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Structural Engineering Design Package

Project
598 Bradford Road
WF17 8LP

Client
Anderson Reinforcement Services Ltd

Job No
AND/001

Date
24.05.2023

Author
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Revision	Description	Date	Author
A	First Issue	24.05.2023	JA

Company number: 13823527

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«Project»	Anderson Reinforcement Services Ltd	AND/001	24.05.2023	JA

Client Brief and Scope of Works

We have been instructed to prepare structural calculations for a reinforced concrete retaining wall along with drawing of a typical section through that wall.

We have visited the site on 12th May and viewed there to be good natural ground at the formation level and we have adopted a conservative safe bearing capacity of 150kN/m². The client had already purchased reinforcing bars in the form of A393 mesh and H12 straights. Our brief was to propose a solution using this reinforcement – refer to the attached calculations.

These calculations should be submitted to the appointed Building Control Company for Building Regulation approval prior to the commencement of work on site.

Where relevant, for items of work listed above, a design philosophy specifying design parameters and assumptions is included at the start of the calculations.

Technical References

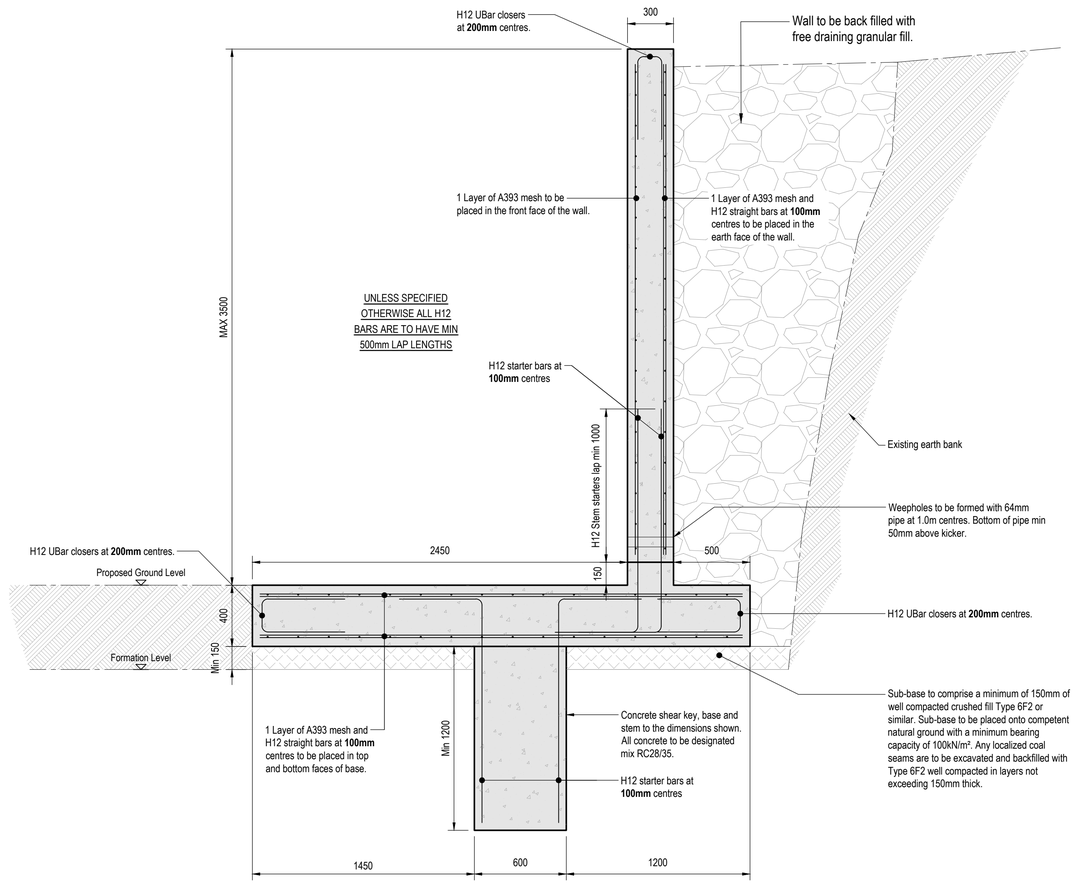
1. BS EN 1990: General Actions
2. BS EN 1991: Actions on Structures
3. BS EN 1992: Concrete
4. BS EN 1993: Steelwork
5. BS EN 1995: Timber
6. BS EN 1996: Masonry
7. BS EN 1997: Geotechnics

Temporary Works

Temporary works design, installation and construction sequence are the sole responsibility of the contractor.

