CAR

Cambridge Architectural Research Ltd

research
design
consultancy

Basement Impact Assessment
And
Construction Sequence Methodology

109 Gloucester Avenue

London

NW1 8LB


Buildings


Urbanism


Energy


Risk

CAR is an independent consultancy providing specialist advice for policy makers, design professions and the construction industry. Founded in 1987, CAR's interdisciplinary team is at the forefront of new thinking in all aspects of the built environment.

Report Contents

1.0 Introduction

The purpose of this report is to assess the potential impact of the basement proposals on neighbouring properties and the natural environment of the site.
The report is set out in accordance with the guidelines given in Camden Planning Guidance CPG4 - Basements and Lightwells (July 2015).

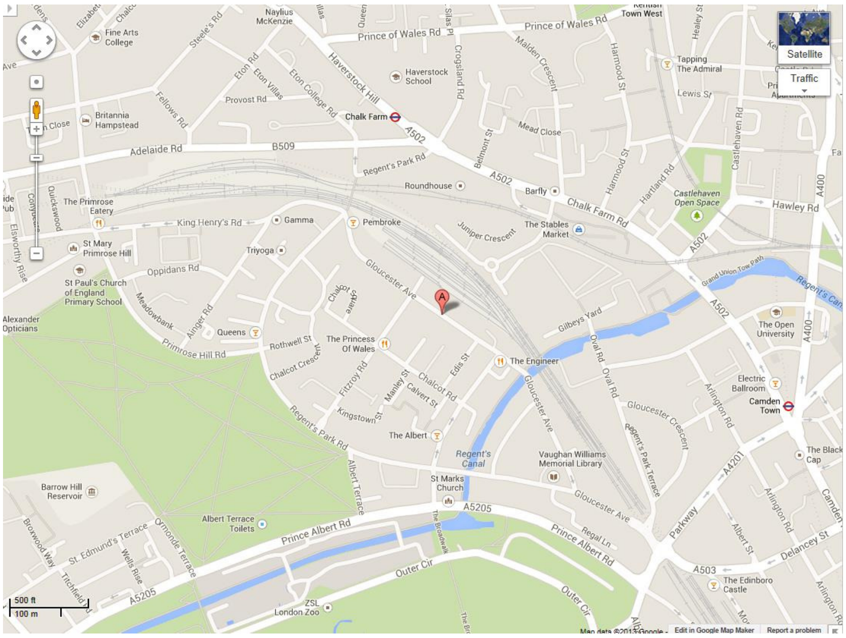
Relevant maps and other figurative information given in Camden Geological, Hydrogeological and Hydrological Study have been referred to in this report.

2.0 Stage 1 - Screening

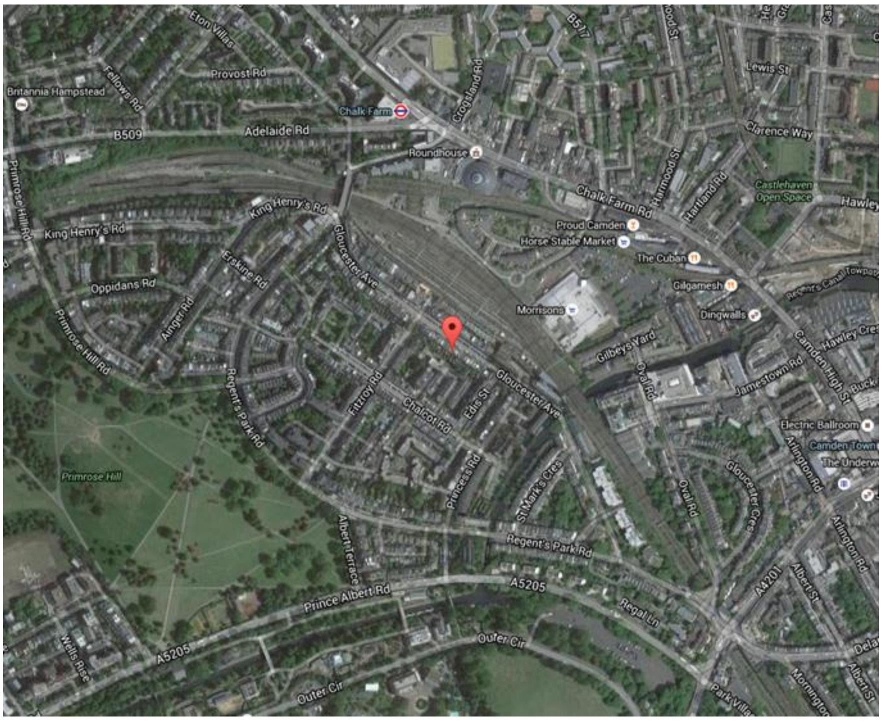
The following sections summarises the outcome of the screening review as identified in CPG4. The results are documented below.

2.01 The site

No 109 Gloucester Avenue is a 5 storey (incl Lower ground floor and loft) mid-terrace property of traditional construction. The Lower Ground level can also be accessed from a front light well. The light well also provides access to the existing brick vaults under the front garden. The vaults extend to the back of the pavement.



Location Plan



Aerial View of site

Front Elevation

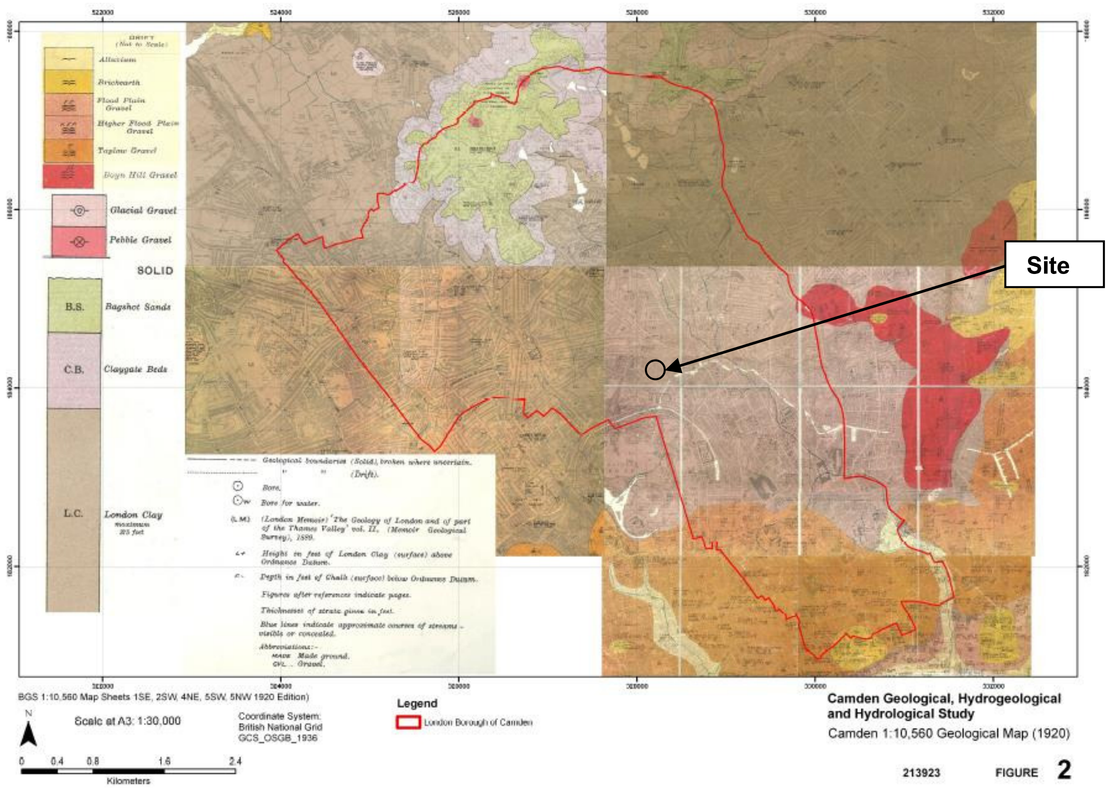
An initial visual survey of the lower ground level and vaults was undertaken. Both areas appeared to be in reasonable to good structural condition. There were no visible signs of structural distress noted at the time of our visit.

