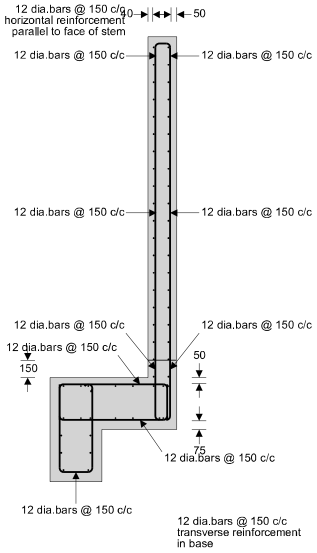
Minimum area of reinforcement – cl.9.3.1.1(2) $A_{bx.req} = 0.2 \times A_{bb.prov}$ = **151** mm^2/m

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

Transverse reinforcement provided 12 dia.bars @ 150 c/c

Area of transverse reinforcement provided $A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx})$ = **754** mm^2/m

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



Reinforcement details

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 2.9.20

Analysis summary

Design summary

Overall design utilisation 0.95

Overall design status Pass

Description	Unit	Capacity	Applied	F o S	Result
Overturning stability	kNm/m	156.2	91.1	1.714	PASS
Bearing pressure	kN/m^2	125	98.3	1.271	PASS

Design summary

Description	Unit	Provided	Required	Utilisation	Result
Shear resistance	kN/m	15.6	167.1	0.093	PASS
Base - Shear resistance	kN/m	167.1	99.8	0.597	PASS
Key - Flexural reinforcement	mm^2/m	754.0	580.2	0.770	PASS
Key - Shear resistance	kN/m	167.1	15.6	0.093	PASS
Min. transverse stem reinf.	mm^2/m	754.0	250.0	0.332	PASS
Min. transverse base reinf.	mm^2/m	754.0	150.8	0.200	PASS

