BASEMENT STRUCTURE

STRUCTURAL REPORT

8 KENTISH TOWN ROAD
CAMDEN
LONDON
NW1 9NX

Property address:	July 2018
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Introduction

Hinerti Ltd will act as Consultant Structural Engineer for the proposed development and will be responsible for the design of the permanent basement. It is envisaged that a specialist basement contractor will be appointed for the basement work, this contractor will be responsible for the design and implementation of the temporary works necessary to build the basement, Hinerti Ltd will check these design and comment as necessary.

Existing Structure

Generally the construction is typical of similar properties in London. The main walls are masonry on spread masonry foundation formed approximately 1.0m below external ground level. The upper floors and roof is timber framed.

Proposal

The proposal involves the construction of a new basement and superstructure. The formation of the new basement slab will be approximately 4.0m below existing ground level. The layouts are shown by the relevant Architects drawings.

Potential impact on 8 Kentish Town Road and Surrendering Properties

The structural design and basement, walls and bases, the design of all necessary temporary works, and the sequencing of the construction will take into account all the geotechnical aspects recorded, and also the locality of the adjoining properties. The formation of the basement walls and bases will made in a sequential underpinning pattern adopting construction legs no wider than 1.0m, this will avoid undue stresses being applied to the walls being underpinned.

Subterranean Condition

The soil at new basement formation level will be LONDON CLAY. Based on Basemnet Impact Assessment report safe bearing pressure on the clay is 150kN/m^2, this value should ensure that differential and total settlements are very minimal.

The basement works will not affect any public services or utilities.

There are no nearby trees that will be affected by the works.

The design of the basement walls and bases and temporary works to construct will take into account the locality of adjoining structures and any loading that may be imposed by these structures. The formation of the basement walls and bases will be made in a sequential underpinning pattern adopting legs no wider than 1.0m will ensure help to avoid undue distress to the walls being underpinned.

Structural Design Principles

Basement Walls

Basement walls are designed as propped cantilevers in reinforced concrete, the basement slab acting as the prop at base level. The walls are designed using parameters relevant to the London Clay. The retaining wall/underpinning will be design for water pressure.

The surcharge load allowed on the external walls is:
- front retaining wall - 15kN/m^2 .
- other retaining walls (sides and back) -10kN/m^2 .

Basement Slab

The slab will be reinforced concrete. It will be designed for either uplift due to water pressure below, or as a clear span as appropriate. The basement slab will act as a prop to the base of the basement walls.

Design Criteria

The design is in accordance with BS 8002: 2015.

The wall and base in design for the following
1. Vertical load from wall above.
2. Surcharge load: 15kN/m^2 - for front wall, other walls - 10kN/m^2 .
3. The design adopts a water head behind the wall – minimum ¾ the hight of the wall below the ground but not less hydrostatic level at 1m below the ground .

An allowance increase in bearing pressure at base formation on the LONDON CLAY will be taken at 150kN/m^2 this will limit settlements as noted above.

Concrete will be grade C32/40 and Class 1 to BRE Digest 363. Reinforcement will be grade 500kN/m^2.

Relevant Codes of Practice and British Standards

Loadings: BS 648; BS 6399, Part 1, 2 & 3;
Steel : BS 5950;
Concrete : BS 8110;
Masonry: BS 5628;
Timber: BS 5268;
Foundations: BS 8004;
Earthworks: BS 6031.

General Underpinning - Notes

1. The site set-up will be as follows: a skip will be placed to the front of the property with the siting of a compressor and materials in the same location. We proposed hoarding around the skip and mateials to ensure this is protected from passers-by.
2. A conveyor belt will be installed initially sited towards the front of the property. A local excavation will be excaveted down to allow the installation of the conveyor belt. Sitting of the initial excavation for the conveyor will be central between the adjoining properties. The conveyor will then extended up to position of the skip at ground level.
3. Spoil will be wheel barrrowed from the excavation faces to the base of the conveyor belt. Spoil will be removed via the conveyor belt and desposited into the skip. The skip will be emptied using a grab lorry when it is full, or alternatively the skip will be exchanged.

General Underpinning – Method Statement

The exact sequence of works will be agreed with Main Contractor and Structural Engineer – Hinerti Ltd, a Construction Method Statement for the works could be as follow.

1. The walls to the perimeter of the new basement will be partly underpinned in reinforced concrete. The underpins will take the vertical force from the walls and horizontal loads from the earth and water. During their construction the walls and bases will require laterally propping. In the temporary condition propping will be made against the central earth pudding.
2. Underpinning legs will be excavated in short sections not exceeding 1000mm in width.
3. The sequence of the the underpinning shall be in the 1, 3, 5, 2, 4 & 6 sequence, such that any given underpinning will be completed, dry packed, and a minimum period of 48 hours lapsed before and adjacent excavation commenced to form another underpin.
4. The actual sequence will be confirmed and agreed with Hinerti Ltd prior to works commencing. Once agreed the sequencing must not be altered without the acceptance from the Consulting Structural Engineer.
5. In the event that the existing foundations to the wall are found to be unstable, sacrificial steel jacks will be installed underneath the foundation to prop the bottom few courses of bricks. These steel jacks will be left in place and will be incorporated into the concrete stem.
6. Whilst forming the wall and in the event that the vertical soil face is unstable, lateral propping will be provided as required to the excavation and to the sides of the working trench. The front and sides faces of the excavation will be propped using trench sheeting or plywood, timber boards and acrow props as appropriate. Cementitious grout will be poured behind the back-shutters to fill up the voids behinds the back-shutters.
7. Due to ground condition it is proposed to use metal trench sheeting to the rear face of the excavation. This will be sacrificial i.e. this will become part of the permanent works.
8. Concrete C32/40 will be ready mixed delivered to site. Concrete will be chuted into a catchment area within the excavated basement and placed by wheelbarrow or alternatively will be pumped.
9. Excavation for an underpin section will be excavated in a day, and the concrete to the base poured by the end of the same day.
10. The concrete to the stem of the underpin will be poured the following day. This will be poured up to within 50-75mm of the underside of the exiting wall foundations. The stem shall be laterally propped until the base slab is cast and cured, either by propping or by

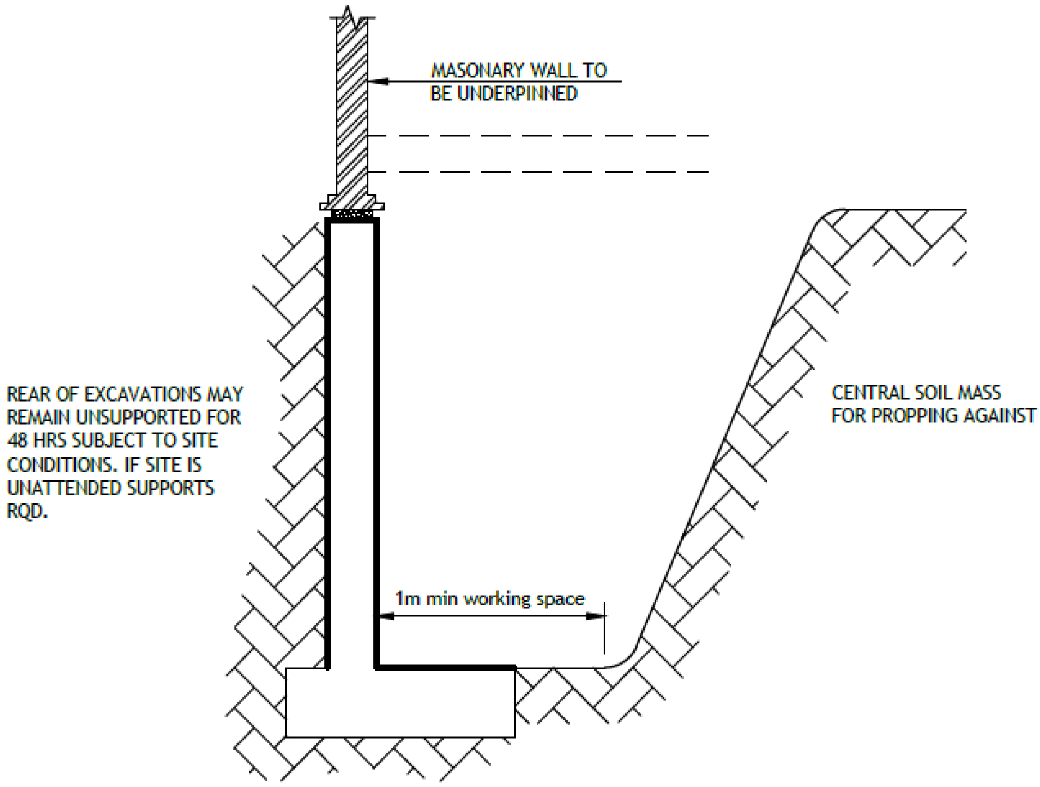
compacted backfilling.

11. On the following day, the gap between the concrete and the underside of the existing foundation will be dry packed with a mixture of sharp sand and cement (ratio 3:1).
12. Once the dry pack has gained sufficient strength, any protrusions of the footing into the site will be carefully trimmed back using hand tools to avoid causing any damage to the foundation. The protrusions will be trimmed back to flush in-line with the face of the wall above.
13. A minimum of 48 hours will be allowed before adjacent sections will be excavated to form a new underpin.
14. Adjacent underpins shall be connected using B12 dowel bars 600mm long, 300mm embedment each side, at 200mm vertical centres.
15. Concrete cover to reinforcement shall be 35mm for cast against shutter or top surface of the basement slab, 50mm for cast against blinding and 75mm for cast against earth.
16. Grade of concrete shall be C32/40 with minimum cement content 300kg/m^3, maximum free water cement 0.6, slump 100mm.

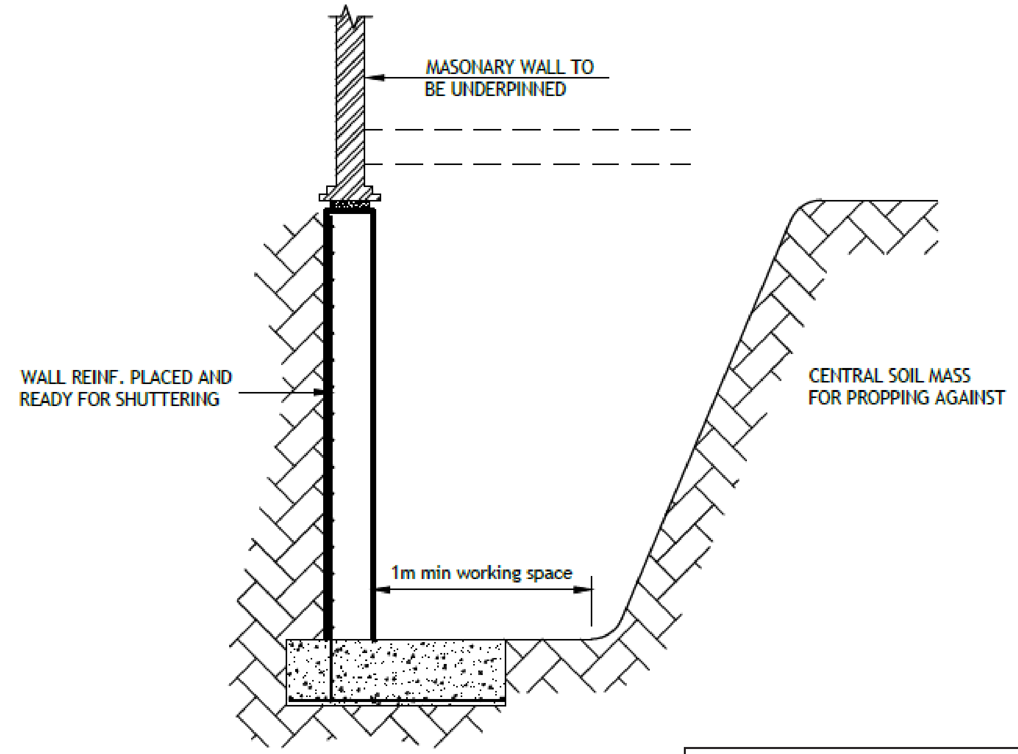
Construction Sequence

1. Carry out excavation to 200mm above base of existing foundations.
2. It is proposed to excavate a shafts beneath the foundations to a depth of approx. 4.0m deep from joist level therefore circa 3.0m from beneath foundations, ensuring the shaft is fully trench sheeted and propped to the full depth of the shaft.
3. Commence underpinning of perimeter walls in sequence agreed with Hinerti Ltd and in accordance design drawings.
4. Underpins will be carried out as noted in the clause above headed ''General Underpinning''.
5. The trench sheets will be installed using a dig and push method so as to negate the need for large machinery.
6. The trench sheets will be proposed across the site using RMD slim shores or similar as props and walers.
7. Bulk excavation will be carried out down to the basement slab formation level. Spoil will continue to be removed from site via the conveyor belt.
8. Excavation will proceed to formation level with at least two levels of props to the trench sheets.
9. The below – slab drainage for foul and ground water, sumps and pumps will be installed. The pumps ill discharge the foul / ground water into the existing sewer system.
10. The basement reinforcement will be be tied and installed prior to the laying on the concrete ground – bearing slab. The ground bearing slab will then be constructed with kickers and starter bars for the RC walls to the RC 'box'.
11. The wall will be poured again with starter bars for the slab and allow to fully cured.
12. A Delta cavity drain membrane will be installed to the walls and floors prior to laying of the floor screed.
13. The top slab will be poured and allowed to cure.
14. After the new under-garden RC box has cured, a drained – cavity layer will be laid to the bottom and top slab and walls.
15. A layer of insulation will be placed on the top of the drained – cavity layer on the slab, and in front of drained – cavity layer on the walls.

