STRUCTURAL METHOD STATEMENT TO ACCOMPANY THE BIA FOR

253 GOLDHURST TERRACE LONDON NW6 3EP

REF:24078/SR-001/SN

REV P2 MAY 2025

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The Institution of StructuralEngineers

CONTENTS

DOCUMENT CONTROL SHEET

Project Title: 253 Goldhurst Terrace

Report Title: Structural Method Statement to Accompany Basement Impact Assessment

Summary: Structural Engineer's Construction Methodology, initial calculations and structural scheme to be included with a Basement Impact Assessment for submission to the Planning Authorities relevant to the proposed works at 256 Goldhurst Terrace, NW6 3EP.

Control Date: 6th May 2025 - This report has been amended further to comments received by Campell Reith Consulting Engineers, via their Basement Impact Assessment Audit, dated April 2025 (report reference 14291-19). This revision pertains to query No. 6, as described in paragraphs 4.20 & 5.10 of the aforementioned BIA Audit report. Specifically, retaining wall RW3 has been redesigned (both in the Temporary and Permanent conditions) with a value of the designed shear strength of 24° which is more conservative. The relevant ameded calculations are included in this report.

Record of Issue

Issue	Status	Author	Date	Check	Date	Authorised	Date
Rev P1	Issued for Review	Stephanos Nicolaou	13.12.2024	Ryan Seagreen	13.12.2024	Antonis Savvides	13.12.2024
Rev P2	Issued for Review	Stephanos Nicolaou	06.05.2025	Ryan Seagreen	06.05.2025	Antonis Savvides	06.05.2025

Distribution

Organisation	Contact	Copies
SF Architect	Silvia Ferrario	Electronic / pdf
Client	Matteo & Anna Falivene	Electronic / pdf

1.0 INTRODUCTION / NON TECHNICAL SUMMARY

1.0 INTRODUCTION

We, ads consultancy, were requested by SF ARCHITECT to compile a structural report consisting of a Construction Methodology / Method Statement to accompany a Basement Impact Assessment (BIA) for the proposed basement at 253 Goldhurst Terrace to supplement the planning application for the proposed development at the aforementioned site. A Basement Impact Assessment has been carried out and compiled by "ground&water" (report reference GWPR6303/BIA&GIR/December 2024) and which includes the Desk Study, Screening and Scoping etc. This report is to compliment that BIA with a Construction Methodology and an initial Structural Scheme. We are Chartered Engineers (Engineering Council UK) and Members of both the Institution of Structural Engineers and the Institution of Engineering and Technology. We have considerable experience in the design and construction of new build and retro-fitted basements in London and have worked on several prestigious basement developments with the UK's top basement Contractors as both Design and Build Engineers and Project Engineers for the Client.

1.1 SITE DESCRIPTION - EXISTING ARRANGEMENT

The site is situated on 253 Goldhurst Terrace, and comprises a four storey semi-detached residential property, which includes a basement, ground, first, second and third floors. The northern boundary is formed by Goldhurst Terrace, the southern boundary is formed by gardens. To the east is No.251 with which there is a shared Party Wall, and to the West is No. 255 which is detached. The site is circa 500m East of South Hampstead Overground Station and circa 800m West of Kilburn High Road Overground Station.

1.2 SCHEME PROPOSAL

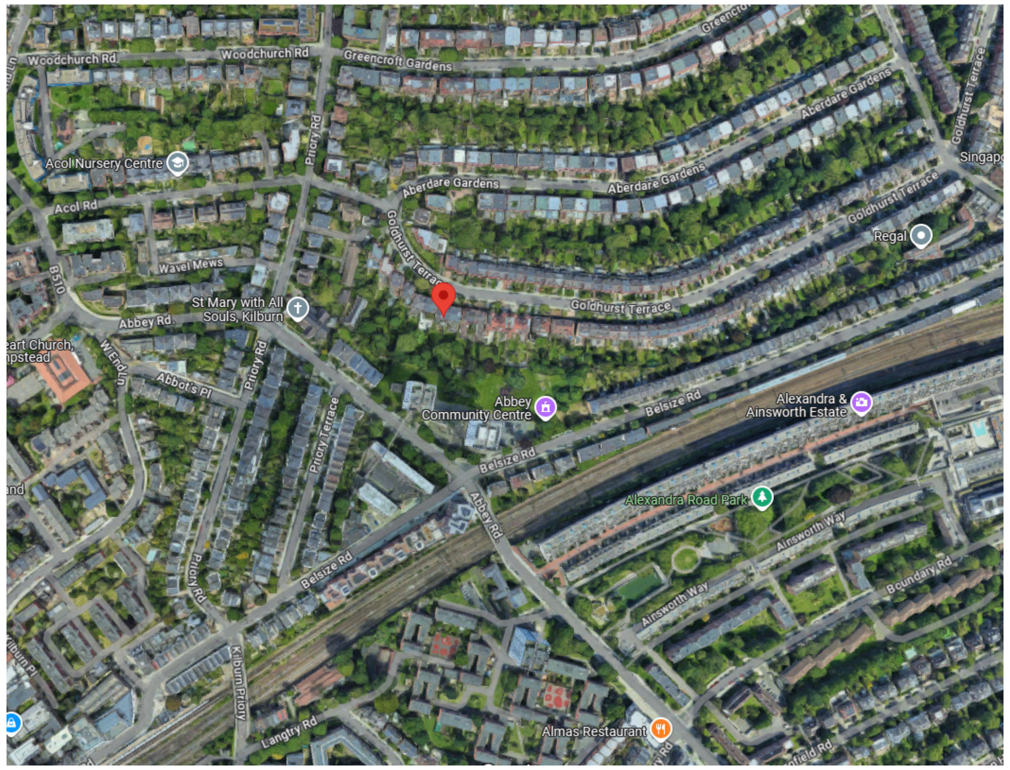
The scheme consists of the extension of the existing basement to the rear, side (i.e. to suit the existing ground floor flank masonry wall towards No. 255) and partly towards the front of the property, i.e. up to and under the existing ground floor wall between the kitchen and bedroom 1. The level of the extended basement will remain the same as the existing basement's level. An opening within the existing ground floor kitchen will also be created to accommodate a new staircase between the basement and ground floors. The proposed scheme also includes rebuilding the existing conservatory to the rear of the ground floor in cavity wall construction, as well as creating an opening through the ground floor wall between the rear reception and the corridor. The latter will require some new steel structure (i.e. a box frame around or steel beam over the new opening).

The new basement extension will be formed of new reinforced concrete retaining walls, constructed in underpinning sequence. The underpins will be constructed in circa 1.0m sections and in a typical staggered underpinning sequence similar to that of typical underpinning. This would negate the need for major temporary works to the existing building. None of the existing Party Walls (i.e. with No. 251) will be underpinned as the proposed extension is inside the boundaries with any of the adjacent properties. A new reinforced concrete ground bearing slab will form the floor of the new basement areas and a mix of timber joists and flat slabs will form the new ground floor to the footprint of the new basement.

Please refer to the attached drawings and sketches in the Drawing Appendix at the rear of this report.

1.4 WORKS PROGRAMME

- The total anticipated construction length will be circa 9-12 months.
- The total duration of the basement works will be circa 5-6 months.



Aerial views of 253 Goldhurst Terrace from Google Maps

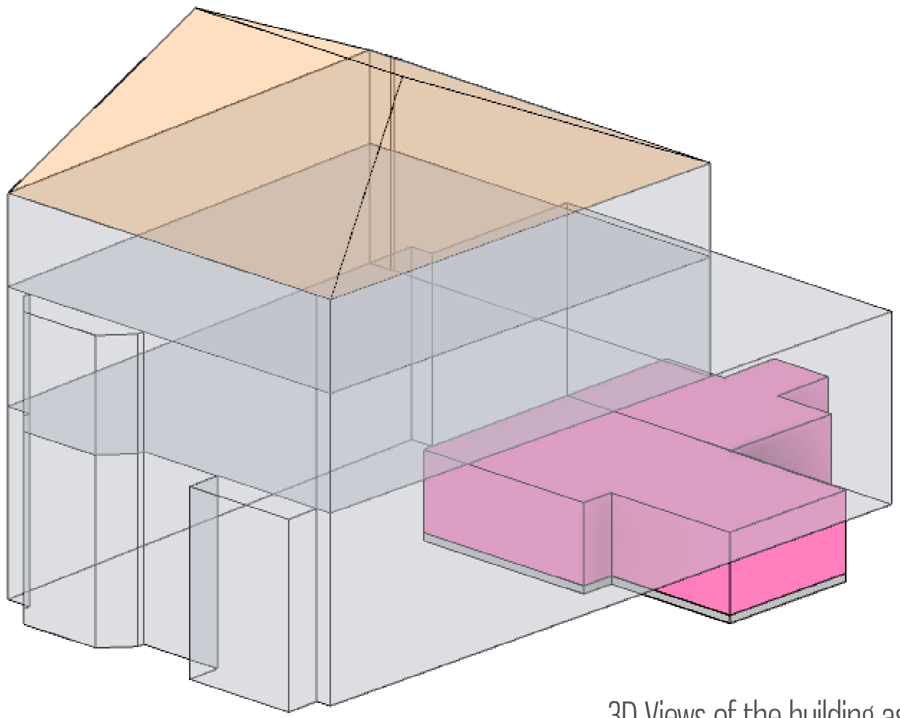
2.0 SITE INVESTIGATION

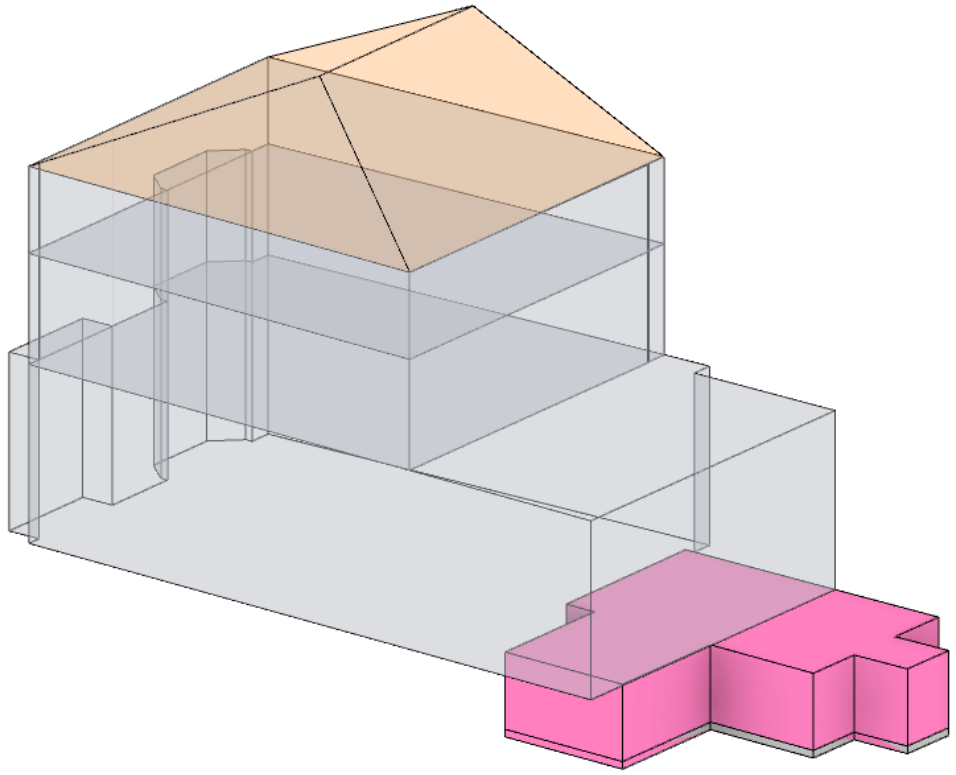
A detailed site investigation had been carried out on site on 7th November 2024 by "ground & water" who are specialist geotechnical engineers, to determine the structural characteristics of the soil along with hydrogeology characteristics. A Basement Impact Assessment report has been prepared by ground&water (report no. GWPR6303/BIA&GIR dated December 2024) which includes their findings which we summarise below.

From consultation with the British Geological Survey (BGS) maps and the recent site investigation report prepared by "ground & water", it appears that the site is located over the London clay formation, with no superficial deposits or made ground found within 250m of the site.
(http://mapapps.bgs.ac.uk/geologyofbritain/home.html)

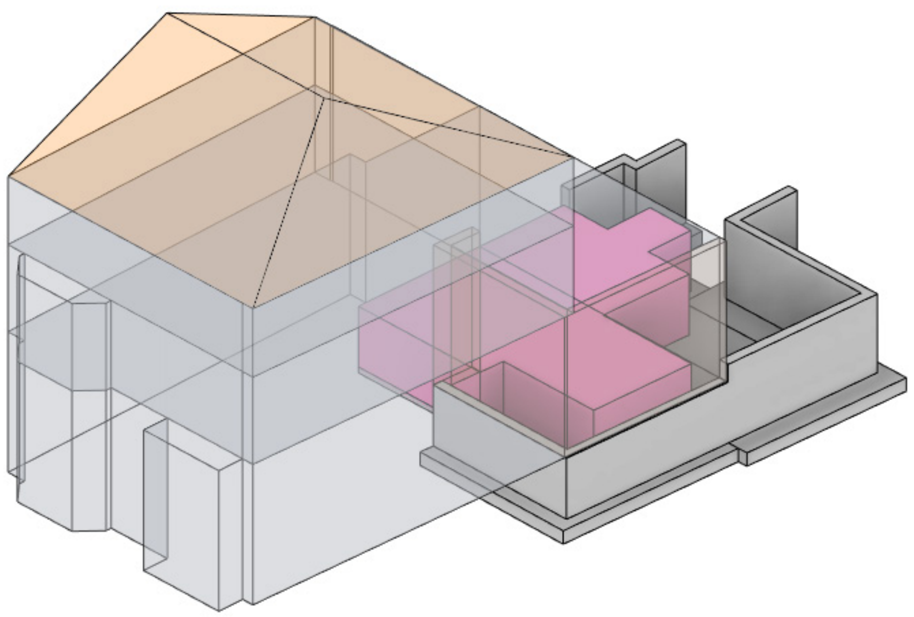
2.1 DESK STUDY / SCREENING / SCOPING

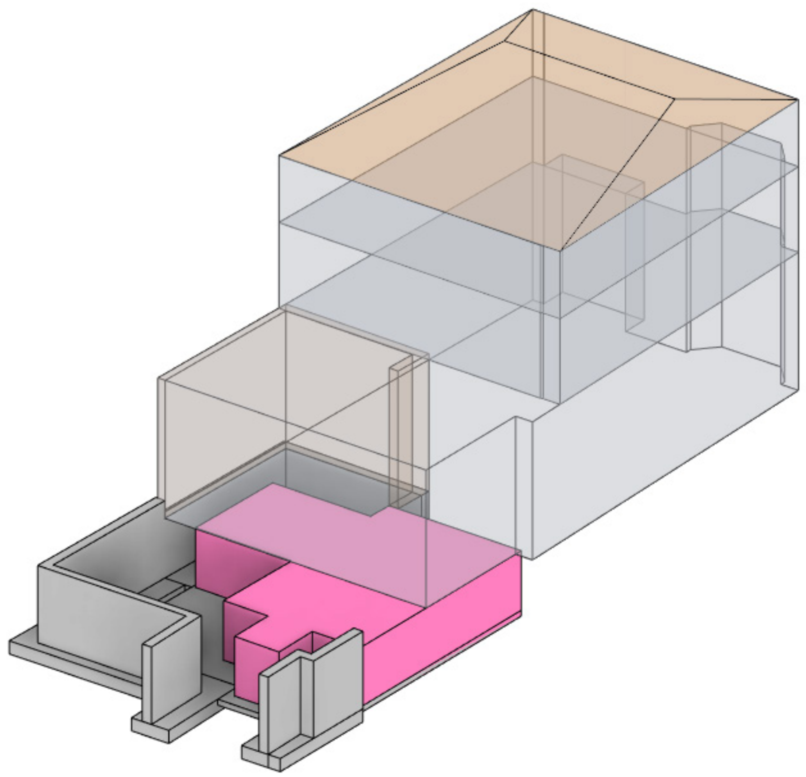
These have been included in the BIA report prepared by ground&water (report no. GWPR6303/BIA&GIR dated December 2024) - this report compliments the aforementioned BIA with a Construction Methodology / Method Statement and an Initial Structural Scheme.





3D Views of the building as Existing





3D Views of the building as Proposed

2.0 SITE INVESTIGATION / DESK STUDY / SCREENING / SCOPING

2.2 FLOOD RISK

The flood risk of the site has been assessed in the Basement Impact Assessment prepared by "ground&water" (report no. GWPR6303/BIA&GIR dated December 2024) and summarised below - for more details please refer to the aforementioned BIA report.

2.2.1 From rivers and sea

The site lies within Flood Zone 1

2.2.2 From reservoirs

The site is not considered to be at risk of flooring from reservoirs, even when rivers are flooded.

2.2.3 From Surface Water

The site is at very low risk of flooding from surface water.

2.2.4 From Groundwater

The site is not in an area with increased susceptibility of elevated ground water. Some properties around and withing 250m from the site have historical issues with flooding from groundwater though.