Retaining wall details

Stem type Cantilever

Stem height h_{stem} = **2950** mm

Stem thickness t_{stem} = **250** mm

Angle to rear face of stem α = **90** deg

Stem density γ_{stem} = **25** kN/m^3

Toe length l_{toe} = **850** mm

Heel length l_{heel} = **850** mm

Base thickness t_{base} = **450** mm

Key position p_{key} = **0** mm

Key depth d_{key} = **450** mm

Key thickness t_{key} = **450** mm

Base density γ_{base} = **25** kN/m^3

Height of retained soil h_{ret} = **2700** mm

Angle of soil surface β = **0** deg

Depth of cover d_{cover} = **0** mm

Height of water h_{water} = **1700** mm

Water density γ_w = **9.8** kN/m^3

Retained soil properties

Soil type Firm silty clay

Moist density γ_{mr} = **18** kN/m^3

Saturated density γ_{sr} = **18** kN/m^3

Characteristic effective shear resistance angle $\phi'_{r.k}$ = **22** deg

Characteristic wall friction angle $\delta_{r.k}$ = **11** deg

Base soil properties

Soil type Firm clay

Soil density γ_b = **20** kN/m^3

Characteristic effective shear resistance angle $\phi'_{b.k}$ = **18** deg

Characteristic wall friction angle $\delta_{b.k}$ = **9** deg

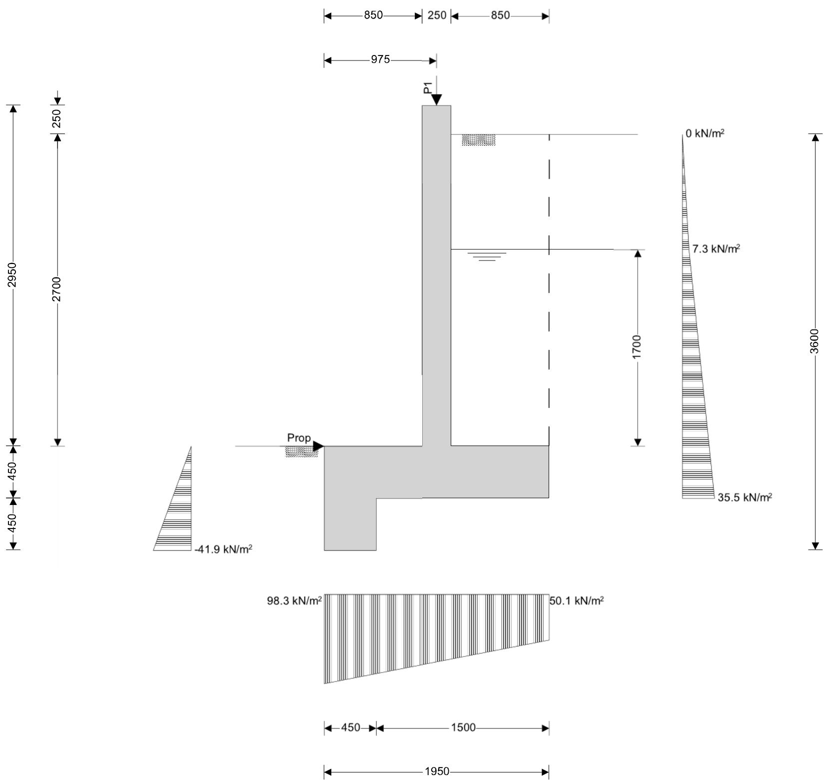
Characteristic base friction angle $\delta_{bb.k}$ = **12** deg

Presumed bearing capacity $P_{bearing}$ = **125** kN/m^2

Loading details

Vertical line load at 975 mm P_{G1} = **54** kN/m

P_{Q1} = **4** kN/m



General arrangement - sketch pressures relate to bearing check

Calculate retaining wall geometry

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

Base height $h_{base} = t_{base} + d_{key}$ = **900** mm

Saturated soil height $h_{sat} = h_{water} + d_{cover}$ = **1700** mm

Moist soil height $h_{moist} = h_{ret} - h_{water}$ = **1000** mm

Retained surface length $l_{sur} = l_{heel}$ = **850** mm

Effective height of wall $h_{eff} = h_{base} + d_{cover} + h_{ret}$ = **3600** mm

Area of wall stem $A_{stem} = h_{stem} \times t_{stem}$ = **0.738** m^2

 - Distance to vertical component $x_{stem} = l_{toe} + t_{stem} / 2$ = **975** mm

Area of wall base $A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key}$ = **1.08** m^2

 - Distance to vertical component $x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base}$ = **834** mm

Area of saturated soil $A_{sat} = h_{sat} \times l_{heel}$ = **1.445** m^2

 - Distance to vertical component $x_{sat\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat}$ = **1525** mm

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

 - Distance to horizontal component above key $x_{sat\_h\_a} = (h_{sat} + t_{base}) / 3$ = **717** mm

Area of water $A_{water} = h_{sat} \times l_{heel} = \mathbf{1.445}\ m^2$

- Distance to vertical component $x_{water\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat} = \mathbf{1525}$ mm
- Distance to horizontal component $x_{water\_h} = (h_{sat} + h_{base}) / 3 - d_{key} = \mathbf{417}$ mm
- Distance to horizontal component above key $x_{water\_h\_a} = (h_{sat} + t_{base}) / 3 = \mathbf{717}$ mm

Area of moist soil $A_{moist} = h_{moist} \times l_{heel} = \mathbf{0.85}\ m^2$

- Distance to vertical component $x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist} = \mathbf{1525}$ mm
- Distance to horizontal component $x_{moist\_h} = (h_{moist} \times (t_{base} + h_{sat} + h_{moist} / 3) / 2 + (h_{sat} + h_{base}) \times ((h_{sat} + h_{base})/2 - d_{key})) / (h_{sat} + h_{base} + h_{moist} / 2) = \mathbf{1113}$ mm
- Distance to horizontal component above key $x_{moist\_h\_a} = (h_{moist} \times (t_{base} + h_{sat} + h_{moist} / 3) / 2 + (h_{sat} + t_{base})^2/2) / (h_{sat} + t_{base} + h_{moist} / 2) = \mathbf{1341}$ mm

