Construction Method Statement
for
22 Marloes Road, London
Job Number: 10-5372

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
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<tr>
<td>A</td>
<td>4 June 2014</td>
<td>First issue</td>
</tr>
<tr>
<td>B</td>
<td>2 September 2014</td>
<td>Revised report</td>
</tr>
<tr>
<td>C</td>
<td>26 February 2016</td>
<td>Revised scheme</td>
</tr>
<tr>
<td>D</td>
<td>7 September 2017</td>
<td>Report updated</td>
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Appendix A ................................................................................................................................................
A1. Structural calculation package

Appendix B

B1. Structural drawing package
1. Project

1.1. Introduction
The structural solution adopted is based on Peter Dann Limited experience gained on many similar projects which have been constructed without detrimental effects to the structure above or to adjoining buildings.

The construction process has been developed to follow familiar tried and tested techniques used on many projects. The method of construction is within the scope and capability of a competent contractor with previous basement construction experience.

The Construction Method Statement is intended to show how the design issues have been addressed and how these relate to or influence the construction of the basement.

The document will aim to define the method of construction of the proposed basement and the temporary works to be carried out by the appointed contractor.

The works will fall within The Party Wall Act 1996 which will require condition surveys to be carried out to the adjoining properties. The proposed structural drawings and calculations will be issued to the adjoining owner’s engineers to ensure that the stability of the adjoining properties is maintained.

1.2. Existing building
22 Marloes Road is a five storey mid-terrace dwelling consisting of self-contained flats with lower ground, upper ground, first, second and third floors.

The existing structure is formed in load bearing masonry with timber joisted floors. There is a three storey extension to the rear of the building. It is assumed that this was part of the original building.

There are internal load bearing walls which are likely to be masonry or load bearing timber stud with what can be assumed to be the original openings. The existing roof is a traditional pitched roof.

The buildings in the area were damaged by a bomb during WWII. The damage to the property and the adjoining properties is not known but it has been reported that cracking is present and chimney breasts are fragile and vulnerable.

1.3. Overview of proposals
The proposed works is the construction of a single level basement beneath the existing building. The basement extension will cover the existing footprint of the building. The basement will cover 50% of the plot. The purpose of the works is to form new dwellings within the new basement space.

It is understood that similar extensions have been granted permission and subsequently built on other houses on the same street recently.
1.4. Basement construction
The proposed basement will be formed using reinforced concrete underpinning to the existing walls around the perimeter of the building. The new lower ground floor level will consist of a concrete slab with down stand ground beams on the load bearing wall lines which will support the load from the walls above. The beams will be formed by using the stalled beams method to negate the need for temporary works to support the walls during construction of the basement.

A drained cavity waterproofing system will be installed to provide a type C form of construction thus providing habitable grade 3 basement. The construction will include the following flood proofing measures: installation of a Delta membrane system (or equivalent waterproof membrane system) to the internal face of the basement walls and floors of the basement; installation of a sump and pump system to expel any water ingress; all joints between walls and frames of windows and doors to basement rooms must be sealed; all pipes must be sealed; and there are no air bricks proposed at basement floor level.

A system of regular monitoring will be adopted during the construction of the substructure to assess any possible structural movement in the existing adjacent buildings. Refer to Section 3.1.1 for more information.

The lowest basement level is to be designed to take account of potential uplift due to an increase in existing water levels and heave of any underlying clay strata. This will be achieved by having the basement slab spanning between the underpinned load bearing walls.

1.5. Stability
The load bearing masonry building above will be capable of transferring the existing lateral loads to the substructure walls and foundations. The substructure will then dissipate this load to the substrata.

Additional tying through strapping of all floors to the masonry walls will enhance the stability and robustness of the building. Where cracking exists in the masonry repair by stitching, for example, by a specialist crack repair company will be specified.

Where existing walls that currently offer stability to the building are removed or additional openings are added, steel stability frames may be required to ensure that no. 22 remains independently stable. This will also mean that no additional lateral load will be imposed on the adjoining properties.

1.6. Robustness
The existing building is currently five storeys plus mansard with basement. The building is to have an additional single storey basement. In accordance with the Building Regulation Approved Document A 2004 Edition, the building falls with the class 2B. However, if the basement is designed as a class 2B structure the superstructure can be designed to the less onerous class 2A level.
The new reinforced concrete basement can easily be designed to fulfil the robustness requirements of the Approved Document.

As stated above additional tying of all floors to the masonry walls will also enhance the robustness of the building.
2. Site and ground conditions

2.1. Ground conditions
The site investigations have been undertaken by Chelmer Site Investigations (CSI). Refer to the site investigation report produced by CSI.

The site investigation by CSI comprised of four trial pits and one borehole. The borehole was drilled at the front of the building, in the light well, using continuous flight auger (CFA) equipment. Three trial pits were excavated at the front of the property at lower basement level in order to expose the foundations; one (TP1) on the front wall and party wall, one (TP2) on the front bay window and one (TP4) on the front wall and party wall. A further trial pit (TP3) was excavated at the rear of the property to also expose the foundations on the rear wall and party wall. For detailed results refer to the CSI site investigation report.

2.1.1. Trial pits
The foundations exposed in the trial pits on the front and rear walls were found to bear onto silty, gravelly, coarse sand. The internal pits showed that the walls were founded on made ground which comprised of clayey, sandy silt with gravel and brick fragments throughout. The footing details are depicted in the CSI report, but are summarised as follows:

- TP1: Founded 0.39m below internal floor level with 2 corbels projecting 130mm from the face of wall;
- TP2: Founded at 0.35m below external ground level with 2 corbels projecting 105mm from the face of wall;
- TP3: On the rear wall it was founded at 0.35m below external ground level with 4 corbels projecting 255mm from the face of wall and on the party wall it was founded at 0.325m below external ground level with 3 corbels projecting 225mm from the face of wall;
- TP4: Founded at 0.34m below internal floor level with 2 corbels projecting 120mm from the face of wall.

2.1.2. Borehole
The borehole (BH1) at the front of the building, in the light well, penetrated a 0.1m thick concrete slab and then 0.7m of made ground, being gravelly, silty, fine sand with numerous brick and concrete fragments. Immediately beneath the made ground was silty, gravelly, medium and coarse sand which can be assumed to be attributed to the River Terrace Deposits. Below 5.4m the borehole recorded very stiff, silty clay with partings of silt and fine sand. The clay continued to the base of the borehole at 10.0m below ground level and is attributed to the London Clay. The base of the London Clay Formation was not proven.

2.1.3. Made ground
As per the CSI site investigation report, the made ground was silt with varying secondary constituents, locally becoming silty sand while there were also gravel and brick fragments present.
throughout. Where the underlying natural soils were located the thickness of the made ground ranged from 0.33m to 0.8m, although the two internal trial pits did not find the base of the made ground at depths of 0.6m. Made ground appeared to form the founding material where footings were investigated by the internal trial pits. No groundwater entries were recorded from the made ground in any of the exploratory holes. The possibility remains that perched groundwater will be present locally and/or intermittently within the made ground.

2.1.4. Kempton Park Gravel
Kempton Park Gravel is a formation combining sand and gravel. These superficial deposits formed up to 2 million years ago in the Quaternary Period in a local environment that was previously dominated by rivers. As a result, these rocks were formed from rivers depositing mainly sand and gravel detrital material in channels to form river terrace deposits, with fine silt and clay from overbank floods forming floodplain alluvium, and some bogs depositing peat; including estuarine and coastal plain deposits mapped as alluvium.

These River Terrace Deposits were proved in trial pits TP2 and TP3, and in borehole BH1 where grading analyses indicated a fining downwards sequence from a sand and gravel around 1.0m to a gravelly medium and coarse sand around 3.0m. These deposits are typically medium dense to dense.

2.1.5. Upper aquifer
Groundwater entry into BH1 was noted at 5.3m, 0.1m above the base of the River Terrace Deposit; although the standpipe installed in that borehole was dry when monitored on 16 May 2014. Thus, minimal or no upper aquifer was present at the time of the investigation which followed an unusually wet winter. This would suggest that the aquifer was being drained in the vicinity of the site, probably by the nearby cutting for London Underground’s railway lines.

2.1.6. London Clay
London Clay is a formation combining clay and silt. It is sedimentary bedrock that formed approximately 34 to 56 million years ago in the Palaeogene Period.

This was proved in the borehole at 5.4m below ground level. It comprised very stiff, silty clay with occasional selenite and partings of silt and fine sand.

These clays are typically fissured which will reduce their strength, and they may contain claystone concretions. Elevated sulphate levels from the selenite, a form of sulphate, will be aggressive to buried concrete.

Groundwater pressures in the London Clay are expected to be hydrostatic within the depth of current interest, with only very limited groundwater seepage through any silt/sand partings which are present and sufficiently interconnected.
2.1.7. Basement heave
Refer to the report by CSI for a Preliminary Heave Assessment. The proposed basement will be founded at a uniform level, with a finished floor Level at 3.35m below the rear courtyard and front light well and 4.05m below the rear garden. As a result, it has been estimated that the excavation of soil to form the proposed basement will result in an approximate unloading of 75kN/m². This unloading could result in heave of the underlying London Clay, which will result in short term elastic movement. Most if not all of the elastic heave beneath each underpinning base will be reversed as soon as the drypack is installed to the pins and the load from the superstructure is transferred to the new foundation. Elastic heave from the excavation could extend beyond the footprint of the basement but this will be complete before the new basement is cast. The rate of the plastic swelling is dependent on the availability of water. The basement slab will be stiff enough to accommodate the swelling pressures/displacements developed underneath it.

Any movement will be resisted to some extent by the weight of the sand and gravel that will remain above the clay and also by the building that will be retained but these movements will be considered in more detail during detailed design of the structure. Typical design heave pressures would be in the region of 20kN/m² less any dead load.

2.1.8. Spread foundations
It will be possible to support the building on the new underpinning in the Kempton Park Gravel below the proposed basement level. Assuming that ground water is not identified it should be possible to complete the basement by traditional underpinning of the existing foundations in this soil layer.

Moderate width spread foundations or the toes to the underpinning will be designed to apply a net allowable bearing pressure of 120kN/m² within the loose sand and gravels.

2.2. Hydrogeological assessment
Refer to report produced by CSI. The hydrogeological regime will be affected by long-term climatic variations as well as seasonal fluctuations, all of which must be taken into account when selecting a design water level for the permanent works. No multi-seasonal monitoring data are available so a conservative approach will be needed, in accordance with current geotechnical design standards which require use of ‘worst credible’ groundwater levels/pressures. Refer to the CSI site investigation report for further details on this.

The construction of a basement beneath the existing lower ground floor would not increase the proportion of hard surfaced/paved areas and additional surface water (rainfall and run-off) should therefore not be generated or introduced to adjacent properties, sewers or the ground. Also refer to the CSI site investigation report.
2.3. Conclusion

Based on the above, the new basement will be founded within the Kempton Park Gravel. It would be prudent to allow for some pumping during excavation should water be encountered.

Care should be taken during excavation to ensure that support is not removed from beneath the building under consideration and adjacent structures including the adjoining dwellings, services and possibly the footpath and highway.

The stability of excavation will need to be assessed during construction. However, a conservative approach in the design of any shoring of excavations should be adopted and it is reasonable to assume that excavations on site will be unstable within the predominately granular strata and will require adequate close support. Support should be designed to prevent loss of material and minimise deflections that could lead to associated settlement of adjacent ground/structures.

The basement excavation to a depth of approximately 3.9m, increasing to 4.6m below the rear garden, below lower ground floor level should not encounter the water table. In addition to the above, some minor inflows of perched water may be experienced during excavation, particularly from above more cohesive layers within the strata. This should be minimal and simple pumping should be adequate to deal with any such flow. Care should be taken to prevent loss of material which may cause loss of support and potential settlements.
3. Construction phase

3.1. Boundaries and adjoining structures
The Party Wall Act etc. (1996) calls for a survey of the boundary walls and the condition of the gardens and any other structures that are close to the works. The survey would be conducted by both the Party Wall Surveyors together and would result in a detailed description of the state of repair and highlight obvious flaws or disrepair to the buildings.

Since it is within a terrace, the property borders 24 Marloes Road to the North and 20 Marloes Road to the South. The rear garden of the property backs on to the gardens of Lexham Gardens to the East.

The existing ground levels in the garden of the property and other surround properties are unknown. Also, it is unknown as to whether or not basement extensions have been undertaken by the surrounding properties. Further investigation will determine the ground levels and the depths of any surrounding basements and also the location of load bearing cross walls and depths of all existing footings will be established prior to the detailed design stage.

3.1.1. Stability of adjoining structures
The new concrete basement structure will be designed to withstand any loads from the adjoining properties, for example surcharges from the cross walls. The retaining walls, or underpinning, will be propped at ground floor by the concrete slab in the permanent situation and propped at all times during construction with temporary works, where necessary. This will be designed to minimise any movements in the adjoining properties.

If cross walls are being removed within the superstructure of the existing building the lateral stability will be maintained by introducing portalised frames that replace the stiffness in the structure to maintain the stability of the terrace. The frames would transfer the lateral loads, via the concrete structure, to the strata below.

3.2. Monitoring
The party walls are to be monitored during the works for movement. Specialist surveying companies will set up a regime of monitoring using targets and, if necessary, tilt sensors on the neighbouring properties and garden walls.

Precise levelling would be conducted on a regular basis but data will be automatically collected at pre agreed intervals and will be made available to the interested parties.

Trigger levels and subsequent actions will be agreed and the following actions will be taken should the agreed levels be exceeded.
3.3. Structural proposals

3.3.1. Underpinning

The perimeter walls to the new basement will be formed by constructing reinforced concrete underpins around the perimeter of the property.

