8 Christchurch Street
London
SW3 4AW

Construction Method Statement

Prepared By: Tyrone Bowen MEng CEng MInstMC
On behalf of CAR Ltd
1.0 **Introduction**

CAR Ltd has been instructed MSpace Architects on behalf of the Client to prepare a Construction Method Statement (CMS) for the subterranean works in support of a Planning Application for a proposed two storey basement at 8 Christchurch Street, London SW3 4AW.

2.0 **The Project**

2.01 **Location**

No 8 Christchurch Street is located close to the junction of Christchurch Street and Ralston Street.

![Figure 1 - Site Location Map](image)

The site is situated in a built up residential area with a number of properties which adjoin the site via party walls.

The site is set back from the edge of the pavement and is currently occupied by a 2 storey residential building of traditional construction.
2.02 Existing Building

The building is a 2 storey traditional structure comprising of a ground floor, first floor and flat asphalt roof structure.

The main structure is likely to consist of brickwork walls supporting timber floors and roof.

The adjoining buildings on the north and east boundaries are 5 storey structures with an existing lower ground floor level.

The Party Wall along the north boundary has a curved brickwork chimney which is of architectural value and will therefore be retained and incorporated into the scheme.

There are a number of projections on the Party Wall on the east boundary which will need to be investigated further during the detailed design stage.

2.03 Ground Conditions

Geological maps of the area indicate that geology of the area consists of Kempton Park Gravel over London Clay Formation.

A preliminary site investigation was carried by Mini Soils Survey (ref LON01067 dated 8th February 2007) revealed the underlying ground conditions consists of approx. 4.2m of Made Ground over very dense Sands and Gravels to an extent of 9m below ground level. The borehole was terminated at this level.

Groundwater was encountered approximately 4.7m below ground level.

A more detailed investigation consisting of further boreholes and trial pits will be carried out before the detailed design stage. The results of the preliminary investigation were used in this outline assessment for planning purposes.
LUL underground lines are approximately 500mm away from the site and are therefore sufficiently distant not to have an impact on the proposal.

LUL Infrastructure in relation to the site.
A review of online information indicates that the area did not suffer from direct bomb damage during the Second World War (see fig.2).
2.04 Site Hydrology

Reference should be made to a separate Flood Risk report prepared by Lanmor Consulting (ref KL/ml/080134/FD01 dated March 2013). This concluded that the proposed development will have any impact on the flood plain or flow paths.

A review of the ‘The Lost Rivers of London’ by Nicholas Barton indicates that there are no hidden or unknown rivers crossing the site.

Figure 4 - Extract from ‘Lost Rivers of London’

Ground water was encountered in the sand and gravel layer in the borehole installed on site. The basement structure will be design to withstand a hydrostatic head of water in accordance with the requirements of BS8102.
3.0 Proposed Development

The proposals involve demolition of the existing 2 storey structure and construction of a new 6 storey structure consisting of 2 subterranean levels with 4 superstructure levels. The new building will occupy the full footprint of the site as indicated on the Architect’s drawings.

The following sections describe the outline structural scheme for the new basement.

3.01 Sub-structure & basement structure

The proposals for the basement construction will take account of the designs indicated on the Architect’s drawings, anticipated ground conditions, stability of adjoining properties, and physical constraints of the site.

The design philosophy for the basement is to maintain existing load paths and extend these down to the new basement level. This will involve the use of a stiff reinforced concrete structure box to form the basement levels.

Underpinning of the adjoining party walls will be required to allow the works to be constructed to the required levels. The underpinning will consist of reinforced concrete elements constructed in a hit and miss sequence agreed with the Engineer. The underpin elements will be designed to withstand imposed lateral pressures, including surcharge from adjacent properties and pavement loading to the front.

Ground water was encountered in the borehole at a depth of 4.7m below ground level. The proposed levels of the basement will mean that excavation will need to be carried out below the water level. The water is within the dense sand and gravels. It is proposed to use permeation grouting to stabilise the soils during construction and to reduce the risk of fines being washed out. Specialist advice will be required during detailed design stage.

An Outline Construction Sequence and Underpinning Specification are included in the following sections.

3.02 Potential Ground Movement

Given the nature of the proposed work, some degree of movement of the property and adjoining properties is to be expected, and from our experience of similar basement excavations the likely movement can be categorised as Risk Category 1 as defined in Table 1 below. The procedures for rectifying any damage caused as a result of the works are usually agreed as part of the Party Wall negotiations.

Permeation grouting is proposed to minimise the risk of fines washout and hence potential ground movement during excavation.
### 3.03 Soil Excavation

It is anticipated that excavated soil will be transported to a skip at pavement level via a conveyor belt.

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

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

### 3.04 Waterproofing and Drainage systems

The proposed basement will a habitable space, therefore the proposal is to provide a drained cavity waterproofing system (designed by a waterproofing specialist) to achieve a Type C environment in accordance with BS8102.
4.0 Outline Sequence of Construction

4.01 General

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

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

All temporary works are the responsibility of the Contractor.

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

4.02 Assumed Sequence

1. A conveyor belt will be set up from the excavation face to convey the spoil to the skip placed on the road for disposal.
2. Existing structure to be removed and excavation for underpinning commenced from ground level.
3. The party walls are to be underpinned in a hit or miss (1 to 5) underpinning sequence to be agreed with the Engineer.
4. Install horizontal propping including suitable excavation support trench sheets and to ensure stability of the ground at all times during the works.
5. Underpins forming the new basement will require horizontal propping in the temporary condition until completion of the new basement slab.
6. Grout the sands and gravels using permeation grouting before excavating below water level and to control water ingress.
7. Bulk excavation to the basement extension to be carried out once all of the underpins to the new basement have been completed. Horizontal propping to be installed between Party Walls at high level.
8. A second level of horizontal props is to be installed at lower level once the bulk excavation is down to approximately 500mm above the proposed basement level.
9. Excavation to be completed down to formation level.
10. Below slab drainage to be installed and discharged into a pumped sump.
11. The pumps will discharge the foul / ground water into the existing sewer system to the front of the property.
12. Cast basement slab and remove lower level of props once the slab has achieved the designed strength.
13. Cast ground floor slab and remove upper level of props once the slab has achieved the designed strength.
5.0 Outline Underpinning Specification

The Contractor shall be responsible for ensuring that his operations do not in any way impair the safety or condition of the existing structure. He shall provide any temporary supports required for this purposes, and shall carefully inspect the condition of the structure both before and during execution of the work, and immediately inform the Engineer.

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

The Contractor shall provide sufficient boards and covers to protect or screen open excavations at the end of each working day and over weekends and Bank Holiday.

The Contractor is to allow for removal of all spoil arising from the works which is not suitable for backfilling purposes.

Underpinning is to be carried out to the satisfaction of the Engineer and Local Authority in short sections generally not exceeding 1.0m in length, in such a manner that adequate support is maintained at all times to the underside of the wall for at least three quarters of its length, and that sections of work in progress at any one time are separated by a distance of at least 3m.

Projecting portions of the existing brick, stone and/or concrete footings are to be carefully cut off where directed, and the undersides of the footings are to be cleaned and hacked free of any dirt, soil or loose material before underpinning.

