SLAB GEOMETRY

Span of slab in x-direction; \( \text{Span}_x = 7200 \text{ mm} \)

Span of slab in y-direction; \( \text{Span}_y = 7200 \text{ mm} \)

Column dimension in x-direction; \( l_x = 400 \text{ mm} \)

Column dimension in y-direction; \( l_y = 400 \text{ mm} \)

External column dimension in x-direction; \( l_{x1} = 250 \text{ mm} \)

External column dimension in y-direction; \( l_{y1} = 250 \text{ mm} \)

Edge dimension in x-direction; \( e_x = l_{x1} / 2 = 125 \text{ mm} \)

Edge dimension in y-direction; \( e_y = l_{y1} / 2 = 125 \text{ mm} \)

Effective span of internal bay in x direction; \( L_x = \text{Span}_x - l_x = 6800 \text{ mm} \)

Effective span of internal bay in y direction; \( L_y = \text{Span}_y - l_y = 6800 \text{ mm} \)

Effective span of end bay in x direction; \( L_{x1} = \text{Span}_x - l_{x1} / 2 = 7000 \text{ mm} \)

Effective span of end bay in y direction; \( L_{y1} = \text{Span}_y - l_y / 2 = 7000 \text{ mm} \)

SLAB DETAILS

Depth of slab; \( h = 250 \text{ mm} \)
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Design slab in the X-direction

End bay A-B

Effective span; L = 7000 mm
Depth of reinforcement; d = 200 mm
Midspan moment; m = (N_{ult} \times L^2) / (2 \times (1 + \sqrt{1 + i})) = 74.823 kNm/m
Support moment; m' = i \times m = 74.823 kNm/m

Design reinforcement

Lever arm; K' = 0.402 \times (b_b - 0.4) - 0.18 \times (b_b - 0.4)^2 = 0.176
K = m / (d^2 \times f_{cu}) = 0.053

Compression reinforcement is not required

z = \min(0.5 + \sqrt{0.25 - (K / 0.9))}, 0.95) \times d = 187.3 mm

Area of reinforcement designed; A_{s,des} = m / (z \times f_y / \gamma_m) = 919 mm^2/m
Minimum area of reinforcement required; A_{s,min} = 0.0013 \times h = 325 mm^2/m
Area of reinforcement required; A_{s,req} = \max(A_{s,des}, A_{s,min}) = 919 mm^2/m
Provide 20 dia bars @ 150 centres

Area of reinforcement provided; A_{s,prov} = \pi \times D^2 / (4 \times s) = 2094 mm^2/m

PASS - Span reinforcement is OK

Check deflection

Design service stress; f_s = 2 \times f_y \times A_{s,req} / (3 \times A_{s,prov} \times b_b) = 146 N/mm^2
Modification factor; k_1 = \min(0.55 + (477N/mm^2 \times f_s) / (120 \times (0.9N/mm^2 + (m/d^2))), 2) = 1.545
Allowable span to depth ratio; 0.9 \times 26 \times k_1 = 36.151
Actual span to depth ratio; L / d = 35.000
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**PASS - Span to depth ratio is OK**

### Internal bay B-C

**Effective span:**  
**L** = 6800 mm

**Depth of reinforcement:**  
**d** = 202 mm

**Midspan moment:**  
**m** = \((N_{ul} \times L^2) / (2 \times (\sqrt{(1 + i)} + \sqrt{1 + i}))\) = 51.442 kNm/m

**Support moment:**  
**m'** = \(i \times m\) = 51.442 kNm/m

**Design reinforcement**

**Lever arm:**  
\(K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176\)

**Compression reinforcement is not required**

**Hogging moments – Internal strip**

**Penultimate column B3**

Consider the reinforcement concentrated in half width strip over the support

**Depth of reinforcement:**  
**d'** = 200 mm

**Area of reinforcement required:**  
\(A_{s\_req} = \pi \times D^2 / (4 \times 4\gamma_r) = 1005 \text{ mm}^2/\text{m}\)

**Allowable span to depth ratio:**  
\(L / d = 33.663\)

**Provide 16 dia bars @ 200 centres**

**Area of reinforcement provided:**  
\(A_{s\_prov} = \pi \times D^2 / (4 \times s) = 1005 \text{ mm}^2/\text{m}\)

**PASS - Support reinforcement is OK**
Internal column C3

Consider the reinforcement concentrated in half width strip over the support

Depth of reinforcement;  \( d' = 200 \text{ mm} \)

Support moment;  \( m' = 2 \times i \times m = 102.884 \text{ kNm/m} \)

Lever arm;  \( K' = 0.402 \times (b_0 - 0.4) - 0.18 \times (b_0 - 0.4)^2 = 0.176 \)

\[ K = \frac{m'}{(d')^2 \times f_{cu}} = 0.073 \]

Compression reinforcement is not required

\[ z = \min((0.5 + \sqrt{(0.25 - (K / 0.9))), 0.95}) \times d' = 182.1 \text{ mm} \]

Provide 20 dia bars @ 200 centres

Area of reinforcement required;  \( A_{s\text{,req}} = \frac{m' \times (z \times f_y / \gamma_m)}{} = 1300 \text{ mm}^2/m \)

Minimum area of reinforcement required;  \( A_{s\text{,min}} = 0.0013 \times h = 325 \text{ mm}^2/m \)

Area of reinforcement provided;  \( A_{s\text{,prov}} = \pi \times D^2 / (4 \times s) = 1571 \text{ mm}^2/m \)

PASS - Support reinforcement is OK

HOGGING MOMENTS – EXTERNAL STRIP

Penultimate column B1, B2

Consider one and a half bays of negative moment being resisted over the edge and penultimate column

Width of span;  \( B = 7200 \text{ mm} \)

Edge distance;  \( e = 125 \text{ mm} \)

Depth of reinforcement;  \( d' = 200 \text{ mm} \)

Support moment;  \( m' = m \times i \times (e + B + B / 2) / ((0.5 \times B) + (0.2 \times B) + e) = 158.265 \text{ kNm/m} \)

Lever arm;  \( K' = 0.402 \times (b_0 - 0.4) - 0.18 \times (b_0 - 0.4)^2 = 0.176 \)

\[ K = \frac{m' \times (d')^2 \times f_{cu}}{} = 0.113 \]

Compression reinforcement is not required

\[ z = \min((0.5 + \sqrt{(0.25 - (K / 0.9))), 0.95}) \times d' = 170.5 \text{ mm} \]

Provide 20 dia bars @ 125 centres

Area of reinforcement required;  \( A_{s\text{,req}} = \frac{m' \times (z \times f_y / \gamma_m)}{} = 2134 \text{ mm}^2/m \)

Minimum area of reinforcement required;  \( A_{s\text{,min}} = 0.0013 \times h = 325 \text{ mm}^2/m \)

Area of reinforcement provided;  \( A_{s\text{,prov}} = \pi \times D^2 / (4 \times s) = 2513 \text{ mm}^2/m \)

PASS - Support reinforcement is OK

Internal column C1, C2

Consider one and a half bays of negative moment being resisted over the edge and penultimate column

Width of span;  \( B = 7200 \text{ mm} \)

Edge distance;  \( e = 125 \text{ mm} \)

Depth of reinforcement;  \( d' = 200 \text{ mm} \)

Support moment;  \( m' = m \times i \times (e + B + B / 2) / ((0.5 \times B) + (0.2 \times B) + e) = 108.810 \text{ kNm/m} \)

Area of reinforcement provided;  \( A_{s\text{,prov}} = \pi \times D^2 / (4 \times s) = 2513 \text{ mm}^2/m \)

PASS - Support reinforcement is OK
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Lever arm;
\[ K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \]
\[ K = m' / (d'^2 \times f_{cu}) = 0.078 \]

Compression reinforcement is not required

Area of reinforcement required;
\[ z = \min((0.5 + \sqrt{0.25 - (K / 0.9)}), 0.95) \times d' = 180.9 \text{ mm} \]
Minimum area of reinforcement required;
\[ A_{s,\text{min}} = 0.0013 \times h = 325 \text{ mm}^2/\text{m} \]
Area of reinforcement required;
\[ A_{s,\text{req}} = \max(A_{s,\text{des}}, A_{s,\text{min}}) = 1383 \text{ mm}^2/\text{m} \]
Provide 20 dia bars @ 200 centres
Area of reinforcement required; \[ A_{s,\text{req}} = \pi \times D^2 / (4 \times s) = 1571 \text{ mm}^2/\text{m} \]
PASS - Support reinforcement is OK