2.2.5 From Sewers

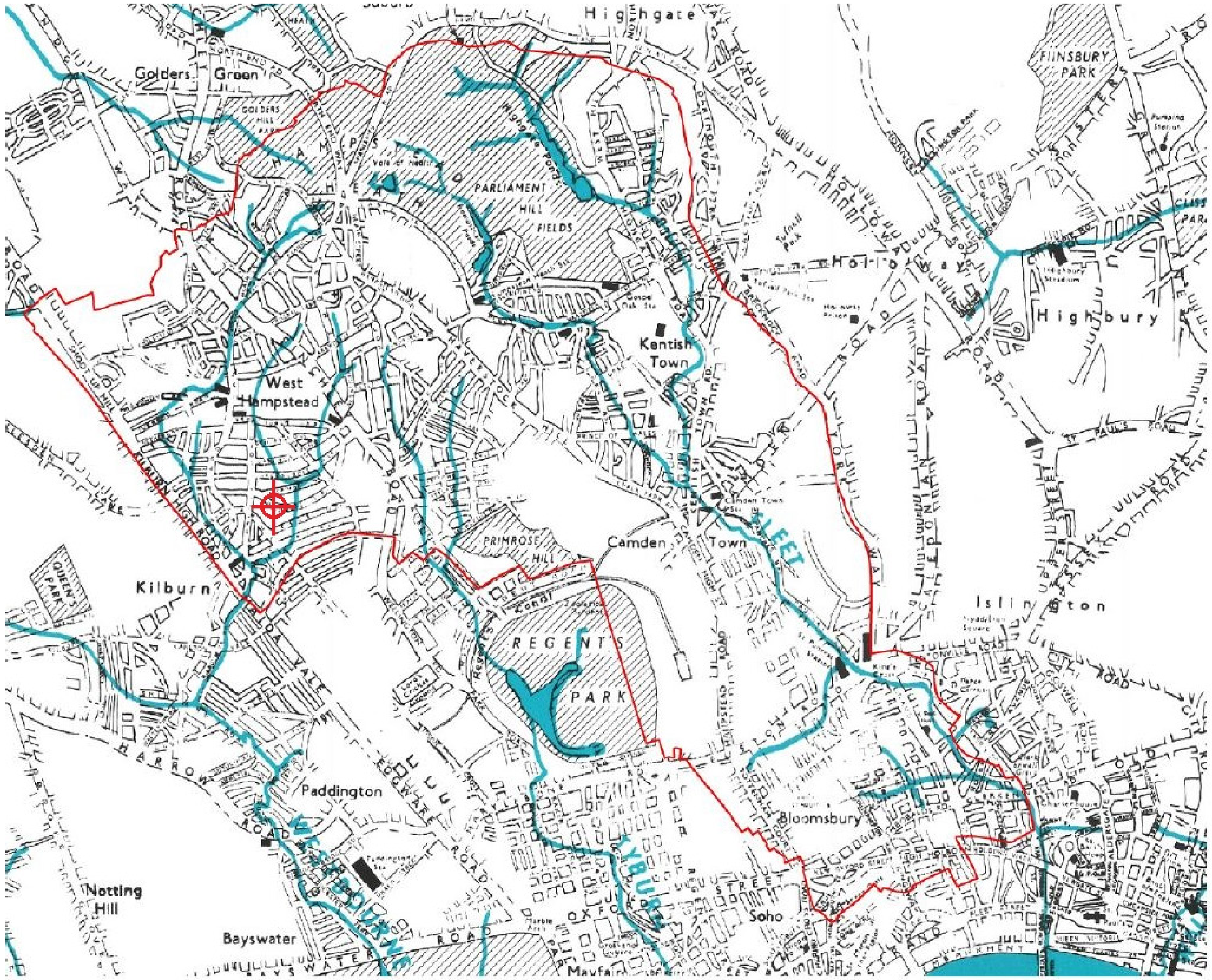
Some records of internal and external sewer flooding have been recorder within the site's postcode area.

2.2.6 Old Rivers

The site does not lie on any old / lost rivers. Streams which join the Westbourne are to the West and East of the site.

2.2.7 Critical Drainage Areas/Local Flood risk Areas

Please refer to Basement Impact Assessment report no. GWPR6303/BIA&GIR dated December 2024, prepared by ground&water for more details on local flood incidents etc.



Source – Barton, Lost Rivers of London

Camden Geological, Hydrogeological and Hydrological Study
Watercourses

3.0 Construction Methodology

1) Once the site has been made safe, underpinning of the relevant existing perimeter masonry walls from inside of the building will commence. There are three walls that will be underpinned and these are indicated in the graphic on page 7 and in the scheme plans starting from page 9. The proposed RC retaining walls underpinning the existing masonry (i.e. RW1 & RW2) have been designed to provide lateral stability for the retained soil, and hence no additional temporary works will be required for these.

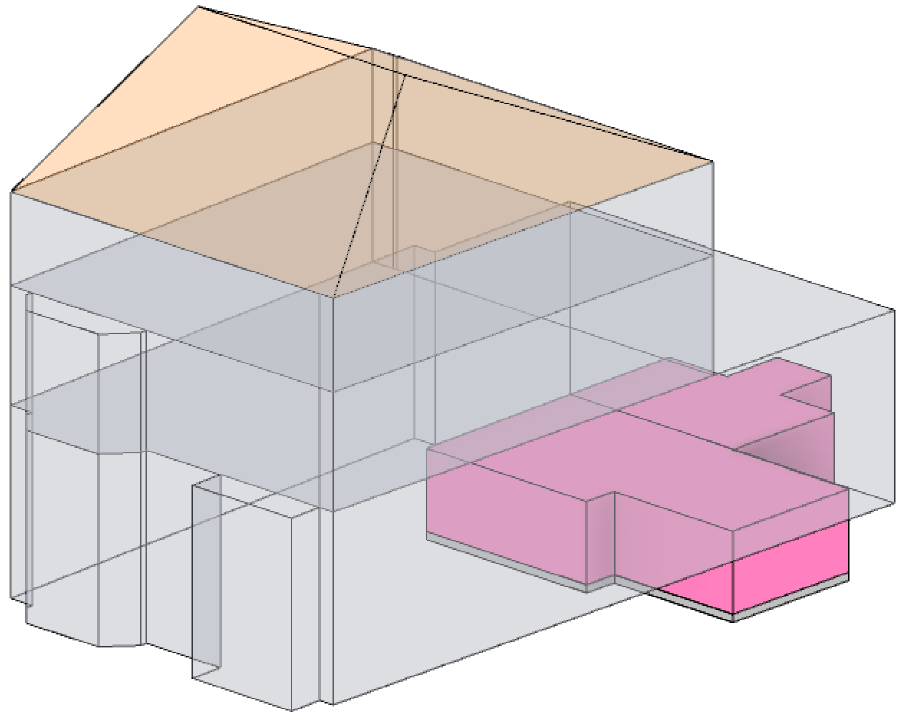
2) Commence construction of the rest of the proposed 300-350mm thick reinforced concrete retaining walls at the same time as point 1 above. This will be done in typical underpinning sequence which is indicated in sketch 24078_SK01 & SK03. Final sequencing of underpinning is to be agreed with the Contractor and Structural Engineer prior to works commencing.
All the wall types forming the proposed basement extension (i.e. RW1, RW2, RW3, RW4) have been designed to provide lateral stability and therefore no additional temporary props will be required during the construction of said retaining walls.

3) After all the new retaining walls have been constructed in underpinning sequence, the soil remaining between the existing basement wall and the newly constructed retaining walls can be removed/excavated down to formation level. The existing basement walls of the existing utility room (which is circa 560mm higher in level than the rest of the basement) can be carefully demolished and the level lowered down to formation level.

5) Construct the new 200mm thick basement floor ground bearing RC slab and subsequently the new ground floor (either a 200mm thick RC slab or a timber joist floor) to the footprint of the new basement extension.

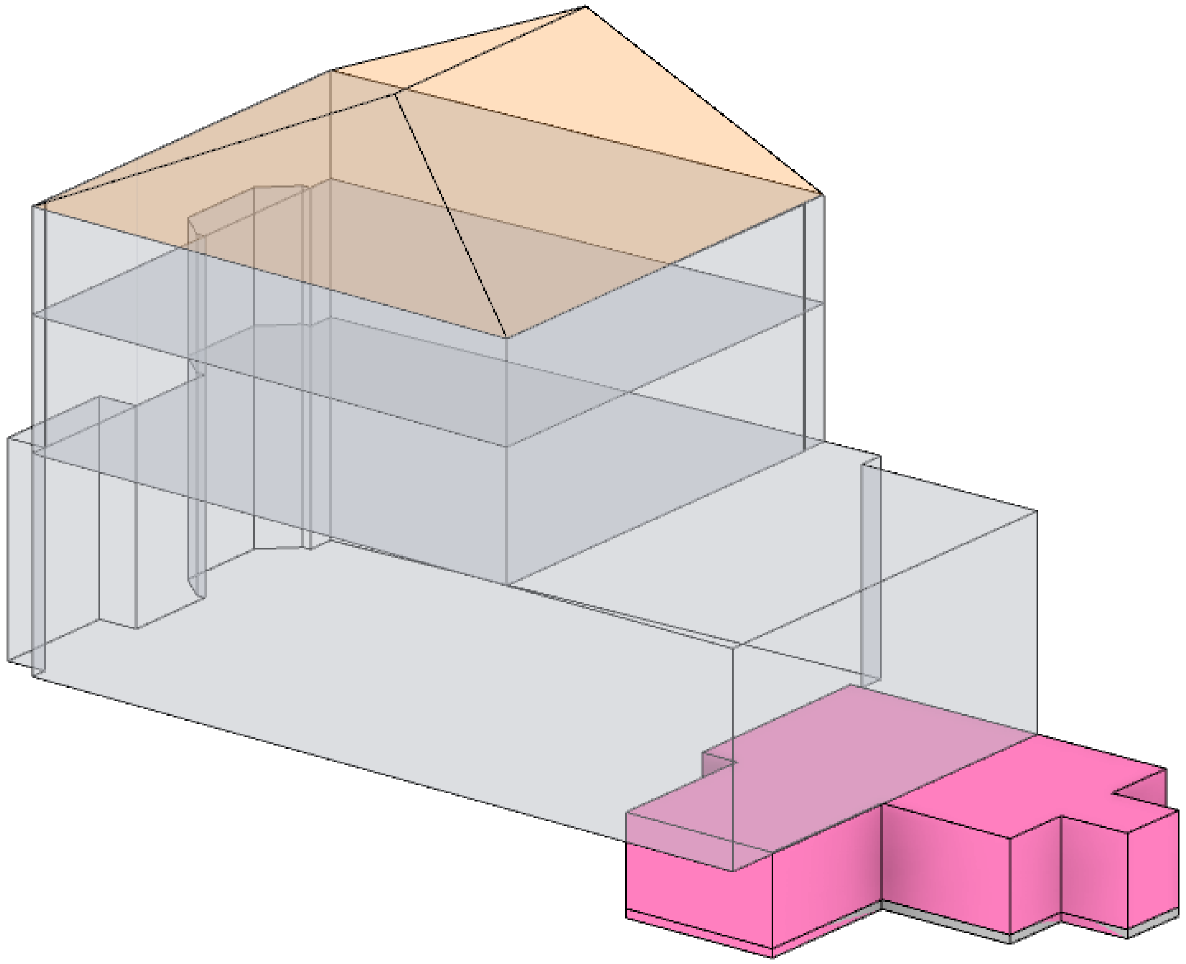
6) Proceed with minor internal alterations to achieve the Architect's requirements and introduce lintels / steel beams as required. At the same time construct retaining wall RW5 along the boundary with No. 255, to allow for raising the external level behind RW3 per the Architect's requirements - RW3 has been designed for the two stages, i.e. initially as unpropped to retain the lower/existing soil level, and subsequently as propped at the base to support the proposed/higher external level.

7) In the event that minor ingress of ground water occurs during the execution of the works this will be dealt with by the use of temporary sump pumps. In the permanent condition waterproofing to the new basement will be based on the Architects proposed details.

