Form

17 EAST HEATH ROAD, LONDON, NW3 1AL

BASEMENT IMPACT ASSESSMENT IN SUPPORT OF PLANNING APPLICATION

Job No: 162611

Date: 03rd November 2016

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Revision: P2

Residential

Commercial

Conservation

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Contents

PREAMBLE

This report has been prepared by Form Structural Design Ltd on the instructions of the project architects, Marek Wojciechowski Architects, acting on behalf of the client and is for the sole use and benefit of the client.

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ABOUT FORM STRUCTURAL DESIGN

Form has undertaken over 250 projects involving subterranean development, both new build and retrospective, using numerous techniques and sequences of construction. This extensive design, site and local geology/hydrology experience has positioned the practice as one of London's leading subterranean engineering design consultants.

Many of our subterranean projects are in the London Boroughs of RBKC, Westminster, Camden, Hammersmith & Fulham and Haringey, making us familiar with the most recent requirements of subterranean development.

Form has designed multi-level basements using techniques including open dig, underpinning (mass and 'L' shaped R.C. special foundations), temporary and permanent steel sheet piling, temporary and permanent concrete piled retaining walls, top down construction and tunnelling.

TERMS OF REFERENCE

We were appointed by the project architects, Marek Wojciechowski Architects, to prepare a Construction Method Statement in support of a planning submission for refurbishment including extending the lower ground floor further into the rear garden at 17 East Heath Road, London, NW3 1AL.

Executive Summary

The proposal complies with the requirements set out in Camden Development Policy DP27 2010 - 2025. Specifically:

- The proposal will have no impact on the structural stability of the existing and adjoining buildings. This is ensured in both the permanent state and for the duration of the site works. Respectively, the permanent and temporary works will be designed to sustain the loads applied by the existing structures where necessary.
- As the services within the property are not to be significantly altered and the extent of hard standings are not proposed to be increased, the flow rate into public sewers in terms of foul or storm runoff is not expected to increase and therefore the existing utilisation of the public sewer will not be altered by the development.
- Alterations to the structure will be designed in such a way as to maintain independent stability and avoid taking any support from adjacent structures. There is no effect on local groundwater levels and flows, this has been assessed by Card Geotechnics in a separate BIA.
- The proposed development will not adversely affect any class A trees in the vicinity.
- As the extension to the lower ground floor is proposed in a location which is currently occupied by a raised terrace, there is no adverse effect on soil provision.
- The site is not expected to be of archaeological significance.

The permanent and temporary works will be designed to relevant British Standards. The temporary works and the method of works will be developed such that the effect on the neighbours is kept to category 1 levels according to CIRIA guide C580 (see **Appendix C**)

Introduction

1.0 Introduction

This report has been prepared as a supporting document to the planning application for the redevelopment of the site currently known as 17 East Heath Road (17EHR). The proposals involve the formation/expansion of some openings in internal loadbearing walls at lower ground floor level, the lowering of the lower ground floor level, the erection of a new single storey glazed extension to the rear and the extension of the lower ground floor further into the rear garden.

This report predominantly presents an outline structural scheme for the construction of the new section of lower ground floor but also touches on the alterations to the superstructure.

Limitations

This report and the structural information produced to date is based on a review of the proposed architectural plans and visual inspection of the existing structure. A borehole has been undertaken to verify the ground conditions and trial pits have been carried out to verify the foundations of adjacent party fence structures and ensure adequate safeguarding is put in place during the works.

2.0 The Site and Existing Building

The existing structure is a late-Victorian semi-detached house located on East Heath Road, close to the junction with Squires Mount. The property is Grade II listed and is within the Hampstead conservation area. The existing property is laid out over four storeys with storage in the roof void and constructed from masonry walls with timber floors and a timber cut roof.

Figure 1 – Front View

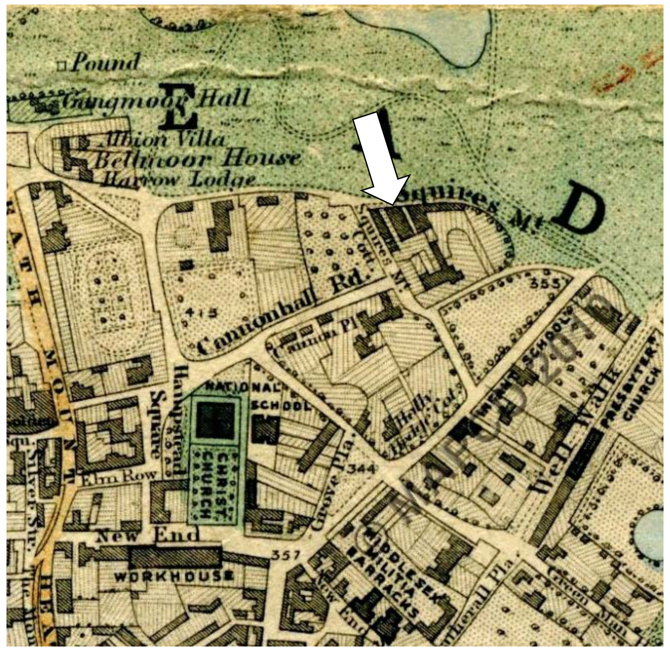


Figure 2 – Stanford's Library Map of London and its Suburbs 1864

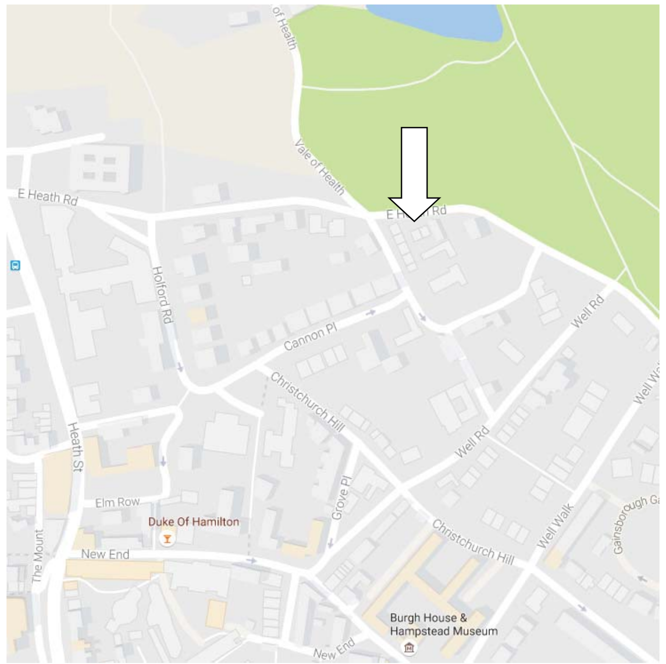


Figure 3 – Current Street Map

Figure 4 – Rear Aerial View

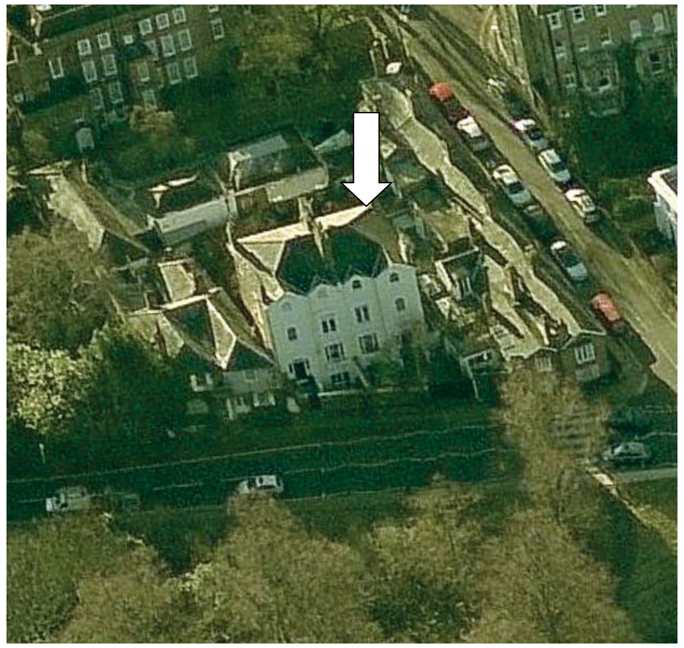


Figure 5 – Front Aerial View

Site Information

3.0 Ground Conditions/Geology

A check on the British Geological Survey website indicates that the site is underlain by sand with no superficial deposits recorded. This is corroborated by a search of local historic boreholes, the nearest being on Squires Mount. This borehole shows made ground and sandy gravel over sand at 2.7m.

A site investigation including boreholes and trial holes has been carried out, is to be submitted as part of the planning application. The borehole information confirmed the presence of sand below a layer of made ground. Sampling and laboratory testing confirmed the soil parameters required for the design of the new foundations.

The construction methods proposed within this report and associated structural proposals are appropriate for the geology and are capable for supporting the structural loads of the proposed development, the techniques that will be used for the construction are well established in the industry. Refer to **Appendix A**.

Summary of Window Sample Log WS1	
Description of Strata	**Depth**
Made Ground Finishes, slab, rubble, gravel and sand.	0.0m – 0.75m
Sand Medium dense yellow grey fine sand with occasional orange brown bands up to 5mm thick. (Bagshot Formation)	0.75m – 4.45m
Sand Yellow grey slightly clayey fine sand. (Bagshot Formation)	4.45m – 4.90m
Sand Medium dense yellow grey fine SAND with occasional orange brown bands up to 5mm thick. (Bagshot Formation)	4.90m – 7.45m

Slope stability

The site is considered to be generally level and not cut into the side of hills or valleys therefore slope stability is not considered to be a problem.

4.0 Hydrogeology & Hydrology

A separate Basement Impact Assessment has been carried out by Card Geotechnics Limited which is to be submitted as part of the planning application. This covers existing ground conditions and reviews possible impacts on ground water and neighbouring structures.

5.0 Arboriculture

An Arboriculture report has been carried out by Simon Pryce which will be submitted as part of this application. Two trees were noted in the front garden and one in the back. The two trees in the front garden have been judged as category U and are to be removed. The category C tree in the rear garden is also to be removed in order to facilitate the works but is not judged to make minimal contribution outside the garden and is easily replaceable.

6.0 Underground Structures

It can be seen from **Figure 7** below that the LUL Northern Line runs to the West of the site through Hampstead, the tunnel is approximately 430m from the property. It will therefore not be necessary to advise London Underground asset protection department to check alignments and agreed works will not affect any existing tunnels or access shafts. No other underground structures, tunnels or vaults are expected in the vicinity of the proposed works.

