

HIGHWAYS RETAINING WALL DESIGN

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 2.9.22

Retaining wall details

Stem type	Cantilever
Stem height	$h_{\text{stem}} = 2850$ mm
Stem thickness	$t_{\text{stem}} = 300$ mm
Angle to rear face of stem	$\alpha = 90$ deg
Stem density	$\gamma_{\text{stem}} = 25$ kN/m ³
Toe length	$l_{\text{toe}} = 1000$ mm
Heel length	$l_{\text{heel}} = 1000$ mm
Base thickness	$t_{\text{base}} = 350$ mm
Base density	$\gamma_{\text{base}} = 25$ kN/m ³
Height of retained soil	$h_{\text{ret}} = 2850$ mm
Angle of soil surface	$\beta = 0$ deg
Depth of cover	$d_{\text{cover}} = 0$ mm

Retained soil properties

Soil type	Medium dense well graded sand
Moist density	$\gamma_{\text{mr}} = 18$ kN/m ³
Saturated density	$\gamma_{\text{sr}} = 23$ kN/m ³
Characteristic effective shear resistance angle	$\phi'_{r,k} = 30$ deg
Characteristic wall friction angle	$\delta_{r,k} = 15$ deg

Base soil properties

Soil type	Very dense rock fill
Soil density	$\gamma_{\text{b}} = 18$ kN/m ³
Characteristic effective shear resistance angle	$\phi'_{b,k} = 42$ deg
Characteristic wall friction angle	$\delta_{b,k} = 21$ deg
Characteristic base friction angle	$\delta_{bb,k} = 36$ deg
Presumed bearing capacity	$P_{\text{bearing}} = 100$ kN/m ²

Loading details

Variable surcharge load	Surcharge _Q = 10 kN/m ²
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Highways Retaining Wall

Job No.

12063

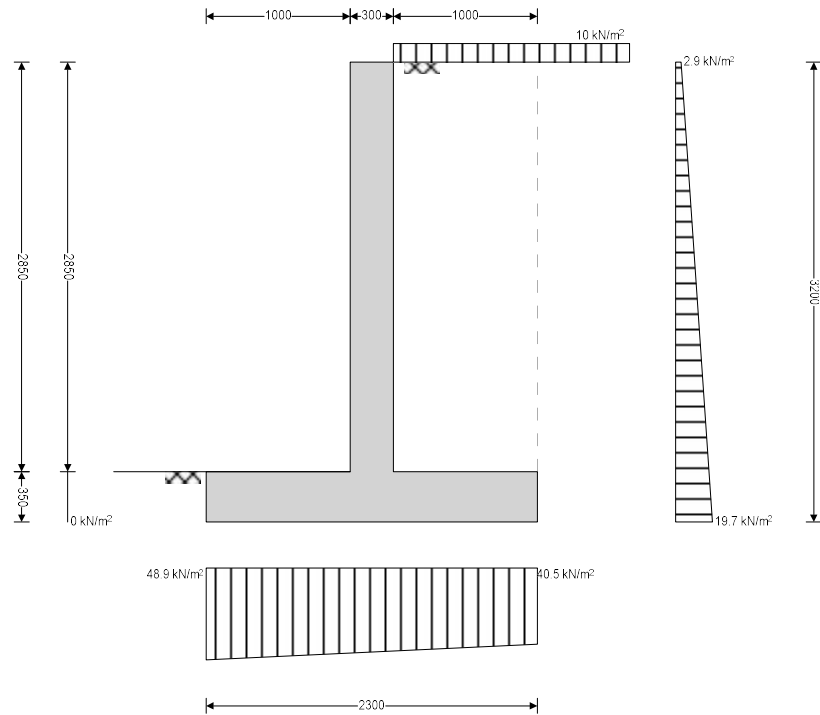
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Calc

By DSH

Calc

Date 01/06/2026



General arrangement - sketch pressures relate to bearing check

Calculate retaining wall geometry

Base length

$$l_{\text{base}} = l_{\text{toe}} + t_{\text{stem}} + l_{\text{heel}} = \mathbf{2300 \text{ mm}}$$

Moist soil height

$$h_{\text{moist}} = h_{\text{soil}} = \mathbf{2850 \text{ mm}}$$

Length of surcharge load

$$l_{\text{sur}} = l_{\text{heel}} = \mathbf{1000 \text{ mm}}$$

- Distance to vertical component

$$x_{\text{sur}_v} = l_{\text{base}} - l_{\text{heel}} / 2 = \mathbf{1800 \text{ mm}}$$