Construction, Design and Management Regulations (CDM) 2015

Under CDM 2015 designers are duty bound to provide adequate information about any significant risks associated with the design project.
The structural concept and form of construction of the proposed works are conventional and as such the designs are deemed to have reduced foreseeable risk to an acceptable level. The level of risk is normal for this type of project and would be obvious to a competent contractor.



TYPICAL SECTION THROUGH RETAINING WALL

SCALE 1:20

NOTES

1. All concrete to be designated mix RC28/35 to BS8500:2002.
2. All mesh to be grade B500A, B or C to BS 4483:2005.
3. All reinforcement bars to be B500A, B or C to BS4449:2005.
4. The sub-base should be cast upon competent natural ground, with an allowable bearing pressure of at least 100kN/m².
5. Provide 50mm cover to all reinforcement bars and mesh.
6. Unless specified otherwise all H12 bars are to have 500mm lap lengths.

NOTES

REV	DESCRIPTION	SIG	CHK	DATE
A	First Issue			

598 BRADFORD ROAD

ANDERSON REINFORCEMENT SERVICES

RETAINING WALL DETAIL

PROJECT NO.	SCALE AT A1	DRAWING STATUS	
AND_001	AS SHOWN	CONSTRUCTION	
DRAWN	DATE	DRAWING NUMBER	REV
JA	16/05/2023	AS/AND/001/001	A

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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 2.9.17

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **3500** 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} = **2450** mm
Heel length	l_{heel} = **500** mm
Base thickness	t_{base} = **400** mm
Key position	p_{key} = **1450** mm
Key depth	d_{key} = **1300** mm
Key thickness	t_{key} = **600** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **3500** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm
Height of water	h_{water} = **0** mm
Water density	γ_w = **9.8** kN/m^3

Retained soil properties

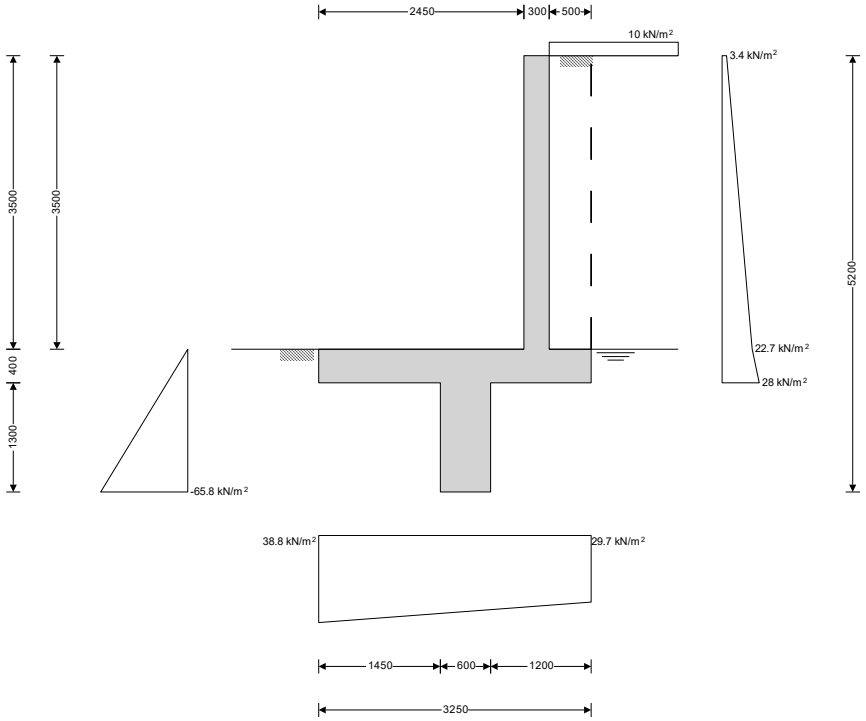
Soil type	Very loose gravel
Moist density	γ_{mr} = **16** kN/m^3
Saturated density	γ_{sr} = **20** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **26** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **13** deg

Base soil properties

Soil type	Very dense rock fill
Soil density	γ_b = **17.5** 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	$\delta_{bb.k}$ = **28** deg
Presumed bearing capacity	$P_{bearing}$ = **150** kN/m^2

