Structural Calculations

for

65 Clarendon Road
London
W11

for

Eric Abraham Esq
65 Clarendon Road
London
W11 4JE

Job No 864

<table>
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<th>Date</th>
<th>Notes</th>
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1. CALCULATION PLAN

This report contains the structural engineering calculations for the proposed development at 65, Clarendon Road.

The works to the existing main building consists of the construction of a new basement level below the current lower ground level with swimming pool and cinema room. There is also some refurbishment and restructuring of the lower ground floor of the main building.

The works to the existing garage and staff rooms consist of a basement level below the existing lower ground floor with a swimming pool and sauna. The lower ground floor is being refurbished with kitchen, living, dining and one bedroom with ensuite bathroom. The existing garage at upper ground level is being demolished and a second bedroom, with dressing and ensuite bathroom built in its place.

1.1. SUMMARY OF STRUCTURE

Proposed Basement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Maximum plan dimensions</td>
<td>24.915m by 14.40m</td>
</tr>
<tr>
<td>Footprint area</td>
<td>286.50m²</td>
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<tr>
<td>Storeys</td>
<td>Basement + two ground floors + first, second and loft floors above</td>
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<tr>
<td>Maximum height</td>
<td>14.862m above ground level</td>
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<tr>
<td>Basement excavation depth</td>
<td>8.675m below ground level</td>
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<tr>
<td>Footings</td>
<td>Basement raft slab &amp; retaining walls</td>
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</table>

1.2. IMPOSED LOADS

The following imposed loads have been assumed

- Typical imposed loads on roofs: 0.75 kN/m²
- Imposed All floors: 1.50 kN/m² (1.00 kN/m² partitions)

1.3. RETAINING WALLS

The proposed basement is formed by constructing perimeter 400mm thick retaining walls that extends almost 8.175 metres below ground level. Other vertical structures in the basement are internal load-bearing concrete walls within the inside of the building.

The basement excavation requires contiguous pile retaining walls for temporary support of the east and west sides of the site. In the permanent case the piles are cantilevers propped by the basement and ground floor slabs. Retaining walls for the effects of underpinning are typically 400mm wide. While at the rear end of the building, retaining are 300mm thick.
1.4. GROUND FLOORS AND SUPERSTRUCTURE

The lower and upper ground floor is constructed of typical RC slabs varying in depth and using strip beams to frame openings. In the upper ground floor on the main building unit, the existing ground beams cast in concrete are to be removed and a series of four transfer structures in the form of steel beams have been added to support the existing building weight which is translated as a series of point reactions from the existing columns. The superstructure (first, second and loft floors) are to remain unaltered.
## 2. RESOURCES

### 2.1. CODES & REFERENCES

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>BS6399 Pt1</td>
<td>Loadings for buildings. Code of practice for dead and imposed loads.</td>
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<td>BS5628 Pt1</td>
<td>Use of masonry. Structural use of unreinforced masonry.</td>
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<tr>
<td>BS5950 Pt1</td>
<td>Structural use of steelwork in building. Code of practice for design in simple and continuous construction hot rolled sections.</td>
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<tr>
<td>BS8110 Pt1</td>
<td>Structural use of concrete</td>
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### 2.2. SOFTWARE

CSC suite of design and analysis tools
### 3.0 AREA LOADS

**Existing timber floors**

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<tr>
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<th>Load</th>
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<tr>
<td>Dead finishes</td>
<td>0.20 kN/m²</td>
</tr>
<tr>
<td>boards</td>
<td>0.20 kN/m²</td>
</tr>
<tr>
<td>Joists/masonite</td>
<td>0.20 kN/m²</td>
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<tr>
<td>ceiling + services</td>
<td>0.30 kN/m²</td>
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<tr>
<td><strong>Total</strong></td>
<td>0.90 kN/m²</td>
</tr>
</tbody>
</table>

Imposed (allowing for partitions) 2.50 kN/m²

**Existing timber roof (pitched)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead Finishes</td>
<td>0.30 kN/m²</td>
</tr>
<tr>
<td>Battens &amp; Felt</td>
<td>0.10 kN/m²</td>
</tr>
<tr>
<td>Rafters &amp; Insulation</td>
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</tr>
<tr>
<td>Ceiling &amp; Services</td>
<td>0.30 kN/m²</td>
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<tr>
<td><strong>Total</strong></td>
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Imposed (access for repair & maintenance) 0.75 kN/m²

**Existing garage roof (assumed as above)**

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<thead>
<tr>
<th>Component</th>
<th>Load</th>
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<tbody>
<tr>
<td>Dead Finishes</td>
<td>0.30 kN/m²</td>
</tr>
<tr>
<td>Battens &amp; Felt</td>
<td>0.10 kN/m²</td>
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<tr>
<td>Rafters &amp; Insulation</td>
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<td>Ceiling &amp; Services</td>
<td>0.30 kN/m²</td>
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<tr>
<td><strong>Total</strong></td>
<td>0.90 kN/m²</td>
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Imposed (access for repair & maintenance) 0.75 kN/m²
### Existing 9 inch Brick wall

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</thead>
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<tr>
<td>Dead</td>
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<tr>
<td></td>
<td>Plaster</td>
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<td>5.40 kN/m²</td>
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### Existing 13.5 inch Brick wall (party wall)

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<tr>
<td></td>
<td>Plaster</td>
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### 250 thk RC slab

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<td>Screed</td>
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<tr>
<td></td>
<td>Insulation</td>
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</tr>
<tr>
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<td>Finishes</td>
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### 300 thk RC slab

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<td>Insulation</td>
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<td>Finishes</td>
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### 350 thk RC slab

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**Proposed concrete slab above pool**

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**Proposed 400 thick RC wall**

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**Proposed 250 thick RC wall**

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EXTERNAL PERIMETER WALLS;

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<th>AREA LOADS</th>
<th>WIDTH/AREA</th>
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<th>POINT LOAD</th>
<th>WEIGHT</th>
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<tr>
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<td>POINT LOAD</td>
<td>WEIGHT</td>
</tr>
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<tr>
<td>till LG level</td>
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<tr>
<td>350 thick LG RC slab</td>
<td>10.50</td>
<td>2.50</td>
<td>1212.5</td>
<td>12.73</td>
<td>126.0</td>
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<tr>
<td>400 thick RC wall</td>
<td>9.80</td>
<td>4990</td>
<td>13000mm long</td>
<td>3.03</td>
<td>635.7</td>
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<td></td>
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<td>Σ 1537</td>
</tr>
<tr>
<td>Side Wall (W9) 8866</td>
<td></td>
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<tr>
<td>flat roof</td>
<td>0.90</td>
<td>1.50</td>
<td>17.75</td>
<td></td>
<td>15.98</td>
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<td>glazing</td>
<td>0.80</td>
<td>1.50</td>
<td>1015</td>
<td>0.81</td>
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<td>brickwork</td>
<td>5.40</td>
<td>2765</td>
<td>14.931</td>
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<td>132.4</td>
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<td>300mm thick RC slab</td>
<td>9.30</td>
<td>2.50</td>
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<td></td>
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<td>Σ 271.5</td>
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### Inner Structure

#### FLOORS

<table>
<thead>
<tr>
<th>Load Description</th>
<th>DL (kN/m²)</th>
<th>LL (kN/m²)</th>
<th>wall Thickness (mm)</th>
<th>Height (m)</th>
<th>DL (kN)</th>
<th>LL (kN)</th>
<th>Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pitched roof</td>
<td>0.90</td>
<td>0.75</td>
<td>14.99</td>
<td></td>
<td>13.49</td>
<td>11.24</td>
<td>24.73</td>
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<tr>
<td>loft timber floor</td>
<td>0.90</td>
<td>2.50</td>
<td>14.42</td>
<td></td>
<td>12.98</td>
<td>36.05</td>
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<td>second floor timber</td>
<td>0.90</td>
<td>2.50</td>
<td>27.18</td>
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<td>24.46</td>
<td>67.95</td>
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<tr>
<td>first floor timber</td>
<td>0.90</td>
<td>2.50</td>
<td>27.73</td>
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<td>24.96</td>
<td>69.33</td>
<td>94.32</td>
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<td>upper ground floor</td>
<td>0.90</td>
<td>2.50</td>
<td>27.11</td>
<td></td>
<td>24.40</td>
<td>67.78</td>
<td>92.18</td>
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</table>

### Party wall south (W6)

<table>
<thead>
<tr>
<th>Load Description</th>
<th>DL (kN/m²)</th>
<th>LL (kN/m²)</th>
<th>wall Thickness (mm)</th>
<th>Height (m)</th>
<th>Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>flat roof</td>
<td>0.90</td>
<td>1.5</td>
<td>14.70</td>
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<td>13.23</td>
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<tr>
<td>13 inch wall</td>
<td>7.80</td>
<td>1.5</td>
<td>1365</td>
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<tr>
<td>400 RC underpin</td>
<td>9.80</td>
<td>1.5</td>
<td>6490</td>
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<td>714.3</td>
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### Side wall south (W10)

<table>
<thead>
<tr>
<th>Load Description</th>
<th>DL (kN/m²)</th>
<th>LL (kN/m²)</th>
<th>wall Thickness (mm)</th>
<th>Height (m)</th>
<th>Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>flat roof</td>
<td>0.90</td>
<td>1.5</td>
<td>19.84</td>
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<td>17.86</td>
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<td>brickwork full height</td>
<td>7.80</td>
<td>4.01</td>
<td>3081</td>
<td>31.832</td>
<td>190.5</td>
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<td>300 thick RC slab (ug)</td>
<td>9.30</td>
<td>2.50</td>
<td>2156.5</td>
<td>20.06</td>
<td>5.39</td>
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<tr>
<td>300 thick RC slab (lg)</td>
<td>9.30</td>
<td>2.50</td>
<td>1061</td>
<td>9.87</td>
<td>2.65</td>
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<tr>
<td>400 thick RC wall</td>
<td>9.80</td>
<td>1.5</td>
<td>6490</td>
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<td>376.2</td>
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### Rear wall (W11)

<table>
<thead>
<tr>
<th>Load Description</th>
<th>DL (kN/m²)</th>
<th>LL (kN/m²)</th>
<th>wall Thickness (mm)</th>
<th>Height (m)</th>
<th>Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>brickwork full height</td>
<td>7.80</td>
<td>1.5</td>
<td>47.892</td>
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<td>303.1</td>
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### WALL TAKEDOWN PER WALL

<table>
<thead>
<tr>
<th>WALL LABEL-LENGTH &amp; LOAD DESCRIPTION</th>
<th>AREA LOADS</th>
<th>WIDTH/HEIGHT</th>
<th>AREA UDL</th>
<th>POINT LOAD</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DL</td>
<td>LL</td>
<td>kN/m²</td>
<td>kN/m</td>
<td>kN</td>
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<tr>
<td></td>
<td>LL</td>
<td>m</td>
<td>m²</td>
<td>kN</td>
<td>kN</td>
</tr>
</tbody>
</table>

#### Front wall (W12)
- 3122
- Flat timber roof: 0.90 m x 1.5 m, 809 mm thick, 2.27 kN/m², 3.79 kN
- 300 thick RC slab (ug): 9.30 m x 2.50 m, 1000 mm thick, 2.50 kN/m², 29.0 kN
- Brickwork: 7.80 m x 5658 mm, 29.0 kN/m², 7.81 kN

**Σ**: 169.1 kN/m², 11.59 kN

#### Front wall (W13)
- 3260
- Flat timber roof: 0.90 m x 1.5 m, 831 mm thick, 2.44 kN/m², 4.06 kN
- Brickwork: 7.80 m x 3130 mm, 79.59 kN/m², 4.06 kN

**Σ**: 82.03 kN/m², 4.06 kN

#### Wall on rear end (W14)
- 5954
- Rear garden: 27 m x 2.50 m, 4303 mm thick, 116.2 kN/m², 10.76 kN
- 400 thick RC slab: 9.60 m x 4303 m, 41.309 kN/m², 10.76 kN
- 250 thick RC wall: 6.20 m x 4640 mm, 28.768 kN/m², 10.76 kN

**Σ**: 186.26 kN/m², 10.76 kN

#### Wall on rear end (W15)
- 9491
- Rear garden: 27 m x 2.50 m, 2651 mm thick, 71.6 kN/m², 6.63 kN
- 400 thick RC slab: 9.60 m x 2651 m, 25.45 kN/m², 6.63 kN
- 250 thick RC wall: 6.20 m x 4640 mm, 28.768 kN/m², 6.63 kN

**Σ**: 125.79 kN/m², 6.63 kN
## Load Calculations

### Structural Load

#### Transfer Structure at Lower GF Level

<table>
<thead>
<tr>
<th>Structural Member</th>
<th>Description</th>
<th>Span</th>
<th>Area Loads</th>
<th>Width</th>
<th>Location</th>
<th>UDL</th>
<th>Point Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS1</td>
<td>COLUMN 7000</td>
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<td></td>
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<tr>
<td></td>
<td>CONCRETE SLAB</td>
<td>2625</td>
<td>8.10 2.50</td>
<td>2218</td>
<td>17.96 5.54</td>
<td>150.8</td>
<td>51.4</td>
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<tr>
<td></td>
<td>GLAZING</td>
<td></td>
<td>0.80 1.50</td>
<td>775</td>
<td>0.62 1.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WALL</td>
<td>3200</td>
<td>7.80</td>
<td>0 3290</td>
<td>24.96</td>
<td></td>
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</tr>
<tr>
<td>BS2</td>
<td>COLUMN 2 span</td>
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<tr>
<td></td>
<td>CONCRETE SLAB</td>
<td>2385</td>
<td>8.10 2.50</td>
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<tr>
<td>BS3</td>
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<tr>
<td></td>
<td>CONCRETE SLAB</td>
<td>1455</td>
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<td>3465</td>
<td>28.07 8.66</td>
<td>50.14</td>
<td>126.17</td>
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<td>BS4</td>
<td>COLUMN 6400</td>
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<td></td>
<td>LG slab</td>
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<td>8.10 2.50</td>
<td>1800</td>
<td>14.58 4.5</td>
<td>47.892</td>
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</tr>
<tr>
<td></td>
<td>UG slab</td>
<td></td>
<td>8.10 2.50</td>
<td>1800</td>
<td>14.58 4.5</td>
<td>47.892</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roof</td>
<td></td>
<td>0.90 1.50</td>
<td>1800</td>
<td>1.62 2.7</td>
<td>47.892</td>
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</tr>
<tr>
<td></td>
<td>GLAZING</td>
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<td>809</td>
<td>0.65 1.2128</td>
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<td>0 3060</td>
<td>47.892</td>
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</table>
4.2 Basement slab external loads

Design raft slab to spread bearing loads over entire slab area

Total load on base of raft as proposed

<table>
<thead>
<tr>
<th></th>
<th>DL</th>
<th>LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building A</td>
<td>75.00</td>
<td>15.00 kN/m²</td>
</tr>
<tr>
<td>Building B</td>
<td>54.00</td>
<td>9.00 kN/m²</td>
</tr>
<tr>
<td>Building C</td>
<td>35.00</td>
<td>5.00 kN/m²</td>
</tr>
</tbody>
</table>

Unloading due to excavation | 113.4 kN/m² |

Assume long term heave to be resisted by slab is 50% of unloading

Heave uplift | 56.7 kN/m² |

Water pressure uplift | 54.0 kN/m² |
STEEL BEAM ANALYSIS & DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.04

Support conditions
Support A  Vertically restrained
            Rotationally free
Support B  Vertically restrained
            Rotationally free

Applied loading
Beam loads  Dead self weight of beam × 1
            Existing column - Dead point load 150.8 kN at 2625 mm
            Imposed point load 51.4 kN at 2625 mm
            Slab - Dead full UDL 23.3 kN/m
            Imposed full UDL 5.55 kN/m
            ext light - Dead full UDL 0.62 kN/m
            Imposed full UDL 1.16 kN/m
            wall - Dead partial UDL 24.96 kN/m from 0 mm to 3290 mm

Load combinations
Load combination 1  Support A  Dead × 1.40
                        Imposed × 1.60
                        Span 1  Dead × 1.40
                        Imposed × 1.60
                        Support B  Dead × 1.40
### Analysis results

**Maximum moment**

\[ M_{\text{max}} = 858.6 \text{ kNm} \quad M_{\text{min}} = 0 \text{ kNm} \]

**Maximum shear**

\[ V_{\text{max}} = 434 \text{ kN} \quad V_{\text{min}} = -299.7 \text{ kN} \]

**Deflection**

\[ \delta_{\text{max}} = 3.6 \text{ mm} \quad \delta_{\text{min}} = 0 \text{ mm} \]

**Maximum reaction at support A**

\[ R_{A_{\text{max}}} = 434 \text{ kN} \quad R_{A_{\text{min}}} = 434 \text{ kN} \]

**Unfactored dead load reaction at support A**

\[ R_{A_{\text{Dead}}} = 246.4 \text{ kN} \]

**Unfactored imposed load reaction at support A**

\[ R_{A_{\text{Imposed}}} = 55.6 \text{ kN} \]

**Maximum reaction at support B**

\[ R_{B_{\text{max}}} = 299.7 \text{ kN} \quad R_{B_{\text{min}}} = 299.7 \text{ kN} \]

**Unfactored dead load reaction at support B**

\[ R_{B_{\text{Dead}}} = 165.2 \text{ kN} \]

**Unfactored imposed load reaction at support B**

\[ R_{B_{\text{Imposed}}} = 42.8 \text{ kN} \]

### Section details

**Section type**

\[ 2 \times UB 457x191x82 \text{ (BS4-1)} \]

**Steel grade**

\[ S275 \]

**From table 9: Design strength \( p_y \)**

- **Thickness of element**
  \[ \max(T, t) = 16.0 \text{ mm} \]

- **Design strength**
  \[ p_y = 275 \text{ N/mm}^2 \]

- **Modulus of elasticity**
  \[ E = 205000 \text{ N/mm}^2 \]

### Lateral restraint

Span 1 has full lateral restraint

### Effective length factors

- **Effective length factor in major axis**
  \[ K_x = 1.00 \]

- **Effective length factor in minor axis**
  \[ K_y = 1.00 \]

- **Effective length factor for lateral-torsional buckling**
  \[ K_{LTA} = 1.00 \]

### Classification of cross sections - Section 3.5

\[ \varepsilon = \sqrt{275 \text{ N/mm}^2 \div p_y} = 1.00 \]

### Internal compression parts - Table 11

- **Depth of section**
  \[ d = 407.6 \text{ mm} \]

\[ d / t = 41.2 \times \varepsilon \leq 80 \times \varepsilon \quad \text{Class 1 plastic} \]
Outstanding flanges - Table 11

<table>
<thead>
<tr>
<th>Width of section</th>
<th>( b = \frac{B}{2} = 95.7 \text{ mm} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b ) / ( T ) = 6.0 × ( \varepsilon ) &lt;= 9 × ( \varepsilon )</td>
<td>Class 1 plastic</td>
</tr>
</tbody>
</table>

**Section is class 1 plastic**

**Shear capacity - Section 4.2.3**

Design shear force

\[ F_v = \max(\text{abs}(V_{\text{max}}), \text{abs}(V_{\text{min}})) = 434 \text{ kN} \]

\( d / t < 70 \times \varepsilon \)

*Web does not need to be checked for shear buckling*

Shear area

\[ A_v = t \times D = 4554 \text{ mm}^2 \]

Design shear resistance

\[ P_v = 0.6 \times N \times p_y \times A_v = 1502.8 \text{ kN} \]

PASS - Design shear resistance exceeds design shear force

**Moment capacity - Section 4.2.5**

Design bending moment

\[ M = \max(\text{abs}(M_{s1_{\text{max}}}), \text{abs}(M_{s1_{\text{min}}})) = 858.6 \text{ kNm} \]

Moment capacity low shear - cl.4.2.5.2

\[ M_c = N \times \min(p_y \times S_{xx}, 1.2 \times p_y \times Z_{xx}) = 1007.2 \text{ kNm} \]

PASS - Moment capacity exceeds design bending moment

**Check vertical deflection - Section 2.5.2**

Consider deflection due to imposed loads

Limiting deflection

\[ \delta_{\text{lim}} = \frac{L_{s1}}{360} = 19.444 \text{ mm} \]

Maximum deflection span 1

\[ \delta = \max(\text{abs}(\delta_{\text{max}}), \text{abs}(\delta_{\text{min}})) = 3.6 \text{ mm} \]

PASS - Maximum deflection does not exceed deflection limit
STEEL BEAM ANALYSIS & DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.04

Load Envelope - Combination 1

Bending Moment Envelope

Shear Force Envelope

Support conditions

Support A  Vertically restrained
Rotationally free

Support B  Vertically restrained
Rotationally free

Support C  Vertically restrained
Rotationally free

Applied loading

Beam loads  Dead self weight of beam × 1
Column - Dead point load 50.14 kN at 2385 mm
Imposed point load 126.2 kN at 2385 mm
Slab - Dead full UDL 23 kN/m
Imposed full UDL 7 kN/m

Load combinations

Load combination 1  Support A  Dead × 1.40
                     Imposed × 1.60
                     Span 1  Dead × 1.40
                     Imposed × 1.60
                     Support B  Dead × 1.40
                     Imposed × 1.60
Span 2
Dead × 1.40
Imposed × 1.60
Support C
Dead × 1.40
Imposed × 1.60

Analysis results
Maximum moment
M_{max} = 151.1 \text{kNm}
M_{min} = -287.1 \text{kNm}

Maximum moment span 1
M_{s1\_max} = 0 \text{kNm}
M_{s1\_min} = -287.1 \text{kNm}

Maximum moment span 2
M_{s2\_max} = 151.1 \text{kNm}
M_{s2\_min} = -287.1 \text{kNm}

Maximum shear
V_{max} = 396.5 \text{kN}
V_{min} = -235.1 \text{kN}

Maximum shear span 1
V_{s1\_max} = -172.1 \text{kN}
V_{s1\_min} = -235.1 \text{kN}

Maximum shear span 2
V_{s2\_max} = 396.5 \text{kN}
V_{s2\_min} = -116.3 \text{kN}