The pins are to be formed in a single stage and are to be constructed in a hit and miss sequence to be agreed with the contractor. The pins are to be founded at a depth approximately 3.9 and 4.6m below the depth of the existing lower ground floor level. Excavation for the pins is to be by hand unless an alternative approach is agreed between the contractor and engineer. It may be that a 2 stage pin would be adopted to the underpinning to the rear garden.

Pins will be individually reinforced and have a maximum width of 1.2m if the existing masonry is of sufficient quality to span unsupported over this length and it is safe to do so. They will be dowelled together to assist with the load spread.

Following the construction of each pin the excavation is to be backfilled until all of the pins are complete. The new lower ground floor slab can then be cast or temporary propping installed depending on the sequence chosen and the mass excavation can commence.

3.3.2. Temporary works

The extent of temporary works depends on the sequence of construction which will be established and finalised with the contractor. The suggested method is given in section 3.3.4.

Temporary works will be required to the pins during the mass excavation for the basement. If a top down method is adopted then the need for high level propping is negated. This method is suggested for the basement beneath the house and the rear garden. There is also a need to prop at the low level until the basement slab is installed. The level will be established during the detailed design and the temporary works will be designed to minimise the movement to the walls. It is possible to construct the basement slab in slots to reduce the need for the low level temporary works.
The use of “stalled beams” at the new ground level on the load bearing wall lines means that temporary works to the superstructure is minimised.

The recommendations given in the CSI report should be adhered to in the sequencing especially with regard to the reduction in ground level and removal of surcharge prior to carrying out the underpinning, which needs to be avoided.

3.3.3. Ground movement

We are of course obliged to point out that, as is inherent with substructure works of this scale, the construction of the basement could result in a small amount of movement of the adjacent ground which may cause some limited damage to adjoining properties. The method statements and sequence of construction, along with the calculations using appropriate factors of safety will be put in place to minimise any movements. In the unlikely event that some minor movement does occur the remedial works and repair will be dealt with under the Party Wall Agreement.

The suggested sequencing and temporary propping proposals will need to be carefully adhered to by the contractor. Every effort will be made to minimise this movement by designing and installing adequate temporary propping and careful sequencing. Detailed analysis of the pins will enable the optimum time and level for temporary propping.

Temporary works will be designed to ensure that any damage to adjacent buildings is limited to category O (negligible) or I (very slight) as stated in BRE Digest 251.

3.3.4. Proposed construction design sequence

The following is the suggested sequence of construction which will be reviewed and finalised with the contractor, with reference to associated drawings:

1. Carry out the underpinning to the perimeter of the basement in an agreed hit and miss sequence. Dry pack to the underside of existing structure and back fill each pin as it is completed. Refer to notes on drawing 10-5372_XX-DR-S301 and 10-5372_XX-DR-S302 for notes on construction of each pin.

2. Once all of the underpinning is complete construct reinforced concrete beams beneath the existing load bearing walls. Construct using the “stalled beam” method. These will span between the pins on each side.

3. Remove remainder of the existing lower ground floor construction and excavate enough for new lower ground floor to be constructed on the ground.

4. Construct the new reinforced concrete lower ground floor slab spanning between the stalled beams and the underpinning, leaving a suitable void at the front to enable the excavated spoil to be removed. Slab to be connected to supporting structure via dowels or Kwikastrip cast into the underpinning.

5. Excavate beneath the new lower ground level once the slab has cured.

6. Excavate to level requiring lateral propping. Exact depth to be determined with the contractor and is subject to detailed design.
7. Install temporary works propping the underpinning across the site.
8. Continue excavation to formation level and install below ground drainage.
9. Construct new basement slab dowelling into underpinning, leaving out enough space to enable pump chamber to be constructed.
10. Remove temporary propping once the basement slab has cured.
11. Excavate and construct pump chamber. Allow for some dewatering for this process.
12. Install drained cavity waterproofing system in line with manufacture details.

An alternative method of construction would involve a bottom up method for the house section also. A further level of temporary propping would be required at the upper level as well as more temporary piles to support the vertical loads should the stalled beam not be adopted.

3.4. Conclusion
The project involves tried and tested methods of construction that have been adopted on many projects in London and local to Marloes Road. The works can be carried out by a competent contractor experienced in this form of construction. It is considered, therefore, that the project can be implemented without any detrimental effect on the property above or the adjoining buildings.

One of the site requirements will be to make sure that the vibration and noise levels will be kept to a minimum. All plant and machinery will be selected based on low vibration and minimal noise. The use of top down construction further reduces the disruption to the neighbours from noise and dust for example.
4. Certification
This report has been produced by:

Richard Broadley BEng MSc
Project Engineer

Kevin Short MEng CEng MICE
Technical Director
Appendix A

A1. Structural calculation package
PROJECT

TITLE 22 Marloes Road
JOB No 10-5372

Client
Ms Pauline Chou

Quality Assurance – Approval Status
This document has been checked in accordance with
Peter Dann’s Management System
(ISO 9001:2000 accredited)

Prepared by

Richard Broadley
BEng MSc

Checked by

Approved by

Kevin Short
MEng CEng MICE

Kevin Short
MEng CEng MICE
GENERAL AND SAFETY NOTES

Building Regulations Approval
Most structural alterations will require Building Regulations approval and must be inspected by an Approved Inspector prior to concealing or covering structural members. It is the client’s and contractor’s responsibility to ensure that applications and inspections have been carried out.

Planning Permission
Planning permission may or may not be required in connection with the work described herein, and a suitably qualified architect or planning advisor should be consulted before commencement of work.

Party Wall Agreements
Structural alterations to a Party Wall, or excavations in the vicinity of a neighbour’s property, will require the adjoining owner’s consent under the Party Wall Act 1996. This will require a Party Wall Agreement to be made before commencement of the works. Advice may be obtained from the government Planning Portal www.planningportal.gov.uk or by contacting a Chartered Building Surveyor.

Safety
This information is provided in the expectation that those appointed to carry out the work are suitably qualified and experienced contractors. If there is any doubt about aspects of the specification, the engineer should be contacted before commencement of work on site. The work described should be capable of being carried out using the normal range of skills and equipment expected of a competent general contractor. If any operations are outside this norm a method statement or more detailed description of the procedure should be requested. Excavations in excess of 1.2 metres deep or in unstable ground should not be entered by any person unless a system of shoring or ground support has been installed. Any variation between the architect’s drawings and specification and this information should be brought to the attention of the architect and engineer immediately.

Temporary Support
Installation of beams, lintels or other supporting structures should be undertaken only with the provision of suitable temporary support to the structure above. Attention should be paid to the nature of the supported loads (from the calculations) and the capacity of props, shores and needle beams as appropriate. If in doubt about the requirements, contact the engineer before commencement of work.

Dimensions etc
The dimensions given in these documents are for design purposes only and should be checked on site for construction. Beam sizes are given for identification of the section and the span dimension is between centrelines of supports (i.e. neither the length of the beam nor the opening width).

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**Calculations**

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Reinforced concrete slab (internal)

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Reinforced concrete slab (external)

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Wall (external)

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| Roof, 25° pitched | **Dead**<br>
<p>|                 | Tiles, slates                                | 0.55            |
|                 | Rafters and insulation                       | 0.20            |
|                 | Ceiling and services                         | 0.15            |
|                 | <strong>0.9</strong>&lt;br&gt;cos 25                            | <strong>0.90</strong>&lt;br&gt;    |
|                 | * = 0.90 ≈ 1.0                               | <strong>g_k = 1.0 kN/m^2</strong> |
|                 | <strong>Imposed load</strong>                             |                 |
|                 | Snow and access                              | 0.75            |
|                 | <strong>0.75</strong>&lt;br&gt;cos 25                           | <strong>0.83</strong>&lt;br&gt;     |
|                 | * = 0.83 ≈ 0.8                               | <strong>g_k = 0.8 kN/m^2</strong> |</p>
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<td>Assumptions</td>
<td></td>
</tr>
<tr>
<td>- Floor piers span front to back.</td>
<td></td>
</tr>
<tr>
<td>- Floor piers are supported on central spine wall.</td>
<td></td>
</tr>
</tbody>
</table>

**Floor spans (without descent roof span)***

- 3F: 9.825 m + (3.425 m)
- 2.5F: 3.625 m
- 2F: 9.9 m
- 1.5F: 3.625 m
- 1F: 9.9 m
- 0.5F: 3.625 m + (1.9 m)
- G: 9.0 m + (2.45 m)
- L.G.F: 6.5 m
- B: 18.5 m

**Roof span**

- 10.5 m

**Load Takedown**

Refer to attached sketches Sk.300, Sk.301 and Sk.302 for load takedown. Loading at each floor level seen in loading as shown on Sk.300.
**Overview**

Design of ground floor reinforced concrete slab.

**Analysis**

- **DL**: 9.9 kN/m²
- **LL**: 1.5 kN/m²

Max. span of slab: 3.850 m

Concrete reinforcement: 30 mm

Assume 12 mm reinforcement bars.

\[
\begin{align*}
d &= \frac{250 - 30 - 1.2}{2} = 214 \text{ mm} \\
W &= 1.4 \times 8.9 + 1.6 \times 1.5 = 14.86 = 14.9 \text{ kN/m}^2 \\
M &= \frac{14.9 \times 3.9^2}{8} = 28.3 \text{ kNm} \\
V &= \frac{14.9 \times 3.9}{2} = 29.06 = 29.1 \text{ kN}
\end{align*}
\]

See attached TEDDS analysis for design of slab.

**Summary**

Use 250 mm reinforced concrete slab with A393 mesh reinforcement.
RC SLAB DESIGN (BS8110:PART1:1997)

CONCRETE SLAB DESIGN (CL 3.5.3 & 4)

SIMPLE ONE WAY SPANNING SLAB DEFINITION

Overall depth of slab \( h = 250 \text{ mm} \)

Cover to tension reinforcement resisting sagging \( c_o = 30 \text{ mm} \)

Trial bar diameter \( D_{tyk} = 12 \text{ mm} \)

Depth to tension steel (resisting sagging)

\[
d_x = h - c_o - D_{tyk}/2 = 214 \text{ mm}
\]

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

Characteristic strength of concrete \( f_{cu} = 35 \text{ N/mm}^2 \)

![One-way spanning slab](image)

ONE WAY SPANNING SLAB (CL 3.5.4)

MAXIMUM DESIGN MOMENTS IN SPAN

Design sagging moment (per m width of slab) \( m_{ax} = 28.3 \text{ kNm/m} \)

CONCRETE SLAB DESIGN – SAGGING – OUTER LAYER OF STEEL (CL 3.5.4)

Design sagging moment (per m width of slab) \( m_{ax} = 28.3 \text{ kNm/m} \)

Moment Redistribution Factor \( \beta_{mx} = 1.0 \)

Area of reinforcement required

\[
K_s = \frac{\text{abs}(m_{ax})}{(d_x^2 \times f_{cu})} = 0.018
\]

\[
K_s' = \min \left( \frac{0.156 \times (0.402 \times (\beta_{mx} - 0.4)) - (0.18 \times (\beta_{mx} - 0.4)^2)}{0.25 - K_s \times 0.9} \right) = 0.166
\]

Outer compression steel not required to resist sagging

Slab requiring outer tension steel only - bars (sagging)

\[
z_x = \min \left( \frac{(0.95 \times d_x)(d_x \times (0.5 + (0.25 - K_s \times 0.9)))}{0.25 - K_s \times 0.9} \right) = 203 \text{ mm}
\]

Neutral axis depth \( x_a = (d_x - z_x) / 0.45 = 24 \text{ mm} \)

Area of tension steel required

\[
A_{sx,req} = \frac{\text{abs}(m_{ax})}{(1/f_{y} \times z_x) = 320 \text{ mm}^2/m}
\]

Tension steel

Provide 10 dia bars @ 200 centres outer tension steel resisting sagging

\[
A_{sx,prov} = A_{sx} = 393 \text{ mm}^2/m
\]
TRANSVERSE BOTTOM STEEL - INNER
Inner layer of transverse steel

Provide 10 dia bars @ 200 centres
\[ A_{st,prov} = A_{st} = 393 \text{ mm}^2/\text{m} \]

Check min and max areas of steel resisting sagging
Total area of concrete \( A_c = h = 250000 \text{ mm}^2/\text{m} \)
Minimum % reinforcement \( k = 0.13 \% \)
\[ A_{st,min} = k \times A_c = 325 \text{ mm}^2/\text{m} \]
\[ A_{st,max} = 4 \% \times A_c = 10000 \text{ mm}^2/\text{m} \]
Steel defined:
Outer steel resisting sagging \( A_{st,prov} = 393 \text{ mm}^2/\text{m} \)  
Area of outer steel provided (sagging) OK

Inner steel resisting sagging \( A_{st,prov} = 393 \text{ mm}^2/\text{m} \)  
Area of inner steel provided (sagging) OK

SHEAR RESISTANCE OF CONCRETE SLABS (CL 3.5.5)
Outer tension steel resisting sagging moments
Depth to tension steel from compression face \( d_a = 214 \text{ mm} \)
Area of tension reinforcement provided (per m width of slab) \( A_{st,prov} = 393 \text{ mm}^2/\text{m} \)
Design ultimate shear force (per m width of slab) \( V_s = 29 \text{ kN/m} \)
Characteristic strength of concrete \( f_{cu} = 35 \text{ N/mm}^2 \)

Applied shear stress
\[ V_s = V_s / d_a = 0.14 \text{ N/mm}^2 \]

Check shear stress to clause 3.5.5.2
\[ V_{allowable} = \min \left( (0.8 \text{ N/mm}^2) \times \sqrt{f_{cu}}, 5 \text{ N/mm}^2 \right) = 4.73 \text{ N/mm}^2 \]
Shear stress - OK

Shear stresses to clause 3.5.5.3
Design shear stress
\[ f_{cu,reqd} = \frac{f_{cu}}{40 \text{ N/mm}^2, 40/25, f_{cu}/(25 \text{ N/mm}^2)} = 1.400 \]
\[ V_{ov} = 0.79 \text{ N/mm}^2 \times \min(3.100 \times A_{st,prov} / d_a^{1/3}) \times \max(0.67(400 \text{ mm} / d_a)^{1/3}) / 1.25 \times f_{cu,reqd}^{1/2} \]
\[ V_{ov} = 0.47 \text{ N/mm}^2 \]

Applied shear stress
\[ V_s = 0.14 \text{ N/mm}^2 \]
No shear reinforcement required
CONCRETE SLAB DEFLECTION CHECK (CL 3.5.7)

Slab span length \( l_s = 3.850 \text{ m} \)

Design ultimate moment in shorter span per m width \( m_{\text{max}} = 28 \text{ kNm/m} \)

Depth to outer tension steel \( d_s = 214 \text{ mm} \)

Tension steel

Area of outer tension reinforcement provided \( A_{\text{as,prov}} = 393 \text{ mm}^2/\text{m} \)

Area of tension reinforcement required \( A_{\text{as,req}} = 320 \text{ mm}^2/\text{m} \)

Moment Redistribution Factor \( \beta_{\text{mr}} = 1.00 \)

Modification Factors

Basic span / effective depth ratio (Table 3.9) \( \text{ratio}_{\text{span,depth}} = 20 \)

The modification factor for spans in excess of 10m (ref. cl 3.4.6.4) has not been included.

\[
I_s = 2 \times l_s \times A_{\text{as,req}} / (3 \times A_{\text{as,prov}} \times \beta_{\text{mr}}) = 271.6 \text{ N/mm}^2
\]

\[
\text{factor}_{\text{tens}} = \min \left( 2 \times 0.55 + \left( 477 \text{ N/mm}^2 - f_s \right) / \left( 120 \times \left( 0.9 \text{ N/mm}^2 + m_{\text{max}} / d_s \right) \right) \right) = 1.678
\]

Calculate Maximum Span

This is a simplified approach and further attention should be given where special circumstances exist. Refer to clauses 3.4.6.4 and 3.4.6.7.