A brief visual overview of the terrace was also carried out at this time. It was noted that several properties have subterranean extensions under the front garden.

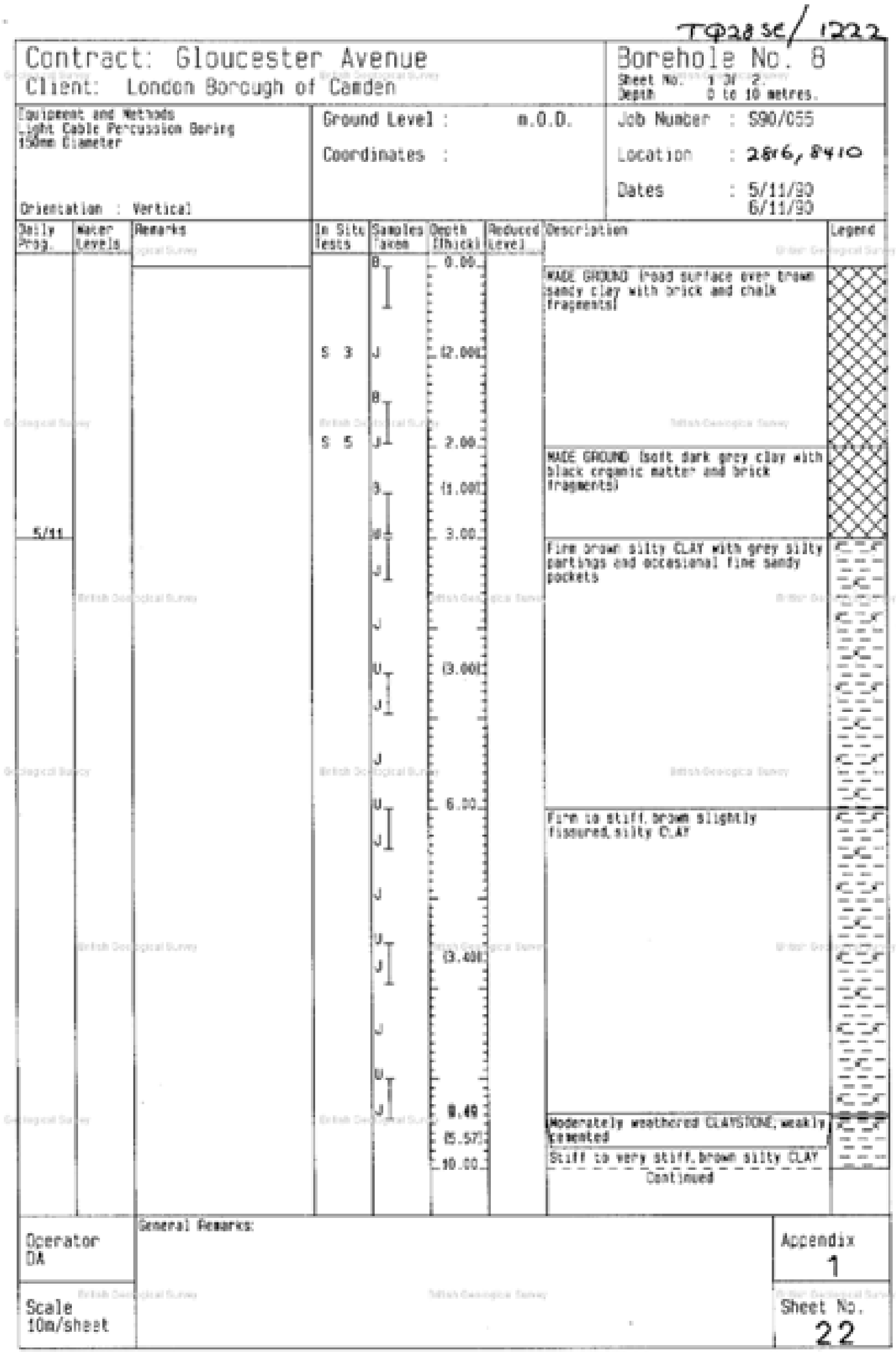
2.02 SUBTERRANEAN (GROUND WATER) FLOW SCREENING FLOWCHART

Q1a: *Is the site located directly above an aquifer?*

A: No. The site is in London Clay which is classified as an unproductive aquifer. See extracts from the Camden Geological Map, BGS historic borehole and extract from Camden Aquifer Designation Map below.



Camden Geological Map


TQ28SE/1222

Contract: Gloucester Avenue
Client: London Borough of Camden

Borehole No. 8
Sheet No. 1 of 2.
Depth 0 to 10 metres.

Equipment and Methods
Light Cable Percussion Boring
150mm Diameter

Orientation : Vertical

Ground Level : m.O.D.
Coordinates :

Job Number : S90/055
Location : 2876, 8410
Dates : 5/11/90
6/11/90

Daily Prog.	Water Levels	Remarks	In Situ Tests	Samples Taken	Depth (Thick)	Reduced Level	Description
				B	0.00		MADE GROUND (road surface over brown sandy clay with brick and chalk fragments)
			S 3	J	(2.00)		
				B			
			S 5	J	2.00		MADE GROUND (soft dark grey clay with black organic matter and brick fragments)
				B	(1.00)		
5/11				W	3.00		Firm brown silty CLAY with grey silty partings and occasional fine sandy pockets
				J			
				J			
				U	(3.00)		
				J			
				J			
				U	6.00		Firm to stiff, brown slightly fissured, silty CLAY
				J			
				J			
				U	(3.40)		
				J			
				J			
				U			
				J	9.40		Moderately weathered CLAYSTONE, weakly cemented
					(0.57)		Stiff to very stiff, brown silty CLAY
					10.00		Continued

Operator
DA

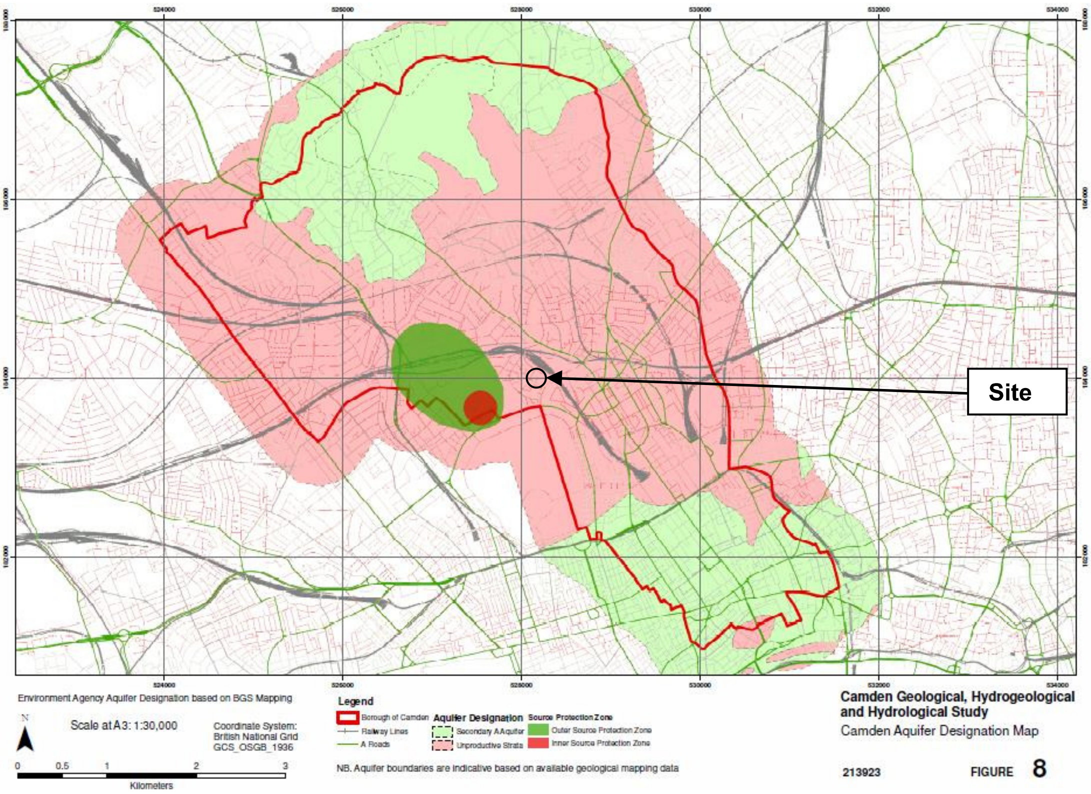
Scale
10m/sheet

General Remarks:

