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 2.9.04

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **5100** mm
Stem thickness	t_{stem} = **300** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **950** mm
Heel length	l_{heel} = **1750** mm
Base thickness	t_{base} = **400** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **5100** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm

Retained soil properties

Soil type	Medium dense gravel
Moist density	γ_{mr} = **17** kN/m^3
Saturated density	γ_{sr} = **20.5** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **36** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **18** deg

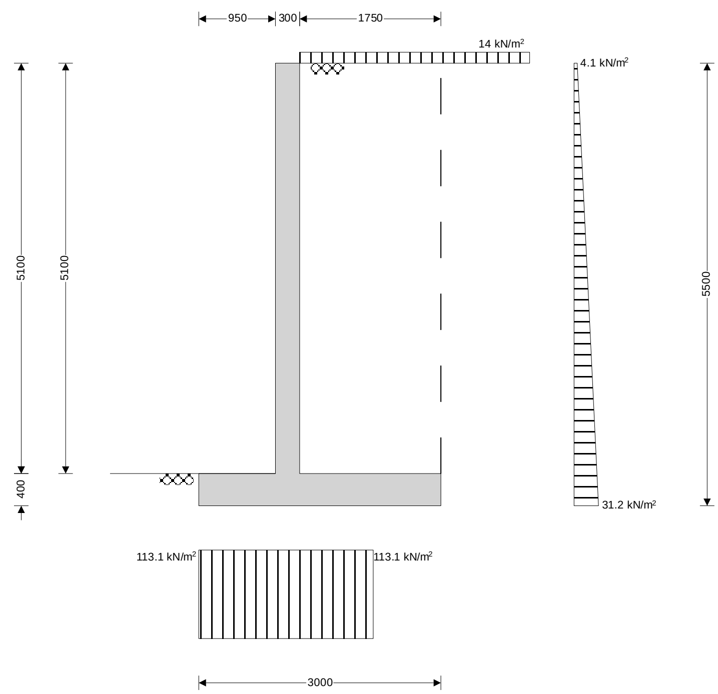
Base soil properties

Soil type	Medium dense well graded sand
Soil density	γ_b = **20** kN/m^3
Characteristic cohesion	$c'_{b.k}$ = **0** kN/m^2
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **36** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **18** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **27** deg

Loading details

Permanent surcharge load	$Surcharge_G$ = **1** kN/m^2
Variable surcharge load	$Surcharge_Q$ = **10** kN/m^2

LEMARG ENGINEERING	Project				Job Ref.	
	Section				Sheet no./rev. 2	
	Calc. by U	Date 10/17/2022	Chk'd by	Date	App'd by	Date



General arrangement

Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} + l_{heel} =$ **3000** mm
Moist soil height	$h_{moist} = h_{soil} =$ **5100** mm
Length of surcharge load	$l_{sur} = l_{heel} =$ **1750** mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2 =$ **2125** mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} =$ **5500** mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 =$ **2750** mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} =$ **1.53** m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 =$ **1100** mm
Area of wall base	$A_{base} = l_{base} \times t_{base} =$ **1.2** m^2
- Distance to vertical component	$x_{base} = l_{base} / 2 =$ **1500** mm
Area of moist soil	$A_{moist} = h_{moist} \times l_{heel} =$ **8.925** m^2
- Distance to vertical component	$x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist} =$ **2125** mm
- Distance to horizontal component	$x_{moist\_h} = h_{eff} / 3 =$ **1833** mm

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**

Variable favourable action γ_{Qf} = **0.00**

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 γ_{γ} = **1.00**

Library item Partial factors output

Retained soil properties

Design moist density $\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma}$ = **17** kN/m^3

Design saturated density $\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma}$ = **20.5** kN/m^3

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

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

Base soil properties

Design soil density $\gamma_b' = \gamma_b / \gamma_{\gamma}$ = **20** kN/m^3

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

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

Design base friction angle $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **27** deg

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

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[}\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2)$ = **0.236**

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

Sliding check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **38.3** kN/m

Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **30** kN/m

Moist retained soil $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}'$ = **151.7** kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **220** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **20.2** kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2$ = **78** kN/m

Total $F_{total\_h} = F_{moist\_h} + F_{sur\_h}$ = **98.2** kN/m

Check stability against sliding

Base soil resistance $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2$ = **12.2** kN/m

