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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 2.9.08

Retaining wall details

Stem type	Cantilever
Stem height	$h_{\text{stem}} = 3250 \text{ mm}$
Stem thickness	$t_{\text{stem}} = 250 \text{ mm}$
Angle to rear face of stem	$\alpha = 90 \text{ deg}$
Stem density	$\gamma_{\text{stem}} = 25 \text{ kN/m}^3$
Toe length	$l_{\text{toe}} = 1500 \text{ mm}$
Heel length	$l_{\text{heel}} = 500 \text{ mm}$
Base thickness	$t_{\text{base}} = 250 \text{ mm}$
Base density	$\gamma_{\text{base}} = 25 \text{ kN/m}^3$
Height of retained soil	$h_{\text{ret}} = 3000 \text{ mm}$
Angle of soil surface	$\beta = 0 \text{ deg}$
Depth of cover	$d_{\text{cover}} = 250 \text{ mm}$

Retained soil properties

Soil type	Very dense gravel
Moist density	$\gamma_{\text{mr}} = 18 \text{ kN/m}^3$
Saturated density	$\gamma_{\text{sr}} = 21 \text{ kN/m}^3$

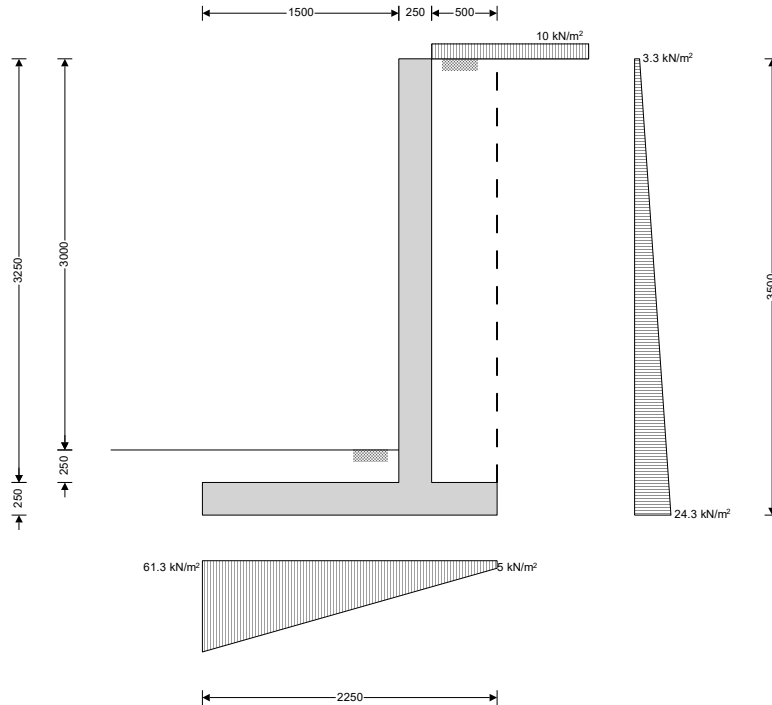
Base soil properties

Soil type	Very loose gravel
Soil density	$\gamma_{\text{b}} = 16 \text{ kN/m}^3$
Presumed bearing capacity	$P_{\text{bearing}} = 75 \text{ kN/m}^2$

Loading details

Variable surcharge load	Surcharge _Q = 10 kN/m ²
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General arrangement

Calculate retaining wall geometry

Base length

Moist soil height

Length of surcharge load

- Distance to vertical component

Effective height of wall

- Distance to horizontal component

Area of wall stem

- Distance to vertical component

Area of wall base

- Distance to vertical component

Area of moist soil

- Distance to vertical component

- Distance to horizontal component

Area of base soil

- Distance to vertical component

- Distance to horizontal component

Area of excavated base soil

- Distance to vertical component

- Distance to horizontal component

Retained soil properties

Design moist density

$$l_{\text{base}} = l_{\text{toe}} + t_{\text{stem}} + l_{\text{heel}} = 2250 \text{ mm}$$

$$h_{\text{moist}} = h_{\text{soil}} = 3250 \text{ mm}$$

$$l_{\text{sur}} = l_{\text{heel}} = 500 \text{ mm}$$

$$x_{\text{sur}_v} = l_{\text{base}} - l_{\text{heel}} / 2 = 2000 \text{ mm}$$

$$h_{\text{eff}} = h_{\text{base}} + d_{\text{cover}} + h_{\text{ret}} = 3500 \text{ mm}$$