Deflection
\delta_{max} = 6.3 \text{mm}
\delta_{min} = 0.5 \text{mm}

Deflection span 1
\delta_{s1\_max} = 0 \text{mm}
\delta_{s1\_min} = 0.5 \text{mm}

Deflection span 2
\delta_{s2\_max} = 6.3 \text{mm}
\delta_{s2\_min} = 0 \text{mm}

Maximum reaction at support A
R_{A\_max} = -172.1 \text{kN}
R_{A\_min} = -172.1 \text{kN}

Unfactored dead load reaction at support A
R_{A\_Dead} = -53.1 \text{kN}

Unfactored imposed load reaction at support A
R_{A\_Imposed} = -61 \text{kN}

Maximum reaction at support B
R_{B\_max} = 631.6 \text{kN}
R_{B\_min} = 631.6 \text{kN}

Unfactored dead load reaction at support B
R_{B\_Dead} = 210.7 \text{kN}

Unfactored imposed load reaction at support B
R_{B\_Imposed} = 210.4 \text{kN}

Maximum reaction at support C
R_{C\_max} = 116.3 \text{kN}
R_{C\_min} = 116.3 \text{kN}

Unfactored dead load reaction at support C
R_{C\_Dead} = 55.2 \text{kN}

Unfactored imposed load reaction at support C
R_{C\_Imposed} = 24.4 \text{kN}

Section details
Section type
UC 305x305x97 (BS4-1)

Steel grade
S275

From table 9: Design strength p_{y}
Thickness of element
max(T, t) = 15.4 \text{mm}

Design strength
p_{y} = 275 \text{N/mm}^2

Modulus of elasticity
E = 205000 \text{ N/mm}^2
Lateral restraint
Span 1 has full lateral restraint
Span 2 has full lateral restraint

Effective length factors
Effective length factor in major axis \( K_x = 1.00 \)
Effective length factor in minor axis \( K_y = 1.00 \)
Effective length factor for lateral-torsional buckling \( K_{LT.A} = 1.00 \)
\( K_{LT.B} = 1.00 \)
\( K_{LT.C} = 1.00 \)

Classification of cross sections - Section 3.5
\( \varepsilon = \sqrt{\frac{275 \text{ N/mm}^2}{p_y}} = 1.00 \)

Internal compression parts - Table 11
Depth of section \( d = 246.7 \text{ mm} \)
\( d / t = 24.9 \times \varepsilon <= 80 \times \varepsilon \) Class 1 plastic

Outstand flanges - Table 11
Width of section \( b = B / 2 = 152.7 \text{ mm} \)
\( b / T = 9.9 \times \varepsilon <= 10 \times \varepsilon \) Class 2 compact

Section is class 2 compact

Shear capacity - Section 4.2.3
Design shear force
\( F_v = \max (\text{abs} (V_{\text{max}}), \text{abs} (V_{\text{min}})) = 396.5 \text{ kN} \)
\( d / t < 70 \times \varepsilon \)

Web does not need to be checked for shear buckling

Design shear resistance
\( P_v = 0.6 \times p_y \times A_v = 503 \text{ kN} \)

PASS - Design shear resistance exceeds design shear force

Moment capacity at span 2 - Section 4.2.5
Design bending moment
\( M = \max (\text{abs} (M_{x2_{\text{max}}}), \text{abs} (M_{x2_{\text{min}}})) = 287.1 \text{ kNm} \)
Reduction factor \( \rho_v = \left[ 2 \times (F_v / P_v) - 1 \right]^2 = 0.332 \)
Plastic modulus of shear area \( S_v = t \times D^2 / 4 = 234636 \text{ mm}^3 \)
Moment capacity high shear - cl.4.2.5.3
\( M_c = \min (p_y \times (S_{xx} - \rho_v \times S_v), 1.5 \times p_y \times Z_{xx}) = 416.4 \text{ kNm} \)

PASS - Moment capacity exceeds design bending moment

Check vertical deflection - Section 2.5.2
Consider deflection due to dead and imposed loads
Limiting deflection \( \delta_{\text{lim}} = L_{x2} / 360 = 14.944 \text{ mm} \)
Maximum deflection span 2 \( \delta = \max (\text{abs} (\delta_{\text{max}}), \text{abs} (\delta_{\text{min}})) = 6.348 \text{ mm} \)

PASS - Maximum deflection does not exceed deflection limit
STEEL BEAM ANALYSIS & DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.04

Load Envelope - Combination 1

Bending Moment Envelope

Shear Force Envelope

Support conditions
Support A  Vertically restrained
           Rotationally free
Support B  Vertically restrained
           Rotationally free

Applied loading
Beam loads
  Dead self weight of beam \times 1
  column - Dead point load 50.14 kN at 1455 mm
  Imposed point load 126.2 kN at 1455 mm
  slab - Dead full UDL 28 kN/m
  Imposed full UDL 9 kN/m

Load combinations
Load combination 1
  Support A  Dead \times 1.40
  Span 1    Dead \times 1.40
  Support B Dead \times 1.40

## Analysis results

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum moment</td>
<td>$M_{\text{max}} = 407.7 \text{ kNm}$</td>
</tr>
<tr>
<td>Maximum shear</td>
<td>$V_{\text{max}} = 320.4 \text{ kN}$</td>
</tr>
<tr>
<td>Deflection</td>
<td>$\delta_{\text{max}} = 5.1 \text{ mm}$</td>
</tr>
<tr>
<td>Maximum reaction at support A</td>
<td>$R_{A,\text{max}} = 320.4 \text{ kN}$</td>
</tr>
<tr>
<td>Unfactored dead load reaction at support A</td>
<td>$R_{A,\text{Dead}} = 104.2 \text{ kN}$</td>
</tr>
<tr>
<td>Unfactored imposed load reaction at support A</td>
<td>$R_{A,\text{Imposed}} = 214.6 \text{ kN}$</td>
</tr>
<tr>
<td>Maximum reaction at support B</td>
<td>$R_{B,\text{max}} = 214.6 \text{ kN}$</td>
</tr>
<tr>
<td>Unfactored dead load reaction at support B</td>
<td>$R_{B,\text{Dead}} = 84.7 \text{ kN}$</td>
</tr>
</tbody>
</table>

## Section details

- **Section type**: UC 305x305x118 (BS4-1)
- **Steel grade**: S275
- **From table 9: Design strength $p_y$**
  - Thickness of element: $\text{max}(T, t) = 18.7 \text{ mm}$
  - Design strength: $p_y = 265 \text{ N/mm}^2$
  - Modulus of elasticity: $E = 205000 \text{ N/mm}^2$

![Section Diagram](image)

## Lateral restraint

Span 1 has full lateral restraint

## Effective length factors

- Effective length factor in major axis: $K_x = 1.00$
- Effective length factor in minor axis: $K_y = 1.00$
- Effective length factor for lateral-torsional buckling: $K_{LTA} = 1.00$

## Classification of cross sections - Section 3.5

$$\epsilon = \sqrt{[275 \text{ N/mm}^2 / p_y]} = 1.02$$

## Internal compression parts - Table 11

- Depth of section: $d = 246.7 \text{ mm}$
- $d / t = 20.2 \times \epsilon <= 80 \times \epsilon$ Class 1 plastic

## Outstanding flanges - Table 11

- Width of section: $b = B / 2 = 153.7 \text{ mm}$
b / T = 8.1 \times \varepsilon \leq 9 \times \varepsilon \quad \text{Class 1 plastic}

\textit{Section is class 1 plastic}

**Shear capacity - Section 4.2.3**

Design shear force

\[
F_v = \max(\abs{V_{\max}}, \abs{V_{\min}}) = 320.4 \text{ kN}
\]

\[
d / t < 70 \times \varepsilon
\]

*Web does not need to be checked for shear buckling*

Shear area

\[
A_v = t \times D = 3774 \text{ mm}^2
\]

Design shear resistance

\[
P_v = 0.6 \times p_y \times A_v = 600.1 \text{ kN}
\]

*PASS - Design shear resistance exceeds design shear force*

**Moment capacity - Section 4.2.5**

Design bending moment

\[
M = \max(\abs{M_{t,\max}}, \abs{M_{t,\min}}) = 407.7 \text{ kNm}
\]

Moment capacity low shear - cl.4.2.5.2

\[
M_c = \min(p_y \times S_{xx}, 1.2 \times p_y \times Z_{xx}) = 518.7 \text{ kNm}
\]

*PASS - Moment capacity exceeds design bending moment*

**Check vertical deflection - Section 2.5.2**

Consider deflection due to imposed loads

Limiting deflection

\[
\delta_{\text{lim}} = L_{s1} / 360 = 13.222 \text{ mm}
\]

Maximum deflection span 1

\[
\delta = \max(\abs{\delta_{\max}}, \abs{\delta_{\min}}) = 5.111 \text{ mm}
\]

*PASS - Maximum deflection does not exceed deflection limit*
STEEL BEAM ANALYSIS & DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.04

Support conditions
Support A  Vertically restrained
           Rotationally free
Support B  Vertically restrained
           Rotationally free

Applied loading
Beam loads
Dead self weight of beam × 1
LG& UG slab - Dead full UDL 30 kN/m
Imposed full UDL 10 kN/m
glazing - Dead full UDL 1 kN/m
Imposed full UDL 1.2 kN/m
Roof - Dead full UDL 1.6 kN/m
Imposed full UDL 3 kN/m
Wall - Dead full UDL 48 kN/m

Load combinations
Load combination 1
Support A  Dead × 1.40
           Imposed × 1.60
Span 1    Dead × 1.40
           Imposed × 1.60
Support B  Dead × 1.40
Analysis results

Maximum moment
- $M_{\text{max}} = 387.9 \text{kNm}$
- $M_{\text{min}} = 0 \text{kNm}$

Maximum shear
- $V_{\text{max}} = 326 \text{kN}$
- $V_{\text{min}} = -326 \text{kN}$

Deflection
- $\delta_{\text{max}} = 1.6 \text{mm}$
- $\delta_{\text{min}} = 0 \text{mm}$

Maximum reaction at support A
- $R_{A,\text{max}} = 326 \text{kN}$
- $R_{A,\text{min}} = 326 \text{kN}$

Unfactored dead load reaction at support A
- $R_{A,\text{Dead}} = 194.2 \text{kN}$

Unfactored imposed load reaction at support A
- $R_{A,\text{Imposed}} = 33.8 \text{kN}$

Maximum reaction at support B
- $R_{B,\text{max}} = 326 \text{kN}$
- $R_{B,\text{min}} = 326 \text{kN}$

Unfactored dead load reaction at support B
- $R_{B,\text{Dead}} = 194.2 \text{kN}$

Unfactored imposed load reaction at support B
- $R_{B,\text{Imposed}} = 33.8 \text{kN}$

Section details

Section type
- $2 \times \text{UB 356x171x51 (BS4-1)}$

Steel grade
- S275

From table 9: Design strength $p_y$
- Thickness of element $\max(T, t) = 11.5 \text{mm}$
- Design strength $p_y = 275 \text{N/mm}^2$
- Modulus of elasticity $E = 205000 \text{N/mm}^2$

Lateral restraint

Span 1 has full lateral restraint

Effective length factors

Effective length factor in major axis $K_x = 1.00$
Effective length factor in minor axis $K_y = 1.00$
Effective length factor for lateral-torsional buckling $K_{LT,A} = 1.00$

Classification of cross sections - Section 3.5

$\epsilon = \sqrt{[275 \text{N/mm}^2 / p_y]} = 1.00$

Internal compression parts - Table 11

Depth of section $d = 311.6 \text{mm}$

$d / t = 42.1 \times \epsilon <= 80 \times \epsilon$

Class 1 plastic
Outstand flanges - Table 11
Width of section

\[ b = B / 2 = 85.8 \text{ mm} \]

\[ b / T = 7.5 \times \varepsilon <= 9 \times \varepsilon \]

Class 1 plastic

Section is class 1 plastic

Shear capacity - Section 4.2.3
Design shear force

\[ F_v = \max(\abs{V_{\text{max}}}, \abs{V_{\text{min}}}) = 326 \text{ kN} \]

\[ d / t < 70 \times \varepsilon \]

Web does not need to be checked for shear buckling

Shear area

\[ A_v = t \times D = 2627 \text{ mm}^2 \]

Design shear resistance

\[ P_v = 0.6 \times N \times p_y \times A_v = 866.9 \text{ kN} \]

PASS - Design shear resistance exceeds design shear force

Moment capacity - Section 4.2.5
Design bending moment

\[ M = \max(\abs{M_{\text{b,1, max}}}, \abs{M_{\text{b,1, min}}}) = 387.9 \text{ kNm} \]

Moment capacity low shear - cl.4.2.5.2

\[ M_c = N \times \min(p_y \times S_{xx}, 1.2 \times p_y \times Z_{xx}) = 492.8 \text{ kNm} \]

PASS - Moment capacity exceeds design bending moment

Check vertical deflection - Section 2.5.2
Consider deflection due to imposed loads

Limiting deflection

\[ \delta_{\text{lim}} = L_{s1} / 360 = 13.222 \text{ mm} \]

Maximum deflection span 1

\[ \delta = \max(\abs{\delta_{\text{max}}}, \abs{\delta_{\text{min}}}) = 1.638 \text{ mm} \]

PASS - Maximum deflection does not exceed deflection limit
**Support conditions**

- **Support A**: Vertically restrained
  Rotationally free
- **Support B**: Vertically restrained
  Rotationally free

**Applied loading**

- **bsmt slab**: Dead full UDL -18 kN/m
- **Heave**: Heave full UDL 57 kN/m
- **Water**: Water full UDL 54 kN/m
- **Total raft**: Dead full UDL 75 kN/m
  Imposed full UDL 15 kN/m

**Load combinations**

- **Load combination 1**
  - **Support A**: Dead × 1.20
    Imposed × 1.20
    Heave × 1.20
    Water × 1.20
  - **Span 1**: Dead × 1.20
    Imposed × 1.20
    Heave × 1.20
    Water × 1.20
  - **Support B**: Dead × 1.20
Imposed $\times 1.20$
Heave $\times 1.20$
Water $\times 1.20$

### Analysis results

- **Maximum moment support A**: $M_{A\text{ max}} = 0$ kNm, $M_{A\text{ red}} = 0$ kNm
- **Maximum moment span 1 at 2750 mm**: $M_{s1\text{ max}} = 803$ kNm, $M_{s1\text{ red}} = 803$ kNm
- **Maximum moment support B**: $M_{B\text{ max}} = 0$ kNm, $M_{B\text{ red}} = 0$ kNm
- **Maximum shear support A**: $V_{A\text{ max}} = 584$ kN, $V_{A\text{ s1 max}} = 446$ kN, $V_{A\text{ red}} = 584$ kN, $V_{A\text{ s1 red}} = 446$ kN
- **Maximum shear support B**: $V_{B\text{ max}} = -584$ kN, $V_{B\text{ s1 max}} = -446$ kN, $V_{B\text{ red}} = -584$ kN, $V_{B\text{ s1 red}} = -446$ kN
- **Maximum reaction at support A**: $R_{A} = 584$ kN
  - Unfactored dead load reaction at support A: $R_{A\text{ Dead}} = 157$ kN
  - Unfactored imposed load reaction at support A: $R_{A\text{ Imposed}} = 41$ kN
  - Unfactored heave load reaction at support A: $R_{A\text{ Heave}} = 157$ kN
  - Unfactored water load reaction at support A: $R_{A\text{ Water}} = 149$ kN
  - Maximum reaction at support B: $R_{B} = 584$ kN
  - Unfactored dead load reaction at support B: $R_{B\text{ Dead}} = 157$ kN
  - Unfactored imposed load reaction at support B: $R_{B\text{ Imposed}} = 41$ kN
  - Unfactored heave load reaction at support B: $R_{B\text{ Heave}} = 157$ kN
  - Unfactored water load reaction at support B: $R_{B\text{ Water}} = 149$ kN

### Rectangular section details

- **Section width**: $b = 1000$ mm
- **Section depth**: $h = 700$ mm

![Rectangular section diagram](image)

### Concrete details

- **Concrete strength class**: C32/40
- **Characteristic compressive cube strength**: $f_{cu} = 40$ N/mm²
- **Modulus of elasticity of concrete**: $E_c = 20kN/mm^2 + 200 \times f_{cu} = 28000$ N/mm²
- **Maximum aggregate size**: $h_{agg} = 20$ mm

### Reinforcement details

- **Characteristic yield strength of reinforcement**: $f_y = 500$ N/mm²
- **Characteristic yield strength of shear reinforcement**: $f_{yv} = 500$ N/mm²

### Nominal cover to reinforcement

- **Nominal cover to top reinforcement**: $c_{nom_t} = 35$ mm
- **Nominal cover to bottom reinforcement**: $c_{nom_b} = 35$ mm
Nominal cover to side reinforcement  \( c_{nom_s} = 35 \text{ mm} \)

**Mid span 1**

![Diagram of mid span reinforcement](image)

**Design moment resistance of rectangular section (cl. 3.4.4) - Positive midspan moment**

- Design bending moment  \( M = \text{abs}(M_{s1, red}) = 803 \text{ kNm} \)
- Depth to tension reinforcement  \( d = h - c_{nom_s} - \phi_v - \phi_{bot}/2 = 645 \text{ mm} \)
- Redistribution ratio  \( \beta_b = \min(1 - m_{rs1}, 1) = 1.000 \)
  
  \[ K = \frac{M}{(b \times d^2 \times f_{cu})} = 0.048 \]
  
  \[ K' = 0.156 \]

\( K' > K - \text{No compression reinforcement is required} \)

- Lever arm  \( z = \min(d \times (0.5 + (0.25 - K / 0.9)^{2/3}), 0.95 \times d) = 608 \text{ mm} \)
- Depth of neutral axis  \( x = (d - z) / 0.45 = 81 \text{ mm} \)
- Area of tension reinforcement provided  \( A_{s, prov} = 3142 \text{ mm}^2 \)
- Area of tension reinforcement provided  \( A_{s, min} = 0.0013 \times b \times h = 910 \text{ mm}^2 \)
- Maximum area of reinforcement  \( A_{s, max} = 0.04 \times b \times h = 28000 \text{ mm}^2 \)

**PASS - Area of reinforcement provided is greater than area of reinforcement required**

**Rectangular section in shear**

- Shear reinforcement provided  \( 2 \times 10\phi \text{ bars at 100 c/c} \)
- Area of shear reinforcement provided  \( A_{sv, prov} = 1571 \text{ mm}^2/\text{m} \)
- Minimum area of shear reinforcement (Table 3.7)  \( A_{sv, min} = 0.4N/\text{mm}^2 \times b / (0.87 \times f_{yv}) = 920 \text{ mm}^2/\text{m} \)

**PASS - Area of shear reinforcement provided exceeds minimum required**

- Maximum longitudinal spacing (cl. 3.4.5.5)  \( s_{vl, max} = 0.75 \times d = 484 \text{ mm} \)

**Shear links provided valid between 0 mm and 5500 mm with tension reinforcement of 3142 mm²**

**Spacing of reinforcement (cl 3.12.11)**

- Actual distance between bars in tension  \( s = (b - 2 \times (c_{nom_s} + \phi_v + \phi_{bot}/2)) / (N_{bot} - 1) - \phi_{bot} = 79 \text{ mm} \)

**Minimum distance between bars in tension (cl 3.12.11.1)**

- Minimum distance between bars in tension  \( s_{min} = h_{agg} + 5 \text{ mm} = 25 \text{ mm} \)
PASS - Satisfies the minimum spacing criteria

Maximum distance between bars in tension (cl 3.12.11.2)
Design service stress \( f_s = \frac{2 \times f_y \times A_{s,req}}{(3 \times A_{s,prov} \times \beta_b)} = 322.0 \text{ N/mm}^2 \)

Maximum distance between bars in tension \( s_{\text{max}} = \min(47000 \text{ N/mm} / f_s, 300 \text{ mm}) = 146 \text{ mm} \)

PASS - Satisfies the maximum spacing criteria

Span to depth ratio (cl. 3.4.6)
Basic span to depth ratio (Table 3.9) \( \text{span}_\text{to}_{\text{depth}}\text{basic} = 20.0 \)
Design service stress in tension reinforcement \( f_s = \frac{2 \times f_y \times A_{s,req}}{(3 \times A_{s,prov} \times \beta_b)} = 322.0 \text{ N/mm}^2 \)
Modification for tension reinforcement \( f_{\text{tens}} = \min(2.0, 0.55 + \frac{477 \text{ N/mm}^2 - f_s}{120 \times (0.9 \text{ N/mm}^2 + (M / (b \times d^2)))}) = 1.006 \)
Modification for compression reinforcement \( f_{\text{comp}} = \min(1.5, 1 + \frac{100 \times A_{s2,prov} / (b \times d)}{3 + (100 \times A_{s2,prov} / (b \times d))}) = 1.140 \)
Modification for span length \( f_{\text{long}} = 1.000 \)
Allowable span to depth ratio \( \text{span}_\text{to}_{\text{depth}}\text{allow} = \text{span}_\text{to}_{\text{depth}}\text{basic} \times f_{\text{tens}} \times f_{\text{comp}} = 22.9 \)
Actual span to depth ratio \( \text{span}_\text{to}_{\text{depth}}\text{actual} = \frac{L_{s1}}{d} = 8.5 \)

PASS - Actual span to depth ratio is within the allowable limit
RC Beam Analysis & Design BS8110

Load Envelope - Combination 1

Bending Moment Envelope

Shear Force Envelope

Support conditions
Support A
Vertically restrained
Rotationally free
Support B
Vertically restrained
Rotationally free

Applied loading
Dead full UDL 15 kN/m
Imposed full UDL 5 kN/m

Load combinations
Load combination 1
Support A
Dead × 1.40
Imposed × 1.60
Span 1
Dead × 1.40
Imposed × 1.60
Support B
Dead × 1.40
Imposed × 1.60

