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38 Meadowbank
London
NW3 3AY

Basement Construction Methodology and Outline Sequence of Works

Project Number: 13065

November 2019

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Project Number	13065
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Contents

Appendices

1.0 EXECUTIVE SUMMARY

1.1. The following report has been produced to show an indicative sequence of works for the construction of a new single storey basement at 38 Meadowbank, London, NW3 3AY. All sketches and information provided within this report are indicative and subject to change following detailed design.

1.2. The final Construction Sequence and Method Statements remain the responsibility of the Contractor. All temporary works design and stability of existing structures remain the responsibility of the Contractor during construction.

1.3. Although the party wall foundations were not fully exposed, probing suggests the party wall foundation between Nos. 37 and 38 Meadowbank extends to 50.28m AOD with the foundation between the site and No. 39 possibly extending to 48.40m AOD.

1.4. Based on the ground investigation, the identified ground conditions and the existing formation level of No. 39, a reinforced concrete (RC) retaining wall is anticipated to be between Nos. 38 and 39 Meadowbank.

1.5. Once the site is set up for construction, it is advised that trial shafts are excavated to establish the existing foundation details as accurately as possible for the full site perimeter, including the rear garden masonry walls.

1.6. It is proposed that RC underpins are designed to support the footings of the existing building at basement level. The RC underpins are also designed to retain the soil behind the foundation. The underpins under the main house's footprint are designed to be propped top and bottom to prevent movement and also to provide an efficient and cost effective design in the permanent case. Similarly, the RC underpins in the rear garden between No. 37 & 38 and also the RC retaining wall supporting the main garden area/soil are designed as propped cantilevered walls in the permanent condition. The top of these RC walls are either directly connected to the ground floor slab or to a capping beam where sky lights are currently proposed, enabling them to transfer and distribute the horizontal force to the main RC box frame.

1.7. It is common during construction of underpinning that cosmetic damage will occur in the form of minor cracking of finishes in the building and its neighbours. As demonstrated in the Ground Movement Assessment (contained in the BIA), it would be expected that any damage observed during the construction underpinning would be no more than Category 1 as defined on the Burland Scale. It should be noted that the movement and damage predictions assume that the neighbouring properties are in good condition and that there is good control of workmanship throughout construction, with temporary and permanent propping.

2.0 OUTLINE SEQUENCE OF WORKS

2.1. Sketches to illustrate a suitable construction sequence below are included in Appendix 1. The proposed sequence is as follows:

- Install temporary works to support floors and masonry walls above.
- As part of the above temporary works, insure adequate horizontal bracings are installed to maintain the lateral stability of the building.
- Demolish existing internal walls, ground to first.
- Break out the existing RC slab at ground floor level and carefully cut back the existing footings as required.
- Construct reinforced concrete underpinning of existing party walls to form basement wall. Carry out works in hit and miss, using a typical 1, 4, 2, 5, 3 underpinning sequence as per items below:
    - Underpinning to be carried out in maximum 1.0m sections in shaft excavations. It is anticipated that this is a single process.
    - Install trench sheeting, struts and walings as excavation proceeds for underpins in shafts.
    - Cast underpins in sections, dry pack on hardened concrete between new and existing foundations.
    - Continue the underpinning to the wall until all the underpinning is completed, underpins are to be back-propped with trench props and walings.
    - Allow for dewatering (by sump pumping) as necessary.
- Carry out underpinning to party walls and to rear and front of the property as outlined above.
- Construct RC wall/column thickening under steel column as part of underpinning outlined in the above items.
- Lower the ground and install the upper row of temporary propping across the site.
- Excavate the basement to near the bottom of the construction and install a second row of props.
- Excavate to formation level and install drainage/sumps etc.
- Pour central area of the basement slab incorporating drainage, sumps and chambers.
- Remove bottom row of propping once the basement slab has gained sufficient strength.
- Install new steel beams and columns of stability boxed between ground and 1st floor.
- Cast the ground floor slab, incorporating concrete encased steel beams as part of ground floor slab construction.
- Cast RC capping beam on top RC wall to rear garden where two large skylights proposed.

- Once the ground floor RC slab and capping beam has achieved sufficient strength, remove all temporary props.
- Re-support upper floor structure off new permanent works and remove temporary propping structure.
- Install waterproofing system as specified by Architect and the specialist subcontractor.
- Provide fire protection to steelworks to Architect's details and Building Control Officer's approval
- Construct non-load bearing walls/studs, insulation, stair, screeds and finishes.

3.0 WATER PROTECTION

3.1. All below ground water protection is to be to the Architect's details. The basement forms part of a dwelling and so it is anticipated this will be classed as Grade 3 in accordance with BS 8102:2009. The tanking system will be an internal drained cavity to the Architect's details.

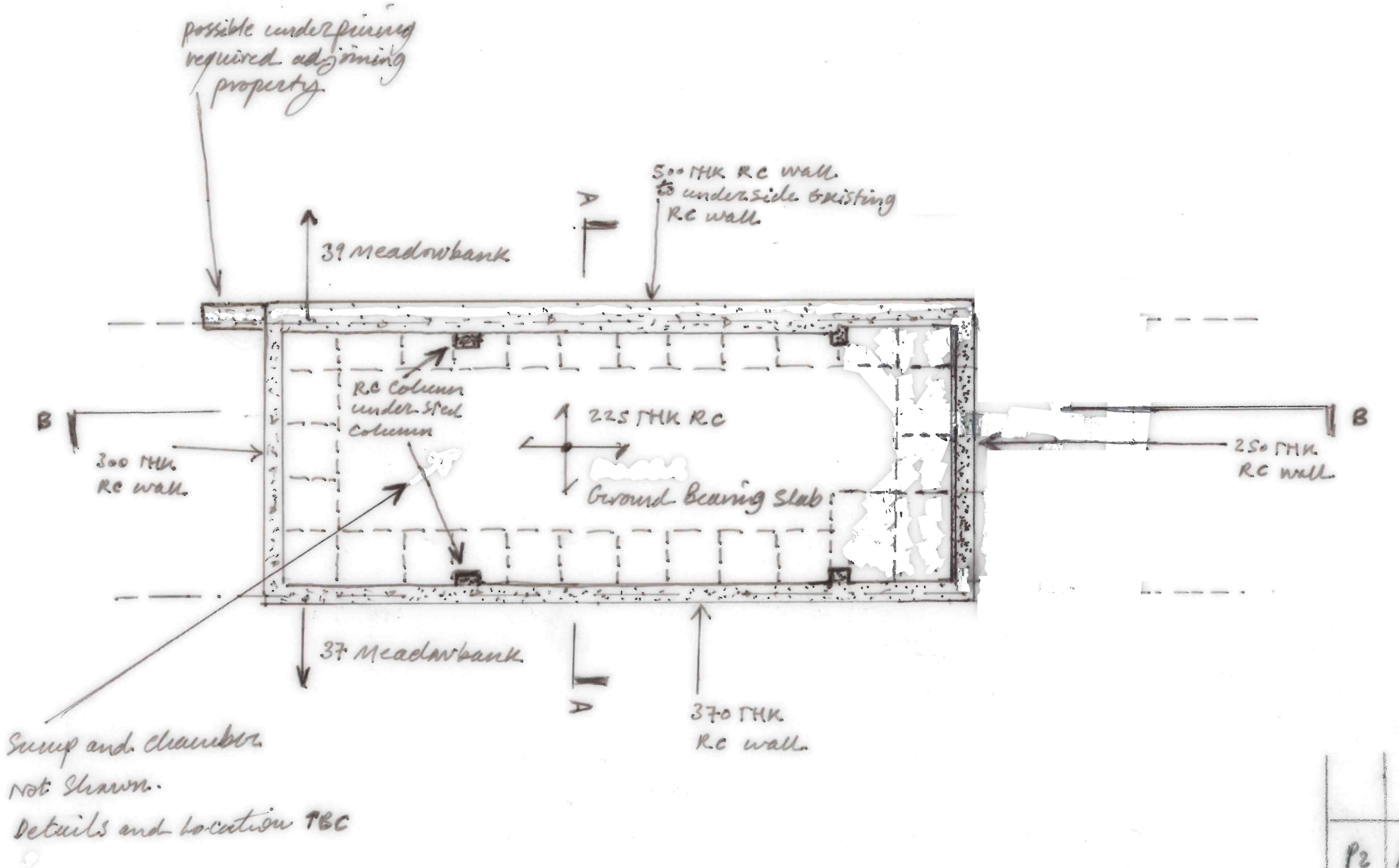
4.0 LIMITATIONS ON MOVEMENT

4.1. Based on the available information and assumptions noted previously in this report, a ground movement assessment has been undertaken based on reasonably conservative assumptions. The ground movement assessment (reported separately) confirms that building damage can be limited to a maximum Burland Category 1 (very slight) damage for the neighbouring properties providing there is good control of workmanship.

4.2. Pre-condition surveys should be undertaken prior to any construction works taking place.

Appendix 1: Sketches

Notes :-
1. Only Status C drawings to be used for construction.
2. Do not scale this drawing on print or electronically



Status/Rev	Description	Date	By
P2	Updated to reflect Architect Revised drawings	25.11.19	AP
P1	Issued For BIA Submission	15.3.19	AP

Job Title

38 Meadowbank

Proposed Lower Ground Floor Plan

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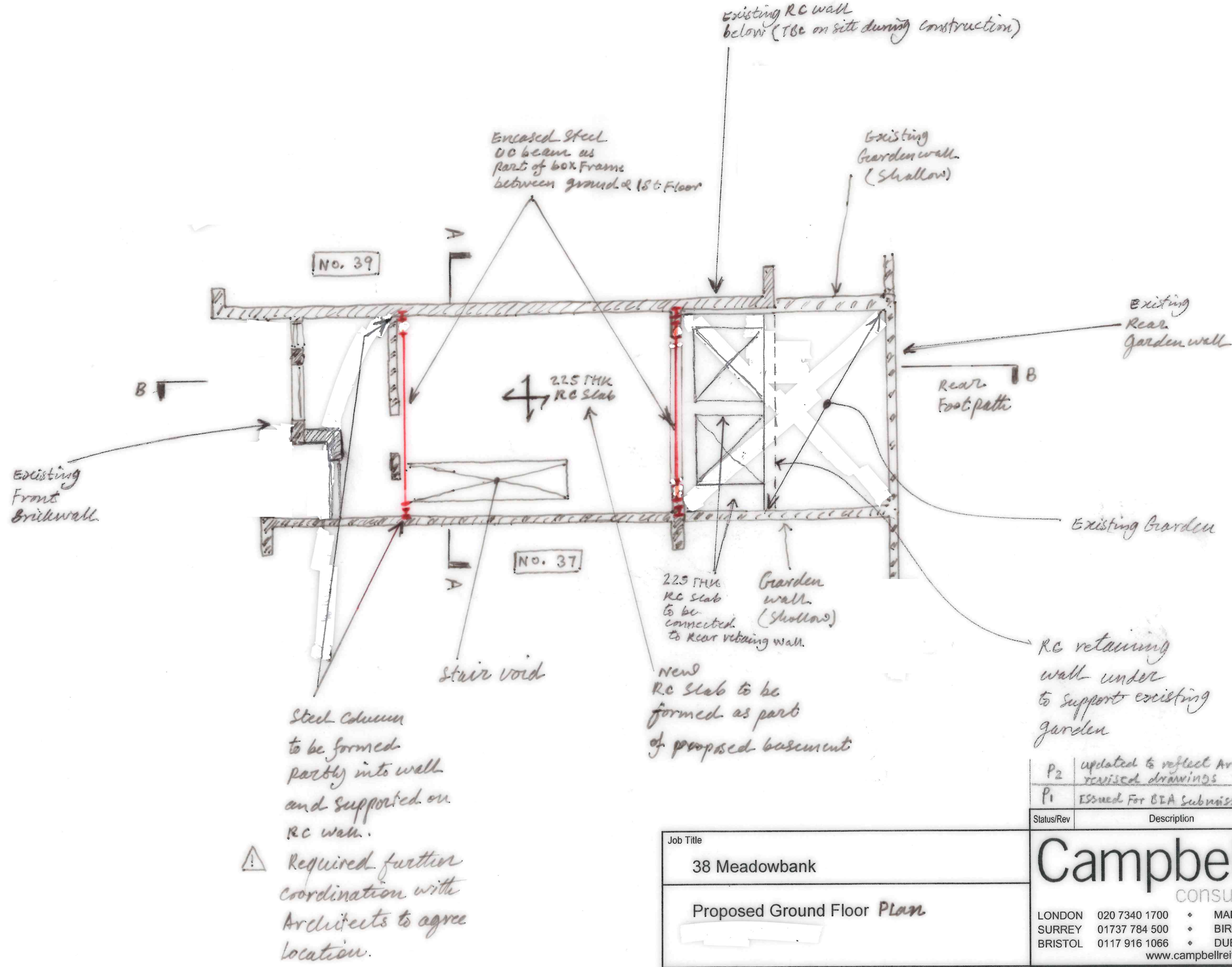