Effective height of wall

$$h_{\text{eff}} = h_{\text{base}} + d_{\text{cover}} + h_{\text{ret}} = \mathbf{3200 \text{ mm}}$$

- Distance to horizontal component

$$x_{\text{sur}_h} = h_{\text{eff}} / 2 = \mathbf{1600 \text{ mm}}$$

Area of wall stem

$$A_{\text{stem}} = h_{\text{stem}} \times t_{\text{stem}} = \mathbf{0.855 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{stem}} = l_{\text{toe}} + t_{\text{stem}} / 2 = \mathbf{1150 \text{ mm}}$$

Area of wall base

$$A_{\text{base}} = l_{\text{base}} \times t_{\text{base}} = \mathbf{0.805 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{base}} = l_{\text{base}} / 2 = \mathbf{1150 \text{ mm}}$$

Area of moist soil

$$A_{\text{moist}} = h_{\text{moist}} \times l_{\text{heel}} = \mathbf{2.85 \text{ m}^2}$$

- Distance to vertical component

$$x_{\text{moist}_v} = l_{\text{base}} - (h_{\text{moist}} \times l_{\text{heel}}^2 / 2) / A_{\text{moist}} = \mathbf{1800 \text{ mm}}$$

- Distance to horizontal component

$$x_{\text{moist}_h} = h_{\text{eff}} / 3 = \mathbf{1067 \text{ mm}}$$

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Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k}) \times [1 + \sqrt{[\sin(\phi'_{r,k} + \delta_{r,k}) \times \sin(\phi'_{r,k} - \beta) / (\sin(\alpha - \delta_{r,k}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.301}$

Passive pressure coefficient $K_P = \sin(90 - \phi'_{b,k})^2 / (\sin(90 + \delta_{b,k}) \times [1 - \sqrt{[\sin(\phi'_{b,k} + \delta_{b,k}) \times \sin(\phi'_{b,k}) / (\sin(90 + \delta_{b,k}))]}]^2) = \mathbf{14.662}$

Bearing pressure check**Vertical forces on wall**

Wall stem $F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{21.4}$ kN/m
 Wall base $F_{base} = A_{base} \times \gamma_{base} = \mathbf{20.1}$ kN/m
 Surcharge load $F_{sur,v} = \text{Surcharge}_Q \times l_{heel} = \mathbf{10}$ kN/m
 Moist retained soil $F_{moist,v} = A_{moist} \times \gamma_{mr} = \mathbf{51.3}$ kN/m
 Total $F_{total,v} = F_{stem} + F_{base} + F_{sur,v} + F_{moist,v} = \mathbf{102.8}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur,h} = K_A \times \cos(\delta_{r,k}) \times \text{Surcharge}_Q \times h_{eff} = \mathbf{9.3}$ kN/m
 Moist retained soil $F_{moist,h} = K_A \times \cos(\delta_{r,k}) \times \gamma_{mr} \times h_{eff}^2 / 2 = \mathbf{26.8}$ kN/m
 Total $F_{total,h} = \max(F_{sur,h} + F_{moist,h} - F_{total,v} \times \tan(\delta_{bb,k}), 0 \text{ kN/m}) = \mathbf{0}$ kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times X_{stem} = \mathbf{24.6}$ kNm/m
 Wall base $M_{base} = F_{base} \times X_{base} = \mathbf{23.1}$ kNm/m
 Surcharge load $M_{sur} = F_{sur,v} \times X_{sur,v} - F_{sur,h} \times X_{sur,h} = \mathbf{3.1}$ kNm/m
 Moist retained soil $M_{moist} = F_{moist,v} \times X_{moist,v} - F_{moist,h} \times X_{moist,h} = \mathbf{63.7}$ kNm/m
 Total $M_{total} = M_{stem} + M_{base} + M_{sur} + M_{moist} = \mathbf{114.5}$ kNm/m

Check bearing pressure

Distance to reaction $\bar{x} = M_{total} / F_{total,v} = \mathbf{1114}$ mm
 Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{-36}$ mm
 Loaded length of base $l_{load} = l_{base} = \mathbf{2300}$ mm
 Bearing pressure at toe $q_{toe} = F_{total,v} / l_{base} \times (1 - 6 \times e / l_{base}) = \mathbf{48.9}$ kN/m²
 Bearing pressure at heel $q_{heel} = F_{total,v} / l_{base} \times (1 + 6 \times e / l_{base}) = \mathbf{40.5}$ kN/m²
 Factor of safety $FO_{S_{bp}} = P_{bearing} / \max(q_{toe}, q_{heel}) = \mathbf{2.046}$

