RAFT FOUNDATION DESIGN IN ACCORDANCE WITH BS8110:PART 1-1997_FOR MULTISTOREY BUILDING (BS8110 : PART 1 : 1997)

Soil and raft definition

Soil definition
Allowable bearing pressure; \( q_{allow} = 75.0 \text{ kN/m}^2 \)
Number of types of soil forming sub-soil; Two or more types
Soil density; Firm to loose
Depth of hardcore beneath slab; \( h_{hcoreslab} = 200 \text{ mm} \); (Dispersal allowed for bearing pressure check)
Depth of hardcore beneath thickenings; \( h_{hcorethick} = 0 \text{ mm} \); (Dispersal allowed for bearing pressure check)
Density of hardcore; \( \gamma_{hcore} = 20.0 \text{ kN/m}^3 \)
Basic assumed diameter of local depression; \( \phi_{depbasic} = 3500\text{mm} \)
Diameter under slab modified for hardcore; \( \phi_{depslab} = \phi_{depbasic} - h_{hcoreslab} = 3300 \text{ mm} \)
Diameter under thickenings modified for hardcore; \( \phi_{deptick} = \phi_{depbasic} - h_{hcorethick} = 3500 \text{ mm} \)

Raft slab definition
Max dimension/max dimension between joints; \( l_{max} = 12.000 \text{ m} \)
Slab thickness; \( h_{slab} = 250 \text{ mm} \)
Concrete strength; \( f_{cu} = 35 \text{ N/mm}^2 \)
Poissons ratio of concrete; \( \nu = 0.2 \)
Slab mesh reinforcement strength; \( f_{yslab} = 500 \text{ N/mm}^2 \)
Partial safety factor for steel reinforcement; \( \gamma_s = 1.15 \)
From C&CA document ‘Concrete ground floors’ Table 5

<table>
<thead>
<tr>
<th>Minimum mesh required in top for shrinkage; A142;</th>
<th>Actual mesh provided in top; A393 ( (A_{a\text{slabbtop}} = 393 \text{ mm}^2/\text{m}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh provided in bottom; A393 ( (A_{a\text{sslabbtm}} = 393 \text{ mm}^2/\text{m}) )</td>
<td></td>
</tr>
<tr>
<td>Top mesh bar diameter; ( \phi_{\text{slabtop}} = 10 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Bottom mesh bar diameter; ( \phi_{\text{slabbtm}} = 10 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Cover to top reinforcement; ( c_{\text{top}} = 20 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Cover to bottom reinforcement; ( c_{\text{btm}} = 40 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Average effective depth of top reinforcement; ( d_{\text{slabav}} = (d_{\text{tslabav}} + d_{\text{bslabav}})/2 = 210 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Average effective depth of bottom reinforcement; ( d_{\text{slabav}} = (d_{\text{tslabav}} + d_{\text{bslabav}})/2 = 210 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Overall average effective depth; ( d_{\text{slabav}} = (d_{\text{tslabav}} + d_{\text{bslabav}})/2 = 210 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Minimum effective depth of top reinforcement; ( d_{\text{tslabmin}} = d_{\text{tslabav}} - \phi_{\text{slabtop}}/2 = 215 \text{ mm} )</td>
<td></td>
</tr>
<tr>
<td>Minimum effective depth of bottom reinforcement; ( d_{\text{tslabmin}} = d_{\text{tslabav}} - \phi_{\text{slabtop}}/2 = 215 \text{ mm} )</td>
<td></td>
</tr>
</tbody>
</table>

**Edge beam definition**

<table>
<thead>
<tr>
<th>Overall depth; ( h_{\text{edge}} = 600 \text{ mm} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width; ( b_{\text{edge}} = 550 \text{ mm} )</td>
</tr>
<tr>
<td>Depth of boot; ( h_{\text{boot}} = 250 \text{ mm} )</td>
</tr>
<tr>
<td>Width of boot; ( b_{\text{boot}} = 250 \text{ mm} )</td>
</tr>
<tr>
<td>Angle of chamfer to horizontal; ( \alpha_{\text{edge}} = 60 \text{ deg} )</td>
</tr>
<tr>
<td>Strength of main bar reinforcement; ( f_y = 500 \text{ N/mm}^2 )</td>
</tr>
<tr>
<td>Strength of link reinforcement; ( f_{ys} = 500 \text{ N/mm}^2 )</td>
</tr>
<tr>
<td>Reinforcement provided in top; 3 H25 bars ( (A_{\text{as\text{dgettop}}} = 1473 \text{ mm}^2) )</td>
</tr>
<tr>
<td>Reinforcement provided in bottom; 3 H20 bars ( (A_{\text{as\text{dgetbtm}}} = 942 \text{ mm}^2) )</td>
</tr>
<tr>
<td>Link reinforcement provided; 2 H12 legs at 250 ctrs ( (A_{\text{asv/sv}} = 0.905 \text{ mm}) )</td>
</tr>
<tr>
<td>Internal beam definition</td>
</tr>
<tr>
<td>Bottom cover to links; ( c_{\text{beam}} = 40 \text{ mm} )</td>
</tr>
<tr>
<td>Effective depth of top reinforcement; ( d_{\text{dgettop}} = h_{\text{edge}} - c_{\text{top}} - \phi_{\text{slabtop}} - \phi_{\text{edgelink}} - \phi_{\text{dgettop}}/2 = 546 \text{ mm} )</td>
</tr>
<tr>
<td>Effective depth of bottom reinforcement; ( d_{\text{dgetbtm}} = h_{\text{edge}} - c_{\text{beam}} - \phi_{\text{edgelink}} - \phi_{\text{dgetbtm}}/2 = 538 \text{ mm} )</td>
</tr>
<tr>
<td>Boot main reinforcement; H8 bars at 250 ctrs ( (A_{\text{boot}} = 201 \text{ mm}^2) )</td>
</tr>
<tr>
<td>Effective depth of boot reinforcement; ( d_{\text{dgetboot}} = h_{\text{boot}} - c_{\text{beam}} - \phi_{\text{boot}}/2 = 206 \text{ mm} )</td>
</tr>
</tbody>
</table>
### Project: Raft Foundation Analysis & Design, In accordance with BS8110:part 1-1997_for multistorey Building.