The body of the underpinning is to be constructed using Grade C40 concrete (suitable for the required sulphate class identified), and is to be cast to the widths and depths shown on the drawings. The formation of excavations are to be prepared as specified for foundations generally, and as far as practicable excavation and concreting of any section of underpinning shall be carried out on the same day. Inform the Engineer immediately if the bearing formation is not as assumed.

The concrete pin is to be stopped off approximately 75mm below the underside of the existing footing, and the final pinning up over the whole extent of the latter is to be carried out with ‘dry pack’ with ‘Conbex 100’ expanding admixture by Frosroc, well rammed in as soon as possible after the foundation has set hard. The pinning up concrete is to consist of 1 part by volume of Portland Cement to 3 parts of sharp sand with a low water/cement ratio.

Minimum curing periods:
Between casting pin and pinning up – 24 hours
Extend curing period to allow for inclement weather.

Excavation to any section of underpinning shall not be commenced until at least 48 hours after completion of any adjacent sections of the works.
Shear keys are to be provided between adjacent pins as indicated on the drawings.

The excavation shall be kept free of water ingress at all times during the works.

The Contractor shall keep a record on site of the following: -
Sequence and dimensions of underpinning as actually executed,
Dates of starting excavation, casting concrete and pinning up for each section.
Details of drains and services built into the pin, and the diameter of any sleeving.
APPENDIX 1
(Structural Drawings)
**KEY:**
- A. 150 x 50 C24 joist 8000
- All steel beams to be 152 x 152 x 800

**NOTE:**
1. DO NOT SCALE, IF IN DOUBT ASK.
2. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL RELEVANT STRUCTURAL ENGINEER'S DRAWINGS AND DETAILS. THE SPECIFICATION FOR THE WORKS, THE RELEVANT ARCHITECT'S DRAWINGS AND ANY OTHER SPECIALIST'S DRAWINGS.

Provide 18mm plywood throughout screwed to joists @ max. 300mm centres.

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**PROPOSED ROOF PLAN**

Cambridge Architectural Research Ltd

2255 - SK100

Drawing Title: 8 CHURCH STREET, LONDON

Preliminary for Planning

Revisions

Scale at A3: 1:100

Date: 14/11/94

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Web: www.carl.com
KEY:
- RC: min ribbed reinforced concrete slab
- P: profiled metal decking
- C/S: col denotes box columns

NOTE:
1. Do not scale, if in doubt ask.
2. This drawing is to be read in conjunction with all relevant structural engineer's drawings and details. The specification for the works, the relevant architect's drawings and any other specialist's drawings.

PRELIMINARY FOR PLANNING.

Drawing Title: 2255, SK200
Proposed Third Floor Plan
Scale at A3: 1:100

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NOTE:
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SECOND FLOOR

PRELIMINARY FOR PLANNING
APPENDIX 2
(Structural Calculations)
i) Wall 'A'

Load taken down:

- Roof: DL = 1.5 x 1.25m = 1.88
  LL = 0.75 x 1.25m = 1.0
- Wall DL = 0.45 x 19 x 6.89 = 58.9
  (450 kN) (450 kN)
- LG DL = 10 x 1.5m = 15
  LL = 1.5 x 1.5 = 2.25
- U/P DL = 0.45 x 2 x 1.5 = 16.2

∑ DL = 91.9 kN/m
∑ LL = 3.25 kN/m

Big strain - Very dense sand & gravel from SI report

Allowable GBP = 200 kN/m² say.

Assume water: full height

Refer to Tedd's output overleaf.
RETAINING WALL ANALYSIS (BS 8002:1994)

Wall details
Retaining wall type
Height of retaining wall stem
Thickness of wall stem
Length of toe
Length of heel
Overall length of base
Thickness of base
Depth of downstand
Position of downstand
Thickness of downstand
Height of retaining wall
Depth of cover in front of wall
Depth of unplanned excavation
Height of ground water behind wall
Height of saturated fill above base
Density of wall construction
Density of base construction
Angle of rear face of wall
Angle of soil surface behind wall
Effective height at virtual back of wall

Retained material details
Mobilisation factor

Cantilever propped at both

\[ h_{\text{stem}} = 3000 \text{ mm} \]
\[ t_{\text{wall}} = 450 \text{ mm} \]
\[ t_{\text{toe}} = 1500 \text{ mm} \]
\[ t_{\text{heel}} = 0 \text{ mm} \]
\[ l_{\text{base}} = l_{\text{toe}} + l_{\text{heel}} + t_{\text{wall}} = 1950 \text{ mm} \]
\[ t_{\text{base}} = 450 \text{ mm} \]
\[ d_{\text{soe}} = 0 \text{ mm} \]
\[ l_{\text{soe}} = 800 \text{ mm} \]
\[ l_{\text{ds}} = 450 \text{ mm} \]
\[ h_{\text{wall}} = h_{\text{stem}} + t_{\text{base}} + d_{\text{soe}} = 3450 \text{ mm} \]
\[ d_{\text{cover}} = 0 \text{ mm} \]
\[ d_{\text{inc}} = 200 \text{ mm} \]
\[ h_{\text{water}} = 3450 \text{ mm} \]
\[ h_{\text{sat}} = \max(h_{\text{water}} - l_{\text{base}} - d_{\text{soe}}, 0 \text{ mm}) = 3000 \text{ mm} \]
\[ \gamma_{\text{wall}} = 23.6 \text{ kN/m}^3 \]
\[ \gamma_{\text{base}} = 23.6 \text{ kN/m}^3 \]
\[ \alpha = 90.0 \text{ deg} \]
\[ \beta = 0.0 \text{ deg} \]
\[ h_{\text{eff}} = h_{\text{wall}} + h_{\text{heel}} \times \tan(\beta) = 3450 \text{ mm} \]

\[ M = 1.5 \]
Moist density of retained material  $\gamma_m = 18.0 \text{ kN/m}^3$
Saturated density of retained material  $\gamma_s = 21.0 \text{ kN/m}^3$
Design shear strength  $\phi' = 24.2 \text{ deg}$
Angle of wall friction  $\delta = 18.6 \text{ deg}$

**Base material details**
Moist density  $\gamma_{mb} = 18.0 \text{ kN/m}^3$
Design shear strength  $\phi_b = 24.2 \text{ deg}$
Design base friction  $\delta_b = 18.6 \text{ deg}$
Allowable bearing pressure  $P_{bearing} = 200 \text{ kN/m}^2$

**Using Coulomb theory**
Active pressure coefficient for retained material

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

Passive pressure coefficient for base material

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

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

**Loading details**
Surcharge load on plan  $\text{Surcharge} = 2.5 \text{ kN/m}^2$
Applied vertical dead load on wall  $W_{dead} = 91.9 \text{ kN/m}$
Applied vertical live load on wall  $W_{live} = 3.3 \text{ kN/m}$
Position of applied vertical load on wall  $l_{load} = 1725 \text{ mm}$
Applied horizontal dead load on wall  $F_{dead} = 0.0 \text{ kN/m}$
Applied horizontal live load on wall  $F_{live} = 0.0 \text{ kN/m}$
Height of applied horizontal load on wall  $h_{load} = 0 \text{ mm}$