Analysis results
Maximum moment support A
\( M_{A,\text{max}} = 0 \text{ kNm} \)
\( M_{A,\text{red}} = 0 \text{ kNm} \)
Maximum moment span 1 at 1900 mm
\( M_{S1,\text{max}} = 52 \text{ kNm} \)
\( M_{S1,\text{red}} = 52 \text{ kNm} \)
Maximum moment support B
\( M_{B,\text{max}} = 0 \text{ kNm} \)
\( M_{B,\text{red}} = 0 \text{ kNm} \)
Maximum shear support A
\( V_{A,\text{max}} = 55 \text{ kN} \)
\( V_{A,\text{red}} = 55 \text{ kN} \)
Maximum shear support A span 1 at 300 mm
\( V_{A,\text{s1, max}} = 46 \text{ kN} \)
\( V_{A,\text{s1, red}} = 46 \text{ kN} \)
Maximum shear support B $V_{B,\text{max}} = -55 \text{ kN}$ $V_{B,\text{red}} = -55 \text{ kN}$
Maximum shear support B span 1 at 3500 mm $V_{B,\text{s1,max}} = -46 \text{ kN}$ $V_{B,\text{s1,red}} = -46 \text{ kN}$
Maximum reaction at support A $R_A = 55 \text{ kN}$
Unfactored dead load reaction at support A $R_{A,\text{Dead}} = 29 \text{ kN}$
Unfactored imposed load reaction at support A $R_{A,\text{Imposed}} = 10 \text{ kN}$
Maximum reaction at support B $R_B = 55 \text{ kN}$
Unfactored dead load reaction at support B $R_{B,\text{Dead}} = 29 \text{ kN}$
Unfactored imposed load reaction at support B $R_{B,\text{Imposed}} = 10 \text{ kN}$

Rectangular section details
Section width $b = 300 \text{ mm}$
Section depth $h = 350 \text{ mm}$

Concrete details
Concrete strength class $C32/40$
Characteristic compressive cube strength $f_{cu} = 40 \text{ N/mm}^2$
Modulus of elasticity of concrete $E_c = 20 \text{ kN/mm}^2 + 200 \times f_{cu} = 28000 \text{ N/mm}^2$
Maximum aggregate size $h_{agg} = 20 \text{ mm}$

Reinforcement details
Characteristic yield strength of reinforcement $f_y = 500 \text{ N/mm}^2$
Characteristic yield strength of shear reinforcement $f_{yv} = 500 \text{ N/mm}^2$

Nominal cover to reinforcement
Nominal cover to top reinforcement $c_{\text{nom},t} = 35 \text{ mm}$
Nominal cover to bottom reinforcement $c_{\text{nom},b} = 35 \text{ mm}$
Nominal cover to side reinforcement $c_{\text{nom},s} = 35 \text{ mm}$

Mid span 1
4 x 10 bars
2 x 10 shear legs at 125 c/c
4 x 20 bars
Design moment resistance of rectangular section (cl. 3.4.4) - Positive midspan moment

Design bending moment
\[ M = \text{abs}(M_{\text{t,mid}}) = 52 \text{ kNm} \]

Depth to tension reinforcement
\[ d = h - c_{\text{nom,b}} - \psi_v - \psi_{\text{bot}} / 2 = 295 \text{ mm} \]

Redistribution ratio
\[ \beta_v = \min(1 - n_{\text{tst}}, 1) = 1.000 \]
\[ K = M / (b \times d^2 \times f_{\text{cu}}) = 0.050 \]
\[ K' = 0.156 \]

**K' > K - No compression reinforcement is required**

Lever arm
\[ z = \min(d \times (0.5 + (0.25 - K / 0.9)^3), 0.95 \times d) = 278 \text{ mm} \]

Depth of neutral axis
\[ x = (d - z) / 0.45 = 39 \text{ mm} \]

Area of tension reinforcement required
\[ A_{s,\text{req}} = M / (0.87 \times f_{\text{y}} \times z) = 434 \text{ mm}^2 \]

Tension reinforcement provided
\[ 4 \times 20\phi \text{ bars} \]

Area of tension reinforcement provided
\[ A_{s,\text{prov}} = 1257 \text{ mm}^2 \]

Minimum area of reinforcement
\[ A_{s,\text{min}} = 0.0013 \times b \times h = 137 \text{ mm}^2 \]

Maximum area of reinforcement
\[ A_{s,\text{max}} = 0.04 \times b \times h = 4200 \text{ mm}^2 \]

**PASS - Area of reinforcement provided is greater than area of reinforcement required**

Rectangular section in shear
Shear reinforcement provided
\[ 2 \times 10\phi \text{ legs at 125 c/c} \]

Area of shear reinforcement provided
\[ A_{s,v,\text{prov}} = 1257 \text{ mm}^2/m \]

Minimum area of shear reinforcement (Table 3.7)
\[ A_{s,v,\text{min}} = 0.4N/mm^2 \times b \times (0.87 \times f_{\text{v}}) = 276 \text{ mm}^2/m \]

**PASS - Area of shear reinforcement provided exceeds minimum required**

Maximum longitudinal spacing (cl. 3.4.5.5)
\[ s_{v,\text{max}} = 0.75 \times d = 221 \text{ mm} \]

**PASS - Longitudinal spacing of shear reinforcement provided is less than maximum**

Design concrete shear stress
\[ \psi_c = 0.79N/mm^2 \times \min(3, [100 \times A_{s,\text{prov}} / (b \times d)]^{1/3}) \times \max(1, (400mm / d)^{1/4}) \times \min(f_{\text{cu}}, 40N/mm^2) / 25N/mm^2^{1/3} / \gamma_m = 0.897 \text{ N/mm}^2 \]

Design shear resistance provided
\[ V_{s,\text{prov}} = A_{s,v,\text{prov}} \times 0.87 \times f_{\text{v}} / b = 1.822 \text{ N/mm}^2 \]

Design shear stress provided
\[ V_{\text{prov}} = V_{s,\text{prov}} + \psi_c = 2.719 \text{ N/mm}^2 \]

Design shear resistance
\[ V_{d} = V_{\text{prov}} \times (b \times d) = 240.6 \text{ kN} \]

**Shear links provided valid between 0 mm and 3800 mm with tension reinforcement of 1257 mm^2**

Spacing of reinforcement (cl 3.12.11)
Actual distance between bars in tension
\[ s = (b - 2 \times (c_{\text{nom,s}} + \psi_v + \psi_{\text{bot}})) / (N_{\text{bot}} - 1) - \psi_{\text{bot}} = 43 \text{ mm} \]

Minimum distance between bars in tension (cl 3.12.11.1)
Minimum distance between bars in tension
\[ s_{\text{min}} = h_{\text{agg}} + 5 \text{ mm} = 25 \text{ mm} \]

**PASS - Satisfies the minimum spacing criteria**

Maximum distance between bars in tension (cl. 3.12.11.2)

Design service stress
\[ f_s = (2 \times f_y \times A_{s,\text{req}}) / (3 \times A_{s,\text{prov}} \times \beta_v) = 115.0 \text{ N/mm}^2 \]

Maximum distance between bars in tension
\[ s_{\text{max}} = \min(47000 \text{ N/mm} / f_s, 300 \text{ mm}) = 300 \text{ mm} \]

**PASS - Satisfies the maximum spacing criteria**

Span to depth ratio (cl. 3.4.6)

Basic span to depth ratio (Table 3.9)
\[ \text{span}_\text{to depth}_\text{basic} = 20.0 \]

Design service stress in tension reinforcement
\[ f_s = (2 \times f_y \times A_{s,\text{req}}) / (3 \times A_{s,\text{prov}} \times \beta_v) = 115.0 \text{ N/mm}^2 \]

Modification for tension reinforcement
\[ f_{\text{tens}} = \min(2.0, 0.55 + (477N/mm^2 - f_s) / (120 \times (0.9N/mm^2 + (M / (b \times d^2)))) = 1.588 \]

Modification for compression reinforcement
\[ f_{\text{comp}} = \min(1.5, 1 + (100 \times A_{s,\text{prov}} / (b \times d)) / (3 + (100 \times A_{s,\text{prov}} / (b \times d))) = 1.106 \]
Modification for span length

- $f_{long} = 1.000$

Allowable span to depth ratio

- $span_{to\_depth}_{allow} = span_{to\_depth}_{basic} \times f_{tens} \times f_{comp} = 35.1$

Actual span to depth ratio

- $span_{to\_depth}_{actual} = L_{s1} / d = 12.9$

PASS - Actual span to depth ratio is within the allowable limit
**RC BEAM ANALYSIS & DESIGN BS8110**

TEDDS calculation version 2.1.11

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### Support conditions
- **Support A**: Vertically restrained, Rotationally free
- **Support B**: Vertically restrained, Rotationally free

### Applied loading
- Dead self weight of beam × 1
- Dead full UDL 27 kN/m
- Imposed full UDL 2.5 kN/m

### Load combinations
- **Load combination 1**
  - **Support A**: Dead × 1.40  
    - Imposed × 1.60
  - **Span 1**: Dead × 1.40  
    - Imposed × 1.60
  - **Support B**: Dead × 1.40  
    - Imposed × 1.60

### Analysis results
- **Maximum moment support A**: $M_{A_{\text{max}}} = 0 \text{ kNm}$  
  - $M_{A_{\text{red}}} = 0 \text{ kNm}$
- **Maximum moment span 1 at 2800 mm**: $M_{s1_{\text{max}}} = 210 \text{ kNm}$  
  - $M_{s1_{\text{red}}} = 210 \text{ kNm}$
- **Maximum moment support B**: $M_{B_{\text{max}}} = 0 \text{ kNm}$  
  - $M_{B_{\text{red}}} = 0 \text{ kNm}$
- **Maximum shear support A**: $V_{A_{\text{max}}} = 150 \text{ kN}$  
  - $V_{A_{\text{red}}} = 150 \text{ kN}$
Maximum shear support A span 1 at 300 mm
\[ V_{A,s1,max} = 134 \text{ kN} \]
\[ V_{A,s1,red} = 134 \text{ kN} \]

Maximum shear support B
\[ V_{B,max} = -150 \text{ kN} \]
\[ V_{B,red} = -150 \text{ kN} \]

Maximum shear support B span 1 at 5300 mm
\[ V_{B,s1,max} = -134 \text{ kN} \]
\[ V_{B,s1,red} = -134 \text{ kN} \]

Maximum reaction at support A
\[ R_A = 150 \text{ kN} \]

Unfactored dead load reaction at support A
\[ R_{A,Dead} = 99 \text{ kN} \]

Unfactored imposed load reaction at support A
\[ R_{A,Imposed} = 7 \text{ kN} \]

Maximum reaction at support B
\[ R_B = 150 \text{ kN} \]

Unfactored dead load reaction at support B
\[ R_{B,Dead} = 99 \text{ kN} \]

Unfactored imposed load reaction at support B
\[ R_{B,Imposed} = 7 \text{ kN} \]

Rectangular section details
Section width \[ b = 1000 \text{ mm} \]
Section depth \[ h = 350 \text{ mm} \]

Concrete details
Concrete strength class \[ C32/40 \]
Characteristic compressive cube strength \[ f_{cu} = 40 \text{ N/mm}^2 \]
Modulus of elasticity of concrete \[ E_c = 20\text{kN/mm}^2 + 200 \times f_{cu} = 28000 \text{ N/mm}^2 \]
Maximum aggregate size \[ h_{agg} = 20 \text{ mm} \]

Reinforcement details
Characteristic yield strength of reinforcement \[ f_y = 500 \text{ N/mm}^2 \]
Characteristic yield strength of shear reinforcement \[ f_{yv} = 500 \text{ N/mm}^2 \]

Nominal cover to reinforcement
Nominal cover to top reinforcement \[ c_{nom,t} = 35 \text{ mm} \]
Nominal cover to bottom reinforcement \[ c_{nom,b} = 35 \text{ mm} \]
Nominal cover to side reinforcement \[ c_{nom,s} = 35 \text{ mm} \]

Mid span 1

- 5 x 10\(\frac{1}{4}\) bars
- 2 x 10\(\frac{1}{4}\) shear legs at 100 c/c
- 7 x 20\(\frac{1}{4}\) bars
Design moment resistance of rectangular section (cl. 3.4.4) - Positive midspan moment

Design bending moment

\[ M = \text{abs}(M_{\text{b,req}}) = 210 \text{ kNm} \]

Depth to tension reinforcement

\[ d = h - c_{\text{nom,b}} - \phi_v - \phi_{\text{bot}} / 2 = 295 \text{ mm} \]

Redistribution ratio

\[ \beta_d = \min(1 - m_{s1,1}, 1) = 1.000 \]

\[ K = M / (b \times d^2 \times f_{yd}) = 0.060 \]

\[ K' = 0.156 \]

\[ K' > K \text{ - No compression reinforcement is required} \]

Lever arm

\[ z = \min(d \times (0.5 + (0.25 - K / 0.9)^{0.5}), 0.95 \times d) = 274 \text{ mm} \]

Depth of neutral axis

\[ x = (d - z) / 0.45 = 47 \text{ mm} \]

Area of tension reinforcement required

\[ A_{s,\text{req}} = M / (0.87 \times f_y \times z) = 1764 \text{ mm}^2 \]

Tension reinforcement provided

7 \times 20\phi \text{ bars}

Area of tension reinforcement provided

\[ A_{s,\text{prov}} = 2199 \text{ mm}^2 \]

Minimum area of reinforcement

\[ A_{s,\text{min}} = 0.0013 \times b \times h = 455 \text{ mm}^2 \]

Maximum area of reinforcement

\[ A_{s,\text{max}} = 0.04 \times b \times h = 14000 \text{ mm}^2 \]

PASS - Area of reinforcement provided is greater than area of reinforcement required

Rectangular section in shear

Shear reinforcement provided

2 \times 10\phi \text{ legs at 100 c/c}

Area of shear reinforcement provided

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

Minimum area of shear reinforcement (Table 3.7)

\[ A_{sv,\text{min}} = 0.4N/mm^2 \times b / (0.87 \times f_{ys}) = 920 \text{ mm}^2 / \text{m} \]

PASS - Area of shear reinforcement provided exceeds minimum required

Maximum longitudinal spacing (cl. 3.4.5.5)

\[ s_{vl,\text{max}} = 0.75 \times d = 221 \text{ mm} \]

PASS - Longitudinal spacing of shear reinforcement provided is less than maximum

Design concrete shear stress

\[ \gamma_c = 0.79N/mm^2 \times \min(3, [100 \times A_{sv,\text{prov}} / (b \times d)]^{1/3}) \times \max(1, (400mm / d)^{1/3}) \times (\min(f_{cu}, 40N/mm^2) / 25N/mm^2)^{1/3} / \gamma_m = 0.723 \text{ N/mm}^2 \]

Design shear resistance provided

\[ V_{s,\text{prov}} = A_{sv,\text{prov}} \times 0.87 \times f_{ys} / b = 0.683 \text{ N/mm}^2 \]

Design shear stress provided

\[ V_{\text{prov}} = V_{s,\text{prov}} + V_c = 1.407 \text{ N/mm}^2 \]

Design shear resistance

\[ V_{\text{prov}} = V_{\text{prov}} \times (b \times d) = 414.9 \text{ kN} \]

Shear links provided valid between 0 mm and 5600 mm with tension reinforcement of 2199 mm²

Spacing of reinforcement (cl 3.12.11)

Actual distance between bars in tension

\[ s = (b - 2 \times (c_{\text{nom,s}} + \phi_v + \phi_{\text{bot}} / 2)) / (N_{\text{bot}} - 1) - \phi_{\text{ct}} = 128 \text{ mm} \]

Minimum distance between bars in tension (cl 3.12.11.1)

\[ s_{\min} = h_{\text{agg}} + 5 \text{ mm} = 25 \text{ mm} \]

PASS - Satisfies the minimum spacing criteria

Maximum distance between bars in tension (cl 3.12.11.2)

Design service stress

\[ f_s = (2 \times f_y \times A_{s,\text{req}}) / (3 \times A_{s,\text{prov}} \times \beta_d) = 267.4 \text{ N/mm}^2 \]

Maximum distance between bars in tension

\[ s_{\max} = \min(47000 \text{ N/mm} / f_s, 300 \text{ mm}) = 176 \text{ mm} \]

PASS - Satisfies the maximum spacing criteria

Span to depth ratio (cl. 3.4.6)

Basic span to depth ratio (Table 3.9)

\[ \text{span_to_depth}_{\text{basic}} = 20.0 \]

Design service stress in tension reinforcement

\[ f_s = (2 \times f_y \times A_{s,\text{req}}) / (3 \times A_{s,\text{prov}} \times \beta_d) = 267.4 \text{ N/mm}^2 \]

Modification for tension reinforcement

\[ f_{\text{mod}} = \min(2.0, 0.55 + (477N/mm^2 - f_s) / (120 \times (0.9N/mm^2 + (M / (b \times d^2)))) = 1.077 \]

Modification for compression reinforcement

\[ f_{\text{comp}} = \min(1.5, 1 + (100 \times A_{s,\text{prov}} / (b \times d)) / (3 + (100 \times A_{s,\text{prov}} / (b \times d))) = 1.042 \]

Modification for span length

\[ f_{\text{long}} = 1.000 \]
<table>
<thead>
<tr>
<th>Allowable span to depth ratio</th>
<th>span_to_depthallow = span_to_depthbasic \times f_{ens} \times f_{comp} = 22.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual span to depth ratio</td>
<td>span_to_depthactual = L_{s1} / d = 19.0</td>
</tr>
</tbody>
</table>

**PASS** - Actual span to depth ratio is within the allowable limit
RC BEAM ANALYSIS & DESIGN BS8110

TEDDS calculation version 2.1.11

Support conditions
Support A: Vertically restrained
Rotationally free
Support B: Vertically restrained
Rotationally free

Applied loading
Dead self weight of beam × 1
Dead full UDL 2.5 kN/m
Imposed full UDL 2.5 kN/m

Load combinations
Load combination 1
Support A: Dead × 1.40
Imposed × 1.60
Span 1: Dead × 1.40
Imposed × 1.60
Support B: Dead × 1.40
Imposed × 1.60

Analysis results
Maximum moment support A: \( M_{A_{max}} = 0 \text{ kNm} \)
\( M_{A_{red}} = 0 \text{ kNm} \)
Maximum moment span 1 at 2250 mm: \( M_{s1_{max}} = 40 \text{ kNm} \)
\( M_{s1_{red}} = 40 \text{ kNm} \)
Maximum moment support B: \( M_{B_{max}} = 0 \text{ kNm} \)
\( M_{B_{red}} = 0 \text{ kNm} \)
Maximum shear support A: \( V_{A_{max}} = 36 \text{ kN} \)
\( V_{A_{red}} = 36 \text{ kN} \)
Maximum shear support A span 1 at 200 mm

\[ V_{A,s1_{\text{max}}} = 33 \text{ kN} \]
\[ V_{A,s1_{\text{red}}} = 33 \text{ kN} \]

Maximum shear support B

\[ V_{B_{\text{max}}} = -36 \text{ kN} \]
\[ V_{B_{s1_{\text{max}}}} = -33 \text{ kN} \]

Maximum shear support B span 1 at 4300 mm

\[ V_{B,s1_{\text{max}}} = -33 \text{ kN} \]
\[ V_{B,s1_{\text{red}}} = -33 \text{ kN} \]

Maximum reaction at support A

\[ R_{A} = 36 \text{ kN} \]

Unfactored dead load reaction at support A

\[ R_{A_{\text{Dead}}} = 19 \text{ kN} \]

Unfactored imposed load reaction at support A

\[ R_{A_{\text{Imposed}}} = 6 \text{ kN} \]

Maximum reaction at support B

\[ R_{B} = 36 \text{ kN} \]

Unfactored dead load reaction at support B

\[ R_{B_{\text{Dead}}} = 19 \text{ kN} \]

Unfactored imposed load reaction at support B

\[ R_{B_{\text{Imposed}}} = 6 \text{ kN} \]

Rectangular section details

Section width \[ b = 1000 \text{ mm} \]

Section depth \[ h = 250 \text{ mm} \]

Concrete details

Concrete strength class \[ C32/40 \]
Characteristic compressive cube strength \[ f_{\text{cu}} = 40 \text{ N/mm}^2 \]
Modulus of elasticity of concrete \[ E_c = 20 \text{kN/mm}^2 + 200 \times f_{\text{cu}} = 28000 \text{ N/mm}^2 \]

Maximum aggregate size \[ h_{\text{agg}} = 20 \text{ mm} \]

Reinforcement details

Characteristic yield strength of reinforcement \[ f_y = 500 \text{ N/mm}^2 \]
Characteristic yield strength of shear reinforcement \[ f_{yv} = 500 \text{ N/mm}^2 \]

Nominal cover to reinforcement

Nominal cover to top reinforcement \[ c_{\text{nom}_t} = 35 \text{ mm} \]
Nominal cover to bottom reinforcement \[ c_{\text{nom}_b} = 35 \text{ mm} \]
Nominal cover to side reinforcement \[ c_{\text{nom}_s} = 35 \text{ mm} \]

Mid span 1

Design moment resistance of rectangular section (cl. 3.4.4) - Positive midspan moment

Design bending moment \[ M = \text{abs}(M_{s1_{\text{red}}}) = 40 \text{ kNm} \]

Depth to tension reinforcement \[ d = h - c_{\text{nom}_b} - \phi_v - \phi_{\text{bot}} / 2 = 197 \text{ mm} \]
Redistribution ratio

\[ \beta_c = \min(1 - \frac{m_{\text{req}}}{1}, 1) = 1.000 \]
\[ K = M / (b \times d^2 \times f_{\text{cu}}) = 0.026 \]
\[ K' = 0.156 \]

\[ K' > K \rightarrow \text{No compression reinforcement is required} \]

Lever arm

\[ z = \min(d \times (0.5 + (0.25 - K / 0.9)^{0.5}), 0.95 \times d) = 187 \text{ mm} \]

Depth of neutral axis

\[ x = (d - z) / 0.45 = 22 \text{ mm} \]

Area of tension reinforcement required

\[ A_{s, \text{req}} = M / (0.87 \times f_y \times z) = 495 \text{ mm}^2 \]

Tension reinforcement provided

\[ 5 \times 16\phi \text{ bars} \]

Area of tension reinforcement provided

\[ A_{s, \text{prov}} = 1005 \text{ mm}^2 \]

Minimum area of reinforcement

\[ A_{s, \text{min}} = 0.0013 \times b \times h = 325 \text{ mm}^2 \]