Loading details

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



General arrangement - sketch pressures relate to bearing check

Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} + l_{heel} =$ **3250** mm
Base height	$h_{base} = t_{base} + d_{key} =$ **1700** mm
Saturated soil height	$h_{sat} = h_{water} + d_{cover} =$ **0** mm
Moist soil height	$h_{moist} = h_{ret} - h_{water} =$ **3500** mm
Length of surcharge load	$l_{sur} = l_{heel} =$ **500** mm
- Distance to vertical component	$x_{sur_v} = l_{base} - l_{heel} / 2 =$ **3000** mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} =$ **5200** mm
- Distance to horizontal component	$x_{sur_h} = h_{eff} / 2 - d_{key} =$ **1300** mm
- Distance to horizontal component above key	$x_{sur_h_a} = (h_{eff} - d_{key}) / 2 =$ **1950** mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} =$ **1.05** m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 =$ **2600** mm
Area of wall base	$A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key} =$ **2.08** m^2
- Distance to vertical component	$x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base} =$ **1672** mm
Area of moist soil	$A_{moist} = h_{moist} \times l_{heel} =$ **1.75** m^2
- Distance to vertical component	$x_{moist_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist} =$ **3000** mm
- Distance to horizontal component	$x_{moist_h} = (h_{moist} \times (t_{base} + h_{sat} + h_{moist} / 3) / 2 + (h_{sat} + h_{base}) \times ((h_{sat} + h_{base})/2 - d_{key})) / (h_{sat} + h_{base} + h_{moist} / 2) =$ **573** mm
- Distance to horizontal component above key	$x_{moist_h_a} = (h_{moist} \times (t_{base} + h_{sat} + h_{moist} / 3) / 2 + (h_{sat} + t_{base})^2/2) / (h_{sat} + t_{base} + h_{moist} / 2) =$ **1312** mm

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.k}) \times [1 + \sqrt{[\sin(\phi'_{r.k} + \delta_{r.k}) \times \sin(\phi'_{r.k} - \beta) / (\sin(\alpha - \delta_{r.k}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.353}$

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 $F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{26.3}$ kN/m

Wall base $F_{base} = A_{base} \times \gamma_{base} = \mathbf{52}$ kN/m

Surcharge load $F_{sur_v} = Surcharge_Q \times l_{heel} = \mathbf{5}$ kN/m

Moist retained soil $F_{moist_v} = A_{moist} \times \gamma_{mr} = \mathbf{28}$ kN/m

Total $F_{total_v} = F_{stem} + F_{base} + F_{sur_v} + F_{water_v} + F_{moist_v} = \mathbf{111.3}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur_h} = K_A \times \cos(\delta_{r.k}) \times Surcharge_Q \times (h_{eff} - d_{key}) = \mathbf{13.4}$ kN/m

Saturated retained soil $F_{sat_h} = K_A \times \cos(\delta_{r.k}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + t_{base})^2 / 2 = \mathbf{0.3}$ kN/m

Water $F_{water_h} = \gamma_w \times (h_{water} + d_{cover} + t_{base})^2 / 2 = \mathbf{0.8}$ kN/m

Moist retained soil $F_{moist_h} = K_A \times \cos(\delta_{r.k}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) = \mathbf{41.4}$ kN/m

Base soil $F_{pass_h} = \max(-K_P \times \cos(\delta_{b.k}) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2, -(F_{sat_h} + F_{moist_h} + F_{water_h} + F_{sur_h})) = \mathbf{-55.9}$ kN/m

Total $F_{total_h} = \max(F_{sur_h} + F_{sat_h} + F_{water_h} + F_{moist_h} + F_{pass_h} - F_{total_v} \times \tan(\delta_{bb.k}), 0\ kN/m) = \mathbf{0}$ kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem} = \mathbf{68.3}$ kNm/m

Wall base $M_{base} = F_{base} \times x_{base} = \mathbf{86.9}$ kNm/m

Surcharge load $M_{sur} = F_{sur_v} \times x_{sur_v} - F_{sur_h} \times x_{sur_h} = \mathbf{-2.4}$ kNm/m

Saturated retained soil $M_{sat} = -F_{sat_h} \times x_{sat_h} = \mathbf{0.2}$ kNm/m

Water $M_{water} = -F_{water_h} \times x_{water_h} = \mathbf{0.6}$ kNm/m

Moist retained soil $M_{moist} = F_{moist_v} \times x_{moist_v} - F_{moist_h} \times x_{moist_h} = \mathbf{60.3}$ kNm/m

Base soil $M_{pass} = -F_{pass_h} \times x_{pass_h} = \mathbf{-41}$ kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_{sur} + M_{sat} + M_{water} + M_{moist} + M_{pass} = \mathbf{172.8}$ kNm/m