<table>
<thead>
<tr>
<th>Section</th>
<th>Civil &amp; Geotechnical Engineering Calculations for</th>
<th>Sheet no./rev.</th>
<th>1</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Calculations for</th>
<th>Sheet no./rev.</th>
<th>1</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Calc. Made by Dr. C. Sachpazis</th>
<th>Date 27/02/2016</th>
<th>Chk’d by</th>
<th>Date</th>
<th>App’d by</th>
<th>Date</th>
</tr>
</thead>
</table>

**Overall depth:**
- *h*<sub>int</sub> = 550 mm
- *b*<sub>int</sub> = 500 mm
- *α*<sub>int</sub> = 60 deg
- *f*<sub>y</sub> = 500 N/mm<sup>2</sup>
- *f*<sub>ysz</sub> = 500 N/mm<sup>2</sup>

**Reinforcement details:**
- 3 H25 bars (*A*<sub>sinttop</sub> = 1473 mm<sup>2</sup>)
- 3 H25 bars (*A*<sub>sintbtm</sub> = 1473 mm<sup>2</sup>)
- 2 H12 legs at 225 ctrs (*A*<sub>slabtop</sub>, *A*<sub>slabbtm</sub>)

**Effective depths:**
- *d*<sub>sinttop</sub> = *h*<sub>int</sub> - *c*<sub>top</sub> - 2 × *ψ*<sub>sinttop</sub> - *φ*<sub>sinttop</sub>/2 = 498 mm
- *d*<sub>sintbtm</sub> = *h*<sub>int</sub> - *c*<sub>beam</sub> - *ψ*<sub>sintbtm</sub> - *φ*<sub>sintbtm</sub>/2 = 486 mm

**Internal slab design checks**

**Basic loading**
- Slab self weight:
  - *w*<sub>slab</sub> = 24 kN/m<sup>3</sup> × *h*<sub>slab</sub> = 6.0 kN/m<sup>2</sup>
- *w*<sub>hcoreslab</sub> = *γ*<sub>hcore</sub> × *h*<sub>hcoreslab</sub> = 4.0 kN/m<sup>2</sup>

**Applied loading**
- Uniformly distributed dead load:
  - *w*<sub>Dudl</sub> = 2.0 kN/m<sup>2</sup>
  - *w*<sub>Ludl</sub> = 2.5 kN/m<sup>2</sup>
Load type; | Dead load; | Live load; | Ultimate load; |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Internal slab bearing pressure check**

Total uniform load at formation level;

**Bearing pressure beneath load number 1**

Net bearing pressure available to resist line load; Net ‘ultimate’ bearing pressure available; Loaded width required at formation; Effective loaded width at u/side slab; Effective net ult bearing pressure at u/side slab; Cantilever bending moment;

**Reinforcement required in bottom**

Maximum cantilever moment; K factor; Lever arm; Area of steel required;

**Internal slab bending and shear check**

**Applied bending moments**

Span of slab; Ultimate self weight udl; Self weight moment at centre; Self weight moment at edge; Self weight shear force at edge;

**Moments due to applied uniformly distributed loads**

Ultimate applied udl; Moment at centre; Moment at edge; Shear force at edge;

**Moment due to load number 1**

Approximate equivalent udl; Moment at centre; Moment at edge; Shear force at edge;

**Resultant moments and shears**

Total moment at edge;
Total moment at centre; $M_{bc} = 4.3 \text{ kNm/m}$
Total shear force; $V_c = 16.5 \text{ kNm/m}$

**Reinforcement required in top**

- **K factor;** $K_{slabtop} = M_{bc}/(f_{su} \times d_{slabav}) = 0.004$
- **Lever arm;** $z_{slabtop} = d_{slabav} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{slabtop}/0.9)) = 209.0 \text{ mm}}$
- **Area of steel required for bending;** $A_{slobtopbend} = M_{bc}/((1.0/\gamma_y) \times f_{yslab} \times Z_{slabtop}) = 80 \text{ mm}^2/m$
- **Minimum area of steel required;** $A_{slobmin} = 0.0013 \times h_{slab} = 325 \text{ mm}^2/m$
- **Area of steel required;** $A_{slobtopreq} = \max(A_{slobtopbend}, A_{slobmin}) = 325 \text{ mm}^2/m$ **PASS - $A_{slobtopreq} <= A_{slobtop}$ - Area of reinforcement provided in top to span local depressions is adequate**

**Reinforcement required in bottom**

- **K factor;** $K_{slobtm} = M_{bc}/(f_{su} \times d_{slabav}) = 0.003$
- **Lever arm;** $z_{slobtm} = d_{slabav} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{slobtm}/0.9)) = 190.0 \text{ mm}}$
- **Area of steel required for bending;** $A_{slobtmmin} = 2.00 \times h_{slab} = 0.004 \times h_{slab} = 325 \text{ mm}^2/m$
- **Area of steel required;** $A_{slobtmreq} = \max(A_{slobtmmin}, A_{slobtbend}) = 325 \text{ mm}^2/m$ **PASS - $A_{slobtmreq} <= A_{slobtm}$ - Area of reinforcement provided in bottom to span local depressions is adequate**

**Shear check**

- Applied shear stress; $v = V_c/d_{slobmin} = 0.077 \text{ N/mm}^2$
- Tension stress ratio; $\rho = 100 \times A_{slobtop}/d_{slobmin} = 0.183$
- Design concrete shear strength; $f_{c} = 0.469 \text{ N/mm}^2$ **PASS - $v <= f_{c}$ - Shear capacity of the slab is adequate**