Corner column A1
Depth of reinforcement;
\[ d' = 206 \text{ mm} \]
Total load on column;
\[ S = (\text{Span}_x / 2) + e_x \times (\text{Span}_y / 2) + e_y \times N_{ult} = 247 \text{ kN} \]
Area of column head;
\[ A = l_x \times l_y = 0.100 \text{ m}^2 \]
Support moment;
\[ m' = S \times (1 - (N_{ult} \times A / S)^{1/3}) = 99.639 \text{ kNm/m} \]
Lever arm;
\[ K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \]
\[ K = m' / (d'^2 \times f_{cu}) = 0.067 \]

Compression reinforcement is not required

Area of reinforcement required;
\[ z = \min((0.5 + \sqrt{0.25 - (K / 0.9)}), 0.95) \times d' = 189.3 \text{ mm} \]
Minimum area of reinforcement required;
\[ A_{s,\text{min}} = 0.0013 \times h = 325 \text{ mm}^2/\text{m} \]
Area of reinforcement required;
\[ A_{s,\text{req}} = \max(A_{s,\text{des}}, A_{s,\text{min}}) = 1211 \text{ mm}^2/\text{m} \]
Provide 16 dia bars @ 150 centres
Area of reinforcement required; \[ A_{s,\text{req}} = \pi \times D^2 / (4 \times s) = 1340 \text{ mm}^2/\text{m} \]
PASS - Support reinforcement is OK

Edge column A2, A3
Depth of reinforcement;
\[ d' = 202 \text{ mm} \]
Total load on column;
\[ S = \text{Span}_x \times (\text{Span}_y / 2 + e_y) \times N_{ult} = 477 \text{ kN} \]
Area of column head;
\[ A = l_x \times l_y = 0.100 \text{ m}^2 \]
Support moment;
\[ m' = S \times (1 - (N_{ult} \times A / S)^{1/3}) / 5.14 = 78.476 \text{ kNm/m} \]
Lever arm;
\[ K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \]
\[ K = m' / (d'^2 \times f_{cu}) = 0.055 \]

Compression reinforcement is not required

Area of reinforcement required;
\[ z = \min((0.5 + \sqrt{0.25 - (K / 0.9)}), 0.95) \times d' = 188.8 \text{ mm} \]
Minimum area of reinforcement required;
\[ A_{s,\text{min}} = 0.0013 \times h = 325 \text{ mm}^2/\text{m} \]
Area of reinforcement required;
\[ A_{s,\text{req}} = \max(A_{s,\text{des}}, A_{s,\text{min}}) = 956 \text{ mm}^2/\text{m} \]
Provide 16 dia bars @ 175 centres
Area of reinforcement provided; \[ A_{s,\text{prov}} = \pi \times D^2 / (4 \times s) = 1149 \text{ mm}^2/\text{m} \]
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**Between columns 1-2, 2-3**

Around the perimeter between the column heads provide a minimum of 50% of the required end span bottom reinforcement.

**Area of reinforcement provided:**

\[ A_{s, prov} = \pi \times D^2 / (4 \times s) = 1340 \text{ mm}^2 / \text{m} \]

**PASS - Support reinforcement is OK**

**Provide 16 dia bars @ 150 centres - 'U' bars with 1600 mm long legs**

**Area of reinforcement provided:**

\[ A_{s, prov} = \pi \times D^2 / (4 \times s) = 1047 \text{ mm}^2 / \text{m} \]

**PASS - Edge reinforcement is OK**

#### Distribution reinforcement

**Provide 12 dia bars @ 300 centres**

**Area of reinforcement provided:**

\[ A_{s, prov} = \pi \times D^2 / (4 \times s) = 377 \text{ mm}^2 / \text{m} \]

#### DESIGN SLAB IN THE Y-DIRECTION

### SAGGING MOMENTS

**End bay 1-2**

**Effective span:**

\[ L = 7000 \text{ mm} \]

**Depth of reinforcement:**

\[ d = 220 \text{ mm} \]

**Midspan moment:**

\[ m = (N_{ult} \times L^2) / (2 \times (1 + \sqrt{1 + i})) = 74.823 \text{ kNm/m} \]

**Support moment:**

\[ m' = i \times m = 74.823 \text{ kNm/m} \]

**Design reinforcement**

**Lever arm:**

\[ K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \]

\[ K = m / (d^2 \times f_{cu}) = 0.044 \]

**Compression reinforcement is not required**

**Area of reinforcement designed:**

\[ A_{s, des} = m / (2 \times f_y / \gamma_m) = 825 \text{ mm}^2 / \text{m} \]

**Minimum area of reinforcement required:**

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

**Area of reinforcement required:**

\[ A_{s, req} = \max(A_{s, des}, A_{s, min}) = 825 \text{ mm}^2 / \text{m} \]

**Provide 20 dia bars @ 200 centres**

**Area of reinforcement provided:**

\[ A_{s, prov} = \pi \times D^2 / (4 \times s) = 1571 \text{ mm}^2 / \text{m} \]

**PASS - Span reinforcement is OK**

**Check deflection**

**Design service stress:**

\[ f_s = 2 \times f_y \times A_{s, req} / (3 \times A_{s, prov} \times \beta_b) = 175 \text{ N/mm}^2 \]

**Modification factor:**

\[ k_1 = \min(0.55+(477N/mm^2-f_s)/(120\times(0.9N/mm^2+(m/d^2))),2) = 1.579 \]

**Allowable span to depth ratio:**

\[ 0.9 \times 26 \times k_1 = 36.942 \]

**Actual span to depth ratio:**

\[ L / d = 31.818 \]

**PASS - Span to depth ratio is OK**

**Internal bay 2-3**

**Effective span:**

\[ L = 6800 \text{ mm} \]

**PASS - Span to depth ratio is OK**
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Depth of reinforcement;
\[ d = 222 \text{ mm} \]

Midspan moment;
\[ m = (N_{ult} \times L^2) / (2 \times (\sqrt{(1 + i)} + \sqrt{(1 + i)})) = 51.442 \text{ kNm/m} \]

Support moment;
\[ m' = i \times m = 51.442 \text{ kNm/m} \]

Design reinforcement
Lever arm;
\[ K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \]
\[ K = m / (d^2 \times f_{cu}) = 0.030 \]

Compression reinforcement is not required

Area of reinforcement designed;
\[ A_{s,des} = m / (2 \times f_y / \gamma_m) = 561 \text{ mm}^2/m \]

Minimum area of reinforcement required;
\[ A_{s,min} = 0.0013 \times h = 325 \text{ mm}^2/m \]

Area of reinforcement required;
\[ A_{s,req} = \max(A_{s,des}, A_{s,min}) = 561 \text{ mm}^2/m \]

Provide 16 dia bars @ 200 centres

Area of reinforcement provided;
\[ A_{s,prov} = \pi \times D^2 / (4 \times s) = 1005 \text{ mm}^2/m \]

PASS - Span reinforcement is OK

Check deflection
Design service stress;
\[ f_s = 2 \times f_y \times A_{s,req} / (3 \times A_{s,prov} \times \beta_b) = 186 \text{ N/mm}^2 \]

Modification factor;
\[ k_1 = \min(0.55+(477N/mm^2-f_s)/(120\times(0.9N/mm^2+(m/d^2))))\times2 = 1.798 \]

Allowable span to depth ratio;
\[ 0.9 \times 26 \times k_1 = 42.062 \]

Actual span to depth ratio;
\[ L / d = 30.631 \]

PASS - Span to depth ratio is OK

HOGGING MOMENTS – INTERNAL STRIP

Penultimate column C2
Consider the reinforcement concentrated in half width strip over the support

Depth of reinforcement;
\[ d' = 220 \text{ mm} \]

Support moment;
\[ m' = 2 \times i \times m = 149.646 \text{ kNm/m} \]

Lever arm;
\[ K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \]
\[ K = m' / (d^2 \times f_{cu}) = 0.088 \]