Base friction $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d})$ = **112.1** kN/m

Resistance to sliding $F_{rest} = F_{exc\_h} + F_{friction}$ = **124.3** kN/m

Factor of safety $FoS_{sl} = F_{rest} / F_{total\_h}$ = **1.266**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem — $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **38.3** kN/m

Wall base — $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **30** kN/m

Moist retained soil — $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}'$ = **151.7** kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **220** kN/m

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **20.2** kN/m

Moist retained soil — $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2$ = **78** kN/m

Base soil — $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2$ = **-12.2** kN/m

Total — $F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h}$ = **85.9** kN/m

Overturning moments on wall

Surcharge load — $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h}$ = **55.5** kNm/m

Moist retained soil — $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h}$ = **142.9** kNm/m

Total — $M_{total\_OT} = M_{moist\_OT} + M_{sur\_OT}$ = **198.5** kNm/m

Restoring moments on wall

Wall stem — $M_{stem\_R} = F_{stem} \times x_{stem}$ = **42.1** kNm/m

Wall base — $M_{base\_R} = F_{base} \times x_{base}$ = **45** kNm/m

Moist retained soil — $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **322.4** kNm/m

Base soil — $M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h}$ = **1.6** kNm/m

Total — $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R}$ = **411.1** kNm/m

Check stability against overturning

Factor of safety — $FoS_{ot} = M_{total\_R} / M_{total\_OT}$ = **2.071**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem — $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem}$ = **51.6** kN/m

Wall base — $F_{base} = \gamma_G \times A_{base} \times \gamma_{base}$ = **40.5** kN/m

Surcharge load — $F_{sur\_v} = (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times l_{heel}$ = **28.6** kN/m

Moist retained soil — $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr}'$ = **204.8** kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v}$ = **325.6** kN/m

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **20.2** kN/m

Moist retained soil — $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2$ = **78** kN/m

Base soil — $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2$ = **-12.2** kN/m

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

Moments on wall

Wall stem — $M_{stem} = F_{stem} \times x_{stem}$ = **56.8** kNm/m

Wall base — $M_{base} = F_{base} \times x_{base}$ = **60.8** kNm/m

Surcharge load $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} = \mathbf{5.3}$ kNm/m

Moist retained soil $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} = \mathbf{292.3}$ kNm/m

Base soil $M_{pass} = -F_{pass\_h} \times x_{pass\_h} = \mathbf{1.6}$ kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{pass} + M_{sur} = \mathbf{416.8}$ kNm/m

Check bearing pressure

Distance to reaction $\bar{x} = M_{total} / F_{total\_v} = \mathbf{1280}$ mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{-220}$ mm

Loaded length of base $l_{load} = 2 \times \bar{x} = \mathbf{2560}$ mm

Bearing pressure at toe $q_{toe} = F_{total\_v} / l_{load} = \mathbf{127.2}$ kN/m^2

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

Effective overburden pressure $q = (t_{base} + d_{cover}) \times \gamma_b' = \mathbf{8}$ kN/m^2

Design effective overburden pressure $q' = q / \gamma_\gamma = \mathbf{8}$ kN/m^2

Bearing resistance factors $N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 = \mathbf{37.752}$

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{50.585}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) = \mathbf{53.405}$

Foundation shape factors $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

Load inclination factors $H = F_{sur\_h} + F_{moist\_h} + F_{pass\_h} = \mathbf{85.9}$ kN/m

$V = F_{total\_v} = \mathbf{325.6}$ kN/m

$m = 2$

$i_q = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^m = \mathbf{0.542}$

$i_\gamma = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^{(m + 1)} = \mathbf{0.399}$

$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b.d})) = \mathbf{0.529}$

Net ultimate bearing capacity

$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_b' \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{708.7}$ kN/m^2

Factor of safety $FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{5.573}$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Design approach 1

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

Partial factor set A2

Permanent unfavourable action $\gamma_G = \mathbf{1.00}$

Permanent favourable action $\gamma_{Gf} = \mathbf{1.00}$

Variable unfavourable action $\gamma_Q = \mathbf{1.30}$

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

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

Soil parameter set M2

Angle of shearing resistance $\gamma_{\phi'} = \mathbf{1.25}$

Effective cohesion $\gamma_{c'} = \mathbf{1.25}$

Weight density $\gamma_\gamma = \mathbf{1.00}$

Library item Partial factors output

Retained soil properties

Design moist density — $\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = \mathbf{17}$ kN/m^3