**Internal slab deflection check**

- Basic allowable span to depth ratio; $\text{Ratio}_{basic} = 26.0$
- Moment factor; $M_{factor} = M_{bc}/d_{slobav}^2 = 0.109 \text{ N/mm}^2$
- Steel service stress; $f_s = 2/3 \times f_{yslab} \times A_{slobtbend}/A_{slobtm} = 44.615 \text{ N/mm}^2$
- Modification factor; $M_{F_{lab}} = \min(2.0, 0.55 + [(477N/mm^2 - f_s)/(120 \times (0.9N/mm^2 + M_{factor}))])$
- $M_{F_{lab}} = 2.000$
- Ratio allow = Ratio$_{basic} \times M_{F_{lab}} = 52.000$
- Ratio actual = $I_{lab}/d_{slobav} = 17.600$
- **PASS - Ratio$_{actual} <= $Ratio$_{allow}$ - Slab span to depth ratio is adequate**

**Edge beam design checks**

**Basic loading**

- **Hardcore;** $w_{hcore} = \gamma_{hcore} \times h_{hcore} = 0.0 \text{ kN/m}^2$
- **Edge beam**
  - Rectangular beam element; $w_{beam} = 24 \text{ kN/m}^3 \times h_{edge} \times b_{edge} = 7.9 \text{ kN/m}$
  - Boot element; $w_{boot} = 24 \text{ kN/m}^3 \times h_{boot} \times b_{boot} = 1.5 \text{ kN/m}$
  - Chamfer element; $w_{chamfer} = 24 \text{ kN/m}^3 \times (h_{edge} \times h_{lab})^3/(2 \times \tan(\alpha_{edge})) = 0.8 \text{ kN/m}$
  - Slab element; $w_{slabelm} = 24 \text{ kN/m}^3 \times h_{lab} \times (h_{edge} + h_{lab})/\tan(\alpha_{edge}) = 1.2 \text{ kN/m}$
  - Edge beam self weight; $w_{edge} = w_{beam} + w_{boot} + w_{chamfer} + w_{slabelm} = 11.5 \text{ kN/m}$
Edge load number 1

Load type;
Dead load;
Live load;
Ultimate load;
Longitudinal line load width;
Centroid of load from outside face of raft;

Longitudinal line load

\[ W_{\text{edge1}} = 13.2 \text{ kN/m} \]

\[ W_{\text{edge1}} = 0.0 \text{ kN/m} \]

\[ W_{\text{ultedge1}} = 1.4 \times W_{\text{edge1}} + 1.6 \times W_{\text{edge1}} = 18.5 \text{ kN/m} \]

\[ b_{\text{edge1}} = 102 \text{ mm} \]

\[ x_{\text{edge1}} = 51 \text{ mm} \]

Edge load number 2

Load type;
Dead load;
Live load;
Ultimate load;
Longitudinal line load width;
Centroid of load from outside face of raft;

Longitudinal line load

\[ W_{\text{edge2}} = 16.1 \text{ kN/m} \]

\[ W_{\text{edge2}} = 5.6 \text{ kN/m} \]

\[ W_{\text{ultedge2}} = 1.4 \times W_{\text{edge2}} + 1.6 \times W_{\text{edge2}} = 31.5 \text{ kN/m} \]

\[ b_{\text{edge2}} = 100 \text{ mm} \]

\[ x_{\text{edge2}} = 230 \text{ mm} \]

Edge beam bearing pressure check

Effective bearing width of edge beam;
Total uniform load at formation level;

\[ b_{\text{bearing}} = b_{\text{edge}} + b_{\text{load}} + (h_{\text{edge}} - h_{\text{slab}}) \tan(\alpha_{\text{edge}}) = 1002 \text{ mm} \]

\[ w_{\text{ultedge}} = w_{\text{Dud}} + w_{\text{Lud}} + w_{\text{edge}} + w_{\text{hoconcethick}} = 16.0 \text{ kN/m}^2 \]

Centroid of longitudinal and equivalent line loads from outside face of raft

Load x distance for edge load 1;
Load x distance for edge load 2;
Sum of ultimate longitudinal and equivalent line loads;
Sum of load x distances;
Centroid of loads;

\[ \Sigma x_{\text{edge}} = 8.2 \text{ kN} \]

\[ x_{\text{car}} = \frac{\Sigma \text{Moment}}{\Sigma \text{UDL}} = 164 \text{ mm} \]

Initially assume no moment transferred into slab due to load/reaction eccentricity

Sum of unfactored longitudinal and effective line loads;
Allowable bearing width;
Bearing pressure due to line/point loads;
Total applied bearing pressure;
\[ q_{\text{point}} = \Sigma \text{UDLs} \]

\[ q_{\text{edge}} = q_{\text{point}} + w_{\text{ultedge}} = 78.4 \text{ kN/m}^2 \]

\[ q_{\text{edge}} > q_{\text{allow}} - The \text{ slab is required to resist a moment due to eccentricity} \]

Now assume moment due to load/reaction eccentricity is resisted by slab

Bearing width required;
Effective bearing width at u/s of slab;
Load/reaction eccentricity;
Ultimate moment to be resisted by slab;
From slab bending check

\[ M_{\text{slab}} = 7.2 \text{ kNm/m} \]

\[ M_{\text{ultslab}} = M_{\text{slab}} + M_{\text{L}} = 8.1 \text{ kNm/m} \]

\[ K_{\text{slab}} = M_{\text{ultslab}}/(f_{\text{cu}} \times d_{\text{slabthick}}^2) = 0.005 \]

\[ z_{\text{slab}} = d_{\text{slabthick}} \min(0.95, 0.5 + \sqrt{(0.25 - K_{\text{slab}}/0.9)}) = 204 \text{ mm} \]

\[ A_{\text{ultslab}} = M_{\text{ultslab}}/((1.0/f_{\text{cu}}) \times 460 \text{ N/mm}^2 \times z_{\text{slab}}) = 99 \text{ mm}^2 \text{/m} \]
Edge beam bending check

Divisor for moments due to udl's;

\[ \beta_{udl} = 12.0 \]

Applied bending moments

Span of edge beam;

\[ l_{edge} = \phi_{depth\, thick} + d_{edgetop} = 4045 \text{ mm} \]

Ultimate self weight udl;

\[ w_{edge} = 1.4 \times w_{edge} = 16.1 \text{ kN/m} \]