Compression reinforcement is not required

Area of reinforcement required;
\[ A_{s,des} = m' / (2 \times f_y / \gamma_m) = 1758 \text{ mm}^2/m \]

Minimum area of reinforcement required;
\[ A_{s,min} = 0.0013 \times h = 325 \text{ mm}^2/m \]

Area of reinforcement required;
\[ A_{s,req} = \max(A_{s,des}, A_{s,min}) = 1758 \text{ mm}^2/m \]

Provide 20 dia bars @ 150 centres

Area of reinforcement provided;
\[ A_{s,prov} = \pi \times D^2 / (4 \times s) = 2094 \text{ mm}^2/m \]

PASS - Support reinforcement is OK

Internal column C3
Consider the reinforcement concentrated in half width strip over the support

Depth of reinforcement;
\[ d' = 220 \text{ mm} \]
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Support moment; \( m' = 2 \times i \times m = 102.884 \text{ kNm/m} \)
Lever arm; \( K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \)
\[ K = \frac{m'}{(d'^2 \times f_{cu})} = 0.061 \]

Compression reinforcement is not required
\[ z = \min((0.5 + \sqrt{0.25 - (K / 0.9)}), 0.95) \times d' = 204.0 \text{ mm} \]
Area of reinforcement required; \( A_{s, des} = \frac{m'}{(z \times f_y / \gamma_m)} = 1160 \text{ mm}^2/\text{m} \)
Minimum area of reinforcement required; \( A_{s, min} = 0.0013 \times h = 325 \text{ mm}^2/\text{m} \)
Area of reinforcement required; \( A_{s, req} = \max(A_{s, des}, A_{s, min}) = 1160 \text{ mm}^2/\text{m} \)
Provide 20 dia bars @ 200 centres
Area of reinforcement provided; \( A_{s, prov} = \pi \times D^2 / (4 \times s) = 1571 \text{ mm}^2/\text{m} \)

PASS - Support reinforcement is OK

HOGGING MOMENTS – EXTERNAL STRIP

Penultimate column A2, B2
Consider one and a half bays of negative moment being resisted over the edge and penultimate column
Width of span; \( B = 7200 \text{ mm} \)
Edge distance; \( e = 125 \text{ mm} \)
Depth of reinforcement; \( d' = 220 \text{ mm} \)
Support moment; \( m' = m \times i \times (e + B + B / 2) / ((0.5 \times B) + (0.2 \times B) + e) = 158.265 \text{ kNm/m} \)
Lever arm; \( K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \)
\[ K = \frac{m'}{(d'^2 \times f_{cu})} = 0.093 \]

Compression reinforcement is not required
\[ z = \min((0.5 + \sqrt{0.25 - (K / 0.9)}), 0.95) \times d' = 194.1 \text{ mm} \]
Area of reinforcement required; \( A_{s, des} = \frac{m'}{(z \times f_y / \gamma_m)} = 1875 \text{ mm}^2/\text{m} \)
Minimum area of reinforcement required; \( A_{s, min} = 0.0013 \times h = 325 \text{ mm}^2/\text{m} \)
Area of reinforcement required; \( A_{s, req} = \max(A_{s, des}, A_{s, min}) = 1875 \text{ mm}^2/\text{m} \)
Provide 20 dia bars @ 150 centres
Area of reinforcement provided; \( A_{s, prov} = \pi \times D^2 / (4 \times s) = 2094 \text{ mm}^2/\text{m} \)

PASS - Support reinforcement is OK

Internal column A3, B3
Consider one and a half bays of negative moment being resisted over the edge and penultimate column
Width of span; \( B = 7200 \text{ mm} \)
Edge distance; \( e = 125 \text{ mm} \)
Depth of reinforcement; \( d' = 220 \text{ mm} \)
Support moment; \( m' = m \times i \times (e + B + B / 2) / ((0.5 \times B) + (0.2 \times B) + e) = 108.810 \text{ kNm/m} \)
Lever arm; \( K' = 0.402 \times (\beta_b - 0.4) - 0.18 \times (\beta_b - 0.4)^2 = 0.176 \)
\[ K = \frac{m'}{(d'^2 \times f_{cu})} = 0.064 \]
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Compression reinforcement is not required

Area of reinforcement required;
\[ A_{s \text{ des}} = m' / (z \times f_y / \gamma_m) = 1233 \text{ mm}^2/m \]

Minimum area of reinforcement required;
\[ A_{s \text{ min}} = 0.0013 \times h = 325 \text{ mm}^2/m \]

Area of reinforcement required;
\[ A_{s \text{ req}} = \max (A_{s \text{ des}}, A_{s \text{ min}}) = 1233 \text{ mm}^2/m \]

Provide 20 dia bars @ 200 centres

Area of reinforcement provided;
\[ A_{s \text{ prov}} = \pi \times D^2 / (4 \times s) = 1571 \text{ mm}^2/m \]

PASS - Support reinforcement is OK

Edge column B1, C1

Depth of reinforcement;
\[ d' = 222 \text{ mm} \]

Total load on column;
\[ S = (\text{Span}_x / 2 + \epsilon_x) \times \text{Span}_y \times N_{ult} = 477 \text{ kN} \]

Area of column head;
\[ A = l x_1 \times l_y = 0.100 \text{ m}^2 \]

Support moment;
\[ m' = S \times (1 - (N_{ult} \times A / S)^{1/3}) / 5.14 = 78.476 \text{ kNm/m} \]

Lever arm;
\[ K' = 0.402 \times (\beta b - 0.4) - 0.18 \times (\beta b - 0.4)^2 = 0.176 \]

Compression reinforcement is not required

Area of reinforcement required;
\[ z = \min((0.5 + \sqrt{(0.25 - (K / 0.9))), 0.95}) \times d' = 203.0 \text{ mm} \]

Area of reinforcement required;
\[ A_{s \text{ des}} = m' / (z \times f_y / \gamma_m) = 203.0 \text{ mm}^2/m \]

Minimum area of reinforcement required;
\[ A_{s \text{ min}} = 0.0013 \times h = 325 \text{ mm}^2/m \]

Area of reinforcement required;
\[ A_{s \text{ req}} = \max (A_{s \text{ des}}, A_{s \text{ min}}) = 203.0 \text{ mm}^2/m \]

Provide 16 dia bars @ 175 centres

Area of reinforcement provided;
\[ A_{s \text{ prov}} = \pi \times D^2 / (4 \times s) = 1149 \text{ mm}^2/m \]

PASS - Edge reinforcement is OK

Between columns A-B, B-C

Around the perimeter between the column heads provide a minimum of 50% of the required end span bottom reinforcement.

Area of reinforcement required;
\[ A_{s \text{ req}} = A_{sy1} / 2 = 785 \text{ mm}^2/m \]

Provide 16 dia bars @ 200 centres - 'U' bars with 1600 mm long legs

Area of reinforcement provided;
\[ A_{s \text{ prov}} = \pi \times D^2 / (4 \times s) = 1005 \text{ mm}^2/m \]

PASS - Edge reinforcement is OK

PUNCHING SHEAR

Corner column A1

Design shear transferred to column;
\[ V_t = ((0.45 \times \text{Span}_x + \epsilon_x) \times ((0.45 \times \text{Span}_y) + \epsilon_y) \times N_{ult} = 202 \text{ kN} \]

Design effective shear transferred to column;
\[ V_{eff} = 1.25 \times V_t = 252 \text{ kN} \]

Area of tension steel in x-direction;
\[ A_{sx \text{ tan}} = A_{scorer} = 1340 \text{ mm}^2/m \]

Area of tension steel in y-direction;
\[ A_{sy \text{ tan}} = A_{scorer} = 1340 \text{ mm}^2/m \]

Column perimeter;
\[ u_c = l_{x1} + l_y = 650 \text{ mm} \]

Average effective depth of reinforcement;
\[ d = h - c - \phi_p = 214 \text{ mm} \]
Maximum allowable shear stress; \( v_{\text{max}} = \min(0.8 \times \sqrt{(f_{\text{cd}})}, 5) = 4.733 \text{ N/mm}^2 \)

Design shear stress at column perimeter; \( v_0 = \frac{V_{\text{eff}}}{(u_c \times d)} = 1.811 \text{ N/mm}^2 \)