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.k}) \times [1 + \sqrt{[\sin(\phi'_{r.k} + \delta_{r.k}) \times \sin(\phi'_{r.k} - \beta) / (\sin(\alpha - \delta_{r.k}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.413}$

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

Bearing pressure check

Vertical forces on wall

Wall stem $F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{18.4}$ kN/m

Wall base $F_{base} = A_{base} \times \gamma_{base} = \mathbf{27}$ kN/m

Line loads $F_{P\_v} = P_{G1} + P_{Q1} = \mathbf{58}$ kN/m

Saturated retained soil $F_{sat\_v} = A_{sat} \times (\gamma_{sr} - \gamma_w) = \mathbf{11.8}$ kN/m

Water $F_{water\_v} = A_{water} \times \gamma_w = \mathbf{14.2}$ kN/m

Moist retained soil $F_{moist\_v} = A_{moist} \times \gamma_{mr} = \mathbf{15.3}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{P\_v} + F_{sat\_v} + F_{water\_v} + F_{moist\_v} = \mathbf{144.7}$ kN/m

Horizontal forces on wall

Saturated retained soil $F_{sat\_h} = K_A \times \cos(\delta_{r.k}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + t_{base})^2 / 2 = \mathbf{7.7}$ kN/m

Water $F_{water\_h} = \gamma_w \times (h_{water} + d_{cover} + t_{base})^2 / 2 = \mathbf{22.7}$ kN/m

Moist retained soil $F_{moist\_h} = K_A \times \cos(\delta_{r.k}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) = \mathbf{19.3}$ kN/m

Base soil $F_{pass\_h} = -K_P \times \cos(\delta_{b.k}) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-18.9}$ kN/m

Total $F_{total\_h} = F_{sat\_h} + F_{water\_h} + F_{moist\_h} + F_{pass\_h} = \mathbf{30.8}$ kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem} = \mathbf{18}$ kNm/m

Wall base $M_{base} = F_{base} \times x_{base} = \mathbf{22.5}$ kNm/m

Line loads $M_P = (P_{G1} + P_{Q1}) \times p_1 = \mathbf{56.6}$ kNm/m

Saturated retained soil $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h} = \mathbf{14.8}$ kNm/m

Water $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h} = \mathbf{12.2}$ kNm/m

Moist retained soil $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} = \mathbf{1.8}$ kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_P + M_{sat} + M_{water} + M_{moist} = \mathbf{125.9}$ kNm/m

Check bearing pressure

Propping force $F_{prop\_base} = F_{total\_h} = \mathbf{30.8}$ kN/m

Distance to reaction $\bar{x} = M_{total} / F_{total\_v} = \mathbf{870}$ mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{-105}$ mm

Loaded length of base $l_{load} = l_{base} = \mathbf{1950}$ mm

Bearing pressure at toe	$q_{toe} = F_{total\_v} / l_{base} \times (1 - 6 \times e / l_{base})$ = **98.3** kN/m^2
Bearing pressure at heel	$q_{heel} = F_{total\_v} / l_{base} \times (1 + 6 \times e / l_{base})$ = **50.1** kN/m^2
Factor of safety	$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel})$ = **1.271**

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 2.9.20

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

Concrete strength class	C32/40
Characteristic compressive cylinder strength	f_{ck} = **32** N/mm^2
Characteristic compressive cube strength	$f_{ck,cube}$ = **40** N/mm^2
Mean value of compressive cylinder strength	$f_{cm} = f_{ck}$ + 8 N/mm^2 = **40** N/mm^2
Mean value of axial tensile strength	f_{ctm} = 0.3 N/mm^2 $\times$ (f_{ck} / 1 N/mm^2)$^{2/3}$ = **3.0** N/mm^2
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm}$ = **2.1** N/mm^2
Secant modulus of elasticity of concrete	E_{cm} = 22 kN/mm^2 $\times$ (f_{cm} / 10 N/mm^2)$^{0.3}$ = **33346** N/mm^2
Partial factor for concrete - Table 2.1N	γ_C = **1.50**
Compressive strength coefficient - cl.3.1.6(1)	α_{cc} = **0.85**
Design compressive concrete strength - exp.3.15	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C$ = **18.1** N/mm^2
Maximum aggregate size	h_{agg} = **20** mm
Ultimate strain - Table 3.1	ε_{cu2} = **0.0035**
Shortening strain - Table 3.1	ε_{cu3} = **0.0035**
Effective compression zone height factor	λ = **0.80**
Effective strength factor	η = **1.00**
Bending coefficient k_1	K_1 = **0.40**
Bending coefficient k_2	$K_2 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2})$ = **1.00**
Bending coefficient k_3	K_3 =**0.40**
Bending coefficient k_4	$K_4 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2})$ =**1.00**