Maximum span \( l_{\text{max}} = \text{ratio}_{\text{span,depth}} \times \text{factor}_{\text{tens}} \times d_s = 7.18 \text{ m} \)

Check the actual beam span

Actual span/depth ratio \( l_s / d_s = 17.99 \)

Span depth limit \( \text{ratio}_{\text{span,depth}} \times \text{factor}_{\text{tens}} = 33.56 \)

\( \text{Span/Depth ratio check satisfied} \)

CHECK OF NOMINAL COVER (SAGGING) – (BS8110:PT 1, TABLE 3.4)

Slab thickness \( h = 250 \text{ mm} \)

Effective depth to bottom outer tension reinforcement \( d_s = 214.0 \text{ mm} \)

Diameter of tension reinforcement \( D_s = 10 \text{ mm} \)

Diameter of links \( D_{\text{link}} = 0 \text{ mm} \)

Cover to outer tension reinforcement

\( C_{\text{as}} = h - d_s - D_s / 2 = 31.0 \text{ mm} \)

Nominal cover to links steel

\( C_{\text{link}} = C_{\text{as}} - D_{\text{link}} = 31.0 \text{ mm} \)

Permissible minimum nominal cover to all reinforcement (Table 3.4)

\( C_{\text{min}} = 30 \text{ mm} \)

\( \text{Cover over steel resisting sagging OK} \)
**Overview**

Design of reinforced concrete retaining wall to act as basement underpin for proposed basement design.

**Analysis**

![Diagram of retaining wall](diagram.png)

**Assumptions**

- Soil density
- Internal angle of friction
- Density of concrete

**Loading on ground floor slab**

\[ DL = 8.9 \times 2.5 = 24.9 \text{ kN/m} \]

\[ IL = 1.5 \times 2.8 = 4.2 \text{ kN/m} \]

**Total loading on party wall (see SK300, SK301, SK202)**

\[ DL = 24.9 + 133.2 = 158.1 \text{ kN/m} \]

\[ IL = 4.2 \text{ kN/m} \]
# Retaining Wall Analysis (BS 8002:1994)

**Wall Details**
- **Retaining Wall Type**: Cantilever propped at both
- **Height of Retaining Wall Stem**: $h_{stem} = 3250 \text{ mm}$
- **Thickness of Wall Stem**: $t_{wall} = 400 \text{ mm}$
- **Length of Toe**: $l_{toe} = 1400 \text{ mm}$
- **Length of Heel**: $l_{heel} = 0 \text{ mm}$
- **Overall Length of Base**: $l_{base} = l_{toe} + l_{heel} + t_{wall} = 1800 \text{ mm}$
- **Thickness of Base**: $t_{base} = 350 \text{ mm}$
- **Depth of Downstand**: $d_{ds} = 0 \text{ mm}$
- **Position of Downstand**: $l_{ds} = 0 \text{ mm}$
- **Thickness of Downstand**: $t_{ds} = 350 \text{ mm}$
- **Height of Retaining Wall**: $h_{wall} = h_{stem} + t_{base} + d_{ds} = 3600 \text{ mm}$
- **Depth of Cover in Front of Wall**: $d_{cover} = 0 \text{ mm}$
- **Depth of Unplanned Excavation**: $d_{exc} = 0 \text{ mm}$
- **Height of Ground Water Behind Wall**: $h_{water} = 3600 \text{ mm}$
- **Height of Saturated Fill Above Base**: $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm}) = 3250 \text{ mm}$
- **Density of Wall Construction**: $\gamma_{wall} = 23.6 \text{ kN/m}^3$
- **Density of Base Construction**: $\gamma_{base} = 23.6 \text{ kN/m}^3$
- **Angle of Rear Face of Wall**: $\alpha = 90.0 \text{ deg}$
- **Angle of Soil Surface Behind Wall**: $\beta = 0.0 \text{ deg}$
- **Effective Height at Virtual Back of Wall**: $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta) = 3600 \text{ mm}$

## Retained Material Details
- **Mobilisation Factor**: $M = 1.5$
- **Moist Density of Retained Material**: $\gamma_{m} = 19.0 \text{ kN/m}^3$
Saturated density of retained material $\gamma_s = 21.0 \text{kN/m}^3$

Design shear strength $\phi' = 34.0 \text{ deg}$

Angle of wall friction $\delta = 0.0 \text{ deg}$

**Base material details**

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

Design shear strength $\phi_b = 34.0 \text{ deg}$

Design base friction $\delta_b = 0.0 \text{ deg}$

Allowable bearing pressure $P_{bearing} = 120 \text{kN/m}^2$

**Using Coulomb theory**

Active pressure coefficient for retained material

$$K_a = \frac{\sin(\alpha + \phi')^2}{(\sin(\alpha)^2 \times \sin(\alpha - \delta) \times \{1 + \sqrt{\sin(\phi' + \delta) \times \sin(\phi' - \beta)} / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))\}^2)} = 0.283$$

Passive pressure coefficient for base material

$$K_p = \frac{\sin(90 - \phi_b)^2}{(\sin(90 - \delta_b) \times \{1 - \sqrt{\sin(\phi_b + \delta_b) \times \sin(\phi_b - \beta)} / (\sin(90 + \delta_b))\}^2)} = 3.537$$

**At-rest pressure**

At-rest pressure for retained material $K_0 = 1 - \sin(\phi') = 0.441$

**Loading details**

Surcharge on plan $W_{sur} = 10.0 \text{kN/m}^2$

Applied vertical dead load on wall $W_{vd} = 158.1 \text{kN/m}$

Applied vertical live load on wall $W_{vl} = 4.2 \text{kN/m}$

Position of applied vertical load on wall $h_{load} = 1600 \text{ mm}$

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

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

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

Vertical forces on wall

Wall stem $W_{wall} = h_{stem} \times l_{wall} \times \gamma_{wall} = 30.7 \text{kN/m}$
<table>
<thead>
<tr>
<th>Wall base</th>
<th>( W_{\text{base}} = l_{\text{base}} \times b_{\text{base}} \times \gamma_{\text{base}} = 14.9 \text{ kN/m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied vertical load</td>
<td>( W_v = W_{\text{dead}} + W_{\text{live}} = 162.3 \text{ kN/m} )</td>
</tr>
<tr>
<td>Total vertical load</td>
<td>( W_{\text{total}} = W_{\text{dead}} + W_{\text{base}} + W_v = 207.8 \text{ kN/m} )</td>
</tr>
</tbody>
</table>

**Horizontal forces on wall**

<table>
<thead>
<tr>
<th>Surcharge</th>
<th>( F_{\text{sur}} = K_s \times \text{Surcharge} \times h_{\text{eff}} = 10.2 \text{ kN/m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated backfill</td>
<td>( F_s = 0.5 \times K_s \times (\gamma_f - \gamma_{\text{water}}) \times h_{\text{water}}^2 = 20.5 \text{ kN/m} )</td>
</tr>
<tr>
<td>Water</td>
<td>( F_{\text{water}} = 0.5 \times h_{\text{water}}^2 \times \gamma_{\text{water}} = 63.6 \text{ kN/m} )</td>
</tr>
<tr>
<td>Total horizontal load</td>
<td>( F_{\text{total}} = F_{\text{sur}} + F_s + F_{\text{water}} = 94.2 \text{ kN/m} )</td>
</tr>
</tbody>
</table>

**Calculate total propping force**

| Passive resistance of soil in front of wall | \( F_p = 0.5 \times K_p \times (d_{\text{over}} + l_{\text{base}} + d_{\text{a}} - d_{\text{exc}}) \times \gamma_{\text{mp}} = 4.1 \text{ kN/m} \) |
| Propping force | \( F_{\text{prop}} = \max(F_{\text{total}} - F_p - (W_{\text{total}} - W_{\text{live}}) \times \tan(\delta)) = 49.1 \text{ kN/m} \) |
| \( F_{\text{prop}} = 90.1 \text{ kN/m} \) |                                                                                             |

**Overturning moments**

<table>
<thead>
<tr>
<th>Surcharge</th>
<th>( M_{\text{sur}} = F_{\text{sur}} \times (h_{\text{eff}} - 2 \times d_{\text{a}}) / 2 = 18.3 \text{ kNm/m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated backfill</td>
<td>( M_s = F_s \times (h_{\text{water}} - 3 \times d_{\text{a}}) / 3 = 24.6 \text{ kNm/m} )</td>
</tr>
<tr>
<td>Water</td>
<td>( M_{\text{water}} = F_{\text{water}} \times (h_{\text{water}} - 3 \times d_{\text{a}}) / 3 = 76.3 \text{ kNm/m} )</td>
</tr>
<tr>
<td>Total overturning moment</td>
<td>( M_{\text{total}} = M_{\text{sur}} + M_s + M_{\text{water}} = 119.2 \text{ kNm/m} )</td>
</tr>
</tbody>
</table>

**Restoring moments**

<table>
<thead>
<tr>
<th>Wall stem</th>
<th>( M_{\text{wall}} = W_{\text{wall}} \times (l_{\text{base}} + t_{\text{wall}} / 2) = 49.1 \text{ kNm/m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall base</td>
<td>( M_{\text{base}} = W_{\text{base}} \times l_{\text{base}} / 2 = 13.4 \text{ kNm/m} )</td>
</tr>
<tr>
<td>Design vertical dead load</td>
<td>( M_{\text{dead}} = W_{\text{dead}} \times l_{\text{base}} = 253 \text{ kNm/m} )</td>
</tr>
<tr>
<td>Total restoring moment</td>
<td>( M_{\text{total}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{dead}} = 315.4 \text{ kNm/m} )</td>
</tr>
</tbody>
</table>

**Check bearing pressure**

| Total vertical reaction | \( R = W_{\text{total}} = 207.8 \text{ kN/m} \) |
| Distance to reaction   | \( x_{\text{bar}} = l_{\text{base}} / 2 = 900 \text{ mm} \)                                     |
| Eccentricity of reaction | \( e = \text{abs}((l_{\text{base}} / 2) - x_{\text{bar}}) = 0 \text{ mm} \)                 |

*Reaction acts within middle third of base*

| Bearing pressure at toe | \( p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R \times e / l_{\text{base}}^2) = 115.5 \text{ kN/m}^2 \) |
| Bearing pressure at heel | \( p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R \times e / l_{\text{base}}^2) = 115.5 \text{ kN/m}^2 \) |

*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 | \( F_{\text{prop\_top}} = (M_{\text{total}} - M_{\text{dead}} + R \times l_{\text{base}} / 2 - F_{\text{prop}} \times l_{\text{base}} / 2) / (h_{\text{sen}} + l_{\text{base}} / 2) = -7.281 \text{ kN/m} \) |
| Propping force to base of wall | \( F_{\text{prop\_base}} = F_{\text{prop}} - F_{\text{prop\_top}} = 97.411 \text{ kN/m} \) |
RETYING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

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 \( W_{wall,f} = \gamma_d \times h_{stem} \times t_{wall} \times \gamma_w = 43 \text{ kN/m} \)

Wall base \( W_{base,f} = \gamma_d \times h_{base} \times t_{base} \times \gamma_{base} = 20.8 \text{ kN/m} \)

Applied vertical load \( W_{L,f} = \gamma_d \times W_{dead} + \gamma_L \times W_{live} = 228.1 \text{ kN/m} \)

Total vertical load \( W_{total,f} = W_{wall,f} + W_{base,f} + W_{L,f} = 291.8 \text{ kN/m} \)

Factored horizontal at-rest forces on wall

Surcharge \( F_{sur,f} = \gamma_s \times K_s \times \text{Surcharge} \times h_{art} = 25.4 \text{ kN/m} \)

Saturated backfill \( F_{sat,f} = \gamma_s \times 0.5 \times K_s \times (\gamma_s \times \gamma_{water}) \times h_{water} = 44.7 \text{ kN/m} \)