16. Finally a layer of screed will be laid to form the finished basement floor.

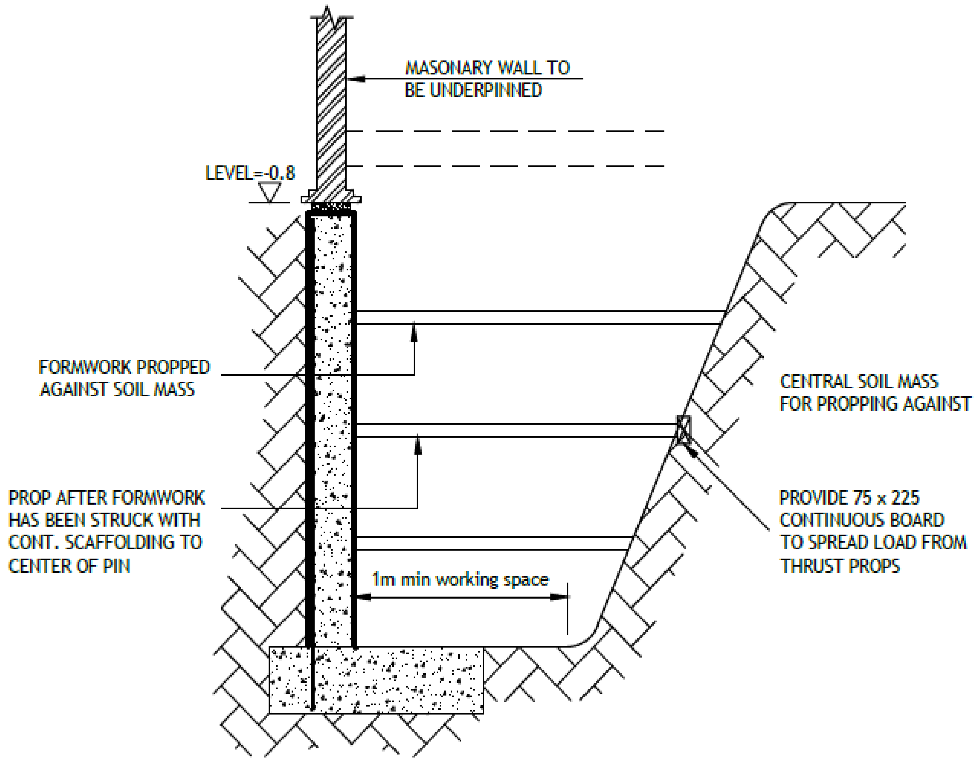


STAGE 1 - Clay Soils

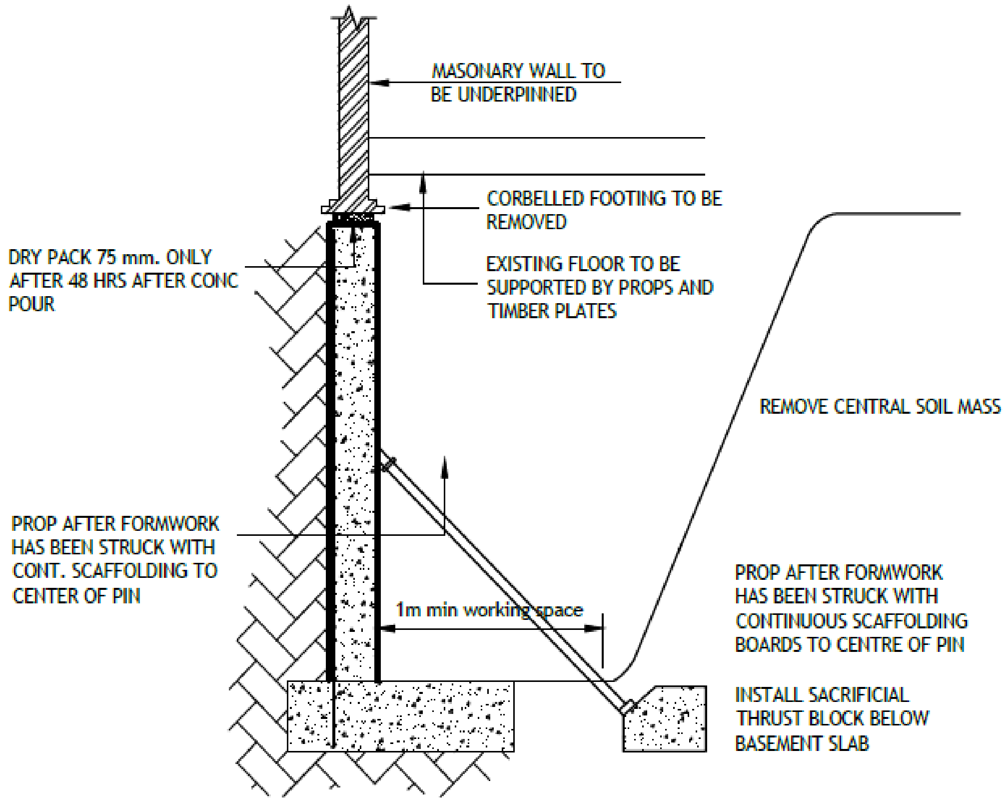


STAGE 2 - Clay Soils

IF THE UNDERSIDE OF EXISTING FOOTINGS ARE UNSTABLE SUCH AS LOOSE BRICKORK THEN THEY ARE TO BE PROPPED SACRIFICIALLY.



STAGE 3 - Clay Soils



STAGE 4 -Clay Soil

Additional requirements

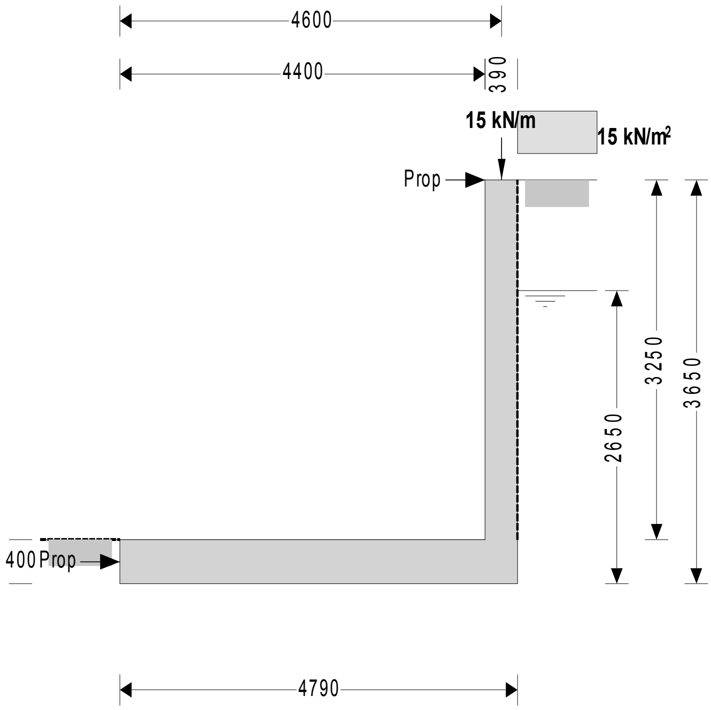
1. The site is only accessible from Kentish Town Road, and therefore all site delivered and operations will take place from here. This entrance will be manned through operational hours by a banksman to ensure construction deliveres do not pose a risk to other users of Kentish Town Road.
2. Construct site hording, entrance gates to provide protection to passers-by from site operations. Site accommodation including welfare facilities will be confined to the main building through the site works.
3. Terminate/protect any incoming services temporarily divert any active drainage.
4. Install any tree protection measures as necessary.

Potential Impact 8 Kentish Town Road and adjoining properties

The foundations to the main house and the neighbouring properties are unlikely to be affected by the excavation for the new room and the proximity of the excavation is unlikely to undermine the foundational to the main house or adjacent properties.
Noticeable settlement can be eliminated by providing an experienced contractor who undertakes the works using good practice and in accordance with structural design. The contractor must follow all agreed method statement, installing all necessary temporary vertical and lateral supports required.

Calculations

RETAINING WALL ANALYSIS - FRONT 390MM



Wall details

Retaining wall type;	**Cantilever propped at both**
Height of retaining wall stem;	h_{stem} = **3250** mm
Thickness of wall stem;	t_{wall} = **390** mm
Length of toe;	l_{toe} = **4400** mm
Length of heel;	l_{heel} = **0** mm
Overall length of base;	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **4790** mm
Thickness of base;	t_{base} = **400** mm
Depth of downstand;	d_{ds} = **0** mm
Position of downstand;	l_{ds} = **1900** mm
Thickness of downstand;	t_{ds} = **400** mm
Height of retaining wall;	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3650** 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} = **2650** mm
Height of saturated fill above base;	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **2250** mm
Density of wall construction;	γ_{wall} = **25.0** kN/m^3
Density of base construction;	γ_{base} = **25.0** 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;	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3650** mm

Retained material details

Mobilisation factor;	M = **2.0**
Moist density of retained material;	γ_m = **19.0** kN/m^3
Saturated density of retained material;	γ_s = **19.0** kN/m^3

Design shear strength; $\phi' = \mathbf{25.0}$ deg

Angle of wall friction; $\delta = \mathbf{25.0}$ deg

Base material details

Moist density; $\gamma_{mb} = \mathbf{19.0}$ kN/m^3

Design shear strength; $\phi'_b = \mathbf{19.0}$ deg

Design base friction; $\delta_b = \mathbf{25.0}$ deg

Allowable bearing pressure; $P_{bearing} = \mathbf{150}$ kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.355}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{3.938}$$