Appendix
1

Sheet No.
22

BGS historic borehole on Gloucester Avenue



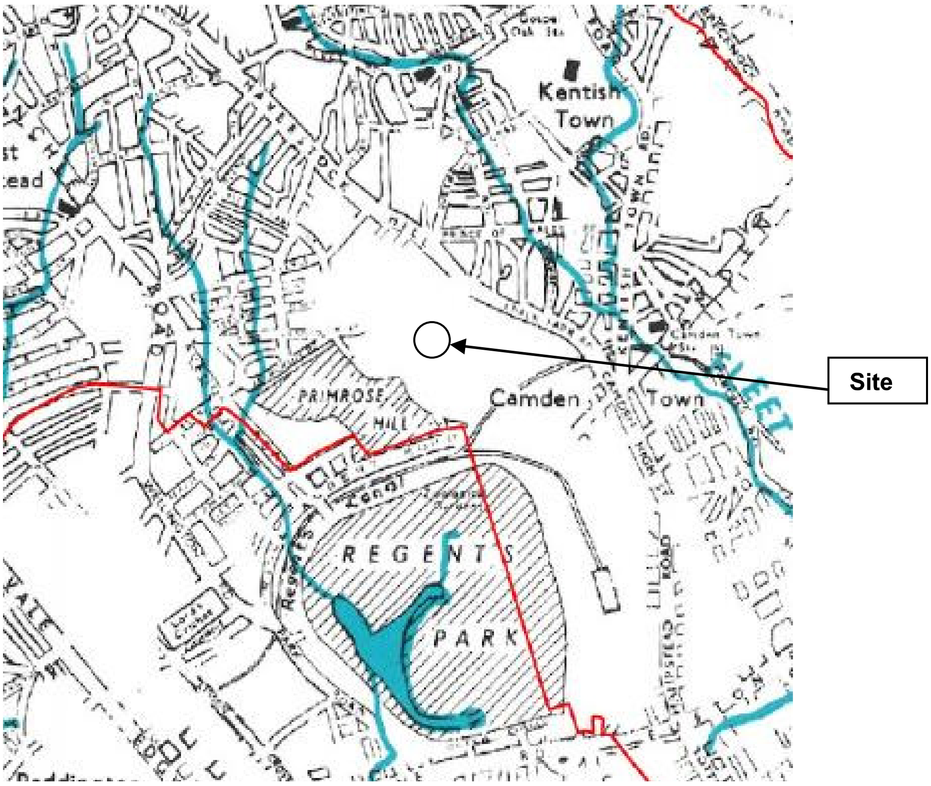
Camden Aquifer Designation Map

Q1b: *Will the proposed basement extend beneath the water table surface?*

A: No.

Q2: *Is the site within 100m of a watercourse, well (used / discussed) or potential spring line?*

A: No. See extract from Figure 11 below. The site is approx. 200m north west of Regent's Canal, however this is an independent man-made body of water and not a natural watercourse.



Extract from Figure 11 - Lost Rivers of London by Nicolas Barton

Q3: *Is the site within the catchment of the pond chains on Hampstead heath?*

A: No

Q4: *Will the proposed basement development result in a change in the proportion of hard surfaced / paved areas?*

A: No. The proposed basement is directly below existing hard landscaping.

Q5: *As part of the site drainage, will more surface water (e.g. rainfall and run-off) than present be discharged to the ground (e.g. via soakaways and/or SUDS)?*

A: No. The current surface water drainage arrangements will remain unchanged.

Q6: *Is the lowest point of the excavation (allowing for any drainage and foundation space under the basement floor) close to, or lower than, the mean water level in any local pond (not just the pond chains on Hampstead Heath) or spring line.*

A: No

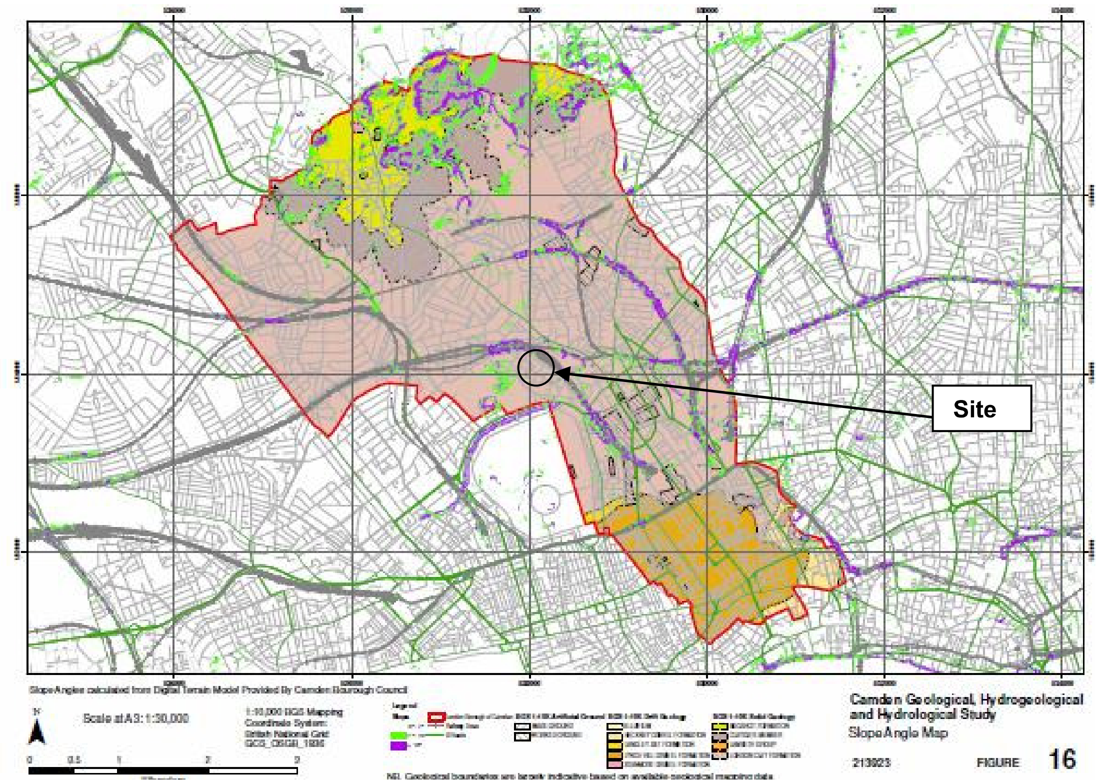
Non-technical summary - Subterranean (ground water) Flowchart

1. The results of the screening flowchart confirm that the proposed development does not affect the subterranean ground water flow.
2. The proposals are to slightly increase the depth of the existing vaults.
3. The existing vaults do not extend below the ground water level.
4. London Clay exists across the site and the site itself is not located above an aquifer.