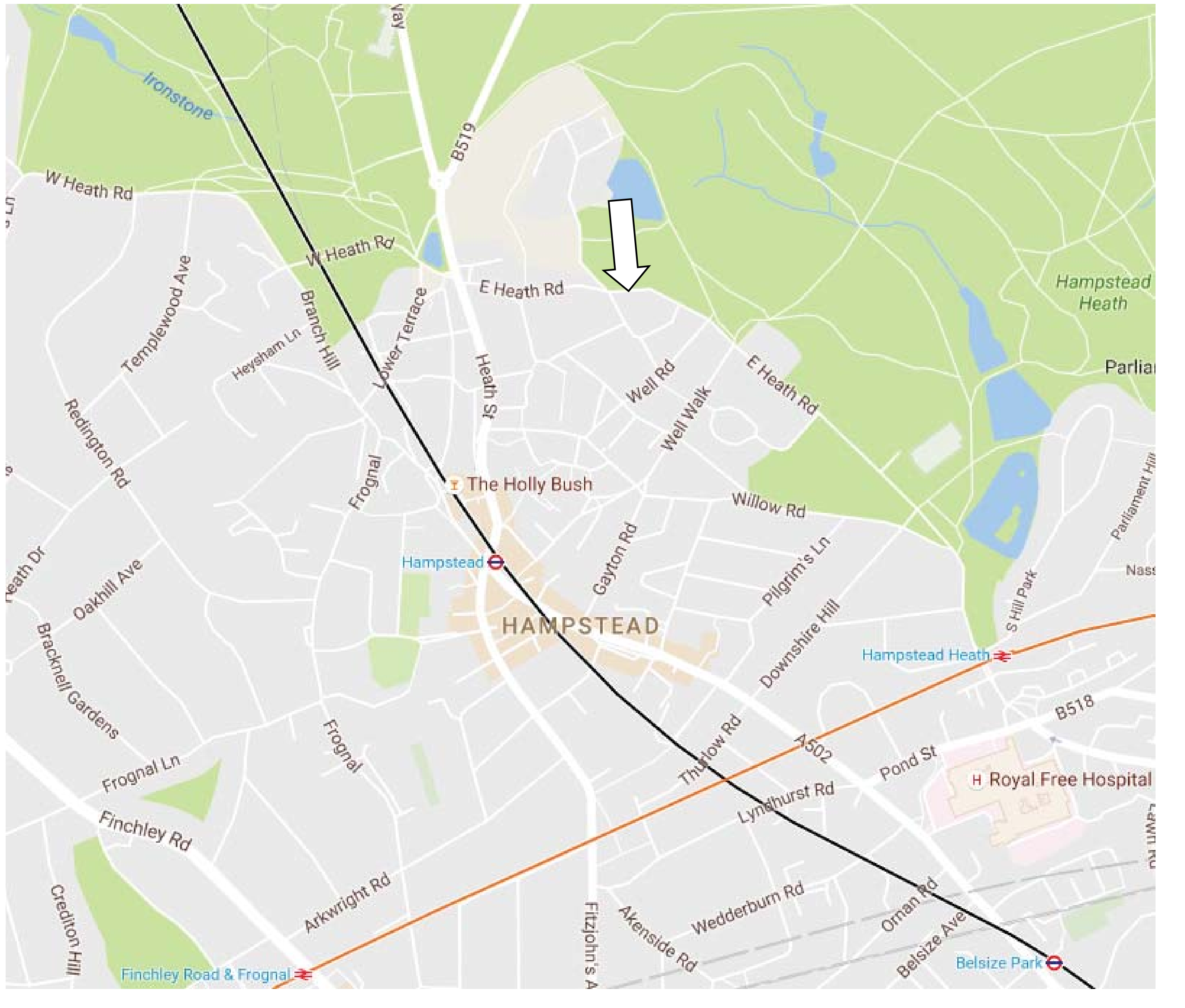


Figure 7- Proximity of LUL Lines to 17 East Heath Road

7.0 Existing Utilities and Underground Drainage

Gas and Electrical

As the extent of excavation is small and to the rear of the house it is assumed that no services will be affected. However if required, services will be diverted and replaced to modern day standards where necessary as determined by the Mechanical and Electrical Engineer for the project. All services that are required to pass through new structure will be sleeved and articulated accordingly to allow for future movements and settlements of the surrounding structure.

Below Ground Drainage

It is assumed that drainage for the property runs to a sewer below East Heath although this has not been verified. This will need to be verified prior to commencement of excavation works.

As the extent of hard standings are not proposed to be increased, the flow rate into public sewers in terms of foul or storm runoff is not expected to increase and therefore the existing utilisation of the public sewer will not be altered by the development.

8.0 Boundary Conditions

The property has six adjoining owners and one boundary with the public highway.

South Eastern (Rear) Boundary

The rear boundary of the property is formed by the rear external wall of The Cottage, Squires Mount which is a grade II listed, two-storey early to mid C19 property with no basement.

North Western (Front) Boundary

The front boundary of the property is separated from the footway of East Heath Road by the front garden wall of 17EHR.

North Eastern Boundary

To the north east the property adjoins 16 East Heath Road. The houses share a party wall with the front and rear gardens separated by a party garden wall. 16EHR is grade II listed in conjunction with 17EHR.

South Western Boundary

To the South West, the property adjoins the rear of No.s 1-4 Squires Mount. In some locations the boundary wall remains a garden wall and in others it has been enclosed upon to form the external wall of a rear extension. This row of properties are mid C19 and grade II listed.

Development Proposals

It is proposed to extend the current rear projection at lower ground floor further back into the garden. As the rear section of the garden is circa 2m higher than the internal ground floor level this will necessitate some excavation and the formation of new RC cantilever retaining walls. It is also proposed to lower the existing floor slabs within the house at lower ground floor level and within the vaults to the front of the property. The slabs within the house are to be reduced in level as much as possible without undermining the existing foundations. The vault walls will need to be underpinned as the proposed slab level reduction would undermine the existing walls. An existing wall is also to be removed within the vault and a new support beam provided.

9.0 Sub-Structure Construction

The proposals for the construction of the substructure to the rear take account of the development proposals as indicated on the architect's drawings, anticipated ground conditions, the stability of the neighbouring properties, health and safety considerations and the physical constraints of the site. (See drawings in **Appendix A** for proposed structural arrangement).

10.0 Temporary Works Systems and Principals to be used on each part of the works

It is proposed to construct the new rear extension by forming L-shaped reinforced concrete cantilever retaining walls in underpin fashion. Some of these sections will be formed below the party wall with Nos. 3 and 4 Squires Mount, some will be simply retaining the high level garden to the rear within the boundary of 17EHR.

The reinforced concrete underpins have been designed to be freestanding i.e. no props are required in the temporary or permanent condition. Conservative levels and loads for the adjoining buildings have been taken at this stage, further investigation will be carried out prior to construction. No groundwater is expected.

The existing boundary garden wall between 17 and 16 East Heath Road may need to be underpinned in order to facilitate the reduction in ground level. The foundation beneath the party wall with 3 Squires mount will need to be investigated further as it was not possible to expose it in the original site investigations. This may also need mass concrete underpinning depending on the actual depth. The wall to the rear of the garden which forms the back wall of The Cottage, Squires Mount will need to be partially underpinned in order to facilitate a reduction in level.

All of the works, particularly the sub-structure, are to be carried out in a manner which minimises any noise and vibration that may affect the neighbouring properties. The engineer will make regular site visits during the basement works in order to ensure good practise is being followed. The ground works contractors will provide detailed method statements for the works and temporary propping to the basement for approval by the engineer prior to commencement of the works.

11.0 Potential Ground Movement and Monitoring of Adjoining Properties

Based on experience from many similar projects within the RBKC, Westminster and Camden, monitoring during the works typically records maximum vertical and horizontal movements of 5mm. We therefore expect the maximum category of movement to be a category 1 of the Building Damage classification table based on Boscardin and Cording / Burland et al. See **Appendix C.** We have extensive experience of underpinning and contiguous piling and will visit the site periodically during the works to ensure it is being carried out to our specifications.

Monitoring of the surrounding buildings will be carried out during the works to assess possible movements and the findings will be reported to the adjoining surveyors periodically. It is anticipated that only the adjacent structures at 3 and 4 Squires mount are within the zone of influence of the sub-structure works, it is therefore proposed to monitor the party wall in this area. The details of the monitoring regime will be agreed with the adjoining owners' surveyors as part of the party wall approval process. Form will produce a full monitoring specification which will form part of the party wall documentation. This will detail, amongst other things, the frequency of monitoring, tolerances and location of monitoring points. Monitoring points will be placed in multiple locations at high and low levels in order to monitor vertical and lateral movement of all structures within the zone of influence of the works. Trigger levels will be suggested and agreed with the adjoining owners' surveyors. These trigger levels will set out quantities of settlement at which the adjoining owners will be notified and works on site reviewed by the project engineer.

12.0 Excavation of Soil

The soil will be excavated and transferred to normal 7m skips kept on site. The excavation would be undertaken by small excavators and transferred to the skip to the front of the site by hand. The footpath and street adjacent to the site will be cleaned each evening. The frequency of vehicle movement will be confirmed by the chosen contractor and approved by the council before works commence. The skip is to be located in the front garden.

13.0 Waterproofing and Drainage systems

Reinforced concrete retaining walls will be designed as a water retaining structure in accordance with BS 8007 and detailed with hydrophyllic strips at all concrete joints in order to minimise water ingress. As the proposed level of the substrycture is not lower than the existing adjacent floor no significant water is expected however final waterproofing details will need to be confirmed by the architect / specialist.

Drainage will remain as a gravity system.

14.0 Demolition, Recycling, Dust/Noise Control & Site Hoarding

The demolition works are to take place within the hoarded confines of the site. Any scaffolding on the site perimeter is to be clad with monoflex sheeting above the 6 foot plywood hoarding line to minimise any dust or debris from falling onto the neighbouring streets.

Materials such as stock-bricks, re-useable timbers, steel beams etc are to be recycled where possible.

To minimise dust and dirt from the demolition phase of the project, the following measures shall be implemented:

- All brickwork and concrete demolition work is to be constantly watered to reduce any airborne dust.
- Demolished materials are to be removed to a skip placed at the front of the site.
- The pavement to the sides of the property is to be washed and cleaned down each day.
- Any debris or dust / dirt falling on to the street and public highway will be cleared as it occurs by designated cleaners and washed down fully every night.

Building work which can be heard at the boundary of the site will not be carried out on Sundays and Bank Holidays and will be carried out within working hours as agreed with the council.