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 $\gamma_G = \mathbf{1.350}$
 Permanent favourable action $\gamma_{Gf} = \mathbf{1.000}$
 Variable unfavourable action $\gamma_Q = \mathbf{1.500}$

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Variable favourable action $\gamma_{Qf} = 0.000$

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

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

Retained soil properties

Design moist density $\gamma_{mr'} = \gamma_{mr} / \gamma_{\gamma} = 18 \text{ kN/m}^3$
 Design saturated density $\gamma_{sr'} = \gamma_{sr} / \gamma_{\gamma} = 23 \text{ kN/m}^3$
 Design effective shear resistance angle $\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\phi'}) = 30 \text{ deg}$
 Design wall friction angle $\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}) = 15 \text{ deg}$

Base soil properties

Design soil density $\gamma_{b'} = \gamma_b / \gamma_{\gamma} = 18 \text{ kN/m}^3$
 Design effective shear resistance angle $\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\phi'}) = 42 \text{ deg}$
 Design wall friction angle $\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi'}) = 21 \text{ deg}$
 Design base friction angle $\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = 36 \text{ deg}$
 Design effective cohesion $c'_{b,d} = c'_{b,k} / \gamma_{c'} = 0 \text{ kN/m}^2$

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{[\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))]}]^2) = 0.301$
 Passive pressure coefficient $K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{[\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d}) / (\sin(90 + \delta_{b,d}))]}]^2) = 14.662$

Sliding check**Vertical forces on wall**

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = 21.4 \text{ kN/m}$
 Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = 20.1 \text{ kN/m}$
 Moist retained soil $F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr'} = 51.3 \text{ kN/m}$
 Total $F_{total_v} = F_{stem} + F_{base} + F_{moist_v} = 92.8 \text{ kN/m}$

Horizontal forces on wall

Surcharge load $F_{sur_h} = K_A \times \cos(\delta_{r,d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = 14 \text{ kN/m}$
 Moist retained soil $F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr'} \times h_{eff}^2 / 2 = 36.2 \text{ kN/m}$
 Total $F_{total_h} = F_{sur_h} + F_{moist_h} = 50.2 \text{ kN/m}$

Check stability against sliding

Base soil resistance $F_{exc_h} = 0 \text{ kN/m}$
 Base friction $F_{friction} = F_{total_v} \times \tan(\delta_{bb,d}) = 67.4 \text{ kN/m}$
 Resistance to sliding $F_{rest} = F_{exc_h} + F_{friction} = 67.4 \text{ kN/m}$
 Factor of safety $FOS_{sl} = F_{rest} / F_{total_h} = 1.343$

PASS - Resistance to sliding is greater than sliding force**Overturning check****Vertical forces on wall**

Wall stem	$F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = 21.4 \text{ kN/m}$
Wall base	$F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = 20.1 \text{ kN/m}$
Moist retained soil	$F_{moist_v} = \gamma_G \times A_{moist} \times \gamma_{mr}' = 51.3 \text{ kN/m}$
Total	$F_{total_v} = F_{stem} + F_{base} + F_{moist_v} = 92.8 \text{ kN/m}$

Horizontal forces on wall

Surcharge load	$F_{sur_h} = K_A \times \cos(\delta_{r,d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = 14 \text{ kN/m}$
Moist retained soil	$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = 36.2 \text{ kN/m}$
Total	$F_{total_h} = F_{sur_h} + F_{moist_h} = 50.2 \text{ kN/m}$

Overturning moments on wall

Surcharge load	$M_{sur_OT} = F_{sur_h} \times X_{sur_h} = 22.4 \text{ kNm/m}$
Moist retained soil	$M_{moist_OT} = F_{moist_h} \times X_{moist_h} = 38.6 \text{ kNm/m}$
Total	$M_{total_OT} = M_{sur_OT} + M_{moist_OT} = 61 \text{ kNm/m}$