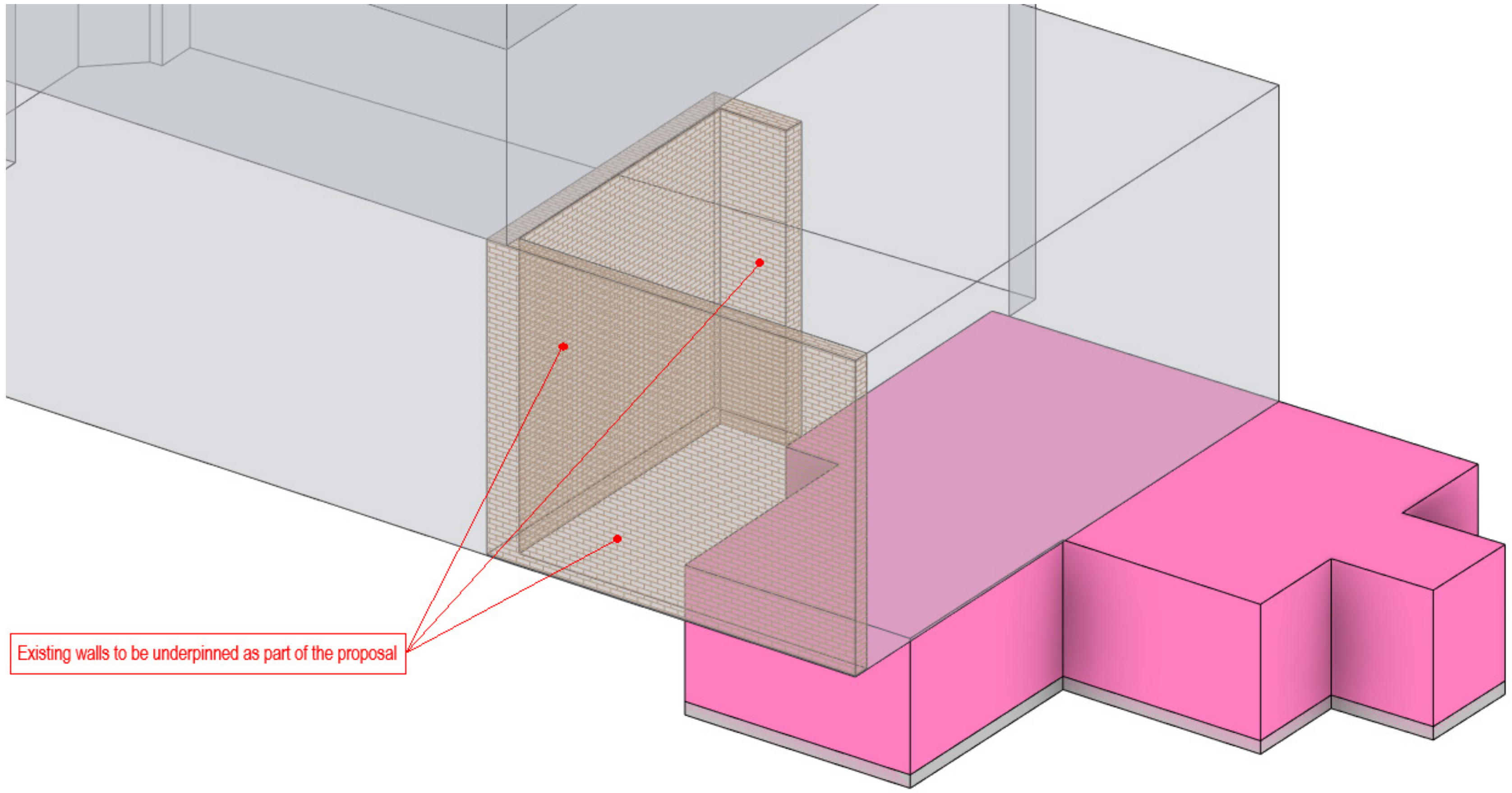


3D View of the building as Existing

3.0 CONSTRUCTION METHODOLOGY / METHOD STATEMENT

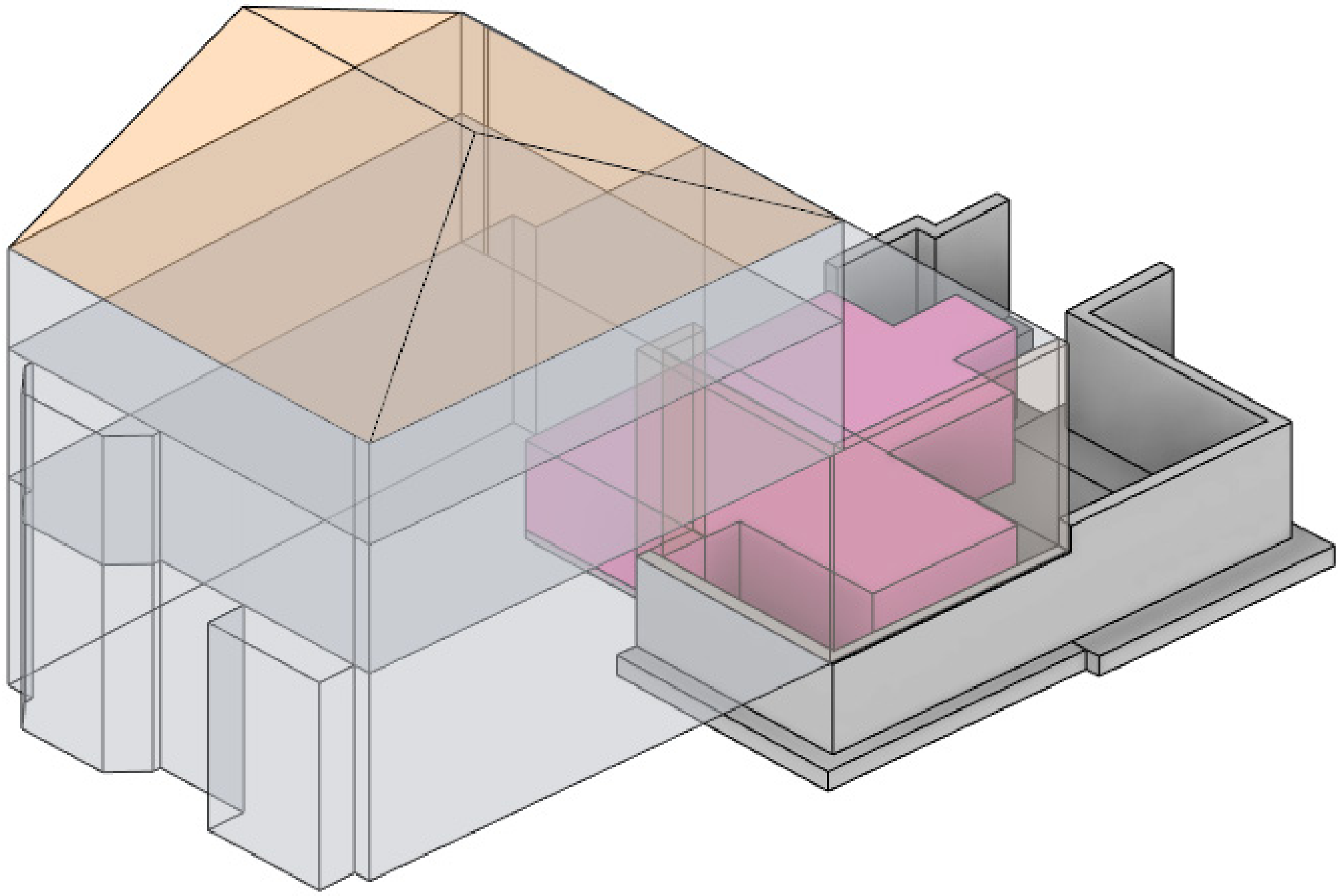


3D View of the building as Existing

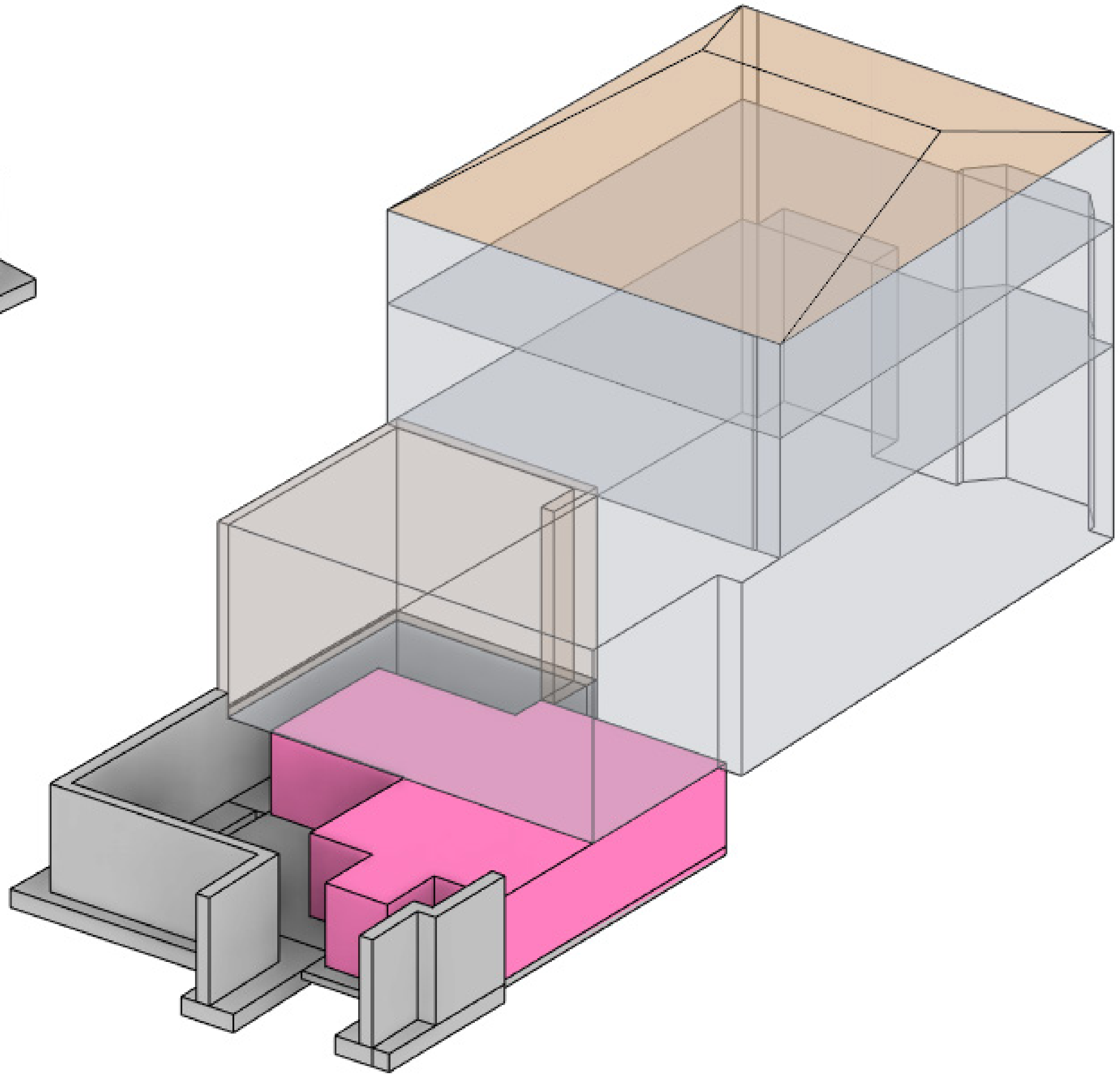


3D View indicating the existing GF walls that will be underpinned as part of the proposal

3.0 CONSTRUCTION METHODOLOGY / METHOD STATEMENT

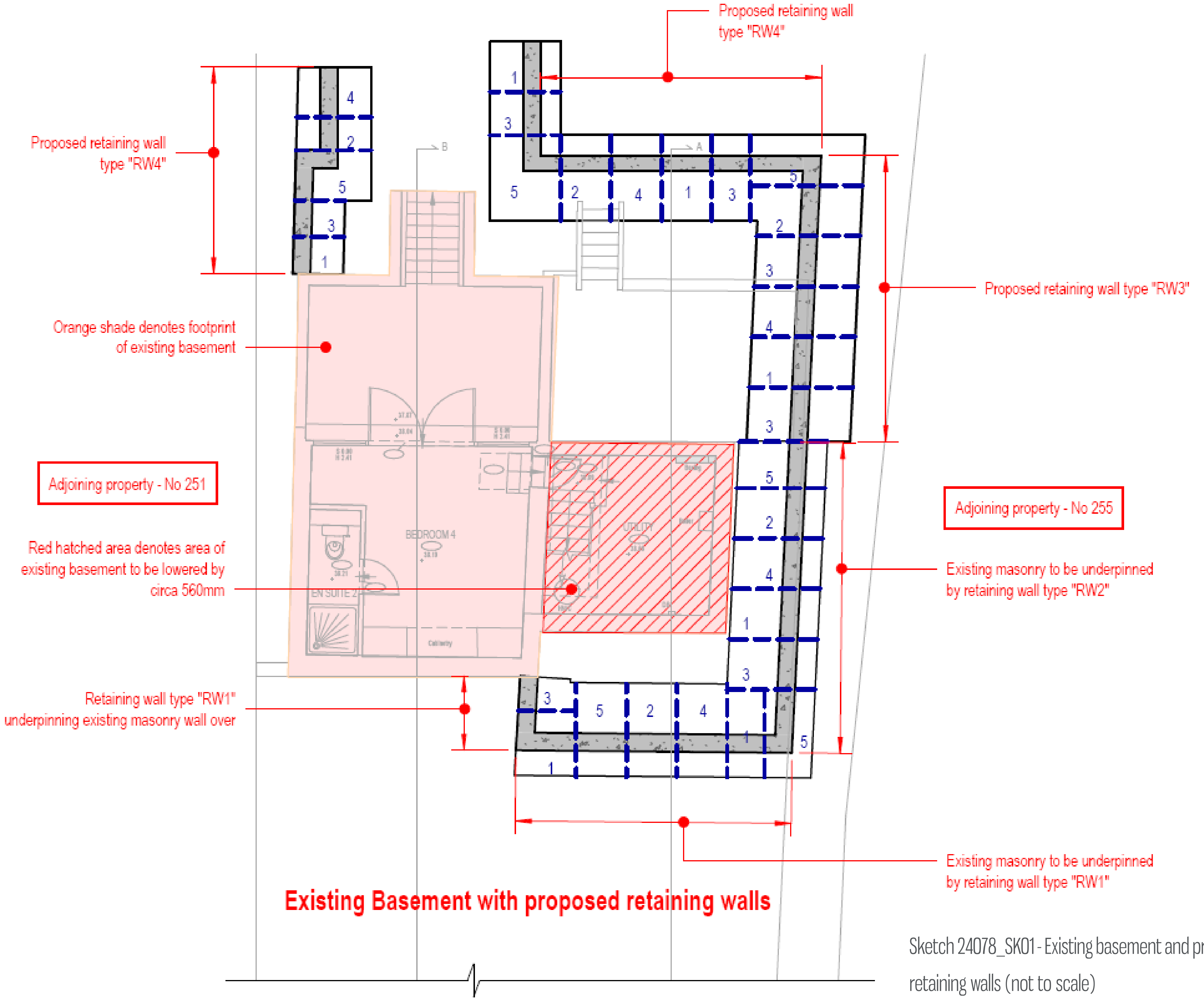


3D View of the building as Proposed



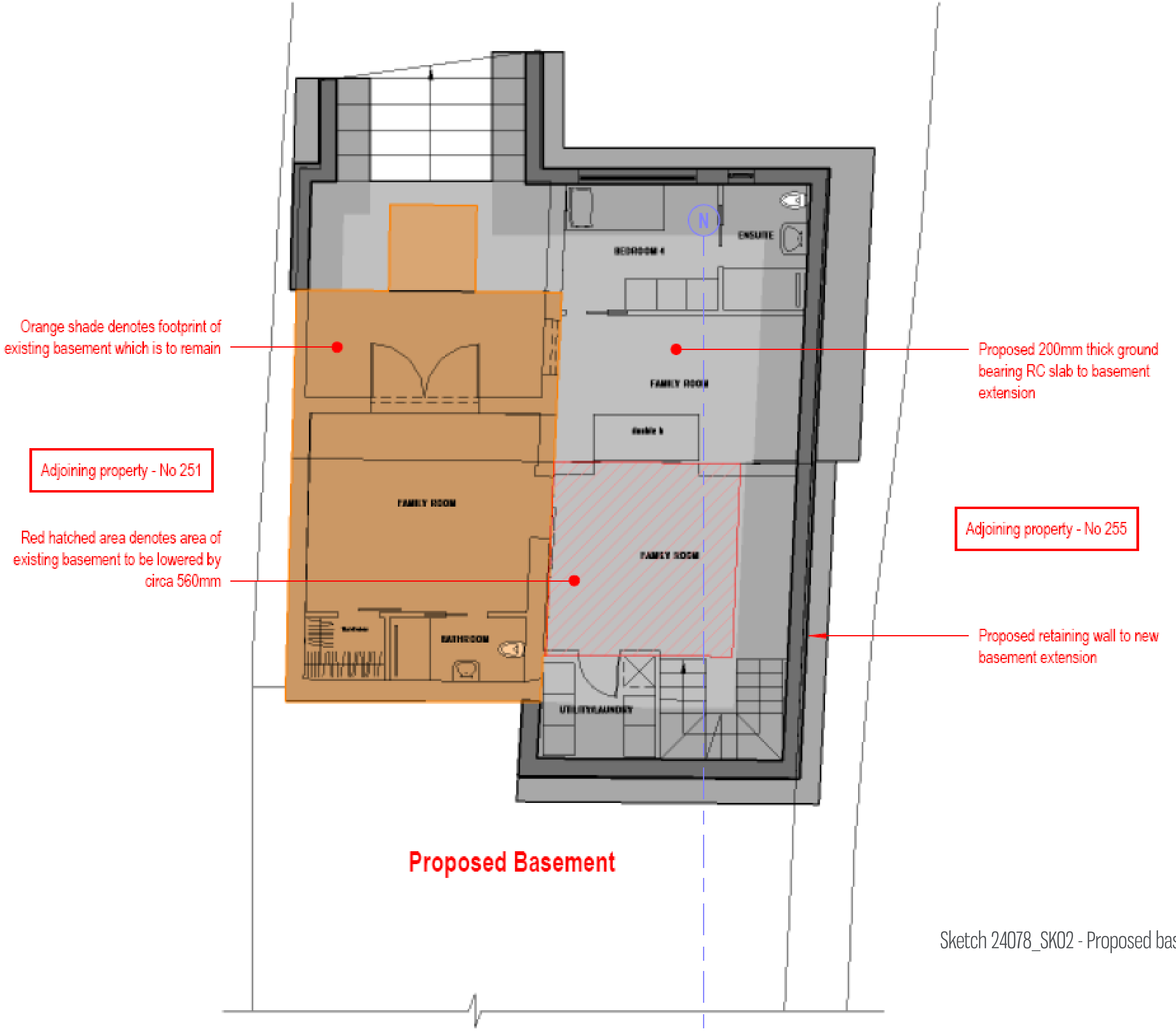
3D View of the building as Proposed

4.0 INITIAL SCHEME DRAWINGS



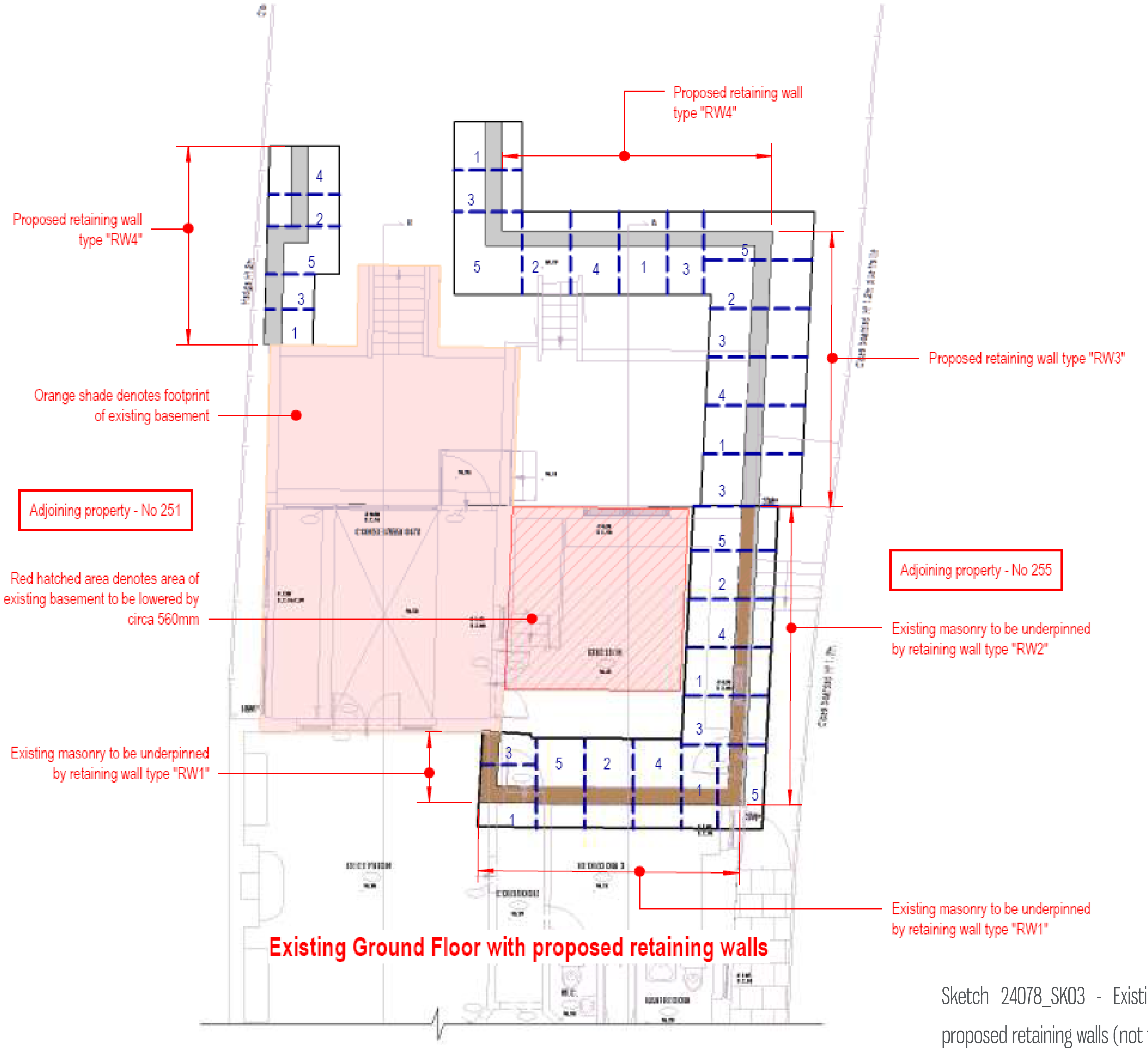
Sketch 24078_SK01 - Existing basement and proposed retaining walls (not to scale)