$$x_{\text{sur}_h} = h_{\text{eff}} / 2 = 1750 \text{ mm}$$

$$A_{\text{stem}} = h_{\text{stem}} \times t_{\text{stem}} = 0.813 \text{ m}^2$$

$$x_{\text{stem}} = l_{\text{toe}} + t_{\text{stem}} / 2 = 1625 \text{ mm}$$

$$A_{\text{base}} = l_{\text{base}} \times t_{\text{base}} = 0.563 \text{ m}^2$$

$$x_{\text{base}} = l_{\text{base}} / 2 = 1125 \text{ mm}$$

$$A_{\text{moist}} = h_{\text{moist}} \times l_{\text{heel}} = 1.625 \text{ m}^2$$

$$x_{\text{moist}_v} = l_{\text{base}} - (h_{\text{moist}} \times l_{\text{heel}}^2 / 2) / A_{\text{moist}} = 2000 \text{ mm}$$

$$x_{\text{moist}_h} = h_{\text{eff}} / 3 = 1167 \text{ mm}$$

$$A_{\text{pass}} = d_{\text{cover}} \times l_{\text{toe}} = 0.375 \text{ m}^2$$

$$x_{\text{pass}_v} = l_{\text{base}} - (d_{\text{cover}} \times l_{\text{toe}} \times (l_{\text{base}} - l_{\text{toe}} / 2)) / A_{\text{pass}} = 750 \text{ mm}$$

$$x_{\text{pass}_h} = (d_{\text{cover}} + h_{\text{base}}) / 3 = 167 \text{ mm}$$

$$A_{\text{exc}} = h_{\text{pass}} \times l_{\text{toe}} = 0.375 \text{ m}^2$$

$$x_{\text{exc}_v} = l_{\text{base}} - (h_{\text{pass}} \times l_{\text{toe}} \times (l_{\text{base}} - l_{\text{toe}} / 2)) / A_{\text{exc}} = 750 \text{ mm}$$

$$x_{\text{exc}_h} = (h_{\text{pass}} + h_{\text{base}}) / 3 = 167 \text{ mm}$$

$$\gamma_{\text{mr}}' = \gamma_{\text{mr}} / \gamma_{\text{r}} = 18 \text{ kN/m}^3$$

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Design saturated density

$$\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = 21 \text{ kN/m}^3$$

Base soil properties

Design soil density

$$\gamma_b' = \gamma_b / \gamma_{\gamma} = 16 \text{ kN/m}^3$$

Soil coefficients

Coefficient of friction to back of wall

$$K_{fr} = 0.325$$

Coefficient of friction to front of wall

$$K_{fb} = 0.325$$

Coefficient of friction beneath base

$$K_{fbb} = 0.325$$

Active pressure coefficient

$$K_A = 0.333$$

Passive pressure coefficient

$$K_P = 4.977$$

Bearing pressure check

Vertical forces on wall

Wall stem

$$F_{stem} = A_{stem} \times \gamma_{stem} = 20.3 \text{ kN/m}$$

Wall base

$$F_{base} = A_{base} \times \gamma_{base} = 14.1 \text{ kN/m}$$

Surcharge load

$$F_{sur_v} = \text{Surcharge}_Q \times l_{heel} = 5 \text{ kN/m}$$

Moist retained soil

$$F_{moist_v} = A_{moist} \times \gamma_{mr} = 29.3 \text{ kN/m}$$

Base soil

$$F_{pass_v} = A_{pass} \times \gamma_b = 6 \text{ kN/m}$$

Total

$$F_{total_v} = F_{stem} + F_{base} + F_{sur_v} + F_{moist_v} + F_{pass_v} = 74.6 \text{ kN/m}$$

Horizontal forces on wall

Surcharge load

$$F_{sur_h} = K_A \times \text{Surcharge}_Q \times h_{eff} = 11.7 \text{ kN/m}$$

Moist retained soil

$$F_{moist_h} = K_A \times \gamma_{mr} \times h_{eff}^2 / 2 = 36.8 \text{ kN/m}$$

Base soil

$$F_{pass_h} = -K_P \times \gamma_b \times (d_{cover} + h_{base})^2 / 2 = -10 \text{ kN/m}$$

Total

$$F_{total_h} = F_{sur_h} + F_{moist_h} + F_{pass_h} - F_{total_v} \times K_{fbb} = 14.2 \text{ kN/m}$$

Moments on wall

Wall stem

$$M_{stem} = F_{stem} \times x_{stem} = 33 \text{ kNm/m}$$

Wall base

$$M_{base} = F_{base} \times x_{base} = 15.8 \text{ kNm/m}$$

Surcharge load

$$M_{sur} = F_{sur_v} \times x_{sur_v} - F_{sur_h} \times x_{sur_h} = -10.4 \text{ kNm/m}$$