Ultimate slab udl (approx);

\[ w_{edgelay} = \max(0 \text{ kN/m}, 1.4 \times w_{slab} \times ((\phi_{depth\, thick}/2) \times 3/4) - (b_{edge} + (h_{edge} - h_{slab}) \tan(\alpha_{edge}))) \]

\[ w_{edgelay} = 4.7 \text{ kN/m} \]

Self weight and slab bending moment;

\[ M_{edge} = (w_{edgelay} + w_{edgelay}) \times l_{edge}^2/2 \beta_{udl} = 28.3 \text{ kNm} \]

Self weight shear force;

\[ V_{edgelay} = (w_{edgelay} + w_{edgelay}) \times l_{edge}/2 = 42.0 \text{ kN} \]

Moments due to applied uniformly distributed loads

Ultimate udl (approx);

\[ w_{edgemy} = w_{udl} \times \phi_{depth\, thick}/2 \times 3/4 = 8.9 \text{ kN/m} \]

Bending moment;

\[ M_{edge1} = w_{edgemy} \times l_{edge}^2/2 \beta_{udl} = 25.2 \text{ kNm} \]

Shear force;

\[ V_{edge1} = w_{edgemy} \times l_{edge}/2 = 37.4 \text{ kN} \]

Moment and shear due to load number 2

Bending moment;

\[ M_{edge2} = w_{edgemy} \times l_{edge}^2/2 \beta_{udl} = 43.0 \text{ kNm} \]

Shear force;

\[ V_{edge2} = w_{edgemy} \times l_{edge}/2 = 63.7 \text{ kN} \]

Resultant moments and shears

Total moment (hogging and sagging);

\[ M_{edge} = 108.7 \text{ kNm} \]

Maximum shear force;

\[ V_{edge} = 161.2 \text{ kN} \]

Reinforcement required in top

Width of section in compression zone;

\[ b_{edgetop} = b_{edge} + b_{bot} = 800 \text{ mm} \]

Average web width;

\[ b_w = b_{edge} + (h_{edge} \times \tan(\alpha_{edge}))/2 = 723 \text{ mm} \]

K factor;

\[ K_{edgetop} = M_{edge}/(f_y \times b_{edgetop} \times d_{edgetop})^2 = 0.013 \]

Lever arm;

\[ z_{edgetop} = d_{edgetop} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{edgetop}/0.9)}) = 518 \text{ mm}^2 \]

Area of steel required for bending;

\[ A_{edgetop\, bend} = M_{edge}/(1.0/f_y) \times f_y \times z_{edgetop} = 482 \text{ mm}^2 \]

Minimum area of steel required;

\[ A_{edgetop\, min} = 0.0013 \times 1.0 \times b_w \times h_{edge} = 564 \text{ mm}^2 \]

\[ A_{edgetop\, req} = \max(0, A_{edgetop\, bend}, A_{edgetop\, min}) = 564 \text{ mm}^2 \]

**PASS - A_{edgetop\, req} \leq A_{edgetop}** - Area of reinforcement provided to transfer moment into slab is adequate

The allowable bearing pressure under the edge beam will not be exceeded

Reinforcement required in bottom

Width of section in compression zone;

\[ b_{edgbot} = b_{edge} + (h_{edge} - h_{slab})/\tan(\alpha_{edge}) + 0.1 \times l_{edge} = 1157 \text{ mm} \]

K factor;

\[ K_{edgbot} = M_{edge}/(f_y \times b_{edgbot} \times d_{edgbot})^2 = 0.009 \]

Lever arm;

\[ z_{edgbot} = d_{edgbot} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{edgbot}/0.9)}) = 511 \text{ mm}^2 \]

Area of steel required for bending;

\[ A_{edgbot\, bend} = M_{edge}/(1.0/f_y) \times f_y \times z_{edgbot} = 489 \text{ mm}^2 \]

Minimum area of steel required;

\[ A_{edgbot\, min} = 0.0013 \times 1.0 \times b_w \times h_{edge} = 564 \text{ mm}^2 \]

\[ A_{edgbot\, req} = \max(0, A_{edgbot\, bend}, A_{edgbot\, min}) = 564 \text{ mm}^2 \]

**PASS - A_{edgbot\, req} \leq A_{edgbot}** - Area of reinforcement provided in top of edge beams is adequate
Area of steel required; \( A_{\text{sedgebtmreq}} = \max(A_{\text{sedgebtmbend}}, A_{\text{sedgebtmmin}}) = 564 \text{ mm}^2 \)

**PASS** - \( A_{\text{sedgebtmreq}} \leq A_{\text{sedgebtm}} \) - Area of reinforcement provided in bottom of edge beams is adequate

**Edge beam shear check**

Applied shear stress; \( \sigma_{\text{edge}} = \frac{V_{\text{edge}}}{b_{\text{w}} \times d_{\text{edgetop}}} = 0.409 \text{ N/mm}^2 \)

Tension steel ratio; \( \rho_{\text{edge}} = 100 \times \frac{A_{\text{sedgetop}}}{b_{\text{w}} \times d_{\text{edgetop}}} = 0.373 \)

**PASS** - \( \rho_{\text{edge}} \leq 0.85 \) - Therefore shear reinforcement provided in edge beams is adequate

**Boot design check**

Effective cantilever span; \( l_{\text{boot}} = b_{\text{boot}} + d_{\text{boot}}/2 = 353 \text{ mm} \)

Approximate ultimate bearing pressure; \( q_{\text{ult}} = 1.55 \times q_{\text{allow}} = 116.3 \text{ kN/m}^2 \)

Cantilever moment; \( M_{\text{boot}} = q_{\text{ult}} \times l_{\text{boot}}^2/2 = 7.2 \text{ kN/m} \)

K factor; \( K_{\text{boot}} = M_{\text{boot}}/f_{\text{cu}} \times d_{\text{boot}}^2 = 0.005 \)

Lever arm; \( z_{\text{boot}} = d_{\text{boot}} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{\text{boot}}/0.9)}) = 196 \text{ mm} \)