Maximum area of reinforcement

\[ A_{s, \text{max}} = 0.04 \times b \times h = 10000 \text{ mm}^2 \]

**PASS - Area of reinforcement provided is greater than area of reinforcement required**

Rectangular section in shear

Shear reinforcement provided

\[ 2 \times 10\phi \text{ legs at 100 c/c} \]

Area of shear reinforcement provided

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

Minimum area of shear reinforcement (Table 3.7)

\[ A_{s, \text{min}} = 0.4N/\text{mm}^2 \times b / (0.87 \times f_y) = 920 \text{ mm}^2 / \text{m} \]

**PASS - Area of shear reinforcement provided exceeds minimum required**

Maximum longitudinal spacing (cl. 3.4.5.5)

\[ s_{\text{V, max}} = 0.75 \times d = 148 \text{ mm} \]

**PASS - Longitudinal spacing of shear reinforcement provided is less than maximum**

Design concrete shear stress

\[ v_c = 0.79N/\text{mm}^2 \times \min[3, (100 \times A_{s, \text{prov}} / (b \times d))^{1/3}] \times \frac{1}{\text{max}[(1, (400mm / d))^{1/3}] \times \frac{1}{\text{min}[(1, (100mm / d))^{1/3}] \times \gamma_m = 0.705 \text{ N/mm}^2} \]

Design shear resistance provided

\[ v_{s, \text{prov}} = A_{s, \text{prov}} \times 0.87 \times f_y / b = 0.683 \text{ N/mm}^2 \]

Design shear stress provided

\[ v_{\text{prov}} = v_{s, \text{prov}} + v_c = 1.388 \text{ N/mm}^2 \]

Design shear resistance

\[ v_{\text{prov}} = v_{\text{prov}} \times (b / d) = 273.5 \text{ kN} \]

**Shear links provided valid between 0 mm and 4500 mm with tension reinforcement of 1005 mm²**

Spacing of reinforcement (cl 3.12.11)

Actual distance between bars in tension

\[ s = (b - 2 \times (c_{\text{nom}, s} + \phi_y + \phi_f / 2)) / (\text{Nod} - 1) = 208 \text{ mm} \]

Minimum distance between bars in tension (cl 3.12.11.1)

\[ s_{\min} = h_{\text{agg}} + 5 \text{ mm} = 25 \text{ mm} \]

**PASS - Satisfies the minimum spacing criteria**

Maximum distance between bars in tension (cl 3.12.11.2)

Design service stress

\[ f_s = (2 \times f_y \times A_{s, \text{req}}) / (3 \times A_{s, \text{prov}} \times \beta) = 164.0 \text{ N/mm}^2 \]

Maximum distance between bars in tension

\[ s_{\max} = \min(47000 \text{ N/mm} / f_s, 300 \text{ mm}) = 287 \text{ mm} \]

**PASS - Satisfies the maximum spacing criteria**

Span to depth ratio (cl. 3.4.6)

Basic span to depth ratio (Table 3.9)

\[ \text{span}_{\text{to depth basic}} = 20.0 \]

Design service stress in tension reinforcement

\[ f_s = (2 \times f_y \times A_{s, \text{req}}) / (3 \times A_{s, \text{prov}} \times \beta) = 164.0 \text{ N/mm}^2 \]

Modification for tension reinforcement

\[ f_{\text{tens}} = \min(2.0, 0.55 + (477N/\text{mm}^2 - f_s) / (120 \times (0.9N/\text{mm}^2 + (M / (b \times d^3)))) = 1.896 \]

Modification for compression reinforcement

\[ f_{\text{comp}} = \min(1.5, 1 + (100 \times A_{s2, \text{prov}} / (b \times d)) / (3 + (100 \times A_{s2, \text{prov}} / (b \times d))) = 1.062 \]

Modification for span length

\[ f_{\text{span}} = 1.000 \]

Allowable span to depth ratio

\[ \text{span}_{\text{to depth allow}} = \text{span}_{\text{to depth basic}} \times f_{\text{tens}} \times f_{\text{comp}} = 40.3 \]

Actual span to depth ratio

\[ \text{span}_{\text{to depth actual}} = L_{\text{st}} / d = 22.8 \]

**PASS - Actual span to depth ratio is within the allowable limit**
### Wall details

- **Retaining wall type:** Cantilever propped at both ends
- **Height of retaining wall stem:** \( h_{stem} = 5090 \text{ mm} \)
- **Thickness of wall stem:** \( t_{wat} = 300 \text{ mm} \)
- **Length of toe:** \( l_{toe} = 2500 \text{ mm} \)
- **Length of heel:** \( l_{heel} = 0 \text{ mm} \)
- **Overall length of base:** \( l_{base} = l_{toe} + l_{heel} + t_{wall} = 2800 \text{ mm} \)
- **Thickness of base:** \( t_{base} = 500 \text{ mm} \)
- **Depth of downstand:** \( d_{ds} = 0 \text{ mm} \)
- **Position of downstand:** \( l_{ds} = 0 \text{ mm} \)
- **Thickness of downstand:** \( t_{ds} = 500 \text{ mm} \)
- **Height of retaining wall:** \( h_{wall} = h_{stem} + t_{base} + d_{ds} = 5590 \text{ mm} \)
- **Depth of cover in front of wall:** \( d_{cover} = 400 \text{ mm} \)
- **Depth of unplanned excavation:** \( d_{exc} = 200 \text{ mm} \)
- **Height of ground water behind wall:** \( h_{water} = 3750 \text{ mm} \)
- **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:** \( h_{eff} = h_{wall} + l_{heel} \times \tan(\beta) = 5590 \text{ mm} \)

### Retained material details

- **Mobilisation factor:** \( M = 1.5 \)
- **Moist density of retained material:** \( \gamma_m = 18.0 \text{ kN/m}^3 \)
Saturated density of retained material \( \gamma_s = 21.0 \text{ kN/m}^3 \)

Design shear strength \( \phi' = 24.2 \text{ deg} \)

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

**Base material details**

Moist density \( \gamma_{mb} = 18.0 \text{ kN/m}^3 \)

Design shear strength \( \phi'' = 24.2 \text{ deg} \)

Design base friction \( \delta_b = 18.6 \text{ deg} \)

Allowable bearing pressure \( P_{bearing} = 150 \text{ kN/m}^2 \)

**Using Coulomb theory**

Active pressure coefficient for retained material

\[
K_a = \frac{\sin(\alpha + \phi')}{(\sin(\alpha - \delta) \times (1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))})^2)} = 0.419
\]

Passive pressure coefficient for base material

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

**At-rest pressure**

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

**Loading details**

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

Applied vertical dead load on wall \( W_{dead} = 125.0 \text{ kN/m} \)

Applied vertical live load on wall \( W_{live} = 6.6 \text{ kN/m} \)

Position of applied vertical load on wall \( l_{load} = 2625 \text{ mm} \)

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

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

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

Loads shown in kN/m, pressures shown in kN/m$^2$
Vertical forces on wall
Wall stem \( W_{\text{wall}} = h_{\text{stem}} \times t_{\text{wall}} \times \gamma_{\text{wall}} = 36 \text{ kN/m} \)
Wall base \( W_{\text{base}} = l_{\text{base}} \times b_{\text{base}} \times \gamma_{\text{base}} = 33 \text{ kN/m} \)
Soil in front of wall \( W_{\text{p}} = l_{\text{toe}} \times d_{\text{cover}} \times \gamma_{\text{mb}} = 18 \text{ kN/m} \)
Applied vertical load \( W_{V} = W_{\text{dead}} + W_{\text{live}} = 131.6 \text{ kN/m} \)
Total vertical load \( W_{\text{total}} = W_{\text{wall}} + W_{\text{base}} + W_{\text{p}} + W_{V} = 218.7 \text{ kN/m} \)

Horizontal forces on wall
Surcharge \( F_{\text{sur}} = K_{a} \times \text{Surcharge} \times h_{\text{eff}} = 23.4 \text{ kN/m} \)
Moist backfill above water table \( F_{m_{a}} = 0.5 \times K_{a} \times \gamma_{m} \times (h_{\text{eff}} - h_{\text{water}})^2 = 12.8 \text{ kN/m} \)
Moist backfill below water table \( F_{m_{b}} = K_{a} \times \gamma_{m} \times (h_{\text{eff}} - h_{\text{water}}) \times h_{\text{water}} = 52 \text{ kN/m} \)
Saturated backfill \( F_{s} = 0.5 \times K_{a} \times (\gamma_{s} - \gamma_{\text{water}}) \times h_{\text{water}}^2 = 32.9 \text{ kN/m} \)
Water \( F_{\text{water}} = 0.5 \times \gamma_{\text{water}} \times h_{\text{water}}^2 = 69 \text{ kN/m} \)
Total horizontal load \( F_{\text{total}} = F_{\text{sur}} + F_{m_{a}} + F_{m_{b}} + F_{s} + F_{\text{water}} = 190 \text{ kN/m} \)

Calculate total propping force
Passive resistance of soil in front of wall \( F_{p} = 0.5 \times K_{p} \times \cos(\delta_{b}) \times (d_{\text{cover}} + b_{\text{base}} + d_{\text{ds}} - d_{\text{exc}}) \times \gamma_{\text{mb}} = 17.5 \text{ kN/m} \)
Propping force \( F_{\text{prop}} = \max(F_{\text{total}} - F_{p} - (W_{\text{total}} - W_{\text{p}} - W_{\text{live}}) \times \tan(\delta_{b}), 0 \text{ kN/m}) \)
\( F_{\text{prop}} = 107.2 \text{ kN/m} \)

Overturning moments
Surcharge \( M_{\text{sur}} = F_{\text{sur}} \times (h_{\text{eff}} - 2 \times d_{\text{ds}}) / 2 = 65.4 \text{ kNm/m} \)
Moist backfill above water table \( M_{m_{a}} = F_{m_{a}} \times (h_{\text{eff}} + 2 \times h_{\text{water}} - 3 \times d_{\text{ds}}) / 3 = 55.6 \text{ kNm/m} \)
Moist backfill below water table \( M_{m_{b}} = F_{m_{b}} \times (h_{\text{water}} - 2 \times d_{\text{ds}}) / 2 = 97.5 \text{ kNm/m} \)
Saturated backfill \( M_{s} = F_{s} \times (h_{\text{water}} - 3 \times d_{\text{ds}}) / 3 = 41.2 \text{ kNm/m} \)
Water \( M_{\text{water}} = F_{\text{water}} \times (h_{\text{water}} - 3 \times d_{\text{ds}}) / 3 = 86.2 \text{ kNm/m} \)
Total overturning moment \( M_{\text{ot}} = M_{\text{sur}} + M_{m_{a}} + M_{m_{b}} + M_{s} + M_{\text{water}} = 345.9 \text{ kNm/m} \)

Restoring moments
Wall stem \( M_{\text{wall}} = W_{\text{wall}} \times (l_{\text{toe}} + t_{\text{wall}} / 2) = 95.5 \text{ kNm/m} \)
Wall base \( M_{\text{base}} = W_{\text{base}} \times l_{\text{base}} / 2 = 46.3 \text{ kNm/m} \)
Design vertical dead load \( M_{\text{dead}} = W_{\text{dead}} \times l_{\text{load}} = 328.1 \text{ kNm/m} \)
Total restoring moment \( M_{\text{rest}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{dead}} = 469.9 \text{ kNm/m} \)

Check bearing pressure
Total vertical reaction \( R = W_{\text{total}} = 218.7 \text{ kN/m} \)
Distance to reaction \( x_{\text{bar}} = l_{\text{base}} / 2 = 1400 \text{ mm} \)
 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 \( p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R \times e / l_{\text{base}}^2) = 78.1 \text{ kN/m}^2 \)
Bearing pressure at heel \( p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R \times e / l_{\text{base}}^2) = 78.1 \text{ kN/m}^2 \)

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 \( F_{\text{prop\_top}} = (M_{\text{ot}} - M_{\text{rest}} + R \times l_{\text{base}} / 2 - F_{\text{prop}} \times t_{\text{base}} / 2) / (h_{\text{stem}} + t_{\text{base}} / 2) = 29.090 \text{ kN/m} \)
Propping force to base of wall \( F_{\text{prop\_base}} = F_{\text{prop}} - F_{\text{prop\_top}} = 78.130 \text{ kN/m} \)
RETAINING 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: \( W_{wall} = \gamma_d \times h_{stem} \times t_{wall} \times \gamma_{wall} = 50.5 \) kN/m
- Wall base: \( W_{base} = \gamma_d \times l_{base} \times t_{base} \times \gamma_{base} = 46.3 \) kN/m
- Soil in front of wall: \( W_{p} = \gamma_d \times l_{toe} \times d_{cover} \times \gamma_{mb} = 25.2 \) kN/m
- Applied vertical load: \( W_v = \gamma_d \times W_{dead} + \gamma_l \times W_{live} = 185.6 \) kN/m
- Total vertical load: \( W_{total} = W_{wall} + W_{base} + W_{p} + W_v = 307.5 \) kN/m

Factored horizontal at-rest forces on wall
- Surcharge: \( F_{sur} = \gamma_l \times K_0 \times \text{Surcharge} \times h_{eff} = 52.8 \) kN/m
- Moist backfill above water table: \( F_{m,a} = \gamma_e \times \frac{0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2}{2} = 25.2 \) kN/m
- Moist backfill below water table: \( F_{m,b} = \gamma_e \times K_0 \times \gamma_m \times (h_{water} - h_{eff}) \times h_{water} = 65 \) kN/m
- Saturated backfill: \( F_s = \gamma_s \times \frac{0.5 \times K_0 \times (\gamma_{s-water})^2 \times h_{water}^2}{3} = 65 \) kN/m
- Water: \( F_{water} = \gamma_e \times \frac{0.5 \times h_{water}^2 \times \gamma_{water}}{3} = 96.6 \) kN/m
- Total horizontal load: \( F_{total} = F_{sur} + F_{m,a} + F_{m,b} + F_s + F_{water} = 342.1 \) kN/m

Calculate total propping force
- Passive resistance of soil in front of wall: \( F_p = \gamma_e \times \frac{0.5 \times K_0 \times \cos(\delta_c) \times (dcover + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}}{2} = 24.5 \) kN/m
- Propping force: \( F_{prop} = \max(F_{total} - F_p - (W_{total} - W_p - \gamma_l \times W_{live}) \times \tan(\delta_b), 0) \) kN/m

Factored overturning moments
- Surcharge: \( M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 = 147.5 \) kN/m
- Moist backfill above water table: \( M_{m,a} = F_{m,a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 109.8 \) kN/m
- Moist backfill below water table: \( M_{m,b} = F_{m,b} \times (h_{water} - 2 \times d_{ds}) / 2 = 192.4 \) kN/m
- Saturated backfill: \( M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3 = 81.2 \) kN/m
- Water: \( M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3 = 120.7 \) kN/m
- Total overturning moment: \( M_{tot} = M_{sur} + M_{m,a} + M_{m,b} + M_s + M_{water} = 651.7 \) kN/m

Restoring moments
- Wall stem: \( M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2) = 133.7 \) kN/m
- Wall base: \( M_{base} = W_{base} \times l_{base} / 2 = 64.8 \) kN/m
- Soil in front of wall: \( M_p = W_p \times l_{toe} / 2 = 31.5 \) kN/m
- Design vertical load: \( M_v = W_v \times l_{load} = 487.1 \) kN/m
- Total restoring moment: \( M_{rest} = M_{wall} + M_{base} + M_p + M_v = 717.1 \) kN/m

Factored bearing pressure
- Total vertical reaction: \( R_t = W_{total} = 307.5 \) kN/m
- Distance to reaction: \( x_{sur} = l_{base} / 2 = 1400 \) mm
- Eccentricity of reaction: \( e_r = \text{abs}(l_{base} / 2 - x_{sur}) = 0 \) mm
- Reaction acts within middle third of base

Bearing pressure at toe: \( p_{toe} = (R_t / l_{base}) - (6 \times R_t \times e_r / l_{base}^2) = 109.8 \) kN/m²
- Bearing pressure at heel: \( p_{heel} = (R_t / l_{base}) + (6 \times R_t \times e_r / l_{base}^2) = 109.8 \) kN/m²
Rate of change of base reaction
\[ \text{rate} = \frac{(p_{\text{toe, f}} - p_{\text{heel, f}})}{l_{\text{base}}} = 0.00 \text{ kN/m}^2/\text{m} \]

Bearing pressure at stem / toe
\[ p_{\text{stem, toe, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times l_{\text{toe}}), 0 \text{ kN/m}^2) = 109.8 \text{ kN/m}^2 \]

Bearing pressure at mid stem
\[ p_{\text{stem, mid, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}} / 2)), 0 \text{ kN/m}^2) = 109.8 \text{ kN/m}^2 \]

Bearing pressure at stem / heel
\[ p_{\text{stem, heel, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}})), 0 \text{ kN/m}^2) = 109.8 \text{ kN/m}^2 \]

Calculate propping forces to top and base of wall
Propping force to top of wall
\[ F_{\text{prop, top, f}} = \frac{(M_{\text{toe, f}} - M_{\text{rest, f}} + R_{f} \times l_{\text{base}} / 2 - F_{\text{prop, f}} \times t_{\text{base}} / 2)}{(h_{\text{stem}} + t_{\text{base}} / 2)} = 57.779 \text{ kN/m} \]

Propping force to base of wall
\[ F_{\text{prop, base, f}} = F_{\text{prop, f}} - F_{\text{prop, top, f}} = 168.400 \text{ kN/m} \]

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

Base details
- Minimum area of reinforcement \[ k = 0.13 \% \]
- Cover to reinforcement in toe \[ c_{\text{toe}} = 30 \text{ mm} \]

Calculate shear for toe design
Shear from bearing pressure
\[ V_{\text{toe, bear}} = (p_{\text{toe, f}} + p_{\text{stem, mid, f}}) \times (l_{\text{toe}} / 2) = 274.5 \text{ kN/m} \]

Shear from weight of base
\[ V_{\text{toe, wt, base}} = (\gamma_{b} \times \gamma_{d, base} \times l_{\text{toe}} \times t_{\text{base}} / 2) = 41.3 \text{ kN/m} \]

Shear from weight of soil
\[ V_{\text{toe, wt, soil}} = w_{f} \times (\gamma_{b} \times \gamma_{m} \times l_{\text{toe}} \times d_{\text{exc}}) = 12.6 \text{ kN/m} \]

Total shear for toe design
\[ V_{\text{toe}} = V_{\text{toe, bear}} - V_{\text{toe, wt, base}} - V_{\text{toe, wt, soil}} = 220.6 \text{ kN/m} \]

Calculate moment for toe design
Moment from bearing pressure
\[ M_{\text{toe, bear}} = \left(2 \times p_{\text{toe, f}} + p_{\text{stem, mid, f}}\right) \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = 385.6 \text{ kNm/m} \]

Moment from weight of base
\[ M_{\text{toe, wt, base}} = (\gamma_{b} \times \gamma_{d, base} \times l_{\text{toe}} \times t_{\text{base}} \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2) = 58 \text{ kNm/m} \]

Moment from weight of soil
\[ M_{\text{toe, wt, soil}} = (w_{f} \times (\gamma_{b} \times \gamma_{m} \times l_{\text{toe}} \times d_{\text{exc}}) \times (l_{\text{toe}} + t_{\text{wall}}) / 2 = 17.6 \text{ kNm/m} \]

Total moment for toe design
\[ M_{\text{toe}} = M_{\text{toe, bear}} - M_{\text{toe, wt, base}} - M_{\text{toe, wt, soil}} = 309.9 \text{ kNm/m} \]

Check toe in bending
Width of toe \[ b = 1000 \text{ mm/m} \]
Depth of reinforcement \[ d_{\text{toe}} = l_{\text{base}} - c_{\text{toe}} - (d_{\text{toe}} / 2) = 462.0 \text{ mm} \]
Constant \[ K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_{\text{cu}}) = 0.036 \]

Compression reinforcement is not required
Lever arm

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

\[ z_{toe} = 439 \text{ mm} \]

Area of tension reinforcement required

\[ A_{s_{toe\_des}} = \frac{M_{toe}}{(0.87 \times f_y \times z_{toe})} = 1623 \text{ mm}^2 / \text{m} \]

Minimum area of tension reinforcement

\[ A_{s_{toe\_min}} = k \times b \times t_{base} = 650 \text{ mm}^2 / \text{m} \]

Area of tension reinforcement required

\[ A_{s_{toe\_req}} = \max(A_{s_{toe\_des}}, A_{s_{toe\_min}}) = 1623 \text{ mm}^2 / \text{m} \]

Reinforcement provided

16 mm dia. bars @ 100 mm centres

Area of tension reinforcement provided

\[ A_{s_{toe\_prov}} = 2011 \text{ mm}^2 / \text{m} \]

Check shear resistance at toe

Design shear stress

\[ v_{toe} = \frac{V_{toe}}{(b \times d_{toe})} = 0.478 \text{ N/mm}^2 \]

Allowable shear stress

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress

\[ v_{c\_toe} = 0.560 \text{ N/mm}^2 \]

\[ v_{toe} < v_{c\_toe} - \text{No shear reinforcement required} \]

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

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

Wall details

Minimum area of reinforcement

\[ k = 0.13 \% \]

Cover to reinforcement in stem

\[ c_{stem} = 30 \text{ mm} \]

Cover to reinforcement in wall

\[ c_{wall} = 30 \text{ mm} \]

Factored horizontal at-rest forces on stem

Surcharge

\[ F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (\text{heff} - \text{tbase} - \text{dds}) = 48.1 \text{ kN/m} \]

Moist backfill above water table

\[ F_{s\_m\_a\_f} = 0.5 \times \gamma_{e\_a} \times K_0 \times \gamma_{m} \times (\text{heff} - \text{tbase} - \text{dds} - \text{hsat}) \times \text{bl} = 25.2 \text{ kN/m} \]

Moist backfill below water table

\[ F_{s\_m\_b\_f} = 0.5 \times \gamma_{e\_b} \times K_0 \times \gamma_{m} \times (\text{heff} - \text{tbase} - \text{dds} - \text{hsat}) \times \text{al} = 88.9 \text{ kN/m} \]

