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3 ARNHILL ROAD

GRETTON

STRUCTURAL CALCULATIONS

Prepared by: **OAM / DS**

Date: **Februray 2021**

Reference: **20 / 41512**

VAT Registration No.: 670 8636 12

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Design Notes **Job Ref: 20 / 41512**

RE: 3 ARNHILL ROAD, GRETTON

The following calculations are in respect of our clients brief relating to **specific structural elements listed on the following page(s).** No responsibility is accepted in respect of other elements of the building. Any assumed bearing stresses must be confirmed on site to the satisfaction of the Building Control Officer.

Dimensions have been obtained from information provided and where no figured dimensions have been provided, scaling has been used. **Dimensions indicated on the following calculations are for design purposes only and must not be used for constructional purposes. All dimensions for construction are to be obtained by site measurements prior to manufacture / building**.

Appended sketches are to demonstrate certain features of the design and are not intended as working drawings. Where shown, details are intended to identify the main structural features. It is assumed that the work will be carried out by experienced and competent personnel, therefore exhaustive detailing is not required.

Where constructional connection details are indicated on these calculations, these shall not be varied. Any proposed changes should be substantiated by calculation, submitted and approved in writing by the Engineer before fabrication is commenced.

Where Building Control approval is required it is essential that this be obtained before the works proceed or materials are ordered. The contractor must ensure the stability of each element, and overall stability of the construction is maintained until all the works are completed.

REFERENCES

British Standards and Codes of Practice indicated below have been used in the preparation of these calculations - all constructional details must be in accordance with all relevant clauses contained in these same standards, associated standards or manufacturer's recommendations and details and normal good practice.

Loadings	[BS 6399 - Part 1:1996, Part 2:1997, Part 3:1988] [BS 648:1964]
Concrete	[BS 8110 - Part 1:1997, Part 3:1985] [BS 8007 : 1987]
Foundations	[BS 8004:1986] [BS 8002 : 1994]
Timber	[BS 5268 - Part 2:2002]
Masonry	[BS 5628 - Part 1:2005, Part 2:2005, Part 3:2005]
Industrial Floor Slabs	[Concrete Society Technical Report 34 (2nd Edition)] [C & CA Technical Report 550] [BCA Tech Note 11]
Steelwork	[BS 5950 - Part 1:2000, Part 3:1990, Part 5:1987, Part 8:1990] [BS 2853:1957]

ISSUE RECORD

Prep. by	Chkd by	Documents / Sheets / Drawings Issued	Description of Relating Structural Elements	Issue Date
OAM		Structural Calculations Pages 1-41	EXTERNAL RETAINING WALLS. .	08/02/2021

HEALTH & SAFETY

Where appropriate, the Client will be the/or appoint a, Principal Designer to act on his behalf who will ensure that where applicable the "Construction (Design and Management) Regulations 2015" are adhered to.

The Principal Contractor must at all times ensure safe working practices, maintain the integrity of the existing structures and conform to all the appropriate requirements of the Health and Safety Executive including the "Construction (Design and Management) Regulations 2015".

The working methods of any hazardous operations must first be discussed with the Principal Designer and the designer prior to commencement.

Below are identified hazards that are either impractical or uneconomic to eliminate at the design stage. The list is not exhaustive and must be read in conjunction with the main contractors own Health & Safety policy.

Hazard	Solution/Precaution/Sequence
Demolition and creation of new openings	To be carried out in accordance with prepared demolition statement ensuring structural integrity of existing building at all times. Openings should follow published procedure in Building Research Establishment publication GBG20 "Removing internal loadbearing walls in older dwellings".
Scaffolds	Scaffolds erected and used in accordance with BS5973. Scaffolds and propping must be inspected by a qualified person before use and at least once per week to ensure they are fit for use.
Personnel working at height	Works to be properly supervised with personnel provided with safe working platforms.
Lifting	Adequate means for moving and positioning elements to be available. Handling and construction to be carried out in accordance with relevant HSE 7 BS guidelines. Individuals are not to manually lift more than 25kg.
Deep excavation	No one shall enter an excavation deeper than 1.2m without adequately designed temporary shoring being in place. Where foundations are deeper than 2.5m they should be constructed in two pours.
Open trenched footings	Access to unattended trenches to be protected.

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Made By:	OAM	Revision:	
Date:	Feb-21	Checked By:	TG

Project: 3 ARNHILL ROAD, GRETTON

DIMENSIONS IN THESE CALCULATIONS ARE ONLY APPROXIMATE AND THE CONTRACTOR MUST CHECK THE LATEST ARCHITECTURAL DRAWINGS AND MEASURE UP ON SITE BEFORE ORDERING ANY MATERIALS.

RETAINING WALL TYPE 1

FOR H 2.5 TO 3 M

SEC 1	H=	103.5-100.98=	2.52 m	design for	**H1**	=	2.52+ .3=	**2.82**	m	SEC 1
SEC 2	H=	104-101.3=	2.70 m	design for	**H2**	=	2.70+ .3=	**3.00**	m	SEC 2
SEC 4	H=	103-100.6=	2.40 m	design for	**H4**	=	2.40+ .3=	**2.70**	m	SEC 4
SEC 8	H=	103.5-100.95=	2.55 m	design for	**H8**	=	2.55+ .4=	**2.95**	m	SEC 8

SEE PAGE 2 - 11

RETAINING WALL TYPE 2

FOR H 2 TO 2.5 M

SEC 3	H=	103.5-101.6=	1.90 m	design for	**H3**	=	1.90+ .3=	**2.20**	m	SEC 3
SEC 6	H=	0.5=	0.50 m	design for	**H6**	=	0.50+ 2=	**2.50**	m	SEC 6
SEC 7	H=	103.2-101.16=	2.04 m	design for	**H7**	=	2.04+ .3=	**2.34**	m	SEC 7

SEE PAGE 12 - 21

RETAINING WALL TYPE 3

FOR H 1.5 TO 2 M

SEC 5	H=	101.6-100.08=	1.52 m	design for	**H5**	=	1.52+ .3=	**1.82**	m	SEC 5

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RETAINING WALL TYPE 4

FOR H 2.4m ADJACENT TO PUBLIC ROAD

SEE PAGE 32 - 41

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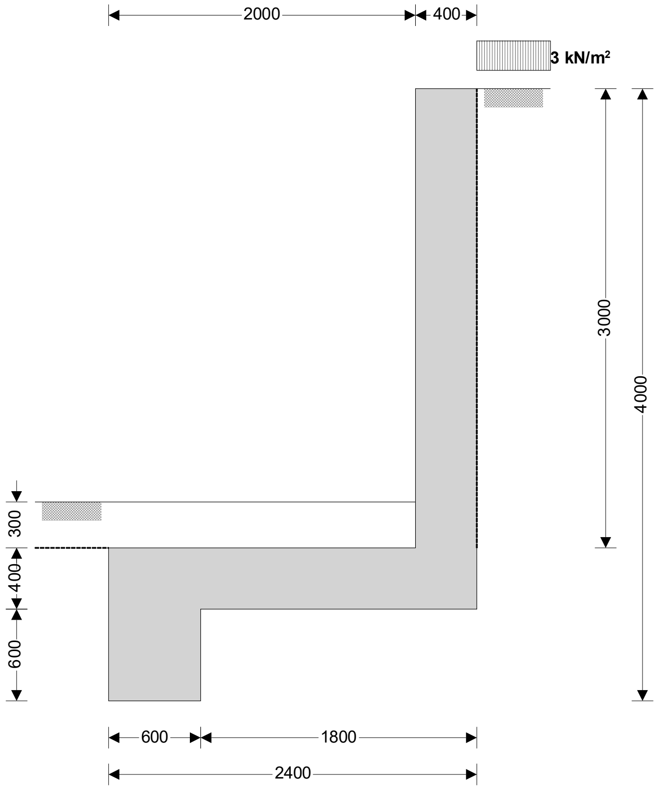
RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **3000** mm
Thickness of wall stem	t_{wall} = **400** mm
Length of toe	l_{toe} = **2000** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2400** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **600** mm
Position of downstand	l_{ds} = **0** mm
Thickness of downstand	t_{ds} = **600** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4000** mm
Depth of cover in front of wall	d_{cover} = **300** mm
Depth of unplanned excavation	d_{exc} = **300** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4000** mm

Retained material details

Mobilisation factor — M = **1.5**

Moist density of retained material — γ_m = **18.0** kN/m^3

Saturated density of retained material — γ_s = **21.0** kN/m^3

Design shear strength — ϕ' = **28.0** deg

Angle of wall friction — δ = **0.0** deg

Base material details

Moist density — γ_{mb} = **18.0** kN/m^3

Design shear strength — ϕ'_b = **24.2** deg

Design base friction — δ_b = **18.6** deg

Allowable bearing pressure — $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{}(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))]^2) = \mathbf{0.361}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{}(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material — $K_0 = 1 - \sin(\phi') = \mathbf{0.531}$

Loading details

Surcharge load on plan — Surcharge = **2.5** kN/m^2

Applied vertical dead load on wall — W_{dead} = **0.0** kN/m

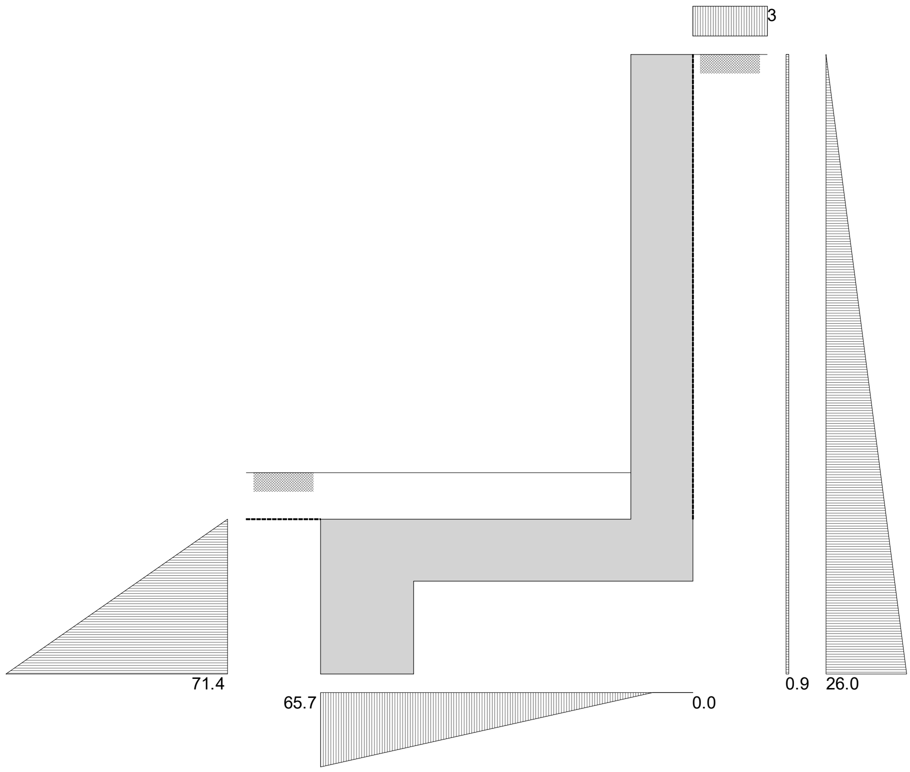
Applied vertical live load on wall — W_{live} = **0.0** kN/m