Area of reinforcement required; \( A_{\text{sbootreq}} = \frac{M_{\text{boot}}}{(1.0/\gamma_{s} \times f_{\text{yboot}} \times z_{\text{boot}})} = 85 \text{ mm}^2/m \)

**PASS** - \( A_{\text{sbootreq}} \leq A_{\text{sboot}} \) - Area of reinforcement provided in base is adequate for bending

Applied shear stress; \( \sigma_{\text{boot}} = \frac{V_{\text{boot}}}{d_{\text{boot}}} = 0.199 \text{ N/mm}^2 \)

Tension steel ratio; \( \rho_{\text{boot}} = 100 \times \frac{A_{\text{sboot}}}{d_{\text{boot}}} = 0.088 \)

**PASS** - \( \rho_{\text{boot}} \leq 0.85 \) - Shear capacity of the base is adequate

**Corner design checks**

**Basic loading**

**Corner load number 1**

Load type;
Dead load;
Live load;
Ultimate load;
Centroid of load from outside face of raft;

**Corner load number 2**

Load type;
Dead load;
Live load;
Ultimate load;
Centroid of load from outside face of raft;

**Corner load number 3**

Load type;
Dead load;
Live load;
Ultimate load;
Centroid of load from outside face of raft;
**Load type:**
- Dead load:
- Live load:
- Ultimate load:

**Corner load number 4**
- Load type:
- Dead load:
- Live load:
- Ultimate load:
- Centroid of load from outside face of raft:

**Corner load number 5**
- Load type:
- Dead load:
- Live load:
- Ultimate load:
- Centroid of load from outside face of raft:

**Corner bearing pressure check**
- Total uniform load at formation level:
- Net bearing press avail to resist line/point loads:

**Total line/point loads**
- Total unfactored line load in x direction:
- Total ultimate line load in x direction:
- Total unfactored line load in y direction:
- Total ultimate line load in y direction:
- Total unfactored point load:
- Total ultimate point load:
- Length of side of sq reqd to resist line/point loads:

**Bending moment about x-axis due to load/reaction eccentricity**
- Moment due to load 1 (x line):
- Moment due to load 2 (x line):
- Total moment about x axis:

**Bending moment about y-axis due to load/reaction eccentricity**
- Moment due to load 3 (y line):
- Moment due to load 4 (y line):
- Moment due to load 5 (y line):
- Total moment about y axis:

**Check top reinforcement in edge beams for load/reaction eccentric moment**
- Max moment due to load/reaction eccentricity:
Assume all of this moment is resisted by edge beam
From edge beam design checks away from corners
Moment due to edge beam spanning depression; \( M_{edge} = 108.7 \text{ kNm} \)
Total moment to be resisted; \( M_{cometop} = M_L + M_{edge} = 143.7 \text{ kNm} \)
Width of section in compression zone; \( b_{dadgetop} = b_{dedge} + b_{dboot} = 800 \text{ mm} \)
K factor; \( K_{cometop} = M_{cometop}/(f_{cd} \times b_{dadgetop} \times d_{dadgetop}^2) = 0.017 \)
Lever arm; \( z_{cometop} = d_{dadgetop} \times \min((0.95, 0.5 + \sqrt{(0.25 - K_{cometop}/0.9})) = 518 \text{ mm} \)
Total area of top steel required; \( A_{cometop} = M_{cometop}/((1.0/10) \times f_y \times z_{cometop}) = 638 \text{ mm}^2 \)

**PASS - A_{cometop} \leq A_{dadgetop}** - Area of reinforcement provided to resist eccentric moment is adequate

**The allowable bearing pressure at the corner will not be exceeded**

Corner beam bending check
Cantilever span of edge beam; \( l_{corner} = \phi_{ddepthic}/(2) + d_{dadgetop}/2 = 2748 \text{ mm} \)

Moment and shear due to self weight
Ultimate self weight udl; \( w_{edgedult} = 1.4 \times w_{edge} = 16.1 \text{ kNm} \)
Average ultimate slab udl (approx); \( w_{comerislub} = \max(0 \text{ kNm/m}, 1.4 \times w_{dusted} \times \phi_{ddepthic}/(2) \times (b_{dedge} + h_{dulate} \times (\tan(\alpha_{dedge})/2))) \)
\( w_{comerislub} = 4.1 \text{ kNm} \)
Self weight and slab bending moment; \( M_{comerw} = (w_{edgedult} + w_{comerislub}) \times l_{corner}^2/2 = 76.1 \text{ kNm} \)
Self weight and slab shear force; \( V_{comerw} = (w_{edgedult} + w_{comerislub}) \times l_{corner} = 55.4 \text{ kN} \)

Moment and shear due to udl s
Maximum ultimate udl; \( w_{comerult} = ((1.4 \times w_{dusted}) + (1.6 \times w_{dusted})) \times \psi_{ddepthic}/(2) = 16.8 \text{ kNm} \)
Bending moment; \( M_{comerult} = w_{comerult} \times l_{corner}^2/6 = 21.2 \text{ kNm} \)
Shear force; \( V_{comerult} = w_{comerult} \times l_{corner}/2 = 23.1 \text{ kN} \)

Moment and shear due to line loads in \( x \) direction
Bending moment; \( M_{comerlinex} = w_{comerlinex} \times l_{corner}^2/2 = 188.7 \text{ kNm} \)
Shear force; \( V_{comerlinex} = w_{comerlinex} \times l_{corner} = 137.3 \text{ kN} \)

Moment and shear due to line loads in \( y \) direction
Bending moment; \( M_{comerliney} = w_{comerliney} \times l_{corner}^2/2 = 216.7 \text{ kNm} \)
Shear force; \( V_{comerliney} = w_{comerliney} \times l_{corner} = 157.7 \text{ kN} \)

Total moments and shears due to point loads
Bending moment about \( x \) axis; \( M_{comerpointx} = 0.0 \text{ kNm} \)
Bending moment about \( y \) axis; \( M_{comerpointy} = 0.0 \text{ kNm} \)
Shear force; \( V_{comerpoint} = 0.0 \text{ kN} \)