Check bearing pressure

Distance to reaction $\bar{x} = M_{total} / F_{total_v} = \mathbf{1553}$ mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{-72}$ mm

Loaded length of base $l_{load} = l_{base} = \mathbf{3250}$ mm

Bearing pressure at toe $q_{toe} = F_{total_v} / l_{base} \times (1 - 6 \times e / l_{base}) = \mathbf{38.8}$ kN/m²

Bearing pressure at heel $q_{heel} = F_{total_v} / l_{base} \times (1 + 6 \times e / l_{base}) = \mathbf{29.7}$ kN/m²

Factor of safety $FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) = \mathbf{3.868}$

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	γ_G = **1.350**
Permanent favourable action	γ_{Gf} = **1.000**
Variable unfavourable action	γ_Q = **1.500**
Variable favourable action	γ_{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	γ_γ = **1.00**

Water properties

Design water density	$\gamma_w' = \gamma_w / \gamma_\gamma$ = **9.8** kN/m^3

Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma$ = **16** kN/m^3
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma$ = **20** kN/m^3
Design effective shear resistance angle	$\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **26** deg
Design wall friction angle	$\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **13** deg

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_\gamma$ = **17.5** kN/m^3
Design effective shear resistance angle	$\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **42** deg
Design wall friction angle	$\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **21** deg
Design base friction angle	$\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **28** deg
Design effective cohesion	$c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **0** kN/m^2

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2)$ = **0.353**
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	$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **26.3** kN/m
Wall base	$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **52** kN/m
Moist retained soil	$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}'$ = **28** kN/m
Total	$F_{total_v} = F_{stem} + F_{base} + F_{water_v} - F_{water_u} + F_{moist_v}$ = **106.3** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff}$ = **26.8** kN/m
Saturated retained soil	$F_{sat_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2$ = **6.8** kN/m
Water	$F_{water_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **19.1** kN/m

Moist retained soil	$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **89.8** kN/m
Total	$F_{total_h} = F_{sur_h} + F_{sat_h} + F_{water_h} + F_{moist_h} =$ **142.6** kN/m

Check stability against sliding

Base soil resistance	$F_{exc_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 =$ **346.1** kN/m
Base friction	$F_{friction} = F_{total_v} \times \tan(\delta_{bb.d}) =$ **56.5** kN/m
Resistance to sliding	$F_{rest} = F_{exc_h} + F_{friction} =$ **402.6** kN/m
Factor of safety	$FoS_{sl} = F_{rest} / F_{total_h} =$ **2.824**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **26.3** kN/m
Wall base	$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **52** kN/m
Moist retained soil	$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' =$ **28** kN/m
Total	$F_{total_v} = F_{stem} + F_{base} + F_{water_v} - F_{water_u} + F_{moist_v} =$ **106.3** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times (h_{eff} - d_{key}) =$ **20.1** kN/m
Saturated retained soil	$F_{sat_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + t_{base})^2 / 2 =$ **0.4** kN/m
Water	$F_{water_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + t_{base})^2 / 2 =$ **1.1** kN/m
Moist retained soil	$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) =$ **55.9** kN/m
Base soil	$F_{exc_h} = \max(-\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2, -(F_{sat_h} + F_{moist_h} + F_{water_h} + F_{sur_h})) =$ **-77.5** kN/m
Total	$F_{total_h} = F_{sur_h} + F_{sat_h} + F_{water_h} + F_{moist_h} + F_{exc_h} =$ **0** kN/m

Overturning moments on wall

Surcharge load	$M_{sur_OT} = F_{sur_h} \times x_{sur_h_a} =$ **39.3** kNm/m
Saturated retained soil	$M_{sat_OT} = F_{sat_h} \times x_{sat_h_a} =$ **0.1** kNm/m
Water	$M_{water_OT} = F_{water_h} \times x_{water_h_a} + 0$ kNm/m = **0.1** kNm/m
Moist retained soil	$M_{moist_OT} = F_{moist_h} \times x_{moist_h_a} =$ **73.4** kNm/m
Base soil	$M_{exc_OT} = F_{exc_h} \times x_{exc_h} =$ **56.8** kNm/m
Total	$M_{total_OT} = M_{sur_OT} + M_{sat_OT} + M_{water_OT} + M_{moist_OT} + M_{exc_OT} =$ **169.7** kNm/m