**PASS - Maximum concrete shear stress not exceeded at column perimeter**

**Shear reinforcement at a perimeter of 1.50d - (321 mm)**

Length of shear perimeter; \( u = u_c + (2 \times (k_x + k_y) \times k \times d) = 1292 \text{ mm} \)

Area of tension steel at shear perimeter; \( A_{s_{\text{ten}}} = (k_y \times (p_x + (k_x + k_y) \times d)) \times \frac{u}{3} \times \frac{(p_x + (k_x + k_y) \times d)}{x} \times \frac{A_{s_{\text{ten}}}}{A_{y_{\text{v}}}} = 1731 \text{ mm}^2 \)

Shear reinforcement required at perimeter; \( A_{s_{\text{req}}} = (V_{\text{eff}} - v_0) \times u \times d / (0.95 \times f_{\text{cu}}) = 119 \text{ mm}^2 \)

**Shear reinforcement at a perimeter of 2.25d - (482 mm)**

Length of shear perimeter; \( u = u_c + (2 \times (k_x + k_y) \times k \times d) = 1613 \text{ mm} \)

Area of tension steel at shear perimeter; \( A_{s_{\text{ten}}} = (k_y \times (p_x + (k_x + k_y) \times d)) \times \frac{u}{3} \times \frac{(p_x + (k_x + k_y) \times d)}{x} \times \frac{A_{s_{\text{ten}}}}{A_{y_{\text{v}}}} = 2161 \text{ mm}^2 \)

Shear reinforcement required at perimeter; \( A_{s_{\text{req}}} = (V_{\text{eff}} - v_0) \times u \times d / (0.95 \times f_{\text{cu}}) = 16 \text{ mm}^2 \)

**Shear reinforcement at a perimeter of 3.00d - (642 mm)**

Length of shear perimeter; \( u = u_c + (2 \times (k_x + k_y) \times k \times d) = 1934 \text{ mm} \)

Area of tension steel at shear perimeter; \( A_{s_{\text{ten}}} = (k_y \times (p_x + (k_x + k_y) \times d)) \times \frac{u}{3} \times \frac{(p_x + (k_x + k_y) \times d)}{x} \times \frac{A_{s_{\text{ten}}}}{A_{y_{\text{v}}}} = 2592 \text{ mm}^2 \)

Shear reinforcement required at perimeter; \( A_{s_{\text{req}}} = (V_{\text{eff}} - v_0) \times u \times d / (0.95 \times f_{\text{cu}}) = 45 \text{ mm}^2 \)

**Penultimate edge column A2**

Design shear transferred to column; \( V_t = (0.45 \times \text{Span}_y + e_x) \times (1.05 \times \text{Span}_y) \times N_{\text{eff}} = 453 \text{ kN} \)

Design effective shear transferred to column; \( V_{\text{eff}} = 1.4 \times V_t = 634 \text{ kN} \)

Area of tension steel in x-direction; \( A_{s_{\text{ten}}} = A_{s_{\text{edge}}} = 1148 \text{ mm}^2/m \)
Area of tension steel in y-direction; \( A_{sy \_tan} = A_{sy \_v} = \frac{2094}{m^2} \)

Column perimeter; \( u_k = (2 \times l_{k}) \times l_{y} = 900 \) mm

Average effective depth of reinforcement; \( d = h - c - \phi_y = 214 \) mm

Maximum allowable shear stress; \( v_{max} = \text{min}(0.8 \times \sqrt{(f_{cu})), 5) = 4.733 \) N/mm²

Design shear stress at column perimeter; \( v_0 = V_{eff} / (u_k \times d) = 0.392 \) N/mm²

\textbf{PASS - Maximum concrete shear stress not exceeded at column perimeter}

Shear reinforcement at a perimeter of 1.50d - (321 mm)

Length of shear perimeter; \( u = u_k + (2 \times (k_y \times k_y) \times k \times d) = 2184 \) mm

Area of tension steel at shear perimeter; \( A_{sy \_tan} = (k_y \times (p_x + (k_y \times k \times d)) \times A_{sy \_v}) + (k_y \times (p_y + (k_y \times k \times d)) \times A_{sy \_v}) \)

Design concrete shear stress; \( v_c = \text{min}(f_{cu},40) / (25)^{1/3} \times 0.79 \times \text{min}(100 \times A_{sy \_tan} / (u \times d),3^{1/3} \times \text{max}(400, d), 1)^{1/3} / 1.25 \)

Nominal design shear stress at perimeter; \( v = V_{eff} / (u \times d) = 1.356 \) N/mm²

Shear reinforcement required at perimeter; \( A_{sy \_req} = 5 \times ((0.7 \times v) - v_c) \times u \times d / (0.95 \times f_{sy}) = 947 \) mm²

Shear reinforcement at a perimeter of 2.25d - (482 mm)

Length of shear perimeter; \( u = u_k + (2 \times (k_y \times k_y) \times k \times d) = 2826 \) mm

Area of tension steel at shear perimeter; \( A_{sy \_tan} = (k_y \times (p_x + (k_y \times k \times d)) \times A_{sy \_v}) + (k_y \times (p_y + (k_y \times k \times d)) \times A_{sy \_v}) \)

Design concrete shear stress; \( v_c = \text{min}(f_{cu},40) / (25)^{1/3} \times 0.79 \times \text{min}(100 \times A_{sy \_tan} / (u \times d),3^{1/3} \times \text{max}(400, d), 1)^{1/3} / 1.25 \)

Nominal design shear stress at perimeter; \( v = V_{eff} / (u \times d) = 1.048 \) N/mm²

Shear reinforcement required at perimeter; \( A_{sy \_req} = (v - v_c) \times u \times d / (0.95 \times f_{sy}) = 372 \) mm²

Shear reinforcement at a perimeter of 3.00d - (642 mm)

Length of shear perimeter; \( u = u_k + (2 \times (k_y \times k_y) \times k \times d) = 3468 \) mm

Area of tension steel at shear perimeter; \( A_{sy \_tan} = (k_y \times (p_x + (k_y \times k \times d)) \times A_{sy \_v}) + (k_y \times (p_y + (k_y \times k \times d)) \times A_{sy \_v}) \)

Design concrete shear stress; \( v_c = \text{min}(f_{cu},40) / (25)^{1/3} \times 0.79 \times \text{min}(100 \times A_{sy \_tan} / (u \times d),3^{1/3} \times \text{max}(400, d), 1)^{1/3} / 1.25 \)

Nominal design shear stress at perimeter; \( v = V_{eff} / (u \times d) = 0.854 \) N/mm²

Shear reinforcement required at perimeter; \( A_{sy \_req} = (v - v_c) \times u \times d / (0.95 \times f_{sy}) = 154 \) mm²
Shear reinforcement at a perimeter of 3.75d - (803 mm)
Length of shear perimeter; \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 4110 \) mm
Area of tension steel at shear perimeter; \( A_{sx_{\text{ten}}} = (k_y \times (p_x + (k_y \times k \times d)) \times A_{sy_{\text{ten}}} + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sy_{\text{ten}}} \)

Design concrete shear stress; \( v_c = \min(0.755 \text{ N/mm}^2) \)
Nominal design shear stress at perimeter; \( v = V_{efl} / (u \times d) = 0.721 \text{ N/mm}^2 \)

Internal edge column A3
Design shear transferred to column; \( V_y = ((0.45 \times \text{Span}_y) + e_y) \times \text{Span}_y \times N_{st} = 431 \text{ kN} \)
Design effective shear transferred to column; \( V_{eff} = 1.4 \times V_y = 604 \text{ kN} \)
Area of tension steel in x-direction; \( A_{sx_{\text{ten}}} = A_{sx_{\text{edge}}} = 1148 \text{ mm}^2/m \)
Area of tension steel in y-direction; \( A_{sy_{\text{ten}}} = A_{sy_0} = 1570 \text{ mm}^2/m \)
Column perimeter; \( u_c = (2 \times l_x) + l_y = 900 \text{ mm} \)
Average effective depth of reinforcement; \( d = h - c - q_y = 214 \text{ mm} \)
Maximum allowable shear stress; \( v_{\text{max}} = \min(0.8 \times \sqrt{(f_{cu}), 5}) = 4.733 \text{ N/mm}^2 \)
Design shear stress at column perimeter; \( V_0 = V_{efl} / (u_c \times d) = 3.135 \text{ N/mm}^2 \)