Position of applied vertical load on wall — l_{load} = **0** mm

Applied horizontal dead load on wall — F_{dead} = **0.0** kN/m

Applied horizontal live load on wall — F_{live} = **0.0** kN/m

Height of applied horizontal load on wall — h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem — $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **28.3** kN/m

Wall base — $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **22.7** kN/m

Wall downstand — $w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base}$ = **8.5** kN/m

Soil in front of wall — $w_p = l_{toe} \times d_{cover} \times \gamma_{mb}$ = **10.8** kN/m

Total vertical load — $W_{total} = w_{wall} + w_{base} + w_{ds} + w_p$ = **70.3** kN/m

Horizontal forces on wall

Surcharge — $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **3.6** kN/m

Moist backfill above water table — $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **52** kN/m

Total horizontal load — $F_{total} = F_{sur} + F_{m\_a}$ = **55.6** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **35.7** kN/m

Resistance to sliding — $F_{res} = F_p + (W_{total} - w_p) \times \tan(\delta_b)$ = **55.7** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge — $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **5.1** kNm/m

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **38.1** kNm/m

Soil in front of wall — $M_{p\_o} = F_p \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **9.5** kNm/m

Total overturning moment — $M_{ot} = M_{sur} + M_{m\_a} + M_{p\_o}$ = **52.7** kNm/m

Restoring moments

Wall stem — $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **62.3** kNm/m

Wall base	$M_{base} = w_{base} \times l_{base} / 2 =$ **27.2** kNm/m
Wall downstand	$M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2) =$ **2.5** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{ds} =$ **92** kNm/m

Check stability against overturning

Total overturning moment	$M_{ot} =$ **52.7** kNm/m
Total restoring moment	$M_{rest} =$ **92.0** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Soil in front of wall	$M_{p\_r} = w_p \times l_{toe} / 2 =$ **10.8** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{p\_r} =$ **50.1** kNm/m
Total vertical reaction	$R = W_{total} =$ **70.3** kN/m
Distance to reaction	$x_{bar} = M_{total} / R =$ **713** mm
Eccentricity of reaction	$e = abs((l_{base} / 2) - x_{bar}) =$ **487** mm

Reaction acts outside middle third of base

Bearing pressure at toe	$p_{toe} = R / (1.5 \times x_{bar}) =$ **65.7** kN/m^2
Bearing pressure at heel	$p_{heel} = 0$ kN/m^2 = **0** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **39.6** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **31.7** kN/m

Wall downstand $w_{ds\_f} = \gamma_{f\_d} \times d_{ds} \times t_{ds} \times \gamma_{base}$ = **11.9** kN/m

Soil in front of wall $w_{p\_f} = \gamma_{f\_d} \times l_{toe} \times d_{cover} \times \gamma_{mb}$ = **15.1** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{ds\_f} + w_{p\_f}$ = **98.4** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **8.5** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **107** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **115.4** kN/m

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **50** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **11.9** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **78.4** kNm/m

Soil in front of wall $M_{p\_o\_f} = F_{p\_f} \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **13.3** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{p\_o\_f}$ = **103.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **87.2** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **38.1** kNm/m

Wall downstand $M_{ds\_f} = w_{ds\_f} \times (l_{ds} + t_{ds} / 2)$ = **3.6** kNm/m

Soil in front of wall $M_{p\_r\_f} = w_{p\_f} \times l_{toe} / 2$ = **15.1** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{ds\_f} + M_{p\_r\_f}$ = **144** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **40.3** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **98.4** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **410** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **790** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **160** kN/m²

Bearing pressure at heel p_{heel_f} = 0 kN/m² = **0** kN/m²

Rate of change of base reaction $rate = p_{toe\_f} / (3 \times x_{bar\_f})$ = **130.12** kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **0** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2)$ = **0** kN/m²

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2)$ = **0** kN/m²

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe c_{toe} = **40** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} / 2$ = **98.4** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **26.4** kN/m

Shear from weight of downstand $V_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds}$ = **11.9** kN/m

Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} - V_{toe\_wt\_ds}$ = **60.1** kN/m

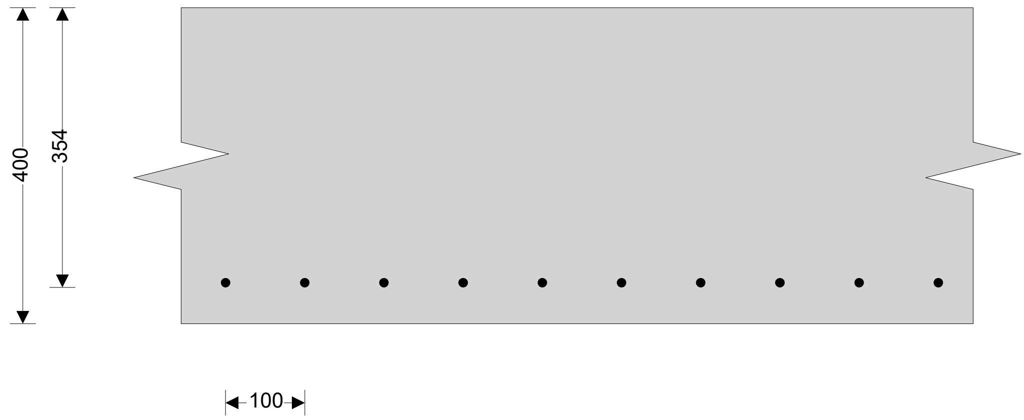
Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} \times (l_{toe} - x_{bar\_f} + t_{wall} / 2) / 2$ = **176.1** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **32** kNm/m

Moment from weight of downstand $M_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds} \times (l_{toe} - l_{ds} + (t_{wall} - t_{ds}) / 2)$ = **22.6** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} - M_{toe\_wt\_ds}$ = **121.5** kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} – c_{toe} – (\phi_{toe} / 2)$ = **354.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.028**

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))},0.95) \times d_{toe}$

z_{toe} = **336** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **831** mm^2/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base}$ = **520** mm^2/m

Area of tension reinforcement required $A_{s\_toe\_req} = \max(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **831** mm^2/m

Reinforcement provided **B1131 mesh**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **1131** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.170** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.498** N/mm^2

v_{toe} < v_{c_toe} - No shear reinforcement required

<u>Design of reinforced concrete retaining wall downstand (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in downstand c_{ds} = **40** mm

Calculate shear for downstand design

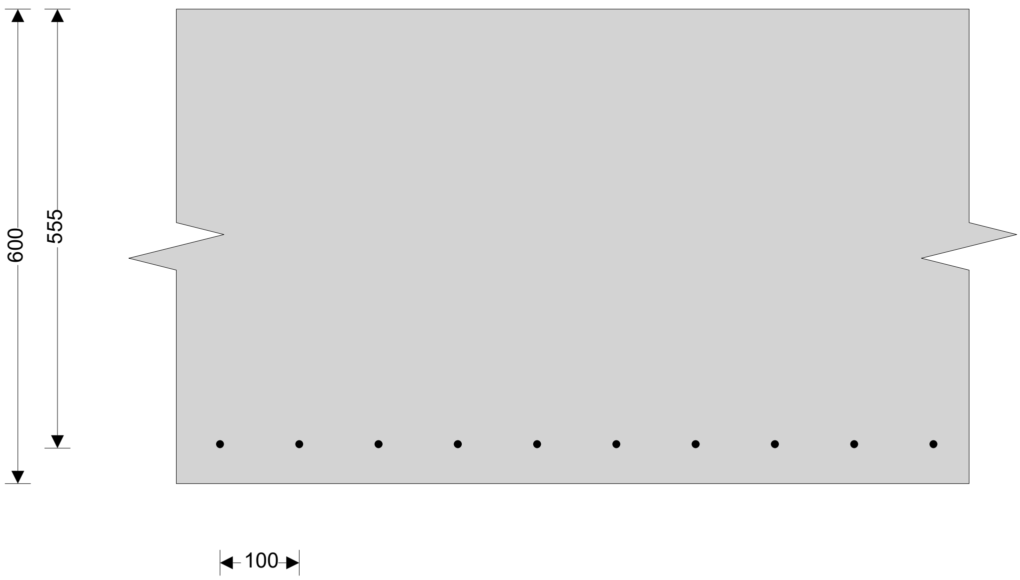
Total shear for downstand design

$V_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times (d_{cover} + t_{base} + d_{ds} / 2)$ = **60** kN/m

Calculate moment for downstand design

Total moment for downstand design

$M_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times [(d_{cover} + t_{base}) \times (t_{base} + d_{ds}) + d_{ds} \times (t_{base} / 2 + 2 \times d_{ds} / 3)] / 2$ = **31.8** kNm/m



Check downstand in bending

Width of downstand b = **1000** mm/m

Depth of reinforcement $d_{down} = t_{ds} - c_{ds} - (\phi_{down} / 2)$ = **555.0** mm

Constant $K_{down} = M_{down} / (b \times d_{down}^2 \times f_{cu})$ = **0.003**

Compression reinforcement is not required

Lever arm $z_{down} = \text{Min}(0.5 + \sqrt{(0.25 - (\min(K_{down}, 0.225) / 0.9))}, 0.95) \times d_{down}$

z_{down} = **527** mm

Area of tension reinforcement required $A_{s\_down\_des} = M_{down} / (0.87 \times f_y \times z_{down})$ = **139** mm^2/m