Water \( F_{water,f} = \gamma_e \times 0.5 \times h_{water} \times \gamma_{water} = 89 \text{ kN/m} \)

Total horizontal load \( F_{total,f} = F_{sur,f} + F_{sat,f} + F_{water,f} = 159.1 \text{ kN/m} \)

Calculate total propping force

Passive resistance of soil in front of wall \( F_{p,f} = \gamma_e \times 0.5 \times K_p \times (\gamma_{cover} + \gamma_{base} + \gamma_{base} - \gamma_{base}) \times \gamma_{m} = 5.8 \text{ kN/m} \)

Propping force \( F_{prop,f} = \max(F_{total,f} - F_{p,f} - (W_{total,f} - \gamma_d \times W_{live}) \times \tan(\theta), 0) \text{ kN/m} \)

\[ F_{prop,f} = 153.4 \text{ kN/m} \]

Factored overturning moments

Surcharge \( M_{sur,f} = F_{sur,f} \times (h_{art} - 2 \times d_{as}) / 2 = 45.7 \text{ kNm/m} \)

Saturated backfill \( M_{sat,f} = F_{sat,f} \times (h_{water} - 3 \times d_{as}) / 3 = 53.7 \text{ kNm/m} \)

Water \( M_{water,f} = F_{water,f} \times (h_{water} - 3 \times d_{as}) / 3 = 106.8 \text{ kNm/m} \)

Total overturning moment \( M_{total,f} = M_{sur,f} + M_{sat,f} + M_{water,f} = 206.2 \text{ kNm/m} \)

Restoring moments

Wall stem \( M_{wall,f} = W_{wall,f} \times (h_{base} + t_{wall} / 2) = 68.7 \text{ kNm/m} \)

Wall base \( M_{base,f} = W_{base,f} \times t_{base} / 2 = 18.7 \text{ kNm/m} \)

Design vertical load \( M_{v,f} = W_{v,f} \times t_{load} = 364.9 \text{ kNm/m} \)

Total restoring moment \( M_{rest,f} = M_{wall,f} + M_{base,f} + M_{v,f} = 452.4 \text{ kNm/m} \)

Factored bearing pressure

Total vertical reaction \( R_t = W_{total,f} = 291.8 \text{ kN/m} \)

Distance to reaction \( x_{sur,f} = t_{base} / 2 = 900 \text{ mm} \)

Eccentricity of reaction \( e_r = \text{abs}(h_{base} / 2 - x_{sur,f}) = 0 \text{ mm} \)

Reaction acts within middle third of base

Bearing pressure at toe \( p_{toe,f} = (R_t / h_{base} - (6 \times R_t \times e_r / h_{base})^2) = 162.1 \text{ kN/m}^2 \)

Bearing pressure at heel \( p_{heel,f} = (R_t / h_{base} + (6 \times R_t \times e_r / h_{base})^2) = 162.1 \text{ kN/m}^2 \)

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

Bearing pressure at stem / toe \( p_{stem,toe,f} = \max(p_{toe,f} - (\text{rate} \times h_{base}), 0) \text{ kN/m}^2 = 162.1 \text{ kN/m}^2 \)

Bearing pressure at mid stem \( p_{stem,mid,f} = \max(p_{toe,f} - (\text{rate} \times (h_{base} + t_{wall} / 2)), 0) \text{ kN/m}^2 = 162.1 \text{ kN/m}^2 \)

Bearing pressure at stem / heel \( p_{stem,heel,f} = \max(p_{toe,f} - (\text{rate} \times (h_{base} + 2 \times t_{wall})), 0) \text{ kN/m}^2 = 162.1 \text{ kN/m}^2 \)

Calculate propping forces to top and base of wall

Propping force to top of wall \( F_{prop,top,f} = (M_{stat,f} - M_{rest,f} + R_t \times t_{base} / 2 - F_{prop,f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = -3.022 \text{ kN/m} \)
Propping force to base of wall

\[ F_{\text{prop, base, f}} = F_{\text{prop, f}} - F_{\text{prop, top, f}} = 156.395 \text{ kN/m} \]

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

**Material properties**
- Characteristic strength of concrete \( f_{cu} = 40 \text{ N/mm}^2 \)
- 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 \( c_{\text{toe}} = 50 \text{ mm} \)

**Calculate shear for toe design**

- Shear from bearing pressure \( V_{\text{toe, base}} = (p_{\text{toe, f}} + p_{\text{stem, toe, f}}) \times h_{\text{toe}} / 2 = 227 \text{ kN/m} \)
- Shear from weight of base \( V_{\text{toe, wt, base}} = \gamma_{c,d} \times \gamma_{\text{base}} \times h_{\text{toe}} \times t_{\text{base}} = 16.2 \text{ kN/m} \)
- Total shear for toe design \( V_{\text{toe}} = V_{\text{toe, base}} - V_{\text{toe, wt, base}} = 210.8 \text{ kN/m} \)

**Calculate moment for toe design**

- Moment from bearing pressure \( M_{\text{toe, base}} = (2 \times p_{\text{toe, f}} + p_{\text{stem, mid, f}}) \times (h_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = 207.5 \text{ kNm/m} \)
- Moment from weight of base \( M_{\text{toe, wt, base}} = (\gamma_{c,d} \times \gamma_{\text{base}} \times t_{\text{base}} \times (h_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2) = 14.8 \text{ kNm/m} \)
- Total moment for toe design \( M_{\text{toe}} = M_{\text{toe, base}} - M_{\text{toe, wt, base}} = 192.7 \text{ kNm/m} \)

**Check toe in bending**

- Width of toe \( b = 1000 \text{ mm/m} \)
- Depth of reinforcement \( d_{\text{toe}} = h_{\text{base}} - c_{\text{toe}} - (h_{\text{toe}} / 2) = 290.0 \text{ mm} \)
- Constant \( K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_y) = 0.057 \)
- Lever arm \( z_{\text{toe}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{toe}}, 0.225) / 0.95)) \times d_{\text{toe}}}) = 270 \text{ mm} \)
- Compression reinforcement is not required

**Area of tension reinforcement required**

- \( A_{\text{toe, des}} = M_{\text{toe}} / (0.87 \times f_y \times z_{\text{toe}}) = 1640 \text{ mm}^2/m \)
- \( A_{\text{toe, min}} = k \times b \times t_{\text{base}} = 455 \text{ mm}^2/m \)
- \( A_{\text{toe, req}} = \max(A_{\text{toe, des}}, A_{\text{toe, min}}) = 1640 \text{ mm}^2/m \)
- 20 mm dia. bars @ 175 mm centres

**Check shear resistance at toe**

- Design shear stress \( V_{\text{toe}} = V_{\text{toe}} / (b \times d_{\text{toe}}) = 0.727 \text{ N/mm}^2 \)
- Allowable shear stress \( V_{\text{adm}} = \min(0.8 \times \sqrt{f_{cu} / 1 \text{ N/mm}^2), 5) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2 \)

**From BS8110:Part 1:1997 – Table 3.8**
- Design concrete shear stress \( V_{c, \text{toe}} = 0.683 \text{ N/mm}^2 \)

**PASS - Reinforcement provided at the retaining wall toe is adequate**
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 $F_{k,\text{surr}j} = \gamma_{j} \times K_0 \times \text{Surcharge} \times (h_{h} - h_{\text{base}} - d_{j}) = 22.9$ kN/m
Saturated backfill $F_{k,b,j} = 0.5 \times \gamma_{j} \times K_0 \times (\gamma_{w} \times \gamma_{\text{water}}) \times h_{\text{sat}}^2 = 36.5$ kN/m
Water $F_{k,\text{water},j} = 0.5 \times \gamma_{j} \times \gamma_{w} \times \gamma_{\text{water}} \times h_{\text{sat}}^2 = 72.5$ kN/m

Calculate shear for stem design
Surcharge $V_{k,surr,j} = 5 \times F_{k,surr,j} / 8 = 14.3$ kN/m
Saturated backfill $V_{k,b,j} = F_{k,b,j} \times (1 - (0.25 \times ((5 \times L) - a) / (20 \times L^3))) = 29.2$ kN/m
Water $V_{k,\text{water},j} = F_{k,\text{water},j} \times (1 - (0.25 \times ((5 \times L) - a) / (20 \times L^3))) = 58$ kN/m
Total shear for stem design $V_{stem} = V_{k,surr,j} + V_{k,b,j} + V_{k,\text{water},j} = 101.5$ kN/m

Calculate moment for stem design
Surcharge $M_{k,surr} = F_{k,surr,j} \times L / 8 = 9.8$ kNm/m
Saturated backfill $M_{k,s} = F_{k,s} \times a \times (3 \times a^2 - (15 \times a \times L) + (20 \times L^3)) / (60 \times L^3) = 16.7$ kNm/m
Water $M_{k,\text{water}} = F_{k,\text{water},j} \times a \times (3 \times a^2 - (15 \times a \times L) + (20 \times L^3)) / (60 \times L^3) = 33.1$ kNm/m
Total moment for stem design $M_{stem} = M_{k,surr} + M_{k,s} + M_{k,\text{water}} = 59.6$ kNm/m

Calculate moment for wall design
Surcharge $M_{k,\text{surr}} = 9 \times F_{k,\text{surr},j} \times L / 128 = 5.5$ kNm/m
Saturated backfill $M_{k,s} = F_{k,s} \times [a^2 \times x \times ((5 \times L) - a) / (15 \times a \times L) + (20 \times L^3) - (3 \times a^3)] / (3 \times a^3) = 7.4$ kNm/m
Water $M_{k,\text{water}} = F_{k,\text{water},j} \times [a^2 \times x \times ((5 \times L) - a) / (15 \times a \times L) + (20 \times L^3) - (3 \times a^3)] / (3 \times a^3) = 14.8$ kNm/m
Total moment for wall design $M_{wall} = M_{k,\text{surr}} + M_{k,s} + M_{k,\text{water}} = 27.8$ kNm/m

Check wall stem in bending
Width of wall stem $b = 1000$ mm/m
<table>
<thead>
<tr>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{stem} = t_{wall} - C_{stem} - (b_{stem} / 2)$</td>
<td>344.0 mm</td>
</tr>
<tr>
<td>$K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{u})$</td>
<td>0.013</td>
</tr>
<tr>
<td>$z_{stem} = \min(0.5 + \sqrt{0.25 - (\min(K_{stem}, 0.225) / 0.9) / 0.5}) \times d_{stem}$</td>
<td></td>
</tr>
<tr>
<td>$A_{s_{stem}} = M_{stem} / (0.87 \times f_y \times z_{stem})$</td>
<td>419 mm²/m</td>
</tr>
<tr>
<td>$A_{s_{stem}} = k \times b \times t_{wall}$</td>
<td>520 mm²/m</td>
</tr>
<tr>
<td>$A_{s_{stem}} = \max(A_{s_{stem,des}}, A_{s_{stem,req}})$</td>
<td>520 mm²/m</td>
</tr>
<tr>
<td>$12$ mm dia. bars @ $200$ mm centres</td>
<td></td>
</tr>
<tr>
<td>$A_{s_{stem,prov}} = 565$ mm²/m</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_{stem} = V_{stem} / (b \times d_{stem})$</td>
<td>0.295 N/mm²</td>
</tr>
<tr>
<td>$v_{adm} = \min(0.8 \times \sqrt{f_{u}} / 1$ N/mm², 5) $\times 1$ N/mm²</td>
<td>5.000 N/mm²</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_{c_{stem}} = 0.420$ N/mm²</td>
<td></td>
</tr>
<tr>
<td>$v_{stem} &lt; v_{c_{stem}}$ - No shear reinforcement required</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{wall} = t_{wall} - C_{wall} - (b_{wall} / 2)$</td>
<td>344.0 mm</td>
</tr>
<tr>
<td>$K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{u})$</td>
<td>0.006</td>
</tr>
<tr>
<td>$z_{wall} = \min(0.5 + \sqrt{0.25 - (\min(K_{wall}, 0.225) / 0.95) / 0.5}) \times d_{wall}$</td>
<td></td>
</tr>
<tr>
<td>$A_{s_{wall,des}} = M_{wall} / (0.87 \times f_y \times z_{wall})$</td>
<td>195 mm²/m</td>
</tr>
<tr>
<td>$A_{s_{wall,req}} = k \times b \times t_{wall}$</td>
<td>520 mm²/m</td>
</tr>
<tr>
<td>$A_{s_{wall,prov}} = 565$ mm²/m</td>
<td></td>
</tr>
</tbody>
</table>

**PASS - Reinforcement provided to the retaining wall at mid height is adequate**

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_s = 2 \times f_y \times A_{s_{stem,req}} / (3 \times A_{s_{stem,prov}})$</td>
<td>306.5 N/mm²</td>
</tr>
<tr>
<td>$\text{factor}<em>{base} = \min(0.55 + (477$ N/mm² $- f_s) / (2 \times 0.9$ N/mm² $+ (M</em>{stem} / (b \times d_{stem}^2))))$</td>
<td>31.24</td>
</tr>
<tr>
<td>$r_{max} = \text{ratio}<em>{base} \times \text{factor}</em>{base}$</td>
<td>31.24</td>
</tr>
<tr>
<td>$r_{act} = h_{stem} / d_{stem}$</td>
<td>9.45</td>
</tr>
</tbody>
</table>

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

Wall reinforcement

Stem reinforcement

Toe reinforcement

Toe bars - 20 mm dia. @ 175 mm centres - (1795 mm²/m)
Wall bars - 12 mm dia. @ 200 mm centres - (565 mm²/m)
Stem bars - 12 mm dia. @ 200 mm centres - (565 mm²/m)
**Overview:**

Design of reinforced concrete retaining wall to act as a basement underpin for the proposed basement.