Restoring moments on wall

Wall stem	$M_{stem_R} = F_{stem} \times X_{stem} = 24.6 \text{ kNm/m}$
Wall base	$M_{base_R} = F_{base} \times X_{base} = 23.1 \text{ kNm/m}$
Moist retained soil	$M_{moist_R} = F_{moist_v} \times X_{moist_v} = 92.3 \text{ kNm/m}$
Total	$M_{total_R} = M_{stem_R} + M_{base_R} + M_{moist_R} = 140.1 \text{ kNm/m}$

Check stability against overturning

Factor of safety	$FO_{Sot} = M_{total_R} / M_{total_OT} = 2.296$
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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	$\gamma_G = 1.000$
Permanent favourable action	$\gamma_{Gf} = 1.000$
Variable unfavourable action	$\gamma_Q = 1.300$
Variable favourable action	$\gamma_{Qf} = 0.000$

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

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

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Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = \mathbf{18 \text{ kN/m}^3}$
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = \mathbf{23 \text{ kN/m}^3}$
Design effective shear resistance angle	$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\phi}) = \mathbf{24.8 \text{ deg}}$
Design wall friction angle	$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi}) = \mathbf{12.1 \text{ deg}}$

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_{\gamma} = \mathbf{18 \text{ kN/m}^3}$
Design effective shear resistance angle	$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\phi}) = \mathbf{35.8 \text{ deg}}$
Design wall friction angle	$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi}) = \mathbf{17.1 \text{ deg}}$
Design base friction angle	$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi}) = \mathbf{30.2 \text{ deg}}$
Design effective cohesion	$C'_{b,d} = C'_{b,k} / \gamma_c' = \mathbf{0 \text{ kN/m}^2}$

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{[\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.371}$
Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{[\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d} - \beta) / (\sin(90 + \delta_{b,d}))]}]^2) = \mathbf{7.553}$

Sliding check**Vertical forces on wall**

Wall stem	$F_{stem} = \gamma Gf \times A_{stem} \times \gamma_{stem} = \mathbf{21.4 \text{ kN/m}}$
Wall base	$F_{base} = \gamma Gf \times A_{base} \times \gamma_{base} = \mathbf{20.1 \text{ kN/m}}$
Moist retained soil	$F_{moist_v} = \gamma Gf \times A_{moist} \times \gamma_{mr}' = \mathbf{51.3 \text{ kN/m}}$
Total	$F_{total_v} = F_{stem} + F_{base} + F_{moist_v} = \mathbf{92.8 \text{ kN/m}}$

Horizontal forces on wall

Surcharge load	$F_{sur_h} = K_A \times \cos(\delta_{r,d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = \mathbf{15.1 \text{ kN/m}}$
Moist retained soil	$F_{moist_h} = \gamma G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{33.4 \text{ kN/m}}$
Total	$F_{total_h} = F_{sur_h} + F_{moist_h} = \mathbf{48.5 \text{ kN/m}}$

Check stability against sliding

Base soil resistance	$F_{exc_h} = \mathbf{0 \text{ kN/m}}$
Base friction	$F_{friction} = F_{total_v} \times \tan(\delta_{bb,d}) = \mathbf{53.9 \text{ kN/m}}$
Resistance to sliding	$F_{rest} = F_{exc_h} + F_{friction} = \mathbf{53.9 \text{ kN/m}}$
Factor of safety	$FO_{Ssl} = F_{rest} / F_{total_h} = \mathbf{1.112}$

PASS - Resistance to sliding is greater than sliding force**Overturning check****Vertical forces on wall**

Wall stem	$F_{stem} = \gamma Gf \times A_{stem} \times \gamma_{stem} = \mathbf{21.4 \text{ kN/m}}$
Wall base	$F_{base} = \gamma Gf \times A_{base} \times \gamma_{base} = \mathbf{20.1 \text{ kN/m}}$

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Moist retained soil $F_{\text{moist}_v} = \gamma_G \times A_{\text{moist}} \times \gamma_{\text{mr}}' = \mathbf{51.3 \text{ kN/m}}$
 Total $F_{\text{Total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{moist}_v} = \mathbf{92.8 \text{ kN/m}}$

Horizontal forces on wall

Surcharge load $F_{\text{sur}_h} = K_A \times \cos(\delta_{r,d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{\text{eff}} = \mathbf{15.1 \text{ kN/m}}$
 Moist retained soil $F_{\text{moist}_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{\text{mr}}' \times h_{\text{eff}}^2 / 2 = \mathbf{33.4 \text{ kN/m}}$
 Total $F_{\text{Total}_h} = F_{\text{sur}_h} + F_{\text{moist}_h} = \mathbf{48.5 \text{ kN/m}}$