Saturated backfill

\[ F_{s\_s\_f} = 0.5 \times \gamma_{e\_s} \times K_0 \times (\gamma_{s\_water} - \gamma_{water}) \times \text{hsat} = 48.8 \text{ kN/m} \]

Water

\[ F_{s\_water\_f} = 0.5 \times \gamma_{e\_water} \times \gamma_{water} \times \text{hsat}^2 = 72.5 \text{ kN/m} \]

Calculate shear for stem design

Surcharge

\[ V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8 = 30 \text{ kN/m} \]

Moist backfill above water table

\[ V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times \text{bl} \times ((5 \times L^2) - (3 \times b^2)) / (5 \times L^2) = 8.5 \text{ kN/m} \]

Moist backfill below water table

\[ V_{s\_m\_b\_f} = \frac{F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n)))}{8} = 73 \text{ kN/m} \]

Saturated backfill

\[ V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a^2 \times ((5 \times L) - a)) / (20 \times L^2)) = 44.3 \text{ kN/m} \]

Water

\[ V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a^2 \times ((5 \times L) - a)) / (20 \times L^2)) = 65.8 \text{ kN/m} \]

Total shear for stem design

\[ V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f} = 221.5 \text{ kN/m} \]

Calculate moment for stem design

Surcharge

\[ M_{s\_sur\_f} = F_{s\_sur\_f} \times L / 8 = 32.1 \text{ kN/m} \]

Moist backfill above water table

\[ M_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b \times ((5 \times L^2) - (3 \times b^2)) / (15 \times L^2) = 14.3 \text{ kN/m} \]

Moist backfill below water table

\[ M_{s\_m\_b\_f} = \frac{F_{s\_m\_b\_f} \times a^2 \times (2 - n)}{8} = 70.3 \text{ kN/m} \]

Saturated backfill

\[ M_{s\_s\_f} = F_{s\_s\_f} \times a^2 \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 32.6 \text{ kN/m} \]

Water

\[ M_{s\_water\_f} = F_{s\_water\_f} \times a^2 \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 48.5 \text{ kN/m} \]

kNm/m

Total moment for stem design

\[ M_{stem} = M_{s\_sur\_f} + M_{s\_m\_a\_f} + M_{s\_m\_b\_f} + M_{s\_s\_f} + M_{s\_water\_f} = 197.9 \text{ kN/m} \]
Calculate moment for wall design

Surcharge
\[ M_{w,\text{sur}} = 9 \times F_{s,\text{sur}} \times \frac{f_s}{128} = 18 \text{ kNm/m} \]

Moist backfill above water table
\[ M_{w,\text{m,a}} = F_{s,\text{m,a}} \times 0.577 \times \frac{b^3}{2} \times \frac{3\pi}{4} = 14.8 \text{ kNm/m} \]

Moist backfill below water table
\[ M_{w,\text{m,b}} = F_{s,\text{m,b}} \times \frac{a_l}{2} \times \left[ (4-n^2) \frac{8}{16} + n \cdot (4-n) \right] = 34.4 \text{ kNm/m} \]

Saturated backfill
\[ M_{w,\text{s}} = F_{s,\text{s}} \times \frac{a_l}{2} \times \left[ (5 \times a_l^2) \times (20 \times L^2) - (x-b) \times (3 \times a_l^2) \right] = 11.6 \text{ kNm/m} \]

Water
\[ M_{w,\text{water}} = F_{s,\text{water}} \times \frac{a_l}{2} \times \left[ (5 \times a_l^2) \times (20 \times L^2) - (x-b) \times (3 \times a_l^2) \right] = 17.3 \text{ kNm/m} \]

Total moment for wall design
\[ M_{\text{wall}} = M_{w,\text{sur}} + M_{w,\text{m,a}} + M_{w,\text{m,b}} + M_{w,\text{s}} + M_{w,\text{water}} = 96.1 \text{ kNm/m} \]

Check wall stem in bending

Width of wall stem
\[ b = 1000 \text{ mm/m} \]

Depth of reinforcement
\[ d_{\text{stem}} = t_{\text{wall}} - c_{\text{stem}} - \left( \frac{\phi_{\text{stem}}}{2} \right) = 260.0 \text{ mm} \]

Constant
\[ k_{\text{stem}} = \frac{M_{\text{stem}}}{(b \times d_{\text{stem}}^2 \times f_{\text{cu}})} = 0.073 \]

Compression reinforcement is not required

Lever arm
\[ z_{\text{stem}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{stem}}, 0.225) / 0.9)),0.95}) \times d_{\text{stem}} = 237 \text{ mm} \]

Area of tension reinforcement required
\[ A_{\text{s,stem,req}} = \frac{M_{\text{stem}}}{(0.87 \times f_t \times z_{\text{stem}})} = 1921 \text{ mm}^2/m \]

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

Reinforcement provided
20 mm dia. bars @ 100 mm centres

Area of reinforcement provided
\[ A_{\text{s,prov,stem}} = 3142 \text{ mm}^2/m \]

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress
\[ v_{\text{stem}} = \frac{V_{\text{stem}}}{(b \times d_{\text{stem}})} = 0.852 \text{ N/mm}^2 \]

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8
Design concrete shear stress
\[ v_{c,\text{stem}} = 0.877 \text{ N/mm}^2 \]

\[ v_{\text{stem}} < v_{c,\text{stem}} - \text{No shear reinforcement required} \]
Check mid height of wall in bending

Depth of reinforcement
\[ d_{\text{wall}} = t_{\text{wall}} - c_{\text{wall}} - (\phi_{\text{wall}} / 2) = 262.0 \text{ mm} \]

Constant
\[ K_{\text{wall}} = M_{\text{wall}} / (b \times d_{\text{wall}}^2 \times f_{\text{cu}}) = 0.035 \]

Compression reinforcement is not required

Lever arm
\[ z_{\text{wall}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{wall}}, 0.225) / 0.95)) \times d_{\text{wall}}}, 0.95) \times d_{\text{wall}} = 249 \text{ mm} \]

Area of tension reinforcement required
\[ A_{s_{\text{wall, req}}} = M_{\text{wall}} / (0.87 \times f_y \times z_{\text{wall}}) = 888 \text{ mm}^2/\text{m} \]

Minimum area of tension reinforcement
\[ A_{s_{\text{wall, min}}} = k \times b \times t_{\text{wall}} = 390 \text{ mm}^2/\text{m} \]

Area of tension reinforcement required
\[ A_{s_{\text{wall, req}}} = \max(A_{s_{\text{wall, req}}} , A_{s_{\text{wall, min}}}) = 888 \text{ mm}^2/\text{m} \]

Reinforcement provided
16 mm dia. bars @ 200 mm centres

Area of reinforcement provided
\[ A_{s_{\text{wall, prov}}} = 1005 \text{ mm}^2/\text{m} \]

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

Check retaining wall deflection

Basic span/effective depth ratio
\[ \text{ratio}_{\text{bas}} = 20 \]

Design service stress
\[ f_s = 2 \times f_y \times A_{s_{\text{stem, req}}} / (3 \times A_{s_{\text{stem, prov}}}) = 203.8 \text{ N/mm}^2 \]

Modification factor
\[ \text{factor}_{\text{tens}} = \min(0.55 + (477 \text{ N/mm}^2 - f_y) / (120 \times (0.9 \text{ N/mm}^2 + (M_{\text{stem}} / (b \times d_{\text{stem}}^2)))), 2) = 1.14 \]

Maximum span/effective depth ratio
\[ \text{ratio}_{\text{max}} = \text{ratio}_{\text{bas}} \times \text{factor}_{\text{tens}} = 22.90 \]

Actual span/effective depth ratio
\[ \text{ratio}_{\text{act}} = h_{\text{stem}} / d_{\text{stem}} = 19.58 \]

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

Toe reinforcement
Wall reinforcement
Stem reinforcement

Toe bars - 16 mm dia.@ 100 mm centres - (2011 mm²/m)
Wall bars - 16 mm dia.@ 200 mm centres - (1005 mm²/m)
Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm²/m)
**RETAINING WALL ANALYSIS (BS 8002:1994)**

**Wall details**
- **Retaining wall type**: Cantilever propped at both
- **Height of retaining wall stem**: \( h_{stem} = 5090 \) mm
- **Thickness of wall stem**: \( t_{wall} = 400 \) mm
- **Length of toe**: \( l_{toe} = 2500 \) mm
- **Length of heel**: \( l_{heel} = 0 \) mm
- **Overall length of base**: \( l_{base} = l_{toe} + l_{heel} + t_{wall} = 2900 \) mm
- **Thickness of base**: \( t_{base} = 500 \) mm
- **Depth of downstand**: \( d_{ds} = 0 \) mm
- **Position of downstand**: \( l_{ds} = 0 \) mm
- **Thickness of downstand**: \( t_{ds} = 500 \) mm
- **Height of retaining wall**: \( h_{wall} = h_{stem} + t_{base} + d_{ds} = 5590 \) mm
- **Depth of cover in front of wall**: \( d_{cover} = 400 \) mm
- **Depth of unplanned excavation**: \( d_{exc} = 200 \) mm
- **Height of ground water behind wall**: \( h_{water} = 3750 \) mm
- **Height of saturated fill above base**: \( h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \) mm\) = 3250 mm
- **Density of wall construction**: \( \gamma_{wall} = 23.6 \) kN/m\(^3\)
- **Density of base construction**: \( \gamma_{base} = 23.6 \) kN/m\(^3\)
- **Angle of rear face of wall**: \( \alpha = 90.0 \) deg
- **Angle of soil surface behind wall**: \( \beta = 0.0 \) deg
- **Effective height at virtual back of wall**: \( h_{eff} = h_{wall} + l_{heel} \times \tan(\beta) = 5590 \) mm

**Retained material details**
- **Mobilisation factor**: \( M = 1.5 \)
Moist density of retained material \( \gamma_m = 18.0 \, \text{kN/m}^3 \)
Saturated density of retained material \( \gamma_s = 21.0 \, \text{kN/m}^3 \)
Design shear strength \( \phi' = 24.2 \, \text{deg} \)
Angle of wall friction \( \delta = 0.0 \, \text{deg} \)

**Base material details**

Moist density \( \gamma_{mb} = 18.0 \, \text{kN/m}^3 \)
Design shear strength \( \phi'_b = 24.2 \, \text{deg} \)
Design base friction \( \delta_b = 18.6 \, \text{deg} \)
Allowable bearing pressure \( P_{bearing} = 150 \, \text{kN/m}^2 \)

**Using Coulomb theory**

Active pressure coefficient for retained material
\[
K_a = \frac{\sin(\alpha + \phi')^2}{\sin(\alpha)^2} \times \frac{\sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))}]^2)}{\sin(90 + \delta)} = 0.419
\]

Passive pressure coefficient for base material
\[
K_p = \frac{\sin(90 - \phi'_b)^2}{\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b))}]^2)} = 4.187
\]

**At-rest pressure**

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

**Loading details**

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

Applied vertical dead load on wall \( W_{dead} = 139.4 \, \text{kN/m} \)

Applied vertical live load on wall \( W_{live} = 5.5 \, \text{kN/m} \)

Position of applied vertical load on wall \( l_{load} = 2700 \, \text{mm} \)

Applied horizontal dead load on wall \( F_{dead} = 0.0 \, \text{kN/m} \)

Applied horizontal live load on wall \( F_{live} = 0.0 \, \text{kN/m} \)

Height of applied horizontal load on wall \( h_{load} = 0 \, \text{mm} \)

Loads shown in kN/m, pressures shown in kN/m²
Vertical forces on wall
- Wall stem: \( W_{\text{wall}} = \text{twall} \times \gamma_{\text{wall}} \times h_{\text{stem}} = 48 \text{ kN/m} \)
- Wall base: \( W_{\text{base}} = \text{tbase} \times \gamma_{\text{base}} \times l_{\text{base}} = 34.2 \text{ kN/m} \)
- Soil in front of wall: \( W_{\text{p}} = \text{dcover} \times \gamma_{\text{mb}} = 18 \text{ kN/m} \)
- Applied vertical load: \( W_v = W_{\text{dead}} + W_{\text{live}} = 144.8 \text{ kN/m} \)
- Total vertical load: \( W_{\text{total}} = W_{\text{wall}} + W_{\text{base}} + W_{\text{p}} + W_v = 245.1 \text{ kN/m} \)

Horizontal forces on wall
- Surcharge: \( F_{\text{sur}} = K_a \times \text{Surcharge} \times h_{\text{eff}} = 23.4 \text{ kN/m} \)
- Moist backfill above water table: \( F_{\text{m,a}} = 0.5 \times K_a \times \gamma_{\text{m}} \times (h_{\text{eff}} - h_{\text{water}})^2 = 12.8 \text{ kN/m} \)
- Moist backfill below water table: \( F_{\text{m,b}} = K_a \times \gamma_{\text{m}} \times (h_{\text{water}} - h_{\text{water}})^2 = 52 \text{ kN/m} \)
- Saturated backfill: \( F_s = 0.5 \times K_a \times \gamma_{\text{s}} \times (h_{\text{water}})^2 = 32.9 \text{ kN/m} \)
- Water: \( F_{\text{water}} = 0.5 \times h_{\text{water}}^2 \times \gamma_{\text{water}} = 69 \text{ kN/m} \)
- Total horizontal load: \( F_{\text{total}} = F_{\text{sur}} + F_{\text{m,a}} + F_{\text{m,b}} + F_s + F_{\text{water}} = 190 \text{ kN/m} \)

Calculate total propping force
- Passive resistance of soil in front of wall: \( F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{\text{cover}} + t_{\text{base}} + d_{\text{soil}} - d_{\text{exc}}) \times \gamma_{\text{mb}} = 17.5 \text{ kN/m} \)
- Propping force: \( F_{\text{prop}} = \max(F_{\text{total}} - F_p - (W_{\text{total}} - W_{\text{p}} - W_v), 0 \text{ kN/m}) \)
  \( F_{\text{prop}} = 97.9 \text{ kN/m} \)

Overturning moments
- Surcharge: \( M_{\text{sur}} = F_{\text{sur}} \times (h_{\text{eff}} - 2 \times d_{\text{soil}}) / 2 = 65.4 \text{ kNm/m} \)
- Moist backfill above water table: \( M_{\text{m,a}} = F_{\text{m,a}} \times (h_{\text{eff}} + 2 \times h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 55.6 \text{ kNm/m} \)
- Moist backfill below water table: \( M_{\text{m,b}} = F_{\text{m,b}} \times (h_{\text{water}} - 2 \times d_{\text{soil}}) / 2 = 97.5 \text{ kNm/m} \)
- Saturated backfill: \( M_s = F_s \times (h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 41.2 \text{ kNm/m} \)
- Water: \( M_{\text{water}} = F_{\text{water}} \times (h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 86.2 \text{ kNm/m} \)
- Total overturning moment: \( M_{\text{tot}} = M_{\text{sur}} + M_{\text{m,a}} + M_{\text{m,b}} + M_s + M_{\text{water}} = 345.9 \text{ kNm/m} \)

Restoring moments
- Wall stem: \( M_{\text{wall}} = W_{\text{wall}} \times (l_{\text{toe}} + t_{\text{wall}} / 2) = 129.7 \text{ kNm/m} \)
- Wall base: \( M_{\text{base}} = W_{\text{base}} \times l_{\text{base}} / 2 = 49.6 \text{ kNm/m} \)
- Design vertical dead load: \( M_{\text{dead}} = W_{\text{dead}} \times l_{\text{load}} = 376.3 \text{ kNm/m} \)
- Total restoring moment: \( M_{\text{rest}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{dead}} = 555.7 \text{ kNm/m} \)

Check bearing pressure
- Total vertical reaction: \( R = W_{\text{total}} = 245.1 \text{ kN/m} \)
- Distance to reaction: \( x_{\text{bar}} = l_{\text{base}} / 2 = 1450 \text{ mm} \)
- 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: \( p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R \times e / l_{\text{base}}^2) = 84.5 \text{ kN/m}^2 \)
- Bearing pressure at heel: \( p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R \times e / l_{\text{base}}^2) = 84.5 \text{ kN/m}^2 \)

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: \( F_{\text{prop, top}} = (M_{\text{sub}} - M_{\text{rest}} + R \times l_{\text{base}} / 2 - F_{\text{prop}} \times t_{\text{base}} / 2) / (h_{\text{stem}} + t_{\text{base}} / 2) = 22.681 \text{ kN/m} \)
- Propping force to base of wall: \( F_{\text{prop, base}} = F_{\text{prop}} - F_{\text{prop, top}} = 75.263 \text{ kN/m} \)
RETAINING WALL DESIGN (BS 8002:1994)

Ultimate limit state load factors

Dead load factor \( \gamma_{f_d} = 1.4 \)

Live load factor \( \gamma_{f_l} = 1.6 \)

Earth and water pressure factor \( \gamma_{f_e} = 1.4 \)

Factored vertical forces on wall

Wall stem

\[
W_{wall} = \gamma_{f_d} \times h_{stem} \times t_{wall} \times \gamma_{wall} = 67.3 \text{ kN/m}
\]

Wall base

\[
W_{base} = \gamma_{f_d} \times l_{base} \times t_{base} \times \gamma_{base} = 47.9 \text{ kN/m}
\]

Soil in front of wall

\[
W_{p} = \gamma_{f_d} \times l_{toe} \times d_{cover} \times \gamma_{mb} = 25.2 \text{ kN/m}
\]

Applied vertical load

\[
W_v = \gamma_{f_d} \times W_{dead} + \gamma_{f_l} \times W_{live} = 203.8 \text{ kN/m}
\]

Total vertical load

\[
W_{total} = W_{wall} + W_{base} + W_p + W_v = 344.2 \text{ kN/m}
\]

Factored horizontal at-rest forces on wall

Surcharge

\[
F_{sur} = \gamma_{f_l} \times K_0 \times \text{Surface} \times h_{eff} = 52.8 \text{ kN/m}
\]

Moist backfill above water table

\[
F_{m_{a}} = \gamma_{f_e} \times 0.5 \times K_0 \times \gamma_{w} \times (h_{eff} - h_{water})^2 = 25.2 \text{ kN/m}
\]

Moist backfill below water table

\[
F_{m_{b}} = \gamma_{f_e} \times K_0 \times \gamma_{w} \times (h_{eff} - h_{water}) \times h_{water} = 65 \text{ kN/m}
\]

Saturated backfill

\[
F_s = \gamma_{f_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2 = 65 \text{ kN/m}
\]

Water

\[
F_{water} = \gamma_{f_e} \times 0.5 \times h_{water}^2 \times \gamma_{water} = 96.6 \text{ kN/m}
\]

Total horizontal load

\[
F_{total} = F_{sur} + F_{m_{a}} + F_{m_{b}} + F_s + F_{water} = 342.1 \text{ kN/m}
\]

Calculate total propping force

Passive resistance of soil in front of wall

\[
P_{p} = \gamma_{f_e} \times 0.5 \times K_0 \times \cos(\delta) \times (d_{cover} + t_{base} + d_{ds} + d_{exc}) \times \gamma_{mb} = 24.5 \text{ kN/m}
\]

Propping force

\[
F_{prop} = \max(F_{total} - F_p - (W_{total} - W_p - \gamma_{f_l} \times W_{live}) \times \tan(\delta), 0 \text{ kN/m}) = 213.2 \text{ kN/m}
\]

Factored overturning moments

Surcharge

\[
M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2 = 147.5 \text{ kNm/m}
\]

Moist backfill above water table

\[
M_{m_{a}} = F_{m_{a}} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = 109.8 \text{ kNm/m}
\]

Moist backfill below water table

\[
M_{m_{b}} = F_{m_{b}} \times (h_{water} - 2 \times d_{ds}) / 2 = 192.4 \text{ kNm/m}
\]

Saturated backfill

\[
M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3 = 81.2 \text{ kNm/m}
\]

Water

\[
M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3 = 120.7 \text{ kNm/m}
\]

Total overturning moment

\[
M_{tot} = M_{sur} + M_{m_{a}} + M_{m_{b}} + M_s + M_{water} = 651.7 \text{ kNm/m}
\]

Restoring moments

Wall stem

\[
M_{wall} = W_{wall} \times (l_{toe} + t_{wall} / 2) = 181.6 \text{ kNm/m}
\]

Wall base

\[
M_{base} = W_{base} \times l_{base} / 2 = 69.5 \text{ kNm/m}
\]

Soil in front of wall

\[
M_{p} = W_p \times l_{toe} / 2 = 31.5 \text{ kNm/m}
\]

Design vertical load

\[
M_v = W_v \times l_{load} = 550.4 \text{ kNm/m}
\]

Total restoring moment

\[
M_{rest} = M_{wall} + M_{base} + M_p + M_v = 833 \text{ kNm/m}
\]

Factored bearing pressure

Total vertical reaction

\[
R = W_{total} = 344.2 \text{ kN/m}
\]

Distance to reaction

\[
x_{surf} = l_{base} / 2 = 1450 \text{ mm}
\]

Eccentricity of reaction

\[
e = \text{abs}(l_{base} / 2 - x_{surf}) = 0 \text{ mm}
\]

Reaction acts within middle third of base

Bearing pressure at toe

\[
p_{toe} = (R / l_{base}) - (6 \times R / e) / (l_{base}^2) = 118.7 \text{ kN/m}^2
\]

Bearing pressure at heel

\[
p_{heel} = (R / l_{base}) + (6 \times R / e) / (l_{base}^2) = 118.7 \text{ kN/m}^2
\]
Rate of change of base reaction
\[ \text{rate} = \frac{(p_{\text{toe, f}} - p_{\text{heel, f}})}{l_{\text{base}}} = 0.00 \text{ kN/m}^2/\text{m} \]

Bearing pressure at stem / toe
\[ p_{\text{stem, toe, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times l_{\text{toe}}), 0 \text{ kN/m}^2) = 118.7 \text{ kN/m}^2 \]

Bearing pressure at mid stem
\[ p_{\text{stem, mid, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}} / 2)), 0 \text{ kN/m}^2) = 118.7 \text{ kN/m}^2 \]