Design saturated density — $\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = \mathbf{20.5}$ kN/m^3

Design effective shear resistance angle — $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{30.2}$ deg

Design wall friction angle — $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{14.6}$ deg

Base soil properties

Design soil density — $\gamma_b' = \gamma_b / \gamma_{\gamma} = \mathbf{20}$ kN/m^3

Design effective shear resistance angle — $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{30.2}$ deg

Design wall friction angle — $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{14.6}$ deg

Design base friction angle — $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{22.2}$ deg

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

Using Coulomb theory

Active pressure coefficient — $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.300}$

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

Sliding check

Vertical forces on wall

Wall stem — $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{38.3}$ kN/m

Wall base — $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{30}$ kN/m

Moist retained soil — $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{151.7}$ kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} = \mathbf{220}$ kN/m

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff} = \mathbf{22.4}$ kN/m

Moist retained soil — $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{74.7}$ kN/m

Total — $F_{total\_h} = F_{moist\_h} + F_{sur\_h} = \mathbf{97}$ kN/m

Check stability against sliding

Base soil resistance — $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{7.6}$ kN/m

Base friction — $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d}) = \mathbf{89.7}$ kN/m

Resistance to sliding — $F_{rest} = F_{exc\_h} + F_{friction} = \mathbf{97.3}$ kN/m

Factor of safety — $FoS_{sl} = F_{rest} / F_{total\_h} = \mathbf{1.003}$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem — $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{38.3}$ kN/m

Wall base — $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{30}$ kN/m

Moist retained soil — $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{151.7}$ kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} = \mathbf{220}$ kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **22.4** kN/m
Moist retained soil	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2$ = **74.7** kN/m
Base soil	$F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2$ = **-7.6** kN/m
Total	$F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h}$ = **89.4** kN/m

Overturning moments on wall

Surcharge load	$M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h}$ = **61.5** kNm/m
Moist retained soil	$M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h}$ = **136.9** kNm/m
Total	$M_{total\_OT} = M_{moist\_OT} + M_{sur\_OT}$ = **198.3** kNm/m

Restoring moments on wall

Wall stem	$M_{stem\_R} = F_{stem} \times x_{stem}$ = **42.1** kNm/m
Wall base	$M_{base\_R} = F_{base} \times x_{base}$ = **45** kNm/m
Moist retained soil	$M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **322.4** kNm/m
Base soil	$M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h}$ = **1** kNm/m
Total	$M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R}$ = **410.5** kNm/m

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{total\_R} / M_{total\_OT}$ = **2.07**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem}$ = **38.3** kN/m
Wall base	$F_{base} = \gamma_G \times A_{base} \times \gamma_{base}$ = **30** kN/m
Surcharge load	$F_{sur\_v} = (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times l_{heel}$ = **24.5** kN/m
Moist retained soil	$F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr}'$ = **151.7** kN/m
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v}$ = **244.5** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_G \times Surcharge_G + \gamma_Q \times Surcharge_Q) \times h_{eff}$ = **22.4** kN/m
Moist retained soil	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2$ = **74.7** kN/m
Base soil	$F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2$ = **-7.6** kN/m
Total	$F_{total\_h} = \max(F_{moist\_h} + F_{pass\_h} + F_{sur\_h} - F_{total\_v} \times \tan(\delta_{bb.d}), 0\ kN/m)$ = **0** kN/m

Moments on wall

Wall stem	$M_{stem} = F_{stem} \times x_{stem}$ = **42.1** kNm/m
Wall base	$M_{base} = F_{base} \times x_{base}$ = **45** kNm/m
Surcharge load	$M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h}$ = **-9.4** kNm/m
Moist retained soil	$M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h}$ = **185.6** kNm/m
Base soil	$M_{pass} = -F_{pass\_h} \times x_{pass\_h}$ = **1** kNm/m
Total	$M_{total} = M_{stem} + M_{base} + M_{moist} + M_{pass} + M_{sur}$ = **264.2** kNm/m

Check bearing pressure

Distance to reaction	$\bar{x} = M_{total} / F_{total\_v}$ = **1081** mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{-419}$ mm