Restoring moments on wall

Wall stem	$M_{stem_R} = F_{stem} \times x_{stem} =$ **68.3** kNm/m
Wall base	$M_{base_R} = F_{base} \times x_{base} =$ **86.9** kNm/m
Moist retained soil	$M_{moist_R} = F_{moist_v} \times x_{moist_v} =$ **84** kNm/m
Total	$M_{total_R} = M_{stem_R} + M_{base_R} + M_{moist_R} =$ **239.2** kNm/m

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{total_R} / M_{total_OT} =$ **1.409**

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	γ_G = **1.000**
Permanent favourable action	γ_{Gf} = **1.000**
Variable unfavourable action	γ_Q = **1.300**
Variable favourable action	γ_{Qf} = **0.000**

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	γ_γ = **1.00**

Water properties

Design water density	$\gamma_w' = \gamma_w / \gamma_\gamma$ = **9.8** kN/m^3

Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma$ = **16** kN/m^3
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma$ = **20** kN/m^3
Design effective shear resistance angle	$\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **21.3** deg
Design wall friction angle	$\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **10.5** deg

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_\gamma$ = **17.5** kN/m^3
Design effective shear resistance angle	$\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **35.8** deg
Design wall friction angle	$\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **17.1** deg
Design base friction angle	$\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **23** deg
Design effective cohesion	$c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **0** kN/m^2

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2)$ = **0.425**
Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2)$ = **7.553**

Sliding check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **26.3** kN/m
Wall base	$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **52** kN/m
Moist retained soil	$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}'$ = **28** kN/m
Total	$F_{total_v} = F_{stem} + F_{base} + F_{water_v} - F_{water_u} + F_{moist_v}$ = **106.3** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff}$ = **28.2** kN/m
Saturated retained soil	$F_{sat_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2$ = **6.2** kN/m
Water	$F_{water_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **14.2** kN/m

Moist retained soil	$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **80.7** kN/m
Total	$F_{total_h} = F_{sur_h} + F_{sat_h} + F_{water_h} + F_{moist_h} =$ **129.3** kN/m

Check stability against sliding

Base soil resistance	$F_{exc_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 =$ **182.6** kN/m
Base friction	$F_{friction} = F_{total_v} \times \tan(\delta_{bb.d}) =$ **45.2** kN/m
Resistance to sliding	$F_{rest} = F_{exc_h} + F_{friction} =$ **227.8** kN/m
Factor of safety	$FoS_{sl} = F_{rest} / F_{total_h} =$ **1.762**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **26.3** kN/m
Wall base	$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **52** kN/m
Moist retained soil	$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' =$ **28** kN/m
Total	$F_{total_v} = F_{stem} + F_{base} + F_{water_v} - F_{water_u} + F_{moist_v} =$ **106.3** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times (h_{eff} - d_{key}) =$ **21.2** kN/m
Saturated retained soil	$F_{sat_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + t_{base})^2 / 2 =$ **0.3** kN/m
Water	$F_{water_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + t_{base})^2 / 2 =$ **0.8** kN/m
Moist retained soil	$F_{moist_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + t_{base})) =$ **50.3** kN/m
Base soil	$F_{exc_h} = \max(-\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2, -(F_{sat_h} + F_{moist_h} + F_{water_h} + F_{sur_h})) =$ **-72.6** kN/m
Total	$F_{total_h} = F_{sur_h} + F_{sat_h} + F_{water_h} + F_{moist_h} + F_{exc_h} =$ **0** kN/m

Overturning moments on wall

Surcharge load	$M_{sur_OT} = F_{sur_h} \times x_{sur_h_a} =$ **41.3** kNm/m
Saturated retained soil	$M_{sat_OT} = F_{sat_h} \times x_{sat_h_a} =$ **0** kNm/m
Water	$M_{water_OT} = F_{water_h} \times x_{water_h_a} + 0$ kNm/m = **0.1** kNm/m
Moist retained soil	$M_{moist_OT} = F_{moist_h} \times x_{moist_h_a} =$ **66** kNm/m
Base soil	$M_{exc_OT} = F_{exc_h} \times x_{exc_h} =$ **53.3** kNm/m
Total	$M_{total_OT} = M_{sur_OT} + M_{sat_OT} + M_{water_OT} + M_{moist_OT} + M_{exc_OT} =$ **160.7** kNm/m