Overtuning moments on wall

Surcharge load $M_{\text{sur}_OT} = F_{\text{sur}_h} \times X_{\text{sur}_h} = \mathbf{24.1 \text{ kNm/m}}$
 Moist retained soil $M_{\text{moist}_OT} = F_{\text{moist}_h} \times X_{\text{moist}_h} = \mathbf{35.7 \text{ kNm/m}}$
 Total $M_{\text{Total}_OT} = M_{\text{sur}_OT} + M_{\text{moist}_OT} = \mathbf{59.8 \text{ kNm/m}}$

Restoring moments on wall

Wall stem $M_{\text{stem}_R} = F_{\text{stem}} \times X_{\text{stem}} = \mathbf{24.6 \text{ kNm/m}}$
 Wall base $M_{\text{base}_R} = F_{\text{base}} \times X_{\text{base}} = \mathbf{23.1 \text{ kNm/m}}$
 Moist retained soil $M_{\text{moist}_R} = F_{\text{moist}_v} \times X_{\text{moist}_v} = \mathbf{92.3 \text{ kNm/m}}$
 Total $M_{\text{Total}_R} = M_{\text{stem}_R} + M_{\text{base}_R} + M_{\text{moist}_R} = \mathbf{140.1 \text{ kNm/m}}$

Check stability against overturning

Factor of safety $FOS_{ot} = M_{\text{Total}_R} / M_{\text{Total}_OT} = \mathbf{2.342}$

PASS - Maximum restoring moment is greater than overturning moment

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 2.9.22

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

Concrete strength class	C30/37	
Characteristic compressive cylinder strength		$f_{ck} = \mathbf{30 \text{ N/mm}^2}$
Characteristic compressive cube strength	$f_{ck,cube} = \mathbf{37 \text{ N/mm}^2}$	
Mean value of compressive cylinder strength		$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = \mathbf{38 \text{ N/mm}^2}$
Mean value of axial tensile strength	$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = \mathbf{2.9 \text{ N/mm}^2}$	
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.0 \text{ N/mm}^2}$	
Secant modulus of elasticity of concrete	$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = \mathbf{32837 \text{ N/mm}^2}$	
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		$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = \mathbf{17.0 \text{ N/mm}^2}$
Maximum aggregate size	$h_{agg} = \mathbf{20 \text{ mm}}$	
Ultimate strain - Table 3.1	$\epsilon_{cu2} = \mathbf{0.0035}$	

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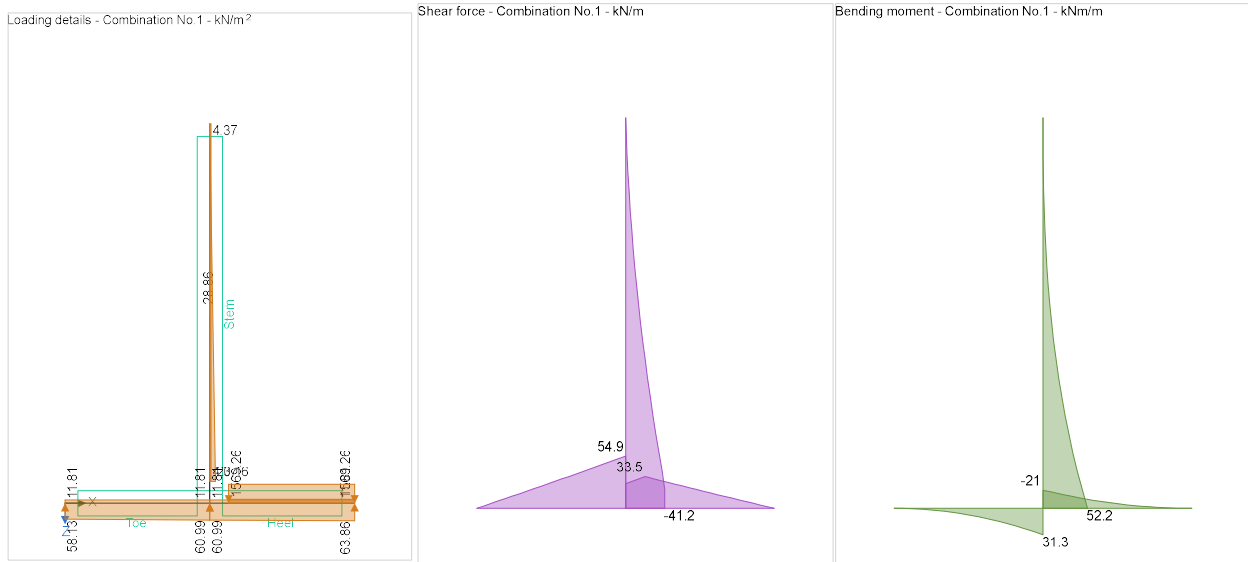
Shortening strain - Table 3.1	$\epsilon_{cu3} = 0.0035$
Effective compression zone height factor	$\lambda = 0.80$
Effective strength factor	$\eta = 1.00$
Bending coefficient k_1	$K_1 = 0.40$
Bending coefficient k_2	$K_2 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$
Bending coefficient k_3	$K_3 = 0.40$
Bending coefficient k_4	$K_4 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$