Loads shown in kN/m, pressures shown in kN/m²
Vertical forces on wall
Wall stem
\[ W_{\text{wall}} = \gamma_{\text{stem}} \times t_{\text{wall}} \times \gamma_{\text{wall}} = 31.9 \text{ kN/m} \]
Wall base
\[ W_{\text{base}} = \gamma_{\text{base}} \times l_{\text{base}} \times \gamma_{\text{base}} = 20.7 \text{ kN/m} \]
Applied vertical load
\[ W_v = W_{\text{dead}} + W_{\text{live}} = 95.2 \text{ kN/m} \]
Total vertical load
\[ W_{\text{total}} = W_{\text{wall}} + W_{\text{base}} + W_v = 147.7 \text{ kN/m} \]

Horizontal forces on wall
Surcharge
\[ F_{\text{sur}} = K_s \times (\gamma_{\text{soil}} \times \cos(90 - \alpha + \delta)) \times \text{Surcharge} \times h_{\text{eff}} = 3 \text{ kN/m} \]
Saturated backfill
\[ F_s = 0.5 \times K_s \times (\gamma_{\text{soil}} \times \cos(90 - \alpha + \delta)) \times (\gamma_{\text{soil}} \times h_{\text{water}}^2) = 23.3 \text{ kN/m} \]
Water
\[ F_{\text{water}} = 0.5 \times h_{\text{water}}^2 \times \gamma_{\text{water}} = 58.4 \text{ kN/m} \]
Total horizontal load
\[ F_{\text{total}} = F_{\text{sur}} + F_s + F_{\text{water}} = 84.7 \text{ kN/m} \]

Calculate total propping force
Passive resistance of soil in front of wall
\[ F_p = 0.5 \times K_s \times (\gamma_{\text{soil}} \times (d_{\text{base}} + d_{\text{soil}} - d_{\text{cover}})^2)) \times \tan(\delta) = 2.2 \text{ kN/m} \]
Propping force
\[ F_{\text{prop}} = \max(F_{\text{total}} - F_p - (W_{\text{total}} - W_v) \times \tan(\delta), 0 \text{ kN/m}) \]
\[ F_{\text{prop}} = 33.8 \text{ kN/m} \]

Overturning moments
Surcharge
\[ M_{\text{sur}} = F_{\text{sur}} \times (h_{\text{eff}} - 2 \times d_{\text{soil}}) / 2 = 5.2 \text{ kNm/m} \]
Saturated backfill
\[ M_s = F_s \times (h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 26.8 \text{ kNm/m} \]
Water
\[ M_{\text{water}} = F_{\text{water}} \times (h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 67.1 \text{ kNm/m} \]
Total overturning moment
\[ M_{\text{tot}} = M_{\text{sur}} + M_s + M_{\text{water}} = 99.1 \text{ kNm/m} \]

Restoring moments
Wall stem
\[ M_{\text{wall}} = W_{\text{wall}} \times (h_{\text{stem}} + h_{\text{wall}} / 2) = 55 \text{ kNm/m} \]
Wall base
\[ M_{\text{base}} = W_{\text{base}} \times (h_{\text{base}} / 2) = 20.2 \text{ kNm/m} \]
Design vertical dead load
\[ M_{\text{dead}} = W_{\text{dead}} \times l_{\text{dead}} = 158.5 \text{ kNm/m} \]
Total restoring moment
\[ M_{\text{rest}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{dead}} = 233.7 \text{ kNm/m} \]

Check bearing pressure
Total vertical reaction
\[ R = W_{\text{total}} = 147.7 \text{ kN/m} \]
Distance to reaction
\[ x_{\text{react}} = l_{\text{base}} / 2 = 975 \text{ mm} \]
Eccentricity of reaction
\[ e = \text{abs}(l_{\text{base}} / 2 - x_{\text{react}}) = 0 \text{ mm} \]

Reaction acts within middle third of base
Bearing pressure at toe
\[ p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R \times e / l_{\text{base}}^2) = 75.8 \text{ kN/m}^2 \]
Bearing pressure at heel
\[ p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R \times e / l_{\text{base}}^2) = 75.8 \text{ kN/m}^2 \]
PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall
Propping force to top of wall
\[ F_{\text{prop, top}} = (M_{\text{rest}} - M_{\text{base}} + R \times l_{\text{base}} / 2 - F_{\text{prop}} \times l_{\text{base}} / 2) / (l_{\text{stem}} + l_{\text{base}} / 2) = 0.580 \text{ kN/m} \]
Propping force to base of wall
\[ F_{\text{prop, base}} = F_{\text{prop}} - F_{\text{prop, top}} = 33.266 \text{ kN/m} \]
RETEAINING WALL DESIGN (BS 8002:1994)

Ultimate limit state load factors

Dead load factor
\[ \gamma_d = 1.4 \]

Live load factor
\[ \gamma_l = 1.6 \]

Earth and water pressure factor
\[ \gamma_e = 1.4 \]

Factored vertical forces on wall

Wall stem
\[ W_{wall, f} = \gamma_d \times h_{stem} \times b_{wall} \times \gamma_{wall} = 44.6 \text{ kN/m} \]

Wall base
\[ W_{base, f} = \gamma_d \times b_{base} \times h_{base} \times \gamma_{base} = 29 \text{ kN/m} \]

Applied vertical load
\[ W_{Applied} = \gamma_d \times W_{dead} + \gamma_l \times W_{live} = 133.9 \text{ kN/m} \]

Total vertical load
\[ W_{total, f} = W_{wall, f} + W_{base, f} + W_{Applied, f} = 207.5 \text{ kN/m} \]

Factored horizontal at-rest forces on wall

Surcharge
\[ F_{sur, f} = \gamma_l \times K_o \times \text{Surcharge} \times h_{eff} = 8.1 \text{ kN/m} \]

Saturated backfill
\[ F_{s, f} = \gamma_e \times 0.5 \times K_o \times (\gamma_r - \gamma_{water}) \times h_{water}^2 = 81 \text{ kN/m} \]

Water
\[ F_{water, f} = \gamma_e \times 0.5 \times h_{water}^2 \times \gamma_{water} = 81.7 \text{ kN/m} \]

Total horizontal load
\[ F_{total, f} = F_{sur, f} + F_{s, f} + F_{water, f} = 144.9 \text{ kN/m} \]

Calculate total propping force

Passive resistance of soil in front of wall
\[ F_p, f = \gamma_e \times 0.5 \times K_o \times \cos(\delta_b) \times (d_{cover} + b_{base} + d_{so} - d_{eso})^2 \times \gamma_{msb} = 3.1 \text{ kN/m} \]

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

\[ F_{prop, f} = 73.7 \text{ kN/m} \]

Factored overturning moments

Surcharge
\[ M_{sur, f} = F_{sur, f} \times (h_{eff} - 2 \times d_{so}) / 2 = 14 \text{ kN/m} \]

Saturated backfill
\[ M_{s, f} = F_{s, f} \times (h_{water} - 3 \times d_{so}) / 3 = 63.3 \text{ kN/m} \]

Water
\[ M_{water, f} = F_{water, f} \times (h_{water} - 3 \times d_{so}) / 3 = 94 \text{ kN/m} \]

Total overturning moment
\[ M_{total, f} = M_{sur, f} + M_{s, f} + M_{water, f} = 171.3 \text{ kN/m} \]

Restoring moments

Wall stem
\[ M_{wall, f} = W_{wall, f} \times (l_{eso} + l_{even} / 2) = 76.9 \text{ kN/m} \]