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Job Title
38 Meadowbank

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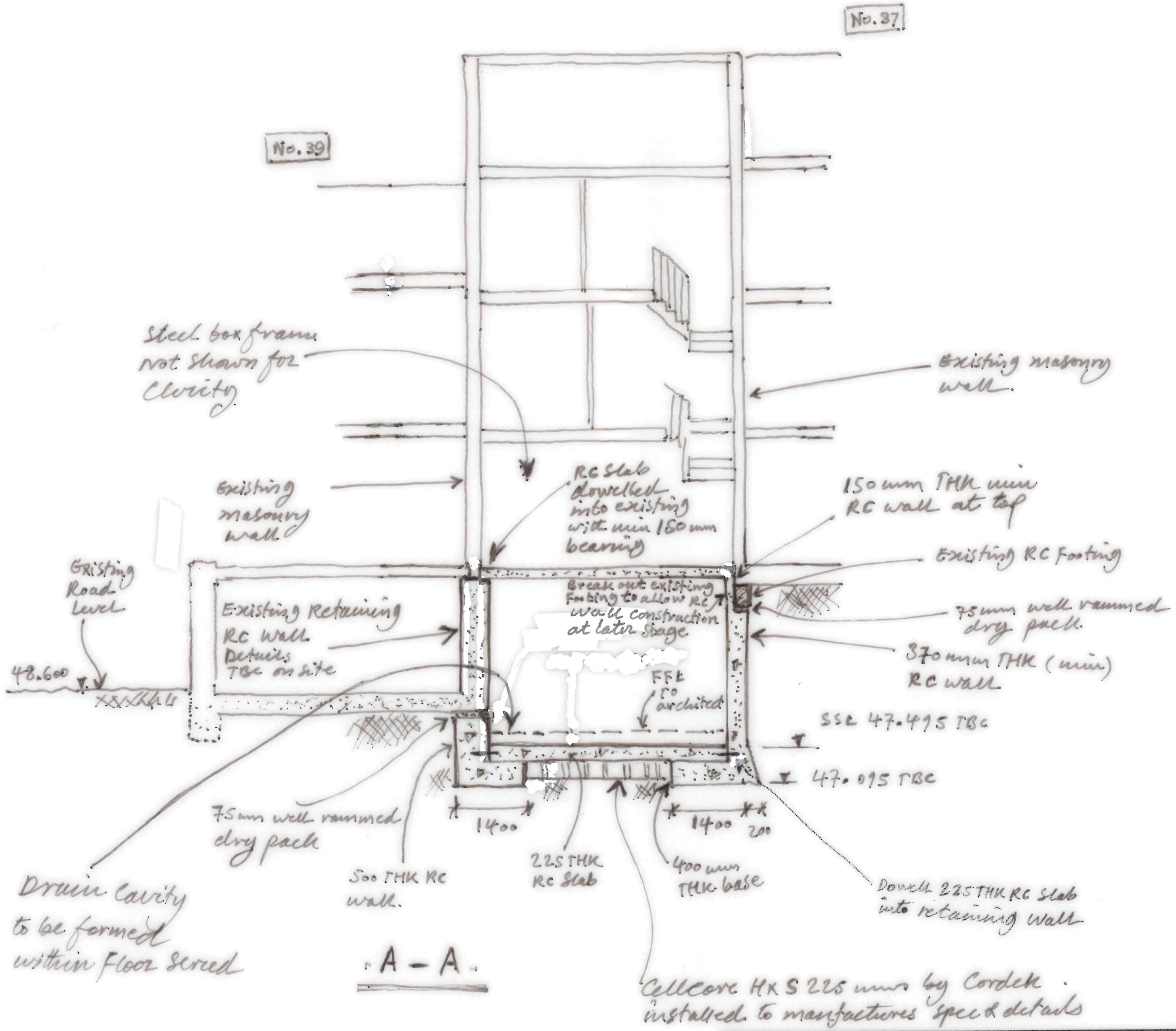

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Job Title

38 Meadowbank

Proposed Ground Floor Cross Section (typical)

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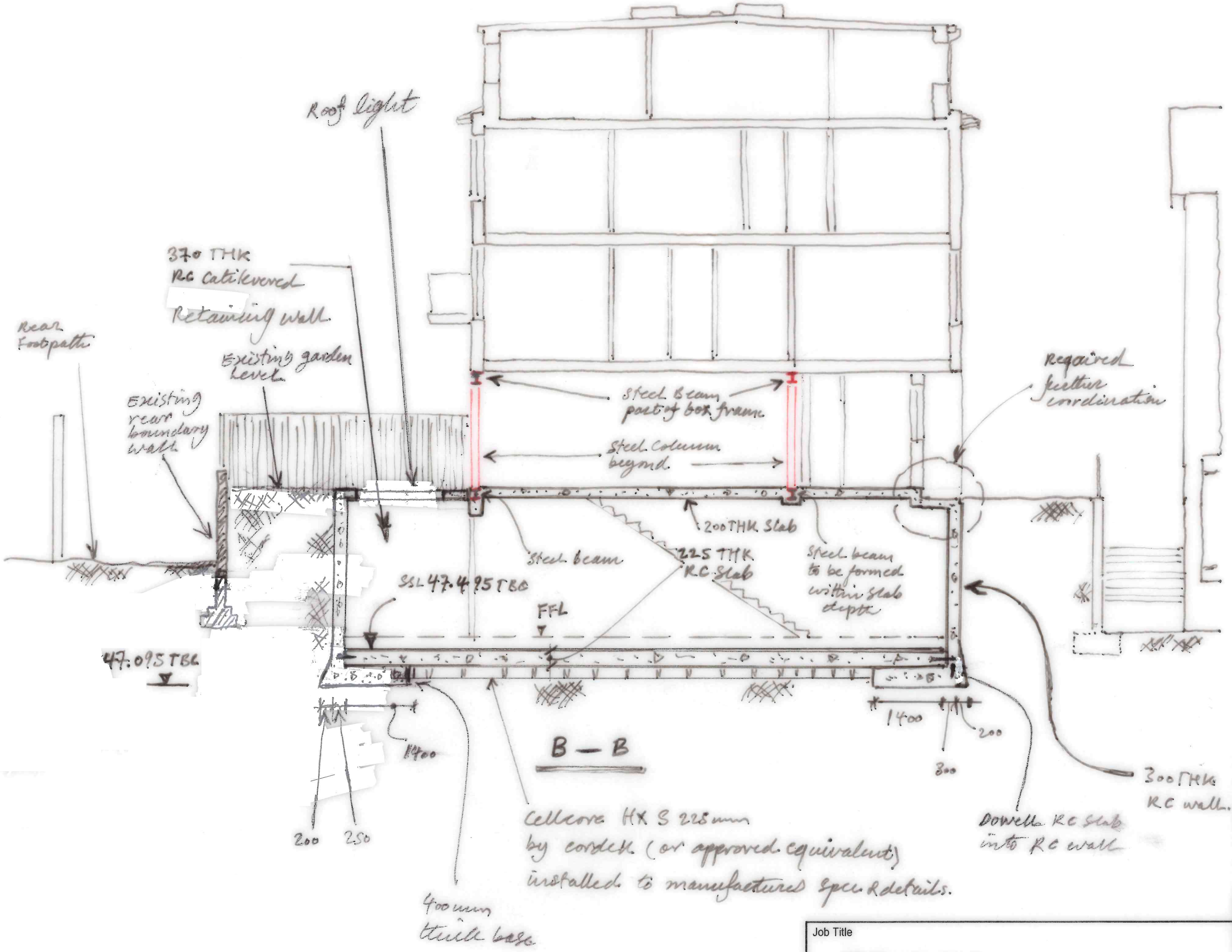

Status/Rev	Description	Date	By
P2	updated to reflect architects revised drawings	25.11.19	
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Job Title

38 Meadowbank

Proposed Ground Floor
Long Section (typical)

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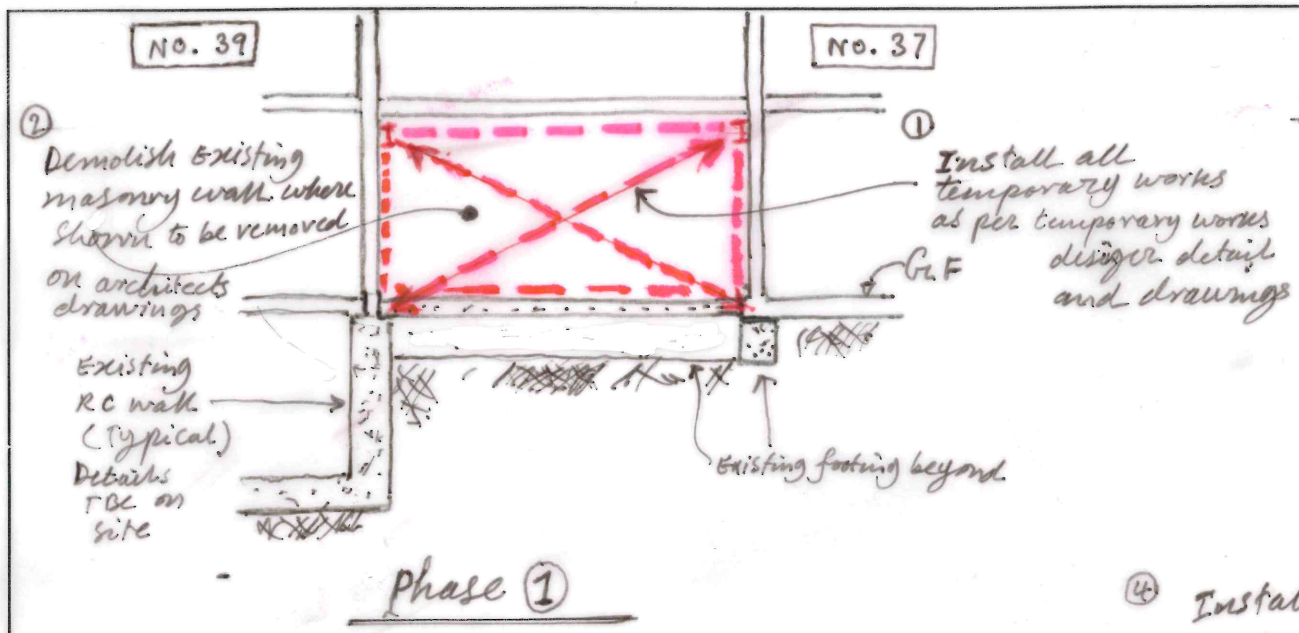