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

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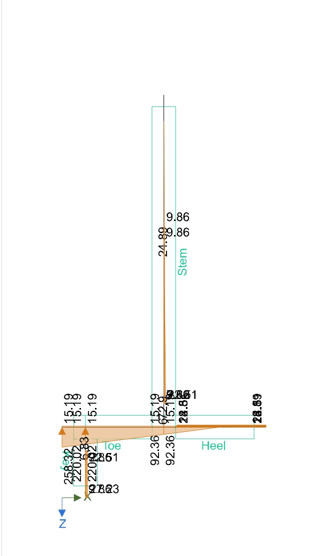
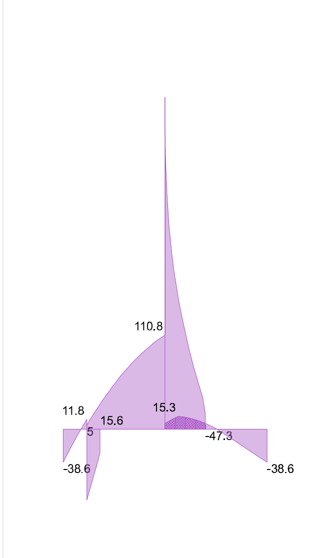
	Calcs for	RW2			Start page no./Revision 5	
	Calcs by I	Calcs date 25/01/2024	Checked by	Checked date	Approved by	Approved date

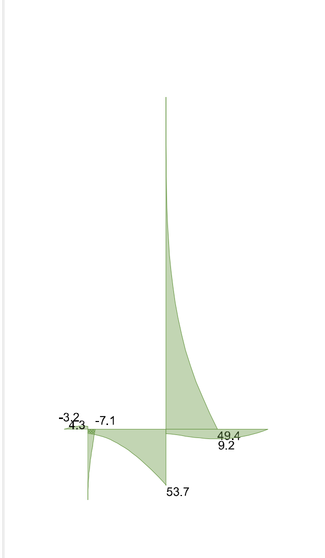
Loading details - Combination No.1 - kN/m²



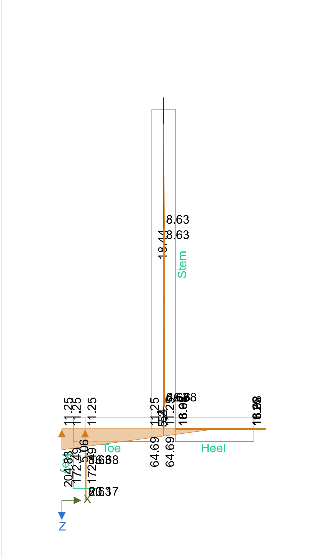
Shear force - Combination No.1 - kN/m



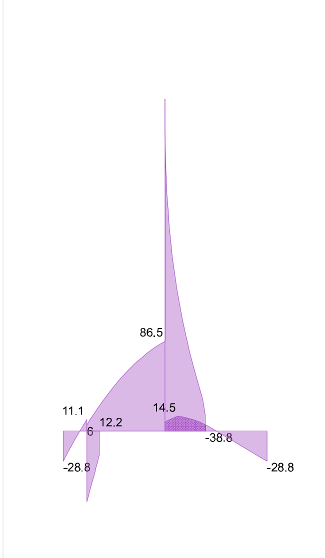
Bending moment - Combination No.1 - kNm/m