**Analysis:**

![Diagram of retaining wall](image)

**Assumptions:**

- Soil density
- Internal angle of friction
- Density of concrete

**Total load on front wall (see SK300, SK301 and SK302):**

- DL = 131.4 kN/m
- LL = 184 kN/m

**SEE CSI REPORT**

<table>
<thead>
<tr>
<th>SEE CSI REPORT</th>
<th>GGE CSI REPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.6 kN/m³</td>
<td>23.6 kN/m³</td>
</tr>
</tbody>
</table>
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 stand
Position of stand
Thickness of stand
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
Moist density of retained material

Cantilever propped at both

\[ h_{stem} = 3250 \text{ mm} \]
\[ t_{wall} = 400 \text{ mm} \]
\[ l_{base} = 1400 \text{ mm} \]
\[ t_{base} = 0 \text{ mm} \]
\[ l_{wall} = l_{base} + t_{wall} = 1800 \text{ mm} \]
\[ t_{base} = 350 \text{ mm} \]
\[ d_{as} = 0 \text{ mm} \]
\[ l_{as} = 0 \text{ mm} \]
\[ t_{as} = 0 \text{ mm} \]
\[ h_{wall} = h_{stem} + l_{base} + d_{as} = 3600 \text{ mm} \]
\[ d_{cover} = 0 \text{ mm} \]
\[ d_{exc} = 0 \text{ mm} \]
\[ h_{water} = 3600 \text{ mm} \]
\[ h_{sat} = \max(h_{water} - l_{base} - d_{as}, 0) = 3250 \text{ mm} \]
\[ \gamma_{wall} = 23.6 \text{ kN/m}^3 \]
\[ \gamma_{base} = 23.6 \text{ kN/m}^3 \]
\[ \alpha = 90.0 \text{ deg} \]
\[ \beta = 0.0 \text{ deg} \]
\[ h_{eff} = h_{wall} + l_{base} \times \tan(\beta) = 3600 \text{ mm} \]

\[ M = 1.5 \]
\[ \gamma_{m} = 19.0 \text{ kN/m}^3 \]
Saturated density of retained material \( \gamma_s = 21.0 \, \text{kN/m}^3 \)
Design shear strength \( \phi' = 34.0 \, \text{deg} \)
Angle of wall friction \( \delta = 0.0 \, \text{deg} \)

**Base material details**
- Moist density \( \gamma_{mb} = 19.0 \, \text{kN/m}^3 \)
- Design shear strength \( \phi_b = 34.0 \, \text{deg} \)
- Design base friction \( \delta_b = 0.0 \, \text{deg} \)
- Allowable bearing pressure \( P_{\text{bearing}} = 120 \, \text{kN/m}^2 \)

**Using Coulomb theory**
- Active pressure coefficient for retained material \( K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi') + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))}]^2) = 0.283 \)
- Passive pressure coefficient for base material \( K_p = \sin(90 - \phi_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi_b + \delta_b) \times \sin(\phi_b) / (\sin(90 + \delta_b))]})^2 = 3.537 \)

**At-rest pressure**
- At-rest pressure for retained material \( K_0 = 1 - \sin(\phi') = 0.441 \)

**Loading details**
- Surcharge load on plan \( \text{Surcharge} = 10.0 \, \text{kN/m}^2 \)
- Applied vertical dead load on wall \( W_{\text{dead}} = 131.4 \, \text{kN/m} \)
- Applied vertical live load on wall \( W_{\text{live}} = 18.4 \, \text{kN/m} \)
- Position of applied vertical load on wall \( h_{\text{load}} = 1600 \, \text{mm} \)
- 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 \( h_{\text{load}} = 0 \, \text{mm} \)

**Vertical forces on wall**
- Wall stem \( W_{\text{wall}} = h_{\text{stem}} \times l_{\text{wall}} \times \gamma_{\text{wall}} = 30.7 \, \text{kN/m} \)

Loads shown in kN/m, pressures shown in kN/m²
### Wall base
\[ W_{\text{base}} = l_{\text{base}} \times t_{\text{base}} \times \gamma_{\text{base}} = 14.9 \text{ kN/m} \]

### Applied vertical load
\[ W_v = W_{\text{dead}} + W_{\text{live}} = 149.8 \text{ kN/m} \]

### Total vertical load
\[ W_{\text{total}} = W_{\text{west}} + W_{\text{base}} + W_v = 195.3 \text{ kN/m} \]

### Horizontal forces on wall

**Surcharge**
\[ F_{\text{sur}} = K_s \times \text{Surcharge} \times h_{\text{eff}} = 10.2 \text{ kN/m} \]

**Saturated backfill**
\[ F_s = 0.5 \times K_s \times (\gamma_{s} \times h_{\text{water}}) \times h_{\text{water}}^2 = 20.5 \text{ kN/m} \]

**Water**
\[ F_{\text{water}} = 0.5 \times h_{\text{water}}^2 \times \gamma_{\text{water}} = 63.6 \text{ kN/m} \]

**Total horizontal load**
\[ F_{\text{total}} = F_{\text{sur}} + F_s + F_{\text{water}} = 94.2 \text{ kN/m} \]

### Calculate total propping force

**Passive resistance of soil in front of wall**
\[ F_p = 0.5 \times K_p \times (d_{\text{cover}} + t_{\text{base}} + d_{\text{as}} - d_{\text{ao}})^2 \times \gamma_{\text{soil}} = 4.1 \text{ kN/m} \]

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

\[ F_{\text{prop}} = 90.1 \text{ kN/m} \]

### Overturning moments

**Surcharge**
\[ M_{\text{sur}} = F_{\text{sur}} \times (h_{\text{eff}} - 2 \times d_{\text{ao}}) / 2 = 18.3 \text{ kNm/m} \]

**Saturated backfill**
\[ M_s = F_s \times (h_{\text{water}} - 3 \times d_{\text{as}}) / 3 = 24.6 \text{ kNm/m} \]

**Water**
\[ M_{\text{water}} = F_{\text{water}} \times (h_{\text{water}} - 3 \times d_{\text{as}}) / 3 = 76.3 \text{ kNm/m} \]

**Total overturning moment**
\[ M_{\text{total}} = M_{\text{sur}} + M_s + M_{\text{water}} = 119.2 \text{ kNm/m} \]

### Restoring moments

**Wall stem**
\[ M_{\text{wall}} = W_{\text{wall}} \times (l_{\text{base}} + l_{\text{wall}}) / 2 = 49.1 \text{ kNm/m} \]

**Wall base**
\[ M_{\text{base}} = W_{\text{base}} \times l_{\text{base}} / 2 = 13.4 \text{ kNm/m} \]

**Design vertical dead load**
\[ M_{\text{dead}} = W_{\text{dead}} \times l_{\text{dead}} = 210.2 \text{ kNm/m} \]

**Total restoring moment**
\[ M_{\text{rest}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{dead}} = 272.7 \text{ kNm/m} \]

### Check bearing pressure

**Total vertical reaction**
\[ R = W_{\text{total}} = 195.3 \text{ kN/m} \]

**Distance to reaction**
\[ x_{\text{base}} = l_{\text{base}} / 2 = 900 \text{ mm} \]

**Eccentricity of reaction**
\[ e = \text{abs}(l_{\text{base}} / 2 - x_{\text{base}}) = 0 \text{ mm} \]

*Reaction acts within middle third of base*

**Bearing pressure at toe**
\[ p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R \times e / l_{\text{base}}^2) = 108.5 \text{ kN/m}^2 \]

**Bearing pressure at heel**
\[ p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R \times e / l_{\text{base}}^2) = 108.5 \text{ kN/m}^2 \]

*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**
\[ F_{\text{prop, top}} = (M_{\text{rest}} - M_{\text{base}} + R \times l_{\text{base}} / 2 - F_{\text{prop}} \times l_{\text{base}} / 2) / (l_{\text{base}} + l_{\text{base}} / 2) = 1.908 \text{ kN/m} \]

**Propping force to base of wall**
\[ F_{\text{prop, base}} = F_{\text{prop}} - F_{\text{prop, top}} = 88.223 \text{ kN/m} \]
RETAINING WALL DESIGN (BS 8002:1994)

Ultimate limit state load factors
Dead load factor \( \gamma_{Ld} = 1.4 \)
Live load factor \( \gamma_{Ll} = 1.6 \)
Earth and water pressure factor \( \gamma_{Ew} = 1.4 \)

Factored vertical forces on wall
Wall stem \( W_{wall,t} = \gamma_{Ld} \times h_{stem} \times t_{wall} \times \gamma_{wall} = 43 \text{ kN/m} \)
Wall base \( W_{base,t} = \gamma_{Ld} \times h_{base} \times t_{base} \times \gamma_{base} = 20.8 \text{ kN/m} \)
Applied vertical load \( W_{u,t} = \gamma_{Ew} \times W_{load} + \gamma_{Ll} \times W_{live} = 213.4 \text{ kN/m} \)
Total vertical load \( W_{total,t} = W_{wall,t} + W_{base,t} + W_{u,t} = 277.2 \text{ kN/m} \)

Factored horizontal at-rest forces on wall
Surcharge \( F_{sur,t} = \gamma_{Ll} \times K_s \times \text{Surcharge} \times h_{eff} = 25.4 \text{ kN/m} \)
Saturated backfill \( F_{s,t} = \gamma_{Ew} \times 0.5 \times K_s \times (\gamma_{Ll} \times \gamma_{water}) \times h_{water}^2 = 44.7 \text{ kN/m} \)
Water \( F_{water,t} = \gamma_{Ew} \times 0.5 \times h_{water}^2 \times \gamma_{water} = 89 \text{ kN/m} \)
Total horizontal load \( F_{total,t} = F_{sur,t} + F_{s,t} + F_{water,t} = 159.1 \text{ kN/m} \)

Calculate total propping force
Passive resistance of soil in front of wall \( F_{p,t} = \gamma_{Ew} \times 0.5 \times K_p \times (d_{cover} + t_{base} + d_s - d_{base})^2 \times \gamma_{nb} = 5.8 \text{ kN/m} \)
Propping force \( F_{prop,t} = \max(F_{total,t} - F_{p,t} \cdot (W_{total,t} - \gamma_{Ll} \times W_{live}) \div \tan(\delta_b), 0 \text{ kN/m}) \)
\( F_{prop,t} = 153.4 \text{ kN/m} \)

Factored overturning moments
Surcharge \( M_{sur,t} = F_{sur,t} \times (h_{eff} - 2 \times d\phi) / 2 = 45.7 \text{ kNm/m} \)
Saturated backfill \( M_{s,t} = F_{s,t} \times (h_{water} - 3 \times d\phi) / 3 = 53.7 \text{ kNm/m} \)
Water \( M_{water,t} = F_{water,t} \times (h_{water} - 3 \times d\phi) / 3 = 106.8 \text{ kNm/m} \)
Total overturning moment \( M_{ot,t} = M_{sur,t} + M_{s,t} + M_{water,t} = 206.2 \text{ kNm/m} \)

Restoring moments
Wall stem \( M_{wall,t} = W_{wall,t} \times (l_{base} + t_{wall} / 2) = 68.7 \text{ kNm/m} \)
Wall base \( M_{base,t} = W_{base,t} \times l_{base} / 2 = 18.7 \text{ kNm/m} \)
Design vertical load \( M_{v,t} = W_{v,t} \times l_{load} = 341.4 \text{ kNm/m} \)
Total restoring moment \( M_{rest,t} = M_{wall,t} + M_{base,t} + M_{v,t} = 428.9 \text{ kNm/m} \)

Factored bearing pressure
Total vertical reaction \( R_t = W_{total,t} = 277.2 \text{ kN/m} \)
Distance to reaction \( x_{bar,t} = l_{base} / 2 = 900 \text{ mm} \)
Eccentricity of reaction \( e_r = \left| (l_{base} / 2) - x_{bar,t} \right| = 0 \text{ mm} \)

Reaction acts within middle third of base

Bearing pressure at toe \( p_{poe,t} = (R_t / l_{base}) - (6 \times R_t \times e_r / l_{base}^2) = 154 \text{ kN/m}^2 \)
Bearing pressure at heel \( p_{poe,h} = (R_t / l_{base}) + (6 \times R_t \times e_r / l_{base}^2) = 154 \text{ kN/m}^2 \)
Rate of change of base reaction \( r = (p_{poe,h} - p_{poe,t}) / l_{base} = 0.00 \text{ kN/m}^2 \)
Bearing pressure at stem / toe \( p_{stem,t} = \max(p_{poe,t} \cdot (rate \times l_{base}), 0 \text{ kN/m}^2) = 154 \text{ kN/m}^2 \)
Bearing pressure at mid stem \( p_{stem,mid} = \max(p_{poe,t} \cdot (rate \times (l_{base} + l_{wall} / 2)), 0 \text{ kN/m}^2) = 154 \text{ kN/m}^2 \)
Bearing pressure at stem / heel \( p_{stem,heel} = \max(p_{poe,t} \cdot (rate \times (l_{base} + l_{wall})), 0 \text{ kN/m}^2) = 154 \text{ kN/m}^2 \)

Calculate propping forces to top and base of wall
Propping force to top of wall \( F_{prop,top,t} = (M_{ot,t} - M_{rest,t} + R_t \times l_{base} / 2 - F_{prop,t} \times l_{base} / 2) / (h_{stem} + l_{base} / 2) = -0.026 \text{ kN/m} \)
Propping force to base of wall

\[ F_{\text{prop, base, f}} = F_{\text{prop, f}} - F_{\text{prop, top, f}} = 153.399 \text{ kN/m} \]

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

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

**Base details**
- Minimum area of reinforcement: \( k = 0.13 \% \)
- Cover to reinforcement in toe: \( C_{\text{coe}} = 50 \text{ mm} \)

**Calculate shear for toe design**

**Shear from bearing pressure**

\[ V_{\text{toe, bear}} = (p_{\text{bear}} + p_{\text{stem, toe, f}}) \times t_{\text{base}} / 2 = 215.6 \text{ kN/m} \]