Wall base
\[ M_{base, f} = W_{base, f} \times b_{base} / 2 = 28.3 \text{ kN/m} \]

Design vertical load
\[ M_{f, f} = W_{f, f} \times l_{load} = 230.9 \text{ kN/m} \]

Total restoring moment
\[ M_{total, f} = M_{wall, f} + M_{base, f} + M_{f, f} = 336.1 \text{ kN/m} \]

Factored bearing pressure

Total vertical reaction
\[ R_t = W_{total, f} = 207.5 \text{ kN/m} \]

Distance to reaction
\[ x_{tar, f} = l_{base} / 2 = 975 \text{ mm} \]

Eccentricity of reaction
\[ \epsilon_l = ab(l_{base} / 2) = 0 \text{ mm} \]

Reaction acts within middle third of base

Bearing pressure at toe
\[ p_{toe, f} = (R_t / l_{base}) \times (6 \times R_t \times \epsilon_l / l_{base})^2 = 106.4 \text{ kN/m}^2 \]

Bearing pressure at heel
\[ p_{heel, f} = (R_t / l_{base}) \times (6 \times R_t \times \epsilon_l / l_{base})^2 = 106.4 \text{ kN/m}^2 \]

Rate of change of base reaction
\[ \text{rate} = (p_{toe, f} - p_{heel, f}) / l_{base} = 0.00 \text{ kN/m}^2 \]

Bearing pressure at stem / toe
\[ p_{stem, toe, f} = \max(p_{toe, f} - \text{(rate \times l_{eso})}, 0 \text{ kN/m}^2) = 106.4 \text{ kN/m}^2 \]

Bearing pressure at mid stem
\[ p_{stem, mid, f} = \max(p_{toe, f} - \text{(rate \times (l_{eso} + l_{even} / 2))}, 0 \text{ kN/m}^2) = 106.4 \text{ kN/m}^2 \]

Bearing pressure at stem / heel
\[ p_{stem, heel, f} = \max(p_{toe, f} - \text{(rate \times l_{eso}}), 0 \text{ kN/m}^2) = 106.4 \text{ kN/m}^2 \]
Calculate propping forces to top and base of wall

Propping force to top of wall

\[ F_{\text{prop, top, f}} = \left( M_{\text{tot, f}} - M_{\text{ext, f}} + R_e \times t_{\text{base}} / 2 - F_{\text{prop, f}} \times t_{\text{base}} / 2 \right) / \left( h_{\text{stem}} + t_{\text{base}} / 2 \right) = 6.474 \text{ kN/m} \]

Propping force to base of wall

\[ F_{\text{prop, base, f}} = F_{\text{prop, f}} - F_{\text{prop, top, f}} = 67.227 \text{ kN/m} \]

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

Material properties

Characteristic strength of concrete

\[ f_{\text{cy}} = 40 \text{ N/mm}^2 \]

Characteristic strength of reinforcement

\[ f_y = 500 \text{ N/mm}^2 \]

Base details

Minimum area of reinforcement

\[ k = 0.13 \% \]

Cover to reinforcement in toe

\[ c_{\text{toe}} = 75 \text{ mm} \]

Calculate shear for toe design

Shear from bearing pressure

\[ V_{\text{toe, bear}} = (p_{\text{tot, f}} + p_{\text{stem, mid}}) \times t_{\text{base}} / 2 = 159.6 \text{ kN/m} \]

Shear from weight of base

\[ V_{\text{toe, wt, base}} = \gamma_d \times \gamma_{\text{base}} \times l_{\text{base}} \times t_{\text{base}} = 22.3 \text{ kN/m} \]

Total shear for toe design

\[ V_{\text{toe}} = V_{\text{toe, bear}} - V_{\text{toe, wt, base}} = 137.3 \text{ kN/m} \]

Calculate moment for toe design

Moment from bearing pressure

\[ M_{\text{toe, bear}} = (2 \times p_{\text{tot, f}} + p_{\text{stem, mid}}) \times (l_{\text{base}} + t_{\text{wall}} / 2)^2 / 6 = 158.3 \text{ kN/m} \]

Moment from weight of base

\[ M_{\text{toe, wt, base}} = (\gamma_d \times \gamma_{\text{base}} \times t_{\text{base}} \times (l_{\text{base}} + t_{\text{wall}} / 2)^2 / 6) = 22.1 \text{ kN/m} \]

Total moment for toe design

\[ M_{\text{toe}} = M_{\text{toe, bear}} - M_{\text{toe, wt, base}} = 136.2 \text{ kN/m} \]

Check toe in bending

Width of toe

\[ b = 1000 \text{ mm/m} \]

Depth of reinforcement

\[ d_{\text{toe}} = t_{\text{base}} - c_{\text{toe}} - (d_{\text{toe}} / 2) = 367.0 \text{ mm} \]

Constant

\[ K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_y) = 0.025 \]

Compression reinforcement is not required

Lever arm

\[ z_{\text{toe}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{toe}}, 0.225) / 0.95)) \times d_{\text{toe}}} \]

\[ z_{\text{toe}} = 349 \text{ mm} \]

Area of tension reinforcement required

\[ A_{\text{t, toe, req}} = M_{\text{toe}} / (0.87 \times f_y \times z_{\text{toe}}) = 898 \text{ mm}^2/\text{m} \]

Minimum area of tension reinforcement

\[ A_{\text{t, toe, min}} = k \times b \times t_{\text{base}} = 585 \text{ mm}^2/\text{m} \]

Area of tension reinforcement required

\[ A_{\text{t, toe, req}} = \max(A_{\text{t, toe, req}}, A_{\text{t, toe, min}}) = 898 \text{ mm}^2/\text{m} \]

Reinforcement provided

16 mm dia. bars @ 200 mm centres

\[ A_{\text{t, toe, prov}} = 1005 \text{ mm}^2/\text{m} \]
Check shear resistance at toe
Design shear stress
Allowable shear stress

From BS8110:Part 1:1997 – Table 3.8
Design concrete shear stress

**PASS - Reinforcement provided at the retaining wall toe is adequate**

\[
V_{\text{toe}} = \frac{V_{\text{too}}}{(b \times d_{\text{toe}})} = \frac{0.374 \text{ N/mm}^2}{0.374 \text{ N/mm}^2}
\]

\[
V_{\text{edrm}} = \min(0.3 \times \sqrt{f_{\text{cd}}/1 \text{ N/mm}^2}, 5) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2
\]

**PASS - Design shear stress is less than maximum shear stress**

\[
V_{\text{cd}} = 0.491 \text{ N/mm}^2
\]

\[
V_{\text{too}} < V_{\text{cd}} \to \text{No shear reinforcement required}
\]

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

**Material properties**
- Characteristic strength of concrete: \( f_{\text{c,0}} = 40 \text{ N/mm}^2 \)
- Characteristic strength of reinforcement: \( f_{\text{y}} = 500 \text{ N/mm}^2 \)

**Wall details**
- Minimum area of reinforcement: \( k = 0.13 \% \)
- Cover to reinforcement in stem: \( c_{\text{stem}} = 75 \text{ mm} \)
- Cover to reinforcement in wall: \( c_{\text{wall}} = 75 \text{ mm} \)