**PASS - Maximum concrete shear stress not exceeded at column perimeter**

Shear reinforcement at a perimeter of 1.50d - (321 mm)
Length of shear perimeter; \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 2184 \text{ mm} \)
Area of tension steel at shear perimeter; \( A_{sx_{\text{ten}}} = (k_y \times (p_x + (k_y \times k \times d)) \times A_{sy_{\text{ten}}} + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sy_{\text{ten}}} \)

Design concrete shear stress; \( v_c = \min(0.712 \text{ N/mm}^2) \)
Nominal design shear stress at perimeter; \( v = V_{efl} / (u \times d) = 1.292 \text{ N/mm}^2 \)

Shear reinforcement at a perimeter of 2.25d - (482 mm)
Length of shear perimeter; \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 2826 \text{ mm} \)
Area of tension steel at shear perimeter; \( A_{sx_{\text{ten}}} = (k_y \times (p_x + (k_y \times k \times d)) \times A_{sy_{\text{ten}}} + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sy_{\text{ten}}} \)

Design concrete shear stress; \( v_c = \min(0.712 \text{ N/mm}^2) \)
Nominal design shear stress at perimeter; \[ v = V_{\text{eff}} / (u \times d) = 0.998 \text{ N/mm}^2 \]

Shear reinforcement required at perimeter; \[ A_{s_{\text{ty}}_{\text{req}}} = (v - v_c) \times u \times d / (0.95 \times f_{\text{ty}}) = 365 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 3.00d - (642 mm)

Length of shear perimeter; \[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 3468 \text{ mm} \]

Area of tension steel at shear perimeter; \[ A_{s_{\text{ty}}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{s_{\text{ty}}} + (k_x \times (p_y + (k_y \times k \times d))) \times A_{s_{\text{ty}}} = 4734 \text{ mm}^2 \]

Design concrete shear stress; \[ v_c = \min(f_{c_{\text{ub}}}, 40) / 25^{1/3} \times 0.79 \times \min(100 \times A_{s_{\text{ty}}}, u \times d), 3^{1/3} \times \max(400 / d, 1)^{1/4} / 1.25 \]

Nominal design shear stress at perimeter; \[ v = V_{\text{eff}} / (u \times d) = 0.814 \text{ N/mm}^2 \]

Shear reinforcement required at perimeter; \[ A_{s_{\text{ty}}_{\text{req}}} = (v - v_c) \times u \times d / (0.95 \times f_{\text{ty}}) = 159 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 3.75d - (803 mm)

Length of shear perimeter; \[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 4110 \text{ mm} \]

Area of tension steel at shear perimeter; \[ A_{s_{\text{ty}}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{s_{\text{ty}}} + (k_x \times (p_y + (k_y \times k \times d))) \times A_{s_{\text{ty}}} = 5607 \text{ mm}^2 \]

Design concrete shear stress; \[ v_c = \min(f_{c_{\text{ub}}}, 40) / 25^{1/3} \times 0.79 \times \min(100 \times A_{s_{\text{ty}}}, u \times d), 3^{1/3} \times \max(400 / d, 1)^{1/4} / 1.25 \]

Nominal design shear stress at perimeter; \[ v = V_{\text{eff}} / (u \times d) = 0.686 \text{ N/mm}^2 \]

Shear reinforcement at column perimeter; \[ A_{s_{\text{ty}}} = V_{\text{eff}} / (u_c \times d) = 3.292 \text{ N/mm}^2 \]

**PASS - Maximum concrete shear stress not exceeded at column perimeter**

Penultimate edge column B1

Design shear transferred to column; \[ V_t = (1.05 \times \text{Span}_{x}) \times (0.45 \times \text{Span}_{y}) + e_y \times N_{\text{eff}} = 453 \text{ kN} \]

Design effective shear transferred to column; \[ V_{\text{eff}} = 1.4 \times V_t = 634 \text{ kN} \]

Area of tension steel in x-direction; \[ A_{s_{\text{ty}}} = A_{s_{\text{ty}}} = 2513 \text{ mm}^2/m \]

Area of tension steel in y-direction; \[ A_{s_{\text{ty}}} = A_{s_{\text{ty}}} = 1148 \text{ mm}^2/m \]

Column perimeter; \[ u_c = l_y + (2 \times l_y) = 900 \text{ mm} \]

Average effective depth of reinforcement; \[ d = h - c - \phi_p = 214 \text{ mm} \]

Maximum allowable shear stress; \[ v_{\text{max}} = \min(0.8 \times \sqrt{(f_{c_{\text{ub}}}), 5}) = 4.733 \text{ N/mm}^2 \]

Design shear stress at column perimeter; \[ v_c = V_{\text{eff}} / (u_c \times d) = 3.292 \text{ N/mm}^2 \]

Shear reinforcement at a perimeter of 1.50d - (321 mm)

Length of shear perimeter; \[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 2184 \text{ mm} \]

Area of tension steel at shear perimeter; \[ A_{s_{\text{ty}}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{s_{\text{ty}}} + (k_x \times (p_y + (k_y \times k \times d))) \times A_{s_{\text{ty}}} = 4066 \text{ mm}^2 \]
Design concrete shear stress:
\[ \nu_c = \left( \min(f_{cu},40)/25 \right)^{1/3} \times 0.79 \times \min(100 \times A_{st,\text{tel}}/(u \times d),3)^{1/3} \times \max(400/(d,1))^{1/4} / 1.25 \]
\[ \nu_c = 0.789 \text{ N/mm}^2 \]
Nominal design shear stress at perimeter;
\[ \nu = V_{\text{eff}} / (u \times d) = 1.356 \text{ N/mm}^2 \]
\[ 1.6 \times \nu_c < \nu \leq 2 \times \nu_c \]
Shear reinforcement required at perimeter;
\[ A_{sv,\text{req}} = 5 \times ((0.7 \times \nu_c) \times u \times d / (0.95 \times f_{vy}) = 789 \text{ mm}^2 \]
Shear reinforcement at a perimeter of 2.25d - (482 mm)
Length of shear perimeter;
\[ u = u_c + (2 \times (k_x + k_y) \times k \times d) = 2826 \text{ mm} \]
Area of tension steel at shear perimeter;
\[ A_{st,\text{tan}} = (k_y \times (p_x + (k_x + k_y) \times d)) \times A_{sy,\text{tan}} \]
\[ A_{st,\text{tan}} = 5241 \text{ mm}^2 \]
Design concrete shear stress;
\[ \nu_c = \left( \min(f_{cu},40)/25 \right)^{1/3} \times 0.79 \times \min(100 \times A_{st,\text{tel}}/(u \times d),3)^{1/3} \times \max(400/(d,1))^{1/4} / 1.25 \]
\[ \nu_c = 0.788 \text{ N/mm}^2 \]
Nominal design shear stress at perimeter;
\[ \nu = V_{\text{eff}} / (u \times d) = 1.048 \text{ N/mm}^2 \]
\[ \nu_c < \nu \leq 1.6 \times \nu_c \]
Shear reinforcement required at perimeter;
\[ A_{sv,\text{req}} = (\nu - \nu_c) \times u \times d / (0.95 \times f_{vy}) = 331 \text{ mm}^2 \]
Shear reinforcement at a perimeter of 3.00d - (642 mm)
Length of shear perimeter;
\[ u = u_c + (2 \times (k_x + k_y) \times k \times d) = 3468 \text{ mm} \]
Area of tension steel at shear perimeter;
\[ A_{st,\text{tan}} = (k_y \times (p_x + (k_x + k_y) \times d)) \times A_{sy,\text{tan}} \]
\[ A_{st,\text{tan}} = 6416 \text{ mm}^2 \]
Design concrete shear stress;
\[ \nu_c = \left( \min(f_{cu},40)/25 \right)^{1/3} \times 0.79 \times \min(100 \times A_{st,\text{tel}}/(u \times d),3)^{1/3} \times \max(400/(d,1))^{1/4} / 1.25 \]
\[ \nu_c = 0.788 \text{ N/mm}^2 \]
Nominal design shear stress at perimeter;
\[ \nu = V_{\text{eff}} / (u \times d) = 0.854 \text{ N/mm}^2 \]
\[ \nu_c < \nu \leq 1.6 \times \nu_c \]
Shear reinforcement required at perimeter;
\[ A_{sv,\text{req}} = (\nu - \nu_c) \times u \times d / (0.95 \times f_{vy}) = 104 \text{ mm}^2 \]
Shear reinforcement at a perimeter of 3.75d - (803 mm)
Length of shear perimeter;
\[ u = u_c + (2 \times (k_x + k_y) \times k \times d) = 4110 \text{ mm} \]
Area of tension steel at shear perimeter;
\[ A_{st,\text{tan}} = (k_y \times (p_x + (k_x + k_y) \times d)) \times A_{sy,\text{tan}} \]
\[ A_{st,\text{tan}} = 7592 \text{ mm}^2 \]
Design concrete shear stress;
\[ \nu_c = \left( \min(f_{cu},40)/25 \right)^{1/3} \times 0.79 \times \min(100 \times A_{st,\text{tel}}/(u \times d),3)^{1/3} \times \max(400/(d,1))^{1/4} / 1.25 \]
\[ \nu_c = 0.787 \text{ N/mm}^2 \]
Nominal design shear stress at perimeter;
\[ \nu = V_{\text{eff}} / (u \times d) = 0.721 \text{ N/mm}^2 \]
\[ \nu_c < \nu \text{ no shear reinforcement required} \]
Penultimate central column B2