Loaded length of base $l_{load} = 2 \times \bar{x} = \mathbf{2162}$ mm

Bearing pressure at toe $q_{toe} = F_{total\_v} / l_{load} = \mathbf{113.1}$ kN/m^2

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

Effective overburden pressure $q = (t_{base} + d_{cover}) \times \gamma_b' = \mathbf{8}$ kN/m^2

Design effective overburden pressure $q' = q / \gamma_\gamma = \mathbf{8}$ kN/m^2

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

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

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

Foundation shape factors $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

Load inclination factors $H = F_{sur\_h} + F_{moist\_h} + F_{pass\_h} = \mathbf{89.4}$ kN/m

$V = F_{total\_v} = \mathbf{244.5}$ kN/m

$m = 2$

$i_q = [1 - H / (V + l_{load} \times c'_{b.d} \times cot(\phi'_{b.d}))]^m = \mathbf{0.403}$

$i_\gamma = [1 - H / (V + l_{load} \times c'_{b.d} \times cot(\phi'_{b.d}))]^{(m + 1)} = \mathbf{0.255}$

$i_c = i_q - (1 - i_q) / (N_c \times tan(\phi'_{b.d})) = \mathbf{0.369}$

Net ultimate bearing capacity

$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_b' \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{174.3}$ kN/m^2

Factor of safety $FoS_{bp} = n_f / max(q_{toe}, q_{heel}) = \mathbf{1.541}$

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 2.9.04

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

Concrete strength class C30/37

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

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

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

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

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

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

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

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

Design compressive concrete strength - exp.3.15 $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = \mathbf{17.0}$ N/mm^2

Maximum aggregate size $h_{agg} = \mathbf{20}$ mm

Ultimate strain - Table 3.1 $\varepsilon_{cu2} = \mathbf{0.0035}$

Shortening strain - Table 3.1 $\varepsilon_{cu3} = \mathbf{0.0035}$

Effective compression zone height factor $\lambda = \mathbf{0.80}$

Effective strength factor $\eta = \mathbf{1.00}$

Bending coefficient k_1 $K_1 = \mathbf{0.40}$

Bending coefficient k_2 — $K_2 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2}) = \mathbf{1.00}$

Bending coefficient k_3 — $K_3 = \mathbf{0.40}$

Bending coefficient k_4 — $K_4 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2}) = \mathbf{1.00}$