At-rest pressure

At-rest pressure for retained material; $K_0 = 1 - \sin(\phi') = \mathbf{0.577}$

Loading details

Surcharge load on plan; Surcharge = **15.0** kN/m^2

Applied vertical dead load on wall; $W_{dead} = \mathbf{10.0}$ kN/m

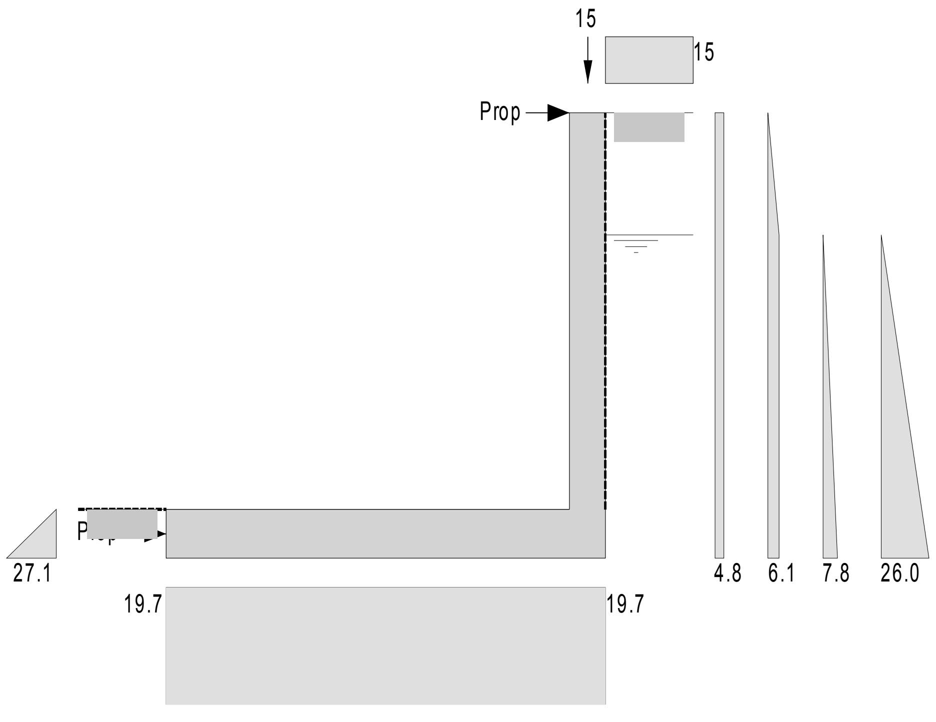
Applied vertical live load on wall; $W_{live} = \mathbf{5.0}$ kN/m

Position of applied vertical load on wall; $l_{load} = \mathbf{4600}$ mm

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

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

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



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

Vertical forces on wall

Wall stem; $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall} = \mathbf{31.7}$ kN/m

Wall base; $w_{base} = l_{base} \times t_{base} \times \gamma_{base} = \mathbf{47.9}$ kN/m

Applied vertical load; $W_v = W_{dead} + W_{live} = \mathbf{15}$ kN/m

Total vertical load; $W_{total} = w_{wall} + w_{base} + W_v = \mathbf{94.6}$ kN/m

Horizontal forces on wall

Surcharge; $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **17.6** kN/m

Moist backfill above water table; $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **3.1** kN/m

Moist backfill below water table; $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **16.2** kN/m

Saturated backfill; $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **10.4** kN/m

Water; $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **34.4** kN/m

Total horizontal load; $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **81.7** kN/m

Calculate total propping force

Passive resistance of soil in front of wall; $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.4** 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} = **34.5** kN/m

Overturning moments

Surcharge; $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **32.2** kNm/m

Moist backfill above water table; $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **9.1** kNm/m

Moist backfill below water table; $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **21.5** kNm/m

Saturated backfill; $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **9.2** kNm/m

Water; $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **30.4** kNm/m

Total overturning moment; $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **102.3** kNm/m

Restoring moments

Wall stem; $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **145.6** kNm/m

Wall base; $M_{base} = w_{base} \times l_{base} / 2$ = **114.7** kNm/m

Design vertical dead load; $M_{dead} = W_{dead} \times l_{load}$ = **46** kNm/m

Total restoring moment; $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **306.3** kNm/m

Check bearing pressure

Total vertical reaction; $R = W_{total}$ = **94.6** kN/m

Distance to reaction; $x_{bar} = l_{base} / 2$ = **2395** mm

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

Reaction acts within middle third of base

Bearing pressure at toe; $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **19.7** kN/m²

Bearing pressure at heel; $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **19.7** 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

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **4.537** kN/m

Propping force to base of wall; $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **29.969** kN/m

RETAINING WALL DESIGN

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; $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **44.4** kN/m

Wall base; $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **67.1** kN/m

Applied vertical load; $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **22** kN/m

Total vertical load; $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **133.4** kN/m

Factored horizontal at-rest forces on wall

Surcharge; $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **50.6** kN/m

Moist backfill above water table; $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **7.7** kN/m

Moist backfill below water table; $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **40.7** kN/m

Saturated backfill; $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **26.1** kN/m

Water; $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **48.2** kN/m

Total horizontal load; $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **173.3** kN/m

Calculate total propping force

Passive resistance of soil in front of wall; $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **7.6** 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} = **107.2** kN/m

Factored overturning moments

Surcharge; $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **92.3** kNm/m

Moist backfill above water table; $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **22.9** kNm/m

Moist backfill below water table; $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **53.9** kNm/m

Saturated backfill; $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **23** kNm/m

Water; $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **42.6** kNm/m

Total overturning moment; $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **234.8** kNm/m

Restoring moments

Wall stem; $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **203.8** kNm/m

Wall base; $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **160.6** kNm/m

Design vertical load; $M_{v\_f} = W_{v\_f} \times l_{load}$ = **101.2** kNm/m

Total restoring moment; $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **465.7** kNm/m

Factored bearing pressure

Total vertical reaction; $R_f = W_{total\_f}$ = **133.4** kN/m

Distance to reaction; $x_{bar\_f} = l_{base} / 2$ = **2395** mm

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

Reaction acts within middle third of base

Bearing pressure at toe; $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **27.9** kN/m^2

Bearing pressure at heel; $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **27.9** 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) = **27.9** 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) = **27.9** kN/m^2

Bearing pressure at stem / heel; $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **27.9** kN/m²

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **19.489** kN/m

Propping force to base of wall; $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f}$ = **87.695** kN/m

<u>Design of reinforced concrete retaining wall toe</u>

<u>Material properties</u>

Characteristic strength of concrete; f_{cu} = **40** N/mm²

Characteristic strength of reinforcement; f_y = **500** N/mm²

Base details

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

Cover to reinforcement in toe; c_{toe} = **50** mm

Calculate shear for toe design

Shear from bearing pressure; $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **122.6** kN/m

Shear from weight of base; $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **61.6** kN/m

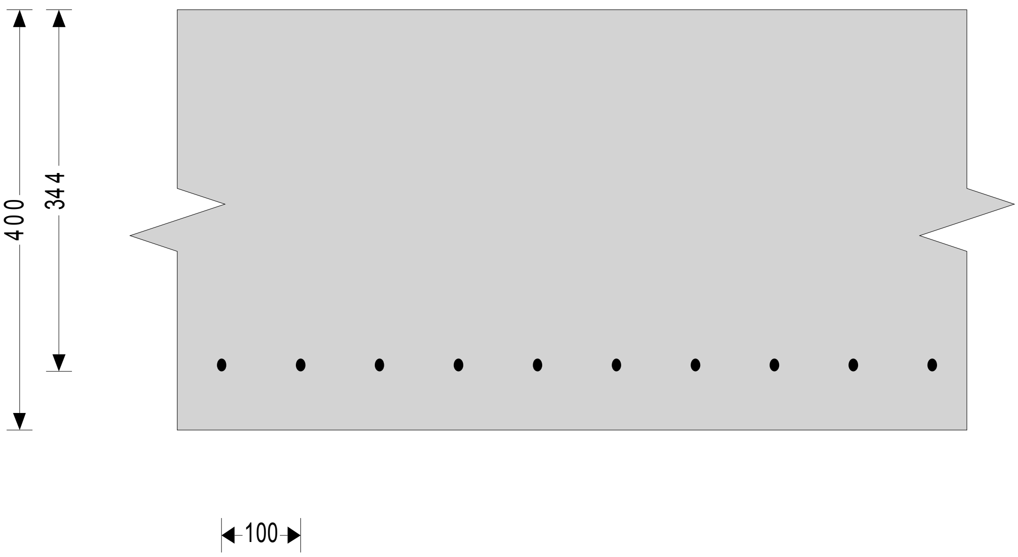
Total shear for toe design; $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **61** kN/m

Calculate moment for toe design

Moment from bearing pressure; $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **294.1** kNm/m

Moment from weight of base; $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **147.8** kNm/m

Total moment for toe design; $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **146.3** kNm/m



Check toe in bending

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

Depth of reinforcement; $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **344.0** mm

Constant; $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.031**

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} = **327** mm

Area of tension reinforcement required; $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **1029** mm²/m

Minimum area of tension reinforcement; $A_{s\_toe\_min} = k \times b \times t_{base}$ = **520** mm^2/m
Area of tension reinforcement required; $A_{s\_toe\_req} = Max(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **1029** mm^2/m
Reinforcement provided; **12 mm dia.bars @ 100 mm centres**
Area of reinforcement provided; $A_{s\_toe\_prov}$ = **1131** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress; $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.177** N/mm^2
Allowable shear stress; $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **5.000** 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} = **0.530** N/mm^2

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

<u>Design of reinforced concrete retaining wall stem</u>

Material properties

Characteristic strength of concrete; f_{cu} = **40** N/mm^2
Characteristic strength of reinforcement; f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement; k = **0.13** %
Cover to reinforcement in stem; c_{stem} = **40** mm
Cover to reinforcement in wall; c_{wall} = **40** mm

Factored horizontal at-rest forces on stem

Surcharge; $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **45** kN/m
Moist backfill above water table; $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **7.7** kN/m
Moist backfill below water table; $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **34.6** kN/m
Saturated backfill; $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **18.8** kN/m
Water; $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **34.8** kN/m

Calculate shear for stem design

Surcharge; $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **28.1** kN/m
Moist backfill above water table; $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **2.2** kN/m
Moist backfill below water table; $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8$ = **27.4** kN/m
Saturated backfill; $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **16.8** kN/m
Water; $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **31** kN/m
Total shear for stem design; $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **105.5** kN/m

Calculate moment for stem design

Surcharge; $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **19.4** kNm/m
Moist backfill above water table; $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **2.4** kNm/m
Moist backfill below water table; $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8$ = **17.6** kNm/m
Saturated backfill; $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **8.3** kNm/m
Water; $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ =

15.4 kNm/m

Total moment for stem design; $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **63.2** kNm/m

Calculate moment for wall design

Surcharge; $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **10.9** kNm/m

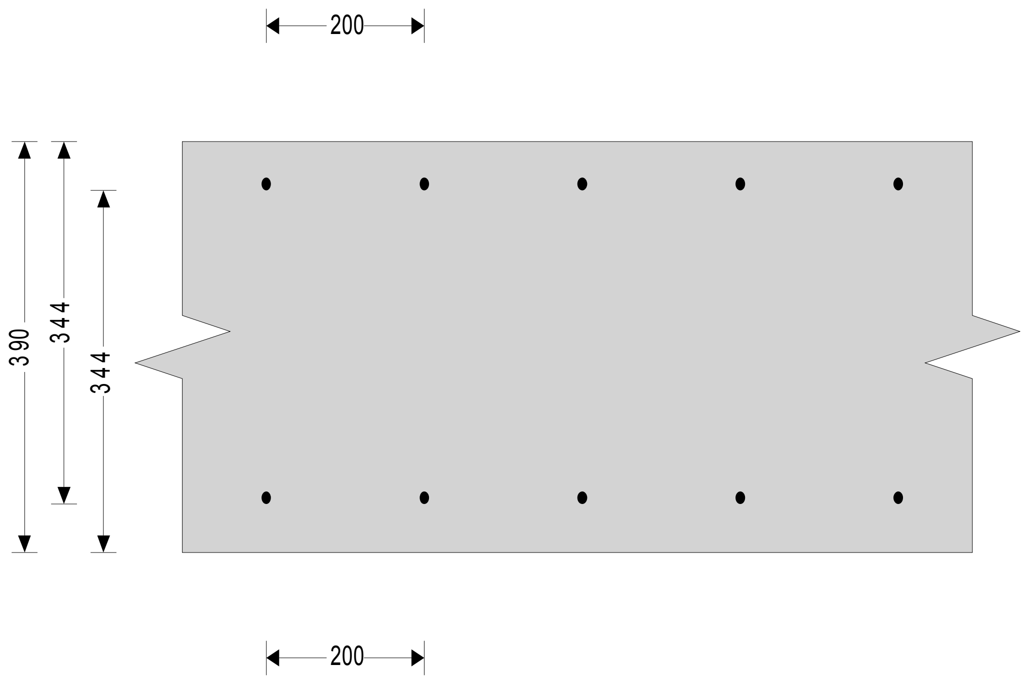
Moist backfill above water table; $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2)/(5 \times L^3) - 0.577^2/3]$ = **2.7** kNm/m