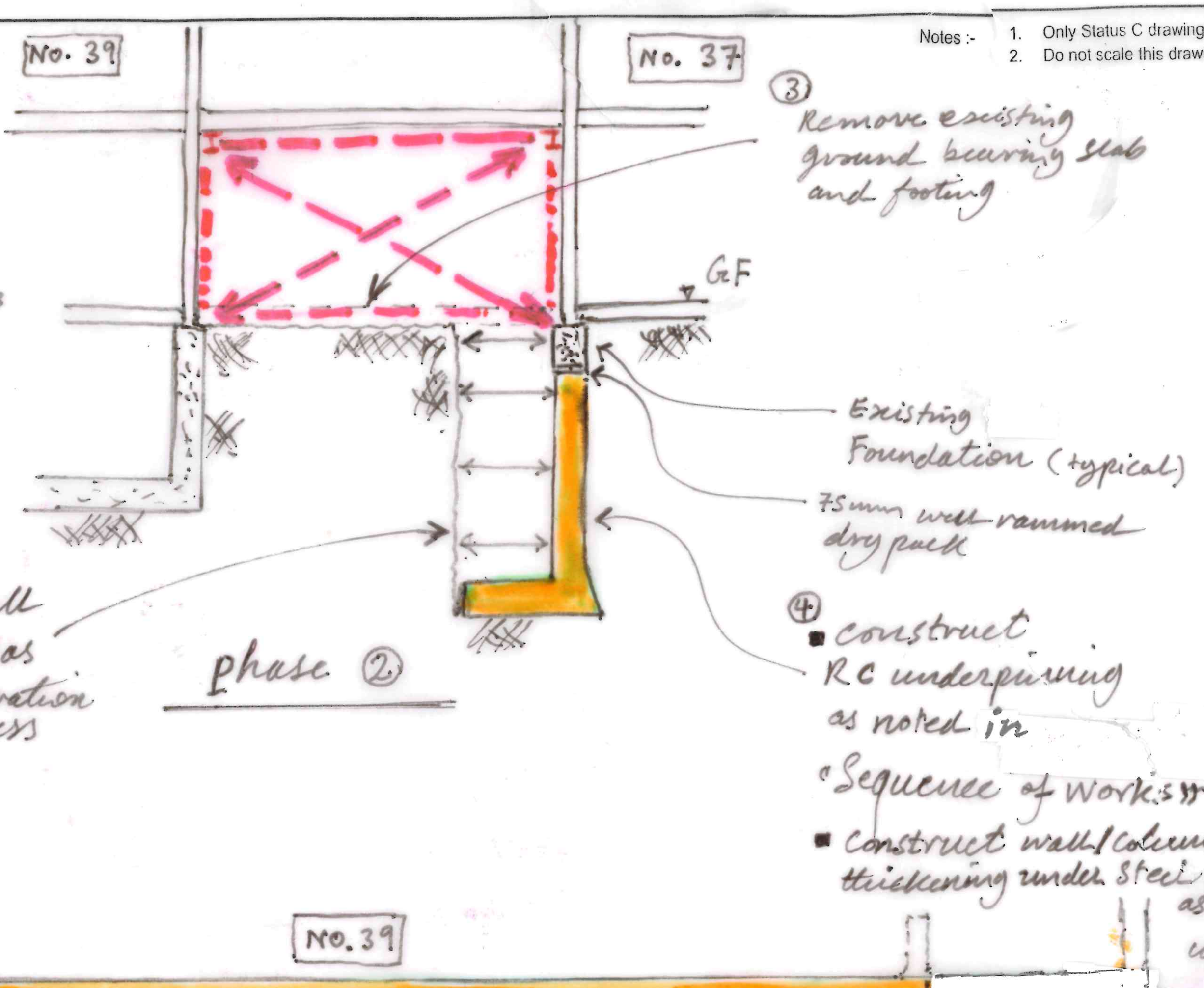

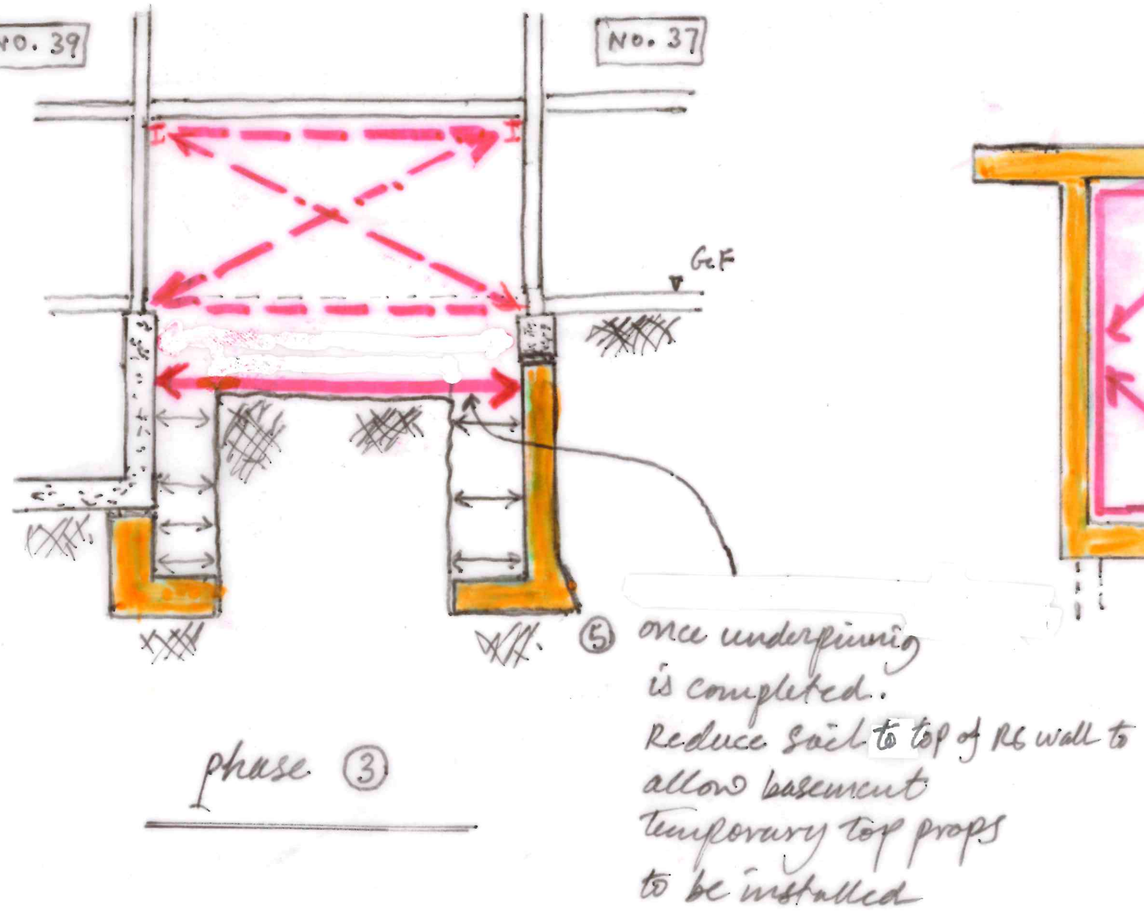

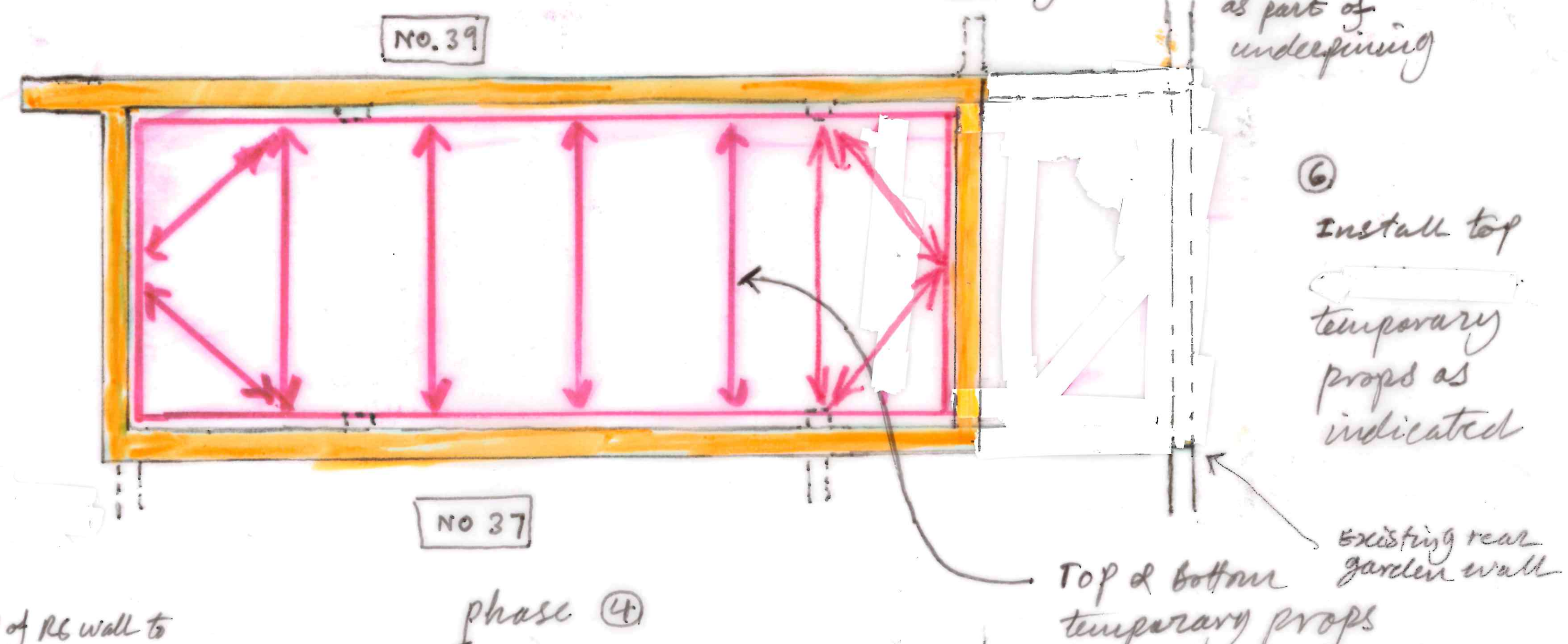

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Job Title

38 Meadowbank

Proposed Construction Sequence
Sheet 1

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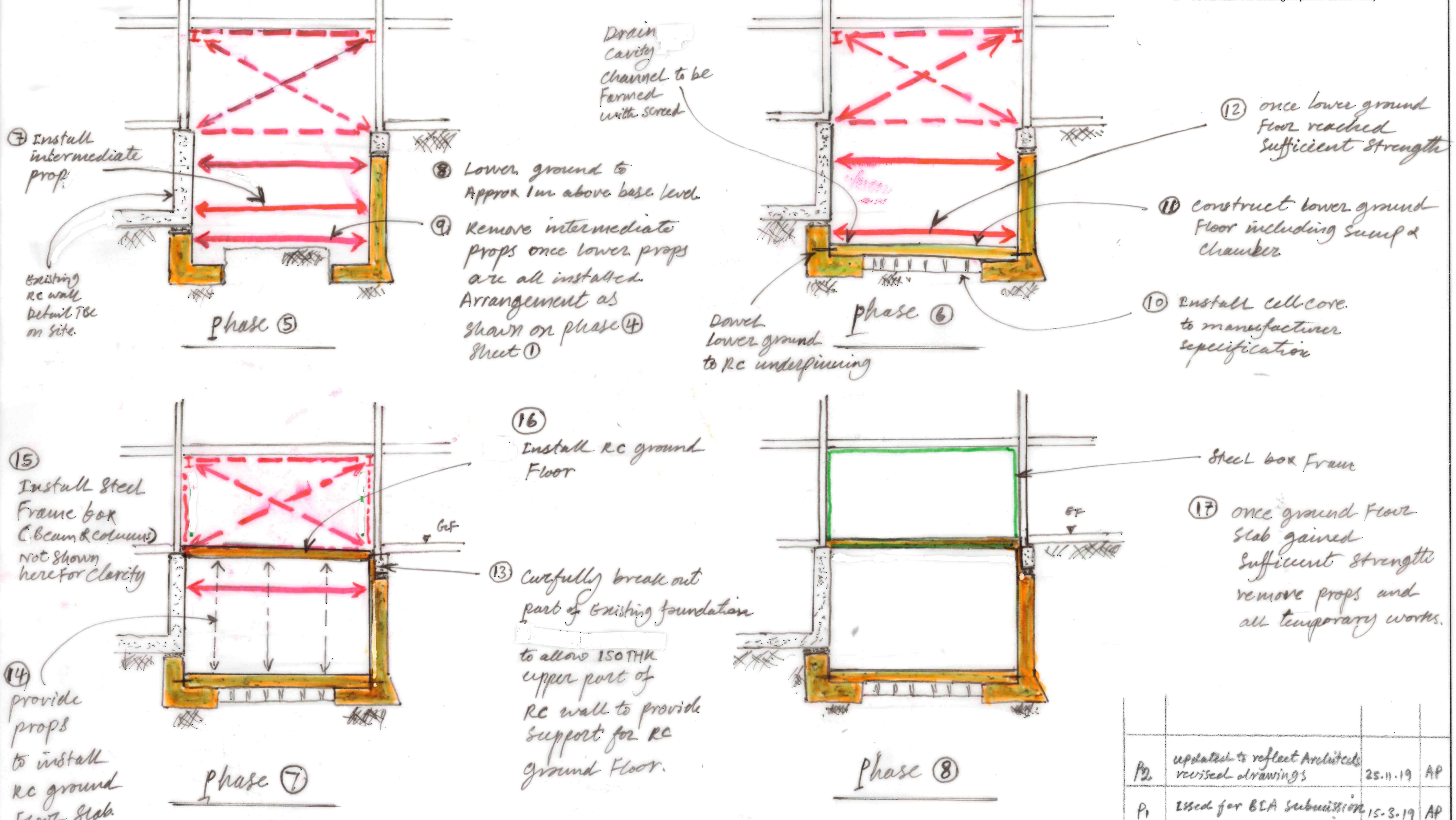

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Note ⚠

For rear garden RC wall, at phase ⑥/⑦ once RC underpins gained sufficient strength remove all props.

Job Title

38 Meadowbank

Proposed Construction Sequence
Sheet 2

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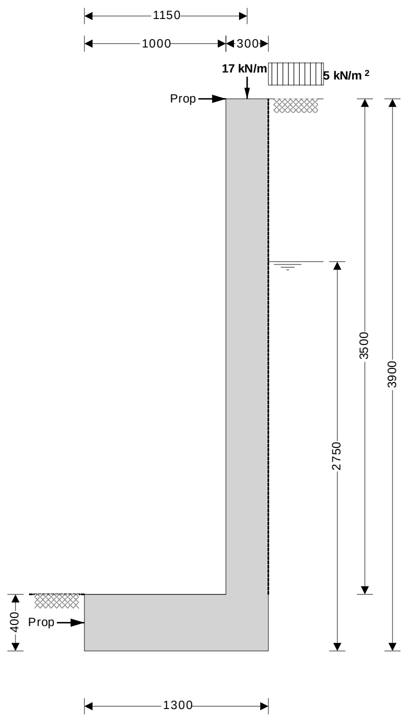
Appendix 2: Outline Calculations

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type — **Cantilever propped at both**

Height of retaining wall stem — h_{stem} = **3500** mm

Thickness of wall stem — t_{wall} = **300** mm

Length of toe — l_{toe} = **1000** mm

Length of heel — l_{heel} = **0** mm

Overall length of base — $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1300** mm

Thickness of base — t_{base} = **400** mm

Depth of downstand — d_{ds} = **0** mm

Position of downstand — l_{ds} = **800** mm

Thickness of downstand — t_{ds} = **400** mm

Height of retaining wall — $h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3900** mm

Depth of cover in front of wall — d_{cover} = **0** mm

Depth of unplanned excavation — d_{exc} = **0** mm

Height of ground water behind wall — h_{water} = **2750** mm

Height of saturated fill above base — $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **2350** 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 — $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3900** mm

Retained material details

Mobilisation factor — M = **1.5**

Moist density of retained material — γ_m = **19.0** kN/m^3

Saturated density of retained material γ_s = **21.5** kN/m^3

Design shear strength ϕ' = **25.8** deg

Angle of wall friction δ = **19.9** deg

Base material details

Firm clay

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

Design shear strength ϕ'_b = **22.6** deg

Design base friction δ_b = **17.3** deg

Allowable bearing pressure $P_{bearing}$ = **135** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.347}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{3.690}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi')$ = **0.565**

Loading details

Surcharge load on plan Surcharge = **5.0** kN/m^2

Applied vertical dead load on wall W_{dead} = **12.0** kN/m

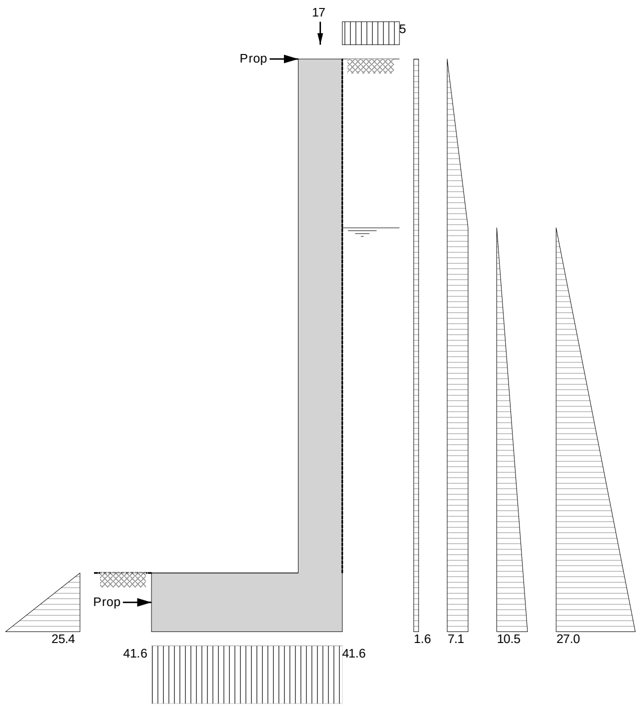
Applied vertical live load on wall W_{live} = **5.0** kN/m

Position of applied vertical load on wall l_{load} = **1150** 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 $W_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **24.8** kN/m

Wall base $W_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **12.3** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **17** kN/m

Total vertical load $W_{total} = W_{wall} + W_{base} + W_v$ = **54.1** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **6.4** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **4.1** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **19.6** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **14.4** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **37.1** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **81.6** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.1** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **61.3** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **12.4** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **12.9** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **27** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **13.2** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **34** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **99.5** kNm/m

Restoring moments

Wall stem $M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2)$ = **28.5** kNm/m

Wall base $M_{base} = W_{base} \times l_{base} / 2$ = **8** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load}$ = **13.8** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **50.3** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **54.1** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **650** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **41.6** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **41.6** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **19.483** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **41.783** kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor $\gamma_{f\_d} = \mathbf{1.4}$

Live load factor $\gamma_{f\_l} = \mathbf{1.6}$

Earth and water pressure factor $\gamma_{f\_e} = \mathbf{1.4}$

Factored vertical forces on wall

Wall stem $W_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall} = \mathbf{34.7}$ kN/m

Wall base $W_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base} = \mathbf{17.2}$ kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live} = \mathbf{24.8}$ kN/m