4.0 INITIAL SCHEME DRAWINGS



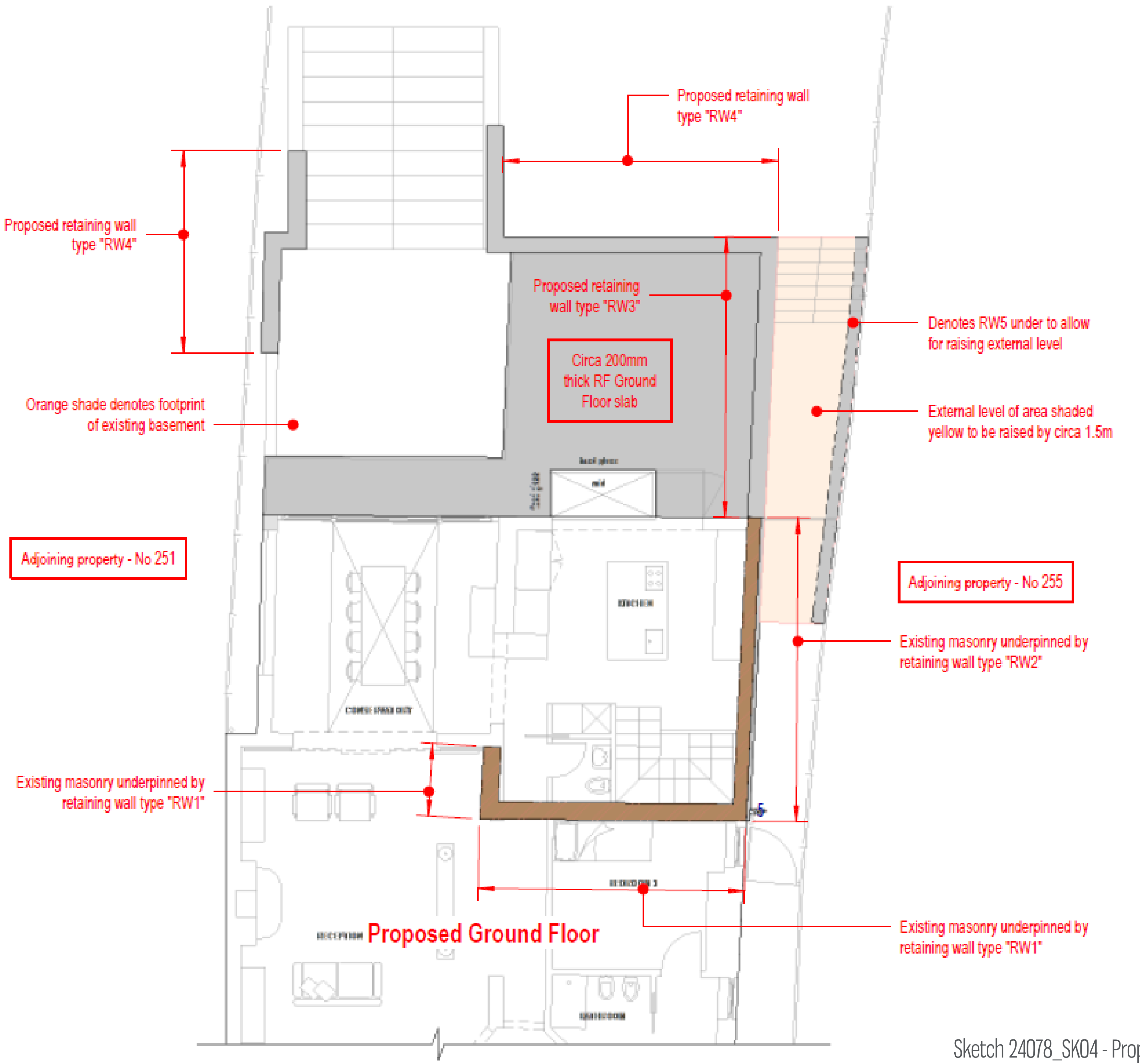
Sketch 24078_SK02 - Proposed basement (not to scale)

4.0 INITIAL SCHEME DRAWINGS



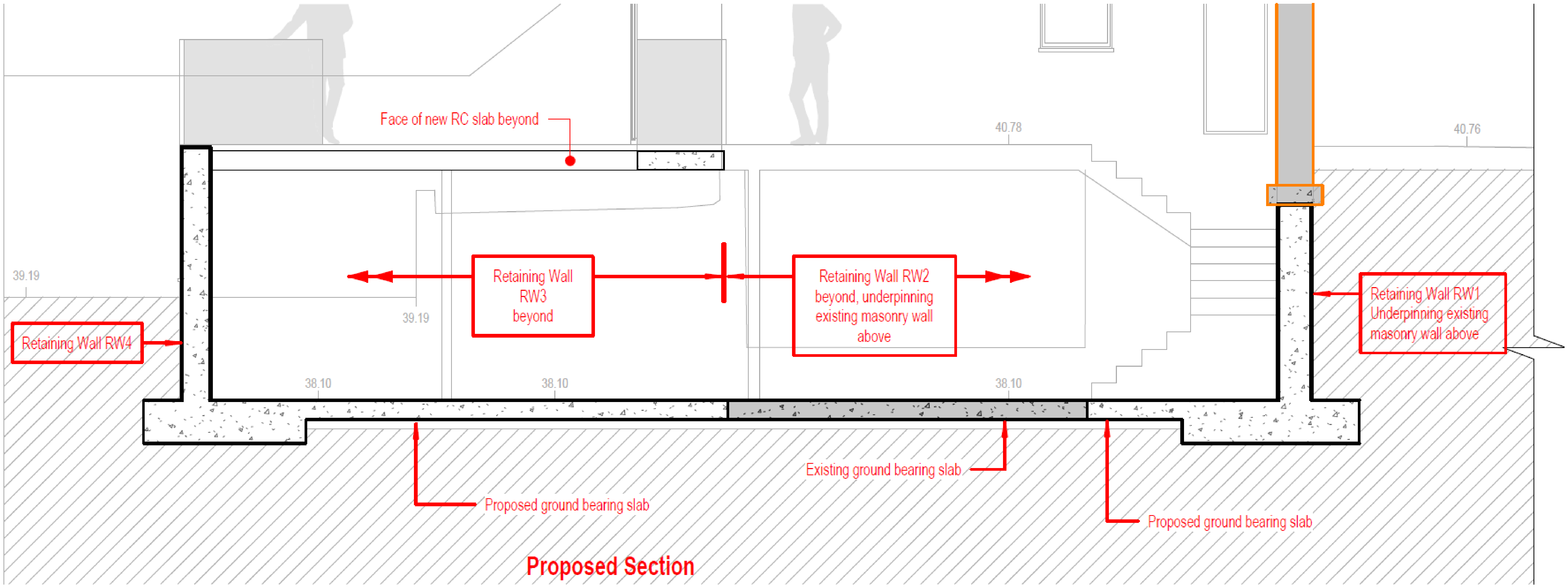
Sketch 24078_SK03 - Existing ground floor and proposed retaining walls (not to scale)

4.0 INITIAL SCHEME DRAWINGS



Sketch 24078_SK04 - Proposed ground floor (not to scale)

4.0 INITIAL SCHEME DRAWINGS



Sketch 24078_SK05 - Proposed Section (not to scale)

5.1 INTRODUCTION

The adjoining properties to 253 Goldhurst Terrace, NW6 3EP, will be monitored during the underpinning, excavation and throughout the construction period of the proposed basement.

5.2 TARGET POINTS

Target points will be fixed on the elevations of the adjoining properties, as per the marked-up drawings included. These include the front and rear elevation walls of Nos.251 & 255 Goldhurst Terrace. These will need to be agreed and finalised as part of the Party Wall process, prior to commencing any works.

5.3 RESULTS

The results/reading shall be recorded in both tabular and graph forms, and an electronic copy must be circulated within twenty-four hours of the readings (refer to 3.2 below). The results should be clear, and indicate the trigger values as well, for reference and comparison to the readings.

The readings / results shall be circulated to the design team, the Building Owner's Party Wall Surveyor and the Adjoining Owner's Party Wall Surveyor and Advising Engineer.

5.4 READINGS

Readings shall be taken as follows:

Activity	Frequency of readings
During underpinning works	Daily
During excavation	Twice Weekly
During construction of the basement and ground floor RC slabs	Twice Weekly
During the rest of the works	Weekly

The above shall be reviewed in case the program of the works is altered due to unforeseen circumstances.

5.5 TRIGGER VALUES

Should a trigger value be reached, the contractor should immediately stop all work that might cause further movement, assesses the situation, and proposes alternative methods of proceeding. The trigger values/limits further to this point can be reviewed and agreed between all parties.

Proposed trigger values for both vertical and horizontal movement of masonry walls of adjoining buildings are to be agreed with the Adjoining Owner's party wall surveyor – a suggestion follows:

AMBER	+/- 5mm	All parties notified
RED	+/- 8mm	Works stop and reviewed

Proposed trigger values for both vertical and horizontal movement of garden walls of adjoining buildings are to be agreed with the Adjoining Owner's party wall surveyor - a suggestion follows:

AMBER	+/- 7mm	All parties notified
RED	+/- 10mm	Works stop and reviewed

5.6 ACTIONS

Should any movement exceed the Amber or Red trigger Values, the Contractor shall act as follows:

AMBER	• Project Engineer is notified immediately • Any work that might cause further movement is stopped • Readings' frequency increases • Contractor proposes alternative methods of proceeding • The project Engineer, Adjoining Owner's Engineer and PW Surveyor meet on site to review the works and decide if any further actions are required • If it is established that any movement is directly related to the underpinning works, the contractor stops all works and all parties review the works • Trigger values from this point on are reviewed further and agreed between all parties
RED	• All works stop • Project Engineer is notified immediately / All parties review the works

5.0 MONITORING

1 Rear Elevation in context
scale 1:100

DENOTES YELLOW RETRO REFLECTIVE TARGET STICKERS FIXED TO CLEANED FACES OF WALLS AS INDICATED.

5.0 MONITORING

1 Existing Front Elevation
scale 1:50

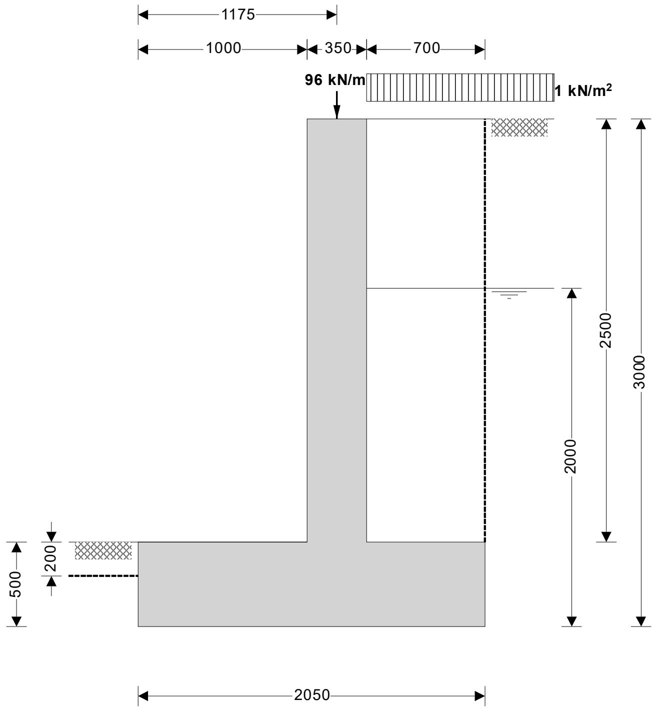
⌖ DENOTES YELLOW RETRO REFLECTIVE TARGET STICKERS FIXED TO CLEANED FACES OF WALLS AS INDICATED.

PRELIMINARY CALCULATIONS

Tekla Tedds ads consultancy 130 East Barnet Road EN4 8RE - New Barnet	Project 253 Goldhurst Terrace				Job no. 24078	
	Calcs for Retaining Wall RW1 - Preliminary				Start page no./Revision 1	
	Calcs by SN	Calcs date 05/12/2024	Checked by	Checked date	Approved by	Approved date

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **2500** mm
Thickness of wall stem	t_{wall} = **350** mm
Length of toe	l_{toe} = **1000** mm
Length of heel	l_{heel} = **700** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2050** mm
Thickness of base	t_{base} = **500** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **1200** mm
Thickness of downstand	t_{ds} = **500** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3000** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **200** mm
Height of ground water behind wall	h_{water} = **2000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **1500** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3000** 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' = **29.3** 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

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.306}$$

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 $K_0 = 1 – \sin(\phi') = \mathbf{0.511}$

Loading details

Surcharge load on plan Surcharge = **1.0** kN/m^2

Applied vertical dead load on wall W_{dead} = **75.0** kN/m

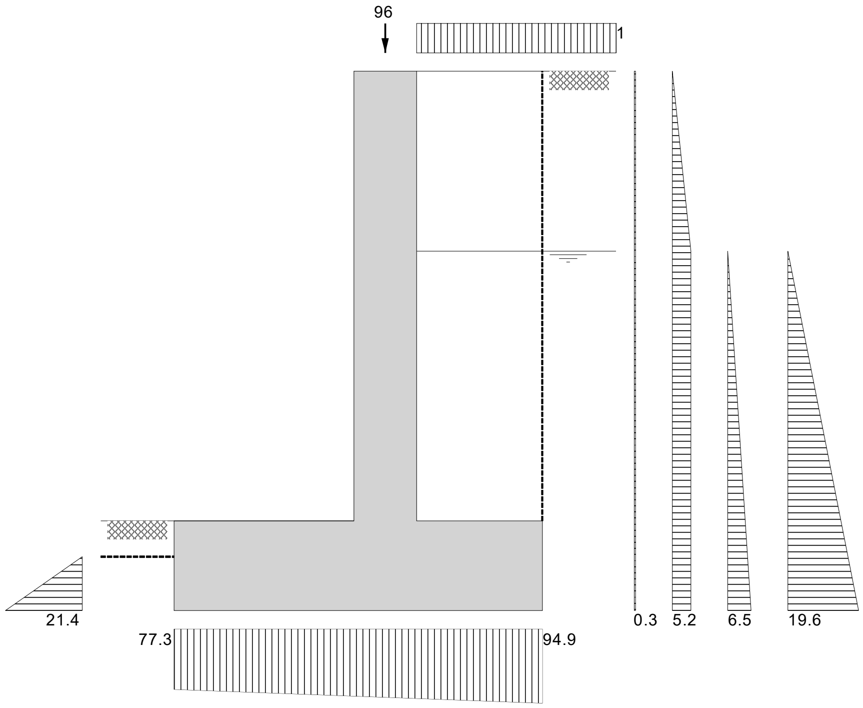
Applied vertical live load on wall W_{live} = **21.4** kN/m

Position of applied vertical load on wall l_{load} = **1175** 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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **20.7** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **24.2** kN/m

Surcharge $w_{sur} = \text{Surcharge} \times l_{heel}$ = **0.7** kN/m

Moist backfill to top of wall $w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **12.6** kN/m

Saturated backfill $w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **22.1** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **96.4** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + w_s + W_v$ = **176.6** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff}$ = **0.9** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **2.6** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **10.4** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **6.5** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **19.6** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **40** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.2** kN/m

Resistance to sliding $F_{res} = F_p + (W_{total} - w_{sur} - W_{live}) \times \tan(\delta_b)$ = **55.2** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **1.3** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **6.1** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **10.4** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **4.3** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **13.1** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **35.3** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **24.3** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **24.8** kNm/m

Moist backfill $M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **21.4** kNm/m

Saturated backfill $M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **37.5** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load}$ = **88.1** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{m\_r} + M_{s\_r} + M_{dead}$ = **196.1** kNm/m

Check stability against overturning

Total overturning moment M_{ot} = **35.3** kNm/m

Total restoring moment M_{rest} = **196.1** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge $M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **1.2** kNm/m

Design vertical live load $M_{live} = W_{live} \times l_{load}$ = **25.1** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{sur\_r} + M_{live}$ = **187.2** kNm/m

Total vertical reaction $R = W_{total}$ = **176.6** kN/m

Distance to reaction $x_{bar} = M_{total} / R$ = **1060** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **35** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) =$ **77.3** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) =$ **94.9** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.08

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 $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **28.9** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **33.9** kN/m

Surcharge $w_{sur\_f} = \gamma_{f\_l} \times Surcharge \times l_{heel}$ = **1.1** kN/m

Moist backfill to top of wall $w_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **17.6** kN/m

Saturated backfill $w_{s\_f} = \gamma_{f\_d} \times l_{heel} \times h_{sat} \times \gamma_s$ = **30.9** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **139.2** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{sur\_f} + w_{m\_w\_f} + w_{s\_f} + W_{v\_f}$ = **251.6** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **2.5** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **6.4** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **25.7** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **16** kN/m

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

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **78.1** kN/m

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.5** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **3.7** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **15** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **25.7** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **10.7** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **18.3** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **73.4** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **34** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **34.7** kNm/m

Surcharge $M_{sur\_r\_f} = w_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **1.9** kNm/m

Moist backfill $M_{m\_r\_f} = (w_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + w_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **30** kNm/m