Rubbish Removal and Recycling:

An important part of the site management process involves site cleansing, rubbish removal and recycling.

To reduce and manage site waste:

- All material removed from site is to be taken to waste recycling stations and separated for recycling where possible. Records of the waste recycling will be provided by the recycling stations.
- Waste types to facilitate recycling activities.
- All Duty of Care and other legal requirements are complied with during the disposal of wastes.
- Suppliers are to be consulted to determine correct / appropriate disposal routes for waste products and containers.

It will be the responsibility of each contractor to keep the site area under his control safe from build-up of rubbish.

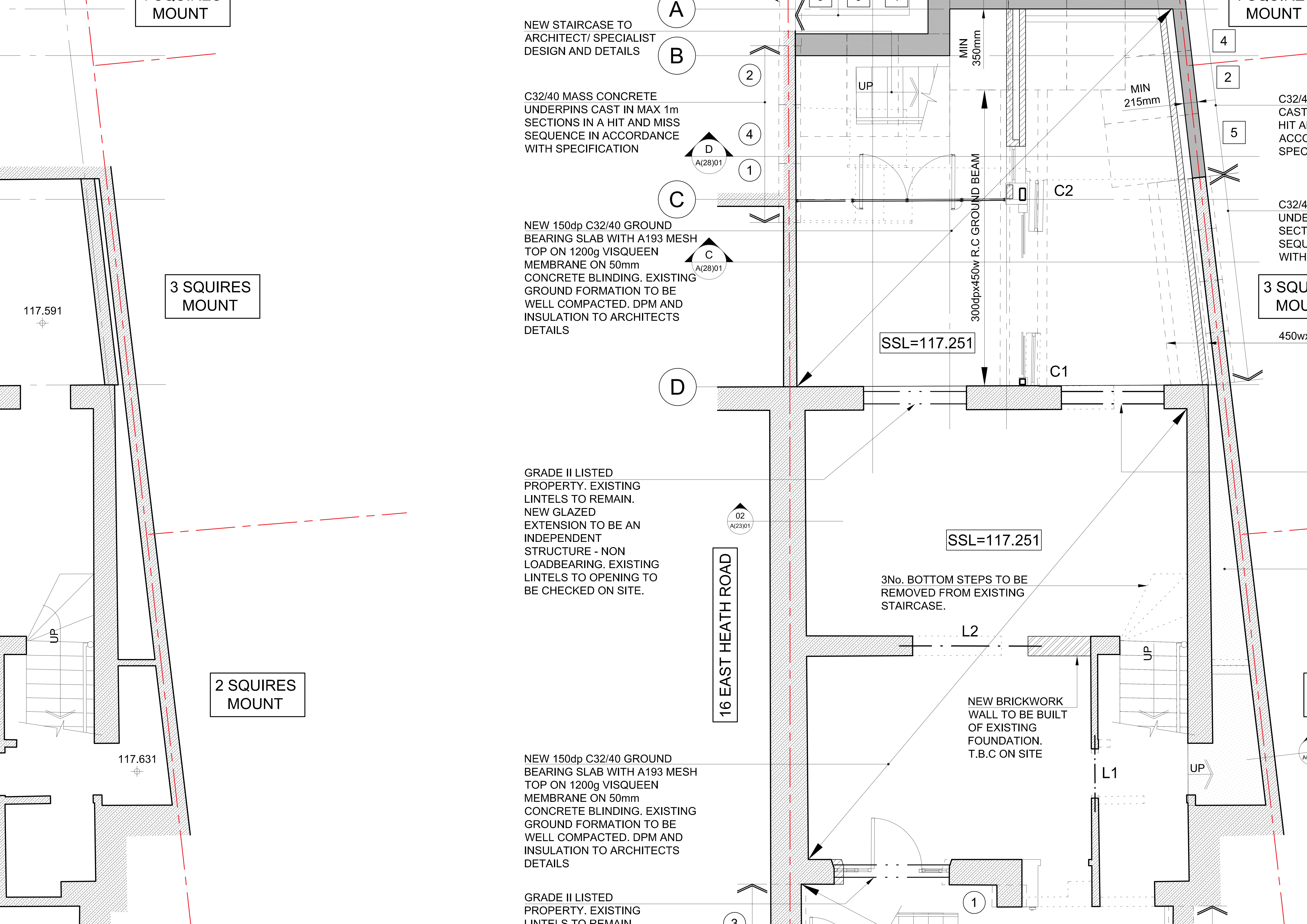
15.0 Superstructure

No structural work is proposed above lower ground floor.

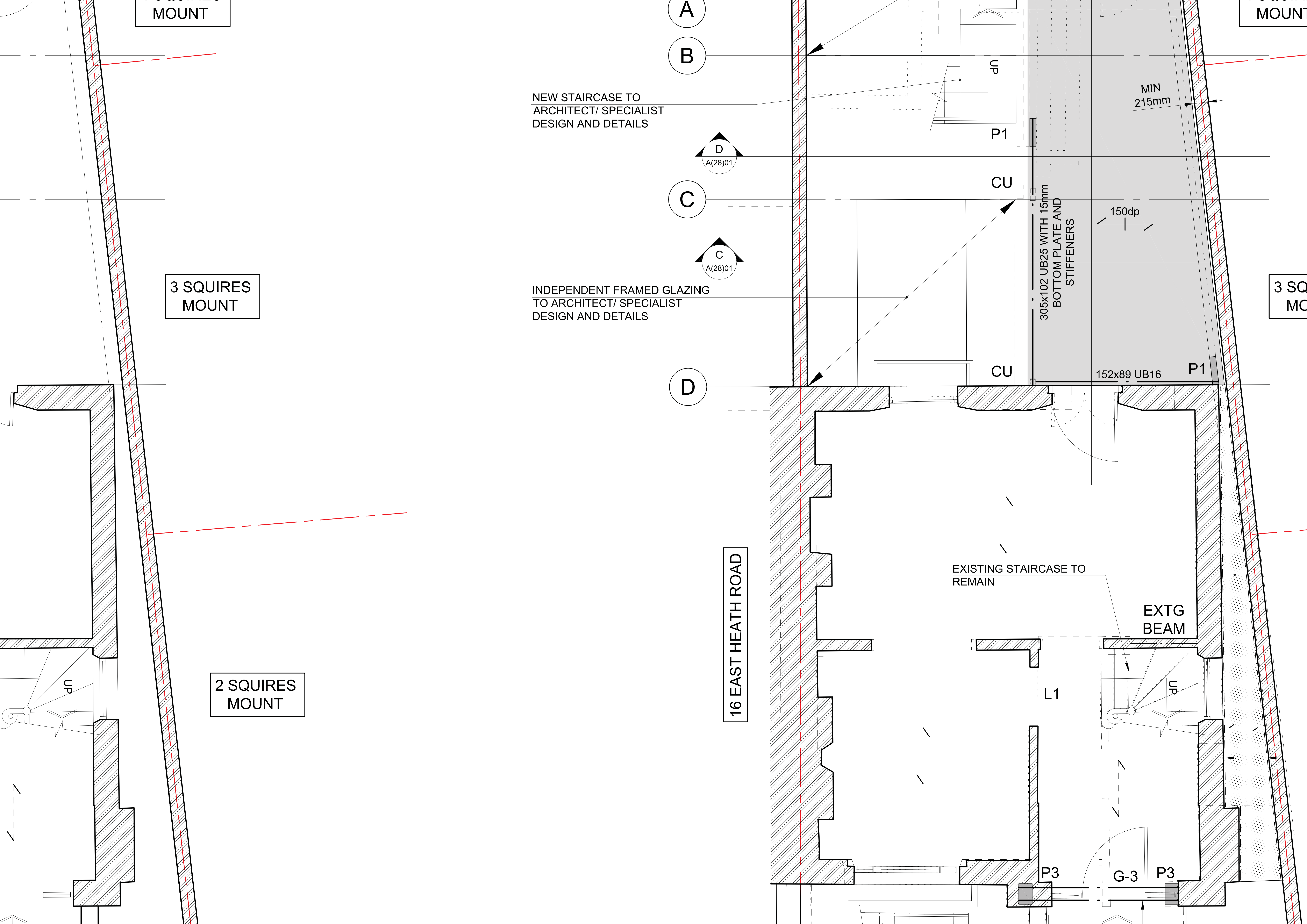
Appendix A

Preliminary Form Structural Drawings

162611 - L(23)01	PROPOSED GROUND FLOOR PLAN	P4
162611 - L(23)02	PROPOSED FIRST FLOOR PLAN	P2
162611 - A(23)01	PROPOSED SECTIONS AND DETAILS GENERAL ARRANGEMENT	P1
162611 - A(28)01	PROPOSED CROSS SECTION A-A GENERAL ARRANGEMENT	P4



3 SQUIRES MOUNT
MOUNT
117.591
2 SQUIRES MOUNT
117.631
UP
NEW STAIRCASE TO ARCHITECT/ SPECIALIST DESIGN AND DETAILS
C32/40 MASS CONCRETE UNDERPINS CAST IN MAX 1m SECTIONS IN A HIT AND MISS SEQUENCE IN ACCORDANCE WITH SPECIFICATION
NEW 150dp C32/40 GROUND BEARING SLAB WITH A193 MESH TOP ON 1200g VISQUEEN MEMBRANE ON 50mm CONCRETE BLINDING. EXISTING GROUND FORMATION TO BE WELL COMPACTED. DPM AND INSULATION TO ARCHITECTS DETAILS
GRADE II LISTED PROPERTY. EXISTING LINTELS TO REMAIN. NEW GLAZED EXTENSION TO BE AN INDEPENDENT STRUCTURE - NON LOADBEARING. EXISTING LINTELS TO OPENING TO BE CHECKED ON SITE.
NEW 150dp C32/40 GROUND BEARING SLAB WITH A193 MESH TOP ON 1200g VISQUEEN MEMBRANE ON 50mm CONCRETE BLINDING. EXISTING GROUND FORMATION TO BE WELL COMPACTED. DPM AND INSULATION TO ARCHITECTS DETAILS
GRADE II LISTED PROPERTY. EXISTING LINTELS TO REMAIN
A
B
C
D
D A(28)01
C A(28)01
02 A(23)01
16 EAST HEATH ROAD
MIN 350mm
MIN 215mm
300dpx450w R.C GROUND BEAM
SSL=117.251
SSL=117.251
C1
C2
L1
L2
3No. BOTTOM STEPS TO BE REMOVED FROM EXISTING STAIRCASE.
NEW BRICKWORK WALL TO BE BUILT OF EXISTING FOUNDATION. T.B.C ON SITE
3 SQU MOU
450wx
C32/4 CAST HIT A ACCO SPEC
C32/4 UNDE SECT SEQU WITH