Resultant moments and shears
Total moment about \( x \) axis; \( M_{comerx} = M_{comerw} + M_{comerult} + M_{comerlinex} + M_{comerpointx} = 313.9 \text{ kNm} \)
Total shear force about \( x \) axis; \( V_{comerx} = V_{comerw} + V_{comerult} + V_{comerlinex} + V_{comerpoint} = 236.2 \text{ kN} \)
Total moment about \( y \) axis; \( M_{comery} = M_{comerw} + M_{comerult} + M_{comerliney} + M_{comerpointy} = 285.9 \text{ kNm} \)
Total shear force about \( y \) axis; \( V_{comery} = V_{comerw} + V_{comerult} + V_{comerliney} + V_{comerpoint} = 215.8 \text{ kN} \)

Deflection of both edge beams at corner will be the same therefore design for average of these moments and shears
Design bending moment; \( M_{comer} = (M_{comerw} + M_{comerult})/2 = 299.9 \text{ kNm} \)
### Design shear force;

**Reinforcement required in top of edge beam**

- **K factor;**
  \[ K_{\text{corner}} = M_{\text{corner}}/(f_u \times d_{\text{edgetop}} \times d_{\text{edgetop}}^2) = 0.036 \]

- **Lever arm;**
  \[ z_{\text{corner}} = d_{\text{edgetop}} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{\text{corner}}/0.9)}) = 518 \text{ mm} \]

- **Area of steel required for bending;**
  \[ A_{\text{comer,bend}} = M_{\text{corner}}/((1.0/f_y) \times f_y \times z_{\text{corner}}) = 1331 \text{ mm}^2 \]

- **Minimum area of steel required;**
  \[ A_{\text{comer,min}} = A_{\text{edgetop,min}} = 564 \text{ mm}^2 \]

- **Area of steel required;**
  \[ A_{\text{comer}} = \max(A_{\text{comer,bend}}, A_{\text{comer,min}}) = 1331 \text{ mm}^2 \]

**PASS -** \( A_{\text{comer,min}} \leq A_{\text{edgetop,min}} - \text{Area of reinforcement provided in top of edge beams at corners is adequate} \)

### Corner beam shear check

- **Average web width;**
  \[ b_w = b_{\text{edge}} + (h_{\text{edge}} \tan(\alpha_{\text{edge}}))/2 = 723 \text{ mm} \]

- **Applied shear stress;**
  \[ V_{\text{corner}} = V_{\text{corner,min}}/(b_w \times d_{\text{edgetop}}) = 0.573 \text{ N/mm}^2 \]

- **Tension steel ratio;**
  \[ \rho_{\text{corner}} = 100 \times A_{\text{edgetop,min}}/(b_w \times d_{\text{edgetop}}) = 0.373 \]

- **Design concrete shear strength;**
  \[ V_{\text{corner}} = 0.471 \text{ N/mm}^2 \]

**V_{\text{corner}} < V_{\text{corner},min} + 0.4N/mm² - Therefore minimum links required**

- **Link area to spacing ratio required;**
  \[ A_{s_{\text{upper,sprov,corner}}} = 0.4N/mm² \times b_{w}/((1.0/f_y) \times f_y) = 0.665 \text{ mm} \]

- **Link area to spacing ratio provided;**
  \[ A_{s_{\text{upper,sprov,edge}}} = N_{\text{diameter}} \times \pi \times f_{\text{diameter}} \times 4/s_{\text{edge}} = 0.905 \text{ mm} \]

**PASS -** \( A_{s_{\text{upper,sprov,corner}}} \leq A_{s_{\text{upper,sprov,edge}} - \text{Shear reinforcement provided in edge beams at corners is adequate} \}

### Corner beam deflection check

- **Basic allowable span to depth ratio;**
  \[ \text{Ratio}_{\text{basic,corner}} = 7.0 \]

- **Moment factor;**
  \[ M_{\text{factor,corner}} = M_{\text{corner}}/(b_{\text{edgetop}} \times d_{\text{edgetop}}^2) = 1.260 \text{ N/mm}^2 \]

- **Steel service stress;**
  \[ f_{\text{corner}} = 2/3 \times f_y \times A_{\text{comer,bend,edgetop}} = 301.285 \text{ N/mm}^2 \]

- **Modification factor;**
  \[ M_{\text{corner}} = \min(2.0, 0.55 + [(477N/mm² \times f_{\text{corner}})/(120 \times (0.9N/mm² + M_{\text{factor,corner}})]) \]

- **Modified allowable span to depth ratio;**
  \[ \text{Ratio}_{\text{allow,corner}} = \text{Ratio}_{\text{basic,corner}} \times M_{\text{corner}} = 8.596 \]

- **Actual span to depth ratio;**
  \[ \text{Ratio}_{\text{actual,corner}} = \text{Ratio}_{\text{corner}} \times d_{\text{edgetop}} = 5.037 \]

**PASS -** \( \text{Ratio}_{\text{actual,corner}} \leq \text{Ratio}_{\text{allow,corner}} - \text{Edge beam span to depth ratio is adequate} \)

### Internal beam design checks

#### Basic loading

- **Hardcore;**
  \[ w_{\text{core,thick}} = \gamma_{\text{core}} \times h_{\text{core,thick}} = 0.0 \text{ kN/m}^2 \]

- **Internal beam self weight;**
  \[ w_{\text{int}} = 24 \text{ kN/m}^3 \times \{(h_{\text{int}} \times b_{\text{int}}) \times \tan(\alpha_{\text{int}}) + 2 \times h_{\text{int}} \times h_{\text{int}} / \tan(\alpha_{\text{int}})\} \]
  \[ w_{\text{int}} = 9.9 \text{ kN/m} \]

#### Internal beam load number 1

- **Load type;**
  \[ w_{\text{Dir}} = 15.0 \text{ kN/m} \]

- **Dead load;**
  \[ w_{\text{Dint}} = 5.3 \text{ kN/m} \]

- **Ultimate load;**
  \[ w_{\text{ult}} = 1.4 \times w_{\text{Dir}} + 1.6 \times w_{\text{Dint}} = 29.5 \text{ kN/m} \]