**Factorized horizontal at-rest forces on stem**
- Surcharge: \( F_{\text{s, sur,f}} = \gamma_{\text{f,t}} \times K_0 \times \text{Surcharge} \times (h_{\text{f,t}} + b_{\text{base}} - d_{\text{b}}) = 7.1 \text{ kN/m} \)
- Saturated backfill: \( F_{\text{s, s,f}} = 0.5 \times \gamma_{\text{s, s}} \times K_0 \times (h_{\text{s, f}} + \gamma_{\text{water}} h_{\text{f, s}}) = 41.6 \text{ kN/m} \)
- Water: \( F_{\text{s, water,f}} = 0.5 \times \gamma_{\text{s, w}} \times \gamma_{\text{water}} h_{\text{f, water}} = 61.8 \text{ kN/m} \)

**Calculate shear for stem design**
- Surcharge: \( V_{\text{s, sur,f}} = 5 \times F_{\text{s, sur,f}} / 8 = 4.4 \text{ kN/m} \)
- Saturated backfill: \( V_{\text{s, s,f}} = F_{\text{s, s,f}} \times (1 - (a^2 \times (5 \times L) - a) / (20 \times L^2)) = 33.3 \text{ kN/m} \)
- Water: \( V_{\text{s, water,f}} = F_{\text{s, water,f}} \times (1 - (a^2 \times (5 \times L) - a) / (20 \times L^2)) = 49.4 \text{ kN/m} \)
- Total shear for stem design: \( V_{\text{stem}} = V_{\text{s, sur,f}} + V_{\text{s, s,f}} + V_{\text{s, water,f}} = 87.1 \text{ kN/m} \)

**Calculate moment for stem design**
- Surcharge: \( M_{\text{s, sur}} = F_{\text{s, sur,f}} \times L / 8 = 2.9 \text{ kN/m} \)
- Saturated backfill: \( M_{\text{s, s}} = F_{\text{s, s,f}} \times (3a^3 + 15a^2L + 20aL^2) / 60L^2 = 17.9 \text{ kN/m} \)
- Water: \( M_{\text{s, water}} = F_{\text{s, water,f}} \times (3a^3 + 15a^2L + 20aL^2) / 60L^2 = 26.6 \text{ kN/m} \)
- Total moment for stem design: \( M_{\text{stem}} = M_{\text{s, sur}} + M_{\text{s, s}} + M_{\text{s, water}} = 47.3 \text{ kN/m} \)

**Calculate moment for wall design**
- Surcharge: \( M_{\text{sur,f}} = 9 \times F_{\text{s, sur,f}} \times L / 128 = 1.6 \text{ kN/m} \)
- Saturated backfill: \( M_{\text{s, s}} = F_{\text{s, s,f}} \times (a^2x^2 + (5xL - a) / (20xL^2)) / 3a^2 = 8 \text{ kN/m} \)
- Water: \( M_{\text{s, water}} = F_{\text{s, water,f}} \times (a^2x^2 + (5xL - a) / (20xL^2)) / 3a^2 = 11.9 \text{ kN/m} \)
- Total moment for wall design: \( M_{\text{wall}} = M_{\text{sur,f}} + M_{\text{s, s}} + M_{\text{s, water}} = 21.5 \text{ kN/m} \)
Check wall stem in bending
Width of wall stem
Depth of reinforcement
Constant
Lever arm
Area of tension reinforcement required
Minimum area of tension reinforcement
Area of tension reinforcement required
Reinforcement provided
Area of reinforcement provided

Check shear resistance at wall stem
Design shear stress
Allowable shear stress
From BS8110:Part 1:1997 – Table 3.8
Design concrete shear stress

Check mid height of wall in bending
Depth of reinforcement
Constant
Lever arm
Area of tension reinforcement required
Minimum area of tension reinforcement
Area of tension reinforcement required
Reinforcement provided
Area of reinforcement provided

\[ b = 1000 \text{ mm/m} \]
\[ d_{\text{stem}} = t_{\text{wall}} - c_{\text{wall}} - (\phi_{\text{stem}} / 2) = 367.0 \text{ mm} \]
\[ K_{\text{stem}} = M_{\text{stem}} / (b \times x_{\text{stem}}^2 \times f_{\text{c}}) = 0.009 \]

**Compression reinforcement is not required**
\[ z_{\text{stem}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{stem}}, 0.225) / 0.9))),0.95 \times d_{\text{stem}} \]
\[ z_{\text{stem}} = 349 \text{ mm} \]
\[ A_{\text{stem,des}} = M_{\text{stem}} / (0.87 \times f_y \times z_{\text{stem}}) = 312 \text{ mm}^2 / \text{m} \]
\[ A_{\text{stem, min}} = k \times b \times t_{\text{wall}} = 585 \text{ mm}^2 / \text{m} \]
\[ A_{\text{stem,req}} = \max(A_{\text{stem,des}}, A_{\text{stem, min}}) = 585 \text{ mm}^2 / \text{m} \]
16 mm dia. bars @ 200 mm centres
\[ A_{\text{stem,prov}} = 1005 \text{ mm}^2 / \text{m} \]

**PASS - Reinforcement provided at the retaining wall stem is adequate**

\[ V_{\text{stem}} = V_{\text{stem}} / (b \times d_{\text{stem}}) = 0.237 \text{ N/mm}^2 \]
\[ V_{\text{c,stem}} = \min(0.8 \times \sqrt{(f_{\text{c}} / 1 \text{ N/mm}^2}), 5) \times 1 \text{ N/mm}^2 = 5000 \text{ N/mm}^2 \]

**PASS - Design shear stress is less than maximum shear stress**
\[ V_{\text{c,stem}} = 0.491 \text{ N/mm}^2 \]

\[ V_{\text{stem}} < V_{\text{c,stem}} - \text{No shear reinforcement required} \]

\[ d_{\text{wall}} = t_{\text{wall}} - c_{\text{wall}} - (\phi_{\text{wall}} / 2) = 367.0 \text{ mm} \]
\[ K_{\text{wall}} = M_{\text{wall}} / (b \times x_{\text{wall}}^2 \times f_{\text{c}}) = 0.004 \]

**Compression reinforcement is not required**
\[ z_{\text{wall}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{wall}}, 0.225) / 0.9))),0.95 \times d_{\text{wall}} \]
\[ z_{\text{wall}} = 349 \text{ mm} \]
\[ A_{\text{wall,des}} = M_{\text{wall}} / (0.87 \times f_y \times z_{\text{wall}}) = 142 \text{ mm}^2 / \text{m} \]
\[ A_{\text{wall, min}} = k \times b \times t_{\text{wall}} = 585 \text{ mm}^2 / \text{m} \]
\[ A_{\text{wall,req}} = \max(A_{\text{wall,des}}, A_{\text{wall, min}}) = 585 \text{ mm}^2 / \text{m} \]
16 mm dia. bars @ 200 mm centres
\[ A_{\text{wall,prov}} = 1005 \text{ mm}^2 / \text{m} \]
PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection
Basic span/effective depth ratio
Design service stress
Modification factor
Maximum span/effective depth ratio
Actual span/effective depth ratio

\[ \text{ratio}_{\text{bas}} = 20 \]
\[ f_s = 2 \times f_y \times \frac{A_{\text{b, stem req}}}{(3 \times A_{\text{b, stem prov}})} = 194.0 \text{ N/mm}^2 \]
\[ \text{factor}_{\text{mod}} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{\text{stem}}/(b \times d_{\text{stem}}^3)))), 2) = 2.00 \]
\[ \text{ratio}_{\text{max}} = \text{ratio}_{\text{bas}} \times \text{factor}_{\text{mod}} = 40.00 \]
\[ \text{ratio}_{\text{act}} = \frac{h_{\text{stem}}}{d_{\text{stem}}} = 8.17 \]