Bearing pressure at stem / heel
\[ p_{\text{stem, heel, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}})), 0 \text{ kN/m}^2) = 118.7 \text{ kN/m}^2 \]

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

**Propping force to top of wall**
\[ F_{\text{prop, top, f}} = \frac{(M_{\text{toe, f}} - M_{\text{rest, f}} + R_f \times l_{\text{base}} / 2 - F_{\text{prop, f}} \times t_{\text{base}} / 2)}{(h_{\text{stem}} + t_{\text{base}} / 2)} = 49.539 \text{ kN/m} \]

**Propping force to base of wall**
\[ F_{\text{prop, base, f}} = F_{\text{prop, f}} - F_{\text{prop, top, f}} = 163.654 \text{ kN/m} \]

**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 \( c_{toe} = 30 \text{ mm} \)

**Calculate shear for toe design**
- Shear from bearing pressure \( V_{\text{toe, bear}} = (p_{\text{toe, f}} + p_{\text{stem, mid, f}}) \times l_{\text{toe}} / 2 = 296.7 \text{ kN/m} \)
- Shear from weight of base \( V_{\text{toe, wt, base}} = \gamma_t \times \gamma_{\text{base}} \times l_{\text{toe}} \times t_{\text{base}} = 41.3 \text{ kN/m} \)
- Shear from weight of soil \( V_{\text{toe, wt, soil}} = w_{p, f} \times (\gamma_t \times \gamma_m \times l_{\text{toe}} \times d_{\text{exc}}) = 12.6 \text{ kN/m} \)
- Total shear for toe design \( V_{\text{toe}} = V_{\text{toe, bear}} - V_{\text{toe, wt, base}} - V_{\text{toe, wt, soil}} = 242.8 \text{ kN/m} \)

**Calculate moment for toe design**
- Moment from bearing pressure \( M_{\text{toe, bear}} = (2 \times p_{\text{toe, f}} + p_{\text{stem, mid, f}}) \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = 432.6 \text{ kNm/m} \)
- Moment from weight of base \( M_{\text{toe, wt, base}} = (\gamma_t \times \gamma_{\text{base}} \times l_{\text{toe}} \times t_{\text{base}} \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2) = 60.2 \text{ kNm/m} \)
- Moment from weight of soil \( M_{\text{toe, wt, soil}} = (w_{p, f} - (\gamma_t \times \gamma_m \times l_{\text{toe}} \times d_{\text{exc}})) \times (l_{\text{toe}} + t_{\text{wall}}) / 2 = 18.3 \text{ kNm/m} \)
- Total moment for toe design \( M_{\text{toe}} = M_{\text{toe, bear}} - M_{\text{toe, wt, base}} - M_{\text{toe, wt, soil}} = 354.2 \text{ kNm/m} \)

**Check toe in bending**
- Width of toe \( b = 1000 \text{ mm/m} \)
- Depth of reinforcement \( d_{\text{toe}} = l_{\text{base}} - c_{\text{toe}} - (p_{\text{toe, f}} / 2) = 462.0 \text{ mm} \)
- Constant \( K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_{cu}) = 0.041 \)

*Compression reinforcement is not required*
Lever arm  
\[ z_{toe} = \text{min}(0.5 + \sqrt{(0.25 - \text{min}(K_{toe}, 0.225) / 0.9)), 0.95) \times d_{toe} \]
\[ z_{toe} = 439 \text{ mm} \]

Area of tension reinforcement required  
\[ A_{s\_toe} = M_{toe} / (0.87 \times f_y \times z_{toe}) = 1855 \text{ mm}^2/\text{m} \]

Minimum area of tension reinforcement  
\[ A_{s\_toe\_min} = k \times b \times t_{base} = 650 \text{ mm}^2/\text{m} \]

Area of tension reinforcement required  
\[ A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min}) = 1855 \text{ mm}^2/\text{m} \]

Reinforcement provided  
16 mm dia. bars @ 100 mm centres

Area of reinforcement provided  
\[ A_{s\_toe\_prov} = 2011 \text{ mm}^2/\text{m} \]

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress  
\[ v_{toe} = V_{toe} / (b \times d_{toe}) = 0.526 \text{ N/mm}^2 \]

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress  
\[ V_{c\_toe} = 0.560 \text{ N/mm}^2 \]

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

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

Wall details

Minimum area of reinforcement  
\[ k = 0.13 \% \]

Cover to reinforcement in stem  
\[ c_{stem} = 30 \text{ mm} \]

Cover to reinforcement in wall  
\[ c_{wall} = 30 \text{ mm} \]

Factored horizontal at-rest forces on stem

Surcharge  
\[ F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (\text{het - base} - d_{so}) = 48.1 \text{ kN/m} \]

Moist backfill above water table  
\[ F_{s\_m\_a\_f} = 0.5 \times \gamma_{e\_m} \times K_0 \times \gamma_{m} \times (\text{het - base} - d_{so} - h_{sat})^2 = 25.2 \text{ kN/m} \]

Moist backfill below water table  
\[ F_{s\_m\_b\_f} = \gamma_{e\_m} \times K_0 \times \gamma_{m} \times (\text{het - base} - d_{so} - h_{sat}) \times h_{sat} = 88.9 \text{ kN/m} \]

Saturated backfill  
\[ F_{s\_s\_f} = 0.5 \times \gamma_{e\_m} \times K_0 \times (\gamma_{\text{water}}) \times h_{sat}^2 = 48.8 \text{ kN/m} \]

Water  
\[ F_{s\_water\_f} = 0.5 \times \gamma_{e\_m} \times \gamma_{\text{water}} \times h_{sat}^2 = 72.5 \text{ kN/m} \]

Calculate shear for stem design

Surcharge  
\[ V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8 = 30 \text{ kN/m} \]

Moist backfill above water table  
\[ V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b \times ((5 \times L^2) - b^2) / (5 \times L^3) = 8.5 \text{ kN/m} \]

Moist backfill below water table  
\[ V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n_2 \times (4 - n))) / 8 = 73 \text{ kN/m} \]

Saturated backfill  
\[ V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_2^2 \times ((5 \times L) - a) / (20 \times L^3))) = 44.3 \text{ kN/m} \]

Water  
\[ V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_2^2 \times ((5 \times L) - a) / (20 \times L^3))) = 65.8 \text{ kN/m} \]

Total shear for stem design  
\[ V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f} = 221.5 \text{ kN/m} \]

Calculate moment for stem design

Surcharge  
\[ M_{s\_sur\_f} = F_{s\_sur\_f} \times L / 8 = 32.1 \text{ kNm/m} \]

Moist backfill above water table  
\[ M_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b \times ((5 \times L^2) - (3 \times b^2)) / (15 \times L^3) = 14.3 \text{ kNm/m} \]

Moist backfill below water table  
\[ M_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times a \times (2 - n)^2 / 8 = 70.3 \text{ kNm/m} \]

Saturated backfill  
\[ M_{s\_s\_f} = F_{s\_s\_f} \times a \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 32.6 \text{ kNm/m} \]

Water  
\[ M_{s\_water\_f} = F_{s\_water\_f} \times a \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 48.5 \text{ kNm/m} \]

kNm/m  
\[ Total \text{ moment for stem design:} M_{stem} = M_{s\_sur\_f} + M_{s\_m\_a\_f} + M_{s\_m\_b\_f} + M_{s\_s\_f} + M_{s\_water\_f} = 197.9 \text{ kNm/m} \]
Calculate moment for wall design

Surcharge
\[ M_{w,\text{sur}} = 9 \times F_s \times F_{t,\text{sur}} \times L / 128 = 18 \text{ kNm/m} \]

Moist backfill above water table
\[ M_{w,\text{m,a}} = F_s \times F_{t,\text{m,a}} \times 0.577 \times b \times \left[ (b^3 + 5 \times a \times L^2) / (5 \times L^3) - 0.577^2 / 3 \right] = 14.8 \text{ kNm/m} \]

Moist backfill below water table
\[ M_{w,\text{m,b}} = F_s \times F_{t,\text{m,b}} \times a \times \left[ ((8 - n^2 \times (4 - n))^2 / 16) - 4 \times n \times (4 - n) \right] / 8 = 34.4 \text{ kNm/m} \]

Saturated backfill
\[ M_{w,\text{s}} = F_s \times F_{t,\text{s}} \times a \times \left[ \frac{(5 \times L - a) \times (a^2 - x^2)}{20 \times L^3} - \frac{4 - n}{3 \times a^2} \right] = 11.6 \text{ kNm/m} \]

Water
\[ M_{w,\text{water}} = F_s \times F_{t,\text{water}} \times a \times \left[ \frac{(5 \times L - a) \times (a^2 - x^2)}{20 \times L^3} - \frac{4 - n}{3 \times a^2} \right] = 17.3 \text{ kNm/m} \]

Total moment for wall design
\[ M_{\text{wall}} = M_{w,\text{sur}} + M_{w,\text{m,a}} + M_{w,\text{m,b}} + M_{w,\text{s}} + M_{w,\text{water}} = 96.1 \text{ kNm/m} \]

Check wall stem in bending

Width of wall stem
\[ b = 1000 \text{ mm/m} \]

Depth of reinforcement
\[ d_{\text{stem}} = t_{\text{wall}} - c_{\text{stem}} - \left( \phi_{\text{stem}} / 2 \right) = 360.0 \text{ mm} \]

Constant
\[ K_{\text{stem}} = M_{\text{stem}} / (b \times d_{\text{stem}}^2 \times f_{\text{cu}}) = 0.038 \]

Compression reinforcement is not required

Lever arm
\[ z_{\text{stem}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{stem}}, 0.225) / 0.95)) \times d_{\text{stem}}}, 342) \text{ mm} \]

Area of tension reinforcement required
\[ A_{s,\text{stem,req}} = \max(A_{s,\text{stem,des}}, A_{s,\text{stem,min}}) = 1330 \text{ mm}^2 / \text{m} \]

Minimum area of tension reinforcement
\[ A_{s,\text{stem,min}} = k \times b \times t_{\text{wall}} = 520 \text{ mm}^2 / \text{m} \]

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

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress
\[ \nu_{\text{stem}} = \nu_{\text{stem}} / (b \times d_{\text{stem}}) = 0.615 \text{ N/mm}^2 \]

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress
\[ \nu_{c,\text{stem}} = 0.576 \text{ N/mm}^2 \]

WARNING - Shear reinforcement required
Check mid height of wall in bending

Depth of reinforcement
\[ d_{\text{wall}} = t_{\text{wall}} - c_{\text{wall}} - \left( \frac{D_{\text{wall}}}{2} \right) = 362.0 \text{ mm} \]

Constant
\[ K_{\text{wall}} = \frac{M_{\text{wall}}}{(b \times d_{\text{wall}}^2 \times f_{\text{cu}})} = 0.018 \]

Compression reinforcement is not required

Lever arm
\[ z_{\text{wall}} = \min(0.5 + \sqrt{0.25 - (\min(K_{\text{wall}}, 0.225) / 0.95) \times d_{\text{wall}}}, 0.95) \times d_{\text{wall}} = 344 \text{ mm} \]

Area of tension reinforcement required
\[ A_{\text{w, wall, req}} = \frac{M_{\text{wall}}}{(0.87 \times f_y \times z_{\text{wall}})} = 643 \text{ mm}^2/\text{m} \]

Minimum area of tension reinforcement
\[ A_{\text{w, wall, min}} = k \times b \times t_{\text{wall}} = 520 \text{ mm}^2/\text{m} \]

Area of tension reinforcement provided
\[ A_{\text{w, wall, prov}} = 16 \text{ mm dia. bars @ 200 mm centres} \]

Area of reinforcement provided
\[ A_{\text{w, wall, prov}} = 1005 \text{ mm}^2/\text{m} \]

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

Check retaining wall deflection

Basic span/effective depth ratio
\[ \text{ratio}_{\text{bas}} = 20 \]

Design service stress
\[ f_s = 2 \times f_y \times A_{\text{w, stem, req}} / (3 \times A_{\text{w, stem, prov}}) = 282.2 \text{ N/mm}^2 \]

Modification factor
\[ \text{factor}_{\text{tens}} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)(120 \times (0.9 \text{ N/mm}^2 + (M_{\text{stem}}(b \times d_{\text{stem}}^2))) / (120 \times (0.9 \text{ N/mm}^2 + (M_{\text{stem}}(b \times d_{\text{stem}}^2))))/2), 0) = 1.22 \]

Maximum span/effective depth ratio
\[ \text{ratio}_{\text{max}} = \text{ratio}_{\text{bas}} \times \text{factor}_{\text{tens}} = 24.38 \]

Actual span/effective depth ratio
\[ \text{ratio}_{\text{act}} = \frac{h_{\text{stem}}}{d_{\text{stem}}} = 14.14 \]

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

- **Toe reinforcement**
- **Stem reinforcement**
- **Wall reinforcement**

**Toe bars** - 16 mm dia. @ 100 mm centres - (2011 mm²/m)
**Wall bars** - 16 mm dia. @ 200 mm centres - (1005 mm²/m)
**Stem bars** - 20 mm dia. @ 200 mm centres - (1571 mm²/m)
RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Wall details
- Retaining wall type: Cantilever propped at both
- Height of retaining wall stem: 5090 mm
- Thickness of wall stem: 350 mm
- Length of toe: 2500 mm
- Length of heel: 0 mm
- Overall length of base: 2850 mm
- Thickness of base: 500 mm
- Depth of downstand: 0 mm
- Position of downstand: 0 mm
- Thickness of downstand: 500 mm
- Height of retaining wall: 5590 mm
- Depth of cover in front of wall: 400 mm
- Depth of unplanned excavation: 200 mm
- Height of ground water behind wall: 3750 mm
- Height of saturated fill above base: 3250 mm
- Density of wall construction: 23.6 kN/m³
- Density of base construction: 23.6 kN/m³
- Angle of rear face of wall: 90.0 deg
- Angle of soil surface behind wall: 0.0 deg
- Effective height at virtual back of wall: 5590 mm

Retained material details
- Mobilisation factor: M = 1.5
Moist density of retained material \( \gamma_m = 18.0 \, \text{kN/m}^3 \)
Saturated density of retained material \( \gamma_s = 21.0 \, \text{kN/m}^3 \)
Design shear strength \( \phi' = 24.2 \, \text{deg} \)
Angle of wall friction \( \delta = 0.0 \, \text{deg} \)

**Base material details**
Moist density \( \gamma_{mb} = 18.0 \, \text{kN/m}^3 \)
Design shear strength \( \phi'_b = 24.2 \, \text{deg} \)
Design base friction \( \delta_b = 18.6 \, \text{deg} \)
Allowable bearing pressure \( P_{bearing} = 150 \, \text{kN/m}^2 \)

**Using Coulomb theory**
Active pressure coefficient for retained material
\[
K_a = \frac{\sin(\alpha + \phi')^2 / (\sin(\alpha))^2 \times \sin(\alpha - \phi) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta)) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))}^2]}{1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta)) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))}^2} = 0.419
\]
Passive pressure coefficient for base material
\[
K_p = \frac{\sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b))}^2})}{1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b))}^2} = 4.187
\]

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

**Loading details**
Surcharge load on plan
\( \text{Surcharge} = 10.0 \, \text{kN/m}^2 \)
Applied vertical dead load on wall \( W_{\text{dead}} = 95.7 \, \text{kN/m} \)
Applied vertical live load on wall \( W_{\text{live}} = 5.4 \, \text{kN/m} \)
Position of applied vertical load on wall \( l_{\text{load}} = 2675 \, \text{mm} \)
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 \( h_{\text{load}} = 0 \, \text{mm} \)

Loads shown in kN/m, pressures shown in kN/m²
Vertical forces on wall
Wall stem  \[ w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall} = 42 \text{kN/m} \]
Wall base  \[ w_{base} = l_{base} \times t_{base} \times \gamma_{base} = 33.6 \text{kN/m} \]
Soil in front of wall  \[ w_{p} = l_{toe} \times d_{cover} \times \gamma_{mb} = 18 \text{kN/m} \]
Applied vertical load  \[ W_v = W_{dead} + W_{live} = 101.2 \text{kN/m} \]
Total vertical load  \[ W_{total} = w_{wall} + w_{base} + w_{p} + W_v = 194.9 \text{kN/m} \]

Horizontal forces on wall
Surcharge  \[ F_{sur} = K_a \times \text{Surcharge} \times \text{heff} = 23.4 \text{kN/m} \]
Moist backfill above water table  \[ F_{m_{a}} = 0.5 \times K_a \times \gamma_m \times (\text{heff} - \text{hwater})^2 = 12.8 \text{kN/m} \]
Moist backfill below water table  \[ F_{m_{b}} = K_a \times \gamma_m \times (\text{hwater} - \text{heff}) \times \text{hwater} = 52 \text{kN/m} \]
Saturated backfill  \[ F_{s} = 0.5 \times K_a \times (\gamma_{s} - \gamma_{water}) \times \text{hwater}^2 = 32.9 \text{kN/m} \]
Water  \[ F_{water} = 0.5 \times \gamma_{water} \times \text{hwater}^2 = 69 \text{kN/m} \]
Total horizontal load  \[ F_{total} = F_{sur} + F_{m_{a}} + F_{m_{b}} + F_{s} + F_{water} = 190 \text{kN/m} \]

Calculate total propping force
Passive resistance of soil in front of wall  \[ F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = 17.5 \text{kN/m} \]
Propping force  \[ F_{prop} = \max(F_{total} - F_p - (W_{total} - w_{p} - W_{live}) \times \tan(\delta_b), 0 \text{kN/m}) \]
\[ F_{prop} = 114.8 \text{kN/m} \]

Overturning moments
Surcharge  \[ M_{sur} = F_{sur} \times (\text{heff} - 2 \times d_{ds}) / 2 = 65.4 \text{kNm/m} \]
Moist backfill above water table  \[ M_{m_{a}} = F_{m_{a}} \times (\text{heff} + 2 \times \text{hwater} - 3 \times d_{ds}) / 3 = 55.6 \text{kNm/m} \]
Moist backfill below water table  \[ M_{m_{b}} = F_{m_{b}} \times (\text{hwater} - 2 \times d_{ds}) / 2 = 95.7 \text{kNm/m} \]
Saturated backfill  \[ M_{s} = F_{s} \times (\text{hwater} - 3 \times d_{ds}) / 3 = 41.2 \text{kNm/m} \]
Water  \[ M_{water} = F_{water} \times (\text{hwater} - 3 \times d_{ds}) / 3 = 86.2 \text{kNm/m} \]
Total overturning moment  \[ M_{ot} = M_{sur} + M_{m_{a}} + M_{m_{b}} + M_{s} + M_{water} = 345.9 \text{kNm/m} \]

Restoring moments
Wall stem  \[ M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2) = 112.5 \text{kNm/m} \]
Wall base  \[ M_{base} = w_{base} \times l_{base} / 2 = 47.9 \text{kNm} \]
Design vertical dead load  \[ M_{dead} = W_{dead} \times l_{load} = 256.1 \text{kNm/m} \]
Total restoring moment  \[ M_{rest} = M_{wall} + M_{base} + M_{dead} = 416.5 \text{kNm/m} \]

Check bearing pressure
Total vertical reaction  \[ R = W_{total} = 194.9 \text{kN/m} \]
Distance to reaction  \[ x_{bar} = l_{base} / 2 = 1425 \text{mm} \]
Eccentricity of reaction  \[ e = \abs((l_{base} / 2) - x_{bar}) = 0 \text{mm} \]

Reaction acts within middle third of base

Bearing pressure at toe  \[ p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = 68.4 \text{kN/m}^2 \]
Bearing pressure at heel  \[ p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) = 68.4 \text{kN/m}^2 \]

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  \[ F_{prop_{top}} = (M_{M_{prop}} - R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + l_{base} / 2) = 33.396 \text{kN/m} \]
Propping force to base of wall  \[ F_{prop_{base}} = F_{prop} - F_{prop_{top}} = 81.451 \text{kN/m} \]
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
\[ W_{wall_f} = \gamma_d \times h_{stem} \times t_{wall} \times \gamma_{wall} = 58.9 \text{ kN/m} \]
Wall base
\[ W_{base_f} = \gamma_d \times l_{base} \times t_{base} \times \gamma_{base} = 47.1 \text{ kN/m} \]
Soil in front of wall
\[ W_{f} = \gamma_d \times l_{toe} \times d_{cover} \times \gamma_{mb} = 25.2 \text{ kN/m} \]
Applied vertical load
\[ W_{v_f} = \gamma_d \times (W_{dead} + \gamma_l \times W_{live}) = 142.7 \text{ kN/m} \]
Total vertical load
\[ W_{total_f} = W_{wall_f} + W_{base_f} + W_{f} + W_{v_f} = 273.9 \text{ kN/m} \]

Factored horizontal at-rest forces on wall
Surcharge
\[ F_{sur_f} = \gamma_l \times K_0 \times \text{Surcharge} \times h_{eff} = 52.8 \text{ kN/m} \]
Moist backfill above water table
\[ F_{m_a_f} = \gamma_e \times 0.5 \times K_0 \times \gamma_m \times (h_{surf} - h_{water})^2 = 25.2 \text{ kN/m} \]
Moist backfill below water table
\[ F_{m_b_f} = \gamma_e \times K_0 \times \gamma_m \times (h_{water} - 3 \times d_{soil}) / 3 = 65 \text{ kN/m} \]
Saturated backfill
\[ F_{s_f} = \gamma_e \times 0.5 \times K_0 \times \gamma_m \times (h_{water} - h_{water})^2 / 6 = 96.6 \text{ kN/m} \]
Water
\[ F_{water_f} = \gamma_e \times 0.5 \times h_{water}^2 \times \gamma_{water} = 96.6 \text{ kN/m} \]
Total horizontal load
\[ F_{total_f} = F_{sur_f} + F_{m_a_f} + F_{m_b_f} + F_{s_f} + F_{water_f} = 342.1 \text{ kN/m} \]