**Shear from weight of base**

\[ V_{\text{toe, wt, base}} = \gamma_{\text{d}} \times \gamma_{\text{base}} \times t_{\text{base}} \times t_{\text{base}} = 16.2 \text{ kN/m} \]

**Total shear for toe design**

\[ V_{\text{toe}} = V_{\text{toe, bear}} - V_{\text{toe, wt, base}} = 199.4 \text{ kN/m} \]

**Calculate moment for toe design**

**Moment from bearing pressure**

\[ M_{\text{toe, bear}} = (2 \times p_{\text{bear}} + p_{\text{stem, mid, f}}) \times (t_{\text{base}} + t_{\text{wall}} / 2)^2 / 6 = 197.1 \text{ kNm/m} \]

**Moment from weight of base**

\[ M_{\text{toe, wt, base}} = (\gamma_{\text{d}} \times \gamma_{\text{base}} \times t_{\text{base}} \times (t_{\text{base}} + t_{\text{wall}} / 2)^2 / 2 = 14.8 \text{ kNm/m} \]

**Total moment for toe design**

\[ M_{\text{toe}} = M_{\text{toe, bear}} - M_{\text{toe, wt, base}} = 182.3 \text{ kNm/m} \]

---

**Check toe in bending**

**Width of toe**

\( b = 1000 \text{ mm/m} \)

**Depth of reinforcement**

\[ d_{\text{coe}} = t_{\text{base}} - C_{\text{coe}} - (t_{\text{base}} / 2) = 290.0 \text{ mm} \]

**Constant**

\[ K_{\text{coe}} = M_{\text{coe}} / (b \times d_{\text{coe}}^2 \times f_{\text{cu}}) = 0.054 \]

**Compression reinforcement is not required**

**Lever arm**

\[ Z_{\text{coe}} = \min(0.5 \times \sqrt{(0.25 - (\min(K_{\text{coe}}, 0.225) / 0.95) \times d_{\text{coe}})} = 271 \text{ mm} \]

**Area of tension reinforcement required**

\[ A_{\text{b, toe, des}} = M_{\text{coe}} / (0.87 \times f_{\text{y}} \times Z_{\text{coe}}) = 1544 \text{ mm}^2/\text{m} \]

**Minimum area of tension reinforcement**

\[ A_{\text{b, toe, min}} = k \times b \times t_{\text{base}} = 455 \text{ mm}^2/\text{m} \]

**Area of tension reinforcement required**

\[ A_{\text{b, toe, req}} = \max(A_{\text{b, toe, des}}, A_{\text{b, toe, min}}) = 1544 \text{ mm}^2/\text{m} \]

**20 mm dia. bars @ 200 mm centres**

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

**Check shear resistance at toe**

**Design shear stress**

\[ V_{\text{toe}} = V_{\text{toe}} / (b \times d_{\text{coe}}) = 0.688 \text{ N/mm}^2 \]

**Allowable shear stress**

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

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

**From BS8110:Part 1:1997 – Table 3.8**

**Design concrete shear stress**

\[ V_{\text{cl, toe}} = 0.653 \text{ N/mm}^2 \]
Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties
Characteristic strength of concrete \( f_{cu} = 40 \text{ N/mm}^2 \)
Characteristic strength of reinforcement \( f_y = 500 \text{ N/mm}^2 \)

Wall details
Minimum area of reinforcement \( k = 0.13 \% \)
Cover to reinforcement in stem \( c_{stem} = 50 \text{ mm} \)
Cover to reinforcement in wall \( c_{wall} = 50 \text{ mm} \)

Factored horizontal at-rest forces on stem
Surcharge \( F_{x,sur,f} = \gamma_{sur} \times K_0 \times \text{Surcharge} \times (h_{base} - h_{top}) = 22.9 \text{ kN/m} \)
Saturated backfill \( F_{x,sat,f} = 0.5 \times \gamma_{sat} \times K_0 \times (\gamma_{sat} - \gamma_{water}) \times h_{sat}^2 = 36.5 \text{ kN/m} \)
Water \( F_{x,water,f} = 0.5 \times \gamma_{water} \times h_{sat}^2 = 72.5 \text{ kN/m} \)

Calculate shear for stem design
Surcharge \( V_{x,sur,f} = 5 \times F_{x,sur,f} \times L / 8 = 14.3 \text{ kN/m} \)
Saturated backfill \( V_{x,sat,f} = F_{x,sat,f} \times (1 - (a^2 \times ((5 \times L) - a) / (20 \times L^2))) = 29.2 \text{ kN/m} \)
Water \( V_{x,water,f} = F_{x,water,f} \times (1 - (a^2 \times ((5 \times L) - a) / (20 \times L^2))) = 58 \text{ kN/m} \)
Total shear for stem design \( V_{stem} = V_{x,sur,f} + V_{x,sat,f} + V_{x,water,f} = 101.5 \text{ kN/m} \)

Calculate moment for stem design
Surcharge \( M_{x,sur} = F_{x,sur,f} \times L / 8 = 9.8 \text{ kNm/m} \)
Saturated backfill \( M_{x,sat} = F_{x,sat,f} \times a \times ((3a^2 - 15axL + 20xL^2)/(60xL^2) = 16.7 \text{ kNm/m} \)
Water \( M_{x,water} = F_{x,water,f} \times a \times ((3a^2 - 15axL + 20xL^2)/(60xL^2) = 33.1 \text{ kNm/m} \)
Total moment for stem design \( M_{stem} = M_{x,sur} + M_{x,sat} + M_{x,water} = 59.6 \text{ kNm/m} \)

Calculate moment for wall design
Surcharge \( M_{w,sur} = 9 \times F_{x,sur,f} \times L / 128 = 5.5 \text{ kNm/m} \)
Saturated backfill \( M_{w,sat} = F_{x,sat,f} \times [a^2x((5xL)-a)/(20xL^2)-(x-b)^3/(3xa^2)] = 7.4 \text{ kNm/m} \)
Water \( M_{w,water} = F_{x,water,f} \times [a^2x((5xL)-a)/(20xL^2)-(x-b)^3/(3xa^2)] = 14.8 \text{ kNm/m} \)
Total moment for wall design \( M_{wall} = M_{w,sur} + M_{w,sat} + M_{w,water} = 27.8 \text{ kNm/m} \)

Check wall stem in bending
Width of wall stem \( b = 1000 \text{ mm/m} \)
### Project Information

- **Location:** 22 Marylebone Road
- **Job No.:** 10-5372

### Calculations for Retaining Wall

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Formula/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of reinforcement</td>
<td>$d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2) = 344.0$ mm</td>
</tr>
<tr>
<td>Constant</td>
<td>$K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = 0.013$</td>
</tr>
<tr>
<td>Lever arm</td>
<td>$z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9)), 0.95}) \times d_{stem}$</td>
</tr>
<tr>
<td>Compression reinforcement is not required</td>
<td>$A_{x_{stem}} = M_{stem} / (0.87 \times f_y \times z_{stem}) = 419$ mm²/m</td>
</tr>
<tr>
<td>Area of tension reinforcement required</td>
<td>$A_{x_{stem}} = k \times b \times t_{wall} = 520$ mm²/m</td>
</tr>
<tr>
<td>Minimum area of tension reinforcement</td>
<td>$A_{x_{stem}<em>{req}} = \max(A</em>{x_{stem}<em>{des}}, A</em>{x_{stem}_{req}}) = 520$ mm²/m</td>
</tr>
<tr>
<td>Reinforcement provided</td>
<td>12 mm dia. bars @ 200 mm centres</td>
</tr>
<tr>
<td>Area of reinforcement provided</td>
<td>$A_{x_{stem}_{prov}} = 565$ mm²/m</td>
</tr>
<tr>
<td><strong>PASS - Reinforcement provided at the retaining wall stem is adequate</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Check Shear Resistance at Wall Stem

- **Stem:** $V_{stem} = V_{stem} / (b \times d_{stem}) = 0.295$ kN/mm²
- **Design:** $V_{des} = \min(0.8 \times (f_{cu} / 1$ N/mm²), 5) $ \times 1$ N/mm² = 5.000 N/mm²

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

- **Stem:** $V_{stem} = 0.420$ kN/mm²

**$V_{stem} < V_{stem} \cdot No\ shear\ reinforcement\ required**

### Check Mid Height of Wall in Bending

- **Depth of reinforcement:** $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2) = 344.0$ mm
- **Constant:** $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu}) = 0.006$

**Compression reinforcement is not required**

- **Wall:** $z_{wall} = \min(0.5 + \sqrt{(0.25 - (\min(K_{wall}, 0.225) / 0.9)), 0.95}) \times d_{wall}$
- **Area of tension reinforcement required:** $A_{x_{wall}_{des}} = M_{wall} / (0.87 \times f_y \times z_{wall}) = 195$ mm²/m
- **Minimum area of tension reinforcement:** $A_{x_{wall}_{min}} = k \times b \times t_{wall} = 520$ mm²/m
- **Area of tension reinforcement required:** $A_{x_{wall}_{req}} = \max(A_{x_{wall}_{des}}, A_{x_{wall}_{req}}) = 520$ mm²/m
- **Reinforcement provided:** 12 mm dia. bars @ 200 mm centres
- **Area of reinforcement provided:** $A_{x_{wall}_{prov}} = 565$ mm²/m

**PASS - Reinforcement provided to the retaining wall at mid height is adequate**

### Check Retaining Wall Deflection

- **Basic span/effective depth ratio:** $\text{ratio}_{bas} = 20$
- **Design service stress:** $f_s = 2 \times f_y \times A_{x_{stem}_{req}} / (3 \times A_{x_{stem}_{prov}}) = 306.5$ N/mm²
- **Modification factor:** $\text{factor}_{fens} = \min(0.55 + (477.5 \times f_s), (120 \times (0.9 \times f_y \times 1000 + (M_{stem} / (b \times d_{stem}^2)))) / 2) = 1.56$
- **Maximum span/effective depth ratio:** $\text{ratio}_{max} = \text{ratio}_{fens} \times \text{factor}_{fens} = 31.24$
- **Actual span/effective depth ratio:** $\text{ratio}_{act} = h_{stem} / d_{stem} = 9.45$

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

<table>
<thead>
<tr>
<th>Wall reinforcement</th>
<th>Stem reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe reinforcement</td>
<td></td>
</tr>
</tbody>
</table>

**Toe bars - 20 mm dia. @ 200 mm centres - (1571 mm²/m)**
**Wall bars - 12 mm dia. @ 200 mm centres - (565 mm²/m)**
**Stem bars - 12 mm dia. @ 200 mm centres - (565 mm²/m)**
### Calculations

**Overview**

Design of reinforced concrete retaining wall to act as a basement underpin for the proposed basement

**Analysis**

![Diagram of retaining wall]

**Assumptions**

- Soil density
- Internal angle of friction
- Density of concrete

Total load on rear wall (see SK 300, SK 301 and SK 302)
- DL: 2.5 kN/m
- IL: 1.5 kN/m

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**Output**

| SEE CSI REPORT
| SEE CSI REPORT
| 2.36 kN/m³

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RETLAINING 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

Cantilever propped at both

$h_{stem} = 4300$ mm
$t_{wall} = 300$ mm
$l_{toe} = 1200$ mm
$h_{heel} = 0$ mm
$h_{base} = l_{toe} + h_{heel} + t_{wall} = 1500$ mm
$b_{base} = 300$ mm
$d_{ds} = 0$ mm
$l_{ds} = 0$ mm
$t_{ds} = 300$ mm
$h_{wall} = h_{stem} + b_{base} + d_{ds} = 4600$ mm
$d_{cover} = 0$ mm
$d_{exc} = 0$ mm
$h_{water} = 4600$ mm
$h_{sat} = \max(h_{water} - b_{base} - d_{ds}, 0)$ mm $= 4300$ mm
$\gamma_{wall} = 23.6$ kN/m$^3$
$\gamma_{base} = 23.6$ kN/m$^3$
$\alpha = 90.0$ deg
$\beta = 0.0$ deg
$h_{eaf} = h_{wall} + h_{heel} \times \tan(\beta) = 4600$ mm

Retained material details
Mobilisation factor
Moist density of retained material

$M = 1.5$
$\gamma_{m} = 19.0$ kN/m$^3$
Saturated density of retained material \( \gamma_s = 21.0 \text{ kN/m}^3 \)

Design shear strength \( \phi' = 34.0 \text{ deg} \)

Angle of wall friction \( \delta = 0.0 \text{ deg} \)

**Base material details**

Moist density \( \gamma_{mb} = 19.0 \text{ kN/m}^3 \)

Design shear strength \( \phi_b = 34.0 \text{ deg} \)

Design base friction \( \delta_b = 0.0 \text{ deg} \)

Allowable bearing pressure \( P_{bearing} = 120 \text{ kN/m}^2 \)

**Using Coulomb theory**

**Active pressure coefficient for retained material**

\[
K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{\sin(\phi' + \delta) \times \sin(\phi' - \delta) / (\sin(\alpha - \delta) \times \sin(\alpha + \phi'))}]) = 0.283
\]

**Passive pressure coefficient for base material**

\[
K_p = \sin(90 - \phi_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{\sin(\phi_b + \delta_b) \times \sin(\phi_b / (\sin(90 + \delta_b))}]) = 3.537
\]

**At-rest pressure**

At-rest pressure for retained material \( K_0 = 1 - \sin(\phi') = 0.441 \)

**Loading details**

Surcharge load on plan \( \text{Surcharge} = 10.0 \text{ kN/m}^2 \)

Applied vertical dead load on wall \( W_{dead} = 25.9 \text{ kN/m} \)

Applied vertical live load on wall \( W_{live} = 1.5 \text{ kN/m} \)

Position of applied vertical load on wall \( l_{load} = 1350 \text{ mm} \)

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 \( h_{load} = 0 \text{ mm} \)

**Vertical forces on wall**

Wall stem \( W_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall} = 30.4 \text{ kN/m} \)