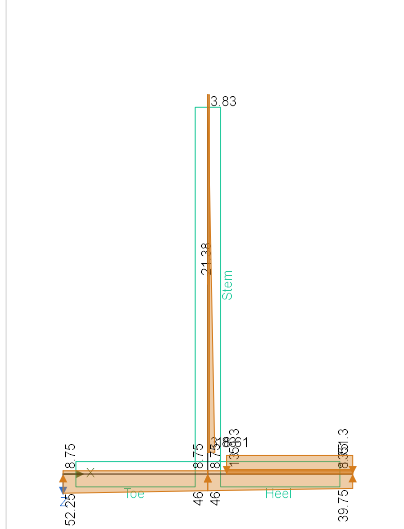
Reinforcement details

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	$f_{yd} = f_{yk} / \gamma_s = 435 \text{ N/mm}^2$

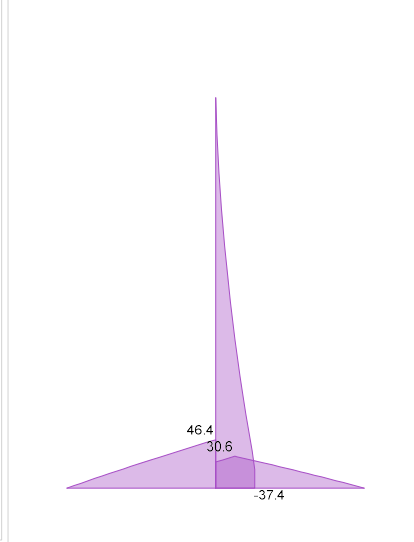
Cover to reinforcement

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	$C_{bb} = 75 \text{ mm}$

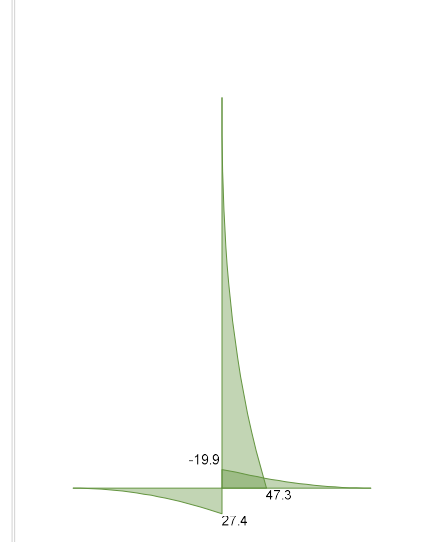


Loading details - Combination No 2 - kN/m²

Shear force - Combination No 2 - kN/m



Bending moment - Combination No 2 - kNm/m

**Check stem design at base of stem**

Depth of section

 $h = 300$ mm**Rectangular section in flexure - Section 6.1**

Design bending moment combination 1

 $M = 45$ kNm/m

Depth to tension reinforcement

 $d = h - c_{sr} - \phi_{sr} / 2 = 242$ mm $K = M / (d^2 \times f_{ck}) = 0.026$ $K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1)) / (2 \times K_2) \times (\lambda \times (\delta - K_1)) / (2 \times$ $K_2))$ $K' = 0.207$ **$K' > K$ - No compression reinforcement is required**

Lever arm

 $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}, 0.95) \times d = 230$

mm

Depth of neutral axis

 $x = 2.5 \times (d - z) = 30$ mm

Area of tension reinforcement required

 $A_{sr,req} = M / (f_{yd} \times z) = 451$ mm²/m

Tension reinforcement provided

16 dia.bars @ 200 c/c

Area of tension reinforcement provided

 $A_{sr,prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = 1005$ mm²/mMinimum area of reinforcement - exp.9.1N $A_{sr,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 364$ mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3)