Moist backfill below water table; $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8-n^2 \times (4-n))^2 /16)-4+n \times (4-n)]/8$ = **9** kNm/m

Saturated backfill; $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **3.1** kNm/m

Water; $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **5.8** kNm/m

Total moment for wall design; $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water}$ = **31.5** kNm/m



Check wall stem in bending

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

Depth of reinforcement; $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **344.0** mm

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

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} = **327** mm

Area of tension reinforcement required; $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **445** mm²/m

Minimum area of tension reinforcement; $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **507** mm²/m

Area of tension reinforcement required; $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **507** mm²/m

Reinforcement provided; **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided; $A_{s\_stem\_prov}$ = **565** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress; $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.307** N/mm²

Allowable shear stress; $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 =$ **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress; $v_{c\_stem} =$ **0.420** N/mm^2

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

Check mid height of wall in bending

Depth of reinforcement; $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2) =$ **344.0** mm

Constant; $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu}) =$ **0.007**

Compression reinforcement is not required

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

$z_{wall} =$ **327** mm

Area of tension reinforcement required; $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall}) =$ **222** mm^2/m

Minimum area of tension reinforcement; $A_{s\_wall\_min} = k \times b \times t_{wall} =$ **507** mm^2/m

Area of tension reinforcement required; $A_{s\_wall\_req} = \mathrm{Max}(A_{s\_wall\_des}, A_{s\_wall\_min}) =$ **507** mm^2/m

Reinforcement provided; **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided; $A_{s\_wall\_prov} =$ **565** 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; $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) =$ **298.9** N/mm^2

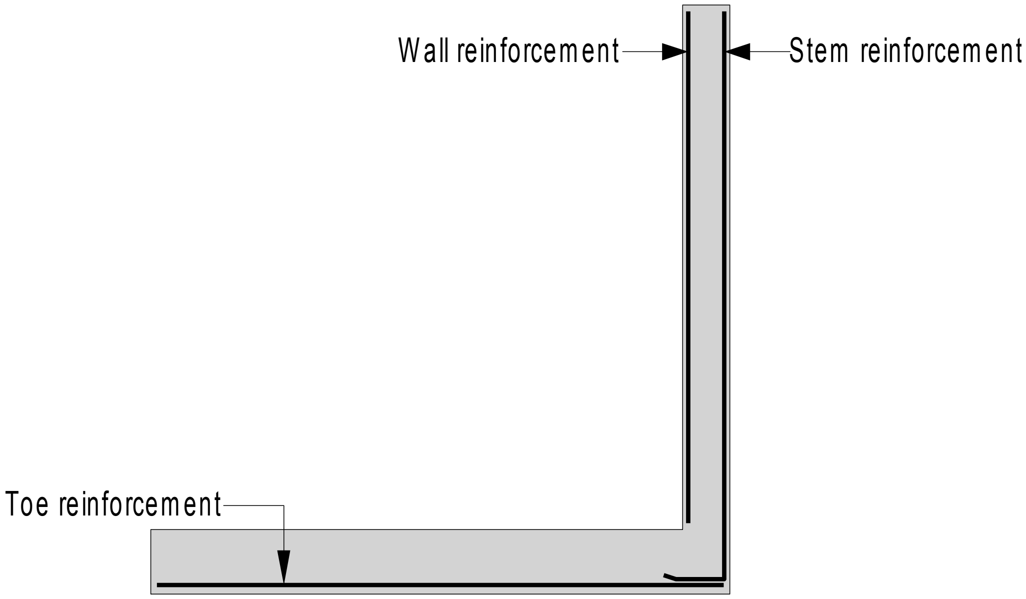
Modification factor; $factor_{tens} = \min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2) =$ **1.59**

Maximum span/effective depth ratio; $ratio_{max} = ratio_{bas} \times factor_{tens} =$ **31.70**

Actual span/effective depth ratio; $ratio_{act} = h_{stem} / d_{stem} =$ **9.45**

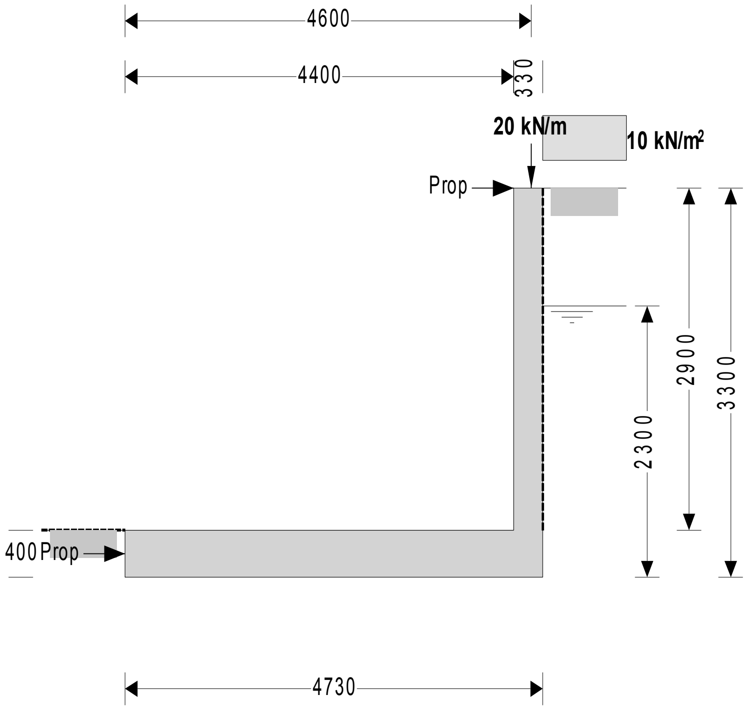
PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 12 mm dia.@ 100 mm centres - (1131 mm^2/m)
Wall bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Stem bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)

RETAINING WALL ANALYSIS – BACK 330MM



Wall details

Retaining wall type;	**Cantilever propped at both**
Height of retaining wall stem;	h_{stem} = **2900** mm
Thickness of wall stem;	t_{wall} = **330** mm
Length of toe;	l_{toe} = **4400** mm
Length of heel;	l_{heel} = **0** mm
Overall length of base;	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **4730** mm
Thickness of base;	t_{base} = **400** mm
Depth of downstand;	d_{ds} = **0** mm
Position of downstand;	l_{ds} = **1900** mm
Thickness of downstand;	t_{ds} = **400** mm
Height of retaining wall;	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3300** 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} = **2300** mm
Height of saturated fill above base;	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **1900** mm
Density of wall construction;	γ_{wall} = **25.0** kN/m^3
Density of base construction;	γ_{base} = **25.0** 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;	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3300** mm

Retained material details

Mobilisation factor;	M = **2.0**
Moist density of retained material;	γ_m = **19.0** kN/m^3
Saturated density of retained material;	γ_s = **19.0** kN/m^3
Design shear strength;	ϕ' = **25.0** deg
Angle of wall friction;	δ = **25.0** deg

Base material details

Moist density; γ_{mb} = **19.0** kN/m^3

Design shear strength; ϕ'_b = **19.0** deg

Design base friction; δ_b = **25.0** deg

Allowable bearing pressure; $P_{bearing}$ = **150** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.355}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{3.938}$$

At-rest pressure

At-rest pressure for retained material; $K_0 = 1 – \sin(\phi') =$ **0.577**

Loading details

Surcharge load on plan; Surcharge = **10.0** kN/m^2

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

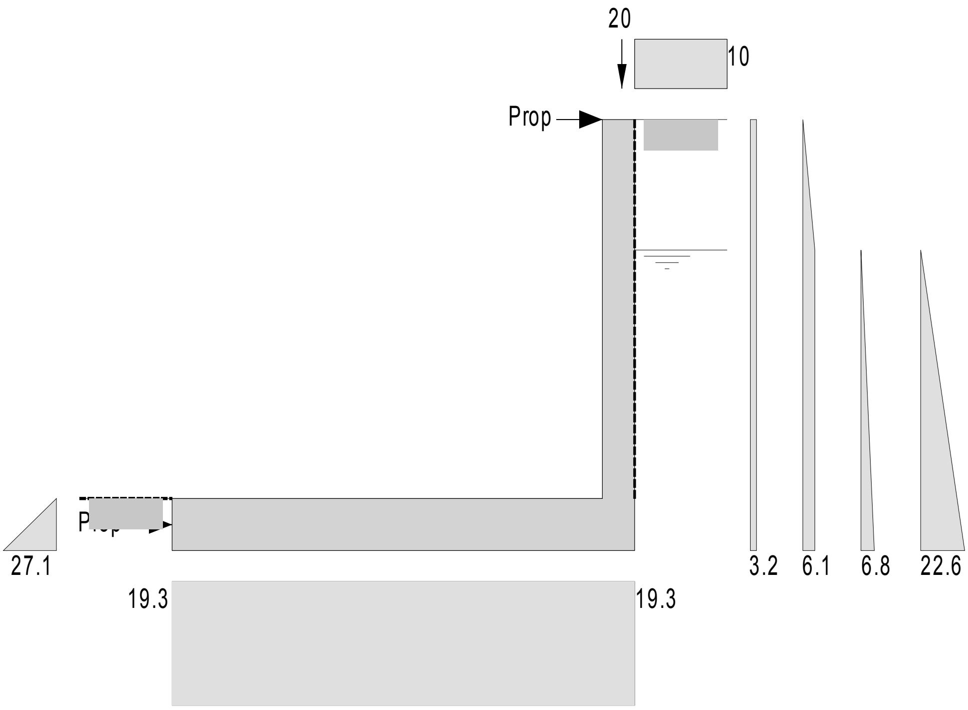
Applied vertical live load on wall; W_{live} = **10.0** kN/m

Position of applied vertical load on wall; l_{load} = **4600** 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; $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **23.9** kN/m

Wall base; $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **47.3** kN/m

Applied vertical load; $W_v = W_{dead} + W_{live}$ = **20** kN/m

Total vertical load; $W_{total} = w_{wall} + w_{base} + W_v$ = **91.2** kN/m

Horizontal forces on wall

Surcharge; $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **10.6** kN/m

Moist backfill above water table; $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **3.1** kN/m

Moist backfill below water table; $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **14.1** kN/m

Saturated backfill; $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **7.8** kN/m

Water; $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **25.9** kN/m

Total horizontal load; $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **61.5** kN/m

Calculate total propping force

Passive resistance of soil in front of wall; $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.4** kN/m

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

F_{prop} = **18.2** kN/m

Overturning moments

Surcharge; $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **17.5** kNm/m

Moist backfill above water table; $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **8.1** kNm/m

Moist backfill below water table; $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **16.2** kNm/m

Saturated backfill; $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **6** kNm/m

Water; $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **19.9** kNm/m

Total overturning moment; $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **67.6** kNm/m

Restoring moments

Wall stem; $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **109.2** kNm/m

Wall base; $M_{base} = w_{base} \times l_{base} / 2$ = **111.9** kNm/m

Design vertical dead load; $M_{dead} = W_{dead} \times l_{load}$ = **46** kNm/m

Total restoring moment; $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **267.1** kNm/m

Check bearing pressure

Total vertical reaction; $R = W_{total}$ = **91.2** kN/m

Distance to reaction; $x_{bar} = l_{base} / 2$ = **2365** 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; $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **19.3** kN/m^2

Bearing pressure at heel; $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **19.3** 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