2.03 SLOPE STABILITY SCREENING FLOWCHART

Q1: *Does the existing site includes slopes, natural or manmade, greater than 7^{o} (approximately 1 in 8)?*

A: No. The site is relatively flat. See Slope Angle Map below.



Q2: *Will the proposed re-profiling of landscaping at site change slopes at the property boundary more than 7^{o} (approximately 1 in 8)?*

A: No

***Q3:** Does the development neighbour land, including railway cuttings and the like, with a slope greater than 7° (approximately 1 in 8)?*

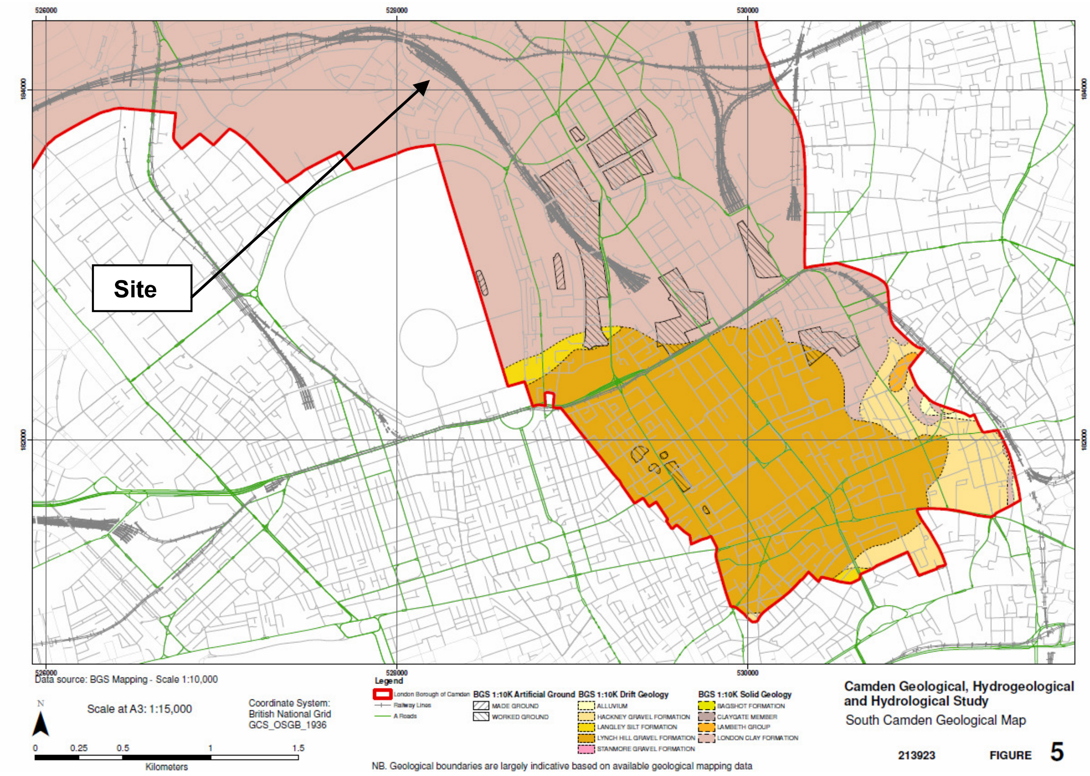
A: No. The site is approximately 65m away from a railway cutting. There is

***Q4:** Is the site within a wider hillside setting in which the general slope is greater than 7° (approximately 1 in 8)?*

A: No

***Q5:** Is the London Clay the shallowest strata at the site?*

A: Yes. See figure 5 below and historical borehole information in Q1a.



. See figure 5 below.

***Q6:** Will any tree/s be felled as part of the proposed development and/or are any works proposed within any tree protection zones where trees are to be retained?*

A: No. The shrubs along the front garden wall will be removed as part of the works.

Q7: *Is there a history of seasonal shrink-swell subsidence in the local area, and /or evidence of such effects at the site?*

A: No. A visual survey of the site and neighbouring buildings did not show signs of shrink-swell subsidence.

Q8: *Is the site within 100m of a watercourse or potential spring line?*

A: No. The site is approx. 200m North West of Regent's Canal; however this is an independent man-made body of water and not a natural watercourse.

Q9: *Is the site within an area of previously worked ground?*

A: No. A review of historic maps did not indicate previous pits or workings.

Q10: *Is the site within an aquifer? If so, will the proposed basement extend beneath the water table such that dewatering may be required during construction?*

A: No. See extracts Camden Aquifer Map in Q1a above.

Q11: *Is the site within 50m of the Hampstead Heath ponds?*

A: No

Q12: *Is the site within 5m of a highway or pedestrian right of way?*

A: Yes. The proposed development extends to the back of the public pavement. The front wall of the development will be designed as a retaining wall for a surcharge from traffic.

Q13: *Will the proposed basement significantly increase the differential depth of foundations relative to neighbouring properties?*

A: No. The front vaults are remote from the main properties.

Q14: *Is the site over (or within the exclusion zone of) any tunnels or railway lines?*

A: No.

Non-technical summary - Slope Stability Screening Flowchart

1. The results of the slope stability flowchart confirm that the proposed extension will not affect slope stability of the area.
2. The works will involve excavtion close to a public highway. The new walls will be designed as retaining walls subject to surcharge loading from traffic.
3. The ground conditions are predominantly London Clay which is cohesive and therefore can be excavated in a controlled fashion using well known techniques used for basement excavations across London.

2.04 SURFACE FLOW AND FLOODING SCREENING FLOWCHART

***Q1:** Is the site within the catchment of the pond chains on Hampstead Heath?*

A: No

***Q2:** As part of the proposed site drainage, will surface water flows (e.g. volume of rainfall and peak run-off) be materially changed from the existing route?*

A: No.

***Q3:** Will the proposed basement development result in a change in the proportion of hard surfaced / paved external areas?*

A: No

***Q4:** Will the proposed basement development result in changes to the profile of inflows (instantaneous and long-term) of surface water being received by adjacent properties or downstream watercourses?*

A: No. There will be no change to the existing inflows of surface water being received by adjacent properties.

***Q5:** Will the proposed basement development result in changes to the quality of surface water being received by adjacent properties or downstream watercourses?*

A: No. Materials used are inert in their nature and will not affect surface water quality.

***Q6:** Is the site in an area identified to have surface water flood risk according to either the Local Flood Risk management Strategy or the Strategic Flood Risk Assessment or is it at risk from flooding, for example because the proposed basement is below the static water level of nearby surface water feature?*