MOUNT
A
B
UP
NEW STAIRCASE TO ARCHITECT/ SPECIALIST DESIGN AND DETAILS
MIN 215mm
P1
D A(28)01
CU
C
305x102 UB25 WITH 15mm BOTTOM PLATE AND STIFFENERS
150dp
C A(28)01
3 SQUIRES MOUNT
INDEPENDENT FRAMED GLAZING TO ARCHITECT/ SPECIALIST DESIGN AND DETAILS
CU
152x89 UB16
P1
D
16 EAST HEATH ROAD
EXISTING STAIRCASE TO REMAIN
EXTG BEAM
L1
UP
UP
2 SQUIRES MOUNT
P3
G-3
P3

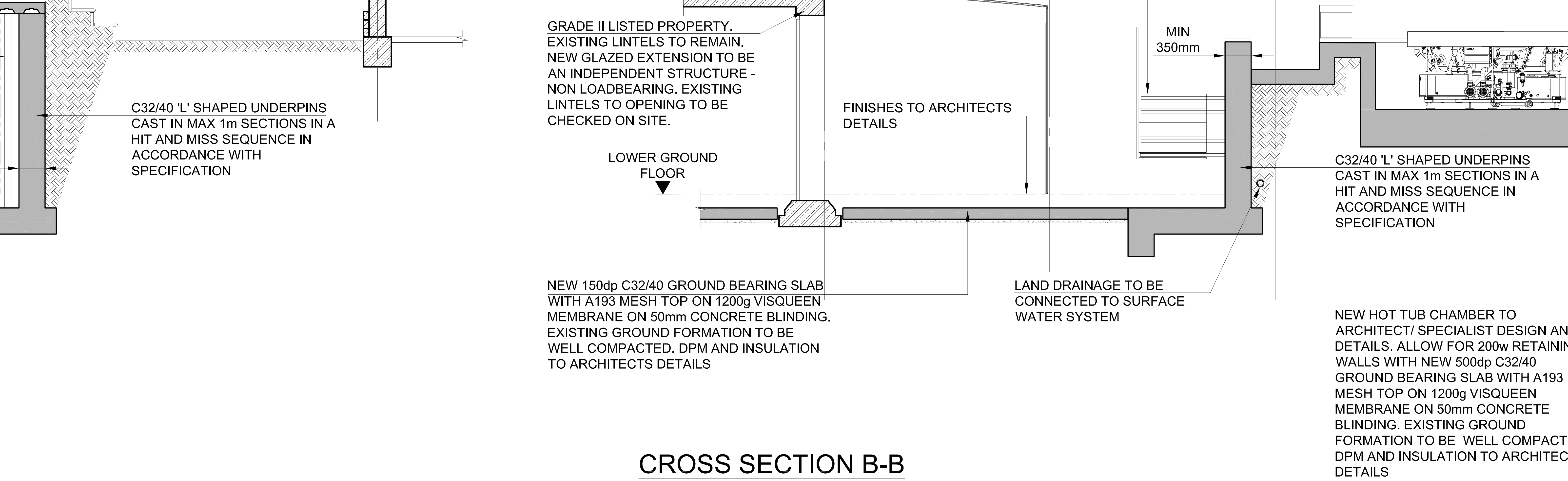
PACTED. DPM AND INSULATION TO
HITECTS DETAILS

n COMPRESSIBLE FILLER
RD WITH 2 PART
SULPHIDE SEALENT

COMPRESSIBLE BOARD

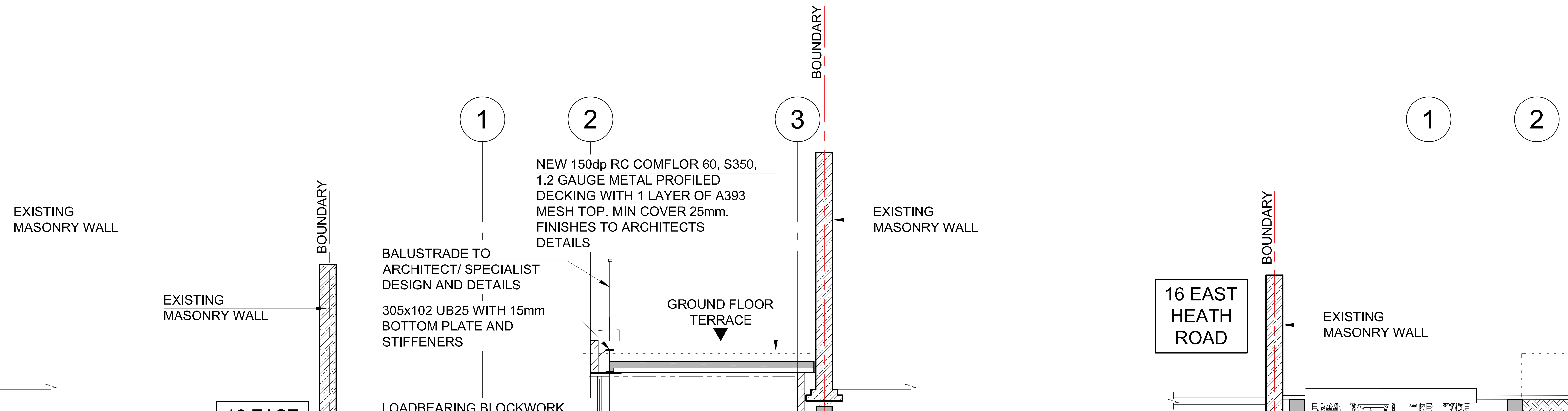
ECTION 02
ALE 1:10 @A1   1:20@A3

SECTION 03
SCALE 1:10 @A1   1:20@A3



CROSS SECTION B-B

SCALE 1:50 @A1 1:100@A3



Appendix B

Underpinning Specification:

To be read in conjunction with the Preliminaries and General Conditions.

WORKMANSHIP: The work shall be carried out in accordance with the Engineer's drawings and instructions and to the approval of the Architect and the Building Control Officer. This specification is intended to be used for mass concrete underpinning.

Any other sequence of operations or method of working proposed by the Contractor is to be submitted to the Architect and copied to the Engineer and agreed in writing a minimum of 14 days before work is to be commenced on site.

CONTRACTORS RESPONSIBILITIES: The Contractor shall be responsible for the safety of the underpinned structure and provide all necessary shoring, strutting and bracing to ensure its safety and stability at all times.

SERVICES: The Contractor is also to carry out a survey of the property and adjacent area to establish the location of obstructions such as service runs or drains. Any obstruction found is to be brought to the attention of the Architect / Engineer. The Contractor is to allow for any temporary support to the services or obstructions during the underpinning.

CONSTRUCTION SEQUENCE: The underpinning is to be undertaken in short sections not exceeding 1 metre in length. The underpinning is to be undertaken on a 'hit and miss' sequence as shown on the drawings.

No adjacent pin is to be excavated until a minimum 48 hours after the adjacent pin has been cast and packed up.

The Contractor is to provide drawings marked up to show the proposed sequence of underpinning a minimum of 14 days before work is commenced.

EXCAVATIONS: Excavation shall be to the depth and width shown on the drawings. However, where tree roots are encountered new underpins are to extend 600mm below the last trace of any root activity. The sides of the excavations shall be adequately shored and propped to prevent subsidence or slip of the soil. Soil faces behind the pin and at the formation level shall be undisturbed.

Any soil faces behind the underpinning that require to be retained shall be by precast concrete poling boards. The boards are to have holes to enable the void behind the boards to be grouted up. The poling boards are to be measured as left in.

INSPECTIONS: All excavations are to be inspected by the Engineer and/or the Building Control Officer. Minimum notice of 24 hours is to be given when excavations are ready for inspection.

PREPARATION: The sides of the completed pin are to be thoroughly cleaned and scabbled to the satisfaction of the Engineer.

The soffit of the existing footings is to be levelled off and cleaned of all loose or detrimental material.

No projecting partitions of the existing footings are to be trimmed except as shown on the drawings or directed by the Engineer.

The Contractor must provide shear keys.

Allow for 150 deep x 100 wide shear keys across width of scabbled interfaces at 1m maximum vertical centres. Minimum 2 per face. Form in timber or polystyrene.

ANTI-HEAVE PRECAUTIONS: Before carrying out concreting introduce anti-heave precautions in the form of clay master as directed by the Engineer to the faces of the excavation.

PLACING CONCRETE: The concrete for the underpinning is to be mass concrete and poured continuously to 75mm below the soffit of the existing footing. The concrete is to be fully compacted using a mechanical vibrator.

The top 75mm of the pin is to be filled to the full depth and width of the void with a well rammed C35 concrete using 5mm – 10mm coarse aggregate and “Conbex 100” expanding admixture by Messrs Fosroc UK Limited in accordance with their instructions. The filling of this void is to be undertaken 24 hours after the mass concrete has been poured.

CONCRETE GRADE: On works where a full specification has not been provided, a FND2 mix should be used. This has characteristic 28 day strength of 35N/mm² and is suitable for Class 2 sulphate soils.

OVER-EXCAVATION: Except where noted otherwise on the drawings, areas of over-excavation are to be backfilled with a granular material and compacted in 225mm layers to provide a stable sub-base compatible with the final finishes.

SPOIL: The contractor will include in his prices for the removal of all spoil arising from the works which is not suitable for backfilling purposes.

RECORDS: A full record of each section underpinned is to be kept on site and readily available for inspection by the Engineer or Building Control Officer.

GUARANTEE The Contractor is to provide a 10 year insurance backed guarantee for the underpinning works.

Appendix C

Building Damage Classification Table

Classification of visible damage to walls (after Burland et al*, 1977, Boscardin and Cording, 1989; and Burland, 2001)*

Category of damage	Description of typical damage (ease of repair is underlined)	Approximate crack width (mm)	Limiting tensile strain ε_{lim} (per cent)
0 Negligible	Hairline cracks of less than about 0.1 mm are classed as negligible.	< 0.1	0.0–0.05
1 Very slight	Fine cracks that can easily be treated during normal decoration. Perhaps isolated slight fracture in building. Cracks in external brickwork visible on inspection.	< 1	0.05–0.075
2 Slight	Cracks easily filled. Redecoration probably required. Several slight fractures showing inside of building. Cracks are visible externally and some repointing may be required externally to ensure weathertightness. Doors and windows may stick slightly.	< 5	0.075–0.15
3 Moderate	The cracks require some opening up and can be patched by a mason. Recurrent cracks can be masked by suitable linings. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired.	5–15 or a number of cracks > 3	0.15–0.3
4 Severe	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Windows and frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15–25 but also depends on number of cracks	> 0.3
5 Very severe	This requires a major repair involving partial or complete rebuilding. Beams lose bearings, walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	usually > 25 but depends on number of cracks.	