Total vertical load $W_{total\_f} = W_{wall\_f} + W_{base\_f} + W_{v\_f} = \mathbf{76.7}$ kN/m

Factored horizontal active forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff} = \mathbf{10.2}$ kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2 = \mathbf{5.7}$ kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water} = \mathbf{27.5}$ kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2 = \mathbf{20.2}$ kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water} = \mathbf{51.9}$ kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f} = \mathbf{115.5}$ kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = \mathbf{7.1}$ kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

$F_{prop\_f} = \mathbf{87.0}$ kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2 = \mathbf{19.9}$ kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = \mathbf{18}$ kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2 = \mathbf{37.8}$ kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3 = \mathbf{18.5}$ kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3 = \mathbf{47.6}$ kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f} = \mathbf{141.8}$ kNm/m

Restoring moments

Wall stem $M_{wall\_f} = W_{wall\_f} \times (l_{toe} + t_{wall} / 2) = \mathbf{39.9}$ kNm/m

Wall base $M_{base\_f} = W_{base\_f} \times l_{base} / 2 = \mathbf{11.2}$ kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load} = \mathbf{28.5}$ kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f} = \mathbf{79.6}$ kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f} = \mathbf{76.7}$ kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2 = \mathbf{650}$ mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f}) = \mathbf{0}$ mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2) = \mathbf{59}$ kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2) = \mathbf{59}$ kN/m^2

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base} = \mathbf{0.00}$ kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2) = \mathbf{59}\ kN/m^2$

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{59}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{59}\ kN/m^2$

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{25.568}\ kN/m$

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{61.479}\ kN/m$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{30}\ N/mm^2$

Characteristic strength of reinforcement $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement $k = \mathbf{0.13}\ \%$

Cover to reinforcement in toe $c_{toe} = \mathbf{50}\ mm$

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{59}\ kN/m$

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{13.2}\ kN/m$

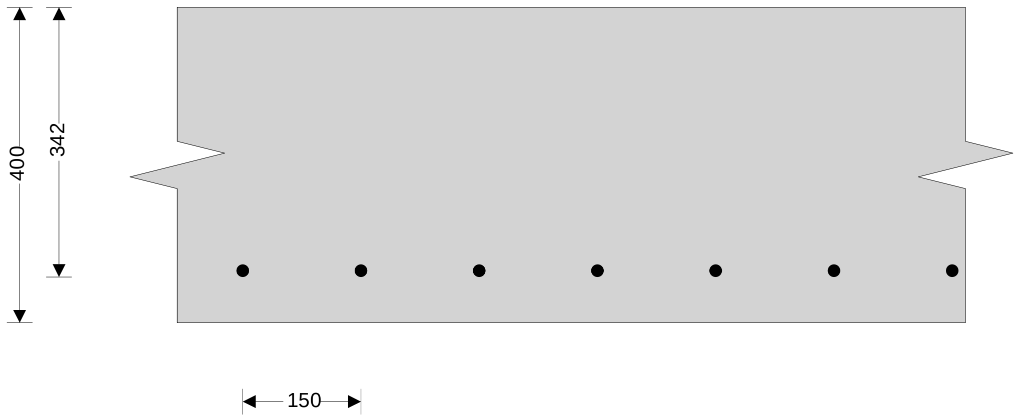
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{45.8}\ kN/m$

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{39}\ kNm/m$

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{8.7}\ kNm/m$

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{30.3}\ kNm/m$



Check toe in bending

Width of toe $b = \mathbf{1000}\ mm/m$

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{342.0}\ mm$

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.009}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{325}\ mm$

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{214}\ mm^2/m$

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

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

Reinforcement provided — **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided — $A_{s\_toe\_prov}$ = **1340** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.134** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2$ = **4.382** 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} = **0.511** N/mm^2

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

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

Material properties

Characteristic strength of concrete — f_{cu} = **30** 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} = **100** mm

Cover to reinforcement in wall — c_{wall} = **50** mm

Factored horizontal active forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **9.1** kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **5.7** kN/m

Moist backfill below water table — $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **23.5** kN/m

Saturated backfill — $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **14.8** kN/m

Water — $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **37.9** kN/m

Calculate shear for stem design

Surcharge — $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **5.7** kN/m

Moist backfill above water table — $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **1.8** kN/m

Moist backfill below water table — $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8$ = **18.9** kN/m

Saturated backfill — $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **13.2** kN/m

Water — $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **34** kN/m

Total shear for stem design — $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **73.6** kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **4.2** kNm/m

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **2.1** kNm/m

Moist backfill below water table — $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8$ = **12.9** kNm/m

Saturated backfill — $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **7** kNm/m

Water — $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **17.9** kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **44** kNm/m

Calculate moment for wall design

Surcharge — $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **2.4** kNm/m

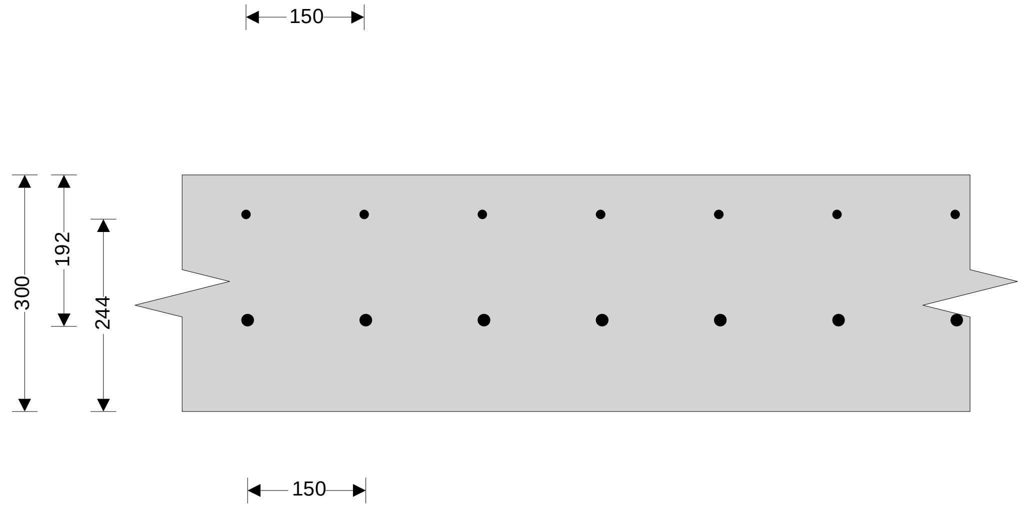
Moist backfill above water table — $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3+5 \times a_l \times L^2)/(5 \times L^3)-0.577^2/3] = \mathbf{2.2}$ kNm/m

Moist backfill below water table — $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8-n^2 \times (4-n))^2 /16)-4+n \times (4-n)]/8 = \mathbf{6.5}$ kNm/m

Saturated backfill — $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)] = \mathbf{2.6}$ kNm/m

Water — $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)] = \mathbf{6.6}$ kNm/m

Total moment for wall design — $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water} = \mathbf{20.2}$ kNm/m



Check wall stem in bending

Width of wall stem — $b = \mathbf{1000}$ mm/m

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2) = \mathbf{192.0}$ mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = \mathbf{0.040}$

Compression reinforcement is not required

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

$z_{stem} = \mathbf{182}$ mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem}) = \mathbf{554}$ mm^2/m

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

Area of tension reinforcement required — $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{554}$ mm^2/m

Reinforcement provided — **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided — $A_{s\_stem\_prov} = \mathbf{1340}$ mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.383}$ N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{4.382}$ 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 — $v_{c\_stem} = \mathbf{0.716}$ N/mm^2

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

Check mid height of wall in bending

Depth of reinforcement — $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2) = \mathbf{244.0}$ mm

Constant — $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu}) = \mathbf{0.011}$

Compression reinforcement is not required

Lever arm z_{wall} = Min(0.5 + √(0.25 - (min(K_{wall}, 0.225) / 0.9)),0.95) × d_{wall}

z_{wall} = **232** mm

Area of tension reinforcement required $A_{s\_wall\_des}$ = M_{wall} / (0.87 × f_y × z_{wall}) = **200** mm^2/m

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

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

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov}$ = **754** mm^2/m

PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas}$ = **20**

Design service stress f_s = 2 × f_y × $A_{s\_stem\_req}$ / (3 × $A_{s\_stem\_prov}$) = **137.8** N/mm^2

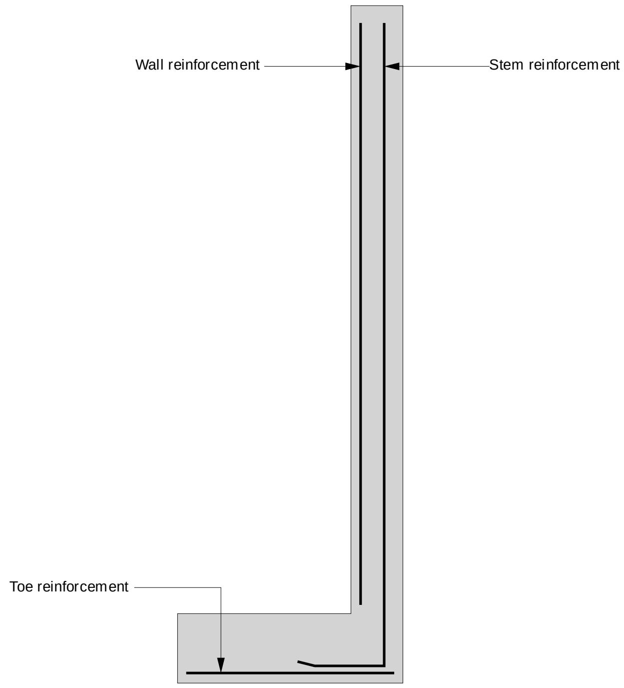
Modification factor $factor_{tens}$ = min(0.55 + (477 N/mm^2 - f_s)/(120 × (0.9 N/mm^2 + (M_{stem}/(b × d_{stem}^2)))),2) = **1.90**

Maximum span/effective depth ratio $ratio_{max}$ = $ratio_{bas}$ × $factor_{tens}$ = **38.01**

Actual span/effective depth ratio $ratio_{act}$ = h_{stem} / d_{stem} = **18.23**

PASS - Span to depth ratio is acceptable

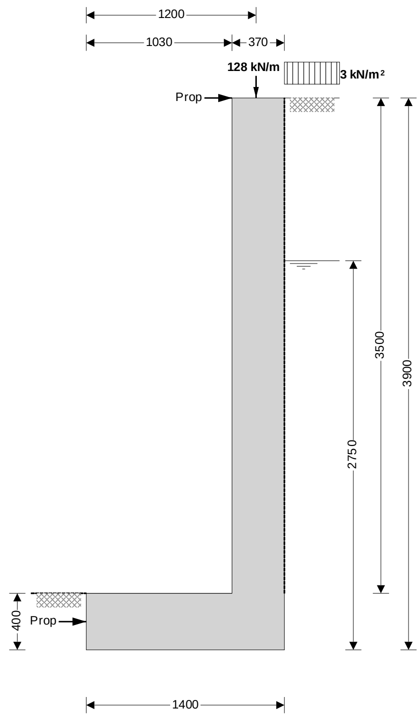
Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)
Wall bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)
Stem bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **3500** mm
Thickness of wall stem	t_{wall} = **370** mm
Length of toe	l_{toe} = **1030** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1400** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **800** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3900** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **2750** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **2350** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3900** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **19.0** kN/m^3

Saturated density of retained material γ_s = **21.5** kN/m^3

Design shear strength ϕ' = **25.8** deg

Angle of wall friction δ = **19.9** deg

Base material details

Firm clay

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

Design shear strength ϕ'_b = **22.6** deg

Design base friction δ_b = **17.3** deg

Allowable bearing pressure $P_{bearing}$ = **135** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.347}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{3.690}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi')$ = **0.565**

Loading details

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

Applied vertical dead load on wall W_{dead} = **98.0** kN/m

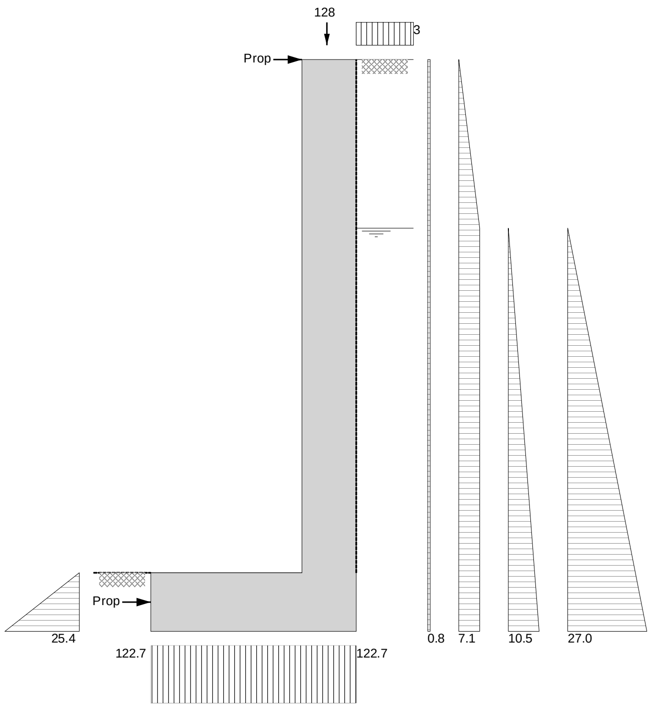
Applied vertical live load on wall W_{live} = **30.0** kN/m

Position of applied vertical load on wall l_{load} = **1200** 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 — $W_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **30.6** kN/m

Wall base — $W_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **13.2** kN/m

Applied vertical load — $W_v = W_{dead} + W_{live}$ = **128** kN/m

Total vertical load — $W_{total} = W_{wall} + W_{base} + W_v$ = **171.8** kN/m

Horizontal forces on wall

Surcharge — $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **3.2** kN/m

Moist backfill above water table — $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **4.1** kN/m

Moist backfill below water table — $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **19.6** kN/m

Saturated backfill — $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **14.4** kN/m

Water — $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **37.1** kN/m

Total horizontal load — $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **78.4** kN/m

Calculate total propping force

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.1** kN/m

Propping force — $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0\ \text{kN/m})$