Calculate total propping force
Passive resistance of soil in front of wall
\[ F_{p_f} = \gamma_e \times 0.5 \times K_0 \times \cos(\delta_c) \times (d_{cover} + t_{base} + d_{soil} - d_{exc})^2 \times \gamma_{mb} = 24.5 \text{ kN/m} \]
Propping force
\[ F_{prop_f} = \max(F_{total_f} - F_{p_f} - (W_{total_f} - W_{f} - \gamma_l \times W_{live}) \times \tan(\delta_s) / 6, 0 \text{ kN/m}) \]
\[ F_{prop_f} = 236.9 \text{ kN/m} \]

Factored overturning moments
Surcharge
\[ M_{sur_f} = F_{sur_f} \times (h_{surf} - 2 \times d_{soil}) / 2 = 147.5 \text{ kNm/m} \]
Moist backfill above water table
\[ M_{m_a_f} = F_{m_a_f} \times (h_{water} + 2 \times h_{water} - 3 \times d_{soil}) / 3 = 109.8 \text{ kNm/m} \]
Moist backfill below water table
\[ M_{m_b_f} = F_{m_b_f} \times (h_{water} - 2 \times d_{soil}) / 2 = 192.4 \text{ kNm/m} \]
Saturated backfill
\[ M_{s_f} = F_{s_f} \times (h_{water} - 3 \times d_{soil}) / 3 = 81.2 \text{ kNm/m} \]
Water
\[ M_{water_f} = F_{water_f} \times (h_{water} - 3 \times d_{soil}) / 3 = 120.7 \text{ kNm/m} \]
Total overturning moment
\[ M_{tota_f} = M_{sur_f} + M_{m_a_f} + M_{m_b_f} + M_{s_f} + M_{water_f} = 651.7 \text{ kNm/m} \]

Restoring moments
Wall stem
\[ M_{wall_f} = W_{wall_f} \times (l_{toe} + t_{wall} / 2) = 157.5 \text{ kNm/m} \]
Wall base
\[ M_{base_f} = W_{base_f} \times l_{base} / 2 = 67.1 \text{ kNm/m} \]
Soil in front of wall
\[ M_{p_r_f} = W_{f} \times l_{base} / 2 = 31.5 \text{ kNm/m} \]
Design vertical load
\[ M_{v_f} = W_{v_f} \times l_{load} = 381.8 \text{ kNm/m} \]
Total restoring moment
\[ M_{rest_f} = M_{wall_f} + M_{base_f} + M_{p_r_f} + M_{v_f} = 637.9 \text{ kNm/m} \]

Factored bearing pressure
Total vertical reaction
\[ R_v = W_{total_f} = 273.9 \text{ kN/m} \]
Distance to reaction
\[ x_{bar_f} = l_{base} / 2 = 1425 \text{ mm} \]
Eccentricity of reaction
\[ e_r = \text{abs}((l_{base} / 2) - x_{bar_f}) = 0 \text{ mm} \]
Bearing pressure at toe
\[ p_{toe_f} = (R_v / l_{base}) - (6 \times R_v \times e_r / l_{base}^2) = 96.1 \text{ kN/m}^2 \]
Bearing pressure at heel
\[ p_{heel_f} = (R_v / l_{base}) + (6 \times R_v \times e_r / l_{base}^2) = 96.1 \text{ kN/m}^2 \]
Rate of change of base reaction

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

Bearing pressure at stem / toe

\[ p_{\text{stem, toe, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times l_{\text{toe}}), 0 \text{ kN/m}^2) = 96.1 \text{ kN/m}^2 \]

Bearing pressure at mid stem

\[ p_{\text{stem, mid, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}} / 2)), 0 \text{ kN/m}^2) = 96.1 \text{ kN/m}^2 \]

Bearing pressure at stem / heel

\[ p_{\text{stem, heel, f}} = \max(p_{\text{toe, f}} - (\text{rate} \times (l_{\text{toe}} + t_{\text{wall}})), 0 \text{ kN/m}^2) = 96.1 \text{ kN/m}^2 \]

Calculate propping forces to top and base of wall

Propping force to top of wall

\[ F_{\text{prop, top, f}} = \frac{(M_{\text{toe, f}} - M_{\text{base, f}} + R_f \times l_{\text{base}} / 2 - F_{\text{prop, f}} \times t_{\text{base}} / 2)}{(h_{\text{stem}} + t_{\text{base}} / 2)} = 64.583 \text{ kN/m} \]

Propping force to base of wall

\[ F_{\text{prop, base, f}} = F_{\text{prop, f}} - F_{\text{prop, top, f}} = 172.274 \text{ kN/m} \]

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 \( f_y = 500 \text{ N/mm}^2 \)

Base details

- Minimum area of reinforcement \( k = 0.13 \% \)
- Cover to reinforcement in toe \( c_{\text{toe}} = 30 \text{ mm} \)

Calculate shear for toe design

- Shear from bearing pressure \( V_{\text{toe, bear}} = (p_{\text{toe, f}} + p_{\text{stem, mid, f}}) \times l_{\text{toe}} / 2 = 240.2 \text{ kN/m} \)
- Shear from weight of base \( V_{\text{toe, wt, base}} = \gamma_{\text{d, s}} \times \gamma_{\text{w, s, base}} \times l_{\text{toe}} \times t_{\text{base}} = 41.3 \text{ kN/m} \)
- Shear from weight of soil \( V_{\text{toe, wt, soil}} = w_p \times (\gamma_{\text{d, s}} \times \gamma_{\text{m}} \times l_{\text{toe}} \times d_{\text{exc}}) = 12.6 \text{ kN/m} \)
- Total shear for toe design \( V_{\text{toe}} = V_{\text{toe, bear}} - V_{\text{toe, wt, base}} - V_{\text{toe, wt, soil}} = 186.3 \text{ kN/m} \)

Calculate moment for toe design

- Moment from bearing pressure \( M_{\text{toe, bear}} = 2 \times (p_{\text{toe, f}} + p_{\text{stem, mid, f}}) \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 6 = 343.8 \text{ kNm/m} \)
- Moment from weight of base \( M_{\text{toe, wt, base}} = \gamma_{\text{d, s}} \times \gamma_{\text{w, s, base}} \times (l_{\text{toe}} + t_{\text{wall}} / 2)^2 / 2 = 59.1 \text{ kNm/m} \)
- Moment from weight of soil \( M_{\text{toe, wt, soil}} = (w_p \times (\gamma_{\text{d, s}} \times \gamma_{\text{m}} \times l_{\text{toe}} \times d_{\text{exc}})) \times (l_{\text{toe}} + t_{\text{wall}}) / 2 = 18 \text{ kNm/m} \)
- Total moment for toe design \( M_{\text{toe}} = M_{\text{toe, bear}} - M_{\text{toe, wt, base}} - M_{\text{toe, wt, soil}} = 266.8 \text{ kNm/m} \)

Check toe in bending

- Width of toe \( b = 1000 \text{ mm/m} \)
- Depth of reinforcement \( d_{\text{toe}} = t_{\text{base}} - c_{\text{toe}} - (d_{\text{exc}} / 2) = 462.0 \text{ mm} \)
- Constant \( K_{\text{toe}} = M_{\text{toe}} / (b \times d_{\text{toe}}^2 \times f_{\text{cu}}) = 0.031 \)

Compression reinforcement is not required
Lever arm

\[ z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.905))}, 0.95) \times d_{toe} \]

\[ z_{toe} = 439 \text{ mm} \]

Area of tension reinforcement required

\[ A_{s, toe\ des} = \frac{M_{toe}}{(0.87 \times f_y \times z_{toe})} = 1397 \text{ mm}^2/\text{m} \]

Minimum area of tension reinforcement

\[ A_{s, toe\ min} = k \times b \times t_{base} = 650 \text{ mm}^2/\text{m} \]

Area of tension reinforcement required

\[ A_{s, toe\ req} = \max(A_{s, toe\ des}, A_{s, toe\ min}) = 1397 \text{ mm}^2/\text{m} \]

Reinforcement provided

16 mm dia. bars @ 100 mm centres

Reinforcement provided

\[ A_{s, toe\ prov} = 2011 \text{ mm}^2/\text{m} \]

Check shear resistance at toe

Design shear stress

\[ v_{toe} = \frac{V_{toe}}{(b \times d_{toe})} = 0.403 \text{ N/mm}^2 \]

Allowable shear stress

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

PASS - Design shear stress is less than maximum shear stress

Design concrete shear stress

\[ v_{c, toe} = 0.560 \text{ N/mm}^2 \]

\[ v_{toe} < v_{c, toe} - \text{No shear reinforcement required} \]

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

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

Wall details

Minimum area of reinforcement

\[ k = 0.13 \% \]

Cover to reinforcement in stem

\[ c_{stem} = 30 \text{ mm} \]

Cover to reinforcement in wall

\[ c_{wall} = 30 \text{ mm} \]

Factored horizontal at-rest forces on stem

Surcharge

\[ F_{s, sur} = \gamma_{f, i} \times K_0 \times \text{Surcharge} \times (\text{het} - \text{base} - d_{ss}) = 48.1 \text{ kN/m} \]

Moist backfill above water table

\[ F_{s, m, a} = 0.5 \times \gamma_{f, a} \times K_0 \times \gamma_{m} \times (\text{het} - \text{base} - d_{ss} - d_{sat}) = 25.2 \text{ kN/m} \]

Moist backfill below water table

\[ F_{s, m, b} = \gamma_{f, e} \times K_0 \times \gamma_{m} \times (\text{het} - \text{base} - d_{ss} - d_{sat}) = 88.9 \text{ kN/m} \]

Saturated backfill

\[ F_{s, s} = 0.5 \times \gamma_{f, e} \times K_0 \times (\gamma_{sat} - \gamma_{water}) \times h_{sat} = 48.8 \text{ kN/m} \]

Water

\[ F_{s, w, a} = 0.5 \times \gamma_{f, e} \times K_0 \times (\gamma_{water}) \times h_{sat} = 72.5 \text{ kN/m} \]

Calculate shear for stem design

Surcharge

\[ V_{s, sur} = \frac{5 \times F_{s, sur}}{8} = 30 \text{ kN/m} \]

Moist backfill above water table

\[ V_{s, m, a} = \frac{F_{s, m, a}}{8} = 8.5 \text{ kN/m} \]

Moist backfill below water table

\[ V_{s, m, b} = \frac{F_{s, m, b}}{8} = 73 \text{ kN/m} \]

Saturated backfill

\[ V_{s, s} = \frac{F_{s, s}}{8} = 44.3 \text{ kN/m} \]

Water

\[ V_{s, w, a} = \frac{F_{s, w, a}}{8} = 65.8 \text{ kN/m} \]

Total shear for stem design

\[ V_{stem} = V_{s, sur} + V_{s, m, a} + V_{s, m, b} + V_{s, s} + V_{s, w, a} = 221.5 \text{ kN/m} \]

Calculate moment for stem design

Surcharge

\[ M_{s, sur} = \frac{F_{s, sur}}{8} \times L = 32.1 \text{ kNm/m} \]

Moist backfill above water table

\[ M_{s, m, a} = \frac{F_{s, m, a}}{8} \times (5 \times L^2) = 14.3 \text{ kNm/m} \]

Moist backfill below water table

\[ M_{s, m, b} = \frac{F_{s, m, b}}{8} \times (a \times (2 - n)^2) = 70.3 \text{ kNm/m} \]

Saturated backfill

\[ M_{s, s} = \frac{F_{s, s}}{8} \times (4 \times a^2) = 32.6 \text{ kNm/m} \]

Water

\[ M_{s, w, a} = \frac{F_{s, w, a}}{8} \times (4 \times a^2) = 48.5 \text{ kNm/m} \]

kN/m

Total moment for stem design

\[ M_{stem} = M_{s, sur} + M_{s, m, a} + M_{s, m, b} + M_{s, s} + M_{s, w, a} = 197.9 \text{ kNm/m} \]
### Calculate moment for wall design

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge</td>
<td>$M_{w,\text{sur}} = 9 \times F_{s,\text{sur}} \times \frac{L}{128} = 18 \text{ kNm/m}$</td>
<td></td>
</tr>
<tr>
<td>Moist backfill above water table</td>
<td>$M_{w,\text{m,a}} = F_{s,\text{m,a}} \times 0.577 \times \frac{bl \times (5L^3 - al \times x)/(20 \times L^3) - (x - bl)^3/(3 \times al^2)}{(3 \times al^2)} = 14.8 \text{ kNm/m}$</td>
<td></td>
</tr>
<tr>
<td>Moist backfill below water table</td>
<td>$M_{w,\text{m,b}} = F_{s,\text{m,b}} \times \frac{al \times [(8 - n^2 \times (4 - n)^2)/(16) - 4 \times n \times (4 - n)]}{8} = 34.4 \text{ kNm/m}$</td>
<td></td>
</tr>
<tr>
<td>Saturated backfill</td>
<td>$M_{w,\text{s}} = F_{s,\text{s}} \times \frac{al^2 \times x \times (5L - al)/(20 \times L^3) - (x - bl)^3/(3 \times al^2)}{(3 \times al^2)} = 11.6 \text{ kNm/m}$</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>$M_{w,\text{water}} = F_{s,\text{water}} \times \frac{al^2 \times x \times (5L - al)/(20 \times L^3) - (x - bl)^3/(3 \times al^2)}{(3 \times al^2)} = 17.3 \text{ kNm/m}$</td>
<td></td>
</tr>
<tr>
<td>Total moment for wall design</td>
<td>$M_{\text{wall}} = M_{w,\text{sur}} + M_{w,\text{m,a}} + M_{w,\text{m,b}} + M_{w,\text{s}} + M_{w,\text{water}} = 96.1 \text{ kNm/m}$</td>
<td></td>
</tr>
</tbody>
</table>

### Check wall stem in bending

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of wall stem</td>
<td>$b = 1000 \text{ mm/m}$</td>
</tr>
<tr>
<td>Depth of reinforcement</td>
<td>$d_{\text{stem}} = t_{\text{wall}} - c_{\text{stem}} - \left(\frac{\phi_{\text{stem}}}{2}\right) = 310.0 \text{ mm}$</td>
</tr>
<tr>
<td>Constant</td>
<td>$K_{\text{stem}} = M_{\text{stem}} / (b \times d_{\text{stem}}^2 \times f_{\text{cu}}) = 0.051$</td>
</tr>
</tbody>
</table>

#### Compression reinforcement is not required

### Check shear resistance at wall stem

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design shear stress</td>
<td>$V_{\text{stem}} = V_{\text{stem}} / (b \times d_{\text{stem}}) = 0.714 \text{ N/mm}^2$</td>
</tr>
<tr>
<td>Allowable shear stress</td>
<td>$V_{\text{adm}} = \min(0.8 \times \sqrt{f_{\text{cu}} / 1 \text{ N/mm}^2}, 5) \times 1 \text{ N/mm}^2 = 5.000 \text{ N/mm}^2$</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design concrete shear stress</td>
<td>$V_{c,\text{stem}} = 0.628 \text{ N/mm}^2$</td>
</tr>
</tbody>
</table>

#### WARNING - Shear reinforcement required
### Check mid height of wall in bending

**Depth of reinforcement**

\[ d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2) = 312.0 \text{ mm} \]

**Constant**

\[ K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu}) = 0.025 \]

*Compression reinforcement is not required*

**Lever arm**

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

\[ z_{wall} = 296 \text{ mm} \]

**Area of tension reinforcement required**

\[ A_{s, wall, req} = M_{wall} / (0.87 \times f_y \times z_{wall}) = 746 \text{ mm}^2/\text{m} \]

**Minimum area of tension reinforcement**

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

**Area of tension reinforcement required**

\[ A_{s, wall, req} = \text{Max}(A_{s, wall, des}, A_{s, wall, min}) = 746 \text{ mm}^2/\text{m} \]

**Reinforcement provided**

16 mm dia. bars @ 200 mm centres

**Area of reinforcement provided**

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

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

### Check retaining wall deflection

**Basic span/effective depth ratio**

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

**Design service stress**

\[ f_s = 2 \times f_y \times A_{s, stem, req} / (3 \times A_{s, stem, prov}) = 331.5 \text{ N/mm}^2 \]

**Modification factor**

\[ \text{factor}_{tens} = \text{min}(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem} / (b \times d_{stem}^2)))),2) = 0.96 \]

**Maximum span/effective depth ratio**

\[ \text{ratio}_{max} = \text{ratio}_{bas} \times \text{factor}_{tens} = 19.19 \]

**Actual span/effective depth ratio**

\[ \text{ratio}_{act} = h_{stem} / d_{stem} = 16.42 \]

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

Toe bars - 16 mm dia. @ 100 mm centres - (2011 mm²/m)
Wall bars - 16 mm dia. @ 200 mm centres - (1005 mm²/m)
Stem bars - 20 mm dia. @ 200 mm centres - (1571 mm²/m)
**RETAINING WALL ANALYSIS (BS 8002:1994)**

**Wall details**
- **Retaining wall type:** Cantilever propped at both
- **Height of retaining wall stem:** \( h_{stem} = 5985 \text{ mm} \)
- **Thickness of wall stem:** \( t_{wall} = 400 \text{ mm} \)
- **Length of toe:** \( l_{toe} = 2500 \text{ mm} \)
- **Length of heel:** \( l_{heel} = 0 \text{ mm} \)
- **Overall length of base:** \( l_{base} = l_{toe} + l_{heel} + t_{wall} = 2900 \text{ mm} \)
- **Thickness of base:** \( t_{base} = 500 \text{ mm} \)
- **Depth of downstand:** \( d_{ds} = 0 \text{ mm} \)
- **Position of downstand:** \( l_{ds} = 0 \text{ mm} \)
- **Thickness of downstand:** \( t_{ds} = 500 \text{ mm} \)
- **Height of retaining wall:** \( h_{wall} = h_{stem} + t_{base} + d_{ds} = 6485 \text{ mm} \)
- **Depth of cover in front of wall:** \( d_{cover} = 400 \text{ mm} \)
- **Depth of unplanned excavation:** \( d_{exc} = 200 \text{ mm} \)
- **Height of ground water behind wall:** \( h_{water} = 3750 \text{ mm} \)
- **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:** \( h_{eff} = h_{wall} + l_{heel} \times \tan(\beta) = 6485 \text{ mm} \)

**Retained material details**
- **Mobilisation factor:** \( M = 1.5 \)
Moist density of retained material \( \gamma_m = 18.0 \text{ kN/m}^3 \)
Saturated density of retained material \( \gamma_s = 21.0 \text{ kN/m}^3 \)
Design shear strength \( \phi' = 24.2 \text{ deg} \)
Angle of wall friction \( \delta = 0.0 \text{ deg} \)

**Base material details**
Moist density \( \gamma_{mb} = 18.0 \text{ kN/m}^3 \)
Design shear strength \( \phi'_b = 24.2 \text{ deg} \)
Design base friction \( \delta_b = 18.6 \text{ deg} \)
Allowable bearing pressure \( P_{bearing} = 150 \text{ kN/m}^2 \)

Using Coulomb theory
Active pressure coefficient for retained material
\[
K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta))}]) = 0.419
\]
Passive pressure coefficient for base material
\[
K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b))}]) = 4.187
\]

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

**Loading details**
Surcharge load on plan \( \text{Surcharge} = 10.0 \text{ kN/m}^2 \)
Applied vertical dead load on wall \( W_{\text{dead}} = 61.8 \text{ kN/m} \)
Applied vertical live load on wall \( W_{\text{live}} = 8.0 \text{ kN/m} \)
Position of applied vertical load on wall \( l_{\text{load}} = 2700 \text{ mm} \)
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 \( h_{\text{load}} = 0 \text{ mm} \)

Loads shown in kN/m, pressures shown in kN/m²
Vertical forces on wall

Wall stem

\[ W_{\text{wall}} = h_{\text{stem}} \times t_{\text{wall}} \times \gamma_{\text{wall}} = 56.5 \text{ kN/m} \]

Wall base

\[ W_{\text{base}} = l_{\text{base}} \times b_{\text{base}} \times \gamma_{\text{base}} = 34.2 \text{ kN/m} \]

Soil in front of wall

\[ W_{\text{p}} = l_{\text{toe}} \times d_{\text{cover}} \times \gamma_{\text{mb}} = 18 \text{ kN/m} \]

Applied vertical load

\[ W_{V} = W_{\text{dead}} + W_{\text{live}} = 69.8 \text{ kN/m} \]

Total vertical load

\[ W_{\text{total}} = W_{\text{wall}} + W_{\text{base}} + W_{\text{p}} + W_{V} = 178.5 \text{ kN/m} \]

Horizontal forces on wall

Surcharge

\[ F_{\text{sur}} = K_{a} \times \text{Surcharge} \times h_{\text{eff}} = 27.1 \text{ kN/m} \]

Moist backfill above water table

\[ F_{m,a} = 0.5 \times K_{a} \times \gamma_{m} \times (h_{\text{eff}} - h_{\text{water}}) \times h_{\text{water}} = 28.2 \text{ kN/m} \]

Moist backfill below water table

\[ F_{m,b} = K_{a} \times \gamma_{m} \times (h_{\text{water}} - h_{\text{water}}) \times h_{\text{water}} = 77.3 \text{ kN/m} \]

Saturated backfill

\[ F_{s} = 0.5 \times K_{a} \times (\gamma_{s} - \gamma_{\text{water}}) \times h_{\text{water}}^{2} = 32.9 \text{ kN/m} \]

Water

\[ F_{\text{water}} = 0.5 \times h_{\text{water}}^{2} \times \gamma_{\text{water}} = 69 \text{ kN/m} \]

Total horizontal load

\[ F_{\text{total}} = F_{\text{sur}} + F_{m,a} + F_{m,b} + F_{s} + F_{\text{water}} = 234.5 \text{ kN/m} \]

Calculate total propping force

Passive resistance of soil in front of wall

\[ F_{p} = 0.5 \times K_{p} \times \cos(\delta_{b}) \times (d_{\text{cover}} + b_{\text{base}} + d_{\text{soil}} - d_{\text{exc}}) \times \gamma_{mb} = 17.5 \text{ kN/m} \]

Propping force

\[ F_{\text{prop}} = \max(F_{\text{total}} - F_{p} - (W_{\text{total}} - W_{p} - W_{\text{live}}) \times \tan(\delta_{b}), 0 \text{ kN/m}) \]

\[ F_{\text{prop}} = 165.7 \text{ kN/m} \]