Restoring moments on wall

Wall stem	$M_{stem_R} = F_{stem} \times x_{stem} =$ **68.3** kNm/m
Wall base	$M_{base_R} = F_{base} \times x_{base} =$ **86.9** kNm/m
Moist retained soil	$M_{moist_R} = F_{moist_v} \times x_{moist_v} =$ **84** kNm/m
Total	$M_{total_R} = M_{stem_R} + M_{base_R} + M_{moist_R} =$ **239.2** kNm/m

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{total_R} / M_{total_OT} =$ **1.488**

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 2.9.17

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

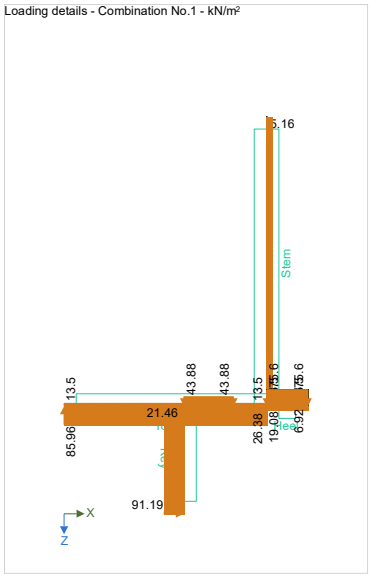
Concrete strength class	C28/35
Characteristic compressive cylinder strength	f_{ck} = **28** N/mm^2
Characteristic compressive cube strength	$f_{ck,cube}$ = **35** N/mm^2
Mean value of compressive cylinder strength	$f_{cm} = f_{ck} + 8$ N/mm^2 = **36** N/mm^2
Mean value of axial tensile strength	$f_{ctm} = 0.3$ N/mm^2 $\times$ $(f_{ck}$ / 1 N/mm$^2)^{2/3}$ = **2.8** N/mm^2
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm}$ = **1.9** N/mm^2
Secant modulus of elasticity of concrete	E_{cm} = 22 kN/mm^2 $\times$ $(f_{cm}$ / 10 N/mm$^2)^{0.3}$ = **32308** N/mm^2
Partial factor for concrete - Table 2.1N	γ_C = **1.50**
Compressive strength coefficient - cl.3.1.6(1)	α_{cc} = **0.85**
Design compressive concrete strength - exp.3.15	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C$ = **15.9** N/mm^2
Maximum aggregate size	h_{agg} = **20** mm
Ultimate strain - Table 3.1	ε_{cu2} = **0.0035**
Shortening strain - Table 3.1	ε_{cu3} = **0.0035**
Effective compression zone height factor	λ = **0.80**
Effective strength factor	η = **1.00**
Bending coefficient k_1	K_1 = **0.40**
Bending coefficient k_2	$K_2 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2})$ = **1.00**
Bending coefficient k_3	K_3 =**0.40**
Bending coefficient k_4	$K_4 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2})$ =**1.00**

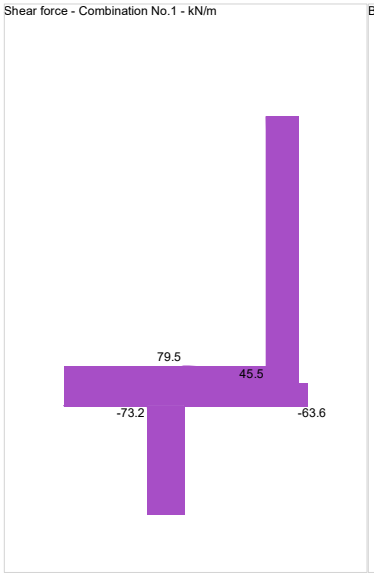
Reinforcement details

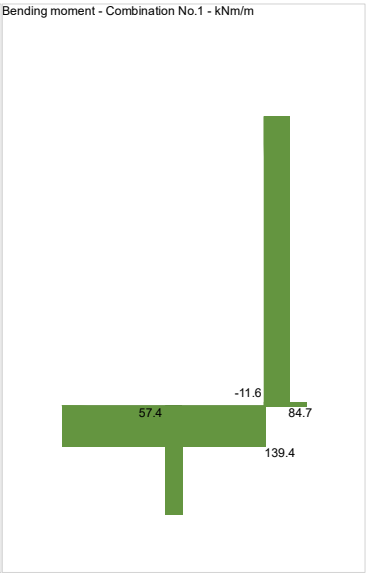
Characteristic yield strength of reinforcement	f_{yk} = **500** N/mm^2
Modulus of elasticity of reinforcement	E_s = **200000** N/mm^2
Partial factor for reinforcing steel - Table 2.1N	γ_S = **1.15**
Design yield strength of reinforcement	$f_{yd} = f_{yk} / \gamma_S$ = **435** N/mm^2