F_{prop} = **29.2** kN/m

Overturning moments

Surcharge — $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **6.2** kNm/m

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **12.9** kNm/m

Moist backfill below water table — $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **27** kNm/m

Saturated backfill — $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **13.2** kNm/m

Water — $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **34** kNm/m

Total overturning moment — $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **93.3** kNm/m

Restoring moments

Wall stem — $M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2)$ = **37.1** kNm/m

Wall base — $M_{base} = W_{base} \times l_{base} / 2$ = **9.3** kNm/m

Design vertical dead load — $M_{dead} = W_{dead} \times l_{load}$ = **117.6** kNm/m

Total restoring moment — $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **164** kNm/m

Check bearing pressure

Total vertical reaction — $R = W_{total}$ = **171.8** kN/m

Distance to reaction — $x_{bar} = l_{base} / 2$ = **700** mm

Eccentricity of reaction — $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe — $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **122.7** kN/m²

Bearing pressure at heel — $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **122.7** kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **11.809** kN/m

Propping force to base of wall — $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **17.393** kN/m

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 $W_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **42.8** kN/m

Wall base $W_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **18.5** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **185.2** kN/m

Total vertical load $W_{total\_f} = W_{wall\_f} + W_{base\_f} + W_{v\_f}$ = **246.5** kN/m

Factored horizontal active forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **5.1** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **5.7** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **27.5** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **20.2** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **51.9** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **110.4** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **7.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0\ kN/m)$

F_{prop_f} = **41.5** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **9.9** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **18** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **37.8** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **18.5** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **47.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **131.8** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = W_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **52** kNm/m

Wall base $M_{base\_f} = W_{base\_f} \times l_{base} / 2$ = **13** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **222.2** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **287.2** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **246.5** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **700** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **176.1** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **176.1** kN/m^2

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2) = \mathbf{176.1}\ kN/m^2$

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{176.1}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{176.1}\ kN/m^2$

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{2.402}\ kN/m$

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{39.118}\ kN/m$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{30}\ N/mm^2$

Characteristic strength of reinforcement $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement $k = \mathbf{0.13}\ \%$

Cover to reinforcement in toe $c_{toe} = \mathbf{50}\ mm$

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{181.3}\ kN/m$

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{13.6}\ kN/m$

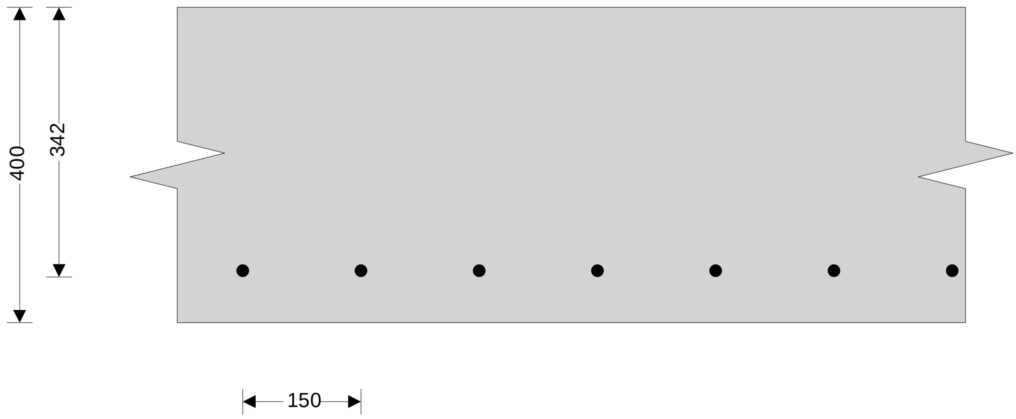
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{167.7}\ kN/m$

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{130}\ kNm/m$

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{9.8}\ kNm/m$

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{120.2}\ kNm/m$



Check toe in bending

Width of toe $b = \mathbf{1000}\ mm/m$

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{342.0}\ mm$

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.034}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{325}\ mm$

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{850}\ mm^2/m$

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

Area of tension reinforcement required $A_{s\_toe\_req} = \mathrm{Max}(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{850}\ mm^2/m$

Reinforcement provided — **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided — $A_{s\_toe\_prov}$ = **1340** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.490** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2$ = **4.382** 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} = **0.511** N/mm^2

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

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

Material properties

Characteristic strength of concrete — f_{cu} = **30** 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} = **100** mm

Cover to reinforcement in wall — c_{wall} = **50** mm

Factored horizontal active forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **4.6** kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **5.7** kN/m

Moist backfill below water table — $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **23.5** kN/m

Saturated backfill — $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **14.8** kN/m

Water — $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **37.9** kN/m

Calculate shear for stem design

Surcharge — $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **2.9** kN/m

Moist backfill above water table — $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **1.8** kN/m

Moist backfill below water table — $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8$ = **18.9** kN/m

Saturated backfill — $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **13.2** kN/m

Water — $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **34** kN/m

Total shear for stem design — $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **70.8** kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **2.1** kNm/m

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **2.1** kNm/m

Moist backfill below water table — $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8$ = **12.9** kNm/m

Saturated backfill — $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **7** kNm/m

Water — $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **17.9** kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **41.9** kNm/m

Calculate moment for wall design

Surcharge — $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **1.2** kNm/m

Tekla Tedds Campbell Reith Friars Bridge Court 41-45 Blackfriars Road London SE1 8NZ	Project 38 Meadowbank				Job no. 13065	
	Calcs for RC retaining wall for party wall No. 37 & 38				Start page no./Revision 7	
	Calcs by AP	Calcs date 14/03/2019	Checked by	Checked date	Approved by	Approved date

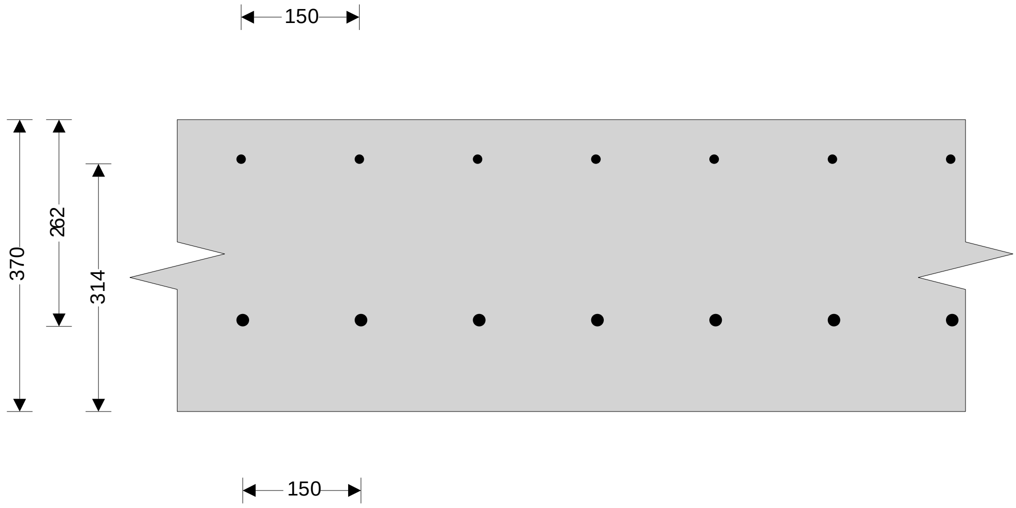
Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3+5 \times a_l \times L^2)/(5 \times L^3)-0.577^2/3]$ = **2.2** kNm/m

Moist backfill below water table $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8-n^2 \times (4-n))^2 /16)-4+n \times (4-n)]/8$ = **6.5** kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **2.6** kNm/m

Water $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **6.6** kNm/m

Total moment for wall design $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water}$ = **19** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **262.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.020**

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} = **249** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **387** mm²/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **481** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **481** mm²/m

Reinforcement provided **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **1340** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.270** N/mm²

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.382** 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} = **0.597** N/mm²

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

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **314.0** mm

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

Compression reinforcement is not required

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

$z_{wall} =$ **298** mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall}) =$ **147** mm^2/m

Minimum area of tension reinforcement $A_{s\_wall\_min} = k \times b \times t_{wall} =$ **481** mm^2/m

Area of tension reinforcement required $A_{s\_wall\_req} = \mathrm{Max}(A_{s\_wall\_des}, A_{s\_wall\_min}) =$ **481** mm^2/m

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov} =$ **754** mm^2/m

PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas} =$ **20**

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) =$ **119.6** N/mm^2

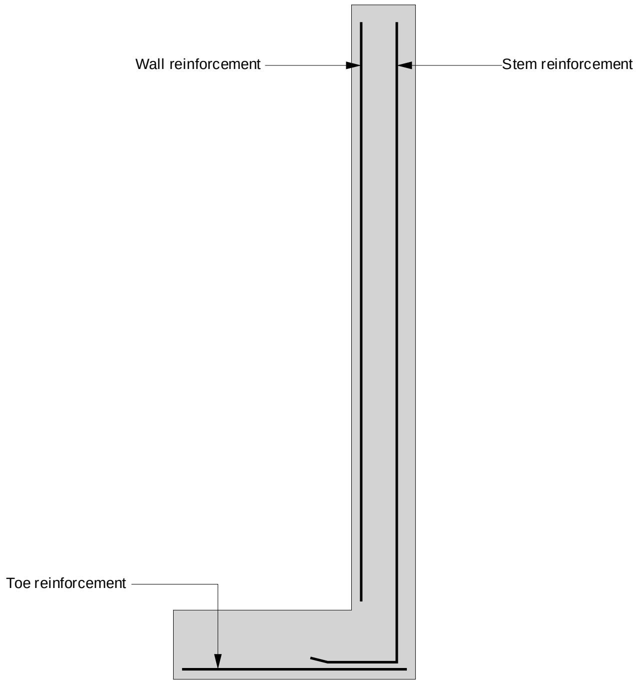
Modification factor $factor_{tens} = \min(0.55 + (477\text{ N/mm}^2 - f_s)/(120 \times (0.9\text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))), 2) =$ **2.00**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens} =$ **40.00**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem} =$ **13.36**

PASS - Span to depth ratio is acceptable

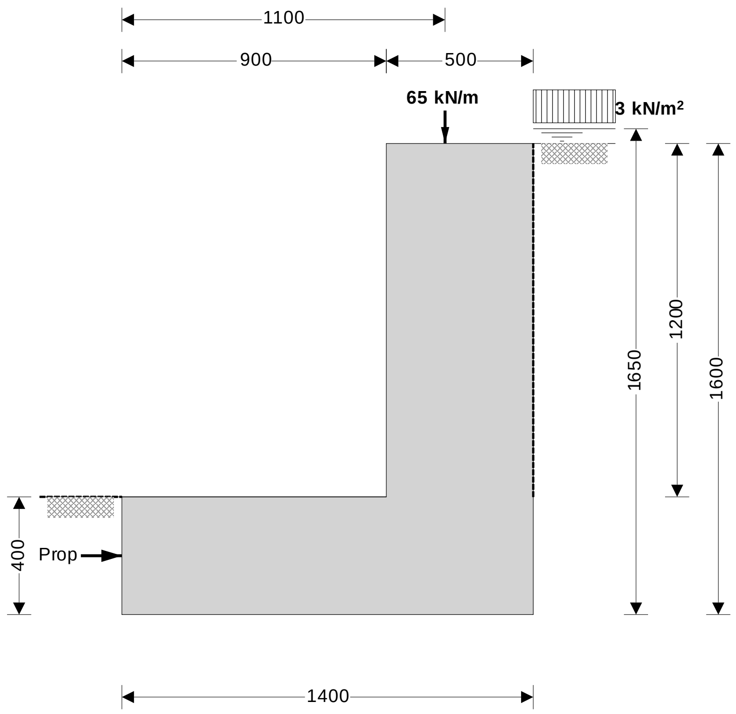
Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)
Wall bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)
Stem bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at base**
Height of retaining wall stem	h_{stem} = **1200** mm
Thickness of wall stem	t_{wall} = **500** mm
Length of toe	l_{toe} = **900** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1400** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **450** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **1600** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **1650** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **1250** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **1600** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **19.0** kN/m^3

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	Calcs for				Start page no./Revision	
	Underpinning under RC wall between No. 38 & 39				2	
	Calcs by	Calcs date	Checked by	Checked date	Approved by	Approved date
	AP	14/03/2019				

Saturated density of retained material γ_s = **21.5** kN/m^3

Design shear strength ϕ' = **25.8** deg

Angle of wall friction δ = **19.9** deg

Base material details

Firm clay

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

Design shear strength ϕ'_b = **22.6** deg

Design base friction δ_b = **17.3** deg

Allowable bearing pressure $P_{bearing}$ = **135** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.347}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{3.690}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 – \sin(\phi')$ = **0.565**

Loading details

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

Applied vertical dead load on wall W_{dead} = **50.0** kN/m

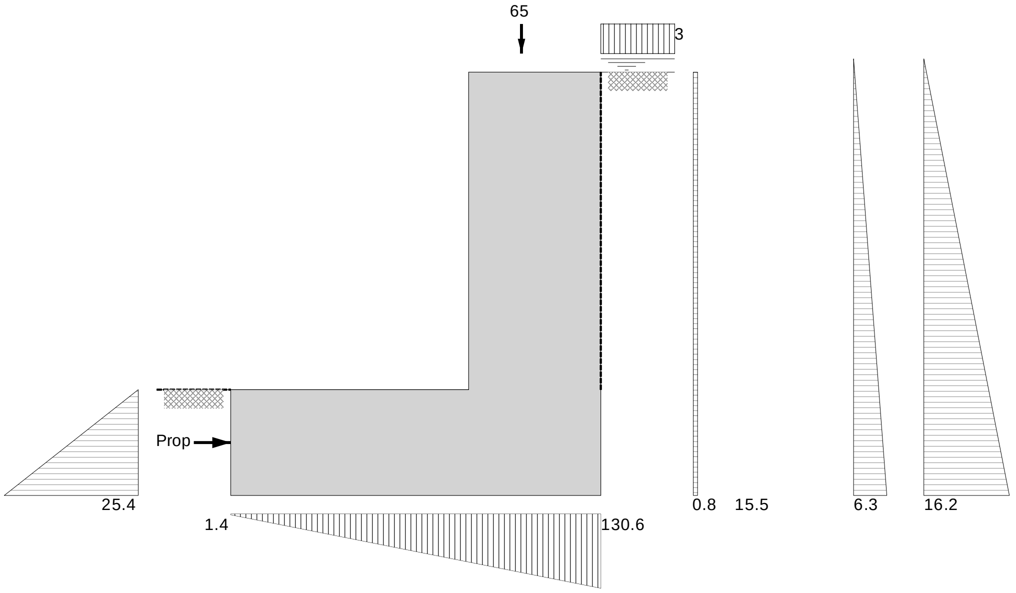
Applied vertical live load on wall W_{live} = **15.0** kN/m