Overturning moments

Surcharge

\[ M_{\text{sur}} = F_{\text{sur}} \times (h_{\text{eff}} - 2 \times d_{\text{soil}}) / 2 = 88 \text{ kNm/m} \]

Moist backfill above water table

\[ M_{m,a} = F_{m,a} \times (h_{\text{eff}} + 2 \times h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 131.3 \text{ kNm/m} \]

Moist backfill below water table

\[ M_{m,b} = F_{m,b} \times (h_{\text{water}} - 2 \times d_{\text{soil}}) / 2 = 144.9 \text{ kNm/m} \]

Saturated backfill

\[ M_{s} = F_{s} \times (h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 41.2 \text{ kNm/m} \]

Water

\[ M_{\text{water}} = F_{\text{water}} \times (h_{\text{water}} - 3 \times d_{\text{soil}}) / 3 = 86.2 \text{ kNm/m} \]

Total overturning moment

\[ M_{\text{ot}} = M_{\text{sur}} + M_{m,a} + M_{m,b} + M_{s} + M_{\text{water}} = 491.6 \text{ kNm/m} \]

Restoring moments

Wall stem

\[ M_{\text{wall}} = W_{\text{wall}} \times (l_{\text{toe}} + t_{\text{wall}} / 2) = 152.5 \text{ kNm/m} \]

Wall base

\[ M_{\text{base}} = W_{\text{base}} \times l_{\text{base}} / 2 = 49.6 \text{ kNm/m} \]

Design vertical dead load

\[ M_{\text{dead}} = W_{\text{dead}} \times l_{\text{load}} = 166.7 \text{ kNm/m} \]

Total restoring moment

\[ M_{\text{rest}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{dead}} = 368.9 \text{ kNm/m} \]

Check bearing pressure

Total vertical reaction

\[ R = W_{\text{total}} = 178.5 \text{ kN/m} \]

Distance to reaction

\[ x_{\text{bar}} = l_{\text{base}} / 2 = 1450 \text{ mm} \]

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

\[ p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R \times e / l_{\text{base}}^{2}) = 61.6 \text{ kN/m}^{2} \]

Bearing pressure at heel

\[ p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R \times e / l_{\text{base}}^{2}) = 61.6 \text{ kN/m}^{2} \]

\[ \text{PASS - Maximum bearing pressure is less than allowable bearing pressure} \]

Calculate propping forces to top and base of wall

Propping force to top of wall

\[ F_{\text{prop, top}} = (M_{s} - M_{\text{rest}} + R \times l_{\text{base}} / 2 - F_{\text{prop}} \times t_{\text{base}} / 2) / (h_{\text{stem}} + t_{\text{base}} / 2) = 54.551 \text{ kN/m} \]

Propping force to base of wall

\[ F_{\text{prop, base}} = F_{\text{prop}} - F_{\text{prop, top}} = 111.124 \text{ kN/m} \]
RETAINING WALL DESIGN (BS 8002:1994)

Ultimate limit state load factors
Dead load factor \( \gamma_f = 1.4 \)
Live load factor \( \gamma_f = 1.6 \)
Earth and water pressure factor \( \gamma_f = 1.4 \)

Factored vertical forces on wall
Wall stem
\[ W_{\text{wall}} = \gamma_f \times h_{\text{stem}} \times t_{\text{wall}} \times \gamma_{\text{wall}} = 79.1 \text{ kN/m} \]
Wall base
\[ W_{\text{base}} = \gamma_f \times l_{\text{base}} \times \gamma_{\text{base}} = 47.9 \text{ kN/m} \]
Soil in front of wall
\[ W_{\text{p}} = \gamma_f \times l_{\text{toe}} \times \gamma_{\text{mb}} = 25.2 \text{ kN/m} \]
Applied vertical load
\[ W_{\text{v}} = \gamma_f \times W_{\text{dead}} + \gamma_f \times W_{\text{live}} = 99.3 \text{ kN/m} \]
Total vertical load
\[ W_{\text{total}} = W_{\text{wall}} + W_{\text{base}} + W_{\text{p}} + W_{\text{v}} = 251.5 \text{ kN/m} \]

Factored horizontal at-rest forces on wall
Surcharge
\[ F_{\text{sur}} = \gamma_f \times K_0 \times \gamma_{\text{hef}} = 61.2 \text{ kN/m} \]
Moist backfill above water table
\[ F_{\text{m_a}} = \gamma_f \times K_0 \times \gamma_{\text{water}} \times \gamma_{\text{hef}}^2 = 55.6 \text{ kN/m} \]
Moist backfill below water table
\[ F_{\text{m_b}} = \gamma_f \times K_0 \times \gamma_{\text{water}} \times \gamma_{\text{hef}}^2 = 152.5 \text{ kN/m} \]
Saturated backfill
\[ F_{\text{s}} = \gamma_f \times K_0 \times (\gamma_s - \gamma_{\text{water}}) \times \gamma_{\text{water}} = 65 \text{ kN/m} \]
Water
\[ F_{\text{water}} = \gamma_f \times \gamma_{\text{water}} \times \gamma_{\text{water}} = 96.6 \text{ kN/m} \]
Total horizontal load
\[ F_{\text{total}} = F_{\text{sur}} + F_{\text{m_a}} + F_{\text{m_b}} + F_{\text{s}} + F_{\text{water}} = 430.9 \text{ kN/m} \]

Calculate total propping force
Passive resistance of soil in front of wall
\[ F_{\text{p}} = \gamma_f \times K_0 \times \cos(\delta) \times (d_{\text{cover}} + t_{\text{base}} + d_{\text{ds}} - d_{\text{exc}}) \times \gamma_{\text{mb}} = 24.5 \text{ kN/m} \]
Propping force
\[ F_{\text{prop}} = \max(F_{\text{total}} - F_{\text{p}} - (W_{\text{total}} - W_{\text{p}} - \gamma_f \times W_{\text{live}}) \times \tan(\delta), 0 \text{ kN/m}) \]
\[ F_{\text{prop}} = 334.6 \text{ kN/m} \]

Factored overturning moments
Surcharge
\[ M_{\text{sur}} = F_{\text{sur}} \times \gamma_{\text{hef}} / 2 = 198.5 \text{ kNm/m} \]
Moist backfill above water table
\[ M_{\text{m_a}} = F_{\text{m_a}} \times \gamma_{\text{water}} / 3 = 259.3 \text{ kNm/m} \]
Moist backfill below water table
\[ M_{\text{m_b}} = F_{\text{m_b}} \times \gamma_{\text{water}} / 2 = 286 \text{ kNm/m} \]
Saturated backfill
\[ M_{\text{s}} = F_{\text{s}} \times \gamma_{\text{water}} / 3 = 81.2 \text{ kNm/m} \]
Water
\[ M_{\text{water}} = F_{\text{water}} \times \gamma_{\text{water}} / 3 = 120.7 \text{ kNm/m} \]
Total overturning moment
\[ M_{\text{total}} = M_{\text{sur}} + M_{\text{m_a}} + M_{\text{m_b}} + M_{\text{s}} + M_{\text{water}} = 945.7 \text{ kNm/m} \]

Restoring moments
Wall stem
\[ M_{\text{wall}} = W_{\text{wall}} \times l_{\text{toe}} / 2 = 213.6 \text{ kNm/m} \]
Wall base
\[ M_{\text{base}} = W_{\text{base}} \times l_{\text{base}} / 2 = 69.5 \text{ kNm/m} \]
Soil in front of wall
\[ M_{\text{p}} = W_{\text{p}} \times l_{\text{toe}} / 2 = 31.5 \text{ kNm/m} \]
Design vertical load
\[ M_{\text{v}} = W_{\text{v}} \times l_{\text{load}} = 268.1 \text{ kNm/m} \]
Total restoring moment
\[ M_{\text{total}} = M_{\text{wall}} + M_{\text{base}} + M_{\text{p}} + M_{\text{v}} = 582.7 \text{ kNm/m} \]

Factored bearing pressure
Total vertical reaction
\[ R = W_{\text{total}} = 251.5 \text{ kN/m} \]
Distance to reaction
\[ x_{\text{bar}} = l_{\text{base}} / 2 = 1450 \text{ mm} \]
Eccentricity of reaction
\[ e_r = abs((l_{\text{base}} / 2) - x_{\text{bar}}) = 0 \text{ mm} \]

Bearing pressure at toe
\[ p_{\text{toe}} = (R / l_{\text{base}}) - (6 \times R / e_r / l_{\text{base}}^2) = 86.7 \text{ kN/m}^2 \]
Bearing pressure at heel
\[ p_{\text{heel}} = (R / l_{\text{base}}) + (6 \times R / e_r / l_{\text{base}}^2) = 86.7 \text{ kN/m}^2 \]
Rate of change of base reaction
rate = (p_{toe, f} - p_{heel, f}) / l_{base} = 0.00 \ \text{kN/m}^2/m

Bearing pressure at stem / toe
p_{stem, toe, f} = \max(p_{toe, f} - (\text{rate} \times l_{toe}), 0 \ \text{kN/m}^2) = 86.7 \ \text{kN/m}^2

Bearing pressure at mid stem
p_{stem, mid, f} = \max(p_{toe, f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0 \ \text{kN/m}^2) = 86.7 \ \text{kN/m}^2

Bearing pressure at stem / heel
p_{stem, heel, f} = \max(p_{toe, f} - (\text{rate} \times (l_{toe} + t_{wall})), 0 \ \text{kN/m}^2) = 86.7 \ \text{kN/m}^2

Calculate propping forces to top and base of wall

Propping force to top of wall
F_{prop, top, f} = (M_{toe, f} - M_{rest, f} + R_t \times l_{base} / 2 - F_{prop, f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = 103.300 \ \text{kN/m}

Propping force to base of wall
F_{prop, base, f} = F_{prop, f} - F_{prop, top, f} = 231.283 \ \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_{toe} = 30 \ \text{mm}

Calculate shear for toe design
Shear from bearing pressure \ V_{toe, bear} = (p_{toe, f} + p_{stem, mid, f}) \times l_{toe} / 2 = 216.8 \ \text{kN/m}
Shear from weight of base \ V_{toe, wt, base} = (\gamma_d \times \gamma_{base} \times l_{toe} \times t_{base}) = 41.3 \ \text{kN/m}
Shear from weight of soil \ V_{toe, wt, soil} = (w_p \times (\gamma_d \times \gamma m \times l_{toe} \times d_{exc})) = 12.6 \ \text{kN/m}
Total shear for toe design \ V_{toe} = V_{toe, bear} - V_{toe, wt, base} - V_{toe, wt, soil} = 162.9 \ \text{kN/m}

Calculate moment for toe design
Moment from bearing pressure \ M_{toe, bear} = (2 \times p_{toe, f} + p_{stem, mid, f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = 316.1 \ \text{kNm/m}
Moment from weight of base \ M_{toe, wt, base} = (\gamma_d \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = 60.2 \ \text{kNm/m}
Moment from weight of soil \ M_{toe, wt, soil} = (w_p \times (\gamma_d \times \gamma m \times l_{toe} \times d_{exc})) \times (l_{toe} + t_{wall}) / 2 = 18.3 \ \text{kNm/m}
Total moment for toe design \ M_{toe} = M_{toe, bear} - M_{toe, wt, base} - M_{toe, wt, soil} = 237.6 \ \text{kNm/m}

Check toe in bending
Width of toe \ b = 1000 \ \text{mm/m}
Depth of reinforcement \ d_{toe} = l_{base} - c_{toe} - (d_{toe} / 2) = 462.0 \ \text{mm}
Constant \ K_{toe} = M_{toe} / (b \times d_{toe}^2 \times \gamma_{toe}) = 0.028

Compression reinforcement is not required
Lever arm  
\[ z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe} \]
\[ z_{toe} = 439 \text{ mm} \]

Area of tension reinforcement required  
\[ A_{s_{toe\text{ des}}} = M_{toe} / (0.87 \times f_y \times z_{toe}) = 1245 \text{ mm}^2/\text{m} \]

Minimum area of tension reinforcement  
\[ A_{s_{toe\text{ min}}} = k \times b \times t_{base} = 650 \text{ mm}^2/\text{m} \]

Area of tension reinforcement required  
\[ A_{s_{toe\text{ req}}} = \max(A_{s_{toe\text{ des}}}, A_{s_{toe\text{ min}}}) = 1245 \text{ mm}^2/\text{m} \]

Reinforcement provided  
16 mm dia. bars @ 100 mm centres

Area of tension reinforcement provided  
\[ A_{s_{toe\text{ prov}}} = 2011 \text{ mm}^2/\text{m} \]

Check shear resistance at toe

Design shear stress  
\[ v_{toe} = V_{toe} / (b \times d_{toe}) = 0.353 \text{ N/mm}^2 \]

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

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress  
\[ v_{c\text{-}toe} = 0.560 \text{ N/mm}^2 \]

\[ v_{toe} < v_{c\text{-}toe} \text{- No shear reinforcement required} \]

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

Wall details

Minimum area of reinforcement  
\[ k = 0.13 \% \]

Cover to reinforcement in stem  
\[ c_{stem} = 30 \text{ mm} \]

Cover to reinforcement in wall  
\[ c_{wall} = 30 \text{ mm} \]

Factored horizontal at-rest forces on stem

Surcharge  
\[ F_{s\text{-}sur} = \gamma' f_o \times K_0 \times \text{Surcharge} \times (\text{h}_{\text{eff}} - t_{base} - d_{ds}) = 56.5 \text{ kN/m} \]

Moist backfill above water table  
\[ F_{s\text{-}m\text{-}a} = 0.5 \times \gamma' f_o \times K_0 \times \gamma' \times (\text{h}_{\text{eff}} - t_{base} - d_{ds} - h_{sat}) = 55.6 \text{ kN/m} \]

Moist backfill below water table  
\[ F_{s\text{-}m\text{-}b} = \gamma' f_o \times K_0 \times \gamma' \times (\text{h}_{\text{eff}} - t_{base} - d_{ds} - h_{sat}) = 132.2 \text{ kN/m} \]

Saturated backfill  
\[ F_{s\text{-}s} = 0.5 \times \gamma' f_o \times K_0 \times (\gamma' \times \gamma_{water}) \times h_{sat} = 48.8 \text{ kN/m} \]

Water  
\[ F_{s\text{-}water} = 0.5 \times \gamma' f_o \times \gamma_{water} \times h_{sat} = 72.5 \text{ kN/m} \]

Total shear for stem design  
\[ V_{stem} = V_{s\text{-}sur} + V_{s\text{-}m\text{-}a} + V_{s\text{-}m\text{-}b} + V_{s\text{-}s} + V_{s\text{-}water} = 285.9 \text{ kN/m} \]

Calculate moment for stem design

Surcharge  
\[ M_{s\text{-}sur} = F_{s\text{-}sur} \times L / 8 = 44 \text{ kNm/m} \]

Moist backfill above water table  
\[ M_{s\text{-}m\text{-}a} = F_{s\text{-}m\text{-}a} \times a \times ((5 \times L^2) - (3 \times b^2)) / (5 \times L^2) = 44.8 \text{ kNm/m} \]

Moist backfill below water table  
\[ M_{s\text{-}m\text{-}b} = F_{s\text{-}m\text{-}b} \times a \times (2 - n)^2 / 8 = 119.7 \text{ kNm/m} \]

Saturated backfill  
\[ M_{s\text{-}s} = F_{s\text{-}s} \times a \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 35.7 \text{ kNm/m} \]

Water  
\[ M_{s\text{-}water} = F_{s\text{-}water} \times a \times ((3 \times a^2) - (15 \times a \times L) + (20 \times L^2)) / (60 \times L^2) = 53 \text{ kNm/m} \]

Total moment for stem design  
\[ M_{stem} = M_{s\text{-}sur} + M_{s\text{-}m\text{-}a} + M_{s\text{-}m\text{-}b} + M_{s\text{-}s} + M_{s\text{-}water} = 297.2 \text{ kNm/m} \]
Calculate moment for wall design

Surcharge
\[ M_{w,\text{sur}} = 9 \times F_{s,\text{sur},f} \times L / 128 = 24.8 \text{kNm/m} \]

Moist backfill above water table
\[ M_{w,\text{m},a} = F_{s,\text{m},a,f} \times 0.577 \times \frac{b \times (5 \times a \times L^2)/(5 \times L^3) - 0.577^2/3}{3} = 41 \text{kNm/m} \]

Moist backfill below water table
\[ M_{w,\text{m},b} = F_{s,\text{m},b,f} \times a \times \left[ \left( \frac{(8-n^2 \times (4-n))}{16} - 4 \times n \times (4-n) / 8 \right) / 16 \right] = 53.2 \text{kNm/m} \]

Saturated backfill
\[ M_{w,s} = F_{s,\text{s},f} \times \left( a^2 \times x^{((5 \times L) - a) / (20 \times L^3)} - (x - b)^3 / (3 \times a^2) \right) = 11.4 \text{kNm/m} \]

Water
\[ M_{w,\text{water}} = F_{s,\text{water},f} \times \left( a^2 \times x^{((5 \times L) - a) / (20 \times L^3)} - (x - b)^3 / (3 \times a^2) \right) = 17 \text{kNm/m} \]

Total moment for wall design
\[ M_{\text{wall}} = M_{w,\text{sur}} + M_{w,\text{m},a} + M_{w,\text{m},b} + M_{w,s} + M_{w,\text{water}} = 147.4 \text{kNm/m} \]

Check wall stem in bending

Width of wall stem
\[ b = 1000 \text{ mm/m} \]

Depth of reinforcement
\[ d_{\text{stem}} = t_{\text{wall}} - c_{\text{stem}} - \left( \phi_{\text{stem}} / 2 \right) = 360.0 \text{ mm} \]

Constant
\[ K_{\text{stem}} = M_{\text{stem}} / (b \times d_{\text{stem}}^2 \times f_{\text{cu}}) = 0.057 \]

Compression reinforcement is not required

Lever arm
\[ z_{\text{stem}} = \min(0.5 + \sqrt{(0.25 - (\min(K_{\text{stem}}, 0.225) / 0.95)) \times d_{\text{stem}}}, 335 \text{ mm} \]

Area of tension reinforcement required
\[ A_{\text{stem,req}} = M_{\text{stem}} / (0.87 \times f_y \times z_{\text{stem}}) = 2037 \text{ mm}^2/\text{m} \]

Minimum area of tension reinforcement
\[ A_{\text{stem,min}} = k \times b \times t_{\text{wall}} = 520 \text{ mm}^2/\text{m} \]

Reinforcement provided
\[ A_{\text{stem,prov}} = 3142 \text{ mm}^2/\text{m} \]

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress
\[ \psi_{\text{stem}} = V_{\text{stem}} / (b \times d_{\text{stem}}) = 0.794 \text{ N/mm}^2 \]

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

PASS - Design shear stress is less than maximum shear stress

Design concrete shear stress
\[ V_{c,\text{stem}} = 0.725 \text{ N/mm}^2 \]

WARNING - Shear reinforcement required
Check mid height of wall in bending

<table>
<thead>
<tr>
<th>Description</th>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of reinforcement</td>
<td>$d_{wall} = t_{wall} - c_{wall} - \left(\frac{\phi_{wall}}{2}\right)$</td>
<td>362.0 mm</td>
</tr>
<tr>
<td>Constant</td>
<td>$K_{wall} = \frac{M_{wall}}{(b \times d_{wall}^2 \times f_{cu})}$</td>
<td>0.028</td>
</tr>
<tr>
<td>Compression reinforcement is not required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lever arm</td>
<td>$z_{wall} = \min(0.5 + \sqrt{(0.25 - (\min(K_{wall}, 0.225) / 0.95)) \times d_{wall}}$</td>
<td>344 mm</td>
</tr>
<tr>
<td>Area of tension reinforcement required</td>
<td>$A_{s_{wall_req}} = \frac{M_{wall}}{(0.87 \times f_{y} \times z_{wall})}$</td>
<td>986 mm²/m</td>
</tr>
<tr>
<td>Minimum area of tension reinforcement</td>
<td>$A_{s_{wall_min}} = k \times b \times t_{wall}$</td>
<td>520 mm²/m</td>
</tr>
<tr>
<td>Area of tension reinforcement required</td>
<td>$A_{s_{wall_req}} = \max(A_{s_{wall_des}}, A_{s_{wall_min}})$</td>
<td>986 mm²/m</td>
</tr>
<tr>
<td>Reinforcement provided</td>
<td>$16$ mm dia. bars @ 200 mm centres</td>
<td></td>
</tr>
<tr>
<td>Area of reinforcement provided</td>
<td>$A_{s_{wall_prov}}$</td>
<td>1005 mm²/m</td>
</tr>
</tbody>
</table>

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

Check retaining wall deflection

<table>
<thead>
<tr>
<th>Description</th>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic span/effective depth ratio</td>
<td>$\text{ratio}_{bas} = 20$</td>
<td></td>
</tr>
<tr>
<td>Design service stress</td>
<td>$f_s = 2 \times f_y \times A_{s_{stem_req}} / (3 \times A_{s_{stem_prov}})$</td>
<td>216.2 N/mm²</td>
</tr>
<tr>
<td>Modification factor</td>
<td>$\text{factor}<em>{tens} = \min(0.55 + \frac{(477 \text{ N/mm}^2 - f_y)(120 \times (0.9 \text{ N/mm}^2 + (M</em>{stem}/(b \times d_{stem}^2))))}{2})$</td>
<td>1.23</td>
</tr>
<tr>
<td>Maximum span/effective depth ratio</td>
<td>$\text{ratio}<em>{max} = \text{ratio}</em>{bas} \times \text{factor}_{tens}$</td>
<td>24.61</td>
</tr>
<tr>
<td>Actual span/effective depth ratio</td>
<td>$\text{ratio}<em>{act} = \frac{h</em>{stem}}{d_{stem}}$</td>
<td>16.63</td>
</tr>
</tbody>
</table>

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

Toe bars - 16 mm dia. @ 100 mm centres - (2011 mm²/m)
Wall bars - 16 mm dia. @ 200 mm centres - (1005 mm²/m)
Stem bars - 20 mm dia. @ 100 mm centres - (3142 mm²/m)