Minimum area of tension reinforcement $A_{s\_down\_min} = k \times b \times t_{ds}$ = **780** mm^2/m

Area of tension reinforcement required $A_{s\_down\_req} = \text{Max}(A_{s\_down\_des}, A_{s\_down\_min})$ = **780** mm^2/m

Reinforcement provided **B785 mesh**

Area of reinforcement provided $A_{s\_down\_prov}$ = **785** mm^2/m

PASS - Reinforcement provided at the retaining wall downstand is adequate

Check shear resistance at downstand

Design shear stress $v_{down} = V_{down} / (b \times d_{down})$ = **0.108** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_down} = **0.368** N/mm^2

$v_{down} < v_{c\_down}$ - No shear reinforcement required

<u>Design of reinforced concrete retaining wall stem (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **40** mm

Cover to reinforcement in wall c_{wall} = **40** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **6.4** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **60.2** kN/m

Calculate shear for stem design

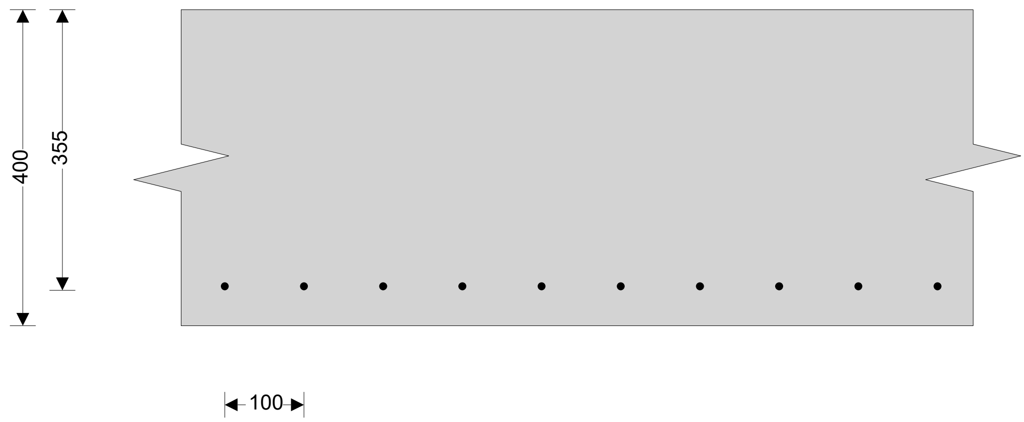
Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f}$ = **66.5** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **10.8** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **72.2** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **83** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **355.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.019**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **337** mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **566** mm²/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **520** mm²/m

Area of tension reinforcement required — $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **566** mm²/m

Reinforcement provided — **B785 mesh**

Area of reinforcement provided — $A_{s\_stem\_prov}$ = **785** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.187** N/mm²

Allowable shear stress — $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **4.733** N/mm²

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress — v_{c_stem} = **0.441** N/mm²

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Check retaining wall deflection

Basic span/effective depth ratio — $ratio_{bas}$ = **7**

Design service stress — $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **240.2** N/mm²

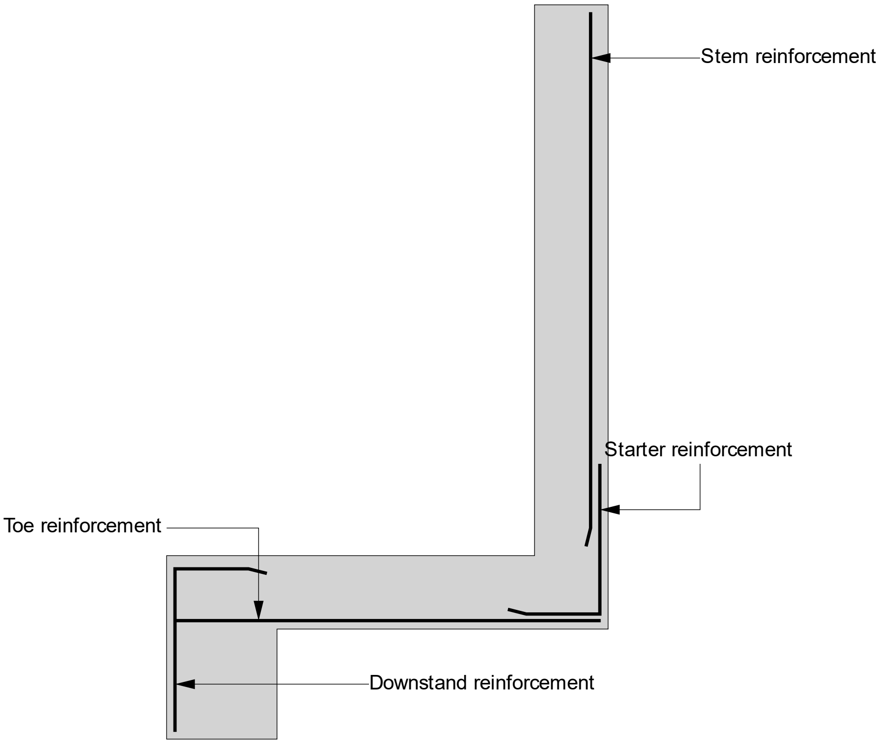
Modification factor — $factor_{tens} = min(0.55 + (477 N/mm^2 - f_s)/(120 \times (0.9 N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.82**

Maximum span/effective depth ratio — $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **12.71**

Actual span/effective depth ratio — $ratio_{act} = h_{stem} / d_{stem}$ = **8.45**

PASS - Span to depth ratio is acceptable

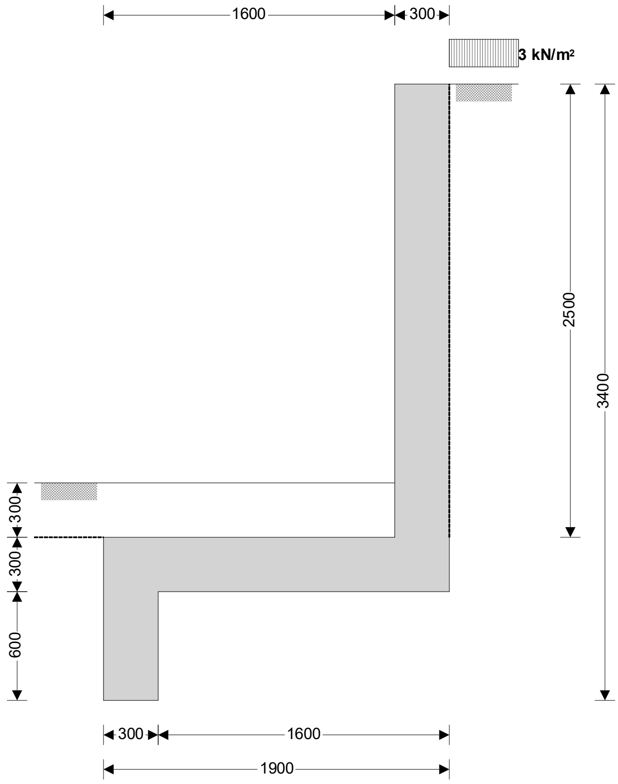
Indicative retaining wall reinforcement diagram



Toe mesh - B1131 - (1131 mm^2/m)
Downstand mesh - B785 - (785 mm^2/m)
Stem mesh - B785 - (785 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **2500** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **1600** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1900** mm
Thickness of base	t_{base} = **300** mm
Depth of downstand	d_{ds} = **600** mm
Position of downstand	l_{ds} = **0** mm
Thickness of downstand	t_{ds} = **300** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3400** mm
Depth of cover in front of wall	d_{cover} = **300** mm
Depth of unplanned excavation	d_{exc} = **300** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3400** mm

Retained material details

Mobilisation factor — M = **1.5**

Moist density of retained material — γ_m = **18.0** kN/m^3

Saturated density of retained material — γ_s = **21.0** kN/m^3

Design shear strength — ϕ' = **28.0** deg

Angle of wall friction — δ = **0.0** deg

Base material details

Moist density — γ_{mb} = **18.0** kN/m^3

Design shear strength — ϕ'_b = **24.2** deg

Design base friction — δ_b = **18.6** deg

Allowable bearing pressure — $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.361}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material — $K_0 = 1 - \sin(\phi') = \mathbf{0.531}$

Loading details

Surcharge load on plan — Surcharge = **2.5** kN/m^2

Applied vertical dead load on wall — W_{dead} = **0.0** kN/m

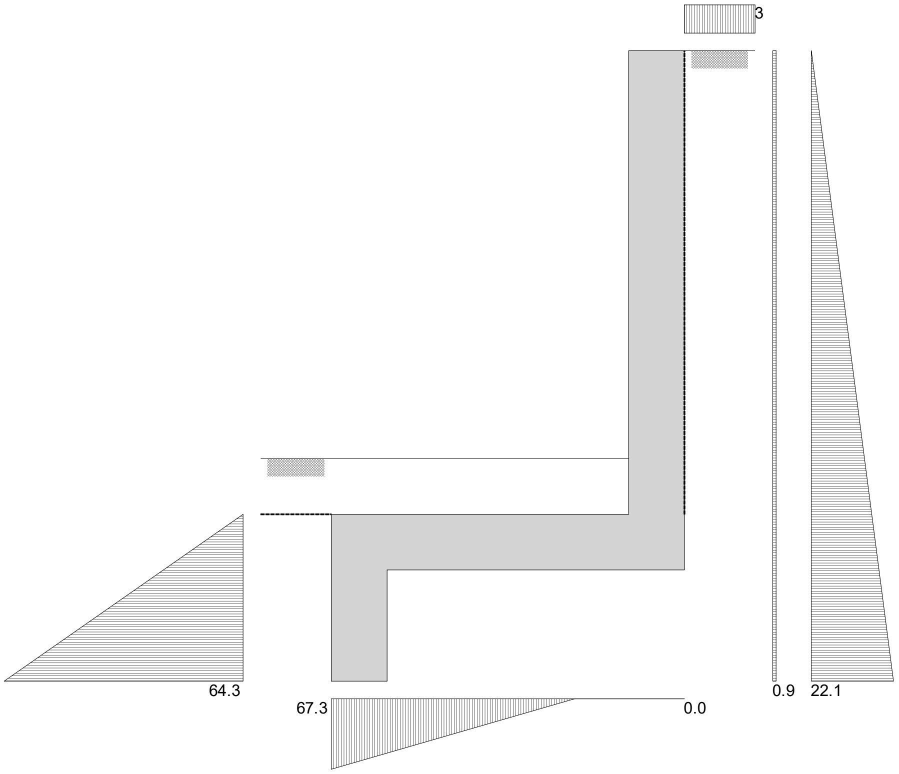
Applied vertical live load on wall — W_{live} = **0.0** kN/m