Notes

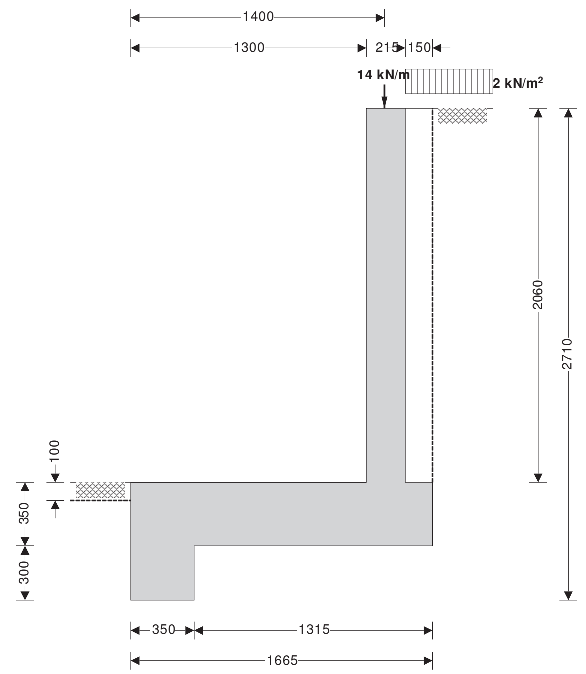
1. In assessing the degree of damage, account must be taken of its location in the building or structure.
2. Crack width is only one aspect of damage and should not be used on its own as a direct measure of it.

Appendix D

Design Philosophy & Preliminary Calculations

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **2060** mm
Thickness of wall stem	t_{wall} = **215** mm
Length of toe	l_{toe} = **1300** mm
Length of heel	l_{heel} = **150** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1665** mm
Thickness of base	t_{base} = **350** mm
Depth of downstand	d_{ds} = **300** mm
Position of downstand	l_{ds} = **0** mm
Thickness of downstand	t_{ds} = **350** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **2710** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **100** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **2710** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **16.0** kN/m^3

Saturated density of retained material	γ_s = **20.0** kN/m^3
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **18.6** deg

Base material details

Firm clay

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

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.369}$$

Passive pressure coefficient for base material

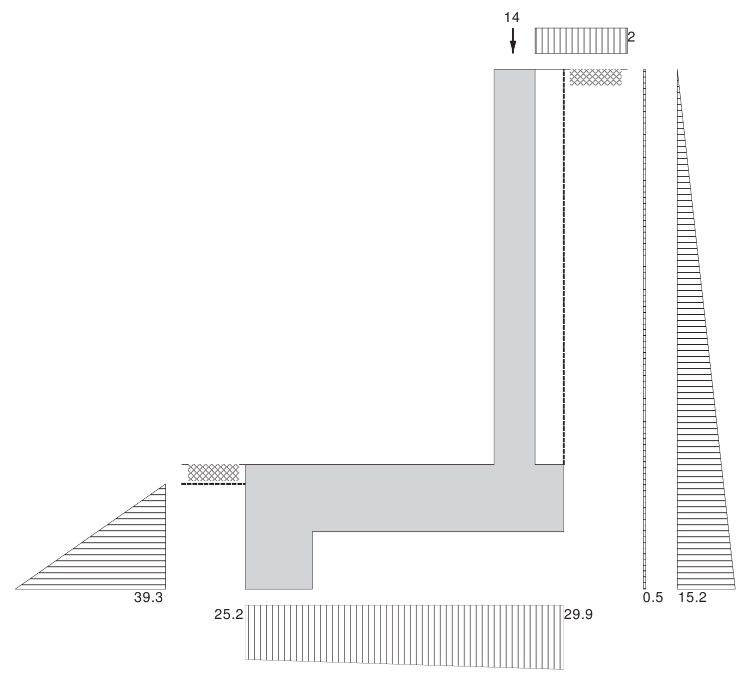
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan	Surcharge = **1.5** kN/m^2
Applied vertical dead load on wall	W_{dead} = **14.0** kN/m
Applied vertical live load on wall	W_{live} = **0.0** kN/m
Position of applied vertical load on wall	l_{load} = **1400** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



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

Vertical forces on wall

Wall stem	$w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **10.5** kN/m
Wall base	$w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **13.8** kN/m
Wall downstand	$w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base}$ = **2.5** kN/m
Surcharge	$w_{sur} = Surcharge \times l_{heel}$ = **0.2** kN/m
Moist backfill to top of wall	$w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **4.9** kN/m
Applied vertical load	$W_v = W_{dead} + W_{live}$ = **14** kN/m
Total vertical load	$W_{total} = w_{wall} + w_{base} + w_{ds} + w_{sur} + w_{m\_w} + W_v$ = **45.9** kN/m

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **1.4** kN/m
Moist backfill above water table	$F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **20.6** kN/m
Total horizontal load	$F_{total} = F_{sur} + F_{m\_a}$ = **22** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **10.8** kN/m
Resistance to sliding	$F_{res} = F_p + (W_{total} - w_{sur}) \times \tan(\delta_b)$ = **26.2** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **1.5** kNm/m
Moist backfill above water table	$M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **12.4** kNm/m
Soil in front of wall	$M_{p\_o} = F_p \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **1.3** kNm/m
Total overturning moment	$M_{ot} = M_{sur} + M_{m\_a} + M_{p\_o}$ = **15.2** kNm/m

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **14.7** kNm/m
Wall base	$M_{base} = w_{base} \times l_{base} / 2$ = **11.4** kNm/m
Wall downstand	$M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2)$ = **0.4** kNm/m
Moist backfill	$M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **7.9** kNm/m
Design vertical dead load	$M_{dead} = W_{dead} \times l_{load}$ = **19.6** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{ds} + M_{m\_r} + M_{dead}$ = **54.1** kNm/m

Check stability against overturning

Total overturning moment	M_{ot} = **15.2** kNm/m
Total restoring moment	M_{rest} = **54.1** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge	$M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **0.4** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{sur\_r}$ = **39.3** kNm/m
Total vertical reaction	$R = W_{total}$ = **45.9** kN/m
Distance to reaction	$x_{bar} = M_{total} / R$ = **856** mm
Eccentricity of reaction	$e = abs((l_{base} / 2) - x_{bar})$ = **24** mm

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **25.2** kN/m^2
Bearing pressure at heel	$p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **29.9** 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	$w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **14.6** kN/m
Wall base	$w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **19.3** kN/m
Wall downstand	$w_{ds\_f} = \gamma_{f\_d} \times d_{ds} \times t_{ds} \times \gamma_{base}$ = **3.5** kN/m
Surcharge	$w_{sur\_f} = \gamma_{f\_l} \times Surcharge \times l_{heel}$ = **0.4** kN/m
Moist backfill to top of wall	$w_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **6.9** kN/m
Applied vertical load	$W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **19.6** kN/m
Total vertical load	$W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{ds\_f} + w_{sur\_f} + w_{m\_w\_f} + W_{v\_f}$ = **64.2** kN/m

Factored horizontal at-rest forces on wall

Surcharge	$F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **3.8** kN/m
Moist backfill above water table	$F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **48.5** kN/m
Total horizontal load	$F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **52.4** kN/m
Passive resistance of soil in front of wall	$F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **15.1** kN/m

Factored overturning moments

Surcharge	$M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **4** kNm/m
Moist backfill above water table	$M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **29.3** kNm/m
Soil in front of wall	$M_{p\_o\_f} = F_{p\_f} \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **1.8** kNm/m
Total overturning moment	$M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{p\_o\_f}$ = **35.1** kNm/m

Restoring moments

Wall stem	$M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **20.6** kNm/m
Wall base	$M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **16** kNm/m
Wall downstand	$M_{ds\_f} = w_{ds\_f} \times (l_{ds} + t_{ds} / 2)$ = **0.6** kNm/m
Surcharge	$M_{sur\_r\_f} = w_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **0.6** kNm/m
Moist backfill	$M_{m\_r\_f} = (w_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + w_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **11** kNm/m
Design vertical load	$M_{v\_f} = W_{v\_f} \times l_{load}$ = **27.4** kNm/m
Total restoring moment	$M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{ds\_f} + M_{sur\_r\_f} + M_{m\_r\_f} + M_{v\_f}$ = **76.3** kNm/m

Factored bearing pressure

Total moment for bearing	$M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **41.2** kNm/m
Total vertical reaction	$R_f = W_{total\_f}$ = **64.2** kN/m
Distance to reaction	$x_{bar\_f} = M_{total\_f} / R_f$ = **641** mm
Eccentricity of reaction	$e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **192** mm

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **65.3** kN/m^2
Bearing pressure at heel	$p_{heel\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **11.9** kN/m^2
Rate of change of base reaction	$rate = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **32.04** kN/m^2/m
Bearing pressure at stem / toe	$p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **23.6** kN/m^2
Bearing pressure at mid stem	$p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2)$ = **20.2** kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2) = \mathbf{16.7} \text{ kN/m}^2$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40} \text{ N/mm}^2$

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

Base details

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

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

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{57.8}$ kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{15}$ kN/m

Shear from weight of downstand $V_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds} = \mathbf{3.5}$ kN/m

Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} - V_{toe\_wt\_ds} = \mathbf{39.3}$ kN/m

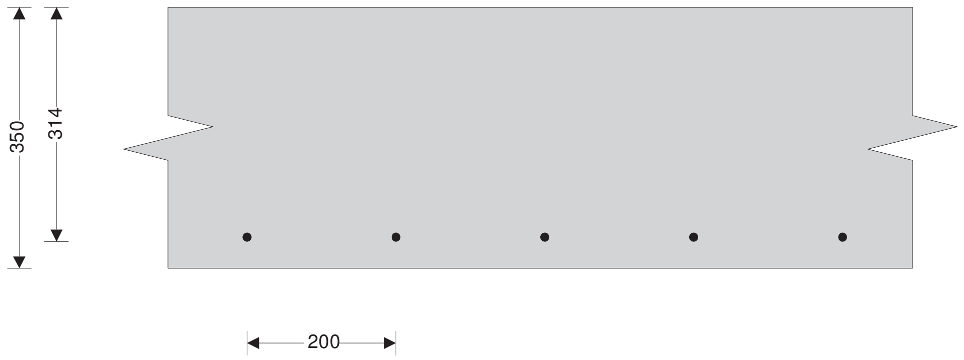
Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{49.7}$ kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{11.5}$ kNm/m