Position of applied vertical load on wall l_{load} = **1100** 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 $W_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **14.2** kN/m

Wall base $W_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **13.2** kN/m

Applied vertical load $W_v = W_{dead} + W_{live} =$ **65** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v =$ **92.4** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff} =$ **1.3** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2 =$ **0** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2 =$ **5.2** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water} =$ **13.4** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_s + F_{water} =$ **19.9** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} =$ **5.1** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

$F_{prop} =$ **0.0** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 =$ **1** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 =$ **0** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3 =$ **2.9** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3 =$ **7.3** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_s + M_{water} =$ **11.3** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2) =$ **16.3** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2 =$ **9.3** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load} =$ **55** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead} =$ **80.5** kNm/m

Check bearing pressure

Design vertical live load $M_{live} = W_{live} \times l_{load} =$ **16.5** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{live} =$ **85.8** kNm/m

Total vertical reaction $R = W_{total} =$ **92.4** kN/m

Distance to reaction $x_{bar} = M_{total} / R =$ **929** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar}) =$ **229** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) =$ **1.4** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) =$ **130.6** 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 $W_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **19.8** kN/m

Wall base $W_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **18.5** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **94** kN/m

Total vertical load $W_{total\_f} = W_{wall\_f} + W_{base\_f} + W_{v\_f}$ = **132.3** kN/m

Factored horizontal active forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff}$ = **2.1** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **0** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **7.3** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **18.7** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{s\_f} + F_{water\_f}$ = **28.1** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **7.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **0.0** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **1.7** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **0** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **4** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **10.3** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{s\_f} + M_{water\_f}$ = **16** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = W_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **22.8** kNm/m

Wall base $M_{base\_f} = W_{base\_f} \times l_{base} / 2$ = **13** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **103.4** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **139.1** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **123.2** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **132.3** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **931** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **231** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **1** kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **188** kN/m²

Rate of change of base reaction $\text{rate} = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **-133.59** kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{heel\_f} + (\text{rate} \times (l_{heel} + t_{wall})), 0 \text{ kN/m}^2)$ = **121.2** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{heel\_f} + (rate \times (l_{heel} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{154.6}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{heel\_f} + (rate \times l_{heel}), 0\ kN/m^2) = \mathbf{188}\ kN/m^2$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{30}\ N/mm^2$

Characteristic strength of reinforcement $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement $k = \mathbf{0.13}\ \%$

Cover to reinforcement in toe $c_{toe} = \mathbf{50}\ mm$

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{55}\ kN/m$

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{11.9}\ kN/m$

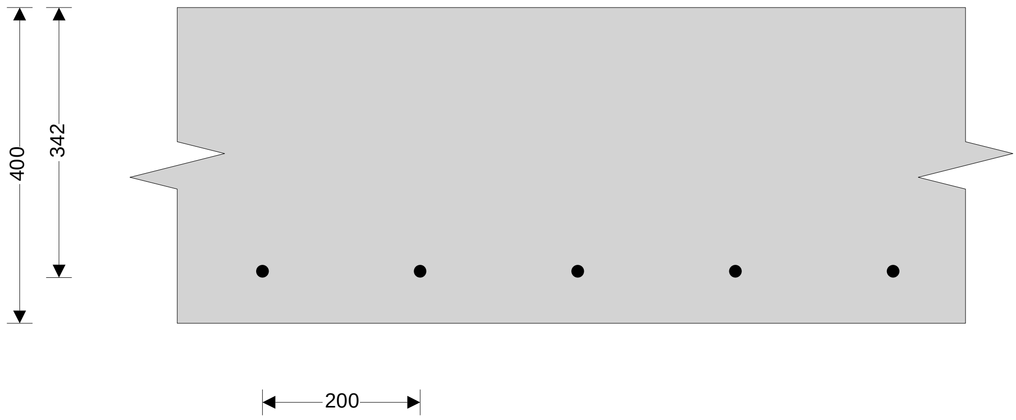
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{43.1}\ kN/m$

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{34.5}\ kNm/m$

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{8.7}\ kNm/m$

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{25.8}\ kNm/m$



Check toe in bending

Width of toe $b = \mathbf{1000}\ mm/m$

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{342.0}\ mm$

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.007}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{325}\ mm$

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{182}\ mm^2/m$

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

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

Reinforcement provided **16 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov} = \mathbf{1005}\ mm^2/m$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.126}\ N/mm^2$

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \text{N/mm}^2)}, 5) \times 1\ \text{N/mm}^2 = \mathbf{4.382}\ \text{N/mm}^2$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_toe} = \mathbf{0.464}\ \text{N/mm}^2$

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

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{30}\ \text{N/mm}^2$

Characteristic strength of reinforcement $f_y = \mathbf{500}\ \text{N/mm}^2$

Wall details

Minimum area of reinforcement $k = \mathbf{0.13}\ \%$

Cover to reinforcement in stem $c_{stem} = \mathbf{100}\ \text{mm}$

Cover to reinforcement in wall $c_{wall} = \mathbf{50}\ \text{mm}$

Factored horizontal active forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = \mathbf{1.6}$ kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 =$ **0** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{sat}^2 = \mathbf{4.2}\ \text{kN/m}$

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2 = \mathbf{10.7}\ \text{kN/m}$

Calculate shear for stem design

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_s\_f} + F_{s\_water\_f} = \mathbf{16.5}\ \text{kN/m}$

Calculate moment for stem design

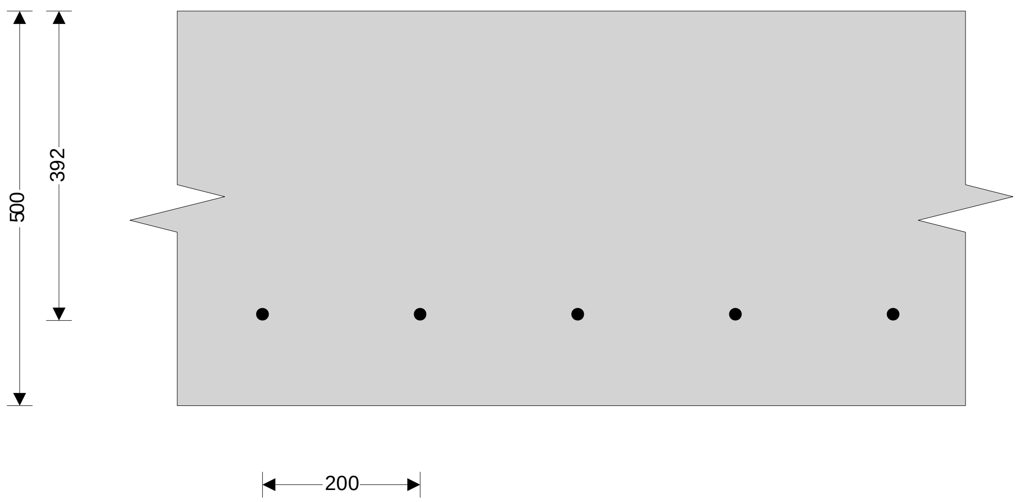
Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2 = \mathbf{1.3}\ \text{kNm/m}$

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = \mathbf{0}\ \text{kNm/m}$

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3 = \mathbf{1.7}\ \text{kNm/m}$

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3 = \mathbf{4.5}\ \text{kNm/m}$

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_s} + M_{s\_water} = \mathbf{7.5}\ \text{kNm/m}$



Check wall stem in bending

Width of wall stem $b = \mathbf{1000}\ \text{mm/m}$

Depth of reinforcement $d_{stem} = t_{wall} – c_{stem} – (\phi_{stem} / 2) = \mathbf{392.0}$ mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = \mathbf{0.002}$

Compression reinforcement is not required

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

$z_{stem} = \mathbf{372}$ mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem}) = \mathbf{46}$ mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall} = \mathbf{650}$ mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = \max(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{650}$ mm^2/m

Reinforcement provided **16 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov} = \mathbf{1005}$ mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.042}$ N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{4.382}$ 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 $v_{c\_stem} = \mathbf{0.429}$ N/mm^2

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

Check retaining wall deflection

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

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) = \mathbf{215.5}$ N/mm^2

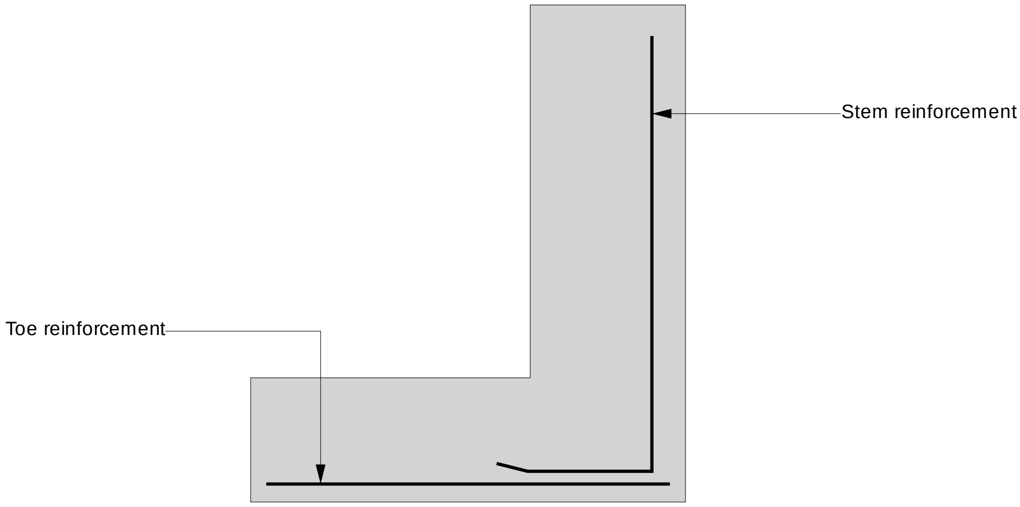
Modification factor $factor_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2) = \mathbf{2.00}$

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

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem} = \mathbf{3.06}$

PASS - Span to depth ratio is acceptable

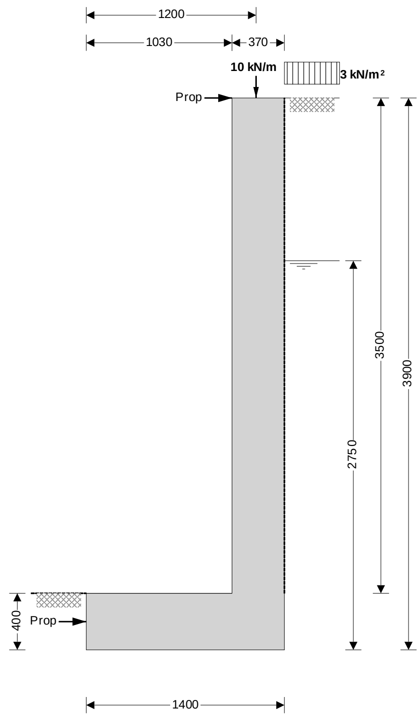
Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 200 mm centres - (1005 mm^2/m)
Stem bars - 16 mm dia.@ 200 mm centres - (1005 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type — **Cantilever propped at both**

Height of retaining wall stem — h_{stem} = **3500** mm

Thickness of wall stem — t_{wall} = **370** mm

Length of toe — l_{toe} = **1030** mm

Length of heel — l_{heel} = **0** mm

Overall length of base — $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1400** mm

Thickness of base — t_{base} = **400** mm

Depth of downstand — d_{ds} = **0** mm

Position of downstand — l_{ds} = **800** mm

Thickness of downstand — t_{ds} = **400** mm

Height of retaining wall — $h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3900** mm

Depth of cover in front of wall — d_{cover} = **0** mm

Depth of unplanned excavation — d_{exc} = **0** mm

Height of ground water behind wall — h_{water} = **2750** mm

Height of saturated fill above base — $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **2350** 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 — $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3900** mm

Retained material details

Mobilisation factor — M = **1.5**

Moist density of retained material — γ_m = **19.0** kN/m^3

Saturated density of retained material — γ_s = **21.5** kN/m^3

Design shear strength — ϕ' = **25.8** deg

Angle of wall friction — δ = **19.9** deg

Base material details

Firm clay

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

Design shear strength — ϕ'_b = **22.6** deg

Design base friction — δ_b = **17.3** deg

Allowable bearing pressure — $P_{bearing}$ = **135** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.347}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{3.690}$$

At-rest pressure

At-rest pressure for retained material — $K_0 = 1 - \sin(\phi')$ = **0.565**

Loading details

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

Applied vertical dead load on wall — W_{dead} = **10.0** kN/m

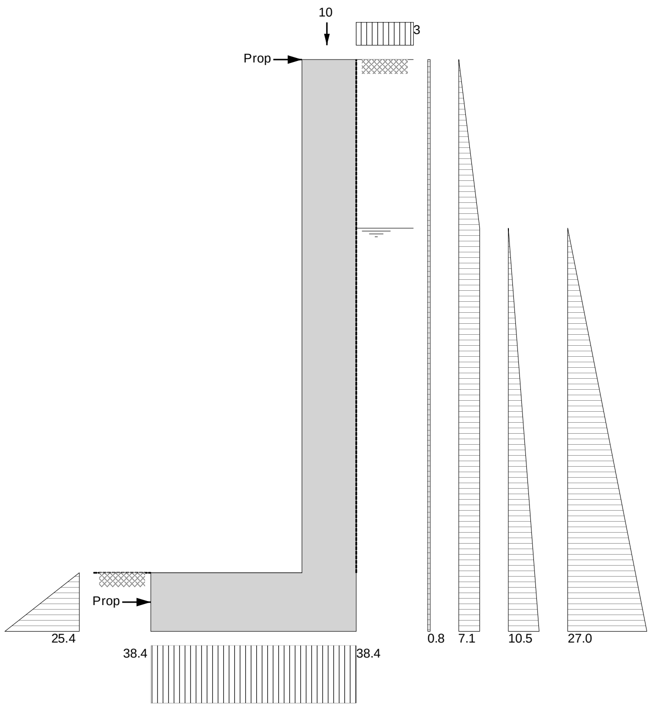
Applied vertical live load on wall — W_{live} = **0.0** kN/m