Design shear transferred to column;
\[ V_t = (1.05 \times \text{Span}_x) \times (1.05 \times \text{Span}_y) \times N_{ut} = 1017 \text{ kN} \]

Design effective shear transferred to column;
\[ V_{\text{eff}} = 1.15 \times V_t = 1170 \text{ kN} \]

Area of tension steel in x-direction;
\[ A_{sx\_tan} = A_{sx\_tan} = 2513 \text{ mm}^2/m \]

Area of tension steel in y-direction;
\[ A_{sy\_tan} = A_{sy\_tan} = 2094 \text{ mm}^2/m \]

Column perimeter;
\[ u_c = 2 \times (k_x + k_y) = 1600 \text{ mm} \]

Average effective depth of reinforcement;
\[ d = h - c - \phi_d = 214 \text{ mm} \]

Maximum allowable shear stress;
\[ v_{max} = \min(0.8 \times \sqrt{(f_{cu})}, 5) = 4.733 \text{ N/mm}^2 \]

Design shear stress at column perimeter;
\[ V_0 = V_{\text{eff}} / (u_c \times d) = 3.417 \text{ N/mm}^2 \]

**PASS - Maximum concrete shear stress not exceeded at column perimeter**

Shear reinforcement required at a perimeter of 1.50d - (321 mm)

Length of shear perimeter;
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 4168 \text{ mm} \]

Area of tension steel at shear perimeter;
\[ A_{sx\_tan} = (k_x \times (p_x + (k_x \times k \times d)) \times A_{sy\_tan}) + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sy\_tan}) \]

Design concrete shear stress;
\[ v_c = \min(f_{cu},40)/25^{1/3} \times 0.79 \times \min(100 \times A_{sx\_tan}/(u \times d),3)^{1/3} \times \max(400/(d,1))^{1/4}/1.25 \]
\[ v_c = 0.847 \text{ N/mm}^2 \]

Nominal design shear stress at perimeter;
\[ v = V_{\text{eff}} / (u \times d) = 1.312 \text{ N/mm}^2 \]
\[ v_c < v \leq 1.6 \times v_c \]

Shear reinforcement required at perimeter;
\[ A_{sv\_req} = (v - v_c) \times u \times d / (0.95 \times f_{cu}) = 872 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 2.25d - (482 mm)

Length of shear perimeter;
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 5452 \text{ mm} \]

Area of tension steel at shear perimeter;
\[ A_{sx\_tan} = (k_x \times (p_x + (k_x \times k \times d)) \times A_{sy\_tan}) + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sy\_tan}) \]

Design concrete shear stress;
\[ v_c = \min(f_{cu},40)/25^{1/3} \times 0.79 \times \min(100 \times A_{sx\_tan}/(u \times d),3)^{1/3} \times \max(400/(d,1))^{1/4}/1.25 \]
\[ v_c = 0.847 \text{ N/mm}^2 \]

Nominal design shear stress at perimeter;
\[ v = V_{\text{eff}} / (u \times d) = 1.003 \text{ N/mm}^2 \]
\[ v_c < v \leq 1.6 \times v_c \]

Shear reinforcement required at perimeter;
\[ A_{sv\_req} = (v - v_c) \times u \times d / (0.95 \times f_{cu}) = 382 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 3.00d - (642 mm)

Length of shear perimeter;
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 6736 \text{ mm} \]

Area of tension steel at shear perimeter;
\[ A_{sx\_tan} = (k_x \times (p_x + (k_x \times k \times d)) \times A_{sy\_tan}) + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sy\_tan}) \]

Design concrete shear stress;
\[ v_c = \min(f_{cu},40)/25^{1/3} \times 0.79 \times \min(100 \times A_{sx\_tan}/(u \times d),3)^{1/3} \times \max(400/(d,1))^{1/4}/1.25 \]
\( v_c = 0.847 \text{ N/mm}^2 \)

Nominal design shear stress at perimeter;
\( v = \frac{V_{\text{eff}}}{u \times d} = 0.812 \text{ N/mm}^2 \)
\( v < v_c \) no shear reinforcement required

Internal central column B3
Design shear transferred to column;  \( V_l = (1.05 \times \text{Span}_x) \times \text{Span}_y \times N_{\text{ult}} = 969 \text{ kN} \)
Design effective shear transferred to column;  \( V_{\text{eff}} = 1.15 \times V_l = 1114 \text{ kN} \)
Area of tension steel in x-direction;  \( A_{s_x\text{, tan}} = 2094 \text{ mm}^2/m \)
Area of tension steel in y-direction;  \( A_{s_y\text{, tan}} = 1570 \text{ mm}^2/m \)
Column perimeter;  \( u_c = 2 \times (l_x + l_y) = 1600 \text{ mm} \)
Average effective depth of reinforcement;  \( d = h - c - \phi_l = 214 \text{ mm} \)
Maximum allowable shear stress;  \( v_{\text{max}} = \min(0.8 \times \sqrt{(f_{cu}^s)}, 5) = 4.733 \text{ N/mm}^2 \)
Design shear stress at column perimeter;  \( v_0 = \frac{V_{\text{eff}}}{(u_c \times d)} = 3.254 \text{ N/mm}^2 \)

**PASS - Maximum concrete shear stress not exceeded at column perimeter**

Shear reinforcement at a perimeter of 1.50d - (321 mm)
Length of shear perimeter;  \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 4168 \text{ mm} \)
Area of tension steel at shear perimeter;  \( A_{s_x\text{, tan}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{s_y\text{, tan}}) + (k_y \times (p_y + (k_x \times k \times d)) \times A_{s_y\text{, tan}}) \)
A\text{~}s_{_x\text{, tan}} = 7636 \text{ mm}^2
Design concrete shear stress;
\( v_c = \frac{(\min(f_{cu}\text{, 40})/25)^{1/3} \times 0.79 \times \min(100 \times A_{s_{_x\text{, tan}}} / (u \times d), 3)^{1/3} \times \max(400 / d, 1)^{1/4}}{1.25} \)
\( v_c = 0.785 \text{ N/mm}^2 \)
Nominal design shear stress at perimeter;  \( v = \frac{V_{\text{eff}}}{(u \times d)} = 1.249 \text{ N/mm}^2 \)
\( v < v_c \leq 1.6 \times v_c \)
Shear reinforcement required at perimeter;  \( A_{s_{_x\text{, req}}} = (v - v_c) \times u \times d / (0.95 \times f_{cu}) = 872 \text{ mm}^2 \)