Moist retained soil

$$M_{moist} = F_{moist_v} \times x_{moist_v} - F_{moist_h} \times x_{moist_h} = 15.6 \text{ kNm/m}$$

Base soil

$$M_{pass} = F_{pass_v} \times x_{pass_v} - F_{pass_h} \times x_{pass_h} = 6.2 \text{ kNm/m}$$

Total

$$M_{total} = M_{stem} + M_{base} + M_{sur} + M_{moist} + M_{pass} = 60.2 \text{ kNm/m}$$

Check bearing pressure

Distance to reaction

$$\bar{x} = M_{total} / F_{total_v} = 807 \text{ mm}$$

Eccentricity of reaction

$$e = \bar{x} - l_{base} / 2 = -318 \text{ mm}$$

Loaded length of base

$$l_{load} = l_{base} = 2250 \text{ mm}$$

Bearing pressure at toe

$$q_{toe} = F_{total_v} / l_{base} \times (1 - 6 \times e / l_{base}) = 61.3 \text{ kN/m}^2$$

Bearing pressure at heel

$$q_{heel} = F_{total_v} / l_{base} \times (1 + 6 \times e / l_{base}) = 5 \text{ kN/m}^2$$

Factor of safety

$$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) = 1.223$$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Design approach 1

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

Partial factor set

$$A1$$

Permanent unfavourable action

$$\gamma_G = 1.35$$

Permanent favourable action

$$\gamma_{Gf} = 1.00$$

Variable unfavourable action

$$\gamma_Q = 1.50$$

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

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

Soil parameter set M1
 Angle of shearing resistance $\gamma_{\psi} = 1.00$
 Effective cohesion $\gamma_{c'} = 1.00$
 Weight density $\gamma_{\gamma} = 1.00$

Library item Partial factors output

Retained soil properties

Design moist density $\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = 18 \text{ kN/m}^3$
 Design saturated density $\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = 21 \text{ kN/m}^3$

Base soil properties

Design soil density $\gamma_b' = \gamma_b / \gamma_{\gamma} = 16 \text{ kN/m}^3$

Soil coefficients

Coefficient of friction to back of wall $K_{fr} = 0.325$
 Coefficient of friction to front of wall $K_{fb} = 0.325$
 Coefficient of friction beneath base $K_{fbb} = 0.325$
 Active pressure coefficient $K_A = 0.333$
 Passive pressure coefficient $K_P = 4.977$

Sliding check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = 20.3 \text{ kN/m}$
 Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = 14.1 \text{ kN/m}$
 Moist retained soil $F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = 29.3 \text{ kN/m}$
 Base soil $F_{exc_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = 6 \text{ kN/m}$
 Total $F_{total_v} = F_{stem} + F_{base} + F_{moist_v} + F_{exc_v} = 69.6 \text{ kN/m}$

Horizontal forces on wall

Surcharge load $F_{sur_h} = K_A \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = 17.5 \text{ kN/m}$
 Moist retained soil $F_{moist_h} = \gamma_G \times K_A \times \gamma_{mr}' \times h_{eff}^2 / 2 = 49.6 \text{ kN/m}$
 Total $F_{total_h} = F_{sur_h} + F_{moist_h} = 67.1 \text{ kN/m}$

Check stability against sliding

Base soil resistance $F_{exc_h} = \gamma_{Gf} \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = 10 \text{ kN/m}$
 Base friction $F_{friction} = F_{total_v} \times K_{fbb} = 22.6 \text{ kN/m}$
 Resistance to sliding $F_{rest} = F_{exc_h} + F_{friction} = 32.6 \text{ kN/m}$
 Factor of safety $FoS_{sl} = F_{rest} / F_{total_h} = 0.485$

FAIL - Sliding force is greater than resistance to sliding

Overturning check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = 20.3 \text{ kN/m}$
 Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = 14.1 \text{ kN/m}$
 Moist retained soil $F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = 29.3 \text{ kN/m}$
 Base soil $F_{exc_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = 6 \text{ kN/m}$
 Total $F_{total_v} = F_{stem} + F_{base} + F_{moist_v} + F_{exc_v} = 69.6 \text{ kN/m}$

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Horizontal forces on wall

Surcharge load	$F_{sur,h} = K_A \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = 17.5 \text{ kN/m}$
Moist retained soil	$F_{moist,h} = \gamma_G \times K_A \times \gamma_{mr}' \times h_{eff}^2 / 2 = 49.6 \text{ kN/m}$
Base soil	$F_{exc,h} = -\gamma_{Gf} \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = -10 \text{ kN/m}$
Total	$F_{total,h} = F_{sur,h} + F_{moist,h} + F_{exc,h} = 57.2 \text{ kN/m}$