- **Centroid of load from centreline of beam;**
  \[ x_{\text{int}} = 0 \text{ mm} \]

- **Longitudinal line load;**
  \[ b_{\text{int}} = 140 \text{ mm} \]

- **Longitudinal line load width;**
  \[ x_{\text{int}} = 0 \text{ mm} \]
### Internal beam load number 2

<table>
<thead>
<tr>
<th>Description</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load type; Full transverse line load;</td>
<td>( W_{\text{Dvir}} = 10.0 \text{ kN/m} )</td>
</tr>
<tr>
<td>Dead load;</td>
<td>( W_{\text{Lir2}} = 4.0 \text{ kN/m} )</td>
</tr>
<tr>
<td>Live load;</td>
<td>( W_{\text{ultir2}} = 1.4 \times W_{\text{Dvir}} + 1.6 \times W_{\text{Lir2}} = 20.4 \text{ kN/m} )</td>
</tr>
<tr>
<td>Ultimate load;</td>
<td>( b_{ir2} = 140 \text{ mm} )</td>
</tr>
<tr>
<td>Transverse line load width;</td>
<td>( )</td>
</tr>
<tr>
<td>Internal beam bearing pressure check Total uniform load at formation level;</td>
<td>( W_{\text{udist}} = W_{\text{Oudist}} + W_{\text{Ucorethick}} + 24 \text{ kN/m}^3 \times h_{\text{net}} = 17.7 \text{ kN/m}^2 )</td>
</tr>
<tr>
<td>Effective point load due to transverse line/point loads Effective point load due to load 2 (Line load);</td>
<td>( W_{\text{int2}} = W_{\text{ultint2}} \times [b_{ir2} + 2 \times (h_{\text{net}} - h_{\text{slab}}) \tan(\alpha_{\text{int}})] = 17.3 \text{ kN} )</td>
</tr>
<tr>
<td>Total effective point load;</td>
<td>( W_{\text{int}} = 17.3 \text{ kN} )</td>
</tr>
<tr>
<td>Minimum width of effective point load;</td>
<td>( b_{\text{intmin}} = 140 \text{ mm} )</td>
</tr>
<tr>
<td>Equivalent and total beam line loads Equivalent ultimate udl of internal load 2;</td>
<td>( W_{\text{ultint2}} = 22.4 \text{ kN/m} )</td>
</tr>
<tr>
<td>Equivalent unfactored udl of internal load 2;</td>
<td>( W_{\text{ultint2fs}} = W_{\text{ultint2}} \times (W_{\text{Dvir}} + W_{\text{Lir2}}) / W_{\text{ultint2}} = 2.1 \text{ kN/m} )</td>
</tr>
<tr>
<td>Sum of factored longitud’l and eff’tive line loads;</td>
<td>( \Sigma \text{UDL}_{\text{int}} = 32.5 \text{ kN/m} )</td>
</tr>
<tr>
<td>Sum of unfactored longitud’l and eff’tive line loads;</td>
<td>( \Sigma \text{UDL}_{\text{int2}} = 22.4 \text{ kN/m} )</td>
</tr>
<tr>
<td>Centroid of loads from centreline of internal beam Load x distance for internal load 1;</td>
<td>( )</td>
</tr>
<tr>
<td>Sum of load x distances;</td>
<td>( \Sigma \text{Mom}_{\text{x}} = 0.0 \text{ kN} )</td>
</tr>
<tr>
<td>Centroid of loads;</td>
<td>( x_{\text{barin}} = \Sigma \text{Mom}<em>{\text{x}} / \Sigma \text{UDL}</em>{\text{int}} = 0.0 \text{ mm} )</td>
</tr>
<tr>
<td>Moment due to eccentricity to be resisted by slab;</td>
<td>( M_{\text{secint}} = \Sigma \text{UDL}<em>{\text{int}} \times \text{abs}(x</em>{\text{barin}}) = 0.0 \text{ kN/m} )</td>
</tr>
<tr>
<td>Assume moment due to eccentricity is resisted equally by top steel of slab on one side and bottom steel of slab on other From slab bending check Moment due to depression under slab (hogging);</td>
<td>( M_{\text{lep}} = 7.2 \text{ kN/m} )</td>
</tr>
<tr>
<td>Total moment to be resisted by slab top steel;</td>
<td>( M_{\text{slabtopint}} = M_{\text{secint}} / 2 + M_{\text{lep}} = 7.2 \text{ kN/m} )</td>
</tr>
<tr>
<td>K factor;</td>
<td>( K_{\text{slabtopint}} = K_{\text{slabtopint}}(0.05, 0.095) = 0.004 )</td>
</tr>
<tr>
<td>Lever arm;</td>
<td>( z_{\text{slabtopint}} = d_{\text{slabmin}} \times \min(0.95, 0.5 + \sqrt{0.25 - K_{\text{slabtopint}}(0.9)}) = 204 \text{ mm} )</td>
</tr>
<tr>
<td>Area of steel required; ( )</td>
<td>( A_{\text{slabtopintreq}} = A_{\text{slabtopint}} \times (1.0 / 0.95) \times f_{\text{ytop}} \times z_{\text{slabtopint}} = 82 \text{ mm}^2 / \text{m} )</td>
</tr>
</tbody>
</table>

\[ \text{PASS} - A_{\text{slabtopintreq}} < A_{\text{slabtopint}} \text{ - Area of reinforcement in top of slab is adequate to transfer moment into slab} \]
**PASS - A_{sslabbtmintreq} <= A_{sslabbtop}** - Area of reinforcement in bottom of slab is adequate to transfer moment into slab

### Bearing pressure

Initially check bearing pressure based on beam soffit/chamfer width only

- Allowable bearing width; \( b_{\text{bearint}} = b_{\text{int}} + 2 \times (h_{\text{int}} - h_{\text{steb}}) \tan(\alpha_{\text{int}}) = 846 \text{ mm} \)
- Bearing pressure due to line/load points;
- Total applied bearing pressure;

\[
q_{\text{int}} = q_{\text{linepointint}} + q_{\text{udlint}} = 44.2 \text{ kN/m}^2
\]