Loads shown in kN/m, pressures shown in kN/m²
Wall base \( W_{\text{base}} = l_{\text{base}} \times b_{\text{base}} \times \gamma_{\text{base}} \) = 10.6 kN/m

Applied vertical load \( W_v = W_{\text{dead}} + W_{\text{live}} \) = 27.4 kN/m

Total vertical load \( W_{\text{total}} = W_{\text{wall}} + W_{\text{base}} + W_v \) = 68.5 kN/m

**Horizontal forces on wall**

Surcharge \( F_{\text{surr}} = K_a \times \text{Surcharge} \times h_{\text{eff}} \) = 13 kN/m

Saturated backfill \( F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{\text{water}}) \times h_{\text{water}}^2 \) = 33.5 kN/m

Water \( F_{\text{water}} = 0.5 \times h_{\text{water}}^2 \times \gamma_{\text{water}} \) = 103.8 kN/m

Total horizontal load \( F_{\text{total}} = F_{\text{surr}} + F_s + F_{\text{water}} \) = 150.3 kN/m

**Calculate total propping force**

Passive resistance of soil in front of wall \( F_p = 0.5 \times K_p \times (d_{\text{cover}} + b_{\text{base}} + d_{\text{as}} - d_{\text{as}})^2 \times \gamma_{\text{soil}} \) = 3 kN/m

Propping force \( F_{\text{prop}} = \max(F_{\text{total}} - F_p - (W_{\text{total}} - W_{\text{live}}) \times \tan(\delta_0), 0 \text{ kN/m}) \)

\( F_{\text{prop}} = 147.2 \text{ kN/m} \)

**Overturning moments**

Surcharge \( M_{\text{surr}} = F_{\text{surr}} \times (h_{\text{eff}} - 2 \times d_{\text{as}}) / 2 \) = 29.9 kNm/m

Saturated backfill \( M_s = F_s \times (h_{\text{water}} - 3 \times d_{\text{as}}) / 3 \) = 51.3 kNm/m

Water \( M_{\text{water}} = F_{\text{water}} \times (h_{\text{water}} - 3 \times d_{\text{as}}) / 3 \) = 159.1 kNm/m

Total overturning moment \( M_{\text{tot}} = M_{\text{surr}} + M_s + M_{\text{water}} \) = 240.4 kNm/m

**Restoring moments**

Wall stem \( M_{\text{wall}} = W_{\text{wall}} \times (l_{\text{base}} + l_{\text{wall}} / 2) \) = 41.1 kNm/m

Wall base \( M_{\text{base}} = W_{\text{base}} \times b_{\text{base}} / 2 \) = 8 kNm/m

Design vertical dead load \( M_{\text{dead}} = W_{\text{dead}} \times l_{\text{dead}} \) = 35 kNm/m

Total restoring moment \( M_{\text{rest}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{dead}} \) = 84 kNm/m

**Check bearing pressure**

Total vertical reaction \( R = W_{\text{total}} \) = 68.5 kN/m

Distance to reaction \( x_{\text{bar}} = l_{\text{base}} / 2 \) = 750 mm

Eccentricity of reaction \( e = \text{abs}(l_{\text{base}} / 2 - x_{\text{bar}}) \) = 0 mm

**Reaction acts within middle third of base**

Bearing pressure at toe \( p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R \times e / l_{\text{base}}^2) \) = 45.6 kN/m²

Bearing pressure at heel \( p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R \times e / l_{\text{base}}^2) \) = 45.6 kN/m²

**PASS - Maximum bearing pressure is less than allowable bearing pressure**

**Calculate propping forces to top and base of wall**

Propping force to top of wall \( F_{\text{prop, top}} = (M_{\text{rest}} - R \times l_{\text{base}} / 2 - F_{\text{prop}} \times l_{\text{base}} / 2) / (l_{\text{stem}} + l_{\text{base}} / 2) \) = 41.710 kN/m

Propping force to base of wall \( F_{\text{prop, base}} = F_{\text{prop}} - F_{\text{prop, top}} \) = 105.531 kN/m
### 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: $W_{wall, f} = \gamma_d \times h_{stem} \times l_{wall} \times \gamma_{wall} = 42.6 \text{ kN/m}$
- Wall base: $W_{base, f} = \gamma_d \times h_{base} \times l_{base} \times \gamma_{base} = 14.9 \text{ kN/m}$
- Applied vertical load: $W_{V, f} = \gamma_d \times W_{dead} + \gamma_l \times W_{live} = 38.7 \text{ kN/m}$
- Total vertical load: $W_{total, f} = W_{wall, f} + W_{base, f} + W_{V, f} = 96.1 \text{ kN/m}$

**Factored horizontal at-rest forces on wall**
- Surcharge: $F_{sur, f} = \gamma_e \times K_o \times \text{Surcharge} \times h_{eff} = 32.4 \text{ kN/m}$
- Saturated backfill: $F_{s, f} = \gamma_e \times 0.5 \times K_o \times (\gamma_r \times \text{Surcharge}) \times h_{water}^2 = 73.1 \text{ kN/m}$
- Water: $F_{water, f} = \gamma_e \times 0.5 \times h_{water}^2 \times \gamma_r \times \text{water} = 145.3 \text{ kN/m}$
- Total horizontal load: $F_{total, f} = F_{sur, f} + F_{s, f} + F_{water, f} = 250.8 \text{ kN/m}$

**Calculate total propping force**
- Passive resistance of soil in front of wall: $F_{P, f} = \gamma_e \times 0.5 \times K_F \times (d_{cove} + l_{base} + d_{as} - d_{slip})^2 \times \gamma_{mb} = 4.2 \text{ kN/m}$
- Propping force: $F_{prop, f} = \max(F_{total, f} - F_{P, f} - (W_{total, f} - \gamma_l \times W_{live} \times tan(\delta_0)), 0 \text{ kN/m})$
  - $F_{prop, f} = 246.6 \text{ kN/m}$

**Factored overturning moments**
- Surcharge: $M_{sur, f} = F_{sur, f} \times (h_{eff} - 2 \times d_{as}) / 2 = 74.6 \text{ kN/m/m}$
- Saturated backfill: $M_{s, f} = F_{s, f} \times (h_{water} - 3 \times d_{as}) / 3 = 112 \text{ kN/m/m}$
- Water: $M_{water, f} = F_{water, f} \times (h_{water} - 3 \times d_{as}) / 3 = 222.8 \text{ kN/m/m}$
- Total overturning moment: $M_{total, f} = M_{sur, f} + M_{s, f} + M_{water, f} = 409.5 \text{ kN/m/m}$

**Restoring moments**
- Wall stem: $M_{wall, f} = W_{wall, f} \times (l_{base} + l_{wall} / 2) = 57.5 \text{ kN/m/m}$
- Wall base: $M_{base, f} = W_{base, f} \times l_{base} / 2 = 11.2 \text{ kN/m/m}$
- Design vertical load: $M_{V, f} = W_{V, f} \times l_{base} = 52.2 \text{ kN/m/m}$
- Total restoring moment: $M_{total, f} = M_{wall, f} + M_{base, f} + M_{V, f} = 120.9 \text{ kN/m/m}$

**Factored bearing pressure**
- Total vertical reaction: $R_t = W_{total, f} = 96.1 \text{ kN/m}$
- Distance to reaction: $x_{base, f} = l_{base} / 2 = 750 \text{ mm}$
- Eccentricity of reaction: $e_r = abs((l_{base} / 2) - x_{base, f}) = 0 \text{ mm}$

*Reaction acts within middle third of base*

- Bearing pressure at toe: $p_{base, f} = (R_t / l_{base}) - (6 \times R_t / e_r / l_{base}^2) = 64.1 \text{ kN/m}^2$
- Bearing pressure at heel: $p_{base, f} = (R_t / l_{base}) + (6 \times R_t / e_r / l_{base}^2) = 64.1 \text{ kN/m}^2$
- Rate of change of base reaction: $rate = (p_{base, f} - p_{wheel, f}) / l_{base} = 0.00 \text{ kN/m}^2$\text{m}$
- Bearing pressure at stem to toe: $p_{stem, toe, f} = \max(p_{base, f} - (rate \times l_{base}), 0 \text{ kN/m}^2) = 64.1 \text{ kN/m}^2$
- Bearing pressure at mid stem: $p_{stem, mid, f} = \max(p_{base, f} - (rate \times (l_{base} + l_{wall} / 2)), 0 \text{ kN/m}^2) = 64.1 \text{ kN/m}^2$
- Bearing pressure at stem to heel: $p_{stem, heel, f} = \max(p_{base, f} - (rate \times (l_{base} + l_{wall})), 0 \text{ kN/m}^2) = 64.1 \text{ kN/m}^2$

**Calculate propping forces to top and base of wall**
- Propping force to top of wall: $F_{prop, top, f} = (M_{total, f} - M_{wheel, f} + R_t \times l_{base} / 2 - F_{prop, f} \times l_{base} / 2) / (h_{stem} + l_{base} / 2) = 72.740 \text{ kN/m}$
Propping force to base of wall

\[ F_{\text{prop\_base\_r}} = F_{\text{prop\_r}} - F_{\text{prop\_top\_r}} = 173.837 \text{ kN/m} \]

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

**Material properties**
- Characteristic strength of concrete \( f_{cu} = 40 \text{ N/mm}^2 \)
- 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 \( C_{\text{rein}} = 50 \text{ mm} \)

**Calculate shear for toe design**
- Shear from bearing pressure
  \[ V_{\text{toe\_bear}} = (p_{\text{toe\_f}} + p_{\text{stem\_toe\_f}}) \times l_{\text{toe}} / 2 = 76.9 \text{ kN/m} \]
- Shear from weight of base
  \[ V_{\text{toe\_wt\_base}} = \gamma_{\text{c}} \times \gamma_{\text{base}} \times l_{\text{base}} \times l_{\text{base}} = 11.9 \text{ kN/m} \]
- Total shear for toe design
  \[ V_{\text{toe}} = V_{\text{toe\_bear}} - V_{\text{toe\_wt\_base}} = 65 \text{ kN/m} \]

**Calculate moment for toe design**
- Moment from bearing pressure
  \[ M_{\text{toe\_bear}} = (2 \times p_{\text{toe\_f}} + p_{\text{stem\_toe\_f}}) \times (l_{\text{toe}} + t_{\text{wt}} / 2)^2 / 6 = 58.4 \text{ kNm/m} \]
- Moment from weight of base
  \[ M_{\text{toe\_wt\_base}} = (\gamma_{\text{c}} \times \gamma_{\text{base}} \times l_{\text{base}} \times (l_{\text{base}} + t_{\text{wt}} / 2)^2 / 2 = 9 \text{ kNm/m} \]
- Total moment for toe design
  \[ M_{\text{toe}} = M_{\text{toe\_bear}} - M_{\text{toe\_wt\_base}} = 48.4 \text{ kNm/m} \]

**Check toe in bending**
- Width of toe \( b = 1000 \text{ mm/m} \)
- Depth of reinforcement \( d_{\text{toe}} = l_{\text{base}} - C_{\text{rein}} - (\phi_{\text{toe}} / 2) = 244.0 \text{ mm} \)
- Constant \( K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}} \times f_{\text{cu}}) = 0.021 \)

*Compression reinforcement is not required*

**Lever arm**
- \( z_{\text{toe}} = \min(0.5 + \sqrt{0.25 - (\min(K_{\text{toe}}, 0.225) / 0.9)), 0.95) \times d_{\text{toe}} = 232 \text{ mm} \)

**Area of tension reinforcement required**
- \( A_{\text{toe\_des}} = M_{\text{toe}} / (0.87 \times f_y \times z_{\text{toe}}) = 490 \text{ mm}^2 / \text{m} \)
- \( A_{\text{toe\_min}} = k \times b \times l_{\text{base}} = 390 \text{ mm}^2 / \text{m} \)

**Reinforcement provided**
- \( A_{\text{toe\_req}} = \max(A_{\text{toe\_des}}, A_{\text{toe\_min}}) = 490 \text{ mm}^2 / \text{m} \)
- 12 mm dia. bars @ 200 mm centres
- \( A_{\text{toe\_prov}} = 565 \text{ mm}^2 / \text{m} \)

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

**Check shear resistance at toe**
- Design shear stress \( V_{\text{toe}} = V_{\text{toe}} / (b \times d_{\text{toe}}) = 0.266 \text{ N/mm}^2 \)
- Allowable shear stress \( V_{\text{adm}} = \min(0.8 \times \sqrt{f_{\text{cu}} / 1 \text{ N/mm}^2}, 5) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2 \)

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

**Design concrete shear stress**
- \( V_{c\_toe} = 0.514 \text{ N/mm}^2 \)

*\( V_{\text{toe}} < V_{c\_toe} - \text{No shear reinforcement required})*
Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties
Characteristic strength of concrete \( f_{cu} = 40 \text{ N/mm}^2 \)
Characteristic strength of reinforcement \( f_s = 500 \text{ N/mm}^2 \)

Wall details
Minimum area of reinforcement \( k = 0.13 \% \)
Cover to reinforcement in stem \( c_{stem} = 50 \text{ mm} \)
Cover to reinforcement in wall \( c_{wall} = 50 \text{ mm} \)

Factored horizontal at-rest forces on stem
Surcharge \( F_{s,sur,f} = \gamma_{L,f} \times K_0 \times \text{Surcharge} \times (\text{Net} - \text{Base} - d_{30}) = 30.3 \text{ kN/m} \)
Saturated backfill \( F_{s,sat,f} = 0.5 \times \gamma_{L,sat} \times K_0 \times (\gamma_w - \gamma_{water}) \times \text{Net}^2 = 63.8 \text{ kN/m} \)
Water \( F_{s,water,f} = 0.5 \times \gamma_{L,water} \times \gamma_w \times \text{Net}^2 = 127 \text{ kN/m} \)