Overturning moments on wall

Surcharge load	$M_{sur,OT} = F_{sur,h} \times X_{sur,h} = 30.6 \text{ kNm/m}$
Moist retained soil	$M_{moist,OT} = F_{moist,h} \times X_{moist,h} = 57.9 \text{ kNm/m}$
Total	$M_{total,OT} = M_{sur,OT} + M_{moist,OT} = 88.5 \text{ kNm/m}$

Restoring moments on wall

Wall stem	$M_{stem,R} = F_{stem} \times X_{stem} = 33 \text{ kNm/m}$
Wall base	$M_{base,R} = F_{base} \times X_{base} = 15.8 \text{ kNm/m}$
Moist retained soil	$M_{moist,R} = F_{moist,v} \times X_{moist,v} = 58.5 \text{ kNm/m}$
Base soil	$M_{exc,R} = F_{exc,v} \times X_{exc,v} - F_{exc,h} \times X_{exc,h} = 6.2 \text{ kNm/m}$
Total	$M_{total,R} = M_{stem,R} + M_{base,R} + M_{moist,R} + M_{exc,R} = 113.5 \text{ kNm/m}$

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{total,R} / M_{total,OT} = 1.282$
PASS - Maximum restoring moment is greater than overturning moment	

Design approach 1

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

Partial factor set	A2
Permanent unfavourable action	$\gamma_G = 1.00$
Permanent favourable action	$\gamma_{Gf} = 1.00$
Variable unfavourable action	$\gamma_Q = 1.30$
Variable favourable action	$\gamma_{Qf} = 0.00$

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

Soil parameter set	M2
Angle of shearing resistance	$\gamma_{\phi'} = 1.25$
Effective cohesion	$\gamma_{c'} = 1.25$
Weight density	$\gamma_{\gamma} = 1.00$

Library item Partial factors output

Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = 18 \text{ kN/m}^3$
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = 21 \text{ kN/m}^3$

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_{\gamma} = 16 \text{ kN/m}^3$
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Soil coefficients

Coefficient of friction to back of wall	$K_{fr} = 0.325$
Coefficient of friction to front of wall	$K_{fb} = 0.325$
Coefficient of friction beneath base	$K_{fbb} = 0.325$
Active pressure coefficient	$K_A = 0.333$
Passive pressure coefficient	$K_P = 4.977$

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Sliding check

Vertical forces on wall

Wall stem	$F_{\text{stem}} = \gamma_{\text{Gf}} \times A_{\text{stem}} \times \gamma_{\text{stem}} = 20.3 \text{ kN/m}$
Wall base	$F_{\text{base}} = \gamma_{\text{Gf}} \times A_{\text{base}} \times \gamma_{\text{base}} = 14.1 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_v} = \gamma_{\text{Gf}} \times A_{\text{moist}} \times \gamma_{\text{mr}}' = 29.3 \text{ kN/m}$
Base soil	$F_{\text{exc}_v} = \gamma_{\text{Gf}} \times A_{\text{exc}} \times \gamma_{\text{b}}' = 6 \text{ kN/m}$
Total	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{moist}_v} + F_{\text{exc}_v} = 69.6 \text{ kN/m}$

Horizontal forces on wall

Surcharge load	$F_{\text{sur}_h} = K_A \times \gamma_Q \times \text{Surcharge}_Q \times h_{\text{eff}} = 15.2 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_h} = \gamma_G \times K_A \times \gamma_{\text{mr}}' \times h_{\text{eff}}^2 / 2 = 36.8 \text{ kN/m}$
Total	$F_{\text{total}_h} = F_{\text{sur}_h} + F_{\text{moist}_h} = 51.9 \text{ kN/m}$

Check stability against sliding

Base soil resistance	$F_{\text{exc}_h} = \gamma_{\text{Gf}} \times K_P \times \gamma_{\text{b}}' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = 10 \text{ kN/m}$
Base friction	$F_{\text{friction}} = F_{\text{total}_v} \times K_{\text{fbb}} = 22.6 \text{ kN/m}$
Resistance to sliding	$F_{\text{rest}} = F_{\text{exc}_h} + F_{\text{friction}} = 32.6 \text{ kN/m}$
Factor of safety	$\text{FoS}_{\text{sl}} = F_{\text{rest}} / F_{\text{total}_h} = 0.628$