Saturated backfill $M_{s\_r\_f} = w_{s\_f} \times (l_{base} - l_{heel} / 2)$ = **52.5** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **163.6** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{sur\_r\_f} + M_{m\_r\_f} + M_{s\_r\_f} + M_{v\_f}$ = **316.7** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **243.3** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **251.6** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **967** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **58** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2) = \mathbf{143.7}$ kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2) = \mathbf{101.8}$ kN/m²

Rate of change of base reaction rate $= (p_{toe\_f} - p_{heel\_f}) / l_{base} = \mathbf{20.45}$ kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0\text{ kN/m}^2) = \mathbf{123.3}$ kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0\text{ kN/m}^2) = \mathbf{119.7}$ kN/m²

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0\text{ kN/m}^2) = \mathbf{116.1}$ kN/m²

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}$ N/mm²

Characteristic strength of reinforcement $f_y = \mathbf{500}$ N/mm²

Base details

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

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

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{133.5}$ kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{16.5}$ kN/m

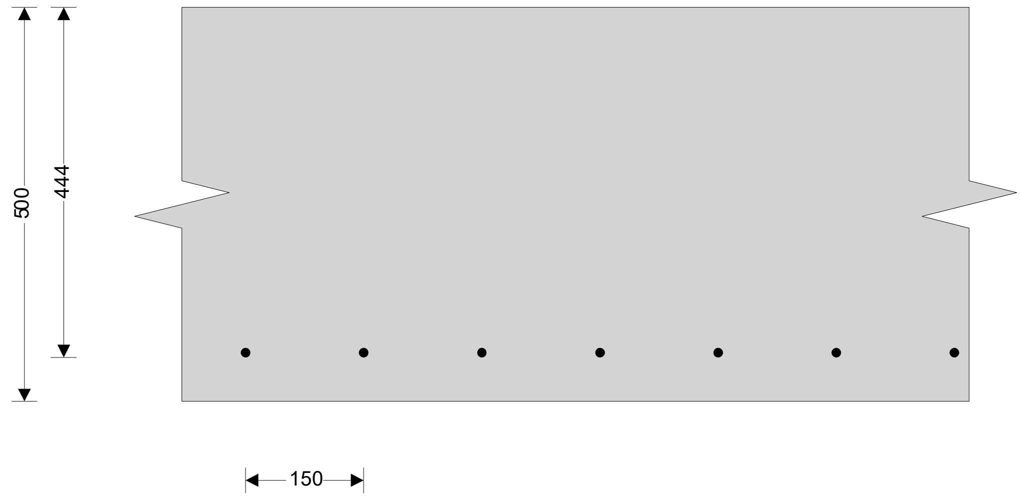
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{117}$ kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{93.7}$ kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{11.4}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{82.3}$ kNm/m



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{444.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.010}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{422}$ mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{448}$ mm²/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{650}$ mm²/m

Area of tension reinforcement required — As_{toe_req} = Max(As_{toe_des}, As_{toe_min}) = **650** mm²/m

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

Area of reinforcement provided — As_{toe_prov} = **754** mm²/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.263** 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 — $vc_{\_toe}$ = **0.409** N/mm²

$v_{toe} < vc_{\_toe}$ - 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} = **50** mm

Calculate shear for heel design

Shear from bearing pressure — $V_{heel\_bear} = (p_{heel\_f} + p_{stem\_heel\_f}) \times l_{heel} / 2$ = **76.3** kN/m

Shear from weight of base — $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base}$ = **11.6** kN/m

Shear from weight of moist backfill — $V_{heel\_wt\_m} = w_{m\_w\_f}$ = **17.6** kN/m

Shear from weight of saturated backfill — $V_{heel\_wt\_s} = w_{s\_f}$ = **30.9** kN/m

Shear from surcharge — $V_{heel\_sur} = w_{sur\_f}$ = **1.1** kN/m

Total shear for heel design — $V_{heel} = - V_{heel\_bear} + V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_wt\_s} + V_{heel\_sur}$ = **-15.1** kN/m

Calculate moment for heel design

Moment from bearing pressure — $M_{heel\_bear} = (2 \times p_{heel\_f} + p_{stem\_mid\_f}) \times (l_{heel} + t_{wall} / 2)^2 / 6$ = **41.3** kNm/m

Moment from weight of base — $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2)$ = **6.3** kNm/m

Moment from weight of moist backfill — $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2$ = **9.3** kNm/m

Moment from weight of saturated backfill — $M_{heel\_wt\_s} = w_{s\_f} \times (l_{heel} + t_{wall}) / 2$ = **16.2** kNm/m

Moment from surcharge — $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2$ = **0.6** kNm/m

Total moment for heel design — $M_{heel} = - M_{heel\_bear} + M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_wt\_s} + M_{heel\_sur}$ = **-8.9** kNm/m

As the moment is negative the design of the retaining wall heel is beyond the scope of this calculation

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

Material properties

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

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

Wall details

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

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

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

Factored horizontal at-rest forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = \mathbf{2}$ kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = \mathbf{6.4}$ kN/m

Moist backfill below water table — $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat} = \mathbf{19.3}$ kN/m

Saturated backfill — $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2 = \mathbf{9}$ kN/m

Water — $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2 = \mathbf{15.5}$ kN/m

Calculate shear for stem design

Shear at base of stem — $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f} = \mathbf{52.2}$ kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2 = \mathbf{3.1}$ kNm/m

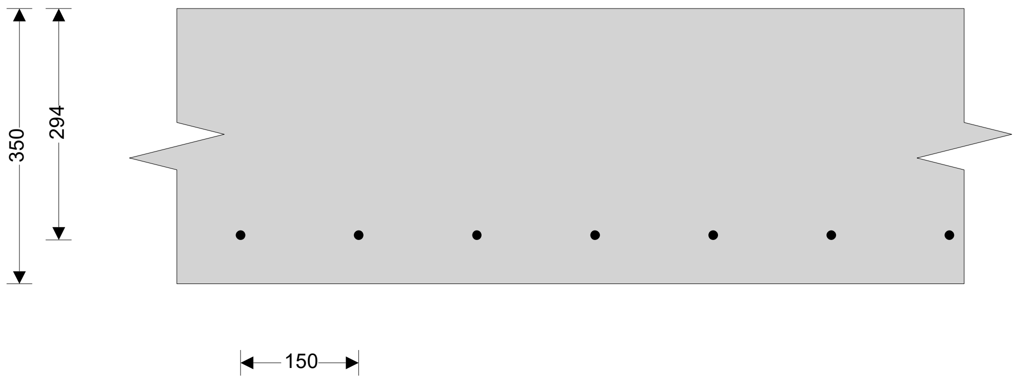
Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3 = \mathbf{13.4}$ kNm/m

Moist backfill below water table — $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2 = \mathbf{14.5}$ kNm/m

Saturated backfill — $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3 = \mathbf{4.5}$ kNm/m

Water — $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3 = \mathbf{7.7}$ kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water} = \mathbf{43.2}$ kNm/m



Check wall stem in bending

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

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2) = \mathbf{294.0}$ mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = \mathbf{0.012}$

Compression reinforcement is not required

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

$z_{stem} = \mathbf{279}$ mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem}) = \mathbf{355}$ mm²/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall} = \mathbf{455}$ mm²/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{455}$ mm²/m

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

Area of reinforcement provided — $A_{s\_stem\_prov} = \mathbf{754}$ mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.178}$ N/mm²

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000}$ N/mm²

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress — $v_{c\_stem} = \mathbf{0.507}$ 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 $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **201.2** N/mm^2

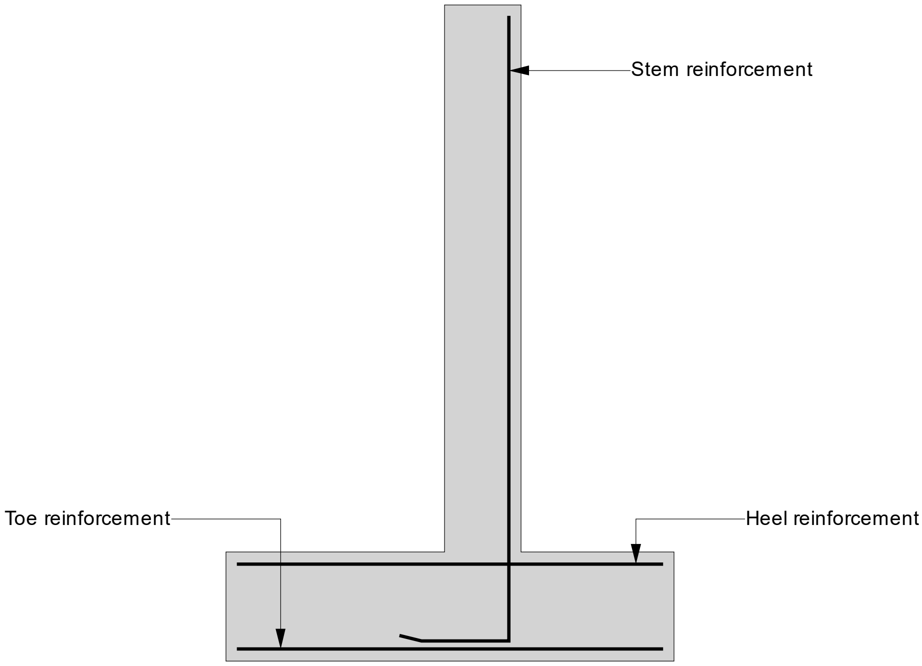
Modification factor $factor_{tens} = \min(0.55 + (477\text{ N/mm}^2 - f_s)/(120 \times (0.9\text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **2.00**

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

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **8.50**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



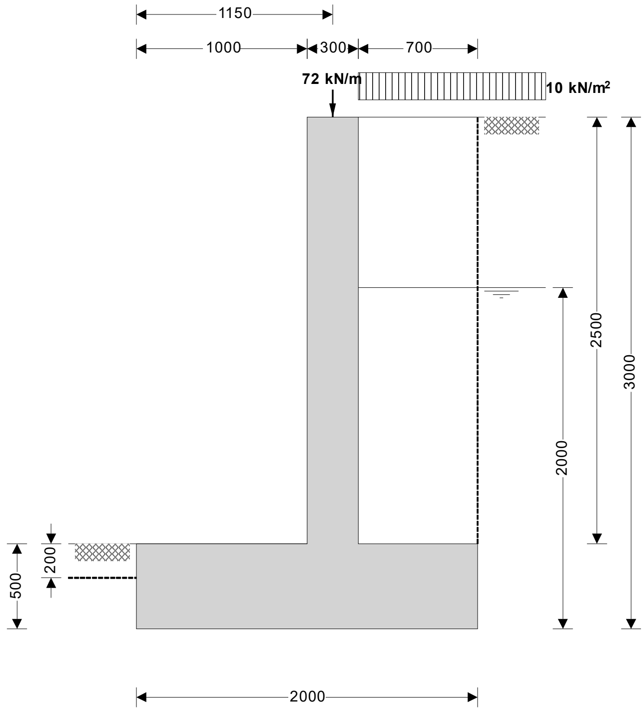
Toe bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)

The design of the retaining wall heel is beyond the scope of this calculation!

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

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **2500** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **1000** mm
Length of heel	l_{heel} = **700** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2000** mm
Thickness of base	t_{base} = **500** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **600** mm
Thickness of downstand	t_{ds} = **500** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3000** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **200** mm
Height of ground water behind wall	h_{water} = **2000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **1500** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3000** 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' = **29.3** 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

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.306}$$

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 $K_0 = 1 – \sin(\phi') =$ **0.511**

Loading details

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

Applied vertical dead load on wall W_{dead} = **60.0** kN/m

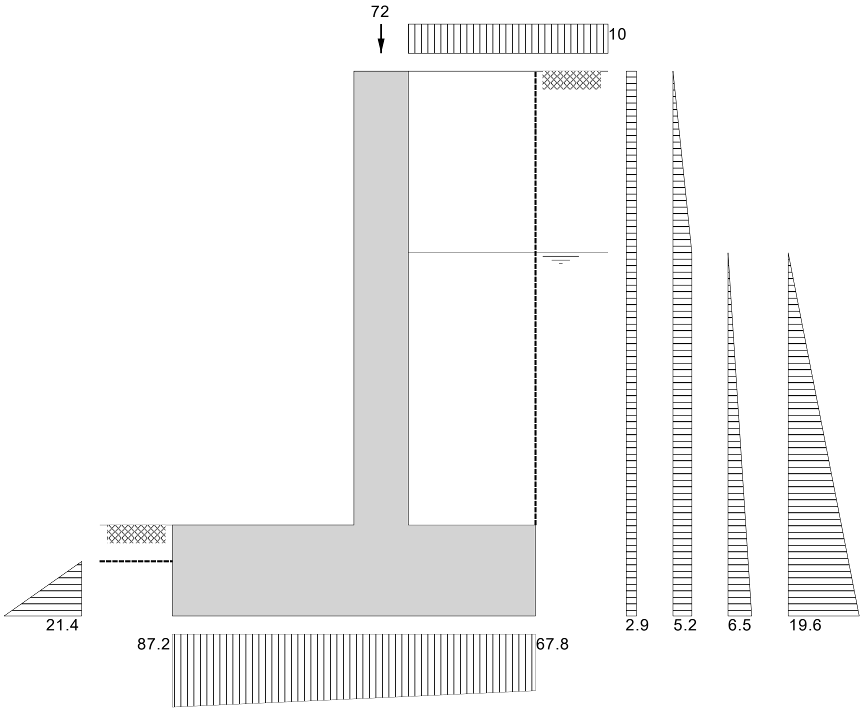
Applied vertical live load on wall W_{live} = **12.0** kN/m

Position of applied vertical load on wall l_{load} = **1150** mm

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

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

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



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

Vertical forces on wall

Wall stem	$w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **17.7** kN/m
Wall base	$w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.6** kN/m
Surcharge	w_{sur} = Surcharge $\times l_{heel}$ = **7** kN/m
Moist backfill to top of wall	$w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **12.6** kN/m
Saturated backfill	$w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **22.1** kN/m
Applied vertical load	$W_v = W_{dead} + W_{live}$ = **72** kN/m
Total vertical load	$W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + w_s + W_v$ = **155** kN/m

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times h_{eff}$ = **8.7** kN/m
Moist backfill above water table	$F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **2.6** kN/m
Moist backfill below water table	$F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **10.4** kN/m
Saturated backfill	$F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **6.5** kN/m
Water	$F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **19.6** kN/m
Total horizontal load	$F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **47.9** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.2** kN/m
Resistance to sliding	$F_{res} = F_p + (W_{total} - w_{sur} - W_{live}) \times \tan(\delta_b)$ = **49.0** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **13.1** kNm/m
Moist backfill above water table	$M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **6.1** kNm/m
Moist backfill below water table	$M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **10.4** kNm/m
Saturated backfill	$M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **4.3** kNm/m
Water	$M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **13.1** kNm/m
Total overturning moment	$M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **47** kNm/m

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **20.4** kNm/m
Wall base	$M_{base} = w_{base} \times l_{base} / 2$ = **23.6** kNm/m
Moist backfill	$M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **20.8** kNm/m
Saturated backfill	$M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **36.4** kNm/m
Design vertical dead load	$M_{dead} = W_{dead} \times l_{load}$ = **69** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{m\_r} + M_{s\_r} + M_{dead}$ = **170.1** kNm/m

Check stability against overturning

Total overturning moment	M_{ot} = **47.0** kNm/m
Total restoring moment	M_{rest} = **170.1** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge	$M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **11.6** kNm/m
Design vertical live load	$M_{live} = W_{live} \times l_{load}$ = **13.8** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{sur\_r} + M_{live}$ = **148.5** kNm/m
Total vertical reaction	$R = W_{total}$ = **155.0** kN/m
Distance to reaction	$x_{bar} = M_{total} / R$ = **958** mm
Eccentricity of reaction	$e = abs((l_{base} / 2) - x_{bar})$ = **42** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) = \mathbf{87.2}$ kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = \mathbf{67.8}$ kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.08

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

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

Factored vertical forces on wall

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

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **33** kN/m

Surcharge $w_{sur\_f} = \gamma_{f\_l} \times Surcharge \times l_{heel}$ = **11.2** kN/m

Moist backfill to top of wall $w_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **17.6** kN/m

Saturated backfill $w_{s\_f} = \gamma_{f\_d} \times l_{heel} \times h_{sat} \times \gamma_s$ = **30.9** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **103.2** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{sur\_f} + w_{m\_w\_f} + w_{s\_f} + W_{v\_f}$ = **220.7** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **24.5** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **6.4** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **25.7** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **16** kN/m

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

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **100.1** kN/m

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.5** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **36.8** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **15** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **25.7** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **10.7** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **18.3** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **106.5** kNm/m

Restoring moments

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

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **33** kNm/m

Surcharge $M_{sur\_r\_f} = w_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **18.5** kNm/m

Moist backfill $M_{m\_r\_f} = (w_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + w_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **29.1** kNm/m

Saturated backfill $M_{s\_r\_f} = w_{s\_f} \times (l_{base} - l_{heel} / 2)$ = **50.9** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **118.7** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{sur\_r\_f} + M_{m\_r\_f} + M_{s\_r\_f} + M_{v\_f}$ = **278.7** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **172.2** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **220.7** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **780** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **220** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2) = \mathbf{183.1}$ kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2) = \mathbf{37.6}$ kN/m²

Rate of change of base reaction rate $= (p_{toe\_f} - p_{heel\_f}) / l_{base} = \mathbf{72.72}$ kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0 \text{ kN/m}^2) = \mathbf{110.4}$ kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2) = \mathbf{99.5}$ kN/m²