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **4.083** kN/m

Propping force to base of wall; $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **14.124** kN/m

RETAINING WALL DESIGN

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; $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **33.5** kN/m

Wall base; $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **66.2** kN/m

Applied vertical load; $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **30** kN/m

Total vertical load; $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **129.7** kN/m

Factored horizontal at-rest forces on wall

Surcharge; $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times h_{eff}$ = **30.5** kN/m

Moist backfill above water table; $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **7.7** kN/m

Moist backfill below water table; $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **35.3** kN/m

Saturated backfill; $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **19.6** kN/m

Water; $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **36.3** kN/m

Total horizontal load; $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **129.5** kN/m

Calculate total propping force

Passive resistance of soil in front of wall; $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$
= **7.6** 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} = **68.8** kN/m

Factored overturning moments

Surcharge; $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **50.3** kNm/m

Moist backfill above water table; $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **20.2** kNm/m

Moist backfill below water table; $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **40.6** kNm/m

Saturated backfill; $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **15.1** kNm/m

Water; $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **27.9** kNm/m

Total overturning moment; $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **154.1** kNm/m

Restoring moments

Wall stem; $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **152.9** kNm/m

Wall base; $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **156.6** kNm/m

Design vertical load; $M_{v\_f} = W_{v\_f} \times l_{load}$ = **138** kNm/m

Total restoring moment; $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **447.5** kNm/m

Factored bearing pressure

Total vertical reaction; $R_f = W_{total\_f}$ = **129.7** kN/m

Distance to reaction; $x_{bar\_f} = l_{base} / 2$ = **2365** 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; $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **27.4** kN/m²

Bearing pressure at heel; $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **27.4** kN/m²

Rate of change of base reaction; $\text{rate} = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m²/m

Bearing pressure at stem / toe; $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2)$ = **27.4** kN/m²

Bearing pressure at mid stem; $p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **27.4**
kN/m²

Bearing pressure at stem / heel; $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2)$ = **27.4** kN/m^2

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **-0.144** kN/m

Propping force to base of wall; $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f}$ = **68.987** kN/m

Design of reinforced concrete retaining wall toe

Material properties

Characteristic strength of concrete; f_{cu} = **40** N/mm^2

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

Base details

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

Cover to reinforcement in toe; c_{toe} = **50** mm

Calculate shear for toe design

Shear from bearing pressure; $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **120.7** kN/m

Shear from weight of base; $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **61.6** kN/m

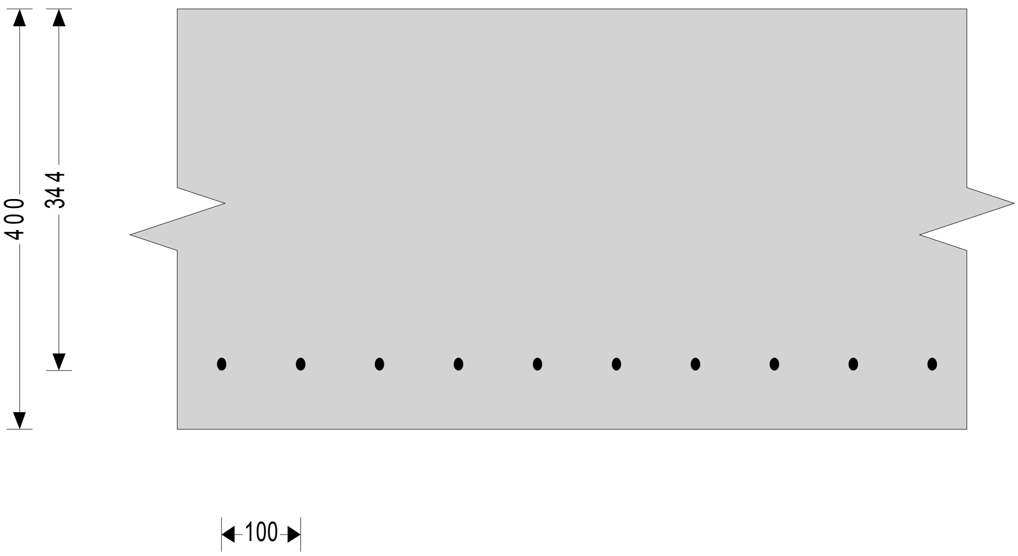
Total shear for toe design; $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **59.1** kN/m

Calculate moment for toe design

Moment from bearing pressure; $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **285.7** kNm/m

Moment from weight of base; $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **145.9** kNm/m

Total moment for toe design; $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **139.9** kNm/m



Check toe in bending

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

Depth of reinforcement; $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **344.0** mm

Constant; $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.030**

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} = **327** mm

Area of tension reinforcement required; $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **984** mm^2/m

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

Area of tension reinforcement required; $A_{s\_toe\_req} = Max(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **984** mm²/m
Reinforcement provided; **12 mm dia.bars @ 100 mm centres**
Area of reinforcement provided; $A_{s\_toe\_prov}$ = **1131** mm²/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress; $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.172** N/mm²
Allowable shear stress; $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **5.000** 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_toe} = **0.530** N/mm²

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

Design of reinforced concrete retaining wall stem

Material properties

Characteristic strength of concrete; f_{cu} = **40** N/mm²
Characteristic strength of reinforcement; f_y = **500** N/mm²

Wall details

Minimum area of reinforcement; k = **0.13** %
Cover to reinforcement in stem; c_{stem} = **40** mm
Cover to reinforcement in wall; c_{wall} = **40** mm

Factored horizontal at-rest forces on stem

Surcharge; $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **26.8** kN/m
Moist backfill above water table; $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **7.7** kN/m
Moist backfill below water table; $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **29.2** kN/m
Saturated backfill; $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **13.4** kN/m
Water; $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **24.8** kN/m

Calculate shear for stem design

Surcharge; $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **16.7** kN/m
Moist backfill above water table; $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **2.4** kN/m
Moist backfill below water table; $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8$ = **23.6** kN/m
Saturated backfill; $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **12.1** kN/m
Water; $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **22.3** kN/m
Total shear for stem design; $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **77.2** kN/m

Calculate moment for stem design

Surcharge; $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **10.4** kNm/m
Moist backfill above water table; $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **2.4** kNm/m
Moist backfill below water table; $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8$ = **13.4** kNm/m
Saturated backfill; $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **5.3** kNm/m
Water; $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **9.7** kNm/m
Total moment for stem design; $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **41.2** kNm/m

Calculate moment for wall design

Surcharge; $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128 =$ **5.8** kNm/m

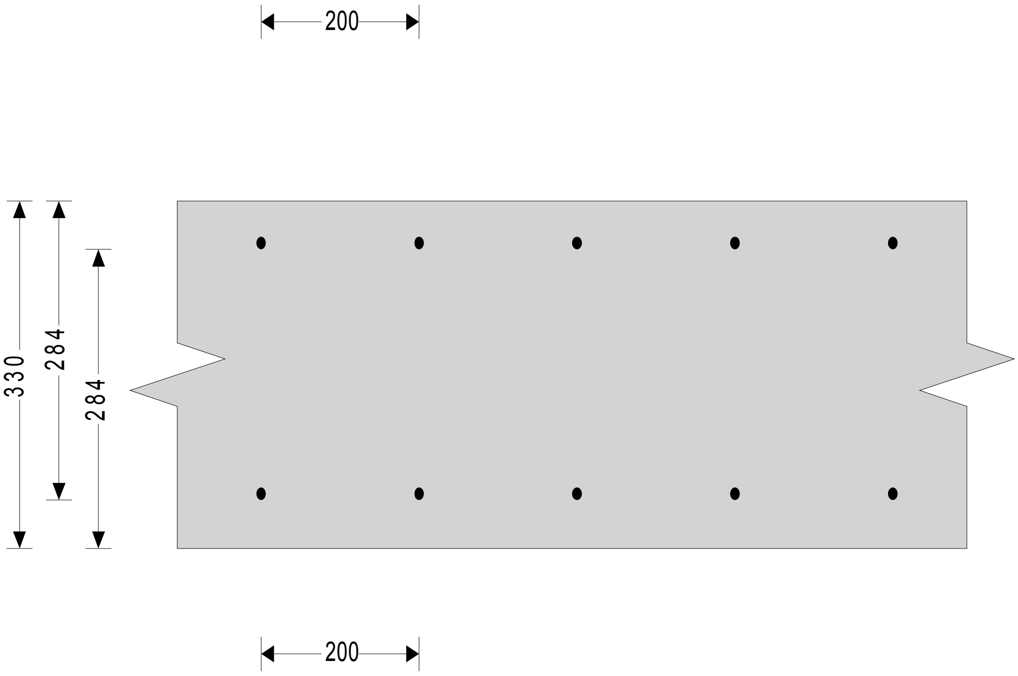
Moist backfill above water table; $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3+5 \times a_l \times L^2)/(5 \times L^3)-0.577^2/3] =$ **2.5** kNm/m

Moist backfill below water table; $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8-n^2 \times (4-n))^2 /16)-4+n \times (4-n)]/8 =$ **6.7** kNm/m

Saturated backfill; $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)] =$ **1.9** kNm/m

Water; $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)] =$ **3.5** kNm/m

Total moment for wall design; $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water} =$ **20.5** kNm/m



Check wall stem in bending

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

Depth of reinforcement; $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2) =$ **284.0** mm

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

Compression reinforcement is not required

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

$z_{stem} =$ **270** mm

Area of tension reinforcement required; $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem}) =$ **351** mm²/m

Minimum area of tension reinforcement; $A_{s\_stem\_min} = k \times b \times t_{wall} =$ **429** mm²/m

Area of tension reinforcement required; $A_{s\_stem\_req} = \max(A_{s\_stem\_des}, A_{s\_stem\_min}) =$ **429** mm²/m

Reinforcement provided; **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided; $A_{s\_stem\_prov} =$ **565** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress; $v_{stem} = V_{stem} / (b \times d_{stem}) =$ **0.272** N/mm²

Allowable shear stress; $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 =$ **5.000** 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} = **0.470** N/mm^2

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

Check mid height of wall in bending

Depth of reinforcement; $d_{wall} = t_{wall} – c_{wall} – (\phi_{wall} / 2)$ = **284.0** mm

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

Compression reinforcement is not required

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

z_{wall} = **270** mm

Area of tension reinforcement required; $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall})$ = **175** mm^2/m

Minimum area of tension reinforcement; $A_{s\_wall\_min} = k \times b \times t_{wall}$ = **429** mm^2/m

Area of tension reinforcement required; $A_{s\_wall\_req} = Max(A_{s\_wall\_des}, A_{s\_wall\_min})$ = **429** mm^2/m

Reinforcement provided; **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided; $A_{s\_wall\_prov}$ = **565** 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; $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **252.9** N/mm^2

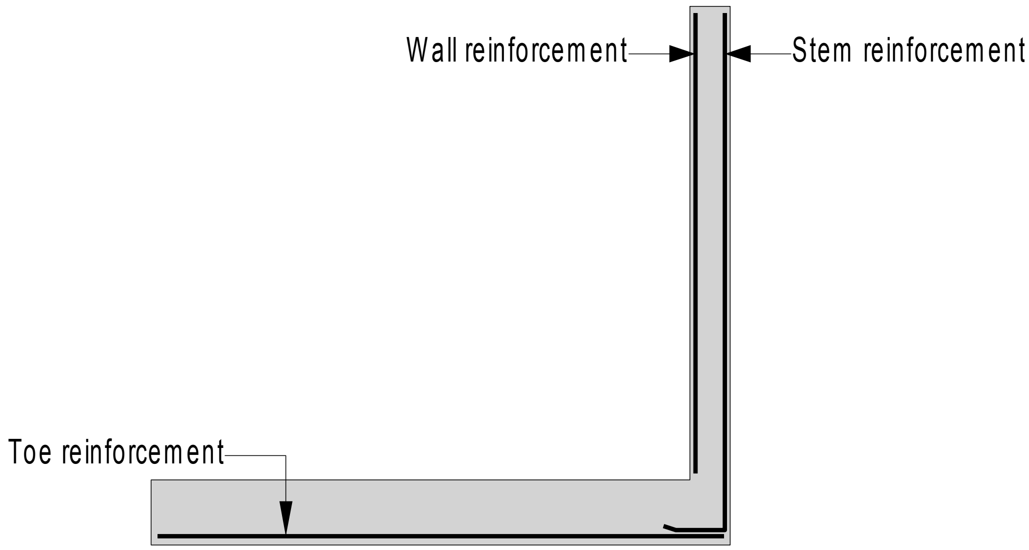
Modification factor; $factor_{tens} = min(0.55 + (477 N/mm^2 - f_s)/(120 \times (0.9 N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.87**