FAIL - Sliding force is greater than resistance to sliding

Overturning check

Vertical forces on wall

Wall stem	$F_{\text{stem}} = \gamma_{\text{Gf}} \times A_{\text{stem}} \times \gamma_{\text{stem}} = 20.3 \text{ kN/m}$
Wall base	$F_{\text{base}} = \gamma_{\text{Gf}} \times A_{\text{base}} \times \gamma_{\text{base}} = 14.1 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_v} = \gamma_{\text{Gf}} \times A_{\text{moist}} \times \gamma_{\text{mr}}' = 29.3 \text{ kN/m}$
Base soil	$F_{\text{exc}_v} = \gamma_{\text{Gf}} \times A_{\text{exc}} \times \gamma_{\text{b}}' = 6 \text{ kN/m}$
Total	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{moist}_v} + F_{\text{exc}_v} = 69.6 \text{ kN/m}$

Horizontal forces on wall

Surcharge load	$F_{\text{sur}_h} = K_A \times \gamma_Q \times \text{Surcharge}_Q \times h_{\text{eff}} = 15.2 \text{ kN/m}$
Moist retained soil	$F_{\text{moist}_h} = \gamma_G \times K_A \times \gamma_{\text{mr}}' \times h_{\text{eff}}^2 / 2 = 36.8 \text{ kN/m}$
Base soil	$F_{\text{exc}_h} = -\gamma_{\text{Gf}} \times K_P \times \gamma_{\text{b}}' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = -10 \text{ kN/m}$
Total	$F_{\text{total}_h} = F_{\text{sur}_h} + F_{\text{moist}_h} + F_{\text{exc}_h} = 42 \text{ kN/m}$

Overturning moments on wall

Surcharge load	$M_{\text{sur}_{\text{OT}}} = F_{\text{sur}_h} \times X_{\text{sur}_h} = 26.5 \text{ kNm/m}$
Moist retained soil	$M_{\text{moist}_{\text{OT}}} = F_{\text{moist}_h} \times X_{\text{moist}_h} = 42.9 \text{ kNm/m}$
Total	$M_{\text{total}_{\text{OT}}} = M_{\text{sur}_{\text{OT}}} + M_{\text{moist}_{\text{OT}}} = 69.4 \text{ kNm/m}$

Restoring moments on wall

Wall stem	$M_{\text{stem}_R} = F_{\text{stem}} \times X_{\text{stem}} = 33 \text{ kNm/m}$
Wall base	$M_{\text{base}_R} = F_{\text{base}} \times X_{\text{base}} = 15.8 \text{ kNm/m}$
Moist retained soil	$M_{\text{moist}_R} = F_{\text{moist}_v} \times X_{\text{moist}_v} = 58.5 \text{ kNm/m}$
Base soil	$M_{\text{exc}_R} = F_{\text{exc}_v} \times X_{\text{exc}_v} - F_{\text{exc}_h} \times X_{\text{exc}_h} = 6.2 \text{ kNm/m}$
Total	$M_{\text{total}_R} = M_{\text{stem}_R} + M_{\text{base}_R} + M_{\text{moist}_R} + M_{\text{exc}_R} = 113.5 \text{ kNm/m}$

Check stability against overturning

Factor of safety	$\text{FoS}_{\text{ot}} = M_{\text{total}_R} / M_{\text{total}_{\text{OT}}} = 1.635$
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PASS - Maximum restoring moment is greater than overturning moment

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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 2.9.08

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

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

Reinforcement details

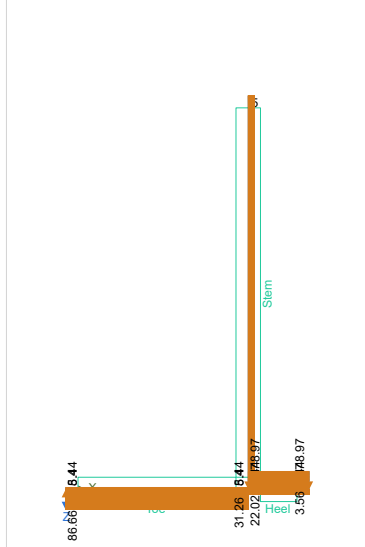
Characteristic yield strength of reinforcement	$f_{yk} = 500 \text{ N/mm}^2$
Modulus of elasticity of reinforcement	$E_s = 200000 \text{ N/mm}^2$
Partial factor for reinforcing steel - Table 2.1N	$\gamma_S = 1.15$
Design yield strength of reinforcement	$f_{yd} = f_{yk} / \gamma_S = 435 \text{ N/mm}^2$

Cover to reinforcement

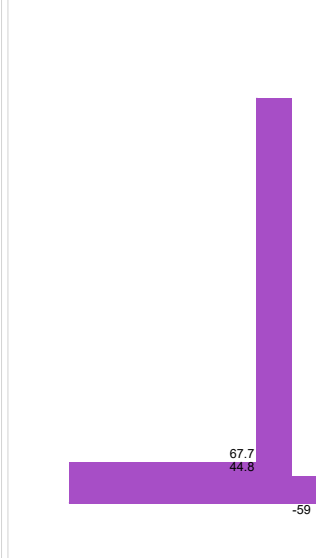
Front face of stem	$c_{sf} = 40 \text{ mm}$
Rear face of stem	$c_{sr} = 50 \text{ mm}$
Top face of base	$c_{bt} = 50 \text{ mm}$
Bottom face of base	$c_{bb} = 75 \text{ mm}$