Calculate shear for stem design
Surcharge \( V_{s,sur,f} = 5 \times F_{s,sur,f} / 8 = 19 \text{ kN/m} \)
Saturated backfill \( V_{s,sat,f} = F_{s,sat,f} \times (1 - (a^2 \times ((5 \times L) - a) / (20 \times L^2))) = 51.1 \text{ kN/m} \)
Water \( V_{s,water,f} = F_{s,water,f} \times (1 - (a^2 \times ((5 \times L) - a) / (20 \times L^2))) = 101.6 \text{ kN/m} \)
Total shear for stem design \( V_{stem} = V_{s,sur,f} + V_{s,sat,f} + V_{s,water,f} = 171.6 \text{ kN/m} \)

Calculate moment for stem design
Surcharge \( M_{s,sur} = F_{s,sur,f} \times L / 8 = 16.9 \text{ kNm/m} \)
Saturated backfill \( M_{s,sat} = F_{s,sat,f} \times a \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 37.9 \text{ kNm/m} \)
Water \( M_{s,water} = F_{s,water,f} \times a \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 75.3 \text{ kNm/m} \)
Total moment for stem design \( M_{stem} = M_{s,sur} + M_{s,sat} + M_{s,water} = 130.1 \text{ kNm/m} \)

Calculate moment for wall design
Surcharge \( M_{w,sur} = 9 \times F_{s,sur,f} \times L / 128 = 9.5 \text{ kNm/m} \)
Saturated backfill \( M_{w,sat} = F_{s,sat,f} \times a \times ((5 \times L) - a) / (20 \times L^2) - (x-b)^3 / (3 \times a^2) = 16.9 \text{ kNm/m} \)
Water \( M_{w,water} = F_{s,water,f} \times a \times ((5 \times L) - a) / (20 \times L^2) - (x-b)^3 / (3 \times a^2) = 33.7 \text{ kNm/m} \)
Total moment for wall design \( M_{wall} = M_{w,sur} + M_{w,sat} + M_{w,water} = 60.1 \text{ kNm/m} \)

Check wall stem in bending
Width of wall stem \( b = 1000 \text{ mm/m} \)
Depth of reinforcement \( d_{stem} = t_{stem} - c_{stem} - (\phi_{stem} / 2) = 240.0 \text{ mm} \)
Constant \( K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = 0.056 \)
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

Check retaining wall deflection

Basic span/effective depth ratio

Design service stress

Modification factor

Maximum span/effective depth ratio

Actual span/effective depth ratio

\[ Z_{\text{stem}} = \min(0.5 + \sqrt{(0.25 - \min(K_{\text{stem}}, 0.225)) / 0.9)}, 0.95) \times d_{\text{stem}} \]

\[ Z_{\text{stem}} = 224 \text{ mm} \]

\[ A_{s,\text{stem}} = \frac{M_{\text{stem}}}{(0.87 \times f_y \times Z_{\text{stem}})} = 1336 \text{ mm}^2/\text{m} \]

\[ A_{s,\text{stem, min}} = k \times b \times t_{\text{wall}} = 390 \text{ mm}^2/\text{m} \]

\[ A_{s,\text{stem, req}} = \max\left(A_{s,\text{stem, des}}, A_{s,\text{stem, min}}\right) = 1336 \text{ mm}^2/\text{m} \]

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

\[ A_{s,\text{stem, prov}} = 1571 \text{ mm}^2/\text{m} \]

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

\[ V_{\text{stem}} = \frac{V_{\text{des}}}{(b \times d_{\text{stem}})} = 0.715 \text{ N/mm}^2 \]

\[ V_{\text{des}} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2), 5}) \times 1 \text{ N/mm}^2 = 5,000 \text{ N/mm}^2 \]

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

\[ V_{c,\text{stem}} = 0.729 \text{ N/mm}^2 \]

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

\[ d_{\text{wall}} = t_{\text{wall}} - d_{\text{wall}} - (t_{\text{wall}} / 2) = 242.0 \text{ mm} \]

\[ K_{\text{wall}} = \frac{M_{\text{wall}}}{(b \times d_{\text{wall}}^2 \times f_{cu})} = 0.026 \]

**Compression reinforcement is not required**

\[ Z_{\text{wall}} = \min(0.5 + \sqrt{(0.25 - \min(K_{\text{wall}}, 0.225)) / 0.9}), 0.95) \times d_{\text{wall}} \]

\[ Z_{\text{wall}} = 230 \text{ mm} \]

\[ A_{s,\text{wall, des}} = \frac{M_{\text{wall}}}{(0.87 \times f_y \times Z_{\text{wall}})} = 601 \text{ mm}^2/\text{m} \]

\[ A_{s,\text{wall, min}} = k \times b \times t_{\text{wall}} = 350 \text{ mm}^2/\text{m} \]

\[ A_{s,\text{wall, req}} = \max\left(A_{s,\text{wall, des}}, A_{s,\text{wall, min}}\right) = 601 \text{ mm}^2/\text{m} \]

\[ 16 \text{ mm dia.bars @ } 200 \text{ mm centres} \]

\[ A_{\text{wall, prov}} = 1005 \text{ mm}^2/\text{m} \]

**PASS - Reinforcement provided to the retaining wall at mid height is adequate**

\[ \text{Ratio}_{\text{bas}} = 20 \]

\[ f_s = 2 \times f_y \times A_{s,\text{stem, req}} / (3 \times A_{s,\text{stem, prov}}) = 283.5 \text{ N/mm}^2 \]

\[ \text{Factor}_{\text{trans}} = \min(0.55 + (477 \text{ N/mm}^2 - f_s) / (120 \times (0.9 \text{ N/mm}^2 + (M_{\text{stem}} / (b \times d_{\text{stem}}^2)))), 2) = 1.06 \]

\[ \text{Ratio}_{\text{max}} = \text{Ratio}_{\text{bas}} \times \text{Factor}_{\text{trans}} = 21.21 \]

\[ \text{Ratio}_{\text{act}} = h_{\text{stem}} / d_{\text{stem}} = 17.92 \]

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

Wall reinforcement

Stem reinforcement

Toe reinforcement

Toe bars - 12 mm dia. @ 200 mm centres - (565 mm²/m)
Wall bars - 16 mm dia. @ 200 mm centres - (1005 mm²/m)
Stem bars - 20 mm dia. @ 200 mm centres - (1571 mm²/m)
Overview

Design of basement floor reinforced concrete slab.

Analysis

<table>
<thead>
<tr>
<th>Load</th>
<th>Calculation</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Dead Load</td>
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<td></td>
</tr>
<tr>
<td>Finish</td>
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<tr>
<td>Screed</td>
<td></td>
<td>2.00</td>
</tr>
<tr>
<td>200 kN/m² slab ($f_c = 24.0$ kN/m²)</td>
<td></td>
<td>7.20</td>
</tr>
<tr>
<td>Imposed Load</td>
<td></td>
<td>1.50</td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Max. span : 5.600 m
Min. span : 5.575 m

Slab to be designed to be suspended

Reinforcement to be determined.

check span \(\leq 2.0\)

\[
\frac{5600}{300} = 18.67 < 20
\]

\[\therefore 300 \text{ kN/m²} \text{ reinforced basement slab sufficient.}\]

Reinforcement subject to detailed design and review on water pressure requirements.

As per CSI report, leave or water pressure with full head = 38.00 kN/m² \(\therefore\) reinforcement to be detailed accordingly.

\[W = 38.00 \text{ kN/m}^2\]

\[M = \frac{38.0 \times 5.6^2}{8} = 148.96 \approx 149.0 \text{ kNm}\]
Appendix B

B1. Structural drawing package
1. All demolition work is to be in accordance with BS6187 and the contractor is to provide and maintain a safe working environment. Any exposed unprotected steel reinforcement is to be regarded as live and precautions taken to prevent contact with live steel.  

2. The Contractor shall open up the floors and walls in selected locations to establish the construction sequence. The Contractor is to provide and maintain a safe working environment. Any exposed unprotected steel reinforcement is to be regarded as live and precautions taken to prevent contact with live steel. 

3. Galvanise to a minimum mean coating thickness of 140 microns in accordance with BS EN ISO 1461.  

4. The position of any construction joints is to be agreed with the Architects. Joints are to be formed once the construction is approximately 25% complete. Provisions are to be made to limit thermal shrinkage and the concrete is to be fully poured in accordance with the Manufacturer’s requirements. 

5. Underpinning method statement & procedure:Underpinning to be carried out in accordance with ASUC guidelines on safe and efficient underpinning & mini piling operations. 

6. Building inspector and engineer to inspect excavation to agreed depth and satisfactory bearing capacity for underpinning. 

7. All columns are to have a minimum cover of 75mm. 

8. Underpinning to be carried out in accordance with ASUC guidelines on safe and efficient underpinning & mini piling operations. 

9. Cast concrete pin to required mix to within 75mm of underside of existing foundation (concrete strength 32/40). 

10. After minimum 48 hours, dry pack gap between underpinning & existing corbel with 1:3 cement/sand/10 grade limestone aggregate. 

11. Remove temporary propping once the basement slab has cured. 

12. Excavate and construct pump chamber. Allow for some dewatering for this process. 

13. Install drained cavity waterproofing system in line with manufacture details. 

14. Reinforce has been detailed using the following notation: number of bars - grade of steel. 

15. Any steelwork that cannot be erected until other trades are completed is to be carefully stored in a well drained and dry area away from the proposed building site. 

16. Galvanized mild steel straps are to have a minimum cross sectional area of 30x5mm and are to be hot dip galvanized in accordance with BS2989:1991.
PROPOSED BASEMENT PLAN
(1:50)

Typically 450mm thick to suit party walls. Should walls be thinner, min 350mm thick to be constructed (eng to be notified).

NOTES
- Thoroughly to be based on condition inspection by Peter Dann Consulting Engineers, Architects, MEP Engineers and Specialists.
- All finishes and works etc. are to be to the satisfaction of Peter Dann Consulting Engineers.
- Any Formal Contractual terms and conditions relating to health and safety, hourly rates of pay, etc. are as per normal contract conditions
- Any variations to the plans and specifications shall be subject to a formal letter from Peter Dann Consulting Engineers
- All sections are to be read in conjunction with all Peter Dann Consulting Engineers, Architects, MEP Engineers and Specialists drawings along with all relevant Specifications.
- All gridlines, building lines, etc. are to be set out in accordance with the relevant Architects drawings. Any discrepancies between the information given by the Engineer and that provided by others must be referred to the Architect before work proceeds.
- All beams are referenced depth x breadth unless noted otherwise.
- All proprietary fixings shall be installed in accordance with the manufacturer’s recommendations.
- The Contractor shall comply with the health and safety requirements as set out by the CDM Regulations, THE HEALTH AND SAFETY EXECUTIVE.
- All works are to be undertaken in accordance with the Building Regulations and latest relevant British Standards.
- The Contractor is solely responsible for maintaining temporary stability of the structure during demolition and construction.
- All Construction products are to be CE Marked in accordance with the Construction Products Regulation (EU) No. 305/2011.

Construction
- It is considered that the proposed works are within the scope of a competent contractor and as such no unusual hazards have been identified, other than noted below:

Reinforced concrete retaining walls designed as propped at top and bottom by reinforced concrete slabs at lower ground floor level and basement level. A qualified structural engineer should be consulted prior to any alterations being undertaken.

Decommissioning/Demolition
- There are no unusual structural aspects to this building that require highlighting in the event that the building is demolished, other than noted below:

Reinforced concrete retaining walls designed as propped at top and bottom by reinforced concrete slabs at lower ground floor level and basement level. A qualified structural engineer should be consulted prior to any alterations being undertaken.

Record Information
- The record drawings/operating manual for the building should be thoroughly studied and its implications assessed by the demolition contractor.

Sump Chamber position to be confirmed

300mm thick reinforced concrete slab (Reinforcement to be confirmed).
1. This drawing is to be read in conjunction with all Peter Dann Consulting Engineers, Architects, MEP Engineers and Specialists drawings along with all relevant Specifications.

2. Dimensions are NOT to be scaled from this drawing. If in doubt ask. Dimensions marked * are subject to confirmation by site.

3. All works are to be undertaken in accordance with the Building Regulations and latest relevant British Standards.

4. All works are to be undertaken in accordance with the Construction Products Regulation (EU) No. 305/2011.

5. All proprietary fixings shall be installed in accordance with the manufacturer's recommendations.

6. All beams are referenced depth x breadth unless noted otherwise.

7. The Contractor is solely responsible for maintaining temporary stability of the structure during demolition and construction.

8. All Construction products are to be CE Marked in accordance with the Construction Products Regulation (EU) No. 305/2011.

9. The Contractor is responsible for maintaining temporary stability of the structure during demolition and construction.

10. Decommissioning/Demolition - There are no unusual structural hazards have been identified, other than noted below:

   - Reinforced concrete retaining walls designed as propped at top and bottom by reinforced concrete slabs at lower ground floor level and basement level. A qualified structural engineer should be consulted prior to any alterations being undertaken.

   - All works shall be undertaken in accordance with the Building Regulations and latest relevant British Standards.

   - All beams are referenced depth x breadth unless noted otherwise.

   - All proprietary fixings shall be installed in accordance with the manufacturer's recommendations.

   - All Construction products are to be CE Marked in accordance with the Construction Products Regulation (EU) No. 305/2011.

   - All works are to be undertaken in accordance with the Building Regulations and latest relevant British Standards.

   - The Contractor is solely responsible for maintaining temporary stability of the structure during demolition and construction.

   - Decommissioning/Demolition - There are no unusual structural hazards have been identified, other than noted below:

   - Reinforced concrete retaining walls designed as propped at top and bottom by reinforced concrete slabs at lower ground floor level and basement level. A qualified structural engineer should be consulted prior to any alterations being undertaken.

   - All works shall be undertaken in accordance with the Building Regulations and latest relevant British Standards.

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