Maximum span/effective depth ratio; $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **37.48**

Actual span/effective depth ratio; $ratio_{act} = h_{stem} / d_{stem}$ = **10.21**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 12 mm dia.@ 100 mm centres - (1131 mm^2/m)
Wall bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Stem bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)

APPENDIX A

LOADINGS

Flat roof

		kN/m^2
Total live load	snow	0.75
	asphalt waterproofing	0.45
	Metsec purlins and Kingspan ThermaRoof	0.05
	plywood	0.15
	ceiling and services	0.15
Total dead load		0.80

Timber pitched roof

		kN/m^2
Total live load	snow	0.60
	slates, timber battens and felt	0.55
	Metsec purlins and Kingspan ThermaRoof	0.05
	plywood	0.15
	ceiling and services	0.15
Total dead load		0.90

Flat roof – plant roof

		kN/m^2
Total live load	snow	7.50
	asphalt waterproofing	0.45
	Metsec purlins and Kingspan ThermaRoof	0.05
	plywood	0.15
	ceiling and services	0.15
Total dead load		0.80

Typical Floor – Passage

		kN/m^2
Total live load	Residential	4.00
	timber boards/plywood	0.20
	timber joists and insulation	0.25
	ceiling and services	0.20
Total dead load		0.65

Restaurant

		kN/m²
Total live load	Restaurant	5.00
	partitions	1.00
	screed	1.20
	solid reinforced slab	6.74
	ceiling and services	0.20
Total dead load		8.14

Restaurant – Kitchen

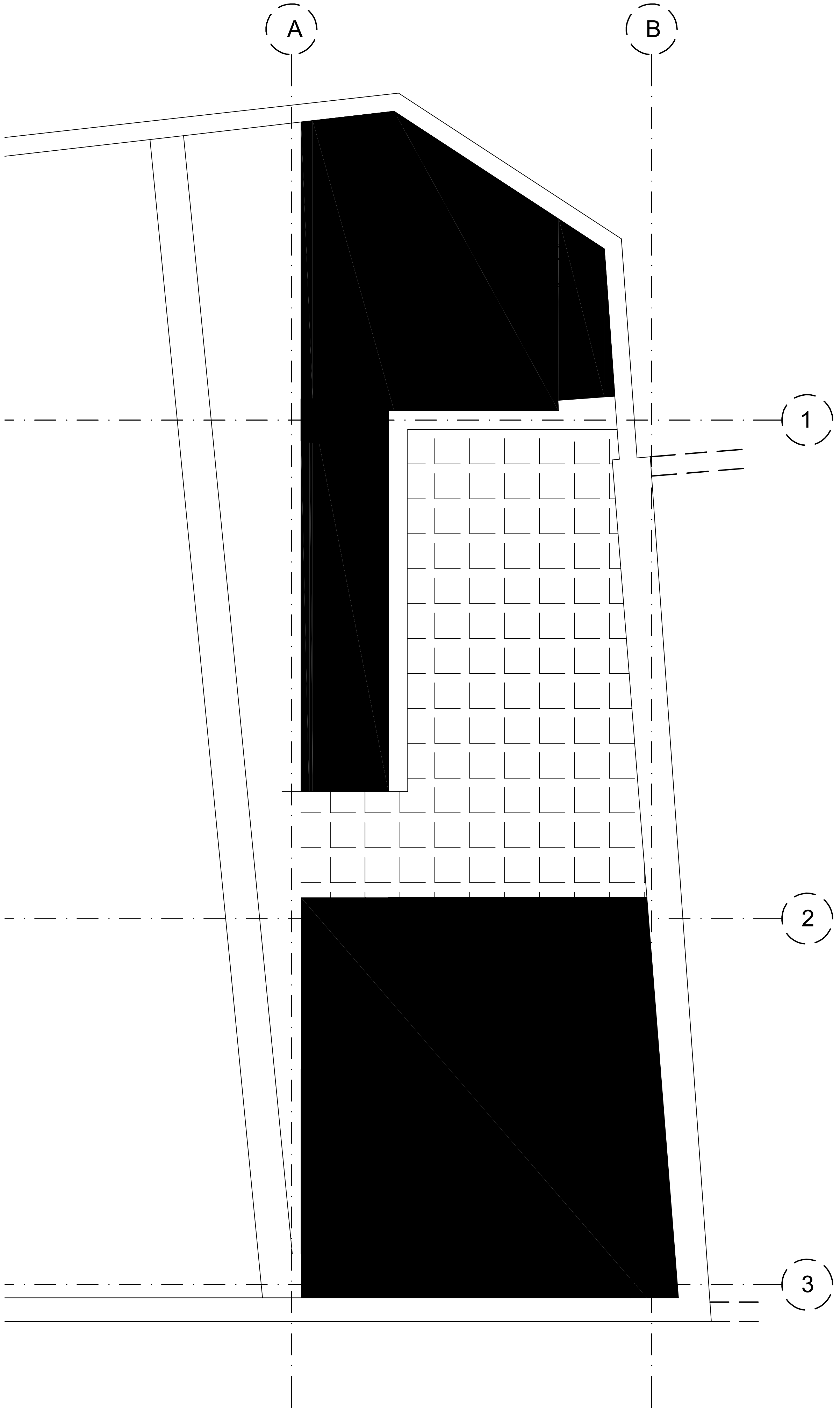
		kN/m²
Total live load	Restaurant	5.00
	partitions	1.00
	screed	1.20
	solid reinforced slab	6.13
	ceiling and services	0.20
Total dead load		8.53

External wall

		kN/m³
	density of brick	24.00
	Kingspan insulation	0.31
	accustic isulation	1.00
	density of plaster	8.49
		kN/m²
	solid brick wall 215 mm	5.16
	Kingspan insulation 75mm	0.0233
	accustic isulation 150mm	0.15
	2 x plaster 15mm	0.25
Total dead load		5.59

Floor level – residential

		kN/m²
Total live load	domestic	1.50
	partitions	1.00
	timber boards/plywood	0.15
	timber joists and insulation	0.20
	ceiling and services	0.15
Total dead load		1.50



ALLOWABLE FLOOR LOAD
[kN/m2]

Solid black fill	Superimposed Dead Load: 2.9 kN/m2 Imposed/Live Load: 29.4 kN/m2
Hatched	Superimposed Dead Load: 2.9 kN/m2 Imposed/Live Load: 4 kN/m2
Blank	Superimposed Dead Load: 2.9 kN/m2 Imposed/Live Load: 5 kN/m2

ALL LOADS ARE NOT FACTORED (SLS).

SELF WEIGHT OF THE BASEMENT SLAB HAS NOT BEEN INCLUDED.

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Mark	Description	Drawn	Checked	Date
A	PRELIMINARY	RJ	EP	May 2018

REVISIONS

Title: Basement – Loading Plan
Allowable floor load

Project: 8 Kentish Town Road
London NW1

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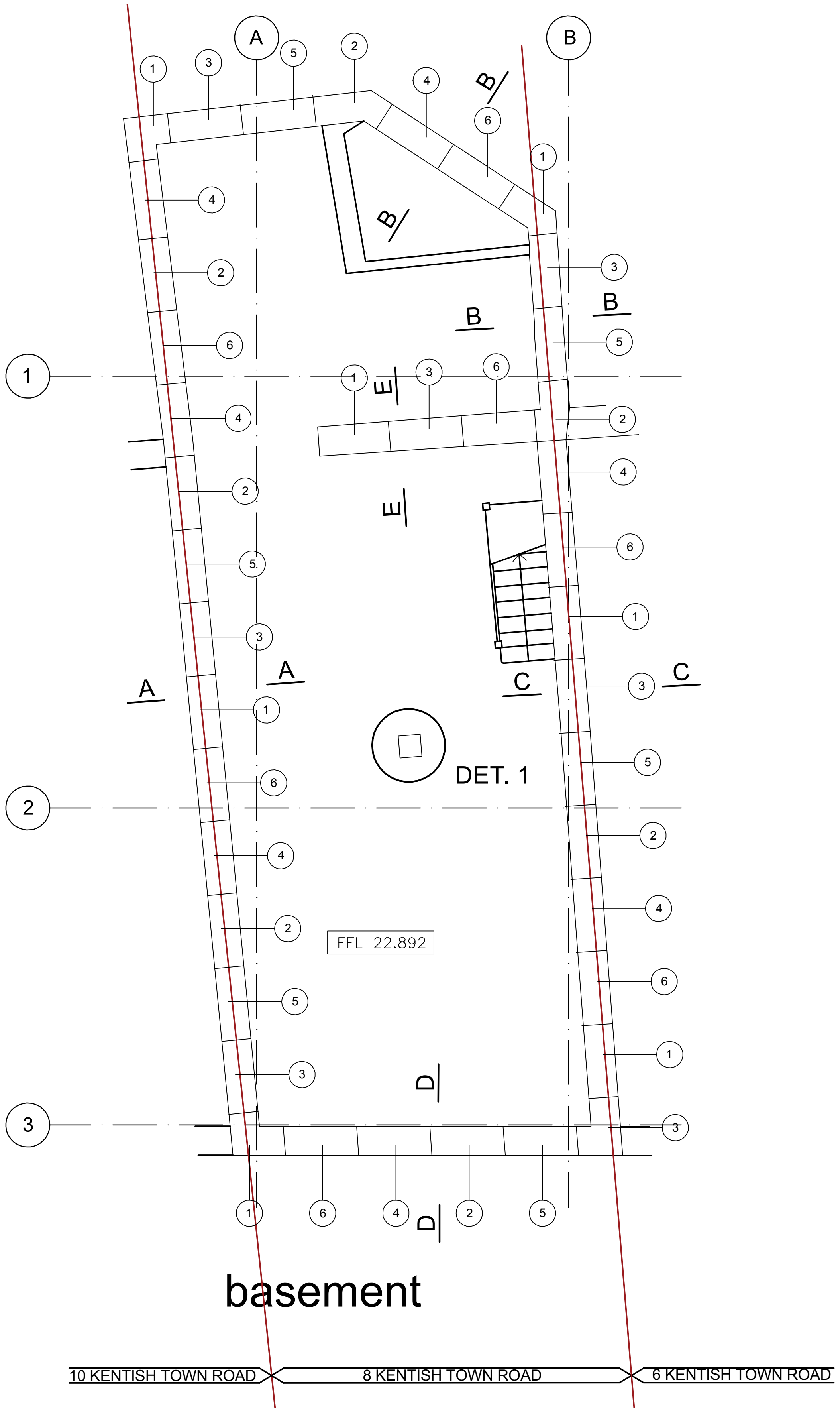
APPENDIX B

DRAWINGS



RC UNDERPINNING SEQUENCE IN MAX 1M LENGTH

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Mark	Description	Drawn	Checked	Date
A	PRELIMINARY	RJ	EP	June 2018