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

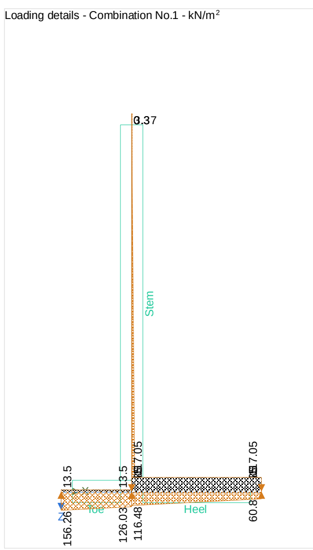
Cover to reinforcement

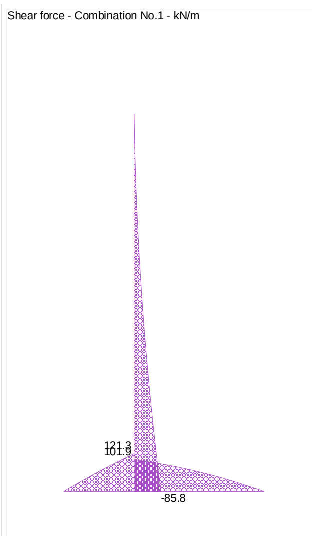
Front face of stem — c_{sf} = **40** mm

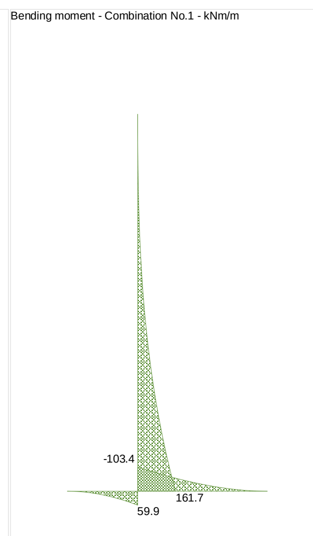
Rear face of stem — c_{sr} = **50** mm

Top face of base — c_{bt} = **50** mm

Bottom face of base — c_{bb} = **75** mm







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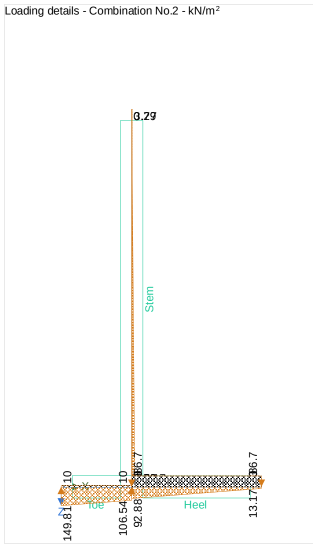
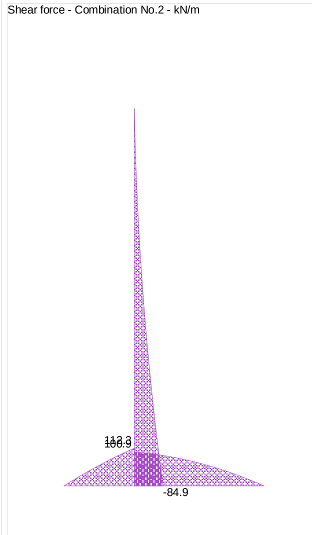
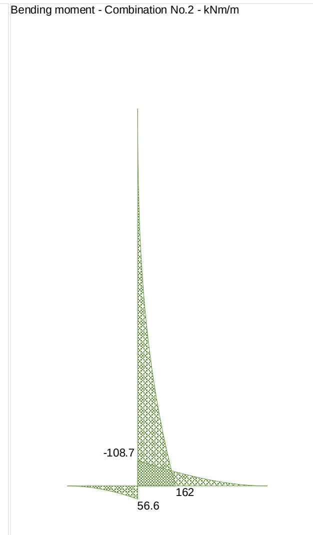






Check stem design at base of stem

Depth of section h = **300** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 2 M = **162** kNm/m

Depth to tension reinforcement $d = h - c_{sr} - \phi_{sr} / 2$ = **242** mm

$K = M / (d^2 \times f_{ck})$ = **0.092**

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

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **220** mm

Depth of neutral axis $x = 2.5 \times (d – z)$ = **54** mm

Area of tension reinforcement required $A_{sr.req} = M / (f_{yd} \times z)$ = **1691** mm²/m

Tension reinforcement provided 16 dia.bars @ 100 c/c

Area of tension reinforcement provided $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **2011** mm²/m

Minimum 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

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.841**

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

Required tension reinforcement ratio $\rho = A_{sr.req} / d$ = **0.007**

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 $K_s = \min(500 \text{ N/mm}^2 / (f_{yk} \times A_{sr.req} / A_{sr.prov}), 1.5)$ = **1.189**

Limiting span to depth ratio - exp.7.16.b $\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{}(f_{ck} / 1 \text{ N/mm}^2) \times \rho_0 / (\rho - \rho') + \sqrt{}(f_{ck} / 1 \text{ N/mm}^2) \times \sqrt{}(\rho' / \rho_0) / 12], 40 \times K_b)$ = **8.3**

Actual span to depth ratio h_{stem} / d = **21.1**

FAIL - Span to depth ratio exceeds 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} = **104.9** kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **236.6** N/mm^2

Load duration — Long term

Load duration factor — k_t = **0.4**

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

$A_{c.eff}$ = **81985** mm^2/m

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

Reinforcement ratio — $\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.025**

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

Bond property coefficient — k_1 = **0.8**

Strain distribution coefficient — k_2 = **0.5**

k_3 = **3.4**

k_4 = **0.425**

Maximum crack spacing - exp.7.11 — $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **281** 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 = **0.256** mm

w_k / w_{max} = **0.854**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — V = **85.8** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.909**

Longitudinal reinforcement ratio — $\rho_l = \min(A_{sr.prov} / d, 0.02)$ = **0.008**

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.506** N/mm^2

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

$V_{Rd.c}$ = **161.9** kN/m

$V / V_{Rd.c}$ = **0.530**

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) — $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem})$ = **503** mm^2/m