PASS - Span to depth ratio is acceptable
Indicative retaining wall reinforcement diagram

- Toe reinforcement
- Wall reinforcement
- Stem reinforcement

Toe bars - 16 mm dia. @ 200 mm centres - (1005 mm²/m)
Wall bars - 16 mm dia. @ 200 mm centres - (1005 mm²/m)
Stem bars - 16 mm dia. @ 200 mm centres - (1005 mm²/m)
2) **Wall B**

<table>
<thead>
<tr>
<th>Component</th>
<th>DL (m)</th>
<th>LL (m)</th>
<th>K (kn/m)</th>
</tr>
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<td>0.7</td>
<td>2.7</td>
<td>1.89</td>
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<tr>
<td>LL</td>
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<td>2.7</td>
<td>1.62</td>
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<td>1.0</td>
<td>0.75</td>
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<tr>
<td>LL</td>
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<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>Extg floor</td>
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<td>2.7</td>
<td>2.03</td>
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<tr>
<td>Angle 45°</td>
<td>1.50</td>
<td>2.7</td>
<td>4.06</td>
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<tr>
<td>New floors</td>
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<td>1.0</td>
<td>10.0</td>
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<tr>
<td>Angle 50°</td>
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<td>1.0</td>
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</tr>
<tr>
<td>Wall</td>
<td>0.33</td>
<td>1.9</td>
<td>94.05</td>
</tr>
</tbody>
</table>

**Total DL:** 108.72 kn/m

**Total LL:** 7.93 kn/m

Surcharge = 2.5 kn/m²

*Refer to Tedd's output overleaf*
RETAINING WALL ANALYSIS (BS 8002:1994)

Wall details
Retaining wall type
Height of retaining wall stem
Thickness of wall stem
Length of toe
Length of heel
Overall length of base
Thickness of base
Depth of downstand
Position of downstand
Thickness of downstand
Height of retaining wall
Depth of cover in front of wall
Depth of unplanned excavation
Height of ground water behind wall
Height of saturated fill above base
Density of wall construction
Density of base construction
Angle of rear face of wall
Angle of soil surface behind wall
Effective height at virtual back of wall
Retained material details
Mobilisation factor

Cantilever propped at both

\[ h_{stem} = 3000 \text{ mm} \]
\[ t_{wall} = 450 \text{ mm} \]
\[ l_{toe} = 1500 \text{ mm} \]
\[ t_{base} = 0 \text{ mm} \]
\[ l_{base} = l_{toe} + t_{base} + t_{wall} = 1950 \text{ mm} \]
\[ t_{base} = 450 \text{ mm} \]
\[ d_{too} = 900 \text{ mm} \]
\[ t_{downstand} = 450 \text{ mm} \]
\[ h_{wall} = h_{stem} + t_{base} + d_{too} = 3450 \text{ mm} \]
\[ d_{cover} = 0 \text{ mm} \]
\[ d_{too} = 200 \text{ mm} \]
\[ h_{saturated} = 3450 \text{ mm} \]
\[ h_{sat} = \max(h_{saturated} - t_{base} - d_{too}, 0) = 3000 \text{ mm} \]
\[ \gamma_{wall} = 23.6 \text{ kN/m}^3 \]
\[ \gamma_{base} = 23.6 \text{ kN/m}^3 \]
\[ \alpha = 90.0 \text{ deg} \]
\[ \beta = 0.0 \text{ deg} \]
\[ h_{eff} = h_{wall} + h_{sat} \times \tan(\beta) = 3450 \text{ mm} \]
\[ M = 1.5 \]
Moist density of retained material \( \gamma_m = 18.0 \text{ kN/m}^3 \)
Saturated density of retained material \( \gamma_s = 21.0 \text{ kN/m}^3 \)
Design shear strength \( \phi' = 24.2 \text{ deg} \)
Angle of wall friction \( \delta = 18.6 \text{ deg} \)
Base material details
Moist density \( \gamma_{mb} = 18.0 \text{ kN/m}^3 \)
Design shear strength \( \phi'_b = 24.2 \text{ deg} \)
Design base friction \( \delta_b = 18.6 \text{ deg} \)
Allowable bearing pressure \( P_{bearing} = 200 \text{ kN/m}^2 \)

Using Coulomb theory
Active pressure coefficient for retained material
\[
K_a = \frac{\sin(\alpha + \phi')^2 / (\sin(\alpha)\sin(\alpha - \delta)) \times [1 + \sqrt{\sin(\phi' + 
\delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))}]}{1}
\]
Passive pressure coefficient for base material
\[
K_p = \frac{\sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b))}]}{1}
\]

At-rest pressure
At-rest pressure for retained material \( K_0 = 1 - \sin(\psi) = 0.590 \)

Loading details
Surcharge load on plan \( 2.5 \text{ kN/m}^2 \)
Applied vertical dead load on wall \( W_{\text{dead}} = 108.7 \text{ kN/m} \)
Applied vertical live load on wall \( W_{\text{live}} = 7.9 \text{ kN/m} \)
Position of applied vertical load on wall \( h_{\text{load}} = 1725 \text{ mm} \)
Applied horizontal dead load on wall \( F_{\text{dead}} = 0.0 \text{ kN/m} \)
Applied horizontal live load on wall \( F_{\text{live}} = 0.0 \text{ kN/m} \)
Height of applied horizontal load on wall \( h_{\text{hload}} = 0 \text{ mm} \)

Loads shown in kN/m, pressures shown in kN/m²
Vertical forces on wall
Wall stem
Wall base
Applied vertical load
Total vertical load
Horizontal forces on wall
Surcharge
Saturated backfill
Water
Total horizontal load
Calculate total propping force
Passive resistance of soil in front of wall
Propping force
Overturning moments
Surcharge
Saturated backfill
Water
Total overturning moment
Restoring moments
Wall stem
Wall base
Design vertical dead load
Total restoring moment
Check bearing pressure
Total vertical reaction
Distance to reaction
Eccentricity of reaction
Bearing pressure at toe
Bearing pressure at heel
Calculate propping forces to top and base of wall
Propping force to top of wall
Propping force to base of wall
RETAINING WALL DESIGN (BS 8002:1994)

Ultimate limit state load factors

Dead load factor
\[ \gamma_d = 1.4 \]

Live load factor
\[ \gamma_l = 1.6 \]

Earth and water pressure factor
\[ \gamma_e = 1.4 \]

Factored vertical forces on wall

Wall stem
\[ W_{wall,t} = \gamma_d \times h_{stem} \times l_{wall} \times \gamma_{wall} = 44.6 \text{ kN/m} \]

Wall base
\[ W_{base,t} = \gamma_d \times l_{base} \times \gamma_{base} = 29 \text{ kN/m} \]