 $A_{sr,max} = 0.04 \times h = 12000$ mm²/m $\max(A_{sr,req}, A_{sr,min}) / A_{sr,prov} = 0.448$ **PASS - Area of reinforcement provided is greater than area of reinforcement required**

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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	$\rho = A_{sr,req} / d = \mathbf{0.002}$
Required compression reinforcement ratio	$\rho' = A_{sr,2,req} / d_2 = \mathbf{0.000}$
Structural system factor - Table 7.4N	$K_b = \mathbf{0.4}$
Reinforcement factor - exp.7.17	$K_s = \min(500 \text{ N/mm}^2 / (f_{yk} \times A_{sr,req} / A_{sr,prov}), 1.5) = \mathbf{1.5}$
Limiting span to depth ratio - exp.7.16.a	$\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b) = \mathbf{16}$
Actual span to depth ratio	$h_{stem} / d = \mathbf{11.8}$

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

Crack control - Section 7.3

Limiting crack width	$w_{max} = \mathbf{0.3} \text{ mm}$
Variable load factor - EN1990 – Table A1.1	$\psi_2 = \mathbf{0.6}$
Serviceability bending moment	$M_{sls} = \mathbf{27.3} \text{ kNm/m}$
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{sr,prov} \times z) = \mathbf{118.2} \text{ N/mm}^2$
Load duration	Long term
Load duration factor	$k_1 = \mathbf{0.4}$
Effective area of concrete in tension	$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ $A_{c,eff} = \mathbf{89917} \text{ mm}^2/\text{m}$
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = \mathbf{2.9} \text{ N/mm}^2$
Reinforcement ratio	$\rho_{p,eff} = A_{sr,prov} / A_{c,eff} = \mathbf{0.011}$
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	$s_{r,max} = k_3 \times C_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p,eff} = \mathbf{413} \text{ mm}$
Maximum crack width - exp.7.8	$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$ $w_k = \mathbf{0.147} \text{ mm}$ $w_k / w_{max} = \mathbf{0.488}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	$V = \mathbf{41.2} \text{ kN/m}$ $C_{Rd,c} = 0.18 / \gamma_c = \mathbf{0.120}$ $k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.909}$
Longitudinal reinforcement ratio	$\rho_l = \min(A_{sr,prov} / d, 0.02) = \mathbf{0.004}$ $v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.506} \text{ N/mm}^2$

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Design shear resistance - exp.6.2a & 6.2b $V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
 $V_{Rd,c} = 128.5 \text{ kN/m}$
 $V / V_{Rd,c} = 0.320$

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)

$$A_{sx,req} = \max(0.25 \times A_{sr,prov},$$

$$0.001 \times t_{stem}) = 300 \text{ mm}^2/m$$

Maximum spacing of reinforcement - cl.9.6.3(2)

$$s_{sx,max} = 400 \text{ mm}$$

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

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

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

Check base design at toe

Depth of section

$$h = 350 \text{ mm}$$

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 $M = 23.6 \text{ kNm/m}$

Depth to tension reinforcement

$$d = h - c_{bb} - \phi_{bb} / 2 = 269 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.011$$

K_2)

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

$$K_2))$$

$$K' = 0.207$$

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

Lever arm

$$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}, 0.95) \times d = 256$$

mm

Depth of neutral axis

$$x = 2.5 \times (d - z) = 34 \text{ mm}$$

Area of tension reinforcement required

$$A_{bb,req} = M / (f_{yd} \times z) = 212 \text{ mm}^2/m$$

Tension reinforcement provided

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

Area of tension reinforcement provided

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

Minimum area of reinforcement - exp.9.1N $A_{bb,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 405 \text{ mm}^2/m$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{bb,max} = 0.04 \times h = 14000$$