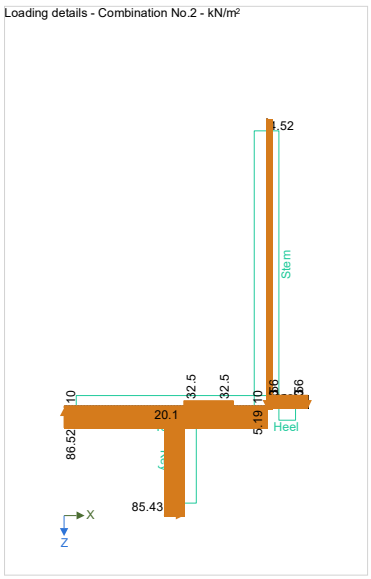
Cover to reinforcement

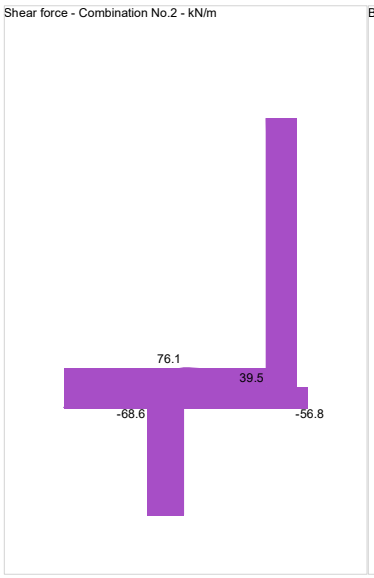
Front face of stem	c_{sf} = **50** mm
Rear face of stem	c_{sr} = **50** mm
Top face of base	c_{bt} = **50** mm
Bottom face of base	c_{bb} = **50** mm

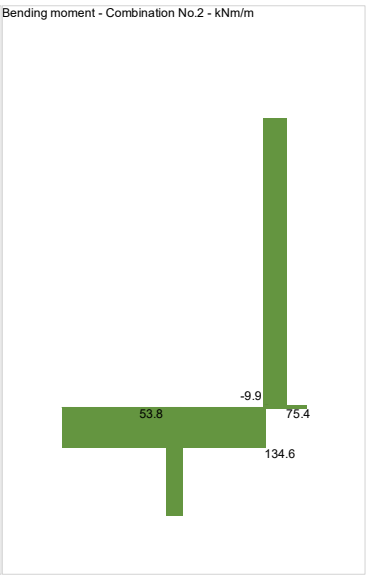












Check stem design at base of stem

Depth of section — h = **300** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **84.7** kNm/m

Depth to tension reinforcement — $d = h - c_{sr} - \phi_{sr} / 2 =$ **243** mm

$K = M / (d^2 \times f_{ck}) =$ **0.051**

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

$K' =$ **0.207**

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d =$ **231** mm

Depth of neutral axis — $x = 2.5 \times (d - z) =$ **30** mm

Area of tension reinforcement required — $A_{sr.req} = M / (f_{yd} \times z) =$ **844** mm²/m

Tension reinforcement provided	14 dia.bars @ 100 c/c *1524 *1 Layer A393 + H12 bars at 100mm centres = 1524mm²/m
Area of tension reinforcement provided	$A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **1539** mm²/m
Minimum area of reinforcement - exp.9.1N	$A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **350** mm²/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{sr.max} = 0.04 \times h$ = **12000** mm²/m
	$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.548**

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

Deflection control - Section 7.4

Reference reinforcement ratio	$\rho_0 = \sqrt{(f_{ck} / 1\ N/mm^2)} / 1000$ = **0.005**
Required tension reinforcement ratio	$\rho = A_{sr.req} / d$ = **0.003**
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	$K_s = \min(500\ N/mm^2 / (f_{yk} \times A_{sr.req} / A_{sr.prov}), 1.5)$ = **1.5**
Limiting span to depth ratio - exp.7.16.a	$\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1\ N/mm^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1\ N/mm^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b)$ = **16**
Actual span to depth ratio	h_{stem} / d = **14.4**

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

Rectangular section in shear - Section 6.2

Design shear force	V = **63.6** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**
	$k = \min(1 + \sqrt{(200\ mm / d)}, 2)$ = **1.907**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{sr.prov} / d, 0.02)$ = **0.006**
	$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.488** N/mm²
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\ N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **145** kN/m
	$V / V_{Rd.c}$ = **0.438**