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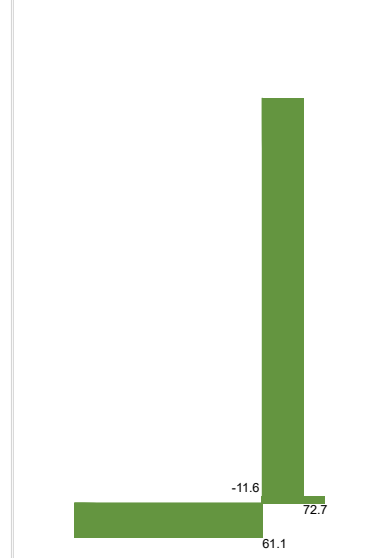
Loading details - Combination No.1 - kN/m²



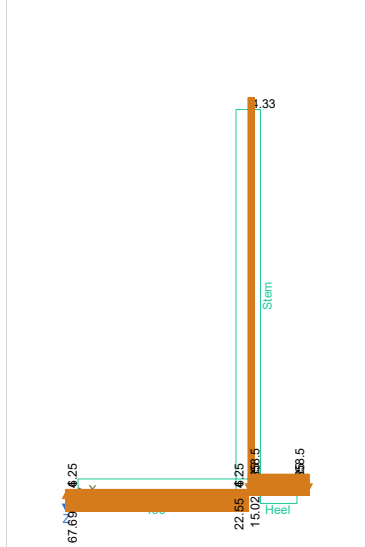
Shear force - Combination No.1 - kN/m



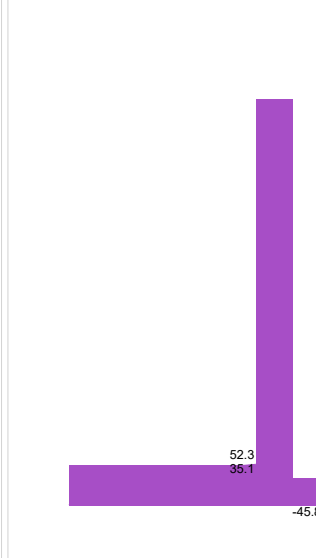
Bending moment - Combination No.1 - kNm/m



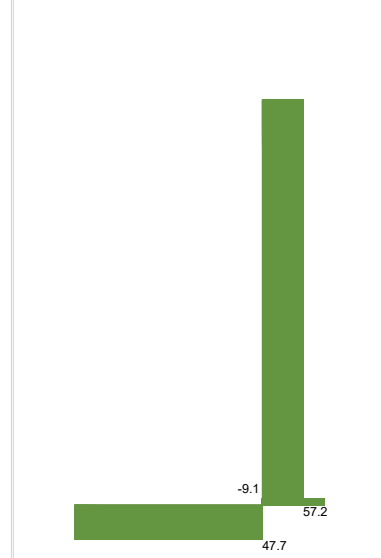
Loading details - Combination No.2 - kN/m²



Shear force - Combination No.2 - kN/m



Bending moment - Combination No.2 - kNm/m



Check stem design at base of stem

Depth of section

$h = 250 \text{ mm}$

Rectangular section in flexure - Section 6.1

Design bending moment combination 1

$M = 72.7 \text{ kNm/m}$

Depth to tension reinforcement

$d = h - c_{sr} - \phi_{sr} / 2 = 192 \text{ mm}$

$K = M / (d^2 \times f_{ck}) = 0.062$

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

$K' = 0.207$

$K' > K$ - No compression reinforcement is required

Lever arm

$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}, 0.95) \times d = 181 \text{ mm}$

Depth of neutral axis

$x = 2.5 \times (d - z) = 28 \text{ mm}$

Area of tension reinforcement required

$A_{sr, req} = M / (f_{yd} \times z) = 925 \text{ mm}^2/\text{m}$

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Tension reinforcement provided

16 dia.bars @ 200 c/c

Area of tension reinforcement provided

$A_{sr,prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = 1005 \text{ mm}^2/\text{m}$

Minimum area of reinforcement - exp.9.1N

$A_{sr,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 302 \text{ mm}^2/\text{m}$

Maximum area of reinforcement - cl.9.2.1.1(3)