Position of applied vertical load on wall — l_{load} = **0** mm

Applied horizontal dead load on wall — F_{dead} = **0.0** kN/m

Applied horizontal live load on wall — F_{live} = **0.0** kN/m

Height of applied horizontal load on wall — h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem	$w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **17.7** kN/m
Wall base	$w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **13.5** kN/m
Wall downstand	$w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base}$ = **4.2** kN/m
Soil in front of wall	$w_p = l_{toe} \times d_{cover} \times \gamma_{mb}$ = **8.6** kN/m
Total vertical load	$W_{total} = w_{wall} + w_{base} + w_{ds} + w_p$ = **44** kN/m

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **3.1** kN/m
Moist backfill above water table	$F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **37.6** kN/m
Total horizontal load	$F_{total} = F_{sur} + F_{m\_a}$ = **40.6** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **28.9** kN/m
Resistance to sliding	$F_{res} = F_p + (W_{total} - w_p) \times \tan(\delta_b)$ = **40.8** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **3.4** kNm/m
Moist backfill above water table	$M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **20** kNm/m
Soil in front of wall	$M_{p\_o} = F_p \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **8.7** kNm/m
Total overturning moment	$M_{ot} = M_{sur} + M_{m\_a} + M_{p\_o}$ = **32.1** kNm/m

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **31** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2 =$ **12.8** kNm/m

Wall downstand $M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2) =$ **0.6** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{ds} =$ **44.4** kNm/m

Check stability against overturning

Total overturning moment $M_{ot} =$ **32.1** kNm/m

Total restoring moment $M_{rest} =$ **44.4** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Soil in front of wall $M_{p\_r} = w_p \times l_{toe} / 2 =$ **6.9** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{p\_r} =$ **19.2** kNm/m

Total vertical reaction $R = W_{total} =$ **44.0** kN/m

Distance to reaction $x_{bar} = M_{total} / R =$ **436** mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar}) =$ **514** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe} = R / (1.5 \times x_{bar}) =$ **67.3** kN/m^2

Bearing pressure at heel $p_{heel} = 0$ kN/m^2 = **0** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **24.8** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **18.8** kN/m

Wall downstand $w_{ds\_f} = \gamma_{f\_d} \times d_{ds} \times t_{ds} \times \gamma_{base}$ = **5.9** kN/m

Soil in front of wall $w_{p\_f} = \gamma_{f\_d} \times l_{toe} \times d_{cover} \times \gamma_{mb}$ = **12.1** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{ds\_f} + w_{p\_f}$ = **61.7** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **7.2** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **77.3** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **84.5** kN/m

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **40.5** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **7.9** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **41.2** kNm/m

Soil in front of wall $M_{p\_o\_f} = F_{p\_f} \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **12.1** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{p\_o\_f}$ = **61.3** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **43.4** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **17.9** kNm/m

Wall downstand $M_{ds\_f} = w_{ds\_f} \times (l_{ds} + t_{ds} / 2)$ = **0.9** kNm/m

Soil in front of wall $M_{p\_r\_f} = w_{p\_f} \times l_{toe} / 2$ = **9.7** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{ds\_f} + M_{p\_r\_f}$ = **71.8** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **10.5** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **61.7** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **171** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **779** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **240.8** kN/m^2

Bearing pressure at heel p_{heel_f} = 0 kN/m^2 = **0** kN/m^2

Rate of change of base reaction $rate = p_{toe\_f} / (3 \times x_{bar\_f})$ = **470.06** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **0** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2)$ = **0** kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2)$ = **0** kN/m^2

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete — f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement — f_y = **500** N/mm^2

Base details

Minimum area of reinforcement — k = **0.13** %

Cover to reinforcement in toe — c_{toe} = **40** mm

Calculate shear for toe design

Shear from bearing pressure — $V_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} / 2$ = **61.7** kN/m

Shear from weight of base — $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **15.9** kN/m

Shear from weight of downstand — $V_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds}$ = **5.9** kN/m

Total shear for toe design — $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} - V_{toe\_wt\_ds}$ = **39.8** kN/m

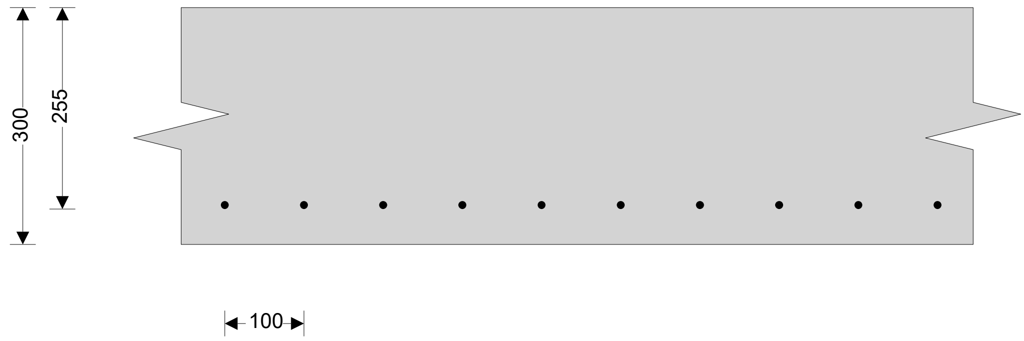
Calculate moment for toe design

Moment from bearing pressure — $M_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} \times (l_{toe} - x_{bar\_f} + t_{wall} / 2) / 2$ = **97.4** kNm/m

Moment from weight of base — $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **15.2** kNm/m

Moment from weight of downstand — $M_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds} \times (l_{toe} - l_{ds} + (t_{wall} - t_{ds}) / 2)$ = **9.5** kNm/m

Total moment for toe design — $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} - M_{toe\_wt\_ds}$ = **72.7** kNm/m



Check toe in bending

Width of toe — b = **1000** mm/m

Depth of reinforcement — $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **255.0** mm

Constant — $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.032**

Compression reinforcement is not required

Lever arm — $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

z_{toe} = **242** mm

Area of tension reinforcement required — $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **690** mm^2/m

Minimum area of tension reinforcement — $A_{s\_toe\_min} = k \times b \times t_{base}$ = **390** mm^2/m

Area of tension reinforcement required — $A_{s\_toe\_req} = \mathrm{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **690** mm^2/m

Reinforcement provided — **B785 mesh**

Area of reinforcement provided — $A_{s\_toe\_prov}$ = **785** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.156** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.534** N/mm^2

v_{toe} < v_{c_toe} - No shear reinforcement required

<u>Design of reinforced concrete retaining wall downstand (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in downstand c_{ds} = **40** mm

Calculate shear for downstand design

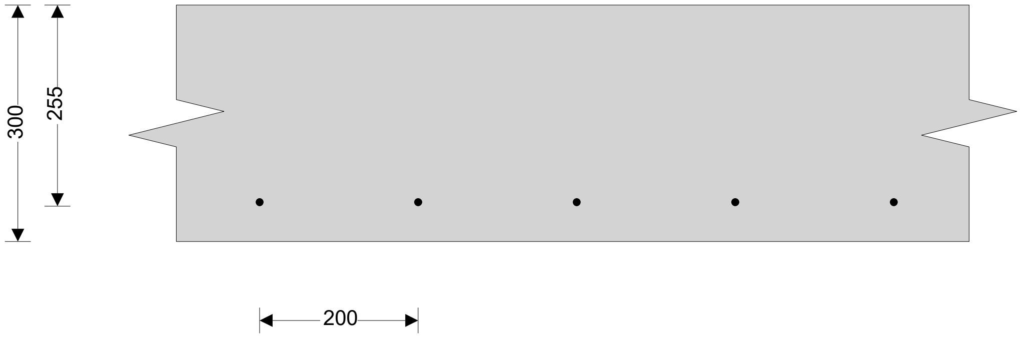
Total shear for downstand design

$V_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times (d_{cover} + t_{base} + d_{ds} / 2)$ = **54** kN/m

Calculate moment for downstand design

Total moment for downstand design

$M_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times [(d_{cover} + t_{base}) \times (t_{base} + d_{ds}) + d_{ds} \times (t_{base} / 2 + 2 \times d_{ds} / 3)] / 2$ = **26.1** kNm/m



Check downstand in bending

Width of downstand b = **1000** mm/m

Depth of reinforcement $d_{down} = t_{ds} - c_{ds} - (\phi_{down} / 2)$ = **255.0** mm

Constant $K_{down} = M_{down} / (b \times d_{down}^2 \times f_{cu})$ = **0.011**

Compression reinforcement is not required

Lever arm $z_{down} = \text{Min}(0.5 + \sqrt{(0.25 - (\min(K_{down}, 0.225) / 0.9))}, 0.95) \times d_{down}$

z_{down} = **242** mm

Area of tension reinforcement required $A_{s\_down\_des} = M_{down} / (0.87 \times f_y \times z_{down})$ = **248** mm^2/m

Minimum area of tension reinforcement $A_{s\_down\_min} = k \times b \times t_{ds}$ = **390** mm^2/m

Area of tension reinforcement required $A_{s\_down\_req} = \text{Max}(A_{s\_down\_des}, A_{s\_down\_min})$ = **390** mm^2/m

Reinforcement provided **A393 mesh**

Area of reinforcement provided $A_{s\_down\_prov}$ = **393** mm^2/m

PASS - Reinforcement provided at the retaining wall downstand is adequate

Check shear resistance at downstand

Design shear stress $v_{down} = V_{down} / (b \times d_{down})$ = **0.212** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1$ N/mm^2 = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_down} = **0.424** N/mm^2

v_{down} < v_{c_down} - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete — f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement — f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement — k = **0.13** %

Cover to reinforcement in stem — c_{stem} = **40** mm

Cover to reinforcement in wall — c_{wall} = **40** mm

Factored horizontal at-rest forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **5.3** kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **41.8** kN/m