Position of applied vertical load on wall — l_{load} = **1200** 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 $W_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **30.6** kN/m

Wall base $W_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **13.2** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **10** kN/m

Total vertical load $W_{total} = W_{wall} + W_{base} + W_v$ = **53.8** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff}$ = **3.2** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **4.1** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **19.6** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **14.4** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **37.1** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **78.4** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.1** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **56.6** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **6.2** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **12.9** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **27** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **13.2** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **34** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **93.3** kNm/m

Restoring moments

Wall stem $M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2)$ = **37.1** kNm/m

Wall base $M_{base} = W_{base} \times l_{base} / 2$ = **9.3** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load}$ = **12** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **58.4** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **53.8** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **700** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **38.4** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **38.4** kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **16.544** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **40.067** kN/m

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 $W_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **42.8** kN/m

Wall base $W_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **18.5** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **14** kN/m

Total vertical load $W_{total\_f} = W_{wall\_f} + W_{base\_f} + W_{v\_f}$ = **75.3** kN/m

Factored horizontal active forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff}$ = **5.1** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **5.7** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **27.5** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **20.2** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **51.9** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **110.4** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **7.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **79.9** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **9.9** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **18** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **37.8** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **18.5** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **47.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **131.8** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = W_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **52** kNm/m

Wall base $M_{base\_f} = W_{base\_f} \times l_{base} / 2$ = **13** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **16.8** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **81.7** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **75.3** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **700** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **53.8** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **53.8** kN/m^2

Rate of change of base reaction $\text{rate} = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2) = \mathbf{53.8}\ kN/m^2$

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{53.8}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{53.8}\ kN/m^2$

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{23.463}\ kN/m$

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{56.430}\ kN/m$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{30}\ N/mm^2$

Characteristic strength of reinforcement $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement $k = \mathbf{0.13}\ \%$

Cover to reinforcement in toe $c_{toe} = \mathbf{50}\ mm$

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{55.4}\ kN/m$

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{13.6}\ kN/m$

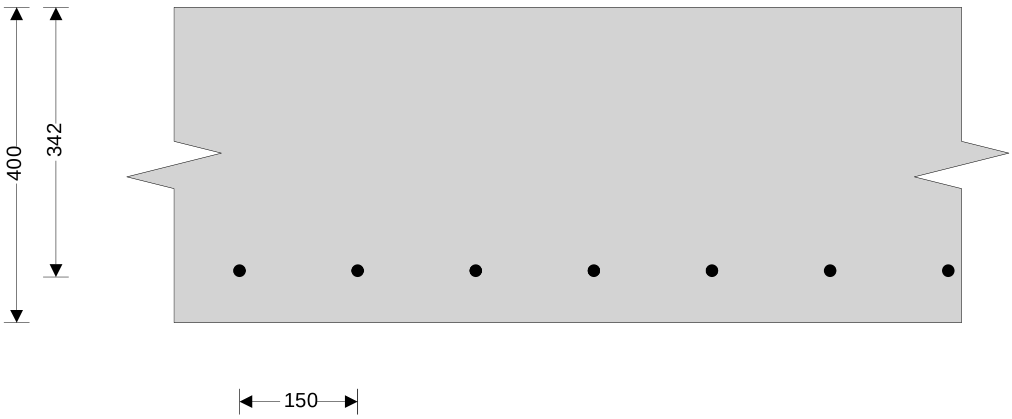
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{41.8}\ kN/m$

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{39.7}\ kNm/m$

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{9.8}\ kNm/m$

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{29.9}\ kNm/m$



Check toe in bending

Width of toe $b = \mathbf{1000}\ mm/m$

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{342.0}\ mm$

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.009}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{325}\ mm$

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{212}\ mm^2/m$

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

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

Reinforcement provided **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **1340** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.122** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **4.382** 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} = **0.511** N/mm^2

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

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

Material properties

Characteristic strength of concrete f_{cu} = **30** 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} = **100** mm

Cover to reinforcement in wall c_{wall} = **50** mm

Factored horizontal active forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **4.6** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **5.7** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **23.5** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **14.8** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **37.9** kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **2.9** kN/m

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **1.8** kN/m

Moist backfill below water table $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8$ = **18.9** kN/m

Saturated backfill $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **13.2** kN/m

Water $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **34** kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **70.8** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **2.1** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **2.1** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8$ = **12.9** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **7** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **17.9** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **41.9** kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **1.2** kNm/m

Tekla Tedds Campbell Reith Friars Bridge Court 41-45 Blackfriars Road London SE1 8NZ	Project 38 Meadowbank				Job no. 13065	
	Calcs for RC retaining wall for rear garden between No. 37 & 38				Start page no./Revision 7	
	Calcs by AP	Calcs date 26/11/2019	Checked by	Checked date	Approved by	Approved date

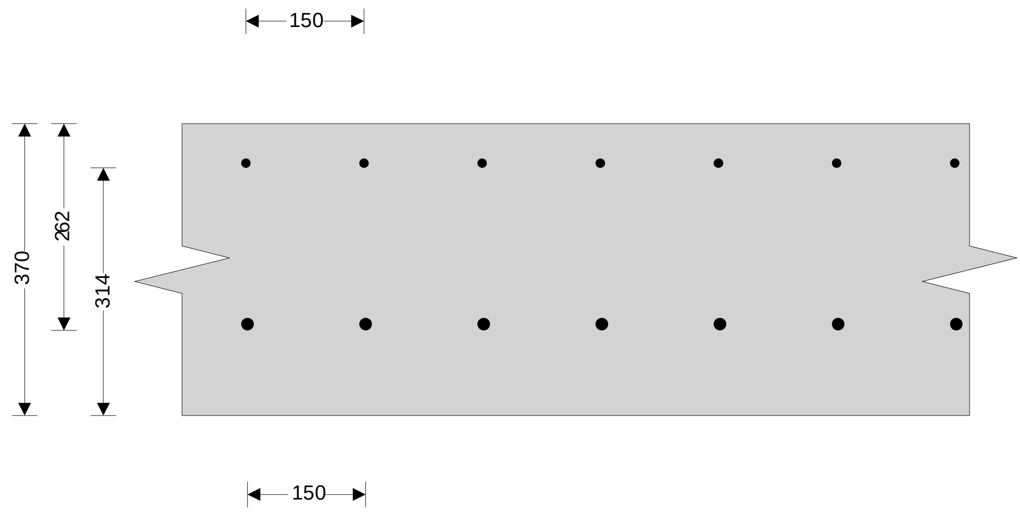
Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3+5 \times a_l \times L^2)/(5 \times L^3)-0.577^2/3]$ = **2.2** kNm/m

Moist backfill below water table $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8-n^2 \times (4-n))^2 /16)-4+n \times (4-n)]/8$ = **6.5** kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **2.6** kNm/m

Water $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **6.6** kNm/m

Total moment for wall design $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water}$ = **19** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **262.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.020**

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} = **249** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **387** mm²/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **481** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **481** mm²/m

Reinforcement provided **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **1340** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.270** N/mm²

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.382** 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} = **0.597** N/mm²

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

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **314.0** mm

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

Compression reinforcement is not required

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

$z_{wall} =$ **298** mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall}) =$ **147** mm^2/m

Minimum area of tension reinforcement $A_{s\_wall\_min} = k \times b \times t_{wall} =$ **481** mm^2/m

Area of tension reinforcement required $A_{s\_wall\_req} = \mathrm{Max}(A_{s\_wall\_des}, A_{s\_wall\_min}) =$ **481** mm^2/m

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov} =$ **754** mm^2/m

PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas} =$ **20**

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) =$ **119.6** N/mm^2

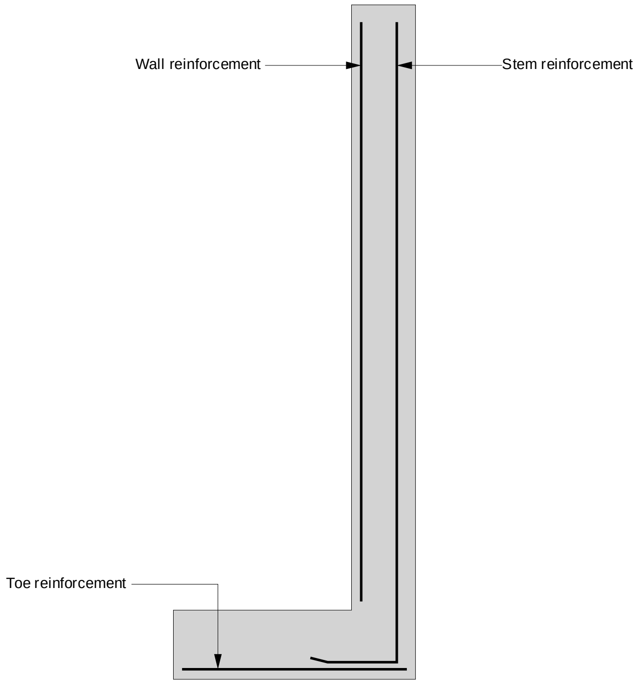
Modification factor $factor_{tens} = \min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2) =$ **2.00**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens} =$ **40.00**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem} =$ **13.36**

PASS - Span to depth ratio is acceptable

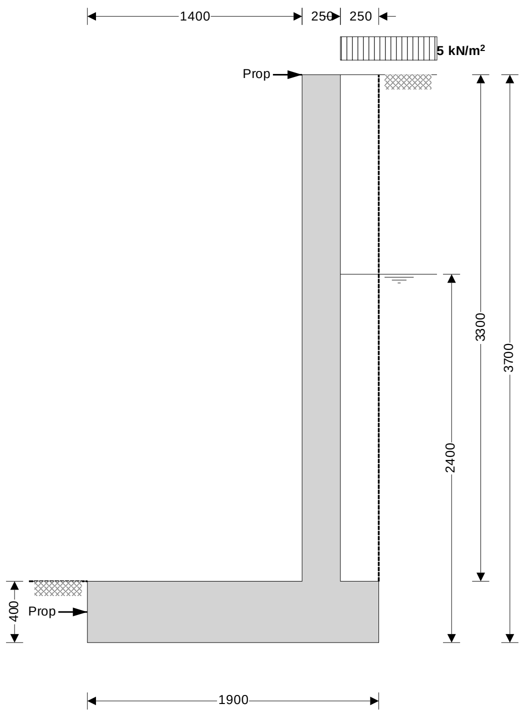
Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)
Wall bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)
Stem bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **3300** mm
Thickness of wall stem	t_{wall} = **250** mm
Length of toe	l_{toe} = **1400** mm
Length of heel	l_{heel} = **250** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1900** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **450** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3700** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **2400** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **2000** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3700** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **19.0** kN/m^3

Saturated density of retained material γ_s = **21.5** kN/m^3

Design shear strength ϕ' = **25.8** deg

Angle of wall friction δ = **19.9** deg

Base material details

Firm clay

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

Design shear strength ϕ'_b = **22.6** deg

Design base friction δ_b = **17.3** deg

Allowable bearing pressure $P_{bearing}$ = **135** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.347}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{3.690}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 – \sin(\phi') = \mathbf{0.565}$

Loading details

Surcharge load on plan Surcharge = **5.0** kN/m^2

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

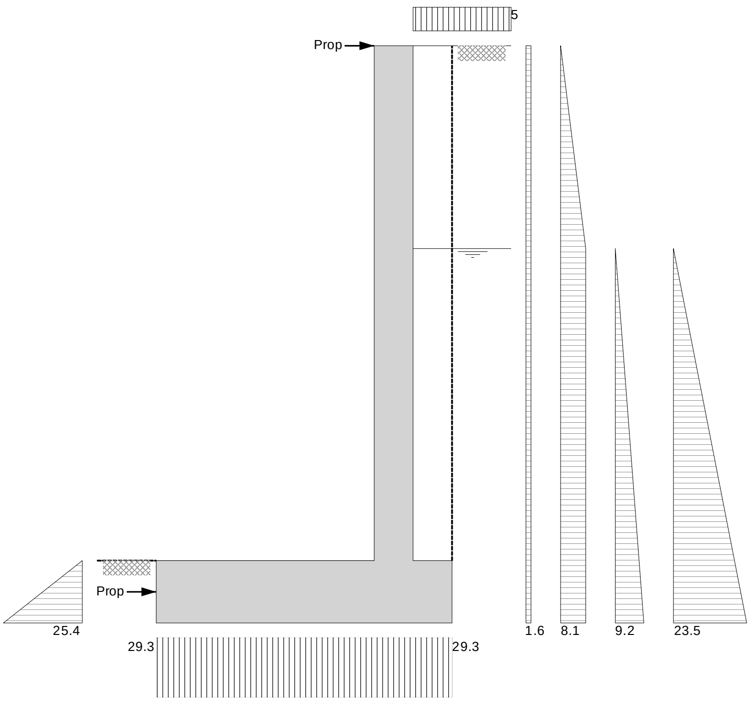
Applied vertical live load on wall W_{live} = **0.0** kN/m

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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **19.5** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **17.9** kN/m

Surcharge w_{sur} = Surcharge $\times\ l_{heel}$ = **1.3** kN/m

Moist backfill to top of wall $w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **6.2** kN/m

Saturated backfill $w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **10.8** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + w_s$ = **55.6** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times\ h_{eff}$ = **6** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **5.2** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **19.4** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **11** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **28.3** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **69.9** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.1** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - w_{sur}) \times \tan(\delta_b), 0\ \text{kN/m})$

F_{prop} = **47.9** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **11.2** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **14.9** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **23.2** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **8.8** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **22.6** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **80.7** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **29.7** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **17** kNm/m

Moist backfill $M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **11** kNm/m

Saturated backfill $M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **19.1** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{m\_r} + M_{s\_r}$ = **76.8** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **55.6** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **950** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **29.3** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **29.3** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **13.458** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **34.432** kN/m

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 $W_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **27.3** kN/m

Wall base $W_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **25.1** kN/m

Surcharge $W_{sur\_f} = \gamma_{f\_l} \times Surcharge \times l_{heel}$ = **2** kN/m

Moist backfill to top of wall $W_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **8.6** kN/m