A: No. See Figure 15 below

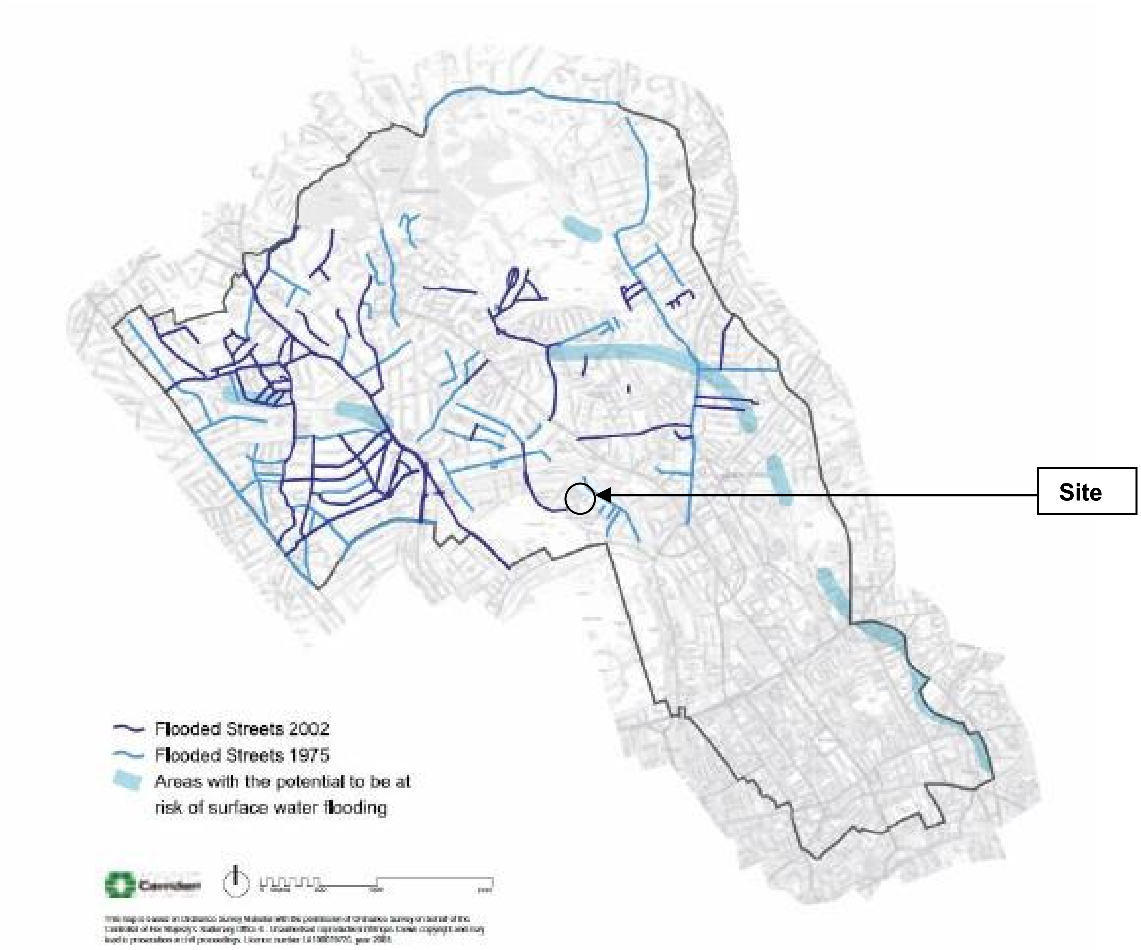


Figure 5 from Core Strategy, London Borough of Camden

Camden Geological, Hydrogeological and Hydrological Study
Flood Map

213923 FIGURE 15

Non-technical summary - Surface Flow and Flooding Screening Flowchart

1. Based on the above flowchart answers, there is no adverse effect or change to existing surface flow or flooding conditions.
2. The site lies outside of areas classified as at risk from surface water flooding.

3.0 Stage 2 - Scoping

The screening stage (Stage 1) identified the following issues that need to be assessed.

3.01 SUBTERRANEAN (GROUND WATER) FLOW SCREENING FLOWCHART

The results of the screening flowchart confirm that the proposed development does not affect the subterranean ground water flow.

3.02 SLOPE STABILITY SCREENING FLOWCHART

Screening identified the following items that need to be assessed.

***Q12:** Is the site within 5m of a highway or pedestrian right of way?*

A: Yes. The proposed development extends to the back of the public pavement. The front wall of the development will be designed as a retaining wall subject to the required surcharge loads from Highway Loading. Preliminary calculations are included in this assessment.

The proposed extension is sufficiently remote from the neighbouring properties to cause structural damage. The potential damage risk can therefore be categorised as Category '0' - negligible in accordance with the Burland Scale below.

Table 1. Building Damage Classification (after Burland et. al., 1977 and Boscarding and Cording, 1989)

Risk Category	Degree of Damage	Description of Typical Damage	Approximate Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks		Less than 0.05
1	Very Slight	Fine cracks easily treated during normal decoration	0.1 to 1	0.05 to 0.075
2	Slight	Cracks easily filled. Several slight fractures inside building. Exterior cracks visible.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Door and windows sticking.	5 to 15 or a number of cracks greater than 3	0.15 to 0.3
4	Severe	Extensive repair involving removal and replacement of walls, especially over doors and windows. Windows and door frames distorted. Floor slopes noticeably.	15 to 25 but also depends on number of cracks	Greater than 0.3
5	Very Severe	Major repair required involving partial or complete reconstruction. Danger of instability.	Greater than 25 but depends on number of cracks	

3.03 SURFACE FLOW AND FLOODING SCREENING FLOWCHART

No items were identified that require further assessment as part of the screening stage.

4.0 Stage 3 - Site Investigation and study

A site specific ground investigation will be required to verify the ground conditions.

Historic borehole information available indicates that the ground conditions consist of a layer of Made Ground over firm to stiff London Clay. Groundwater was not encountered.

4.01 Existing sub-structure and Foundations
The existing vaults are solid brickwork walls with corbelled brick footings likely.

4.02 Proposed Development
Details of the proposed basement development are illustrated on drawings included in Appendix 2 and on the relevant Architectural drawings.

The development of the basement in terms of ground works will consist of the following:

- Excavation beneath the existing front vaults in the front garden of the property.
- Reinforced concrete walls / underpins.

4.03 Topography
The site is relatively flat and is in the middle of a row of terrace houses. There are existing pavement vaults under the front garden.

The proposed subterranean extension is not under the footprint of the building and therefore will not affect the surrounding topography.

4.04 Drainage - surface water
The proposed extension is directly under existing hard landscaping. Therefore the surface water runoff from the property will not be increased.

4.05 Flooding
Based on the appropriate checks as part of the Stage 1 screening, there is no perceived risk of flooding of the site.

4.06 Geology
The geology on the site consists of London Clay.

5.0 Construction Sequence Methodology

This Outline Sequence of Construction should be read in conjunction with all Structural Engineering drawings and specifications.

The sequence outlined in this document is based on assumptions made in the design of the structural elements. The Contractor is to develop his own sequence of construction for which he shall remain totally responsible.

All temporary works are the responsibility of the Contractor.

The Contractor is therefore responsible for the stability of the existing structure and earthworks on the site and supporting adjoining properties affected by the works. All necessary precautions must be taken to safeguard this. Adequate shoring must be installed during the works and shall be founded on sound formation.

Prior to works commencing detailed schedules of condition should be carried out as part of the Party Wall negotiations.

Soil Excavation / Disposal

The overall site waste management plan is to be developed by the Contractor, but it is envisaged that excavated soil will be bagged and lifted to a skip at pavement level for cart away.

The movement of vehicles to and from the site are to be carefully marshalled and adequate protective hoardings erected to ensure no unauthorised access to the site. Measures are also to be put in place by the Contractor to safeguard the public.

All works are to be carried out in a manner to minimise any noise and vibration that may affect the existing and adjacent properties.

The procedure for disposal of the soil and proposed routes will need to be agreed with the Local Authority Highways Department in accordance with an agreed Construction Waste Management plan.

Assumed Construction Sequence Methodology

1. Erect hoarding and signage to protect public from the construction works.
2. Carefully break out existing vault slab to side walls in 1m intervals to allow for underpinning in short hit and miss sections as indicated on the drawings.
3. Once underpinning to side walls are complete remove finishes from the existing vault roof and carefully demolish the roof. Leave cross walls in place.
4. Demolish front wall supporting the highway in short sections (max 1 m length) down to a max depth of 1m. Install temporary earth support as the work progresses.
5. Construct 1m deep reinforced concrete beam along edge footpath and tie into return walls. Install horizontal propping.
6. Carefully remove brickwork under concrete beam for 2nd stage pins. Brickwork to be removed in short sections (max 1m length) in a hit and miss sequence as indicated on the drawings.
7. Install horizontal propping new pins and existing walls at high and low level.

8. Demolish existing roof slab / vaults.
9. Carryout bulk excavation down to new basement slab formation.
10. Cast new slab and remove lower props once slab has achieved design strength. The new slab will provide a permanent prop at basement level.
11. Cast new roof slab and remove upper props once slab has achieved design strength. The new slab will provide a permanent prop at roof level.