Applied vertical load
\[ W_L = \gamma_d \times W_{dead} + \gamma_l \times W_{line} = 164.9 \text{ kN/m} \]

Total vertical load
\[ W_{total,t} = W_{wall,t} + W_{base,t} = 233.5 \text{ kN/m} \]

Factored horizontal at-rest forces on wall

Surcharge
\[ F_{sur,t} = \gamma_l \times K_0 \times \text{Surcharge} \times h_{art} = 8.1 \text{ kN/m} \]

Saturated backfill
\[ F_{s,t} = \gamma_l \times 0.5 \times K_0 \times (k_s \times \gamma_{water}) \times h_{water} = 55 \text{ kN/m} \]

Water
\[ F_{water,t} = \gamma_l \times 0.5 \times h_{water}^2 \times \gamma_{water} = 81.7 \text{ kN/m} \]

Total horizontal load
\[ F_{total,t} = F_{sur,t} + F_{s,t} = 144.9 \text{ kN/m} \]

Calculate total propping force

Passive resistance of soil in front of wall
\[ F_{pr} = \gamma_e \times 0.5 \times K_0 \times \cos(\delta_0) \times (d_{cover} + l_{base} + d_{60} - d_{60}) \times \tan(\delta_0) = 3.1 \text{ kN/m} \]

Propping force
\[ F_{prop} = \max(F_{total,t} - F_{pr}, 0) \times (d_{cover} + l_{base}) \times \tan(\delta_0) = 65.8 \text{ kN/m} \]

Factored overturning moments

Surcharge
\[ M_{sur,t} = F_{sur,t} \times (h_{art} - 2 \times d_{60}) / 2 = 14 \text{ kNm/m} \]

Saturated backfill
\[ M_{s,t} = F_{s,t} \times (h_{water} - 3 \times d_{60}) / 3 = 63.3 \text{ kNm/m} \]

Water
\[ M_{water,t} = F_{water,t} \times (h_{water} - 3 \times d_{60}) / 3 = 94 \text{ kNm/m} \]

Total overturning moment
\[ M_{total,t} = M_{sur,t} + M_{s,t} + M_{water,t} = 171.3 \text{ kNm/m} \]

Restoring moments

Wall stem
\[ M_{wall,t} = W_{wall,t} \times (l_{wall} / 2) = 76.9 \text{ kNm/m} \]

Wall base
\[ M_{base,t} = W_{base,t} \times l_{base} / 2 = 28.3 \text{ kNm/m} \]

Design vertical load
\[ M_v = W \times l_{base} = 284.4 \text{ kNm/m} \]

Total restoring moment
\[ M_{total,t} = M_{wall,t} + M_{base,t} + M_v = 389.7 \text{ kNm/m} \]

Factored bearing pressure

Total vertical reaction
\[ R_t = W_{total,t} = 238.5 \text{ kNm} \]

Distance to reaction
\[ x_{sur,t} = l_{base} / 2 = 975 \text{ mm} \]

Eccentricity of reaction
\[ e_t = abs((l_{base} / 2) - x_{sur,t}) = 0 \text{ mm} \]

Reaction acts within middle third of base

Bearing pressure at toe
\[ p_{toe,t} = (R_t / l_{base}) \times (6 \times R_t \times e_t / l_{base}^2) = 122.3 \text{ kN/m}^2 \]

Bearing pressure at heel
\[ p_{heel,t} = (R_t / l_{base}) \times (6 \times R_t \times e_t / l_{base}^2) = 122.3 \text{ kN/m}^2 \]

Rate of change of base reaction
\[ \text{rate} = (p_{toe,t} - p_{heel,t}) / l_{base} = 0.0 \text{ kN/m}^2 \]

Bearing pressure at stem / toe
\[ p_{stem, toe,t} = \max(p_{toe,t} - (\text{rate} \times l_{base}), 0 \text{ kN/m}^2) = 122.3 \text{ kN/m}^2 \]

Bearing pressure at mid stem
\[ p_{stem,mid,t} = \max(p_{toe,t} - (\text{rate} \times (l_{base} + l_{wall} / 2)), 0 \text{ kN/m}^2) = 122.3 \text{ kN/m}^2 \]

Bearing pressure at stem / heel
\[ p_{stem, heel,t} = \max(p_{toe,t} - (\text{rate} \times (l_{base} + l_{wall})), 0 \text{ kN/m}^2) = 122.3 \text{ kN/m}^2 \]
Calculate propping forces to top and base of wall

Propping force to top of wall

\[ F_{\text{prop\_top\_f}} = (M_{\text{at\_f}} - M_{\text{at\_f}} + R_t \times h_{\text{base}} / 2 - F_{\text{prop\_f}} \times h_{\text{base}} / 2) / (h_{\text{stem}} + h_{\text{base}} / 2) = -0.191 \text{ kN/m} \]

Propping force to base of wall

\[ F_{\text{prop\_base\_f}} = F_{\text{prop\_f}} - F_{\text{prop\_top\_f}} = 65.967 \text{ kN/m} \]

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

Material properties

Characteristic strength of concrete

\[ f_{\text{ct}} = 40 \text{ N/mm}^2 \]

Characteristic strength of reinforcement

\[ f_y = 500 \text{ N/mm}^2 \]

Base details

Minimum area of reinforcement

\[ k = 0.13 \% \]

Cover to reinforcement in toe

\[ c_{\text{toe}} = 75 \text{ mm} \]

Calculate shear for toe design

Shear from bearing pressure

\[ V_{\text{toe\_bear}} = (p_{\text{toe\_f}} + p_{\text{stem\_mid\_f}}) \times h_{\text{toe}} / 2 = 183.5 \text{ kN/m} \]

Shear from weight of base

\[ V_{\text{toe\_wt\_base}} = \gamma_d \times \gamma_{\text{base}} \times h_{\text{toe}} \times b_{\text{base}} = 22.3 \text{ kN/m} \]

Total shear for toe design

\[ V_{\text{toe}} = V_{\text{toe\_bear}} - V_{\text{toe\_wt\_base}} = 161.2 \text{ kN/m} \]

Calculate moment for toe design

Moment from bearing pressure

\[ M_{\text{toe\_bear}} = (2 \times p_{\text{toe\_f}} + p_{\text{stem\_mid\_f}}) \times (h_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = 182 \text{ kNm/m} \]

Moment from weight of base

\[ M_{\text{toe\_wt\_base}} = (\gamma_d \times \gamma_{\text{base}} \times h_{\text{toe}} \times (h_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2 = 22.1 \text{ kNm/m} \]

Total moment for toe design

\[ M_{\text{toe}} = M_{\text{toe\_bear}} - M_{\text{toe\_wt\_base}} = 159.8 \text{ kNm/m} \]

Check toe in bending

Width of toe

\[ b = 1000 \text{ mm/m} \]

Depth of reinforcement

\[ d_{\text{toe}} = d_{\text{base}} - c_{\text{toe}} = (d_{\text{toe}} / 2) = 365.0 \text{ mm} \]

Constant

\[ K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_{\text{ct}}) = 0.030 \]

Compression reinforcement is not required

\[ z_{\text{toe}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{toe}}, 0.225) / 0.9)), 0.95}) \times d_{\text{toe}} = 347 \text{ mm} \]