mm²/m

$$\max(A_{bb,req}, A_{bb,min}) / A_{bb,prov} = 0.716$$

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

$$M_{sls} = 15 \text{ kNm/m}$$

Tensile stress in reinforcement

$$\sigma_s = M_{sls} / (A_{bb,prov} \times z) = 103.5 \text{ N/mm}^2$$

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Load duration	Long term
Load duration factor	$k_t = 0.4$
Effective area of concrete in tension	$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ $A_{c,eff} = 105458 \text{ mm}^2/\text{m}$
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = 2.9 \text{ N/mm}^2$
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	$s_{r,max} = k_3 \times C_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p,eff} = 635 \text{ mm}$
Maximum crack width - exp.7.8	$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$ $w_k = 0.197 \text{ mm}$ $w_k / w_{max} = 0.658$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	$V = 47.6 \text{ kN/m}$ $C_{Rd,c} = 0.18 / \gamma_c = 0.120$ $k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.862$
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb,prov} / d, 0.02) = 0.002$ $v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.487 \text{ N/mm}^2$
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$ $V_{Rd,c} = 131.1 \text{ kN/m}$ $V / V_{Rd,c} = 0.363$

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section	$h = 350 \text{ mm}$
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Rectangular section in flexure - Section 6.1

Design bending moment combination 1	$M = 16.5 \text{ kNm/m}$
Depth to tension reinforcement	$d = h - C_{bt} - \phi_{bt} / 2 = 294 \text{ mm}$ $K = M / (d^2 \times f_{ck}) = 0.006$ $K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$ $K' = 0.207$

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

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Lever arm mm	$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}, 0.95) \times d = \mathbf{279}$
Depth of neutral axis	$x = 2.5 \times (d - z) = \mathbf{37}$ mm
Area of tension reinforcement required	$A_{bt,req} = M / (f_{yd} \times z) = \mathbf{136}$ mm ² /m
Tension reinforcement provided	12 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{bt,prov} = \pi \times \phi_{bt}^2 / (4 \times S_{bt}) = \mathbf{565}$ mm ² /m
Minimum area of reinforcement - exp.9.1N	$A_{bt,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{443}$ mm ² /m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bt,max} = 0.04 \times h = \mathbf{14000}$ mm ² /m
	$\max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = \mathbf{0.783}$

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	$\psi_2 = \mathbf{0.6}$
Serviceability bending moment	$M_{sls} = \mathbf{9.4}$ kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bt,prov} \times z) = \mathbf{59.5}$ N/mm ²
Load duration	Long term
Load duration factor	$k_t = \mathbf{0.4}$
Effective area of concrete in tension	$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ $A_{c,eff} = \mathbf{104417}$ mm ² /m
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = \mathbf{2.9}$ N/mm ²
Reinforcement ratio	$\rho_{p,eff} = A_{bt,prov} / A_{c,eff} = \mathbf{0.005}$
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	$s_{r,max} = k_3 \times C_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = \mathbf{547}$ mm
Maximum crack width - exp.7.8	$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$ $w_k = \mathbf{0.098}$ mm $w_k / w_{max} = \mathbf{0.325}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	$V = \mathbf{33.5}$ kN/m
	$C_{Rd,c} = 0.18 / \gamma_c = \mathbf{0.120}$
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.825}$

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Longitudinal reinforcement ratio

$$\rho_l = \min(A_{bt,prov} / d, 0.02) = \mathbf{0.002}$$

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

Design shear resistance - exp.6.2a & 6.2b

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

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

$$V / V_{Rd,c} = \mathbf{0.241}$$

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)

$$A_{bx,req} = 0.2 \times A_{bb,prov} = \mathbf{113}$$

mm²/m

Maximum spacing of reinforcement – cl.9.3.1.1(3)

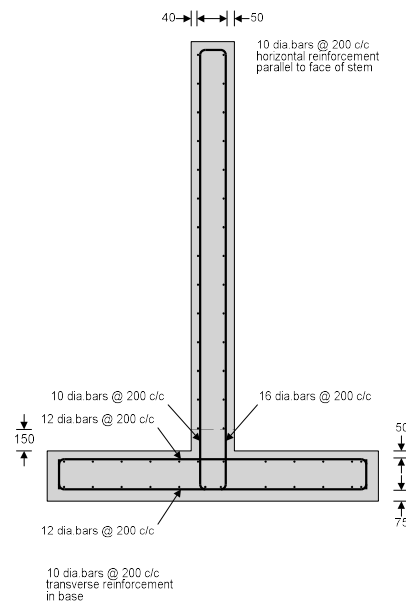
$$S_{bx,max} = \mathbf{450 \text{ mm}}$$

Transverse reinforcement provided

10 dia.bars @ 200 c/c

Area of transverse reinforcement provided

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

PASS - Area of reinforcement provided is greater than area of reinforcement required**Reinforcement details**