$A_{sr,max} = 0.04 \times h = 10000 \text{ mm}^2/\text{m}$

$\max(A_{sr,req}, A_{sr,min}) / A_{sr,prov} = 0.92$

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

$\rho = A_{sr,req} / d = 0.005$

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

$K_s = \min(500 \text{ N/mm}^2 / (f_{yk} \times A_{sr,req} / A_{sr,prov}), 1.5) = 1.087$

Limiting span to depth ratio - exp.7.16.a

$\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b) = 9.7$

Actual span to depth ratio

$h_{stem} / d = 16.9$

FAIL - Span to depth ratio exceeds deflection control limit

Crack control - Section 7.3

Limiting crack width

$w_{max} = 0.3 \text{ mm}$

Variable load factor - EN1990 – Table A1.1

$\psi_2 = 0.6$

Serviceability bending moment

$M_{sls} = 44.9 \text{ kNm/m}$

Tensile stress in reinforcement

$\sigma_s = M_{sls} / (A_{sr,prov} \times z) = 246.8 \text{ N/mm}^2$

Load duration

Long term

Load duration factor

$k_t = 0.4$

Effective area of concrete in tension

$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$

$A_{c,eff} = 74093 \text{ mm}^2/\text{m}$

Mean value of concrete tensile strength

$f_{ct,eff} = f_{ctm} = 3.0 \text{ N/mm}^2$

Reinforcement ratio

$\rho_{p,eff} = A_{sr,prov} / A_{c,eff} = 0.014$

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

$s_{r,max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p,eff} = 370 \text{ mm}$

Maximum crack width - exp.7.8

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

$w_k = 0.279 \text{ mm}$

$w_k / w_{max} = 0.929$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$V = 59 \text{ kN/m}$

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

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

Longitudinal reinforcement ratio

$\rho_l = \min(A_{sr,prov} / d, 0.02) = 0.005$

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

Design shear resistance - exp.6.2a & 6.2b

$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$

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$$V_{Rd,c} = 117.9 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.501$$

PASS - Design shear resistance exceeds design shear force

Horizontal reinforcement parallel to face of stem - Section 9.6

$$\text{Minimum area of reinforcement - cl.9.6.3(1)} \quad A_{sx,req} = \max(0.25 \times A_{sr,prov}, 0.001 \times t_{stem}) = 251 \text{ mm}^2/\text{m}$$

$$\text{Maximum spacing of reinforcement - cl.9.6.3(2)} \quad s_{sx,max} = 400 \text{ mm}$$

$$\text{Transverse reinforcement provided} \quad 10 \text{ dia.bars @ } 200 \text{ c/c}$$

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

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

Check base design at toe

$$\text{Depth of section} \quad h = 250 \text{ mm}$$

Rectangular section in flexure - Section 6.1

$$\text{Design bending moment combination 1} \quad M = 61.1 \text{ kNm/m}$$

$$\text{Depth to tension reinforcement} \quad d = h - c_{bb} - \phi_{bb} / 2 = 169 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.067$$

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

$$K' = 0.207$$

K' > K - No compression reinforcement is required

$$\text{Lever arm} \quad z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}, 0.95) \times d = 158 \text{ mm}$$

$$\text{Depth of neutral axis} \quad x = 2.5 \times (d - z) = 27 \text{ mm}$$

$$\text{Area of tension reinforcement required} \quad A_{bb,req} = M / (f_{yd} \times z) = 888 \text{ mm}^2/\text{m}$$

$$\text{Tension reinforcement provided} \quad 12 \text{ dia.bars @ } 200 \text{ c/c}$$

$$\text{Area of tension reinforcement provided} \quad A_{bb,prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = 565 \text{ mm}^2/\text{m}$$

$$\text{Minimum area of reinforcement - exp.9.1N} \quad A_{bb,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 266 \text{ mm}^2/\text{m}$$

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

$$\max(A_{bb,req}, A_{bb,min}) / A_{bb,prov} = 1.571$$

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

Library item: Rectangular single output

Crack control - Section 7.3

$$\text{Limiting crack width} \quad w_{max} = 0.3 \text{ mm}$$

$$\text{Variable load factor - EN1990 - Table A1.1} \quad \psi_2 = 0.6$$

$$\text{Serviceability bending moment} \quad M_{sls} = 43.4 \text{ kNm/m}$$

$$\text{Tensile stress in reinforcement} \quad \sigma_s = M_{sls} / (A_{bb,prov} \times z) = 484.4 \text{ N/mm}^2$$

$$\text{Load duration} \quad \text{Long term}$$

$$\text{Load duration factor} \quad k_t = 0.4$$

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

$$A_{c,eff} = 74460 \text{ mm}^2/\text{m}$$

$$\text{Mean value of concrete tensile strength} \quad f_{ct,eff} = f_{ctm} = 3.0 \text{ N/mm}^2$$

$$\text{Reinforcement ratio} \quad \rho_{p,eff} = A_{bb,prov} / A_{c,eff} = 0.008$$