Moment from weight of downstand $M_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds} \times (l_{toe} - l_{ds} + (t_{wall} - t_{ds}) / 2) = \mathbf{4.3}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} - M_{toe\_wt\_ds} = \mathbf{34}$ kNm/m



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{314.0}$ mm

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

Compression reinforcement is not required

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

$z_{toe} = \mathbf{298}$ mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{262} \text{ mm}^2\text{/m}$

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{455} \text{ mm}^2\text{/m}$

Area of tension reinforcement required $A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{455} \text{ mm}^2\text{/m}$

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

Area of reinforcement provided $A_{s\_toe\_prov} = \mathbf{565} \text{ mm}^2\text{/m}$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.125} \text{ N/mm}^2$

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_toe} = \mathbf{0.443} \text{ N/mm}^2$

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

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40} \text{ N/mm}^2$

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

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 $V_{heel\_bear} = (p_{heel\_f} + p_{stem\_heel\_f}) \times l_{heel} / 2 = \mathbf{2.1}$ kN/m

Shear from weight of base $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base} = \mathbf{1.7}$ kN/m

Shear from weight of moist backfill $V_{heel\_wt\_m} = w_{m\_w\_f} = \mathbf{6.9}$ kN/m

Shear from surcharge $V_{heel\_sur} = w_{sur\_f} = \mathbf{0.4}$ kN/m

Total shear for heel design $V_{heel} = - V_{heel\_bear} + V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_sur} = \mathbf{6.9}$ kN/m

Calculate moment for heel design

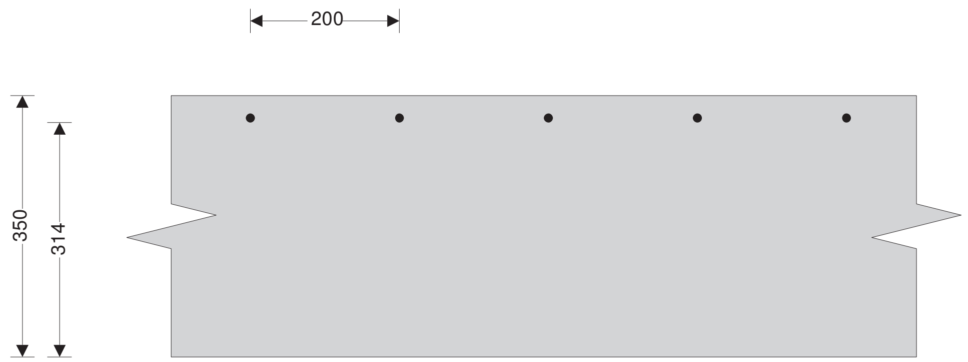
Moment from bearing pressure $M_{heel\_bear} = (2 \times p_{heel\_f} + p_{stem\_mid\_f}) \times (l_{heel} + t_{wall} / 2)^2 / 6 = \mathbf{0.5}$ kNm/m

Moment from weight of base $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2) = \mathbf{0.4}$ kNm/m

Moment from weight of moist backfill $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2 = \mathbf{1.3}$ kNm/m

Moment from surcharge $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2 = \mathbf{0.1}$ kNm/m

Total moment for heel design $M_{heel} = - M_{heel\_bear} + M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_sur} = \mathbf{1.2}$ kNm/m



Check heel in bending

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

Depth of reinforcement $d_{heel} = t_{base} - c_{heel} - (\phi_{heel} / 2) = \mathbf{314.0}$ mm

Constant $K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu}) = \mathbf{0.000}$

Compression reinforcement is not required

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

$z_{heel} = \mathbf{298}$ mm

Area of tension reinforcement required $A_{s\_heel\_des} = M_{heel} / (0.87 \times f_y \times z_{heel}) = \mathbf{9} \text{ mm}^2\text{/m}$

Minimum area of tension reinforcement $A_{s\_heel\_min} = k \times b \times t_{base} = \mathbf{455} \text{ mm}^2\text{/m}$

Area of tension reinforcement required $A_{s\_heel\_req} = \text{Max}(A_{s\_heel\_des}, A_{s\_heel\_min}) = \mathbf{455} \text{ mm}^2\text{/m}$

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

Area of reinforcement provided — $A_{s\_heel\_prov}$ = **565** mm^2/m

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress — $v_{heel} = V_{heel} / (b \times d_{heel})$ = **0.022** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **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_heel} = **0.443** N/mm^2

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

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

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 downstand — c_{ds} = **30** mm

Calculate shear for downstand design

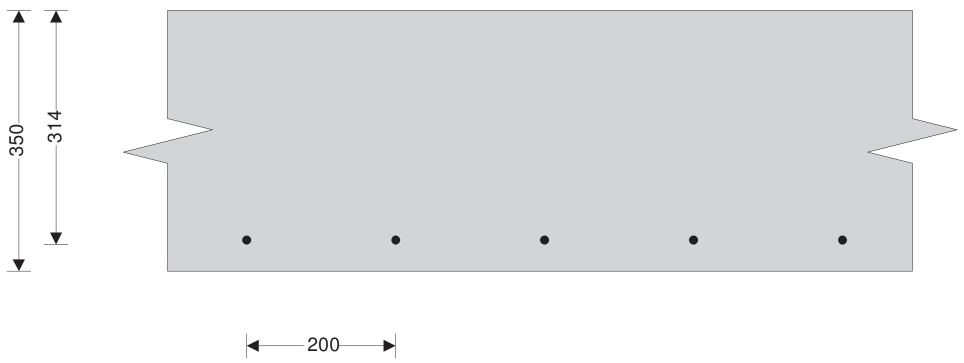
Total shear for downstand design

$V_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times (d_{cover} + t_{base} + d_{ds} / 2)$ = **13.3** kN/m

Calculate moment for downstand design

Total moment for downstand design

$M_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times [(d_{cover} + t_{base}) \times (t_{base} + d_{ds}) + d_{ds} \times (t_{base} / 2 + 2 \times d_{ds} / 3)] / 2$ = **4.5** kNm/m



Check downstand in bending

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

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

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

Compression reinforcement is not required

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

z_{down} = **298** mm

Area of tension reinforcement required — $A_{s\_down\_des} = M_{down} / (0.87 \times f_y \times z_{down})$ = **35** mm^2/m

Minimum area of tension reinforcement — $A_{s\_down\_min} = k \times b \times t_{ds}$ = **455** mm^2/m

Area of tension reinforcement required — $A_{s\_down\_req} = \text{Max}(A_{s\_down\_des}, A_{s\_down\_min})$ = **455** mm^2/m

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

Area of reinforcement provided — $A_{s\_down\_prov}$ = **565** mm^2/m

PASS - Reinforcement provided at the retaining wall downstand is adequate

Check shear resistance at downstand

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

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **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_down} = **0.443** N/mm^2

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

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

Material properties

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

Cover to reinforcement in wall — c_{wall} = **30** mm

Factored horizontal at-rest forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **2.9** kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **28** kN/m

Calculate shear for stem design

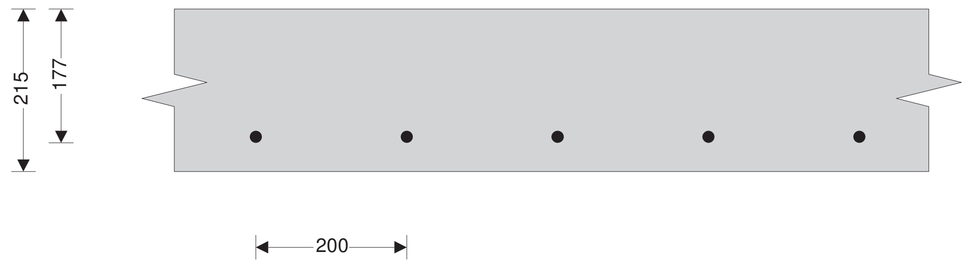
Shear at base of stem — $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f}$ = **31** kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **3.5** kNm/m

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **24.2** kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **27.7** kNm/m



Check wall stem in bending

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

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **177.0** mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.022**

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} = **168** mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **378** mm^2/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **280** mm^2/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **378** mm^2/m

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

Area of reinforcement provided $A_{s\_stem\_prov}$ = **1005** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.175** 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} = **0.751** N/mm²

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

Check retaining wall deflection

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

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **125.5** N/mm²

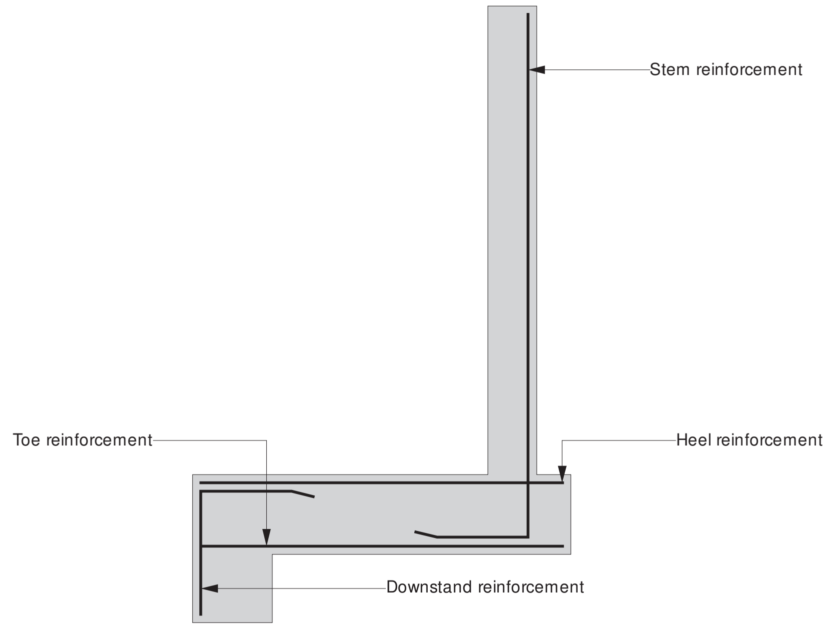
Modification factor $factor_{tens} = \min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **2.00**

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

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **11.64**

PASS - Span to depth ratio is acceptable

<u>Indicative retaining wall reinforcement diagram</u>



Toe bars - 12 mm dia.@ 200 mm centres - (565 mm²/m)