6.0 Conclusions

Based on the existing site conditions and our assessment of the likely building damage, it is concluded that the proposed basement development will not adversely impact on neighbouring properties and the natural environment of the site.

The key items assessed within this report are summarised as follows:

- Subterranean (ground water) flows - no adverse effect
- Slope stability - no adverse effect
- Flooding - no perceived risk of either localised flooding or within the surrounding area.
- Geology - a site specific investigation was undertaken. Water was not encountered during the investigation. The underlying stratum is firm to very stiff Clay which is suitable for basement developments of this size.
- Anticipated extent of structural damage - this has been categorised as category '0' - Negligible in accordance with Burland et al.

Tyrone Bowen MEng CEng MIStructE
Director - Structural Engineering
CAR Ltd

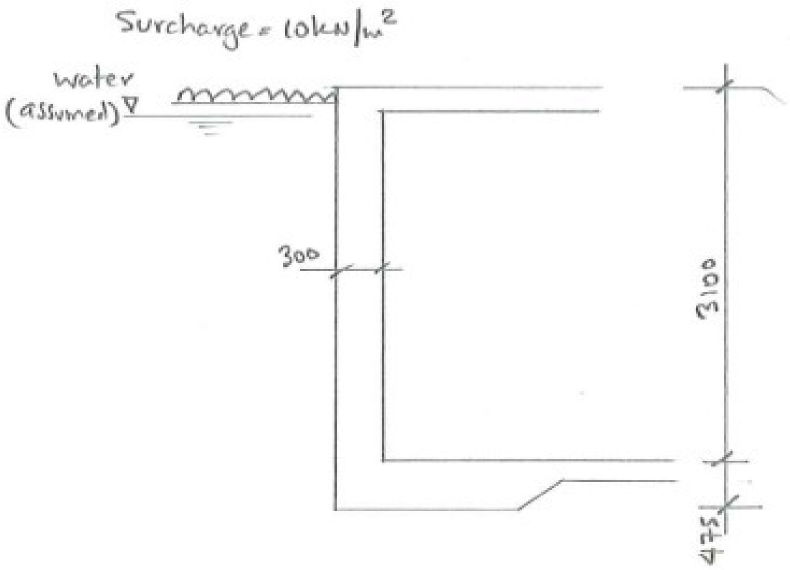
CAR Ltd	Date	Job No	Sheet No	Rev
Unit 6, 25 Gwydir Street	Mar-16	2812		
Cambridge, CB1 2LG	Eng	Project		
Tel: 01223 460475	TB	109 Gloucester Avenue, London		

Front Retaining Wall

The front retaining wall is to be designed to retain the existing pavement.

Assume a surcharge of $10 kN/m^2$ acts on the wall.

Take water level to be acting at the top of the wall.

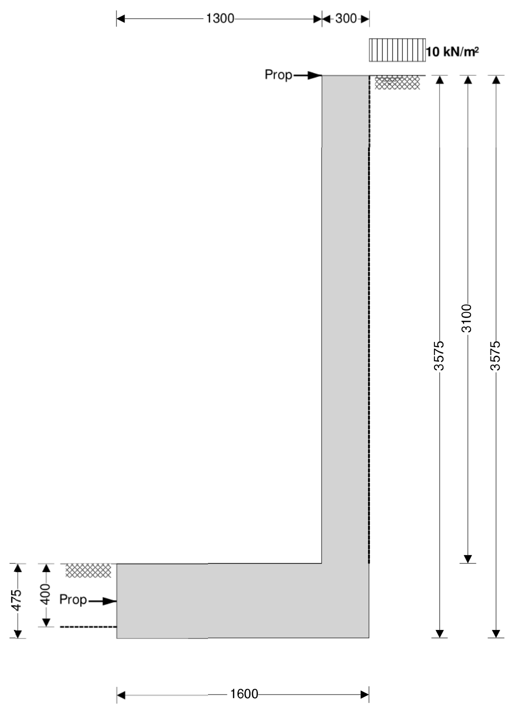


Refer to Tedds output overleaf for analysis.

TEKLA Tedds CAR Ltd 25 Gwydir Street Cambridge CB1 2LG	Project 109 Gloucester Avenue, London				Job no. 2812	
	Calcs for Front Retaining Wall				Start page no./Revision RW 2	
	Calcs by TB	Calcs date	Checked by	Checked date	Approved by	Approved date

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **3100** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **1300** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1600** mm
Thickness of base	t_{base} = **475** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **900** mm
Thickness of downstand	t_{ds} = **475** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3575** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **400** mm
Height of ground water behind wall	h_{water} = **3575** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **3100** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3575** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3

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

Design shear strength ϕ' = **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 $P_{bearing}$ = **150** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

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

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 $K_0 = 1 - \sin(\phi') = \mathbf{0.590}$

Loading details

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

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

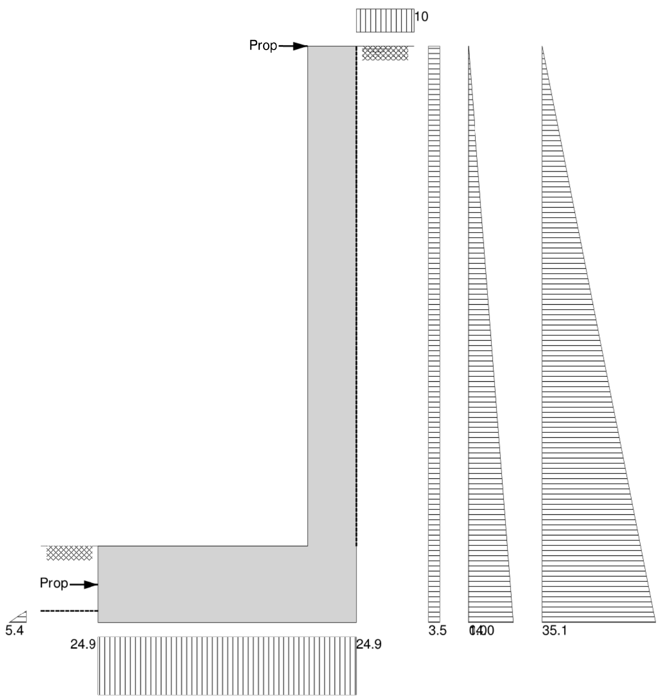
Applied vertical live load on wall W_{live} = **0.0** kN/m

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

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

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

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



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

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **21.9** kN/m

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

Total vertical load $W_{total} = w_{wall} + w_{base}$ = **39.9** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff}$ = **12.5** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **25** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **62.7** kN/m

Total horizontal load $F_{total} = F_{sur} + F_s + F_{water}$ = **100.2** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **0.2** kN/m

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

F_{prop} = **86.6** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **22.4** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **29.8** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **74.7** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_s + M_{water}$ = **126.9** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **31.8** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **14.3** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base}$ = **46.2** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **39.9** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **800** 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 $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **24.9** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **24.9** 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

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **27.578** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **59.012** kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

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

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **30.7** kN/m

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

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f}$ = **55.8** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **33.8** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **59.1** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **87.8** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{s\_f} + F_{water\_f}$ = **180.6** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **0.3** kN/m

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

F_{prop_f} = **161.5** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **60.3** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **70.4** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **104.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{s\_f} + M_{water\_f}$ = **235.3** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **44.6** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **20.1** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f}$ = **64.6** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **55.8** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **800** 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 $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **34.9** kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **34.9** kN/m²

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

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0 \text{ kN/m}^2)$ = **34.9** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **34.9** kN/m²

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **34.9** kN/m²

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **53.028** kN/m

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f}$ = **108.489** kN/m

Design of reinforced concrete retaining wall toe (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 toe — c_{toe} = **75** mm

Calculate shear for toe design

Shear from bearing pressure — $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **45.4** kN/m

Shear from weight of base — $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **20.4** kN/m