R E V I S I O N S

Title: BASEMENT – UNDERPINNING PLAN

Project: 8 Kentish Town Road London NW1

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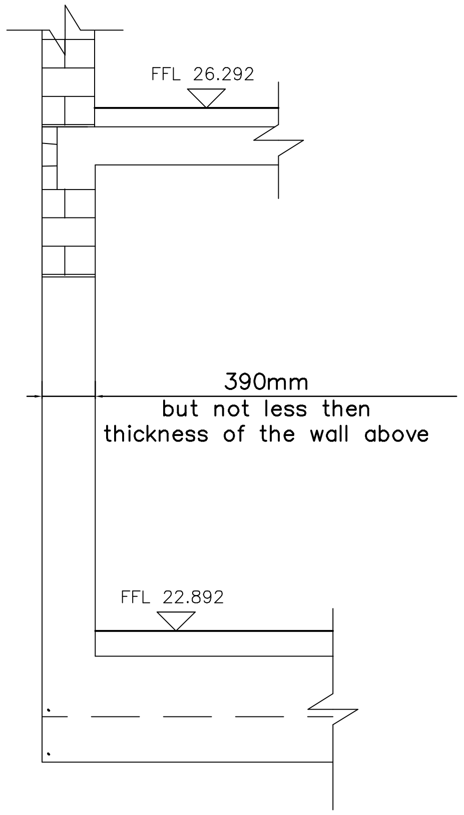
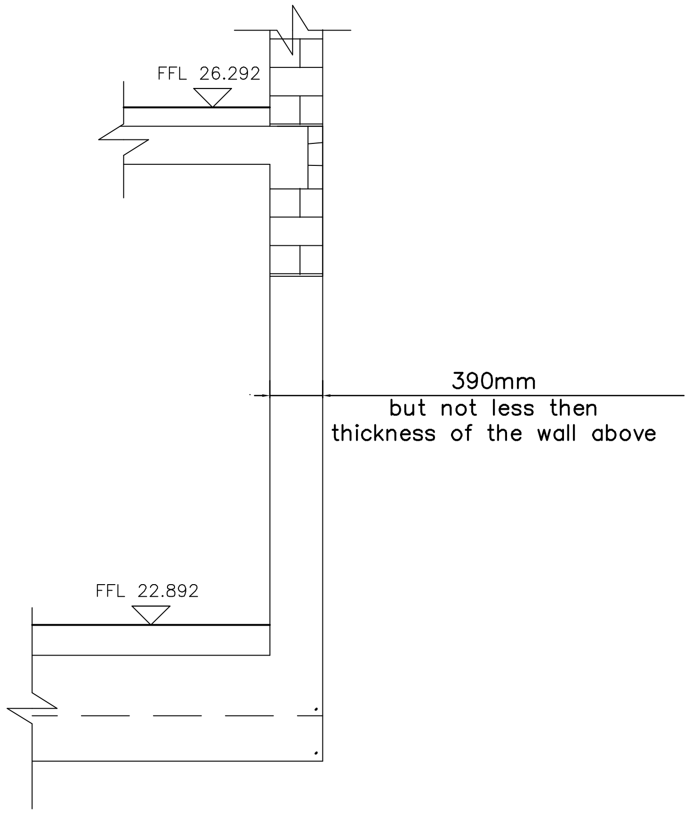
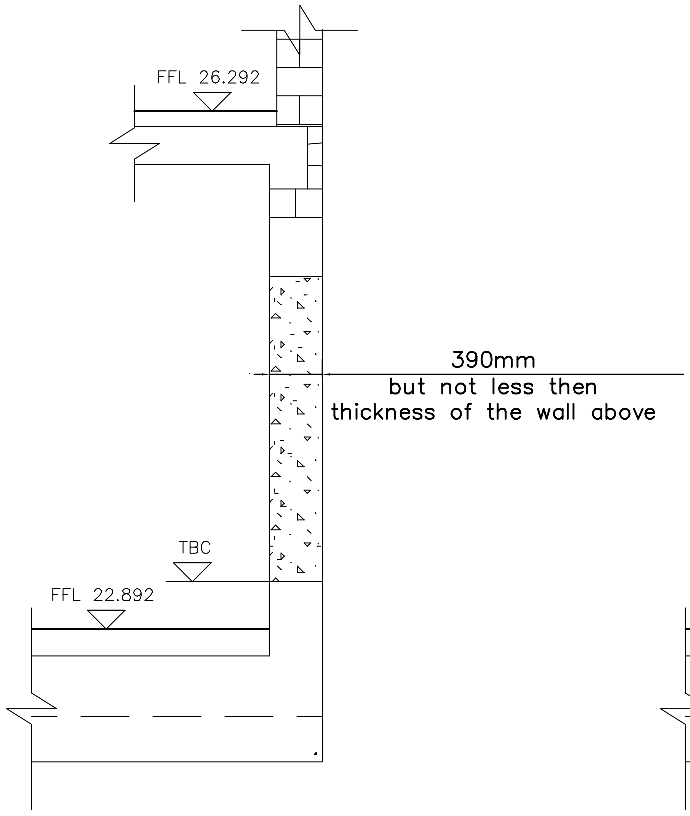
Drawing No. 051



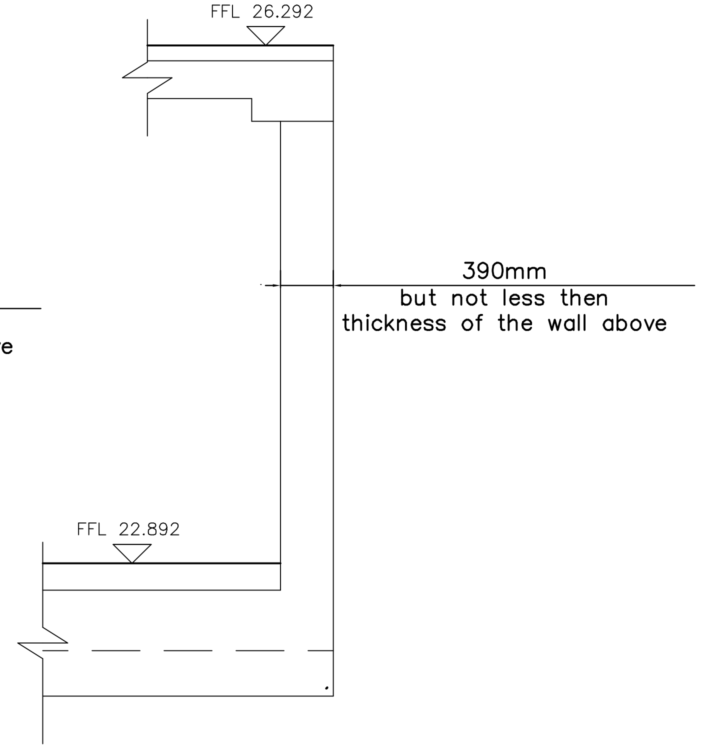
A–A



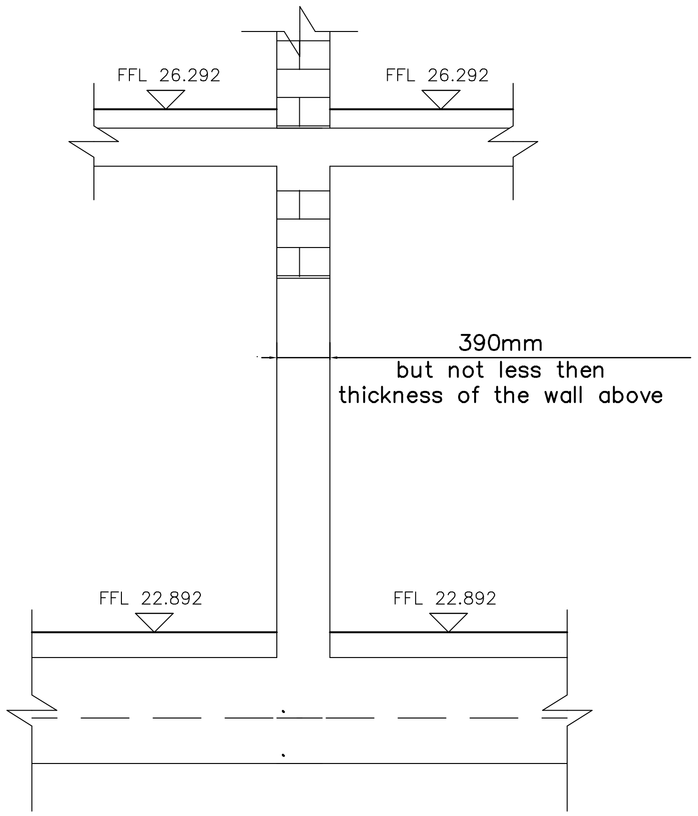
B–B



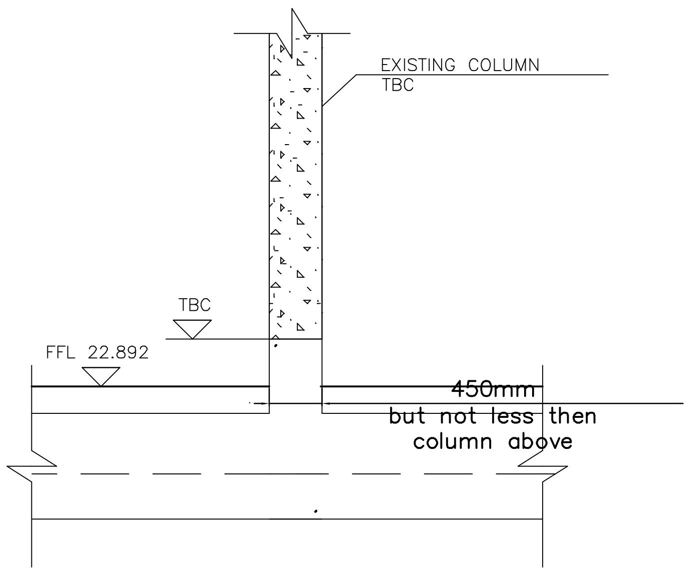
C–C



D–D



E–E



DET. 1

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A	PRELIMINARY	RJ	EP	June 2018
Mark	Description	Drawn	Checked	Date