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2) = \mathbf{88.5}$ kN/m²

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}$ N/mm²

Characteristic strength of reinforcement $f_y = \mathbf{500}$ N/mm²

Base details

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

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

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{146.7}$ kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{16.5}$ kN/m

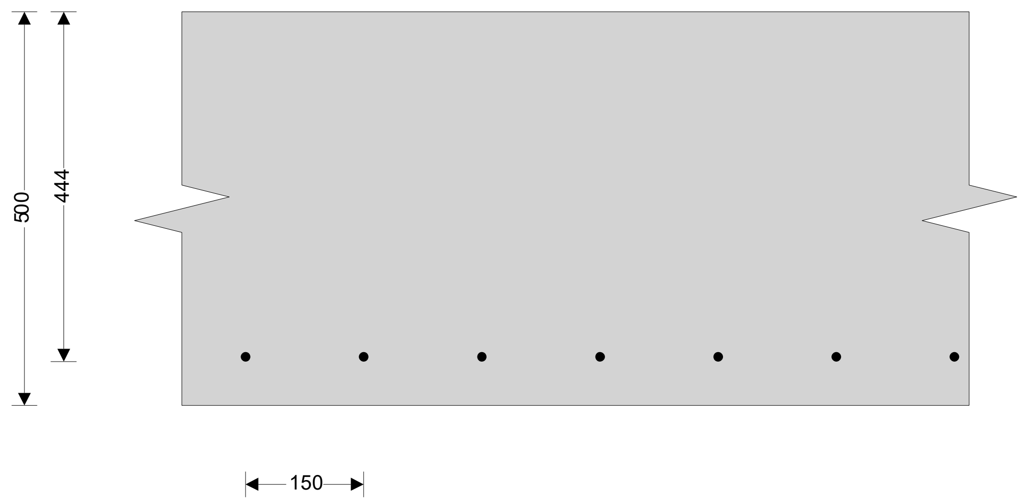
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{130.2}$ kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{102.6}$ kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{10.9}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{91.7}$ kNm/m



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{444.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.012}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{422}$ mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{500}$ mm²/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{650}$ mm²/m

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

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

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

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.293** N/mm^2

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.409** 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} = **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 heel c_{heel} = **50** mm

Calculate shear for heel design

Shear from bearing pressure $V_{heel\_bear} = (p_{heel\_f} + p_{stem\_heel\_f}) \times l_{heel} / 2$ = **44.2** kN/m

Shear from weight of base $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base}$ = **11.6** kN/m

Shear from weight of moist backfill $V_{heel\_wt\_m} = w_{m\_w\_f}$ = **17.6** kN/m

Shear from weight of saturated backfill $V_{heel\_wt\_s} = w_{s\_f}$ = **30.9** kN/m

Shear from surcharge $V_{heel\_sur} = w_{sur\_f}$ = **11.2** kN/m

Total shear for heel design $V_{heel} = - V_{heel\_bear} + V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_wt\_s} + V_{heel\_sur}$ = **27.1** kN/m

Calculate moment for heel design

Moment from bearing pressure $M_{heel\_bear} = (2 \times p_{heel\_f} + p_{stem\_mid\_f}) \times (l_{heel} + t_{wall} / 2)^2 / 6$ = **21** kNm/m

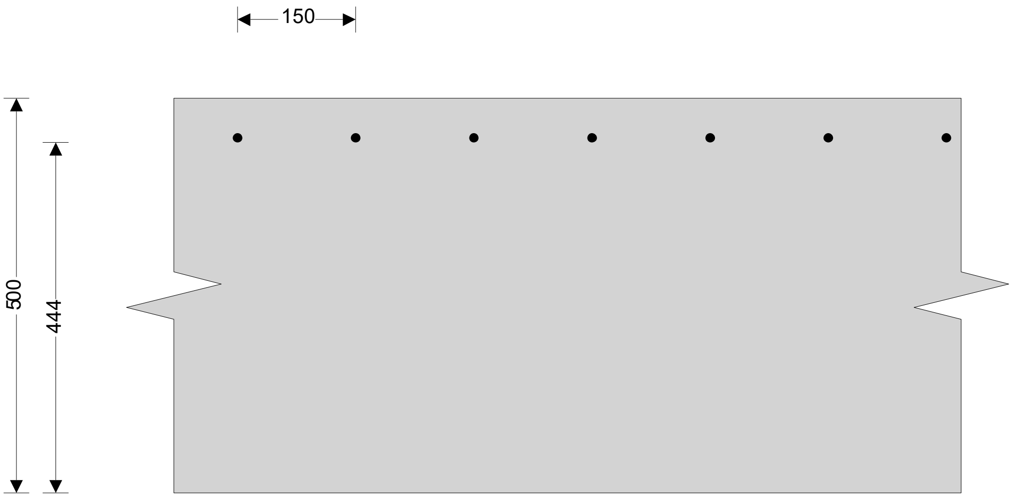
Moment from weight of base $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2)$ = **6** kNm/m

Moment from weight of moist backfill $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2$ = **8.8** kNm/m

Moment from weight of saturated backfill $M_{heel\_wt\_s} = w_{s\_f} \times (l_{heel} + t_{wall}) / 2$ = **15.4** kNm/m

Moment from surcharge $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2$ = **5.6** kNm/m

Total moment for heel design $M_{heel} = - M_{heel\_bear} + M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_wt\_s} + M_{heel\_sur}$ = **14.8** kNm/m



Check heel in bending

Width of heel — b = **1000** mm/m

Depth of reinforcement — $d_{heel} = t_{base} - c_{heel} - (\phi_{heel} / 2)$ = **444.0** mm

Constant — $K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu})$ = **0.002**

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} = **422** mm

Area of tension reinforcement required — $As_{\_heel\_des} = M_{heel} / (0.87 \times f_y \times z_{heel})$ = **81** mm²/m

Minimum area of tension reinforcement — $As_{\_heel\_min} = k \times b \times t_{base}$ = **650** mm²/m

Area of tension reinforcement required — $As_{\_heel\_req} = \max(As_{\_heel\_des}, As_{\_heel\_min})$ = **650** mm²/m

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

Area of reinforcement provided — $As_{\_heel\_prov}$ = **754** mm²/m

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress — $v_{heel} = V_{heel} / (b \times d_{heel})$ = **0.061** 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_heel} = **0.409** N/mm²

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

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

Material properties

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

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

Wall details

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

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

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

Factored horizontal at-rest forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **20.4** kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **6.4** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **19.3** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **9** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **15.5** kN/m

Calculate shear for stem design

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f}$ = **70.6** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **30.6** kNm/m

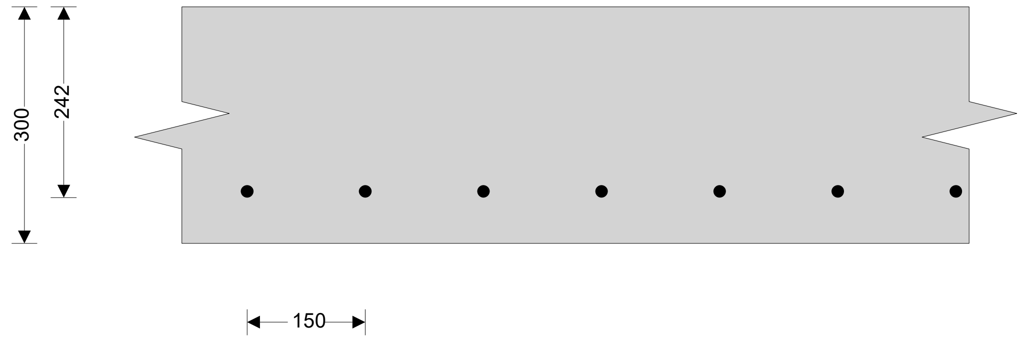
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **13.4** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2$ = **14.5** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3$ = **4.5** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3$ = **7.7** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **70.7** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **242.0** mm

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

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} = **230** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **707** mm²/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **707** mm²/m

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

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

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.292** 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_stem} = **0.688** 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 $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **175.9** N/mm²

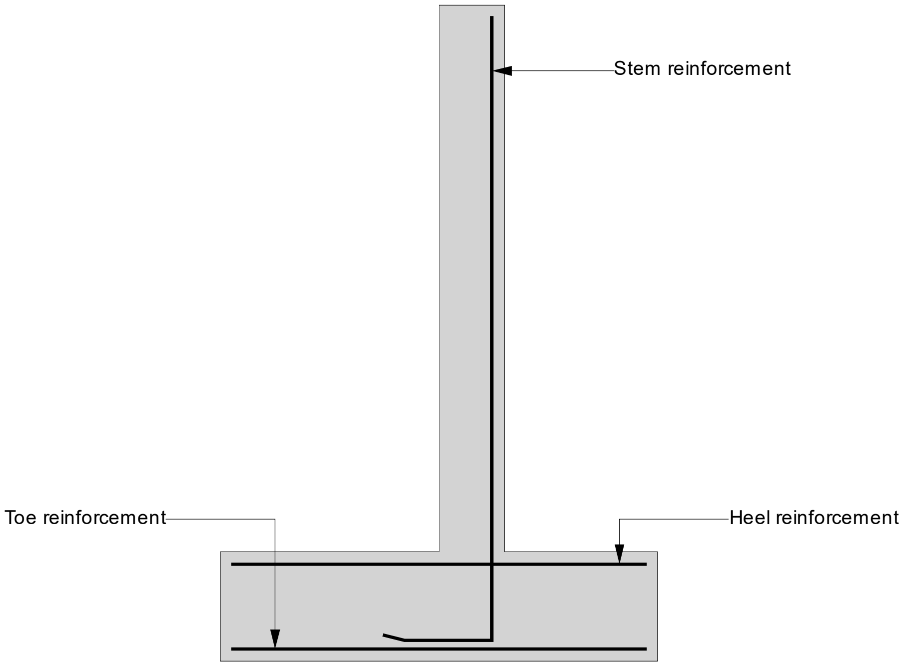
Modification factor $factor_{tens} = min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.74**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **12.18**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **10.33**

PASS - Span to depth ratio is acceptable

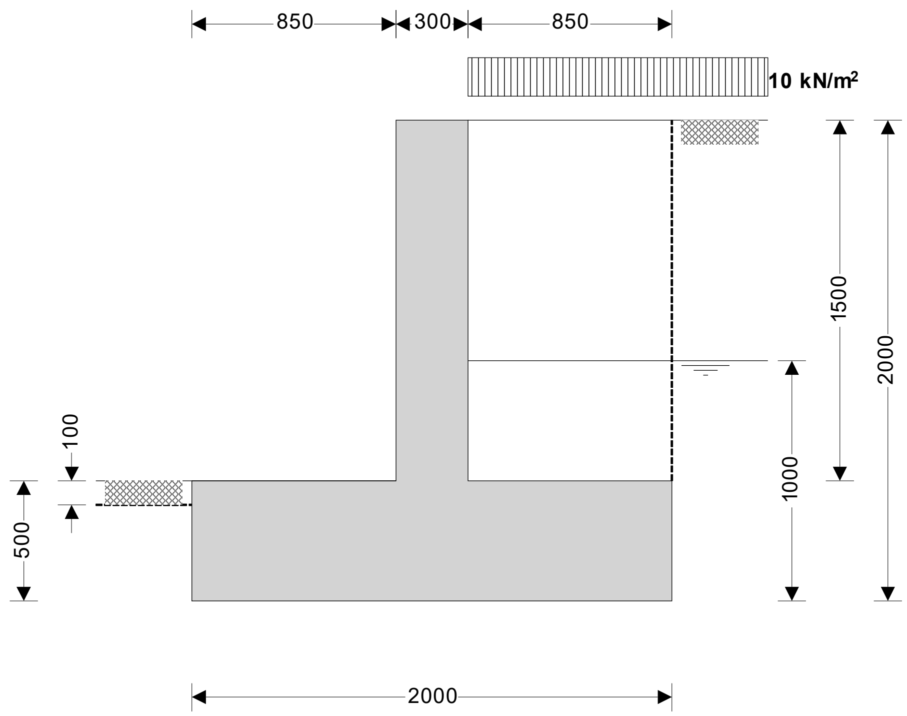
Indicative retaining wall reinforcement diagram



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

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **1500** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **850** mm
Length of heel	l_{heel} = **850** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2000** mm
Thickness of base	t_{base} = **500** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **600** mm
Thickness of downstand	t_{ds} = **500** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **2000** 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} = **1000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **500** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **2000** 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' = **24.0** 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

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.372}$$

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 $K_0 = 1 - \sin(\phi') = \mathbf{0.593}$

Loading details

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

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

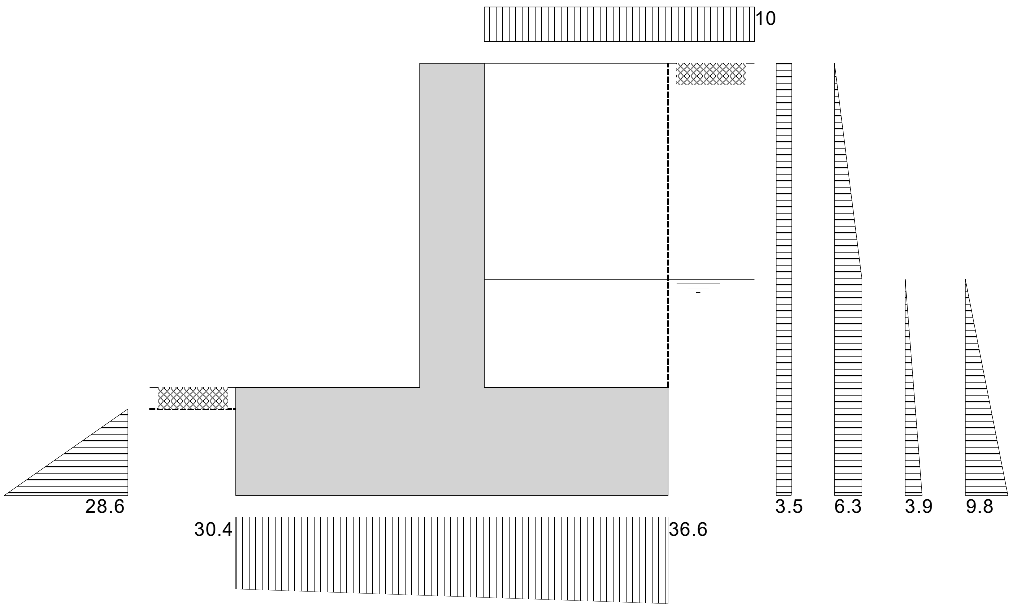
Applied vertical live load on wall W_{live} = **0.0** kN/m

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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **10.6** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.6** kN/m

Surcharge	w_{sur} = Surcharge × l_{heel} = **8.5** kN/m
Moist backfill to top of wall	$w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **15.3** kN/m
Saturated backfill	$w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **8.9** kN/m
Total vertical load	$W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + w_s$ = **66.9** kN/m

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times h_{eff}$ = **7** kN/m
Moist backfill above water table	$F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **3.2** kN/m
Moist backfill below water table	$F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **6.3** kN/m
Saturated backfill	$F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **2** kN/m
Water	$F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **4.9** kN/m
Total horizontal load	$F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **23.4** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.7** kN/m
Resistance to sliding	$F_{res} = F_p + (W_{total} - w_{sur}) \times \tan(\delta_b)$ = **25.4** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **7** kNm/m
Moist backfill above water table	$M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **4.2** kNm/m
Moist backfill below water table	$M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **3.2** kNm/m
Saturated backfill	$M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **0.7** kNm/m
Water	$M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **1.6** kNm/m
Total overturning moment	$M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **16.7** kNm/m

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **10.6** kNm/m
Wall base	$M_{base} = w_{base} \times l_{base} / 2$ = **23.6** kNm/m
Moist backfill	$M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **24.1** kNm/m
Saturated backfill	$M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **14.1** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{m\_r} + M_{s\_r}$ = **72.4** kNm/m

Check stability against overturning

Total overturning moment	M_{ot} = **16.7** kNm/m
Total restoring moment	M_{rest} = **72.4** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge	$M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **13.4** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{sur\_r}$ = **69** kNm/m
Total vertical reaction	$R = W_{total}$ = **66.9** kN/m
Distance to reaction	$x_{bar} = M_{total} / R$ = **1031** mm
Eccentricity of reaction	$e = \text{abs}((l_{base} / 2) - x_{bar})$ = **31** mm

Reaction acts within middle third of base

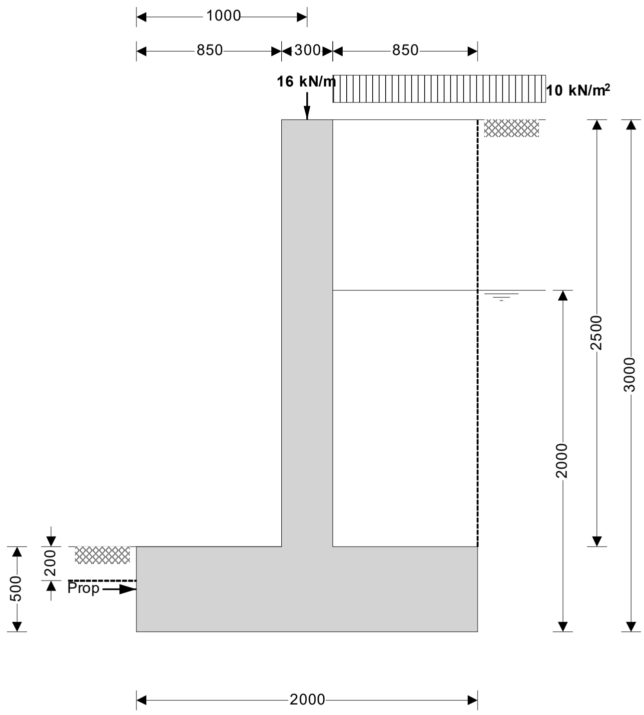
Bearing pressure at toe	$p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **30.4** kN/m^2
Bearing pressure at heel	$p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **36.6** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

ads consultancy — consulting structural engineers 130 East Barnet Road, New Barnet, Herts, EN4 8RE tel: 020 8441 4123 fax: 020 8441 7114 em: mail@adsconsultancy.com ads consultancy	Project 253 Goldhurst Terrace			Job no. 24078	
	Calcs for Retaining Wall RW3 - Permanent (Preliminary)			Start page no./Revision 1	
	Calcs by SN	Calcs date 06/05/2025	Checked by	Checked date	Approved by	Approved date