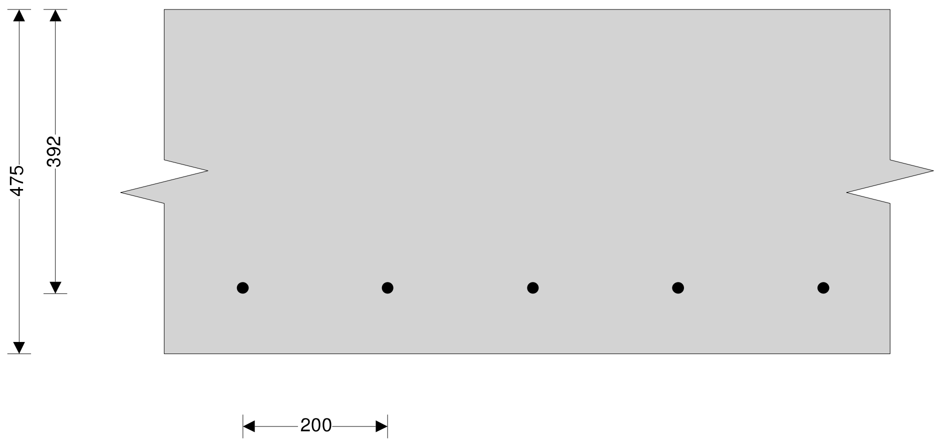
Total shear for toe design — $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **25** kN/m

Calculate moment for toe design

Moment from bearing pressure — $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **36.7** kNm/m

Moment from weight of base — $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **16.5** kNm/m

Total moment for toe design — $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **20.2** kNm/m



Check toe in bending

Width of toe — b = **1000** mm/m

Depth of reinforcement — $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **392.0** mm

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

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} = **372** mm

Area of tension reinforcement required — $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **125** mm^2/m

Minimum area of tension reinforcement — $A_{s\_toe\_min} = k \times b \times t_{base}$ = **618** mm^2/m

Area of tension reinforcement required — $A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **618** mm^2/m

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

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

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.064** 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_toe} = **0.472** N/mm^2

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

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

Material properties

Characteristic strength of concrete f_{cu} = **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} = **75** mm

Cover to reinforcement in wall c_{wall} = **75** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **29.3** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **44.4** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **66** kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **18.3** kN/m

Saturated backfill $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **35.5** kN/m

Water $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **52.8** kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **106.6** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **12.2** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2)-(15 \times a_l \times L)+(20 \times L^2))/(60 \times L^2)$ = **19.8** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2)-(15 \times a_l \times L)+(20 \times L^2))/(60 \times L^2)$ = **29.4**

kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_s} + M_{s\_water}$ = **61.3** kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **6.9** kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **8.8** kNm/m

Water $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **13.1**

kNm/m

Total moment for wall design $M_{wall} = M_{w\_sur} + M_{w\_s} + M_{w\_water}$ = **28.8** kNm/m

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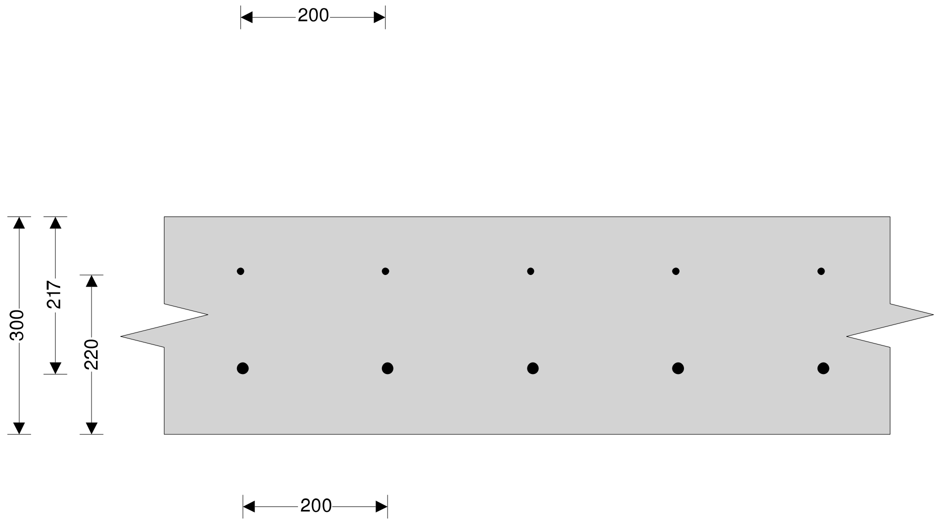

Check wall stem in bending

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

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **217.0** mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.033**

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} = **206** mm

Area of tension reinforcement required — $As_{\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **684** mm^2/m

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

Area of tension reinforcement required — $As_{\_stem\_req} = \text{Max}(As_{\_stem\_des}, As_{\_stem\_min})$ = **684** mm^2/m

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

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

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.491** 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} = **0.666** N/mm^2

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

Check mid height of wall in bending

Depth of reinforcement — $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **220.0** mm

Constant — $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu})$ = **0.015**

Compression reinforcement is not required

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

z_{wall} = **209** mm

Area of tension reinforcement required — $As_{\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall})$ = **317** mm^2/m

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

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

Reinforcement provided — **A393 mesh**

Area of reinforcement provided — $As_{\_wall\_prov}$ = **393** 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 $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **226.8** N/mm²

Modification factor $factor_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.50**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **29.93**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **14.29**

PASS - Span to depth ratio is acceptable

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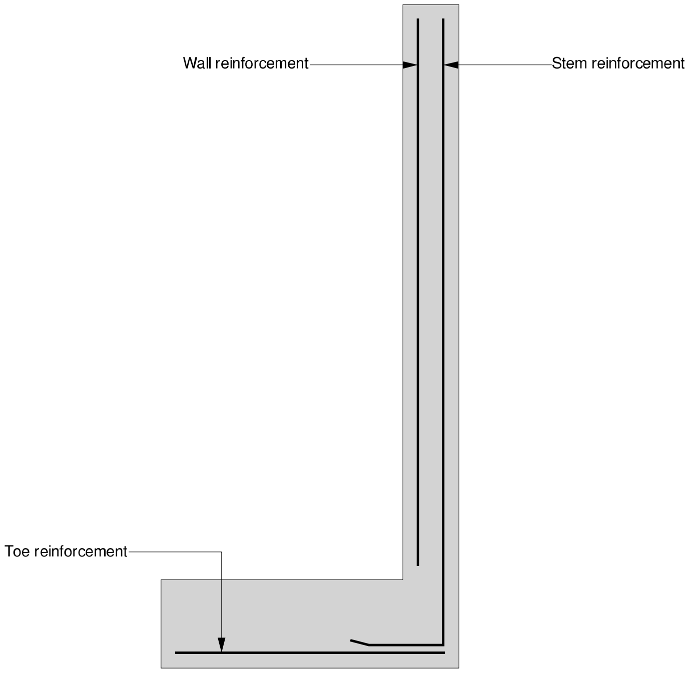
Indicative retaining wall reinforcement diagram



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

Wall mesh - A393 - (393 mm^2/m)