**PASS - q_{\text{int}} <= q_{\text{allow}}** - Allowable bearing pressure is not exceeded

### Internal beam bending check

- Divider for moments due to udl’s; \( \beta_{\text{int2}} = 12.0 \)
- Divider for moments due to point loads; \( \beta_{\text{point}} = 7.0 \)

### Applied bending moments

- Span of internal beam; \( l_{\text{int}} = \phi_{\text{depthick}} + d_{\text{inttop}} = 3998 \text{ mm} \)
- Ultimate self weight udl; \( w_{\text{ultint}} = 1.4 \times w_{\text{int}} = 13.9 \text{ kN/m} \)
- Ultimate slab udl (approx); \( w_{\text{ultslab}} = \max(0, \text{kN/m}, 1.4 \times w_{\text{int}} \times (\phi_{\text{depthick}} \times 3/4) \times (b_{\text{int}} + 2 \times (h_{\text{int}} - h_{\text{steb}}) \tan(\alpha_{\text{int}}))) \)
- Self weight and slab bending moment; \( M_{\text{intb}} = (w_{\text{ultint}} + w_{\text{ultslab}}) \times l_{\text{int}}^2 / \beta_{\text{int}} = 38.4 \text{ kNm} \)
- Self weight shear force; \( V_{\text{intw}} = (w_{\text{ultint}} + w_{\text{ultslab}}) \times l_{\text{int}} / 2 = 57.6 \text{ kN} \)

### Moments due to applied uniformly distributed loads

- Ultimate udl (approx); \( w_{\text{ultint}} = w_{\text{ultint}} \times \phi_{\text{depthick}} \times 3/4 = 17.9 \text{ kN/m} \)
- Bending moment; \( M_{\text{intb}} = w_{\text{ultint}} \times l_{\text{int}}^2 / \beta_{\text{int}} = 23.8 \text{ kNm} \)
- Shear force; \( V_{\text{intw}} = V_{\text{ultint}} \times l_{\text{int}} / 2 = 35.7 \text{ kN} \)

#### Moment and shear due to load number 1

- Bending moment; \( M_{\text{int1}} = w_{\text{ultint1}} \times l_{\text{int}}^2 / \beta_{\text{int}} = 39.3 \text{ kNm} \)
- Shear force; \( V_{\text{intw}} = V_{\text{ultint1}} \times l_{\text{int}} / 2 = 58.9 \text{ kN} \)

#### Moment and shear due to load number 2

- Ultimate point load; \( w_{\text{ultint2}} = w_{\text{ultint2}} \times \phi_{\text{depthick}} \times 3/4 = 53.6 \text{ kN} \)
- Bending moment; \( M_{\text{int2}} = w_{\text{ultint2}} \times l_{\text{int}} / \beta_{\text{point}} = 30.6 \text{ kNm} \)
- Shear force; \( V_{\text{intw}} = V_{\text{ultint2}} = 53.6 \text{ kN} \)

### Resultant moments and shears

- Total moment (hoggimg and sagging); \( M_{\text{ult}} = 132.0 \text{ kNm} \)
- Maximum shear force; \( V_{\text{ult}} = 205.8 \text{ kN} \)

### Reinforcement required in top

- Width of section in compression zone; \( b_{\text{inttop}} = b_{\text{int}} = 500 \text{ mm} \)
- Average web width; \( b_{\text{int}} = b_{\text{int}} + h_{\text{int}} / \tan(\alpha_{\text{int}}) = 818 \text{ mm} \)
- K factor; \( K_{\text{inttop}} = M_{\text{inttop}} / (f_y \times b_{\text{inttop}} \times d_{\text{inttop}}) = 0.030 \)
- Lever arm; \( z_{\text{inttop}} = d_{\text{inttop}} \times \min(0.95, 0.5 + \sqrt{(0.25 - K_{\text{inttop}} / 0.9)}) = 473 \text{ mm} \)
- Area of steel required for bending; \( A_{\text{inttopbend}} = M_{\text{inttop}} / ((1 / f_y) \times f_y \times z_{\text{inttop}}) = 642 \text{ mm}^2 \)
- Area of top reinforcement; \( A_{\text{inttopmax}} = 0.0013 \times b_{\text{int}} \times h_{\text{int}} = 585 \text{ mm}^2 \)
- Area of steel required; \( A_{\text{inttopreq}} = \max(A_{\text{inttopbend}}, A_{\text{inttopmax}}) = 642 \text{ mm}^2 \)
**Project:** Raft Foundation Analysis & Design, In accordance with BS8110:part 1-1997 for multistorey Building.

**Section:** Civil & Geotechnical Engineering Calculations for Sheet no./rev. 1

**Calc. Made by:** Dr. C. Sachpazis

**Date:** 27/02/2016

**Chk’d by:**

**Date:**

**App’d by:**

**Date:**

---

**Reinforcement required in bottom**

Width of section in compression zone; $b_{intbot} = b_{int} + 2 \times (h_{int} - h_{slab})/\tan(\alpha_{int}) + 0.2 \times l_{ext} = 1646$ mm

K factor;

Lever arm;

Area of steel required for bending;

Minimum area of steel required;

Area of steel required;

**PASS - $A_{sintreq} < A_{sint}$ - Area of reinforcement provided in top of internal beams is adequate**

---

**Internal beam shear check**

Applied shear stress;

Tension steel ratio;

From BS8110-1:1997 - Table 3.8 Design concrete shear strength;

Link area to spacing ratio required;

Link area to spacing ratio provided;

**PASS - $A_{sintreq} < A_{sint}$ - Area of reinforcement provided in bottom of internal beams is adequate**

---

**PASS - $A_{sintreq} < A_{sint}$ - Area of reinforcement provided in top of internal beams is adequate**

---

**PASS - $A_{sintreq} < A_{sint}$ - Area of reinforcement provided in bottom of internal beams is adequate**

---

**PASS - $A_{sintreq} < A_{sint}$ - Area of reinforcement provided in top of internal beams is adequate**