Calculate shear for stem design

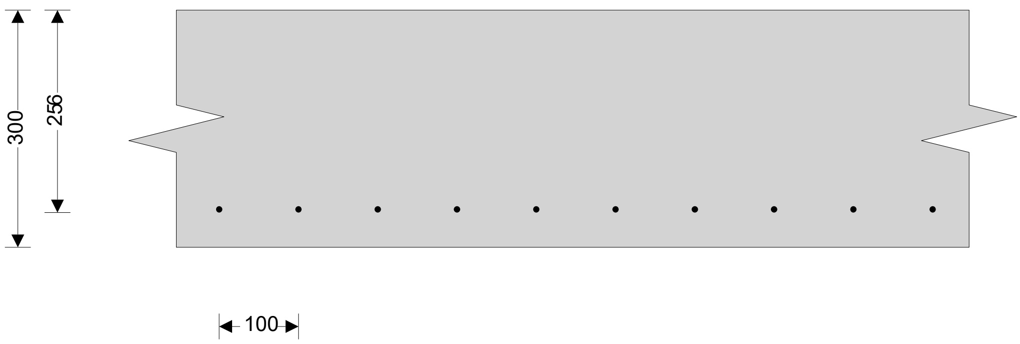
Shear at base of stem — $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f}$ = **47.1** kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **7.4** kNm/m

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **41.1** kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **48.5** kNm/m



Check wall stem in bending

Width of wall stem — b = **1000** mm/m

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **256.0** mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.021**

Compression reinforcement is not required

Lever arm — $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **243** mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **459** mm^2/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm^2/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **459** mm^2/m

Reinforcement provided — **B503 mesh**

Area of reinforcement provided — $A_{s\_stem\_prov}$ = **503** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.184** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.459** N/mm^2

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas}$ = **7**

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **304.1** N/mm^2

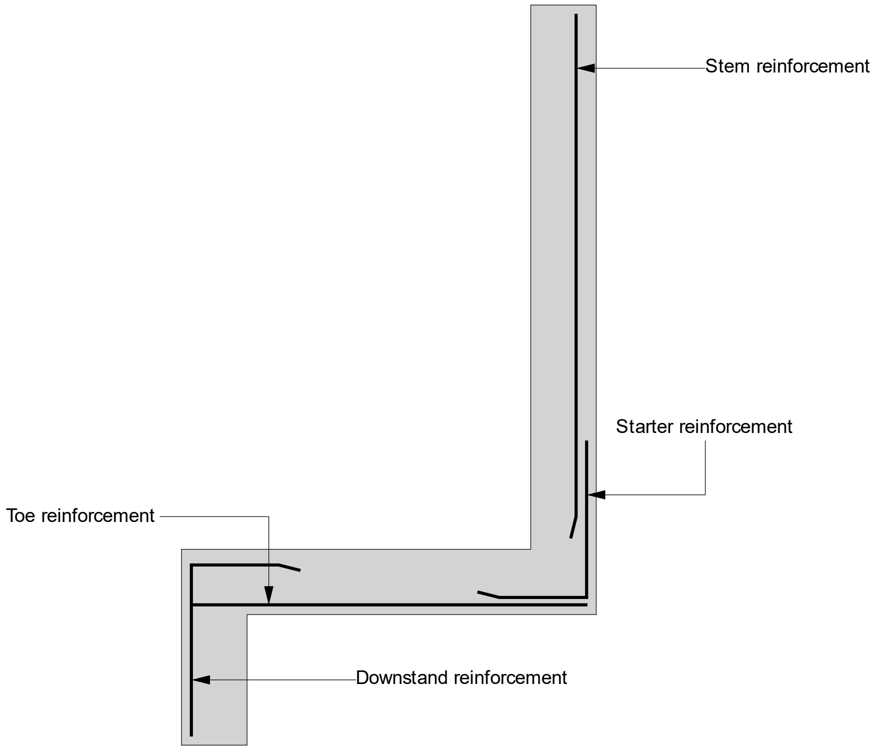
Modification factor $factor_{tens} = \min(0.55 + (477 N/mm^2 - f_s)/(120 \times (0.9 N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.43**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **10.00**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **9.77**

PASS - Span to depth ratio is acceptable

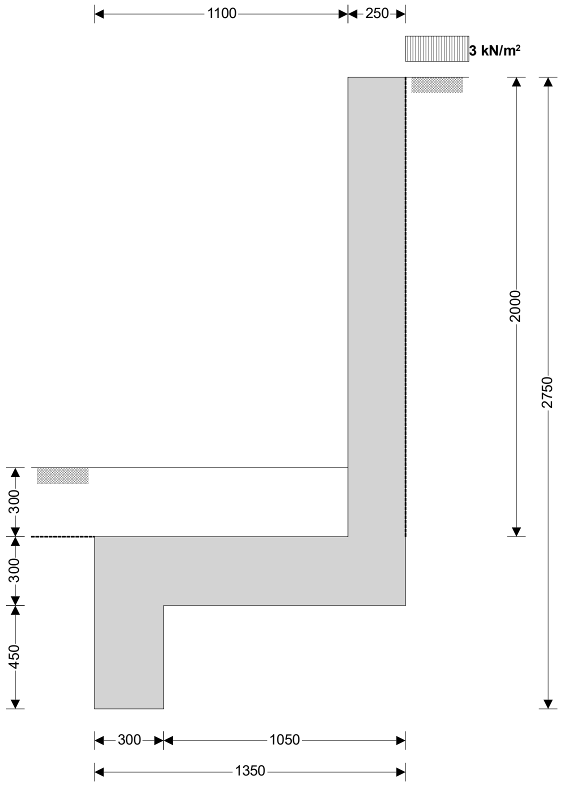
Indicative retaining wall reinforcement diagram



Toe mesh - B785 - (785 mm^2/m)
Downstand mesh - A393 - (393 mm^2/m)
Stem mesh - B503 - (503 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **2000** mm
Thickness of wall stem	t_{wall} = **250** mm
Length of toe	l_{toe} = **1100** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1350** mm
Thickness of base	t_{base} = **300** mm
Depth of downstand	d_{ds} = **450** mm
Position of downstand	l_{ds} = **0** mm
Thickness of downstand	t_{ds} = **300** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **2750** mm
Depth of cover in front of wall	d_{cover} = **300** mm
Depth of unplanned excavation	d_{exc} = **300** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **2750** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3
Saturated density of retained material	γ_s = **21.0** kN/m^3
Design shear strength	ϕ' = **28.0** deg
Angle of wall friction	δ = **0.0** deg

Base material details

Moist density	γ_{mb} = **18.0** kN/m^3
Design shear strength	ϕ'_b = **24.2** deg
Design base friction	δ_b = **18.6** deg
Allowable bearing pressure	$P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{}(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))]^2) = \mathbf{0.361}$$

Passive pressure coefficient for base material

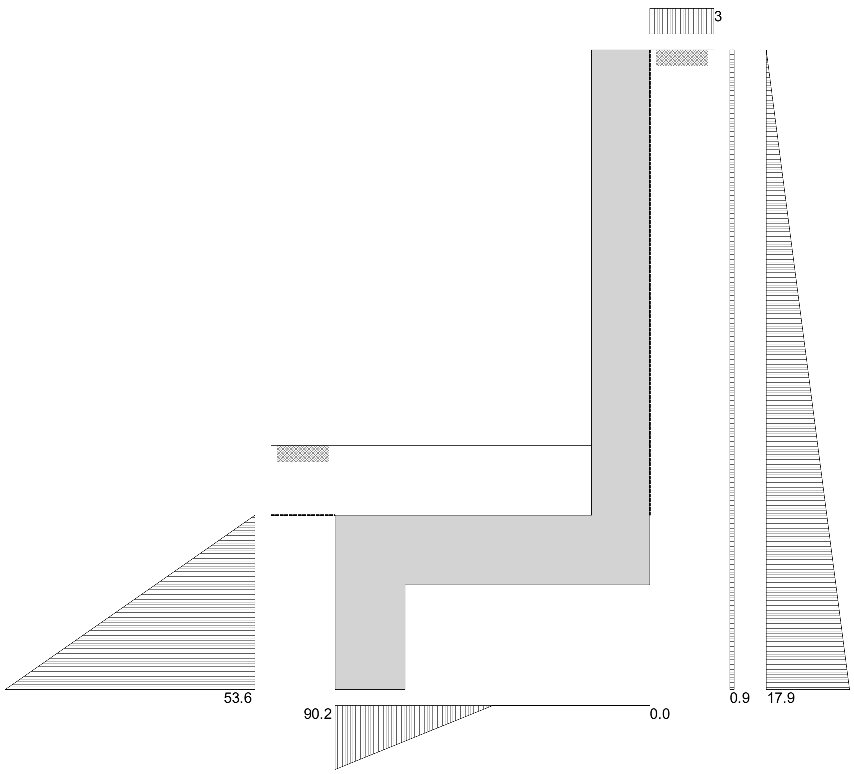
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{}(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 – \sin(\phi')$ = **0.531**

Loading details

Surcharge load on plan	Surcharge = **2.5** kN/m^2
Applied vertical dead load on wall	W_{dead} = **0.0** kN/m
Applied vertical live load on wall	W_{live} = **0.0** kN/m
Position of applied vertical load on wall	l_{load} = **0** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m²

Vertical forces on wall

Wall stem — $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **11.8** kN/m

Wall base — $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **9.6** kN/m

Wall downstand — $w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base}$ = **3.2** kN/m

Soil in front of wall — $w_p = l_{toe} \times d_{cover} \times \gamma_{mb}$ = **5.9** kN/m

Total vertical load — $W_{total} = w_{wall} + w_{base} + w_{ds} + w_p$ = **30.5** kN/m

Horizontal forces on wall

Surcharge — $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **2.5** kN/m

Moist backfill above water table — $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **24.6** kN/m

Total horizontal load — $F_{total} = F_{sur} + F_{m\_a}$ = **27.1** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **20.1** kN/m

Resistance to sliding — $F_{res} = F_p + (W_{total} - w_p) \times \tan(\delta_b)$ = **28.3** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge — $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **2.3** kNm/m

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **11.5** kNm/m

Soil in front of wall — $M_{p\_o} = F_p \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **4** kNm/m

Total overturning moment — $M_{ot} = M_{sur} + M_{m\_a} + M_{p\_o}$ = **17.8** kNm/m

Restoring moments

Wall stem — $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **14.5** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2 =$ **6.5** kNm/m

Wall downstand $M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2) =$ **0.5** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{ds} =$ **21.4** kNm/m