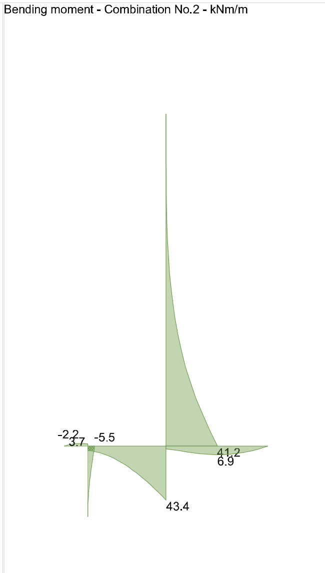
Loading details - Combination No.2 - kN/m²



Shear force - Combination No.2 - kN/m



Bending moment - Combination No.2 - kNm/m



Check stem design at base of stem

Depth of section h = **250** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 M = **38.8** kNm/m

Depth to tension reinforcement $d = h - c_{sr} - \phi_{sr} / 2 =$ **194** mm

$K = M / (d^2 \times f_{ck}) =$ **0.032**

$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d =$ **184** mm

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

Area of tension reinforcement required $A_{sr.req} = M / (f_{yd} \times z) =$ **484** mm²/m

Tension reinforcement provided — 12 dia.bars @ 150 c/c

Area of tension reinforcement provided — $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **754** mm²/m

Minimum area of reinforcement - exp.9.1N — $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **305** mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{sr.max} = 0.04 \times h$ = **10000** mm²/m

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.642**

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

Library item: Rectangular single output

Deflection control - Section 7.4

Reference reinforcement ratio — $\rho_0 = \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} / 1000$ = **0.006**

Required tension reinforcement ratio — $\rho = A_{sr.req} / d$ = **0.002**

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

Structural system factor - Table 7.4N — K_b = **0.4**

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 — $\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b)$ = **16**

Actual span to depth ratio — h_{stem} / d = **15.2**

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} = **28.7** kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **206.7** N/mm²

Load duration — Long term

Load duration factor — k_t = **0.4**

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

$A_{c.eff}$ = **75250** mm²/m

Mean value of concrete tensile strength — $f_{ct.eff} = f_{ctm}$ = **3.0** N/mm²

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

Modular ratio — $\alpha_e = E_s / E_{cm}$ = **5.998**

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 — $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **374** 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 = **0.232** mm

w_k / w_{max} = **0.772**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — V = **47.3** kN/m

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

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

Longitudinal reinforcement ratio — $\rho_l = \min(A_{sr.prov} / d, 0.02)$ = **0.004**

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.560** N/mm²

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

$V_{Rd.c}$ = **108.6** kN/m

$V / V_{Rd.c}$ = **0.435**

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) $A_{sx.req} = max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem})$ = **250** mm^2/m

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

Transverse reinforcement provided 12 dia.bars @ 150 c/c

Area of transverse reinforcement provided $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **754** 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 = **40.5** kNm/m

Depth to tension reinforcement $d = h - c_{bb} - \phi_{bb} / 2$ = **369** mm

$K = M / (d^2 \times f_{ck})$ = **0.009**

$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **351** mm

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

Area of tension reinforcement required $A_{bb.req} = M / (f_{yd} \times z)$ = **266** mm^2/m

Tension reinforcement provided 12 dia.bars @ 150 c/c

Area of tension reinforcement provided $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **754** mm^2/m

Minimum area of reinforcement - exp.9.1N $A_{bb.min} = max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **580** mm^2/m

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

$max(A_{bb.req}, A_{bb.min}) / A_{bb.prov}$ = **0.77**

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

Library item: Rectangular single output

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} = **29.5** kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{bb.prov} \times z)$ = **111.4** N/mm^2

Load duration Long term

Load duration factor k_t = **0.4**

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

$A_{c.eff}$ = **134625** mm^2/m

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2

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

Modular ratio $\alpha_e = E_s / E_{cm}$ = **5.998**

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 = **0.207** mm

w_k / w_{max} = **0.69**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — V = **99.8** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.736**

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

v_{min} = 0.035 $N^{1/2}$/mm × $k^{3/2}$ × $f_{ck}^{0.5}$ = **0.453** 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