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type	**Cantilever propped at base**
Height of retaining wall stem	h_{stem} = **2500** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **850** mm
Length of heel	l_{heel} = **850** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2000** mm
Thickness of base	t_{base} = **500** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **600** mm
Thickness of downstand	t_{ds} = **500** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3000** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **200** mm
Height of ground water behind wall	h_{water} = **2000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **1500** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3000** 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' = **24.0** 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

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.372}$$

Passive pressure coefficient for base material

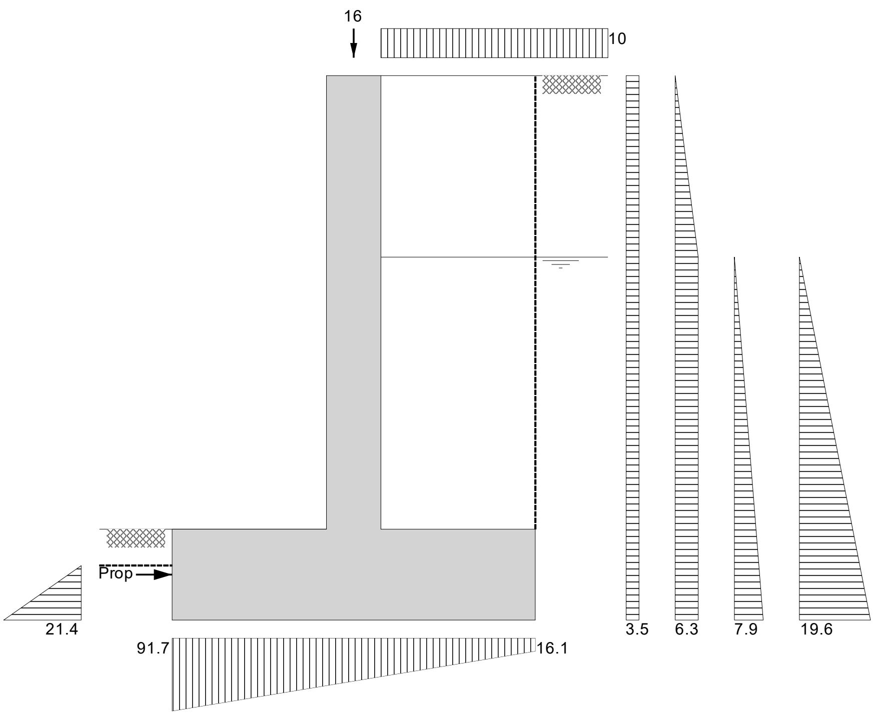
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material — $K_0 = 1 - \sin(\phi')$ = **0.593**

Loading details

Surcharge load on plan	Surcharge = **10.0** kN/m^2
Applied vertical dead load on wall	W_{dead} = **12.0** kN/m
Applied vertical live load on wall	W_{live} = **4.0** kN/m
Position of applied vertical load on wall	l_{load} = **1000** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



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

Vertical forces on wall

Wall stem	$w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **17.7** kN/m
Wall base	$w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.6** kN/m
Surcharge	w_{sur} = Surcharge $\times l_{heel}$ = **8.5** kN/m
Moist backfill to top of wall	$w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **15.3** kN/m
Saturated backfill	$w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **26.8** kN/m
Applied vertical load	$W_v = W_{dead} + W_{live}$ = **16** kN/m
Total vertical load	$W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + w_s + W_v$ = **107.9** kN/m

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times h_{eff}$ = **10.6** kN/m
Moist backfill above water table	$F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **3.2** kN/m
Moist backfill below water table	$F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **12.7** kN/m
Saturated backfill	$F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **7.9** kN/m
Water	$F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **19.6** kN/m
Total horizontal load	$F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **53.9** kN/m

Calculate propping force

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.2** kN/m
Propping force	$F_{prop} = \max(F_{total} - F_p - (W_{total} - w_{sur} - W_{live}) \times \tan(\delta_b), 0$ kN/m$)$
	F_{prop} = **18.6** kN/m

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **15.9** kNm/m
Moist backfill above water table	$M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **7.4** kNm/m
Moist backfill below water table	$M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **12.7** kNm/m
Saturated backfill	$M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.3** kNm/m
Water	$M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **13.1** kNm/m
Total overturning moment	$M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **54.3** kNm/m

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **17.7** kNm/m
Wall base	$M_{base} = w_{base} \times l_{base} / 2$ = **23.6** kNm/m
Moist backfill	$M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **24.1** kNm/m
Saturated backfill	$M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **42.2** kNm/m
Design vertical dead load	$M_{dead} = W_{dead} \times l_{load}$ = **12** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{m\_r} + M_{s\_r} + M_{dead}$ = **119.6** kNm/m

Check bearing pressure

Surcharge	$M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **13.4** kNm/m
Design vertical live load	$M_{live} = W_{live} \times l_{load}$ = **4** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{sur\_r} + M_{live}$ = **82.7** kNm/m
Total vertical reaction	$R = W_{total}$ = **107.9** kN/m
Distance to reaction	$x_{bar} = M_{total} / R$ = **766** mm
Eccentricity of reaction	$e = \text{abs}((l_{base} / 2) - x_{bar})$ = **234** mm

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **91.7** kN/m^2
Bearing pressure at heel	$p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **16.1** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

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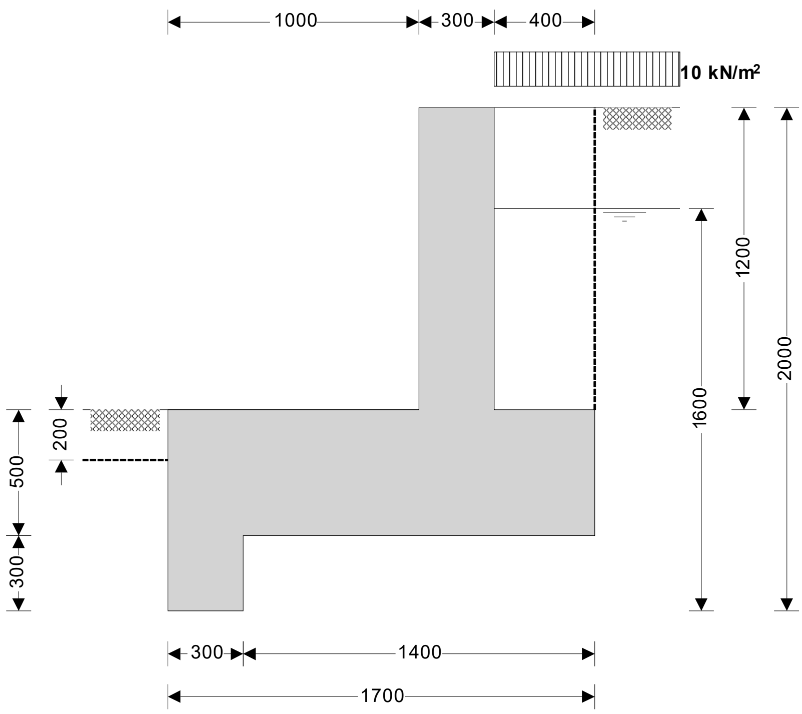
	Calcs for Retaining Wall RW4 - Preliminary				Start page no./Revision 1	
	Calcs by SN	Calcs date 13/12/2024	Checked by	Checked date	Approved by	Approved date

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type	**Unpropped cantilever**
Height of retaining wall stem	h_{stem} = **1200** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **1000** mm
Length of heel	l_{heel} = **400** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1700** mm
Thickness of base	t_{base} = **500** mm
Depth of downstand	d_{ds} = **300** mm
Position of downstand	l_{ds} = **0** mm
Thickness of downstand	t_{ds} = **300** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **2000** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **200** mm
Height of ground water behind wall	h_{water} = **1600** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **800** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **2000** 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' = **29.3** 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

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.306}$$

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 $K_0 = 1 - \sin(\phi') = \mathbf{0.511}$

Loading details

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

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

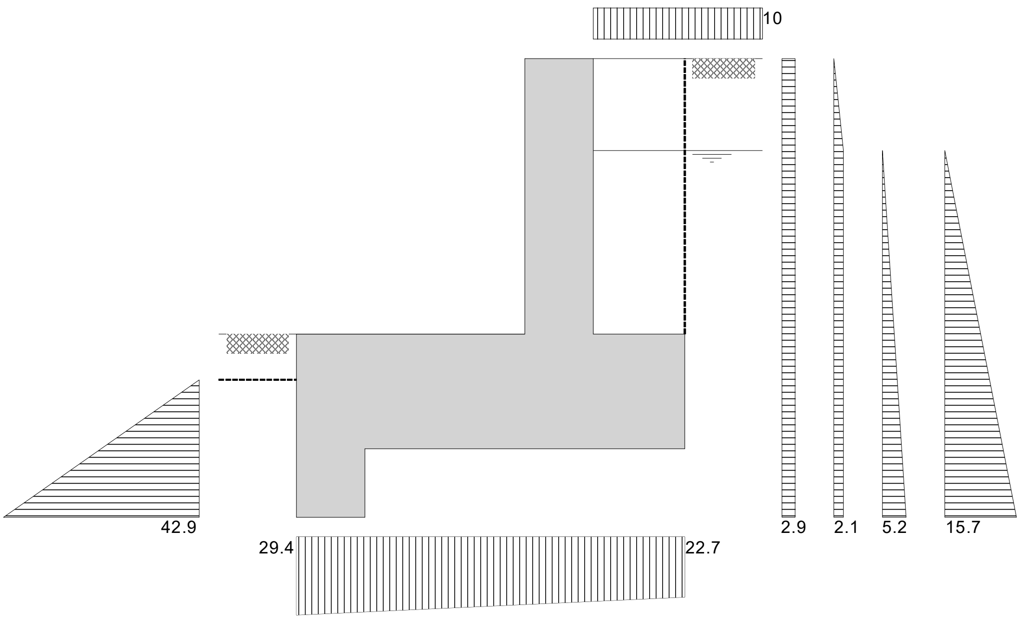
Applied vertical live load on wall W_{live} = **0.0** kN/m

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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **8.5** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **20.1** kN/m

Wall downstand $w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base}$ = **2.1** kN/m

Surcharge w_{sur} = Surcharge $\times l_{heel}$ = **4** kN/m

Moist backfill to top of wall $w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **2.9** kN/m

Saturated backfill $w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **6.7** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + w_{ds} + w_{sur} + w_{m\_w} + w_s$ = **44.3** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times h_{eff}$ = **5.8** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **0.4** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **3.3** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **4.2** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **12.6** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **26.3** kN/m

Calculate stability against sliding

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **12.9** kN/m

Resistance to sliding $F_{res} = F_p + (W_{total} - w_{sur}) \times \tan(\delta_b)$ = **26.4** kN/m

PASS - Resistance force is greater than sliding force

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **4.1** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **0.6** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **1.7** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **1** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **2.9** 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 $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water} + M_{p\_o}$ = **11.5** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **9.8** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **17.1** kNm/m

Wall downstand $M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2)$ = **0.3** kNm/m

Moist backfill $M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **4.3** kNm/m

Saturated backfill $M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **10.1** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{ds} + M_{m\_r} + M_{s\_r}$ = **41.5** kNm/m

Check stability against overturning

Total overturning moment M_{ot} = **11.5** kNm/m

Total restoring moment M_{rest} = **41.5** kNm/m

PASS - Restoring moment is greater than overturning moment

Check bearing pressure

Surcharge $M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **6** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{sur\_r}$ = **36** kNm/m

Total vertical reaction $R = W_{total}$ = **44.3** kN/m

Distance to reaction $x_{bar} = M_{total} / R$ = **814** mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar})$ = **36** mm

Reaction acts within middle third of base

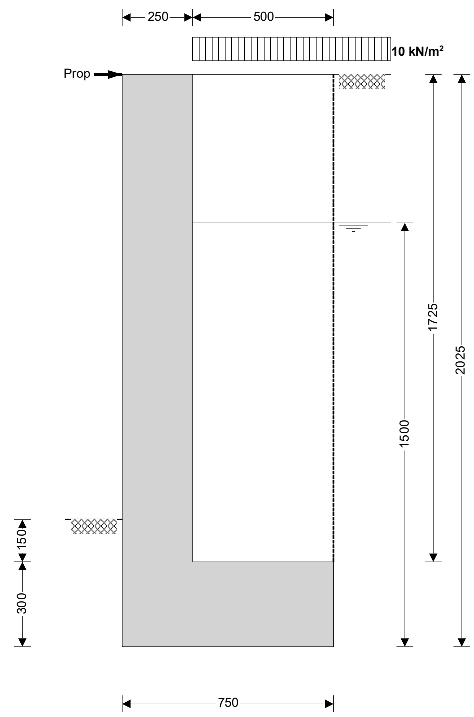
Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **29.4** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = \mathbf{22.7}\ kN/m^2$

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

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

Height of retaining wall stem — h_{stem} = **1725** mm

Thickness of wall stem — t_{wall} = **250** mm

Length of toe — l_{toe} = **0** mm

Length of heel — l_{heel} = **500** mm

Overall length of base — $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **750** mm

Thickness of base — t_{base} = **300** mm

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

Position of downstand — l_{ds} = **200** mm

Thickness of downstand — t_{ds} = **300** mm

Height of retaining wall — $h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **2025** mm

Depth of cover in front of wall — d_{cover} = **150** mm

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

Height of ground water behind wall — h_{water} = **1500** mm

Height of saturated fill above base — $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **1200** 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 — $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **2025** 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' = **29.3** deg

Angle of wall friction δ = **22.8** 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

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.304}$$

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 $K_0 = 1 - \sin(\phi') = \mathbf{0.511}$

Loading details

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

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

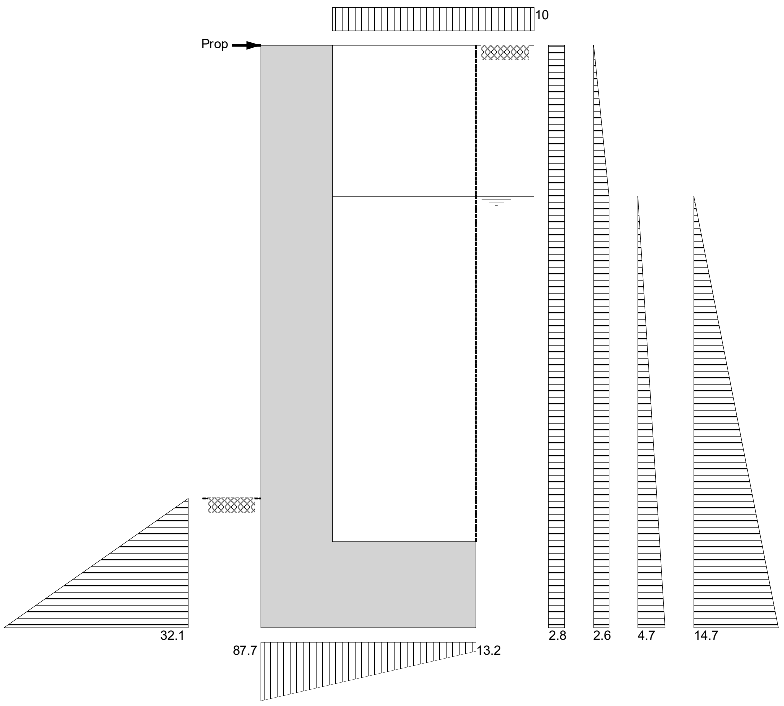
Applied vertical live load on wall W_{live} = **0.0** kN/m

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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **10.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **5.3** kN/m

Surcharge w_{sur} = Surcharge $\times l_{heel}$ = **5** kN/m

Moist backfill to top of wall $w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **4.7** kN/m

Saturated backfill $w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **12.6** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + w_s$ = **37.8** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times h_{eff}$ = **5.7** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **0.7** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **4** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **3.5** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **11** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **24.9** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **7.2** kN/m

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

F_{prop} = **6.6** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **5.7** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **1.2** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **3** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **1.8** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.5** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **17.2** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **1.3** kNm/m

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

Moist backfill $M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **2.4** kNm/m

Saturated backfill $M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **6.3** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{m\_r} + M_{s\_r}$ = **11.9** kNm/m

Check bearing pressure

Propping force $M_{prop} = F_{prop} \times (h_{wall} - d_{ds})$ = **13.4** kNm/m

Surcharge $M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **2.5** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{prop} + M_{sur\_r}$ = **10.7** kNm/m

Total vertical reaction $R = W_{total}$ = **37.8** kN/m

Distance to reaction $x_{bar} = M_{total} / R$ = **283** mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar})$ = **92** mm