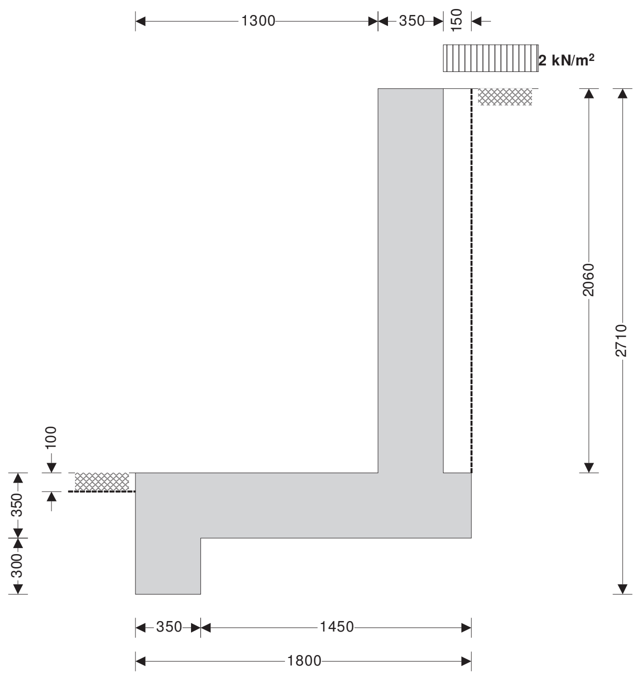
Heel bars - 12 mm dia.@ 200 mm centres - (565 mm²/m)

Downstand bars - 12 mm dia.@ 200 mm centres - (565 mm²/m)

Stem bars - 16 mm dia.@ 200 mm centres - (1005 mm²/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **2060** mm
Thickness of wall stem	t_{wall} = **350** mm
Length of toe	l_{toe} = **1300** mm
Length of heel	l_{heel} = **150** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1800** mm
Thickness of base	t_{base} = **350** mm
Depth of downstand	d_{ds} = **300** mm
Position of downstand	l_{ds} = **0** mm
Thickness of downstand	t_{ds} = **350** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **2710** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **100** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m³
Density of base construction	γ_{base} = **23.6** kN/m³
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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **2710** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **16.0** kN/m³

Saturated density of retained material	γ_s = **20.0** kN/m³
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **18.6** deg

Base material details

Firm clay

Moist density	γ_{mb} = **18.0** kN/m³
Design shear strength	ϕ'_b = **24.2** deg
Design base friction	δ_b = **18.6** deg
Allowable bearing pressure	$P_{bearing}$ = **100** kN/m²

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.369}$$

Passive pressure coefficient for base material

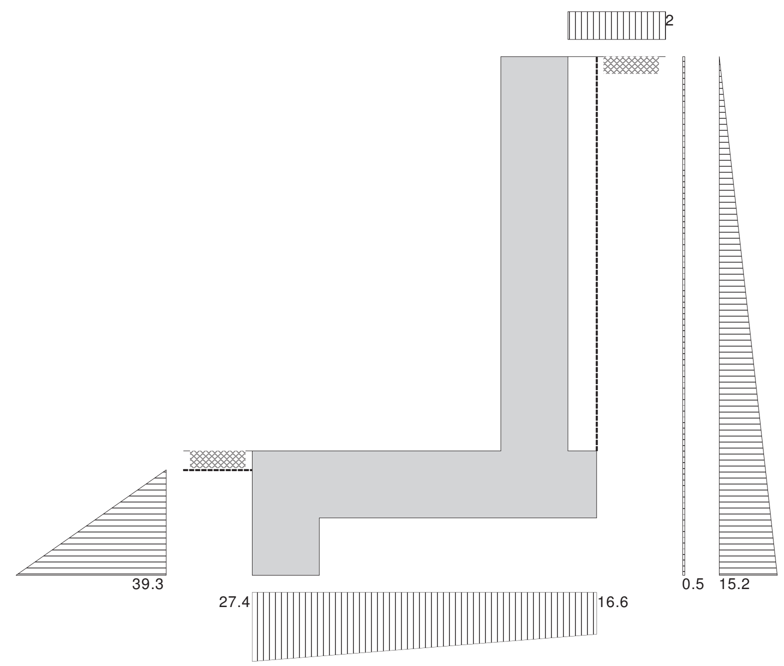
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan	Surcharge = **1.5** kN/m²
Applied vertical dead load on wall	W_{dead} = **0.0** kN/m
Applied vertical live load on wall	W_{live} = **0.0** kN/m
Position of applied vertical load on wall	l_{load} = **0** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



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

Vertical forces on wall

Wall stem	$w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **17** kN/m
Wall base	$w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **14.9** kN/m
Wall downstand	$w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base}$ = **2.5** kN/m
Surcharge	w_{sur} = Surcharge $\times l_{heel}$ = **0.2** kN/m
Moist backfill to top of wall	$w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **4.9** kN/m
Total vertical load	$W_{total} = w_{wall} + w_{base} + w_{ds} + w_{sur} + w_{m\_w}$ = **39.5** kN/m

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times h_{eff}$ = **1.4** kN/m
Moist backfill above water table	$F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **20.6** kN/m
Total horizontal load	$F_{total} = F_{sur} + F_{m\_a}$ = **22** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **10.8** kN/m
Resistance to sliding	$F_{res} = F_p + (W_{total} - w_{sur}) \times \tan(\delta_b)$ = **24.0** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **1.5** kNm/m
Moist backfill above water table	$M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **12.4** kNm/m
Soil in front of wall	$M_{p\_o} = F_p \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **1.3** kNm/m
Total overturning moment	$M_{ot} = M_{sur} + M_{m\_a} + M_{p\_o}$ = **15.2** kNm/m

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **25.1** kNm/m
Wall base	$M_{base} = w_{base} \times l_{base} / 2$ = **13.4** kNm/m
Wall downstand	$M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2)$ = **0.4** kNm/m
Moist backfill	$M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **8.5** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{ds} + M_{m\_r}$ = **47.4** kNm/m

Check stability against overturning

Total overturning moment	M_{ot} = **15.2** kNm/m
Total restoring moment	M_{rest} = **47.4** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge	$M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **0.4** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{sur\_r}$ = **32.7** kNm/m
Total vertical reaction	$R = W_{total}$ = **39.5** kN/m
Distance to reaction	$x_{bar} = M_{total} / R$ = **826** mm
Eccentricity of reaction	$e = \mathrm{abs}((l_{base} / 2) - x_{bar})$ = **74** mm

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **27.4** kN/m²
Bearing pressure at heel	$p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **16.6** kN/m²

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	$w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **23.8** kN/m
Wall base	$w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **20.8** kN/m
Wall downstand	$w_{ds\_f} = \gamma_{f\_d} \times d_{ds} \times t_{ds} \times \gamma_{base}$ = **3.5** kN/m
Surcharge	$w_{sur\_f} = \gamma_{f\_l} \times$ Surcharge $\times l_{heel}$ = **0.4** kN/m
Moist backfill to top of wall	$w_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **6.9** kN/m
Total vertical load	$W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{ds\_f} + w_{sur\_f} + w_{m\_w\_f}$ = **55.4** kN/m

Factored horizontal at-rest forces on wall

Surcharge	$F_{sur\_f} = \gamma_{f\_l} \times K_0 \times$ Surcharge $\times h_{eff}$ = **3.8** kN/m
Moist backfill above water table	$F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **48.5** kN/m
Total horizontal load	$F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **52.4** kN/m
Passive resistance of soil in front of wall	$F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **15.1** kN/m

Factored overturning moments

Surcharge	$M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **4** kNm/m
Moist backfill above water table	$M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **29.3** kNm/m
Soil in front of wall	$M_{p\_o\_f} = F_{p\_f} \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **1.8** kNm/m
Total overturning moment	$M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{p\_o\_f}$ = **35.1** kNm/m

Restoring moments

Wall stem	$M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **35.1** kNm/m
Wall base	$M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **18.7** kNm/m
Wall downstand	$M_{ds\_f} = w_{ds\_f} \times (l_{ds} + t_{ds} / 2)$ = **0.6** kNm/m
Surcharge	$M_{sur\_r\_f} = w_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **0.6** kNm/m
Moist backfill	$M_{m\_r\_f} = (w_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + w_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **11.9** kNm/m
Total restoring moment	$M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{ds\_f} + M_{sur\_r\_f} + M_{m\_r\_f}$ = **67** kNm/m

Factored bearing pressure

Total moment for bearing	$M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **31.9** kNm/m
Total vertical reaction	$R_f = W_{total\_f}$ = **55.4** kN/m
Distance to reaction	$x_{bar\_f} = M_{total\_f} / R_f$ = **577** mm
Eccentricity of reaction	$e_f = \mathrm{abs}((l_{base} / 2) - x_{bar\_f})$ = **323** mm

Reaction acts outside middle third of base

Bearing pressure at toe	$p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **64** kN/m²
Bearing pressure at heel	p_{heel_f} = 0 kN/m² = **0** kN/m²
Rate of change of base reaction	rate = $p_{toe\_f} / (3 \times x_{bar\_f})$ = **37.01** kN/m²/m
Bearing pressure at stem / toe	$p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0\ \text{kN/m}^2)$ = **15.9** kN/m²
Bearing pressure at mid stem	$p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0\ \text{kN/m}^2)$ = **9.4** kN/m²
Bearing pressure at stem / heel	$p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0\ \text{kN/m}^2)$ = **3** kN/m²

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

Material properties

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} = **30** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **52** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **15** kN/m

Shear from weight of downstand $V_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds}$ = **3.5** kN/m

Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} - V_{toe\_wt\_ds}$ = **33.5** kN/m

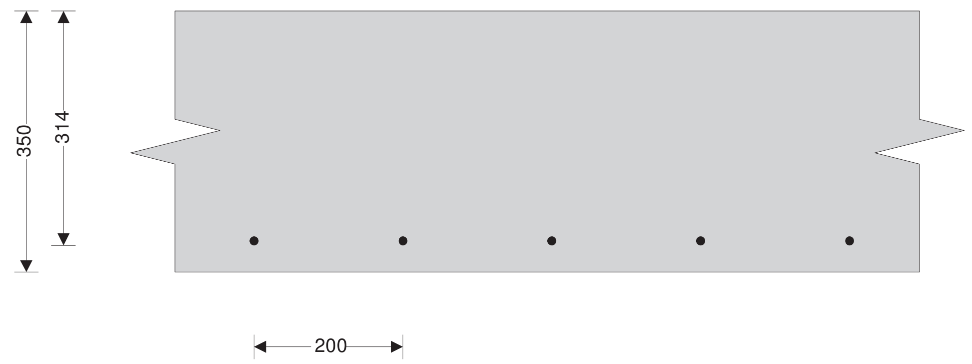
Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **49.9** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **12.6** kNm/m