Lever arm

Area of tension reinforcement required

\[ A_{s\_\text{toe\_dec}} = M_{\text{toe}} / (0.87 \times f_y \times z_{\text{toe}}) = 1060 \text{ mm}^2 / \text{m} \]

Minimum area of tension reinforcement

\[ A_{s\_\text{toe\_min}} = k \times d \times h_{\text{base}} = 585 \text{ mm}^2 / \text{m} \]

Area of tension reinforcement required

\[ A_{s\_\text{toe\_req}} = \max(A_{s\_\text{toe\_dec}}, A_{s\_\text{toe\_min}}) = 1060 \text{ mm}^2 / \text{m} \]

Reinforcement provided

\[ 20 \text{ mm dia. bars @ 200 mm centres} \]

Area of reinforcement provided

\[ A_{s\_\text{toe\_proj}} = 1571 \text{ mm}^2 / \text{m} \]
Check shear resistance at toe

Design shear stress

Allowable shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress

Material properties

Characteristic strength of concrete

Characteristic strength of reinforcement

Wall details

Minimum area of reinforcement

Cover to reinforcement in stem

Cover to reinforcement in wall

Factored horizontal at-rest forces on stem

Surcharge

Saturated backfill

Water

Calculate shear for stem design

Surcharge

Saturated backfill

Water

Total shear for stem design

Calculate moment for stem design

Surcharge

Saturated backfill

Water

Total moment for stem design

Calculate moment for wall design

Surcharge

Saturated backfill

Water

Total moment for wall design

PASS - Reinforcement provided at the retaining wall toe is adequate

\[ v_{toe} = V_{tol} / (b \times d_{toe}) = 0.442 \text{ N/mm}^2 \]

\[ v_{adm} = \min (0.8 \times \sqrt{f_{cu} / 1 \text{ N/mm}^2}), 5 \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2 \]

PASS - Design shear stress is less than maximum shear stress

\[ V_{toe} \leq V_{c, toe} = 0.571 \text{ N/mm}^2 \]

\[ V_{toe} < V_{c, toe} - \text{No shear reinforcement required} \]
Check wall stem in bending
Width of wall stem
Depth of reinforcement
Constant
Lever arm
Area of tension reinforcement required
Minimum area of tension reinforcement
Area of tension reinforcement required
Reinforcement provided
Area of reinforcement provided

Check shear resistance at wall stem
Design shear stress
Allowable shear stress

From BS8110:Part 1:1997 – Table 3.8
Design concrete shear stress

Check mid height of wall in bending
Depth of reinforcement
Constant
Lever arm
Area of tension reinforcement required
Minimum area of tension reinforcement
Area of tension reinforcement required
Reinforcement provided
Area of reinforcement provided

\[ b = 1000 \text{ mm/m} \]
\[ d_{\text{stem}} = t_{\text{wall}} - c_{\text{stem}} - (\phi_{\text{stem}} / 2) = 367.0 \text{ mm} \]
\[ K_{\text{stem}} = M_{\text{stem}} / (b \times d_{\text{stem}}^2 \times f_{\text{cu}}) = 0.009 \]

**Compression reinforcement is not required**

\[ z_{\text{stem}} = \text{min}(0.5 \times \sqrt{(0.25 - (\text{min}(K_{\text{stem}}, 0.225) / 0.95)), 0.95} \times d_{\text{stem}} \]
\[ z_{\text{stem}} = 349 \text{ mm} \]
\[ A_{s_{\text{stem-des}}} = N_{\text{stem}} / (0.87 \times f_y \times z_{\text{stem}}) = 312 \text{ mm}^2 / \text{m} \]
\[ A_{s_{\text{stem-min}}} = k \times b \times t_{\text{wall}} = 585 \text{ mm}^2 / \text{m} \]
\[ A_{s_{\text{stem-req}}} = \text{Max}(A_{s_{\text{stem-des}}}, A_{s_{\text{stem-min}}}) = 585 \text{ mm}^2 / \text{m} \]

16 mm dia.bars @ 200 mm centres
\[ A_{s_{\text{stem-prov}}} = 1005 \text{ mm}^2 / \text{m} \]

**PASS - Reinforcement provided at the retaining wall stem is adequate**

\[ V_{\text{stem}} = V_{\text{stem}} / (b \times d_{\text{stem}}) = 0.237 \text{ N/mm}^2 \]
\[ V_{\text{stem}} = \text{min}(0.8 \times \sqrt{(f_{\text{cu}} / 1 \text{ N/mm}^2), 5}) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2 \]

**PASS - Design shear stress is less than maximum shear stress**

\[ V_{\text{c-stem}} = 0.491 \text{ N/mm}^2 \]

\[ V_{\text{c-stem}} < V_{\text{c-stem}} - \text{No shear reinforcement required} \]

\[ d_{\text{wall}} = t_{\text{wall}} - c_{\text{wall}} - (\phi_{\text{wall}} / 2) = 367.0 \text{ mm} \]
\[ K_{\text{wall}} = M_{\text{wall}} / (b \times d_{\text{wall}}^2 \times f_{\text{cu}}) = 0.004 \]

**Compression reinforcement is not required**

\[ z_{\text{wall}} = \text{min}(0.5 \times \sqrt{(0.25 - (\text{min}(K_{\text{wall}}, 0.225) / 0.95)), 0.95} \times d_{\text{wall}} \]
\[ z_{\text{wall}} = 349 \text{ mm} \]
\[ A_{s_{\text{wall-des}}} = M_{\text{wall}} / (0.87 \times f_y \times z_{\text{wall}}) = 142 \text{ mm}^2 / \text{m} \]
\[ A_{s_{\text{wall-min}}} = k \times b \times t_{\text{wall}} = 585 \text{ mm}^2 / \text{m} \]
\[ A_{s_{\text{wall-req}}} = \text{Max}(A_{s_{\text{wall-des}}}, A_{s_{\text{wall-min}}}) = 585 \text{ mm}^2 / \text{m} \]

16 mm dia.bars @ 200 mm centres
\[ A_{s_{\text{wall-prov}}} = 1005 \text{ mm}^2 / \text{m} \]
PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection
Basic span/effective depth ratio
Design service stress
Modification factor
Maximum span/effective depth ratio
Actual span/effective depth ratio

\[
\text{ratio}_{bas} = 20
\]
\[
f_s = 2 \times f_y \times A_{s, \text{stem, req}} / (3 \times A_{s, \text{stem, prov}}) = 194.0 \, \text{N/mm}^2
\]
\[
factor_{\text{mod}} = \min (0.55 + (477 \, \text{N/mm}^2 - f_s) / (120 \times (0.9 \, \text{N/mm}^2 + (M_{\text{stem}} / (b \times d_{\text{stem}}))^2)), 2) = 2.00
\]
\[
\text{ratio}_{\text{max}} = \text{ratio}_{bas} \times factor_{\text{mod}} = 40.00
\]
\[
\text{ratio}_{\text{act}} = \frac{h_{\text{stem}}}{d_{\text{stem}}} = 8.17
\]

PASS - Span to depth ratio is acceptable
Indicative retaining wall reinforcement diagram

Toe bars - 20 mm dia.@ 200 mm centres - (1571 mm²/m)
Wall bars - 16 mm dia.@ 200 mm centres - (1005 mm²/m)
Stem bars - 16 mm dia.@ 200 mm centres - (1005 mm²/m)