$V_{Rd.c}$ = **167.1** kN/m

V / $V_{Rd.c}$ = **0.597**

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section — h = **450** mm

Rectangular section in shear - Section 6.2

Design shear force — V = **15.3** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.736**

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

v_{min} = 0.035 $N^{1/2}$/mm × $k^{3/2}$ × $f_{ck}^{0.5}$ = **0.453** 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

$V_{Rd.c}$ = **167.1** kN/m

V / $V_{Rd.c}$ = **0.091**

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section — h = **450** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **3.6** kNm/m

Depth to tension reinforcement — d = h - c_{bb} - ϕ_k / 2 = **369** mm

K = M / (d^2 × f_{ck}) = **0.001**

K' = (2 × η × α_{cc}/γ_C)×(1 - λ × (δ - K_1)/(2 × K_2))×(λ × (δ - K_1)/(2 × K_2))

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm — z = min(0.5 + 0.5 × (1 - 2 × K / (η × α_{cc} / γ_C))$^{0.5}$, 0.95) × d = **351** mm

Depth of neutral axis — x = 2.5 × (d – z) = **46** mm

Area of tension reinforcement required — $A_{k.req}$ = M / (f_{yd} × z) = **24** mm^2/m

Tension reinforcement provided — 12 dia.bars @ 150 c/c

Area of tension reinforcement provided — $A_{k.prov}$ = π × ϕ_k^2 / (4 × s_k) = **754** mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{k.min}$ = max(0.26 × f_{ctm} / f_{yk}, 0.0013) × d = **580** mm^2/m

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

max($A_{k.req}$, $A_{k.min}$) / $A_{k.prov}$ = **0.77**

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

Library item: Rectangular single output

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} = **2.7** kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{k.prov} \times z)$ = **10.1** N/mm^2
Load duration	Long term
Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$
	$A_{c.eff}$ = **134625** mm^2/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{k.prov} / A_{c.eff}$ = **0.006**
Modular ratio	$\alpha_e = E_s / E_{cm}$ = **5.998**
Bond property coefficient	k_1 = **0.8**
Strain distribution coefficient	k_2 = **0.5**
	k_3 = **3.4**
	k_4 = **0.425**
Maximum crack spacing - exp.7.11	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p.eff}$ = **619** mm
Maximum crack width - exp.7.8	$w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	w_k = **0.019** mm
	w_k / w_{max} = **0.062**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	V = **15.6** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.736**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{k.prov} / d, 0.02)$ = **0.002**
	$v_{min} = 0.035 \text{ N}^{1/2}\text{/mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.453** N/mm^2
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2\text{/mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **167.1** kN/m
	$V / V_{Rd.c}$ = **0.093**

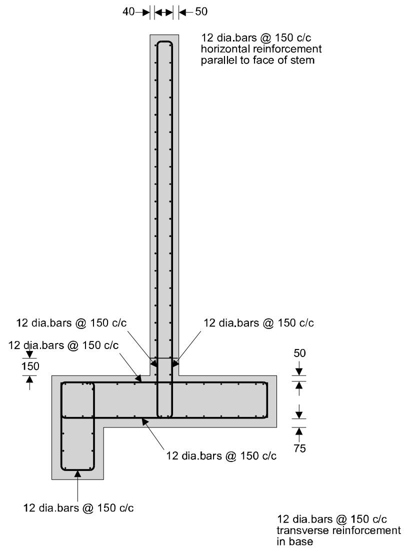
PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

Minimum area of reinforcement – cl.9.3.1.1(2)	$A_{bx.req} = 0.2 \times A_{bb.prov}$ = **151** mm^2/m
Maximum spacing of reinforcement – cl.9.3.1.1(3)	s_{bx_max} = **450** mm
Transverse reinforcement provided	12 dia.bars @ 150 c/c
Area of transverse reinforcement provided	$A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx})$ = **754** mm^2/m

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

Tekla Tedds	Project				Job no.	
	Calcs for RW2				Start page no./Revision 10	
	Calcs by I	Calcs date 25/01/2024	Checked by	Checked date	Approved by	Approved date



Reinforcement details