Check stability against overturning

Total overturning moment $M_{ot} =$ **17.8** kNm/m

Total restoring moment $M_{rest} =$ **21.4** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Soil in front of wall $M_{p\_r} = w_p \times l_{toe} / 2 =$ **3.3** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{p\_r} =$ **6.9** kNm/m

Total vertical reaction $R = W_{total} =$ **30.5** kN/m

Distance to reaction $x_{bar} = M_{total} / R =$ **225** mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar}) =$ **450** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe} = R / (1.5 \times x_{bar}) =$ **90.2** kN/m^2

Bearing pressure at heel $p_{heel} = 0$ kN/m^2 = **0** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **16.5** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **13.4** kN/m

Wall downstand $w_{ds\_f} = \gamma_{f\_d} \times d_{ds} \times t_{ds} \times \gamma_{base}$ = **4.5** kN/m

Soil in front of wall $w_{p\_f} = \gamma_{f\_d} \times l_{toe} \times d_{cover} \times \gamma_{mb}$ = **8.3** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{ds\_f} + w_{p\_f}$ = **42.7** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **5.8** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **50.6** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **56.4** kN/m

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **28.1** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **5.4** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **23.6** kNm/m

Soil in front of wall $M_{p\_o\_f} = F_{p\_f} \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **5.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{p\_o\_f}$ = **34.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **20.2** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **9** kNm/m

Wall downstand $M_{ds\_f} = w_{ds\_f} \times (l_{ds} + t_{ds} / 2)$ = **0.7** kNm/m

Soil in front of wall $M_{p\_r\_f} = w_{p\_f} \times l_{toe} / 2$ = **4.6** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{ds\_f} + M_{p\_r\_f}$ = **34.5** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **-0.1** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **42.7** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **-2** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **677** mm

WARNING - Beyond scope of calculation

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **-11945.3** kN/m^2

Bearing pressure at heel p_{heel_f} = 0 kN/m^2 = **0** kN/m^2

Rate of change of base reaction rate = $p_{toe\_f} / (3 \times x_{bar\_f})$ = **1671716.13** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **0** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2)$ = **0** kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2)$ = **0** kN/m^2

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe c_{toe} = **40** mm

Calculate shear for toe design

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **10.9** kN/m

Shear from weight of downstand $V_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds}$ = **4.5** kN/m

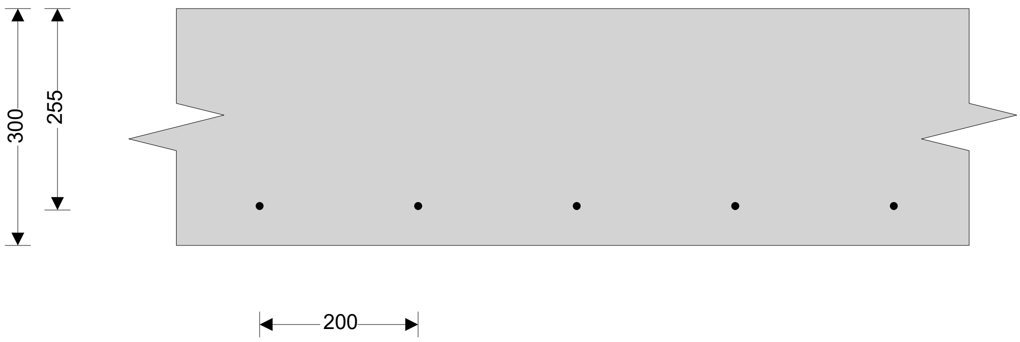
Total shear for toe design $V_{toe} = V_{toe\_wt\_base} - V_{toe\_wt\_ds}$ = **6.4** kN/m

Calculate moment for toe design

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **7.4** kNm/m

Moment from weight of downstand $M_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds} \times (l_{toe} - l_{ds} + (t_{wall} - t_{ds}) / 2)$ = **4.8** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_wt\_base} - M_{toe\_wt\_ds}$ = **2.6** kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **255.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.001**

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

z_{toe} = **242** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **25** mm^2/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base}$ = **390** mm^2/m

Area of tension reinforcement required $A_{s\_toe\_req} = \max(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **390** mm^2/m

Reinforcement provided **A393 mesh**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **393** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.025** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1$ N/mm^2 = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.424** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall downstand (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in downstand c_{ds} = **40** mm

Calculate shear for downstand design

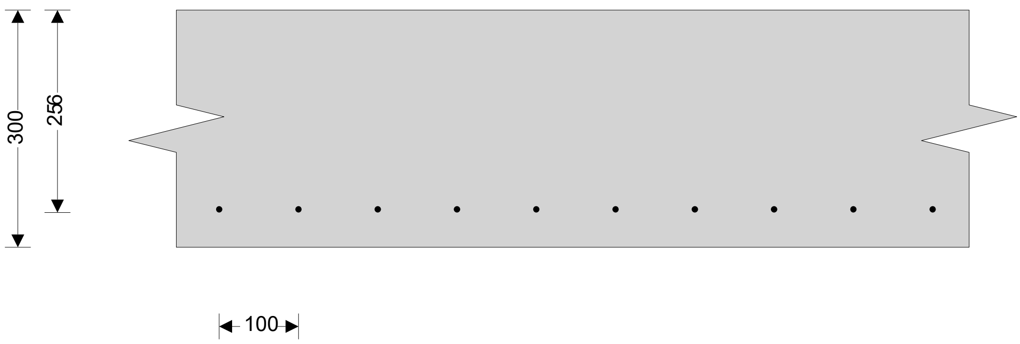
Total shear for downstand design

$V_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times (d_{cover} + t_{base} + d_{ds} / 2)$ = **37.1** kN/m

Calculate moment for downstand design

Total moment for downstand design

$M_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times [(d_{cover} + t_{base}) \times (t_{base} + d_{ds}) + d_{ds} \times (t_{base} / 2 + 2 \times d_{ds} / 3)] / 2$ = **14.7** kNm/m



Check downstand in bending

Width of downstand b = **1000** mm/m

Depth of reinforcement $d_{down} = t_{ds} - c_{ds} - (\phi_{down} / 2)$ = **256.0** mm

Constant $K_{down} = M_{down} / (b \times d_{down}^2 \times f_{cu})$ = **0.006**

Compression reinforcement is not required

Lever arm $z_{down} = \text{Min}(0.5 + \sqrt{(0.25 - (\min(K_{down}, 0.225) / 0.9))}, 0.95) \times d_{down}$

z_{down} = **243** mm

Area of tension reinforcement required $A_{s\_down\_des} = M_{down} / (0.87 \times f_y \times z_{down})$ = **139** mm^2/m

Minimum area of tension reinforcement $A_{s\_down\_min} = k \times b \times t_{ds}$ = **390** mm^2/m

Area of tension reinforcement required $A_{s\_down\_req} = \text{Max}(A_{s\_down\_des}, A_{s\_down\_min})$ = **390** mm^2/m

Reinforcement provided **B503 mesh**

Area of reinforcement provided $A_{s\_down\_prov}$ = **503** mm^2/m

PASS - Reinforcement provided at the retaining wall downstand is adequate

Check shear resistance at downstand

Design shear stress $v_{down} = V_{down} / (b \times d_{down})$ = **0.145** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_down} = **0.459** N/mm^2

$v_{down} < v_{c\_down}$ - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete — f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement — f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement — k = **0.13** %

Cover to reinforcement in stem — c_{stem} = **40** mm

Cover to reinforcement in wall — c_{wall} = **40** mm

Factored horizontal at-rest forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **4.2** kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **26.7** kN/m

Calculate shear for stem design

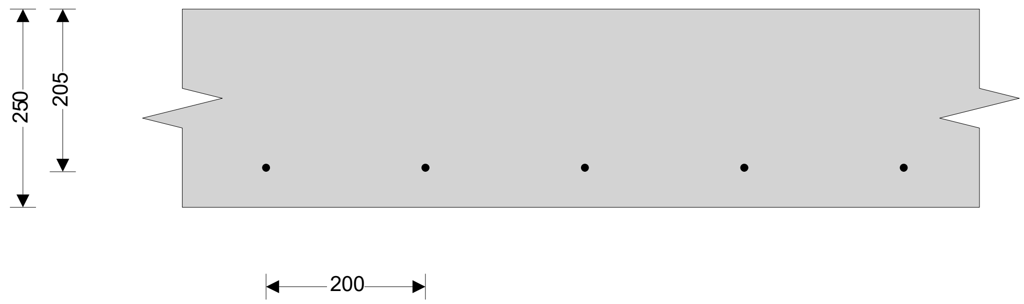
Shear at base of stem — $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f}$ = **31** kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **4.9** kNm/m

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **21.8** kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **26.7** kNm/m



Check wall stem in bending

Width of wall stem — b = **1000** mm/m

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **205.0** mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.018**

Compression reinforcement is not required

Lever arm — $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **195** mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **315** mm^2/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **325** mm^2/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **325** mm^2/m

Reinforcement provided — **A393 mesh**

Area of reinforcement provided — $A_{s\_stem\_prov}$ = **393** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.151** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress — v_{c_stem} = **0.482** N/mm^2

v_{stem} < v_{c_stem} - No shear reinforcement required

Check retaining wall deflection

Basic span/effective depth ratio: $ratio_{bas}$ = **7**

Design service stress: $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **275.9** N/mm^2