Shear reinforcement at a perimeter of 2.25d - (482 mm)
Length of shear perimeter;  \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 5452 \text{ mm} \)
Area of tension steel at shear perimeter;  \( A_{s_x\text{, tan}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{s_y\text{, tan}}) + (k_y \times (p_y + (k_x \times k \times d)) \times A_{s_y\text{, tan}}) \)
A\text{~}s_{_x\text{, tan}} = 9988 \text{ mm}^2
Design concrete shear stress;
\( v_c = \frac{(\min(f_{cu}\text{, 40})/25)^{1/3} \times 0.79 \times \min(100 \times A_{s_{_x\text{, tan}}} / (u \times d), 3)^{1/3} \times \max(400 / d, 1)^{1/4}}{1.25} \)
\( v_c = 0.785 \text{ N/mm}^2 \)
Nominal design shear stress at perimeter;  \( v = \frac{V_{\text{eff}}}{(u \times d)} = 0.955 \text{ N/mm}^2 \)
\( v < v_c \leq 1.6 \times v_c \)
Shear reinforcement required at perimeter;  \( A_{s_{_x\text{, req}}} = (v - v_c) \times u \times d / (0.95 \times f_{cu}) = 418 \text{ mm}^2 \)

Shear reinforcement at a perimeter of 3.00d - (642 mm)
Length of shear perimeter;  \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 6736 \text{ mm} \)
Area of tension steel at shear perimeter;  \( A_{s_x\text{, tan}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{s_y\text{, tan}}) + (k_y \times (p_y + (k_x \times k \times d)) \times A_{s_y\text{, tan}}) \)

Design concrete shear stress;
\[ v_c = \left( \min(f_{cu}, 40)/25 \right)^{1/3} \times 0.79 \times \min(100 \times A_{st,tan}/(u \times d), 3)^{1/3} \times \max(400/d, 1)^{1/3}/1.25 \]
\[ v_c = 0.785 \text{ N/mm}^2 \]
Nominal design shear stress at perimeter;
\[ v = V_{dl} / (u \times d) = 0.773 \text{ N/mm}^2 \]
\[ v < v_c \text{ no shear reinforcement required} \]

**Internal edge column C1**

Design shear transferred to column;
\[ V_t = \text{Span}_x \times ((0.45 \times \text{Span}_y) + e_y) \times N_{ult} = 431 \text{ kN} \]
Design effective shear transferred to column;
\[ V_{eff} = 1.4 \times V_1 = 604 \text{ kN} \]
Area of tension steel in x-direction;
\[ A_{sx,tan} = A_{sx,te} = 1570 \text{ mm}^2/m \]
Area of tension steel in y-direction;
\[ A_{sy,tan} = A_{sy,te} = 1148 \text{ mm}^2/m \]
Column perimeter;
\[ u_c = (l_y + (2 \times l_y)) = 900 \text{ mm} \]

(Maximum allowable shear stress;
\[ \nu_{max} = \min(0.8 \times \sqrt{(f_{cu}), 5}) = 4.733 \text{ N/mm}^2 \]
Design shear stress at column perimeter;
\[ \nu_0 = V_{eff} / (u_c \times d) = 3.135 \text{ N/mm}^2 \]
**PASS - Maximum concrete shear stress not exceeded at column perimeter**

Shear reinforcement at a perimeter of 1.50d - (321 mm)

Length of shear perimeter;
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 2184 \text{ mm} \]
Area of tension steel at shear perimeter;
\[ A_{sx,tan} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{sy,tan}) + (k_x \times (p_y + (k_y \times k \times d))) \times A_{sy,tan} \]
\[ A_{sx,tan} = 2989 \text{ mm}^2 \]

Design concrete shear stress;
\[ v_c = \left( \min(f_{cu}, 40)/25 \right)^{1/3} \times 0.79 \times \min(100 \times A_{st,tan}/(u \times d), 3)^{1/3} \times \max(400/d, 1)^{1/3}/1.25 \]
\[ v_c = 0.712 \text{ N/mm}^2 \]
Nominal design shear stress at perimeter;
\[ v = V_{dl} / (u \times d) = 1.292 \text{ N/mm}^2 \]
\[ 1.6 \times v_c < v <= 2 \times v_c \]
Shear reinforcement required at perimeter;
\[ A_{sy,req} = 5 \times ((0.7 \times v) - v_c) \times u \times d / (0.95 \times f_{yv}) = 945 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 2.25d - (482 mm)

Length of shear perimeter;
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 2826 \text{ mm} \]
Area of tension steel at shear perimeter;
\[ A_{sx,tan} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{sy,tan}) + (k_x \times (p_y + (k_y \times k \times d))) \times A_{sy,tan} \]
\[ A_{sx,tan} = 3862 \text{ mm}^2 \]

Design concrete shear stress;
\[ v_c = \left( \min(f_{cu}, 40)/25 \right)^{1/3} \times 0.79 \times \min(100 \times A_{st,tan}/(u \times d), 3)^{1/3} \times \max(400/d, 1)^{1/3}/1.25 \]
\[ v_c = 0.712 \text{ N/mm}^2 \]
Nominal design shear stress at perimeter;
\[ v = V_{dl} / (u \times d) = 0.998 \text{ N/mm}^2 \]
\[ v_c < v <= 1.6 \times v_c \]
Shear reinforcement required at perimeter;
\[ A_{sy,req} = (v - v_c) \times u \times d / (0.95 \times f_{yv}) = 365 \text{ mm}^2 \]
Shear reinforcement at a perimeter of 3.00d - (642 mm)

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**Design concrete shear stress**

\[ A_{sx,tan} = 12340 \text{ mm}^2 \]
Length of shear perimeter; \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 3468 \text{ mm} \)

Area of tension steel at shear perimeter; \( A_{\text{ton}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{\text{sy,ton}} + (k_x \times (p_y + (k_y \times k \times d)) \times A_{\text{sy,ton}}) \times A_{\text{ton}} = 4734 \text{ mm}^2 \)

Design concrete shear stress; \( \nu_c = \min(f_{cu,40}/25)^{1/3} \times 0.79 \times \min(100 \times A_{\text{ton}}/(u \times d), 3)^{1/3} \times \max(400/(d \times 1.15)/1.25 \text{ N/mm}^2 \)

Nominal design shear stress at perimeter; \( \nu = V_{\text{eff}}/(u \times d) = 0.814 \text{ N/mm}^2 \)

Shear reinforcement required at perimeter; \( A_{\text{sy,req}} = (\nu - \nu_c) \times u \times d / (0.95 \times f_{cu}) = 159 \text{ mm}^2 \)

Shear reinforcement at a perimeter of 3.75d - (803 mm)

Length of shear perimeter; \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 4110 \text{ mm} \)

Area of tension steel at shear perimeter; \( A_{\text{ton}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{\text{sy,ton}} + (k_x \times (p_y + (k_y \times k \times d)) \times A_{\text{sy,ton}}) \times A_{\text{ton}} = 5607 \text{ mm}^2 \)

Design concrete shear stress; \( \nu_c = \min(f_{cu,40}/25)^{1/3} \times 0.79 \times \min(100 \times A_{\text{ton}}/(u \times d), 3)^{1/3} \times \max(400/(d \times 1.15)/1.25 \text{ N/mm}^2 \)

Nominal design shear stress at perimeter; \( \nu = V_{\text{eff}}/(u \times d) = 0.686 \text{ N/mm}^2 \)

\( \nu < \nu_c \) no shear reinforcement required

Internal central column C2

Design shear transferred to column; \( V_i = \text{Span}_{x} \times (1.05 \times \text{Span}_{y}) \times N_{\text{ult}} = 969 \text{ kN} \)

Design effective shear transferred to column; \( V_{\text{eff}} = 1.15 \times V_i = 1114 \text{ kN} \)

Area of tension steel in x-direction; \( A_{\text{sx,ton}} = A_{\text{sx}} = 1570 \text{ mm}^2/m \)

Area of tension steel in y-direction; \( A_{\text{sy,ton}} = A_{\text{sy1}} = 2094 \text{ mm}^2/m \)

Column perimeter; \( u_c = 2 \times (l_x + l_y) = 1600 \text{ mm} \)

Average effective depth of reinforcement; \( d = h - c - \phi_p = 214 \text{ mm} \)

Maximum allowable shear stress; \( \nu_{\text{max}} = \min(0.8 \times \sqrt{(f_{cu})}, 5) = 4.733 \text{ N/mm}^2 \)