R E V I S I O N S

Title: BASEMENT – UNDERPINNING SECTIONS

Project: 8 Kentish Town Road
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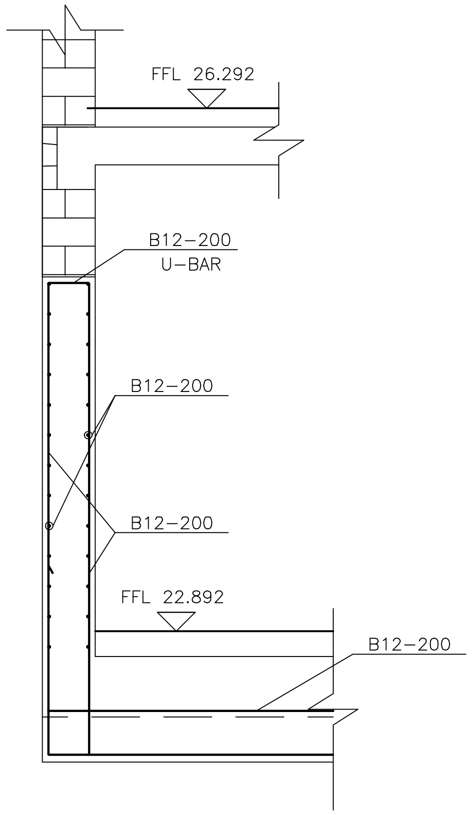
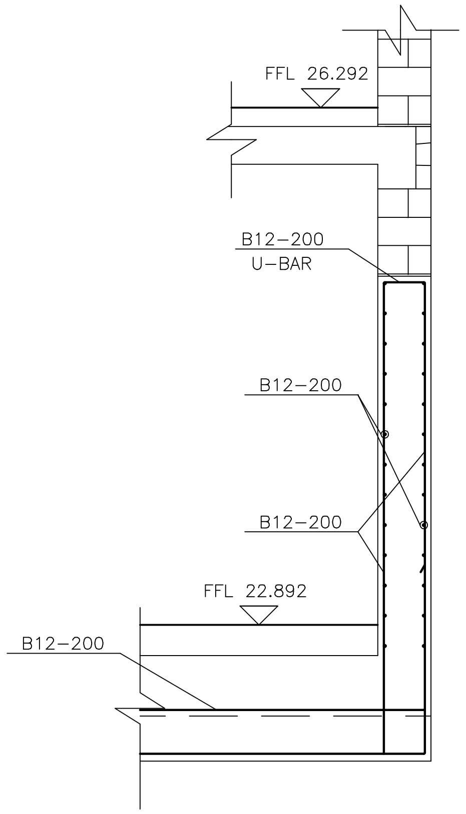
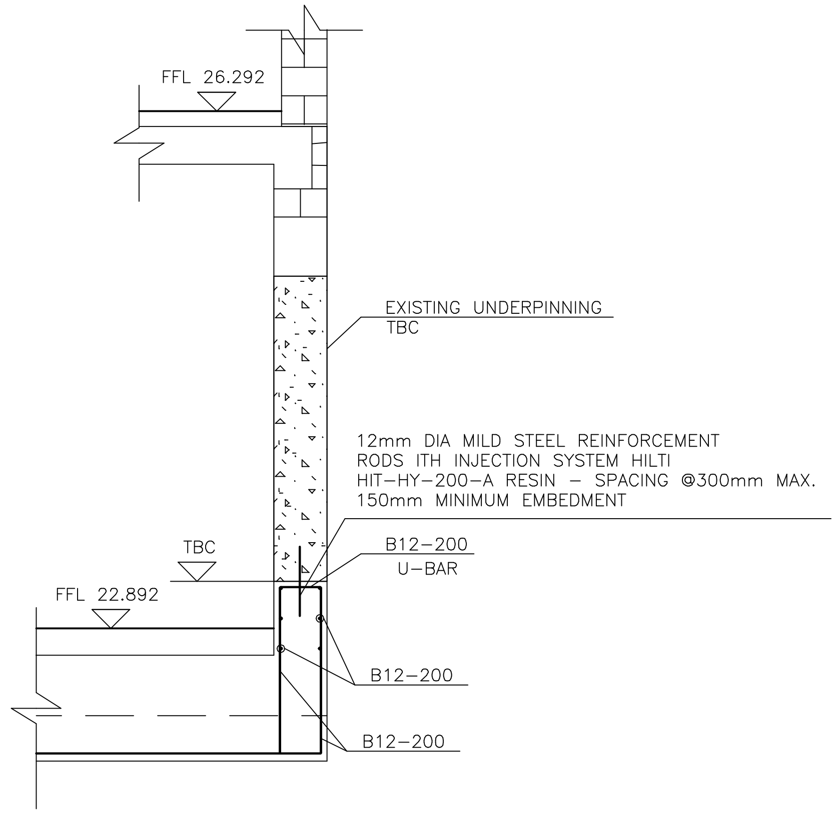
Drawing No. 052



A–A



B–B



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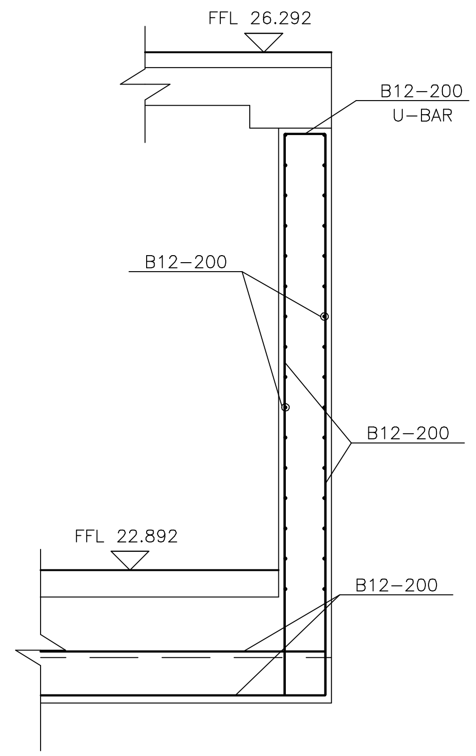

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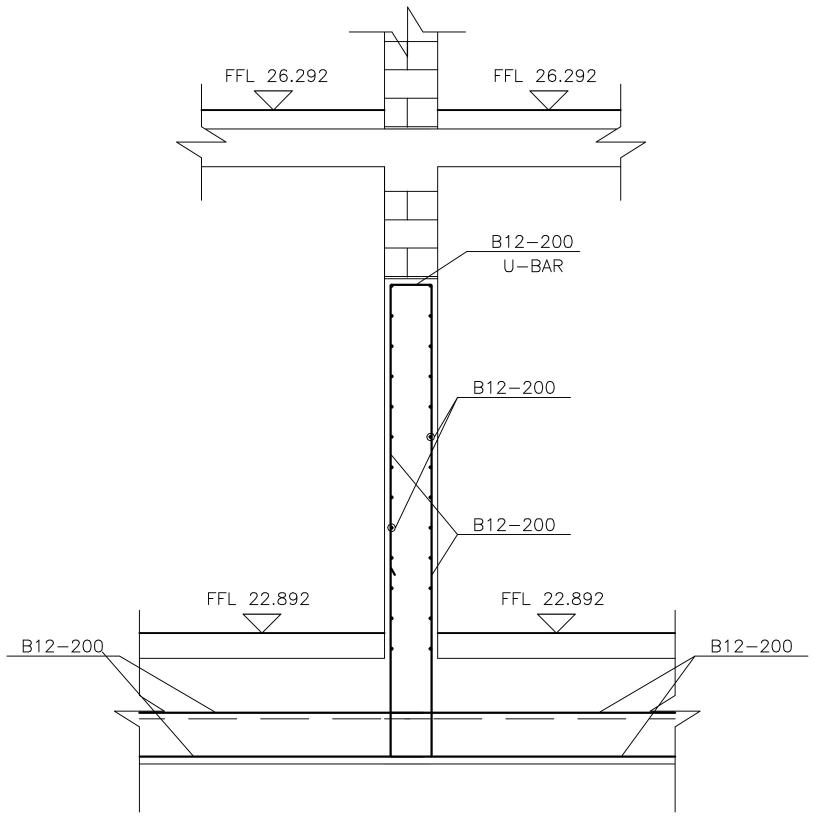
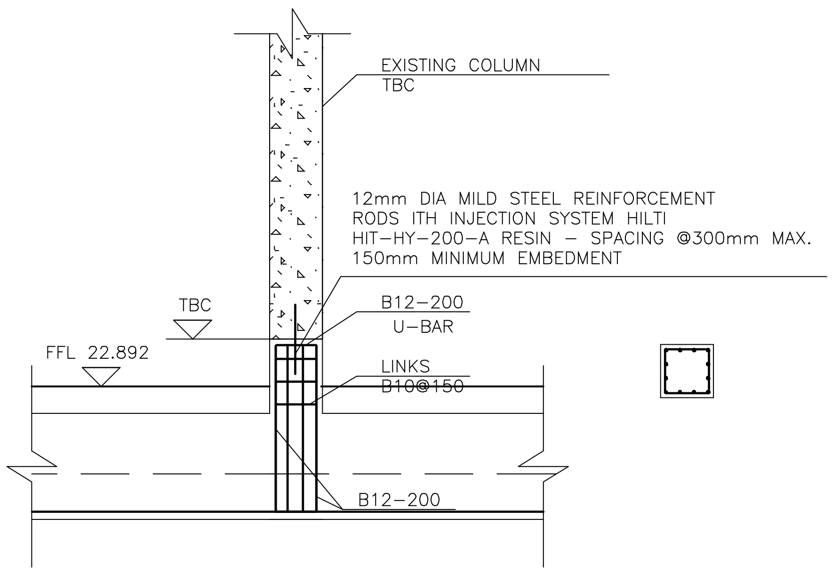


E–E



DET. 1

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CONTRACTORS TO CHECK ALL DIMENSIONS ON SITE TO PRIOR
TO ORDERING MATERIALS / COMMENCING WORK.

Mark	Description	Drawn	Checked	Date
A	PRELIMINARY	RJ	EP	June 2018

R E V I S I O N S

Title
BASEMENT – UNDERPINNING REINFORCEMENT

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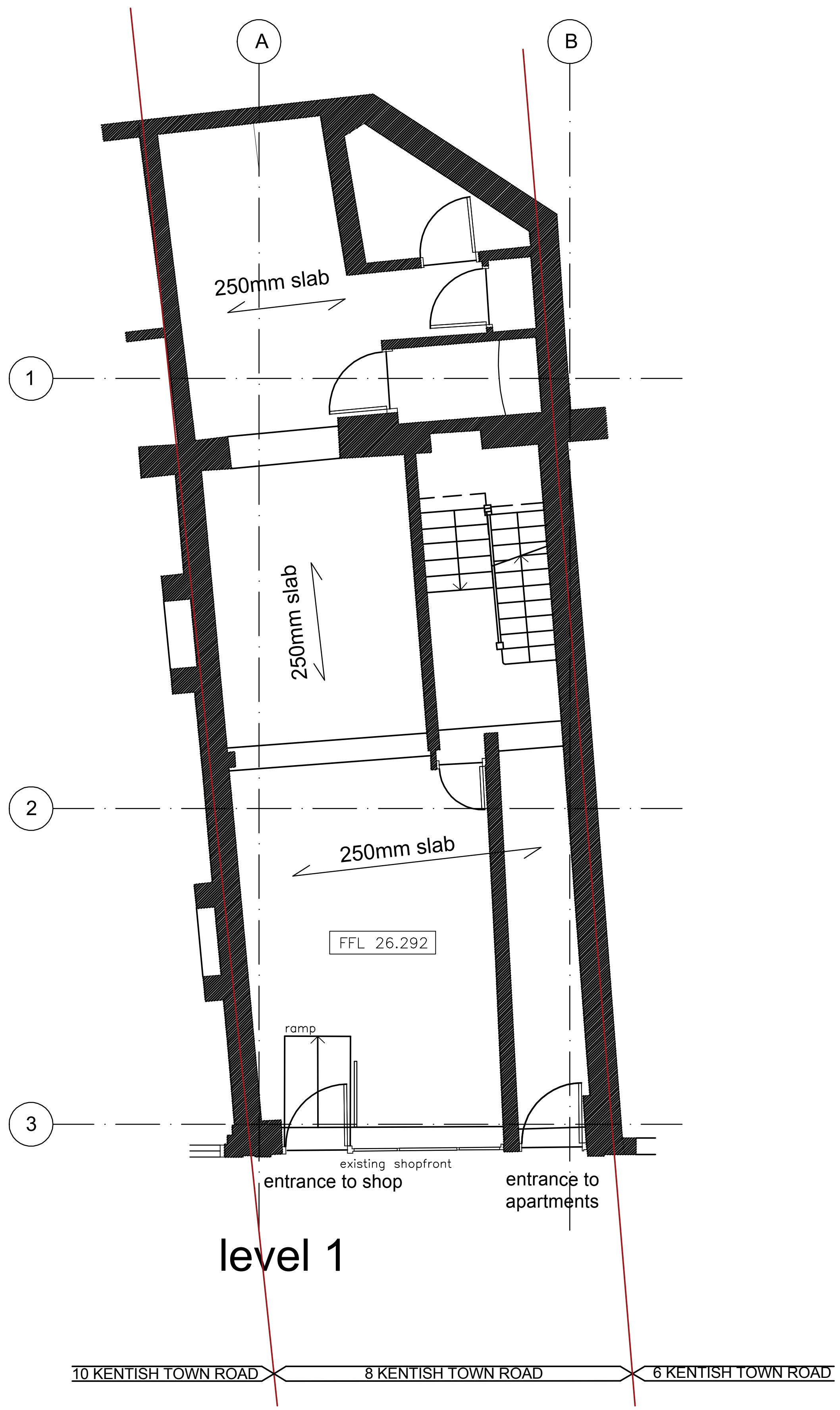

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CONTRACTORS TO CHECK ALL DIMENSIONS ON SITE TO PRIOR TO ORDERING MATERIALS / COMMENCING WORK.

Mark	Description	Drawn	Checked	Date
A	PRELIMINARY	RJ	EP	June 2018

REVISIONS

Title: GROUND FLOOR PLAN

Project: 8 Kentish Town Road, London NW1

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