Reaction acts within middle third of base

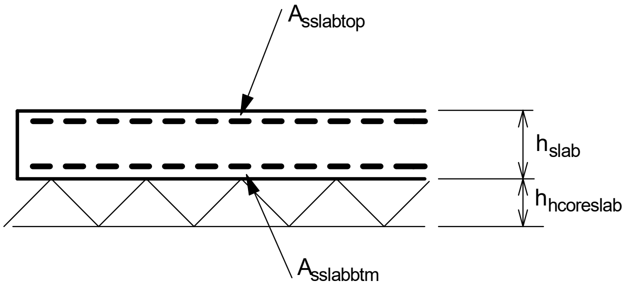
Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **87.7** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **13.2** kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

RAFT FOUNDATION DESIGN (BS8110 : PART 1 : 1997)

Tedds calculation version 1.0.13



Soil and raft definition

Soil definition

Allowable bearing pressure	q_{allow} = **50.0** kN/m^2
Number of types of soil forming sub-soil	**One type only**
Soil density	**Firm**
Depth of hardcore beneath slab	$h_{hcoreslab}$ = **0** mm (Dispersal allowed for bearing pressure check)
Density of hardcore	γ_{hcore} = **20.0** kN/m^3
Basic assumed diameter of local depression	$\phi_{depbasic}$ = **1500**mm
Diameter under slab modified for hardcore	$\phi_{depslab} = \phi_{depbasic} - h_{hcoreslab}$ = **1500** mm

Raft slab definition

Max dimension/max dimension between joints	l_{max} = **5.000** m
Slab thickness	h_{slab} = **200** mm
Concrete strength	f_{cu} = **40** N/mm^2
Poissons ratio of concrete	ν = **0.2**
Slab mesh reinforcement strength	f_{yslab} = **500** N/mm^2
Partial safety factor for steel reinforcement	γ_s = **1.15**
From C&CA document 'Concrete ground floors' Table 5	
Minimum mesh required in top for shrinkage	**A142**
Actual mesh provided in top	**A393 ($A_{sslabtop}$ = 393 mm^2/m)**
Mesh provided in bottom	**A393 ($A_{sslabbtm}$ = 393 mm^2/m)**
Top mesh bar diameter	$\phi_{slabtop}$ = **10** mm
Bottom mesh bar diameter	$\phi_{slabbtm}$ = **10** mm
Cover to top reinforcement	c_{top} = **35** mm
Cover to bottom reinforcement	c_{btm} = **50** mm
Average effective depth of top reinforcement	$d_{tslabav} = h_{slab} - c_{top} - \phi_{slabtop}$ = **155** mm
Average effective depth of bottom reinforcement	$d_{bslabav} = h_{slab} - c_{btm} - \phi_{slabbtm}$ = **140** mm
Overall average effective depth	$d_{slabav} = (d_{tslabav} + d_{bslabav})/2$ = **148** mm
Minimum effective depth of top reinforcement	$d_{tslabmin} = d_{tslabav} - \phi_{slabtop}/2$ = **150** mm
Minimum effective depth of bottom reinforcement	$d_{bslabmin} = d_{bslabav} - \phi_{slabbtm}/2$ = **135** mm

Slab edge reinforcement

Mesh provided in top	**A393 ($A_{sedgetop}$ = 393 mm^2/m)**
Mesh provided in bottom	**A393 ($A_{sedgebtm}$ = 393 mm^2/m)**

Internal slab design checks

Basic loading

Slab self weight — w_{slab} = 24 kN/m^3 × h_{slab} = **4.8** kN/m^2

Hardcore — $w_{hcoreslab} = \gamma_{hcore} \times h_{hcoreslab}$ = **0.0** kN/m^2

Applied loading

Uniformly distributed dead load — w_{Dudl} = **3.0** kN/m^2

Uniformly distributed live load — w_{Ludl} = **1.5** kN/m^2

Internal slab bearing pressure check

Total uniform load at formation level — $w_{udl} = w_{slab} + w_{hcoreslab} + w_{Dudl} + w_{Ludl}$ = **9.3** kN/m^2

PASS - w_{udl} <= q_{allow} - Applied bearing pressure is less than allowable

Internal slab bending and shear check

Applied bending moments

Span of slab — $l_{slab} = \phi_{depslab} + d_{tslabav}$ = **1655** mm

Ultimate self weight udl — $w_{swult} = 1.4 \times w_{slab}$ = **6.7** kN/m^2

Self weight moment at centre — $M_{csw} = w_{swult} \times l_{slab}^2 \times (1 + \nu) / 64$ = **0.3** kNm/m

Self weight moment at edge — $M_{esw} = w_{swult} \times l_{slab}^2 / 32$ = **0.6** kNm/m

Self weight shear force at edge — $V_{sw} = w_{swult} \times l_{slab} / 4$ = **2.8** kN/m

Moments due to applied uniformly distributed loads

Ultimate applied udl — $w_{udlult} = 1.4 \times w_{Dudl} + 1.6 \times w_{Ludl}$ = **6.6** kN/m^2

Moment at centre — $M_{cudl} = w_{udlult} \times l_{slab}^2 \times (1 + \nu) / 64$ = **0.3** kNm/m

Moment at edge — $M_{eudl} = w_{udlult} \times l_{slab}^2 / 32$ = **0.6** kNm/m

Shear force at edge — $V_{udl} = w_{udlult} \times l_{slab} / 4$ = **2.7** kN/m

Resultant moments and shears

Total moment at edge — $M_{\Sigma e}$ = **1.1** kNm/m

Total moment at centre — $M_{\Sigma c}$ = **0.7** kNm/m

Total shear force — V_{Σ} = **5.5** kN/m

Reinforcement required in top

K factor — $K_{slabtop} = M_{\Sigma e}/(f_{cu} \times d_{tslabav}^2)$ = **0.001**

Lever arm — $z_{slabtop} = d_{tslabav} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{slabtop}/0.9)})$ = **147.3** mm

Area of steel required for bending — $A_{sslabtopbend} = M_{\Sigma e}/((1.0/\gamma_s) \times f_{yslab} \times z_{slabtop})$ = **18** mm^2/m

Minimum area of steel required — $A_{sslabmin} = 0.0013 \times h_{slab}$ = **260** mm^2/m

Area of steel required — $A_{sslabtopreq} = \max(A_{sslabtopbend}, A_{sslabmin})$ = **260** mm^2/m

PASS - $A_{sslabtopreq}$ <= $A_{sslabtop}$ - Area of reinforcement provided in top to span local depressions is adequate

Reinforcement required in bottom

K factor — $K_{slabbtm} = M_{\Sigma c}/(f_{cu} \times d_{bslabav}^2)$ = **0.001**

Lever arm — $z_{slabbtm} = d_{bslabav} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{slabbtm}/0.9)})$ = **133.0** mm

Area of steel required for bending — $A_{sslabbtmbend} = M_{\Sigma c}/((1.0/\gamma_s) \times f_{yslab} \times z_{slabbtm})$ = **12** mm^2/m

Area of steel required — $A_{sslabbtmreq} = \max(A_{sslabbtmbend}, A_{sslabmin})$ = **260** mm^2/m

PASS - $A_{sslabbtmreq}$ <= $A_{sslabbtm}$ - Area of reinforcement provided in bottom to span local depressions is adequate

Shear check

Applied shear stress — $v = V_{\Sigma}/d_{tslabmin}$ = **0.037** N/mm^2

Tension steel ratio — $\rho = 100 \times A_{sslabtop}/d_{tslabmin}$ = **0.262**

From BS8110-1:1997 - Table 3.8

Design concrete shear strength v_c = **0.604** N/mm^2

PASS - v <= v_c - Shear capacity of the slab is adequate

Internal slab deflection check

Basic allowable span to depth ratio $Ratio_{basic}$ = **26.0**

Moment factor $M_{factor} = M_{\Sigma c}/d_{bslabav}^2$ = **0.035** N/mm^2

Steel service stress $f_s = 2/3 \times f_{yslab} \times A_{sslabbtmbend}/A_{sslabbtm}$ = **10.034** N/mm^2

Modification factor $MF_{slab} = \min(2.0, 0.55 + [(477N/mm^2 - f_s)/(120 \times (0.9N/mm^2 + M_{factor}))])$

MF_{slab} = **2.000**

Modified allowable span to depth ratio $Ratio_{allow} = Ratio_{basic} \times MF_{slab}$ = **52.000**

Actual span to depth ratio $Ratio_{actual} = l_{slab}/ d_{bslabav}$ = **11.821**

PASS - $Ratio_{actual}$ <= $Ratio_{allow}$ - Slab span to depth ratio is adequate

Slab edge design checks

Basic loading

Hardcore $w_{hcoreslab} = \gamma_{hcore} \times h_{hcoreslab}$ = **0.0** kN/m^2

Slab self weight $w_{slab} = 24 kN/m^3 \times h_{slab}$ = **4.8** kN/m^2

Slab edge bearing pressure check

Total uniform load at formation level $w_{udledge} = w_{Dudl} + w_{Ludl} + w_{slab} + w_{hcoreslab}$ = **9.3** kN/m^2

PASS - $w_{udledge}$ <= q_{allow} - Applied bearing pressure is less than allowable

Slab edge bending check

Considering a 1.0m width of slab

Divider for moments due to udl's β_{udl} = **10.0**

Applied bending moments

Span of slab $l_{edge} = \phi_{depslab} + d_{tslabmin}$ = **1650** mm

Ultimate self weight udl $w_{edgeult} = 1.4 \times w_{slab}$ = **6.7** kN/m^2

Self weight bending moment $M_{edgesw} = w_{edgeult} \times l_{edge}^2/10$ = **1.8** kNm/m

Self weight shear force $V_{edgesw} = w_{edgeult} \times l_{edge}/2$ = **5.5** kN/m

Moments due to applied uniformly distributed loads

Ultimate udl $w_{edgeudl} = w_{udlult}$ = **6.6** kN/m^2

Bending moment $M_{edgeudl} = w_{edgeudl} \times l_{edge}^2/\beta_{udl}$ = **1.8** kNm/m

Shear force $V_{edgeudl} = w_{edgeudl} \times l_{edge}/2$ = **5.4** kN/m

Resultant moments and shears

Total moment (hogging and sagging) $M_{\Sigma edge}$ = **3.6** kNm/m

Maximum shear force $V_{\Sigma edge}$ = **11.0** kN/m

Reinforcement required in top

K factor $K_{edgetop} = M_{\Sigma edge}/(f_{cu} \times d_{tslabmin}^2)$ = **0.004**

Lever arm $z_{edgetop} = d_{tslabmin} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{edgetop}/0.9)})$ = **143** mm

Area of steel required for bending $A_{sedgetopbend} = M_{\Sigma edge}/((1.0/\gamma_s) \times f_{yslab} \times z_{edgetop})$ = **59** mm^2/m

Area of steel required $A_{sedgetopreq} = \max(A_{sedgetopbend}, A_{sslabmin})$ = **260** mm^2/m

PASS - $A_{sedgetopreq}$ <= $A_{sedgetop}$ - Area of reinforcement provided in top of slab is adequate

Reinforcement required in bottom

K factor $K_{edgebtm} = M_{\Sigma edge}/(f_{cu} \times d_{bslabmin}^2)$ = **0.005**

Lever arm $z_{edgebtm} = d_{bslabmin} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{edgebtm}/0.9)})$ = **128** mm

Area of steel required for bending $A_{sedgebtmbend} = M_{\Sigma edge}/((1.0/\gamma_s) \times f_{yslab} \times z_{edgebtm})$ = **65** mm^2/m

Area of steel required $A_{sedgebtmreq}$ = max($A_{sedgebtmbend}$, $A_{sslabmin}$) = **260** mm^2/m

PASS - $A_{sedgebtmreq}$ <= $A_{sedgebtm}$ - Area of reinforcement provided in bottom of slab is adequate

Applied shear stress $v_{edge} = V_{\Sigma edge} \times 1.0m/(1000mm \times d_{tslabmin})$ = **0.073** N/mm^2

Tension steel ratio $\rho_{edge} = 100 \times A_{sedgetop} \times 1.0m/(1000mm \times d_{tslabmin})$ = **0.262**

From BS8110-1:1997 - Table 3.8

Design concrete shear strength v_{cedge} = **0.604** N/mm^2

PASS - v_{edge} <= v_{cedge} - Shear capacity of the slab is not exceeded

Slab edge deflection check

Basic allowable span to depth ratio $Ratio_{basicedge}$ = **26.0**

Moment factor $M_{factoredge} = M_{\Sigma edge}/d_{bslabmin}^2$ = **0.199** N/mm^2

Steel service stress $f_{sedge} = 2/3 \times f_{yslab} \times A_{sedgebtmbend}/A_{sedgebtm}$ = **55.161** N/mm^2

Modification factor MF_{edge}=min(2.0,0.55+[(477N/mm^2-f_{sedge})/(120×(0.9N/mm^2+$M_{factoredge}$))])

MF_{edge} = **2.000**

Modified allowable span to depth ratio $Ratio_{allowedge} = Ratio_{basicedge} \times MF_{edge}$ = **52.000**

Actual span to depth ratio $Ratio_{actualedge} = l_{edge}/ d_{tslabmin}$ = **11.000**

PASS - $Ratio_{actualedge}$ <= $Ratio_{allowedge}$ - Slab span to depth ratio is adequate

Corner design checks

Basic loading

Corner bearing pressure check

Total uniform load at formation level $w_{udlcorner} = w_{Dudl} + w_{Ludl} + w_{slab} + w_{hcoreslab}$ = **9.3** kN/m^2

PASS - $w_{udlcorner}$ <= q_{allow} - Applied bearing pressure is less than allowable

Slab corner bending check

Cantilever span of slab at corner $l_{corner} = \phi_{depslab}/\sqrt{(2)} + d_{tslabav}/2$ = **1138** mm

Moment and shear due to self weight

Considering triangular loading

Maximum ultimate self weight udl $w_{swult} = 1.4 \times w_{slab} \times \phi_{depslab}/\sqrt{(2)}$ = **7.1** kN/m

Self weight bending moment $M_{cornersw} = w_{swult} \times l_{corner}^2/(6 \times \phi_{depslab}/\sqrt{(2)})$ = **1.5** kNm/m

Self weight shear force $V_{cornersw} = w_{swult} \times l_{corner}/(2 \times \phi_{depslab}/\sqrt{(2)})$ = **3.8** kN/m

Moment and shear due to udls

Maximum ultimate udl $w_{cornerudl} = ((1.4 \times w_{Dudl})+(1.6 \times w_{Ludl})) \times \phi_{depslab}/\sqrt{(2)}$ = **7.0** kN/m

Bending moment $M_{cornerudl} = w_{cornerudl} \times l_{corner}^2/(6 \times \phi_{depslab}/\sqrt{(2)})$ = **1.4** kNm/m

Shear force $V_{cornerudl} = w_{cornerudl} \times l_{corner}/(2 \times \phi_{depslab}/\sqrt{(2)})$ = **3.8** kN/m

Resultant moments and shears

Total design moment $M_{\Sigma corner} = M_{cornersw} + M_{cornerudl}$ = **2.9** kNm/m

Total design shear force $V_{\Sigma corner} = V_{cornersw} + V_{cornerudl}$ = **7.6** kN/m

Reinforcement required in top of slab at corners

K factor $K_{corner} = M_{\Sigma corner}/(f_{cu} \times d_{tslabmin}^2)$ = **0.003**

Lever arm $z_{corner} = d_{tslabmin} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{corner}/0.9)})$ = **143** mm

Area of steel required for bending $A_{scornerbend} = M_{\Sigma corner}/((1.0/\gamma_s) \times f_{yslab} \times z_{corner})$ = **46** mm^2/m

Area of steel required $A_{scorner}$ = max($A_{scornerbend}$, $A_{sslabmin}$) = **260** mm^2/m

PASS - $A_{scorner}$ <= $A_{sedgetop}$ - Area of reinforcement provided in top of slab at corners is adequate

Applied shear stress $v_{corner} = V_{\Sigma corner}/d_{tslabmin}$ = **0.051** N/mm^2

Tension steel ratio $\rho_{corner} = 100 \times A_{sedgetop}/d_{tslabmin}$ = **0.262**

From BS8110-1:1997 - Table 3.8

Design concrete shear strength $v_{ccorner}$ = **0.604** N/mm^2

Pass - v_{corner} <= $v_{ccorner}$ - Shear capacity of the slab is not exceeded

Slab corner deflection check

Basic allowable span to depth ratio $Ratio_{basiccorner}$ = **7.0**

Moment factor $M_{factorcorner} = M_{\Sigma corner}/d_{tslabmin}^2$ = **0.128** N/mm^2

Steel service stress $f_{scorner} = 2/3 \times f_{yslab} \times A_{scornerbend}/A_{sedgetop}$ = **39.369** N/mm^2

Modification factor $MF_{corner}=\min(2.0,0.55+[(477N/mm^2-f_{scorner})/(120\times(0.9N/mm^2+M_{factorcorner}))])$

MF_{corner} = **2.000**

Modified allowable span to depth ratio $Ratio_{allowcorner} = Ratio_{basiccorner} \times MF_{corner}$ = **14.000**

Actual span to depth ratio $Ratio_{actualcorner} = l_{corner}/ d_{tslabmin}$ = **7.588**

PASS - $Ratio_{actualcorner}$ <= $Ratio_{allowcorner}$ - Slab span to depth ratio is adequate