Saturated backfill $W_{s\_f} = \gamma_{f\_d} \times l_{heel} \times h_{sat} \times \gamma_s$ = **15.1** kN/m

Total vertical load $W_{total\_f} = W_{wall\_f} + W_{base\_f} + W_{sur\_f} + W_{m\_w\_f} + W_{s\_f}$ = **78.1** kN/m

Factored horizontal active forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **9.7** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **7.3** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **27.1**
kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **15.4** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **39.6** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **99** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **7.1**
kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - W_{sur\_f}) \times \tan(\delta_b), 0\ kN/m)$

F_{prop_f} = **68.3** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **17.9** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **20.8** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **32.5** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **12.3** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **31.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **115.2** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = W_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **41.6** kNm/m

Wall base $M_{base\_f} = W_{base\_f} \times l_{base} / 2$ = **23.9** kNm/m

Surcharge $M_{sur\_r\_f} = W_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **3.6** kNm/m

Moist backfill $M_{m\_r\_f} = (W_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + W_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **15.3** kNm/m

Saturated backfill $M_{s\_r\_f} = W_{s\_f} \times (l_{base} - l_{heel} / 2)$ = **26.7** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{sur\_r\_f} + M_{m\_r\_f} + M_{s\_r\_f}$ = **111** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **78.1** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **950** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f}) = \mathbf{0}$ mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2) = \mathbf{41.1}$ kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2) = \mathbf{41.1}$ kN/m^2

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base} = \mathbf{0.00}$ kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2) = \mathbf{41.1}$ kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{41.1}$ kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{41.1}$ kN/m^2

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{18.465}$ kN/m

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{49.790}$ kN/m

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{30}$ N/mm^2

Characteristic strength of reinforcement $f_y = \mathbf{500}$ N/mm^2

Base details

Minimum area of reinforcement $k = \mathbf{0.13}$ %

Cover to reinforcement in toe $c_{toe} = \mathbf{50}$ mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{57.5}$ kN/m

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

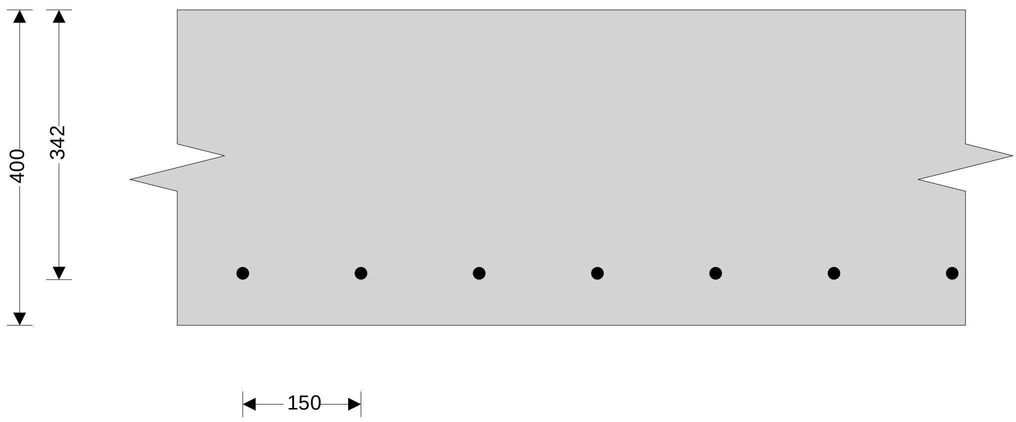
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{39}$ kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{47.8}$ kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{15.4}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{32.4}$ kNm/m



Check toe in bending

Width of toe $b = \mathbf{1000}$ mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{342.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.009}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{325}$ mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{229}$ mm^2/m

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

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

Reinforcement provided **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov} = \mathbf{1340}$ mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.114}$ N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \mathrm{N/mm^2})}, 5) \times 1\ \mathrm{N/mm^2} = \mathbf{4.382}$ 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 $v_{c\_toe} = \mathbf{0.511}$ N/mm^2

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

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{30}$ N/mm^2

Characteristic strength of reinforcement $f_y = \mathbf{500}$ N/mm^2

Base details

Minimum area of reinforcement $k = \mathbf{0.13}$ %

Cover to reinforcement in heel $c_{heel} = \mathbf{30}$ mm

Calculate shear for heel design

Shear from bearing pressure $V_{heel\_bear} = (p_{heel\_f} + p_{stem\_heel\_f}) \times l_{heel} / 2 = \mathbf{10.3}$ kN/m

Shear from weight of base $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base} = \mathbf{3.3}$ kN/m

Shear from weight of moist backfill $V_{heel\_wt\_m} = w_{m\_w\_f} = \mathbf{8.6}$ kN/m

Shear from weight of saturated backfill $V_{heel\_wt\_s} = w_{s\_f} = \mathbf{15.1}$ kN/m

Shear from surcharge $V_{heel\_sur} = w_{sur\_f} = \mathbf{2}$ kN/m

Total shear for heel design $V_{heel} = -V_{heel\_bear} + V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_wt\_s} + V_{heel\_sur} = \mathbf{18.7}$ kN/m

Calculate moment for heel design

Moment from bearing pressure $M_{heel\_bear} = (2 \times p_{heel\_f} + p_{stem\_mid\_f}) \times (l_{heel} + t_{wall} / 2)^2 / 6 = \mathbf{2.9}$ kNm/m

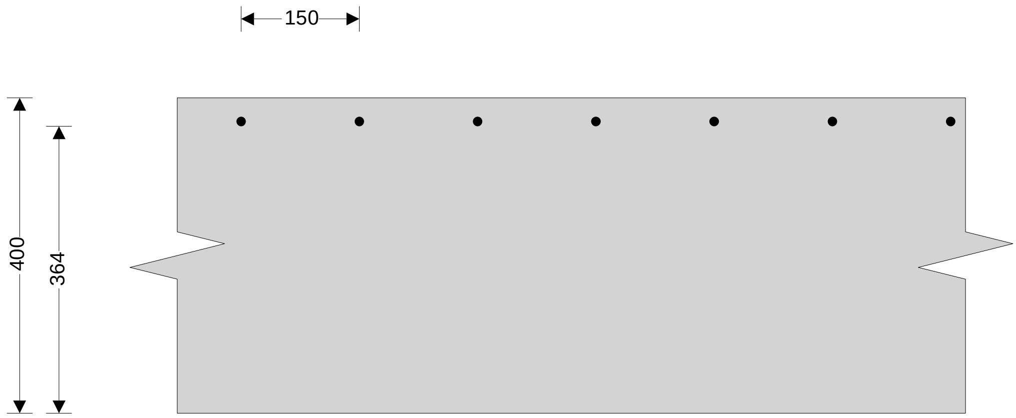
Moment from weight of base $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) = \mathbf{0.9}$ kNm/m

Moment from weight of moist backfill $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2 = \mathbf{2.2}$ kNm/m

Moment from weight of saturated backfill $M_{heel\_wt\_s} = w_{s\_f} \times (l_{heel} + t_{wall}) / 2 = \mathbf{3.8}$ kNm/m

Moment from surcharge $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2 = \mathbf{0.5}$ kNm/m

Total moment for heel design $M_{heel} = -M_{heel\_bear} + M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_wt\_s} + M_{heel\_sur} = \mathbf{4.5}$ kNm/m



Check heel in bending

Width of heel $b = \mathbf{1000}$ mm/m

Depth of reinforcement $d_{heel} = t_{base} - c_{heel} - (\phi_{heel} / 2) = \mathbf{364.0}$ mm

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

Compression reinforcement is not required

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

$z_{heel} = \mathbf{346}$ mm

Area of tension reinforcement required $A_{s\_heel\_des} = M_{heel} / (0.87 \times f_y \times z_{heel}) = \mathbf{30}$ mm^2/m

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

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

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_heel\_prov} = \mathbf{754}$ mm^2/m

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress $v_{heel} = V_{heel} / (b \times d_{heel}) = \mathbf{0.051}$ N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \surd(f_{cu} / 1\ \text{N/mm}^2), 5) \times 1\ \text{N/mm}^2 = \mathbf{4.382}$ 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 $v_{c\_heel} = \mathbf{0.407}$ 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 $f_{cu} = \mathbf{30}$ N/mm^2

Characteristic strength of reinforcement $f_y = \mathbf{500}$ N/mm^2

Wall details

Minimum area of reinforcement $k = \mathbf{0.13}$ %

Cover to reinforcement in stem $c_{stem} = \mathbf{100}$ mm

Cover to reinforcement in wall $c_{wall} = \mathbf{50}$ mm

Factored horizontal active forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = \mathbf{8.6}$ kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = \mathbf{7.3}$ kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat} =$ **22.6** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{sat}^2 =$ **10.7** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2 =$ **27.5** kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8 =$ **5.4** kN/m

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3) =$ **2.7** kN/m

Moist backfill below water table $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8 =$ **18.8** kN/m

Saturated backfill $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3))) =$ **9.8** kN/m

Water $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3))) =$ **25.1** kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f} =$ **61.7** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8 =$ **3.8** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2) =$ **2.9** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8 =$ **11.7** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2) =$ **4.6** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2) =$ **11.8** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water} =$ **34.8** kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128 =$ **2.1** kNm/m

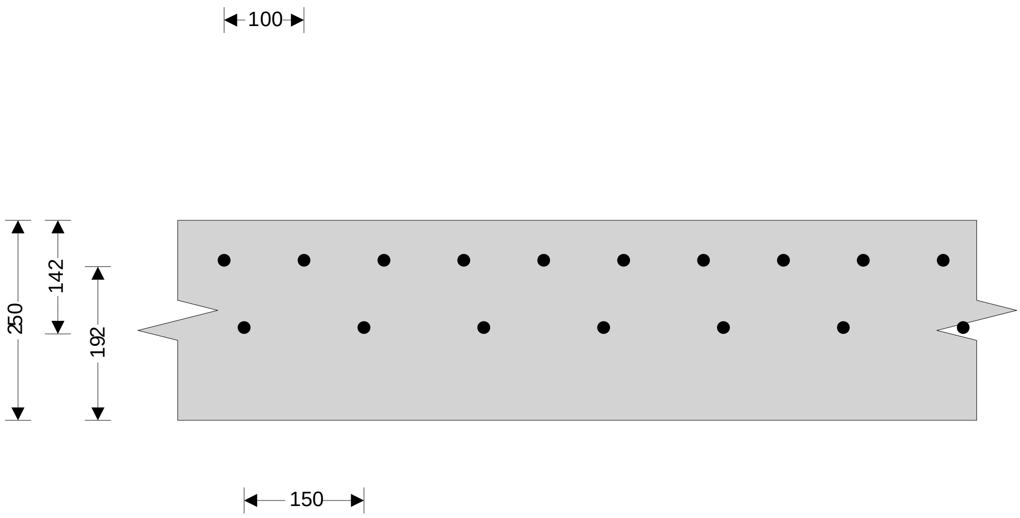
Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2) / (5 \times L^3) - 0.577^2 / 3] =$ **2.9** kNm/m

Moist backfill below water table $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8 - n^2 \times (4 - n))^2 / 16) - 4 + n \times (4 - n)] / 8 =$ **5.6** kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l) / (20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)] =$ **1.6** kNm/m

Water $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l) / (20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)] =$ **4.1** kNm/m

Total moment for wall design $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water} =$ **16.3** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} – c_{stem} – (\phi_{stem} / 2) = \mathbf{142.0}$ mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = \mathbf{0.058}$

Compression reinforcement is not required

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

$z_{stem} = \mathbf{132}$ mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem}) = \mathbf{605}$ mm^2/m

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

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{605}$ mm^2/m

Reinforcement provided **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov} = \mathbf{1340}$ mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.435}$ N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{4.382}$ 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 $v_{c\_stem} = \mathbf{0.854}$ N/mm^2

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

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} – c_{wall} – (\phi_{wall} / 2) = \mathbf{192.0}$ mm

Constant $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu}) = \mathbf{0.015}$

Compression reinforcement is not required

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

$z_{wall} = \mathbf{182}$ mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall}) = \mathbf{206}$ mm^2/m

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

Area of tension reinforcement required $A_{s\_wall\_req} = \mathrm{Max}(A_{s\_wall\_des}, A_{s\_wall\_min}) = \mathbf{325}$ mm^2/m

Reinforcement provided **16 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov} = \mathbf{2011}$ mm^2/m

PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas} = \mathbf{20}$

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) = \mathbf{150.5}$ N/mm^2

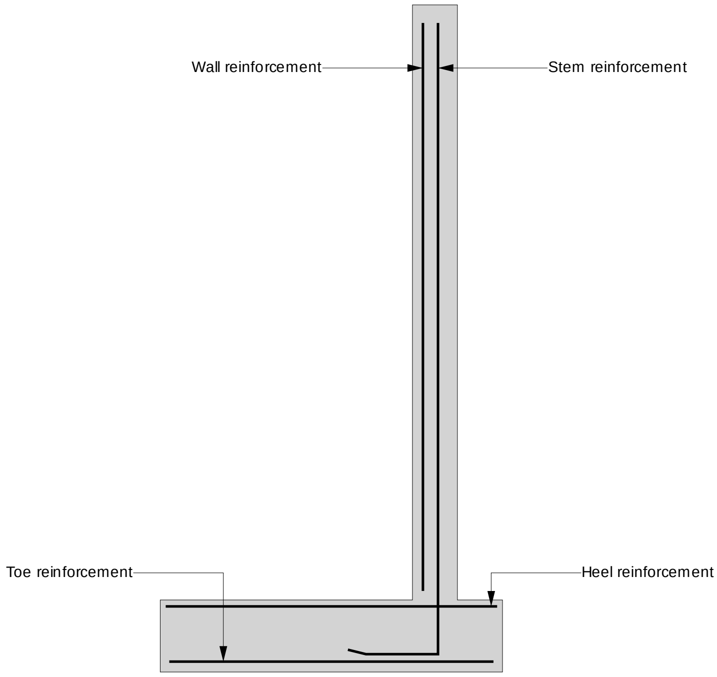
Modification factor $factor_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2) = \mathbf{1.59}$

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens} = \mathbf{31.72}$

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem} = \mathbf{23.24}$

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)
Heel bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)
Wall bars - 16 mm dia.@ 100 mm centres - (2011 mm^2/m)
Stem bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)

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