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

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

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

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

Check base design at toe

Depth of section — h = **400** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **59.9** kNm/m

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

	$K = M / (d^2 \times f_{ck}) = \mathbf{0.020}$
	$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C) \times (1 - \lambda \times (\delta - K_1)/(2 \times K_2)) \times (\lambda \times (\delta - K_1)/(2 \times K_2))$
	$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d = \mathbf{301}$ mm
Depth of neutral axis	$x = 2.5 \times (d - z) = \mathbf{40}$ mm
Area of tension reinforcement required	$A_{bb.req} = M / (f_{yd} \times z) = \mathbf{457}$ mm^2/m
Tension reinforcement provided	16 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = \mathbf{1005}$ mm^2/m
Minimum area of reinforcement - exp.9.1N	$A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{477}$ mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bb.max} = 0.04 \times h = \mathbf{16000}$ mm^2/m
	$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} = \mathbf{0.475}$

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	$M_{sls} = \mathbf{43.3}$ kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bb.prov} \times z) = \mathbf{143.2}$ N/mm^2
Load duration	Long term
Load duration factor	$k_t = \mathbf{0.4}$
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$
	$A_{c.eff} = \mathbf{120125}$ mm^2/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm} = \mathbf{2.9}$ N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff} = \mathbf{0.008}$
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	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} = \mathbf{580}$ mm
Maximum crack width - exp.7.8	$w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	$w_k = \mathbf{0.249}$ mm
	$w_k / w_{max} = \mathbf{0.83}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	$V = \mathbf{121.3}$ kN/m
	$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.794}$
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb.prov} / d, 0.02) = \mathbf{0.003}$
	$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.461}$ N/mm^2
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c} = \mathbf{146.1}$ kN/m
	$V / V_{Rd.c} = \mathbf{0.830}$

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section — h = **400** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 2 — M = **108.7** kNm/m

Depth to tension reinforcement — $d = h - c_{bt} - \phi_{bt} / 2$ = **342** mm

$K = M / (d^2 \times f_{ck})$ = **0.031**

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

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **325** mm

Depth of neutral axis — $x = 2.5 \times (d – z)$ = **43** mm

Area of tension reinforcement required — $A_{bt.req} = M / (f_{yd} \times z)$ = **769** mm²/m

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

Area of tension reinforcement provided — $A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt})$ = **1340** mm²/m

Minimum area of reinforcement - exp.9.1N — $A_{bt.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **515** mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{bt.max} = 0.04 \times h$ = **16000** mm²/m

$\max(A_{bt.req}, A_{bt.min}) / A_{bt.prov}$ = **0.574**

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} = **67.9** kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{bt.prov} \times z)$ = **155.9** N/mm²

Load duration — Long term

Load duration factor — k_t = **0.4**

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

$A_{c.eff}$ = **119083** mm²/m

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

Reinforcement ratio — $\rho_{p.eff} = A_{bt.prov} / A_{c.eff}$ = **0.011**

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 — $s_{r.max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p.eff}$ = **412** 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 = **0.193** mm

w_k / w_{max} = **0.642**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — V = **101.9** kN/m

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

$k = \min(1 + \sqrt{(200\ mm / d)}, 2) = \mathbf{1.765}$

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

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.449}\ N/mm^2$

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

$V_{Rd.c} = \mathbf{164.7}\ kN/m$

$V / V_{Rd.c} = \mathbf{0.619}$

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

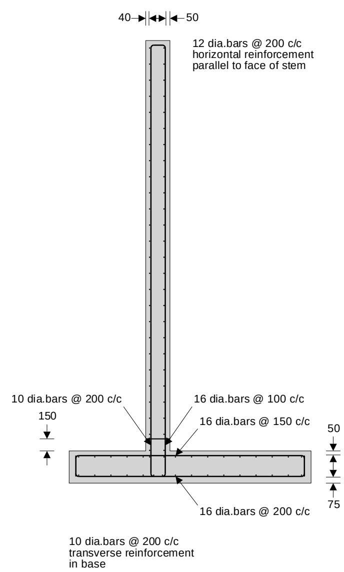
Minimum area of reinforcement – cl.9.3.1.1(2) — $A_{bx.req} = 0.2 \times A_{bt.prov} = \mathbf{268}\ mm^2/m$

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

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

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

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



Reinforcement details