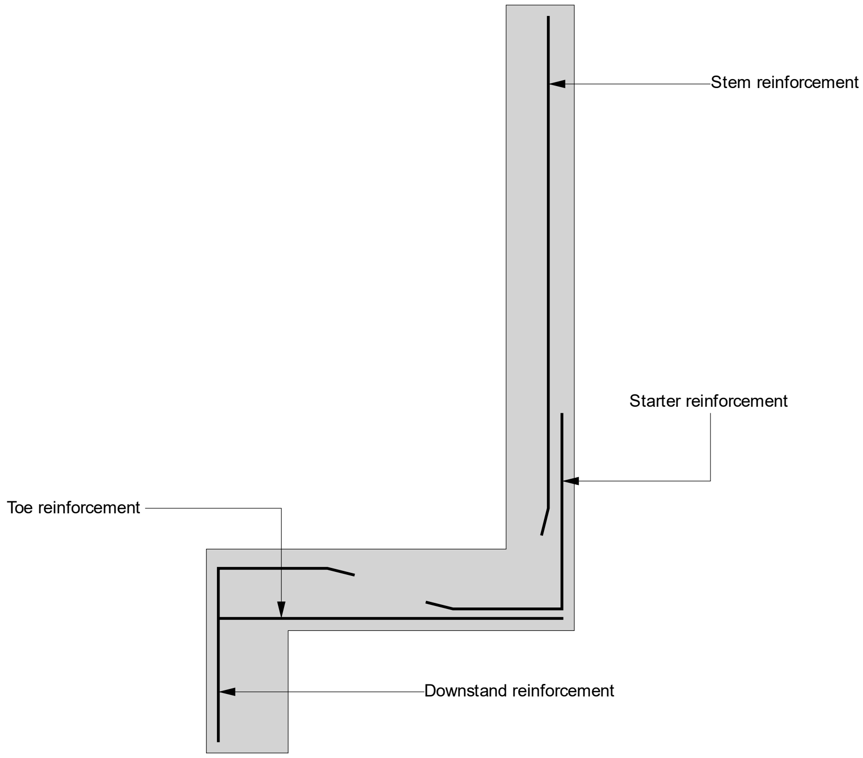
Modification factor: $factor_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.64**

Maximum span/effective depth ratio: $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **11.49**

Actual span/effective depth ratio: $ratio_{act} = h_{stem} / d_{stem}$ = **9.76**

PASS - Span to depth ratio is acceptable

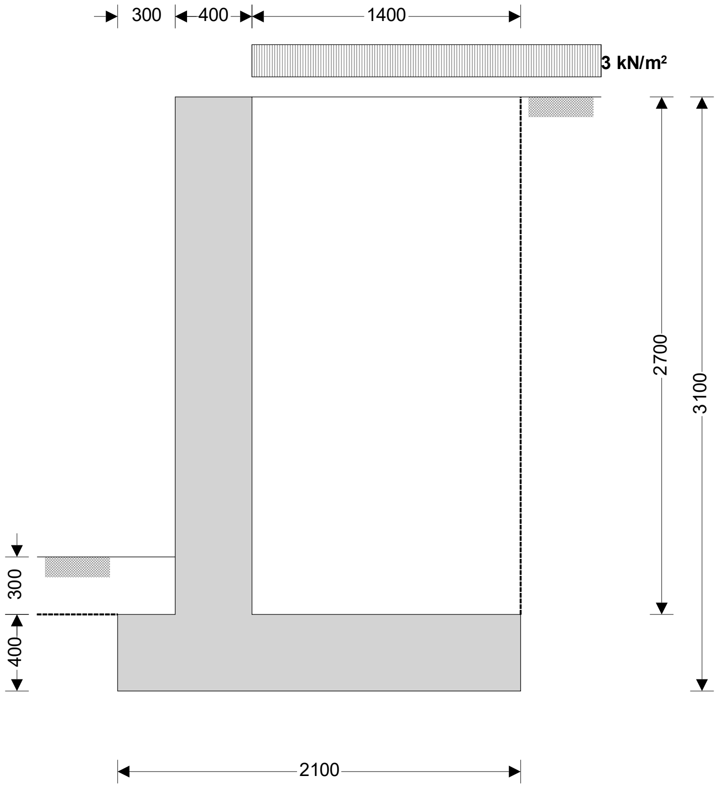
Indicative retaining wall reinforcement diagram



Toe mesh - A393 - (393 mm^2/m)
Downstand mesh - B503 - (503 mm^2/m)
Stem mesh - A393 - (393 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **2700** mm
Thickness of wall stem	t_{wall} = **400** mm
Length of toe	l_{toe} = **300** mm
Length of heel	l_{heel} = **1400** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2100** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **0** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3100** mm
Depth of cover in front of wall	d_{cover} = **300** mm
Depth of unplanned excavation	d_{exc} = **300** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\ mm)$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3100** mm

Retained material details

Mobilisation factor $M = \mathbf{1.5}$

Moist density of retained material $\gamma_m = \mathbf{18.0}$ kN/m^3

Saturated density of retained material $\gamma_s = \mathbf{21.0}$ kN/m^3

Design shear strength $\phi' = \mathbf{28.0}$ deg

Angle of wall friction $\delta = \mathbf{0.0}$ deg

Base material details

Moist density $\gamma_{mb} = \mathbf{18.0}$ kN/m^3

Design shear strength $\phi'_b = \mathbf{24.2}$ deg

Design base friction $\delta_b = \mathbf{18.6}$ deg

Allowable bearing pressure $P_{bearing} = \mathbf{100}$ kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.361}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi') = \mathbf{0.531}$

Loading details

Surcharge load on plan Surcharge = **2.5** kN/m^2

Applied vertical dead load on wall $W_{dead} = \mathbf{0.0}$ kN/m

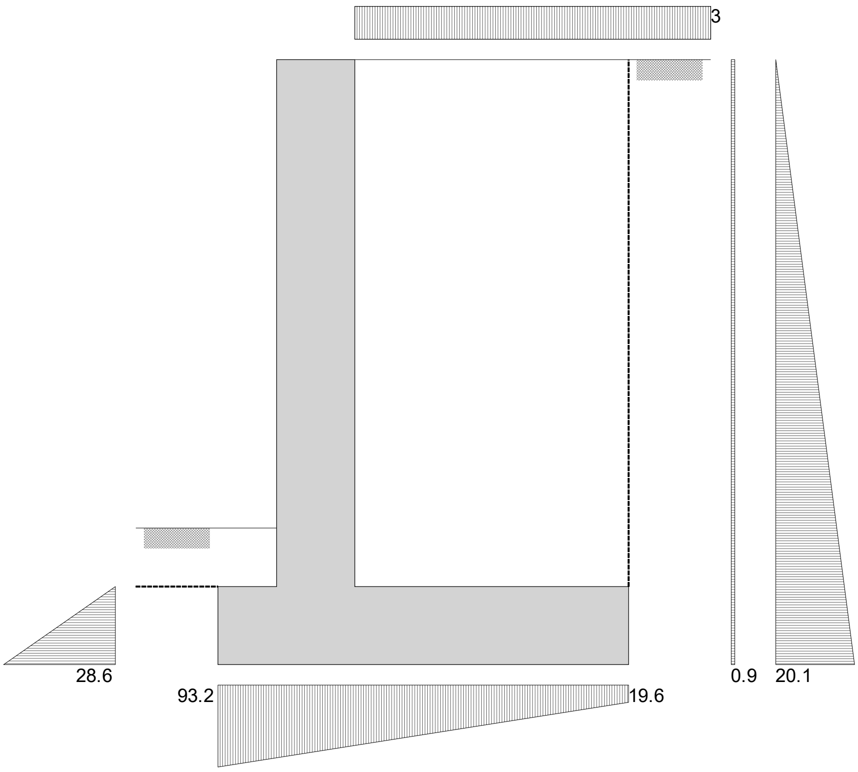
Applied vertical live load on wall $W_{live} = \mathbf{0.0}$ kN/m

Position of applied vertical load on wall $l_{load} = \mathbf{0}$ mm

Applied horizontal dead load on wall $F_{dead} = \mathbf{0.0}$ kN/m

Applied horizontal live load on wall $F_{live} = \mathbf{0.0}$ kN/m

Height of applied horizontal load on wall $h_{load} = \mathbf{0}$ mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **25.5** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **19.8** kN/m

Surcharge w_{sur} = Surcharge $\times l_{heel}$ = **3.5** kN/m

Moist backfill to top of wall $w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **68** kN/m

Soil in front of wall $w_p = l_{toe} \times d_{cover} \times \gamma_{mb}$ = **1.6** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + w_p$ = **118.5** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times$ Surcharge $\times h_{eff}$ = **2.8** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **31.2** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a}$ = **34** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.7** kN/m

Resistance to sliding $F_{res} = F_p + (W_{total} - w_{sur} - w_p) \times \tan(\delta_b)$ = **43.9** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **4.3** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **32.3** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a}$ = **36.6** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **12.7** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2 =$ **20.8** kNm/m

Moist backfill $M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3)) =$ **95.3** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{m\_r} =$ **128.8** kNm/m

Check stability against overturning

Total overturning moment $M_{ot} =$ **36.6** kNm/m

Total restoring moment $M_{rest} =$ **128.8** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge $M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2) =$ **4.9** kNm/m

Soil in front of wall $M_{p\_r} = w_p \times l_{toe} / 2 =$ **0.2** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{sur\_r} + M_{p\_r} =$ **97.4** kNm/m

Total vertical reaction $R = W_{total} =$ **118.5** kN/m

Distance to reaction $x_{bar} = M_{total} / R =$ **822** mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar}) =$ **228** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) =$ **93.2** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) =$ **19.6** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **35.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **27.8** kN/m

Surcharge $w_{sur\_f} = \gamma_{f\_l} \times Surcharge \times l_{heel}$ = **5.6** kN/m

Moist backfill to top of wall $w_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **95.3** kN/m

Soil in front of wall $w_{p\_f} = \gamma_{f\_d} \times l_{toe} \times d_{cover} \times \gamma_{mb}$ = **2.3** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{sur\_f} + w_{m\_w\_f} + w_{p\_f}$ = **166.6** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **6.6** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **64.2** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **70.8** kN/m

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **8** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **10.2** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **66.4** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f}$ = **76.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **17.8** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **29.1** kNm/m

Surcharge $M_{sur\_r\_f} = w_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **7.8** kNm/m

Moist backfill $M_{m\_r\_f} = (w_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + w_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **133.4**
kNm/m

Soil in front of wall $M_{p\_r\_f} = w_{p\_f} \times l_{toe} / 2$ = **0.3** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{sur\_r\_f} + M_{m\_r\_f} + M_{p\_r\_f}$ = **188.5** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **111.9** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **166.6** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **672** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **378** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **165.2** kN/m^2

Bearing pressure at heel p_{heel_f} = 0 kN/m^2 = **0** kN/m^2

Rate of change of base reaction $rate = p_{toe\_f} / (3 \times x_{bar\_f})$ = **81.94** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **140.6** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2)$ = **124.2** kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2)$ = **107.9** kN/m^2

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe c_{toe} = **40** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **45.9** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **4** kN/m