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

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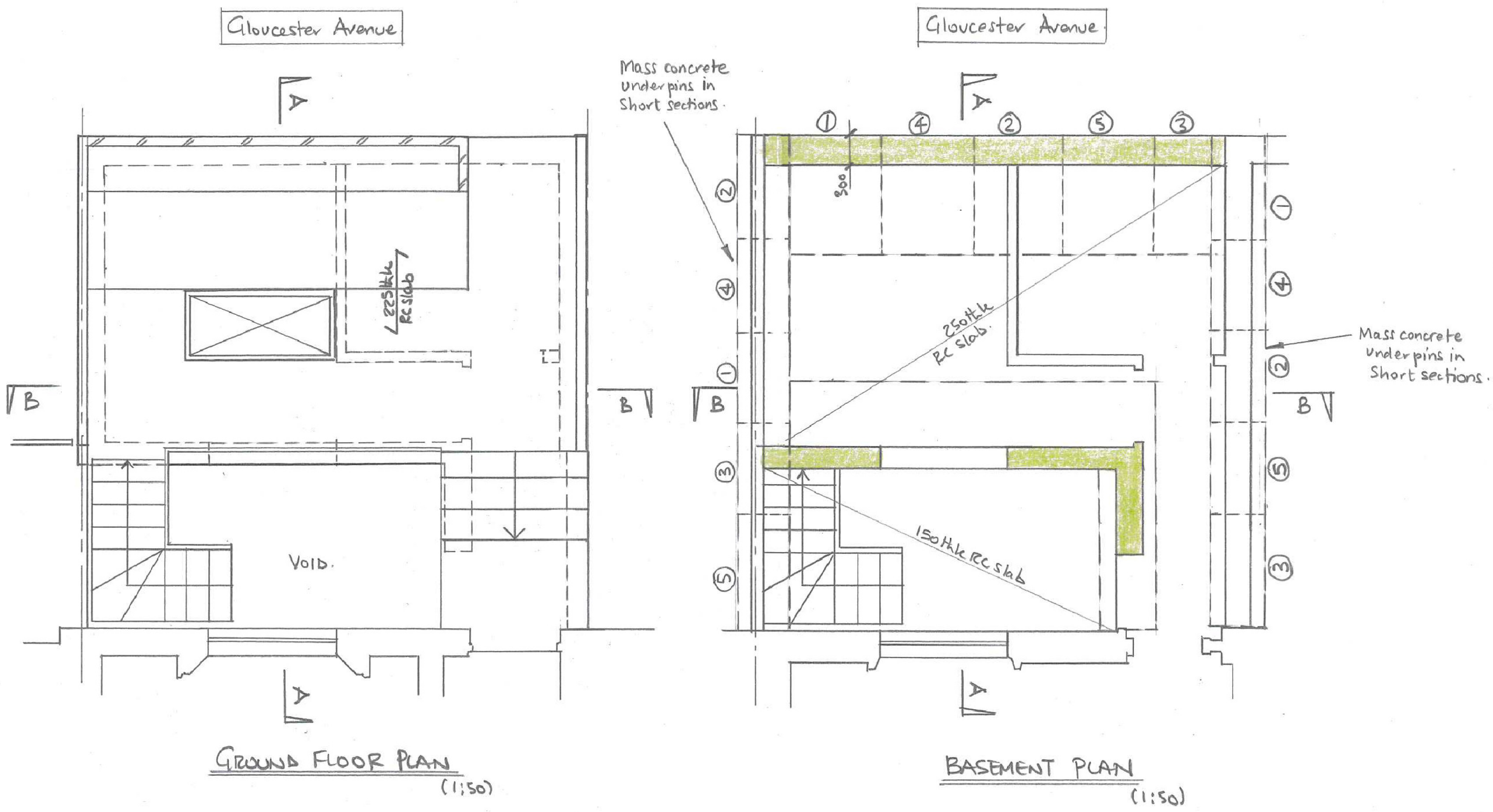

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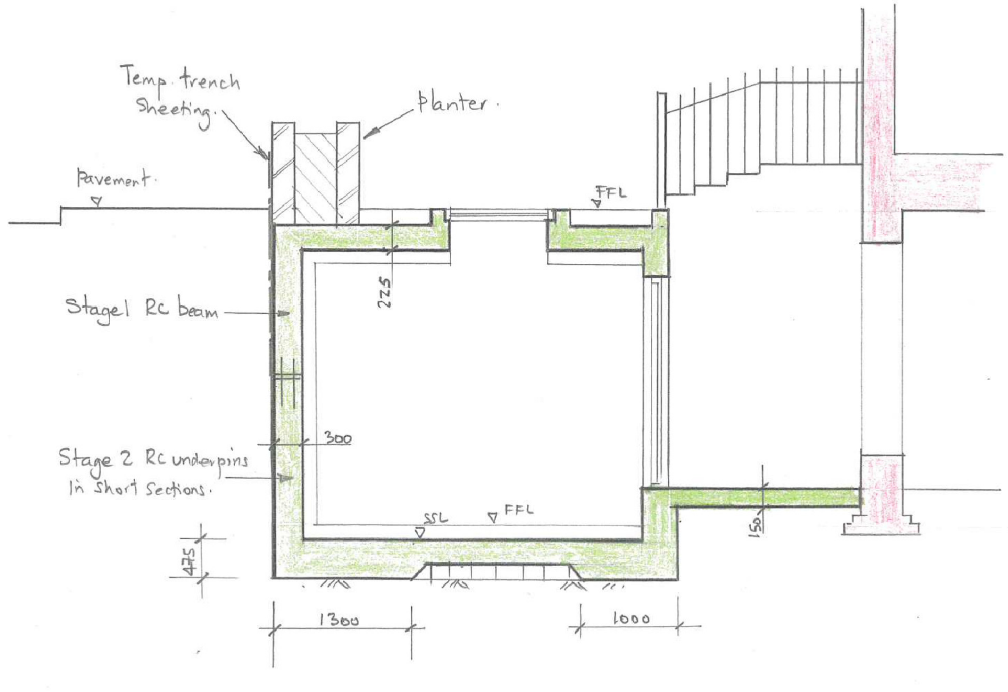
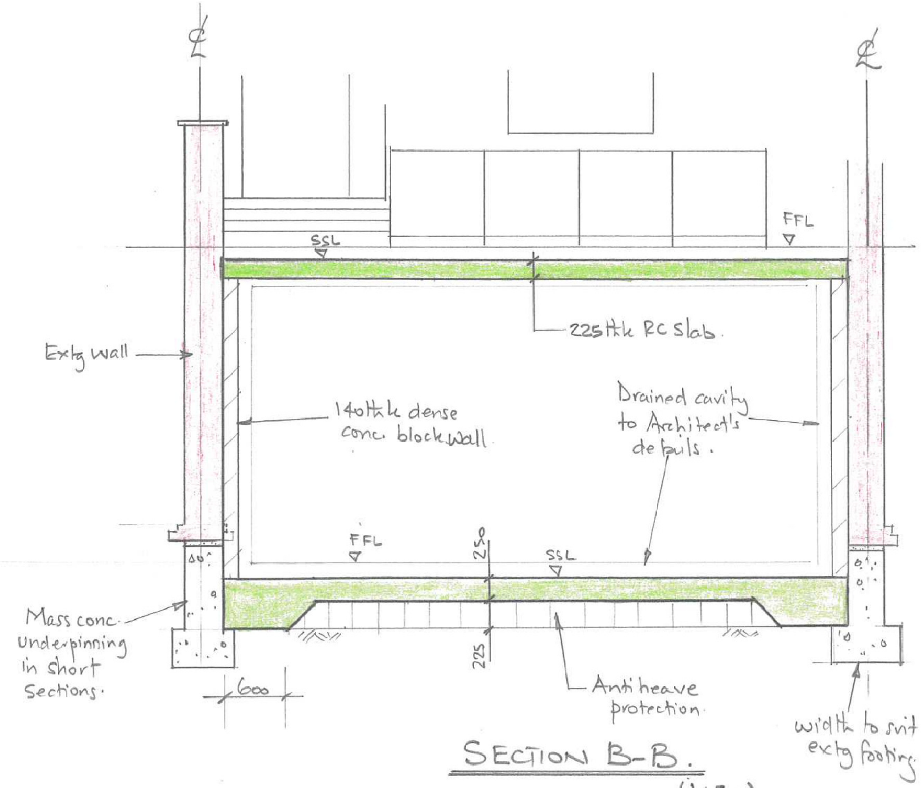


SECTION A-A. (1:50)



SECTION B-B. (1:50)

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