Moment from weight of downstand $M_{toe\_wt\_ds} = \gamma_{f\_d} \times \gamma_{base} \times d_{ds} \times t_{ds} \times (l_{toe} - l_{ds} + (t_{wall} - t_{ds}) / 2)$ = **4.5** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} - M_{toe\_wt\_ds}$ = **32.8** kNm/m



Check toe in bending

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

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

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.008**

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} = **298** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **253** mm²/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base}$ = **455** mm²/m

Area of tension reinforcement required $A_{s\_toe\_req} = \mathrm{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **455** mm²/m

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

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

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.107** 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} = **0.443** N/mm²

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

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

Material properties

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

Calculate shear for heel design

Shear from bearing pressure $V_{heel\_bear} = p_{stem\_heel\_f} \times ((3 \times x_{bar\_f}) - l_{toe} - t_{wall}) / 2$ = **0.1** kN/m

Shear from weight of base $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base}$ = **1.7** kN/m

Shear from weight of moist backfill $V_{heel\_wt\_m} = w_{m\_w\_f}$ = **6.9** kN/m

Shear from surcharge $V_{heel\_sur} = w_{sur\_f}$ = **0.4** kN/m

Total shear for heel design $V_{heel} = - V_{heel\_bear} + V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_sur}$ = **8.9** kN/m

Calculate moment for heel design

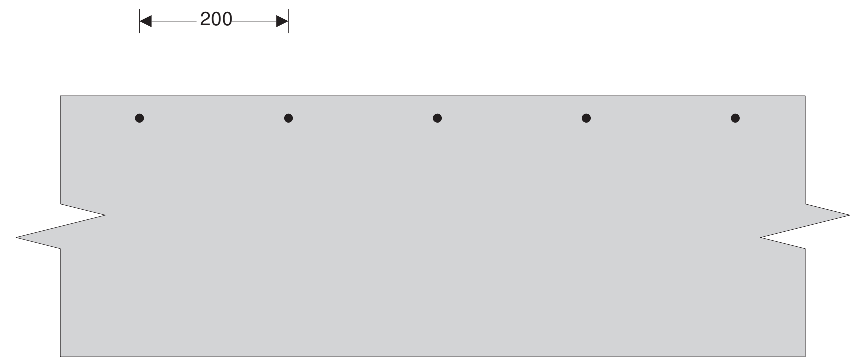
Moment from bearing pressure $M_{heel\_bear} = p_{stem\_mid\_f} \times ((3 \times x_{bar\_f}) - l_{toe} - t_{wall} / 2)^2 / 6$ = **0.1** kNm/m

Moment from weight of base $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2)$ = **0.6** kNm/m

Moment from weight of moist backfill $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2$ = **1.7** kNm/m

Moment from surcharge $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2$ = **0.1** kNm/m

Total moment for heel design $M_{heel} = - M_{heel\_bear} + M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_sur}$ = **2.3** kNm/m



Check heel in bending

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

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

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

Compression reinforcement is not required

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

z_{heel} = **298** mm

Area of tension reinforcement required $A_{s\_heel\_des} = M_{heel} / (0.87 \times f_y \times z_{heel})$ = **18** mm²/m

Minimum area of tension reinforcement $A_{s\_heel\_min} = k \times b \times t_{base}$ = **455** mm²/m

Area of tension reinforcement required $A_{s\_heel\_req} = \mathrm{Max}(A_{s\_heel\_des}, A_{s\_heel\_min})$ = **455** mm²/m

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

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

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress — $v_{heel} = V_{heel} / (b \times d_{heel}) = \mathbf{0.028}$ N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000}$ 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 — $v_{c\_heel} = \mathbf{0.443}$ N/mm^2

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

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

Material properties

Characteristic strength of concrete — $f_{cu} = \mathbf{40}$ N/mm^2

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

Base details

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

Cover to reinforcement in downstand — $c_{ds} = \mathbf{30}$ mm

Calculate shear for downstand design

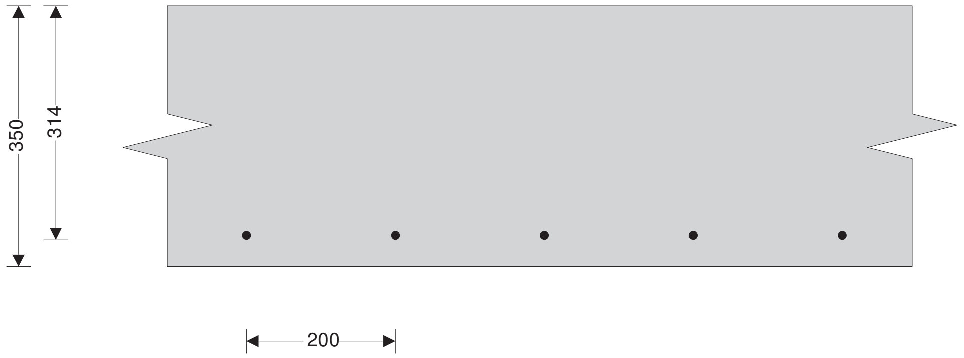
Total shear for downstand design

$$V_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times (d_{cover} + t_{base} + d_{ds} / 2) = \mathbf{13.3} \text{ kN/m}$$

Calculate moment for downstand design

Total moment for downstand design

$$M_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times [(d_{cover} + t_{base}) \times (t_{base} + d_{ds}) + d_{ds} \times (t_{base} / 2 + 2 \times d_{ds} / 3)] / 2 = \mathbf{4.5} \text{ kNm/m}$$



Check downstand in bending

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

Depth of reinforcement — $d_{down} = t_{ds} - c_{ds} - (\phi_{down} / 2) = \mathbf{314.0}$ mm

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

Compression reinforcement is not required

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

$z_{down} = \mathbf{298}$ mm

Area of tension reinforcement required — $A_{s\_down\_des} = M_{down} / (0.87 \times f_y \times z_{down}) = \mathbf{35}$ mm^2/m

Minimum area of tension reinforcement — $A_{s\_down\_min} = k \times b \times t_{ds} = \mathbf{455}$ mm^2/m

Area of tension reinforcement required — $A_{s\_down\_req} = \text{Max}(A_{s\_down\_des}, A_{s\_down\_min}) = \mathbf{455}$ mm^2/m

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

Area of reinforcement provided — $A_{s\_down\_prov} = \mathbf{565}$ mm^2/m

PASS - Reinforcement provided at the retaining wall downstand is adequate

Check shear resistance at downstand

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

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000}$ 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 — $v_{c\_down} = \mathbf{0.443}$ N/mm^2

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

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

Material properties

Characteristic strength of concrete — $f_{cu} = \mathbf{40}$ N/mm^2

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

Wall details

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

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

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

Factored horizontal at-rest forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = \mathbf{2.9}$ kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = \mathbf{28}$ kN/m

Calculate shear for stem design

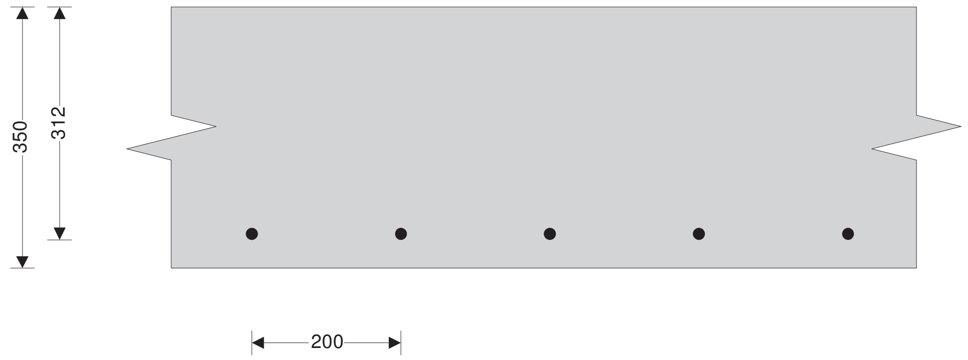
Shear at base of stem — $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} = \mathbf{31}$ kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2 = \mathbf{3.5}$ kNm/m

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = \mathbf{24.2}$ kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a} = \mathbf{27.7}$ kNm/m



Check wall stem in bending

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

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2) = \mathbf{312.0}$ mm

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

Compression reinforcement is not required

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

$z_{stem} = \mathbf{296}$ mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem}) = \mathbf{215}$ mm^2/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall} = \mathbf{455}$ mm^2/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{455}$ mm^2/m

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

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

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.099** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **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} = **0.539** N/mm^2

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

Check retaining wall deflection

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

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **150.9** N/mm^2

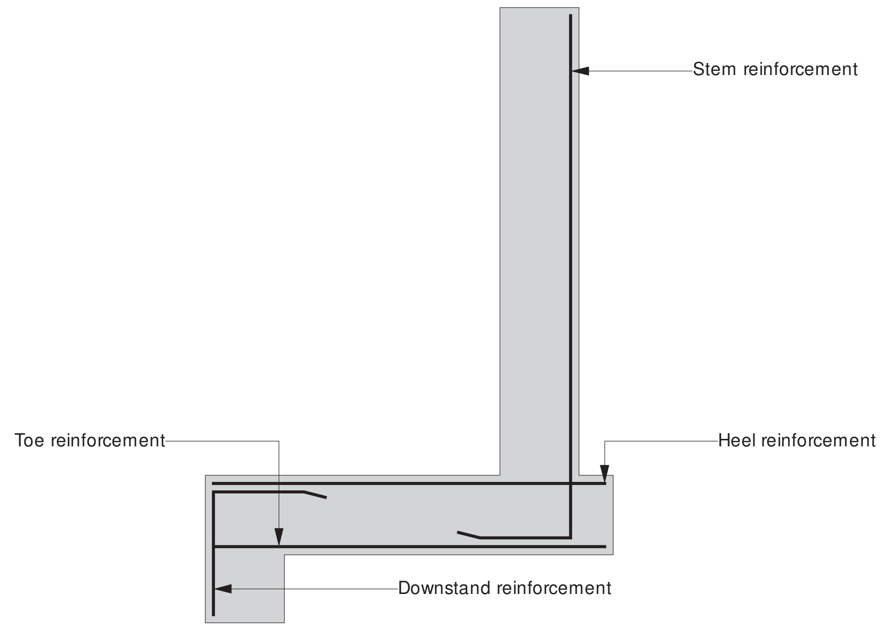
Modification factor $factor_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **2.00**

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

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **6.60**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



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

Heel bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)

Downstand bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)

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