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

$$\text{Bond property coefficient} \quad k_1 = 0.8$$

$$\text{Strain distribution coefficient} \quad k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

$$\text{Maximum crack spacing - exp.7.11} \quad s_{r,max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p,eff} = 524 \text{ mm}$$

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

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$$w_k = 0.832 \text{ mm}$$

$$w_k / w_{\max} = 2.774$$

FAIL - Maximum crack width exceeds limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = 67.7 \text{ kN/m}$$

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

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

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bb,prov} / d, 0.02) = 0.003$$

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

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{\min}) \times d$$

$$V_{Rd,c} = 94.6 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.715$$

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section

$$h = 250 \text{ mm}$$

Rectangular section in flexure - Section 6.1

Design bending moment combination 1

$$M = 11.6 \text{ kNm/m}$$

Depth to tension reinforcement

$$d = h - c_{bt} - \phi_{bt} / 2 = 194 \text{ mm}$$

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

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

$$K' = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

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

Depth of neutral axis

$$x = 2.5 \times (d - z) = 24 \text{ mm}$$

Area of tension reinforcement required

$$A_{bt,req} = M / (f_{yd} \times z) = 145 \text{ mm}^2/\text{m}$$

Tension reinforcement provided

$$12 \text{ dia.bars @ } 200 \text{ c/c}$$

Area of tension reinforcement provided

$$A_{bt,prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) = 565 \text{ mm}^2/\text{m}$$

Minimum area of reinforcement - exp.9.1N

$$A_{bt,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 305 \text{ mm}^2/\text{m}$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{bt,max} = 0.04 \times h = 10000 \text{ mm}^2/\text{m}$$

$$\max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = 0.539$$

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

$$w_{\max} = 0.3 \text{ mm}$$

Variable load factor - EN1990 – Table A1.1

$$\psi_2 = 0.6$$

Serviceability bending moment

$$M_{sls} = 7.7 \text{ kNm/m}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{bt,prov} \times z) = 73.8 \text{ N/mm}^2$$

Load duration

Long term

Load duration factor

$$k_t = 0.4$$

Effective area of concrete in tension

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = 75250 \text{ mm}^2/\text{m}$$

Mean value of concrete tensile strength

$$f_{ct,eff} = f_{ctm} = 3.0 \text{ N/mm}^2$$

Reinforcement ratio

$$\rho_{p,eff} = A_{bt,prov} / A_{c,eff} = 0.008$$

Modular ratio

$$\alpha_e = E_s / E_{cm} = 5.998$$

Bond property coefficient

$$k_1 = 0.8$$

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Strain distribution coefficient

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

Maximum crack spacing - exp.7.11

$$s_{r,max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = 441 \text{ mm}$$

Maximum crack width - exp.7.8

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

$$w_k = 0.098 \text{ mm}$$

$$w_k / w_{max} = 0.326$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force

$$V = 44.8 \text{ kN/m}$$

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

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

Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bt,prov} / d, 0.02) = 0.003$$

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

Design shear resistance - exp.6.2a & 6.2b

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$$

$$V_{Rd,c} = 108.6 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.412$$

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)

$$A_{bx,req} = 0.2 \times A_{bb,prov} = 113 \text{ mm}^2/\text{m}$$

Maximum spacing of reinforcement – cl.9.3.1.1(3)

$$s_{bx,max} = 450 \text{ mm}$$

Transverse reinforcement provided

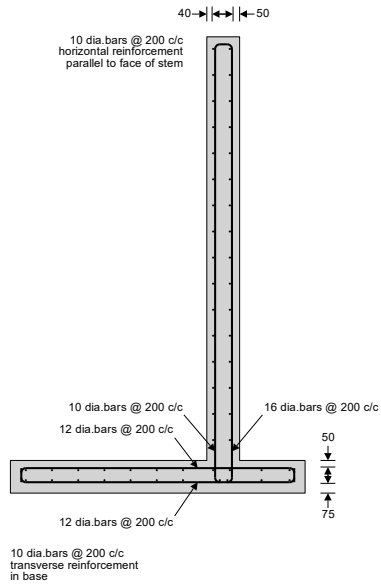
$$10 \text{ dia.bars @ } 200 \text{ c/c}$$

Area of transverse reinforcement provided

$$A_{bx,prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx}) = 393 \text{ mm}^2/\text{m}$$

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

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Reinforcement details