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)	$A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem})$ = **385** mm²/m
Maximum spacing of reinforcement – cl.9.6.3(2)	s_{sx_max} = **400** mm
Transverse reinforcement provided	10 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **393** mm²/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 = **139.4** kNm/m
Depth to tension reinforcement	$d = h - c_{bb} - \phi_{bb} / 2$ = **343** mm
	$K = M / (d^2 \times f_{ck})$ = **0.042**
	$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C) \times (1 - \lambda \times (\delta - K_1)/(2 \times K_2)) \times (\lambda \times (\delta - K_1)/(2 \times K_2))$
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **326** mm
Depth of neutral axis	$x = 2.5 \times (d - z)$ = **43** mm

Area of tension reinforcement required	$A_{bb.req} = M / (f_{yd} \times z) =$ **984** mm²/m
Tension reinforcement provided	14 dia.bars @ 100 c/c *1524
Area of tension reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) =$ **1539** mm²/m
Minimum area of reinforcement - exp.9.1N	$A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **493** mm²/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bb.max} = 0.04 \times h =$ **16000** mm²/m
	$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} =$ **0.639**

*1 Layer A393 + H12 bars at 100mm centres = 1524mm²/m

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

Rectangular section in shear - Section 6.2

Design shear force	V = **79.5** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C =$ **0.120**
	$k = \min(1 + \sqrt{(200\ mm / d)}, 2) =$ **1.764**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb.prov} / d, 0.02) =$ **0.004**
	$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} =$ **0.434** N/mm²
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\ N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c} =$ **168.8** kN/m
	$V / V_{Rd.c} =$ **0.471**

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 1	M = **11.6** kNm/m
Depth to tension reinforcement	$d = h - c_{bt} - \phi_{bt} / 2 =$ **343** mm
	$K = M / (d^2 \times f_{ck}) =$ **0.004**
	$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C) \times (1 - \lambda \times (\delta - K_1)/(2 \times K_2)) \times (\lambda \times (\delta - K_1)/(2 \times K_2))$
	K' = **0.207**
	K' > K - No compression reinforcement is required
Lever arm	$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d =$ **326** mm
Depth of neutral axis	$x = 2.5 \times (d - z) =$ **43** mm
Area of tension reinforcement required	$A_{bt.req} = M / (f_{yd} \times z) =$ **82** mm²/m
Tension reinforcement provided	14 dia.bars @ 100 c/c *1524
Area of tension reinforcement provided	$A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) =$ **1539** mm²/m
Minimum area of reinforcement - exp.9.1N	$A_{bt.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **493** mm²/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bt.max} = 0.04 \times h =$ **16000** mm²/m
	$\max(A_{bt.req}, A_{bt.min}) / A_{bt.prov} =$ **0.321**

*1 Layer A393 + H12 bars at 100mm centres = 1524mm²/m

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

Rectangular section in shear - Section 6.2

Design shear force	V = **45.5** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C =$ **0.120**
	$k = \min(1 + \sqrt{(200\ mm / d)}, 2) =$ **1.764**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bt.prov} / d, 0.02) =$ **0.004**
	$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} =$ **0.434** N/mm²
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\ N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$

$V_{Rd.c}$ = **168.8** kN/m

$V / V_{Rd.c}$ = **0.270**

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section — h = **600** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **57.4** kNm/m

Depth to tension reinforcement — $d = h - c_{bb} - \phi_k / 2$ = **544** mm

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

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

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **517** mm

Depth of neutral axis — $x = 2.5 \times (d - z)$ = **68** mm

Area of tension reinforcement required — $A_{k.req} = M / (f_{yd} \times z)$ = **256** mm^2/m

Tension reinforcement provided — 12 dia.bars @ 100 c/c

Area of tension reinforcement provided — $A_{k.prov} = \pi \times \phi_k^2 / (4 \times s_k)$ = **1131** mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{k.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **783** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{k.max} = 0.04 \times h$ = **24000** mm^2/m

$\max(A_{k.req}, A_{k.min}) / A_{k.prov}$ = **0.692**

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

Rectangular section in shear - Section 6.2

Design shear force — V = **73.2** kN/m

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

$k = \min(1 + \sqrt{(200\ mm / d)}, 2)$ = **1.606**

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

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.377** N/mm^2

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

$V_{Rd.c}$ = **205.1** kN/m

$V / V_{Rd.c}$ = **0.357**

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) — $A_{bx.req} = 0.2 \times A_{bb.prov}$ = **308** mm^2/m

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

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

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

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