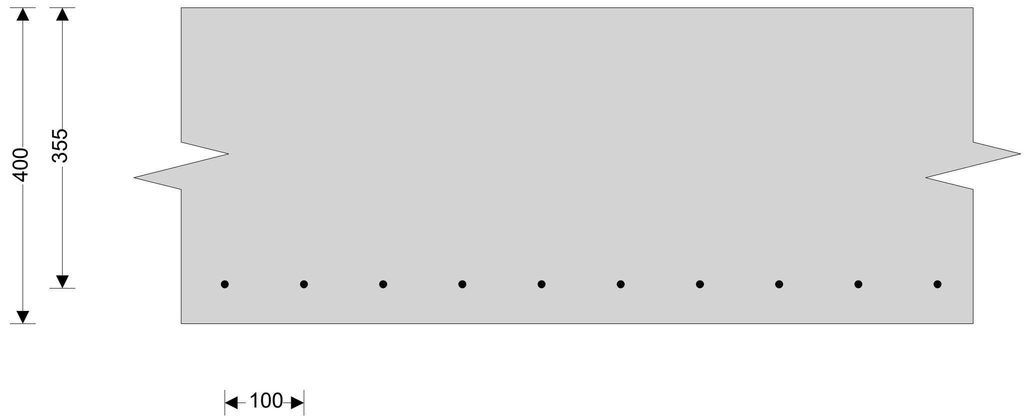
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **41.9** kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **18.9** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **1.7** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **17.3** kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **355.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.004**

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

z_{toe} = **337** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **118** mm^2/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base}$ = **520** mm^2/m

Area of tension reinforcement required $A_{s\_toe\_req} = \max(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **520** mm^2/m

Reinforcement provided **B785 mesh**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **785** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.118** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.441** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall heel (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in heel c_{heel} = **30** mm

Calculate shear for heel design

Shear from bearing pressure $V_{heel\_bear} = p_{stem\_heel\_f} \times ((3 \times x_{bar\_f}) - l_{toe} - t_{wall}) / 2 =$ **71** kN/m

Shear from weight of base $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base} =$ **18.5** kN/m

Shear from weight of moist backfill $V_{heel\_wt\_m} = w_{m\_w\_f} =$ **95.3** kN/m

Shear from surcharge $V_{heel\_sur} = w_{sur\_f} =$ **5.6** kN/m

Total shear for heel design $V_{heel} = - V_{heel\_bear} + V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_sur} =$ **48.4** kN/m

Calculate moment for heel design

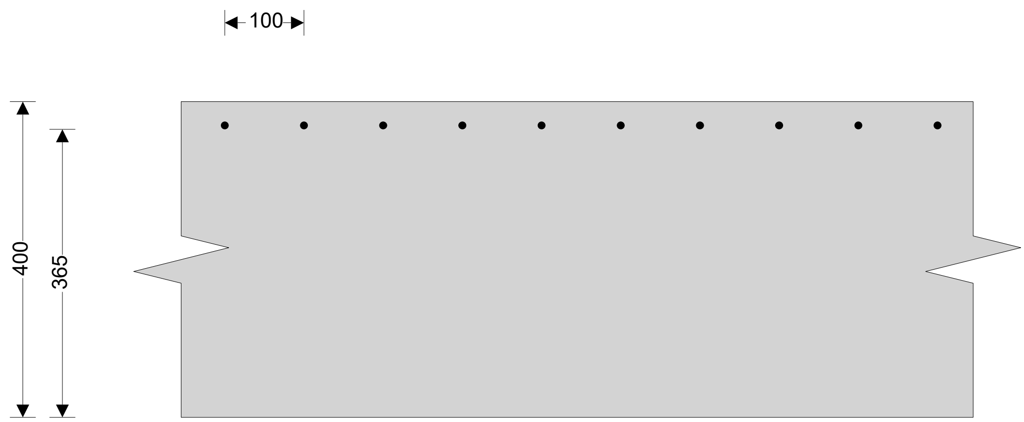
Moment from bearing pressure $M_{heel\_bear} = p_{stem\_mid\_f} \times ((3 \times x_{bar\_f}) - l_{toe} - t_{wall} / 2)^2 / 6 =$ **47.6** kNm/m

Moment from weight of base $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) =$ **16.9** kNm/m

Moment from weight of moist backfill $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2 =$ **85.7** kNm/m

Moment from surcharge $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2 =$ **5** kNm/m

Total moment for heel design $M_{heel} = - M_{heel\_bear} + M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_sur} =$ **60.1** kNm/m



Check heel in bending

Width of heel b = **1000** mm/m

Depth of reinforcement $d_{heel} = t_{base} - c_{heel} - (\phi_{heel} / 2) =$ **365.0** mm

Constant $K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu}) =$ **0.013**

Compression reinforcement is not required

Lever arm $z_{heel} = \min(0.5 + \sqrt{(0.25 - (\min(K_{heel}, 0.225) / 0.9))},0.95) \times d_{heel}$

z_{heel} = **347** mm

Area of tension reinforcement required $A_{s\_heel\_des} = M_{heel} / (0.87 \times f_y \times z_{heel}) =$ **398** mm^2/m

Minimum area of tension reinforcement $A_{s\_heel\_min} = k \times b \times t_{base} =$ **520** mm^2/m

Area of tension reinforcement required $A_{s\_heel\_req} = \text{Max}(A_{s\_heel\_des}, A_{s\_heel\_min}) =$ **520** mm^2/m

Reinforcement provided **B785 mesh**

Area of reinforcement provided $A_{s\_heel\_prov}$ = **785** mm^2/m

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress $v_{heel} = V_{heel} / (b \times d_{heel})$ = **0.133** N/mm^2

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_heel} = **0.433** N/mm^2

$v_{heel} < v_{c\_heel}$ - No shear reinforcement required

<u>Design of reinforced concrete retaining wall stem (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete f_{cu} = **35** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **40** mm

Cover to reinforcement in wall c_{wall} = **40** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **5.7** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **48.7** kN/m

Calculate shear for stem design

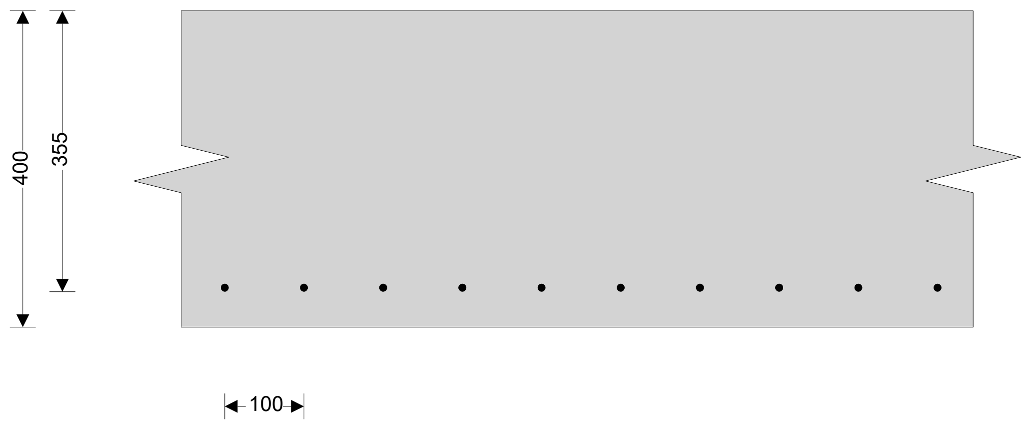
Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f}$ = **54.5** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **8.9** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **53.6** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **62.5** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} – c_{stem} – (\phi_{stem} / 2)$ = **355.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.014**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))},0.95) \times d_{stem}$

z_{stem} = **337** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **426** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **520** mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **520** mm^2/m

Reinforcement provided **B785 mesh**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **785** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.153** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **4.733** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.441** N/mm^2

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas}$ = **7**

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **220.7** N/mm^2

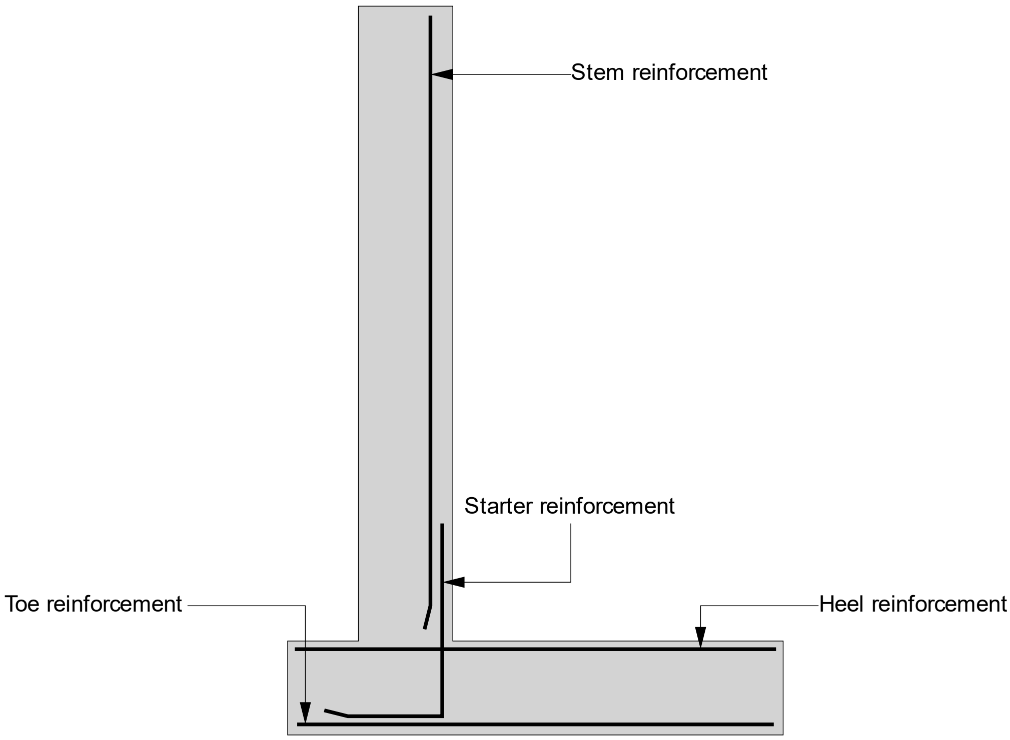
Modification factor $factor_{tens} = \min(0.55 + (477 N/mm^2 - f_s)/(120 \times (0.9 N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **2.00**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **14.00**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **7.61**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe mesh - B785 - (785 mm^2/m)
Heel mesh - B785 - (785 mm^2/m)
Stem mesh - B785 - (785 mm^2/m)