Design shear stress at column perimeter; \( \nu_0 = V_{\text{eff}}/(u_c \times d) = 3.254 \text{ N/mm}^2 \)

PASS - Maximum concrete shear stress not exceeded at column perimeter

Shear reinforcement at a perimeter of 1.50d - (321 mm)

Length of shear perimeter; \( u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 4168 \text{ mm} \)

Area of tension steel at shear perimeter; \( A_{\text{ton}} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{\text{sy,ton}} + (k_x \times (p_y + (k_y \times k \times d)) \times A_{\text{sy,ton}}) \times A_{\text{ton}} = 7636 \text{ mm}^2 \)

Design concrete shear stress; \( \nu_c = \min(f_{cu,40}/25)^{1/3} \times 0.79 \times \min(100 \times A_{\text{ton}}/(u \times d), 3)^{1/3} \times \max(400/(d \times 1.15)/1.25 \text{ N/mm}^2 \)

Nominal design shear stress at perimeter; \( \nu = V_{\text{eff}}/(u \times d) = 1.249 \text{ N/mm}^2 \)
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Section: Civil & Geotechnical Engineering

Calc. by: Dr. C. Sachpazis
Date: 18/01/2014

Shear reinforcement required at perimeter; 
\[ A_{sv,req} = (v - v_c) \times u \times d \times (0.95 \times f_{yd}) = 872 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 2.25d - (482 mm)
Length of shear perimeter; 
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 5452 \text{ mm} \]
Area of tension steel at shear perimeter; 
\[ A_{sy,ton} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{ss,ton}) + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sx,ton}) \]

Design concrete shear stress; 
\[ v_c = \min(\frac{f_{cd,40} \times 25}{2})^{1/3} \times 0.79 \times \min(100 \times A_{ss,ton} / (u \times d), 3)^{1/3} \times \max(400 / d, 1)^{1/4} \times 1.25 \]
\[ v_c = 0.785 \text{ N/mm}^2 \]

Nominal design shear stress at perimeter; 
\[ v = V_{eff} / (u \times d) = 0.955 \text{ N/mm}^2 \]
\[ v < v_c < 1.6 \times v_c \]

Shear reinforcement at a perimeter of 3.00d - (642 mm)
Length of shear perimeter; 
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 6736 \text{ mm} \]
Area of tension steel at shear perimeter; 
\[ A_{sy,ton} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{ss,ton}) + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sx,ton}) \]
\[ A_{sy,ton} = 12340 \text{ mm}^2 \]

Design concrete shear stress; 
\[ v_c = \min(\frac{f_{cd,40} \times 25}{2})^{1/3} \times 0.79 \times \min(100 \times A_{ss,ton} / (u \times d), 3)^{1/3} \times \max(400 / d, 1)^{1/4} \times 1.25 \]
\[ v_c = 0.785 \text{ N/mm}^2 \]

Nominal design shear stress at perimeter; 
\[ v = V_{eff} / (u \times d) = 0.773 \text{ N/mm}^2 \]
\[ v < v_c \text{ no shear reinforcement required} \]

Internal column C3
Design shear transferred to column; 
\[ V_s = \text{Span}_x \times \text{Span}_y \times N_{sd} = 923 \text{ kN} \]
Design effective shear transferred to column; 
\[ V_{eff} = 1.15 \times V_s = 1061 \text{ kN} \]
Area of tension steel in x-direction; 
\[ A_{sx,ton} = A_{ssx} = 1570 \text{ mm}^2/m \]
Area of tension steel in y-direction; 
\[ A_{sy,ton} = A_{ssy} = 1570 \text{ mm}^2/m \]
Column perimeter; 
\[ u_c = 2 \times (l_x + l_y) = 1600 \text{ mm} \]
Average effective depth of reinforcement; 
\[ d = h - c - \phi_p = 214 \text{ mm} \]
Maximum allowable shear stress; 
\[ v_{max} = \min(0.8 \times \sqrt{(f_{cd,40})}, 5) = 4.733 \text{ N/mm}^2 \]
Design shear stress at column perimeter; 
\[ v_0 = V_{eff} / (u_c \times d) = 3.099 \text{ N/mm}^2 \]

PASS - Maximum concrete shear stress not exceeded at column perimeter

Shear reinforcement at a perimeter of 1.50d - (321 mm)
Length of shear perimeter; 
\[ u = u_c + (2 \times (k_x \times k_y) \times k \times d) = 4168 \text{ mm} \]
Area of tension steel at shear perimeter; 
\[ A_{sy,ton} = (k_y \times (p_x + (k_x \times k \times d)) \times A_{ss,ton}) + (k_x \times (p_y + (k_y \times k \times d)) \times A_{sx,ton}) \]
\[ A_{sy,ton} = 6544 \text{ mm}^2 \]
Design concrete shear stress;

\[ v_c = \left( \min(f_{cu}, 40) \right) / 25^{1/3} \times 0.79 \times \min(100 \times A_{s\_ten} / (u \times d), 3) ^{1/3} \times \max(400 / d, 1) ^{1/4} / 1.25 \]

\[ v_c = 0.746 \text{ N/mm}^2 \]

Nominal design shear stress at perimeter;

\[ v = V_{eff} / (u \times d) = 1.190 \text{ N/mm}^2 \]

\[ v_c < v \leq 1.6 \times v_c \]

Shear reinforcement required at perimeter;

\[ A_{sv\_req} = (v - v_c) \times u \times d / (0.95 \times f_{pu}) = 834 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 2.25d - (482 mm)

Length of shear perimeter;

\[ u = u_c + (2 \times (k_x + k_y) \times k \times d) = 5452 \text{ mm} \]

Area of tension steel at shear perimeter;

\[ A_{s\_ten} = (k_y \times (p_x + (k_x + k_y) \times d) \times A_{sv\_ten}) + (k_x \times (p_y + (k_y + k_x) \times d) \times A_{sv\_ten}) \]

\[ A_{s\_ten} = 8560 \text{ mm}^2 \]

Design concrete shear stress;

\[ v_c = \left( \min(f_{cu}, 40) / 25^{1/3} \times 0.79 \times \min(100 \times A_{s\_ten} / (u \times d), 3) ^{1/3} \times \max(400 / d, 1) ^{1/4} / 1.25 \]

\[ v_c = 0.746 \text{ N/mm}^2 \]

Nominal design shear stress at perimeter;

\[ v = V_{eff} / (u \times d) = 0.910 \text{ N/mm}^2 \]

\[ v_c < v \leq 1.6 \times v_c \]

Shear reinforcement required at perimeter;

\[ A_{sv\_req} = (v - v_c) \times u \times d / (0.95 \times f_{pu}) = 403 \text{ mm}^2 \]

Shear reinforcement at a perimeter of 3.00d - (642 mm)

Length of shear perimeter;

\[ u = u_c + (2 \times (k_x + k_y) \times k \times d) = 6736 \text{ mm} \]

Area of tension steel at shear perimeter;

\[ A_{s\_ten} = (k_y \times (p_x + (k_x + k_y) \times d) \times A_{sv\_ten}) + (k_x \times (p_y + (k_y + k_x) \times d) \times A_{sv\_ten}) \]

\[ A_{s\_ten} = 10576 \text{ mm}^2 \]

Design concrete shear stress;

\[ v_c = \left( \min(f_{cu}, 40) / 25^{1/3} \times 0.79 \times \min(100 \times A_{s\_ten} / (u \times d), 3) ^{1/3} \times \max(400 / d, 1) ^{1/4} / 1.25 \]

\[ v_c = 0.746 \text{ N/mm}^2 \]

Nominal design shear stress at perimeter;

\[ v = V_{eff} / (u \times d) = 0.736 \text{ N/mm}^2 \]

\[ v_c < v \leq \text{no shear reinforcement required} \]

**CURTAILMENT OF REINFORCEMENT**

**Internal column**

Radius of circular yield line;

\[ r = (l_x \times l_y / \pi)^{1/2} \times (1.05 \times Span_x \times 1.05 \times Span_y / (l_x \times l_y))^{1/2} = 1601 \text{ mm} \]

Minimum curtailment length in x-direction;

\[ l_{int\_x} = \text{Max}(r + 12 \times D, 0.25 \times \text{Span}_x) = 1841 \text{ mm} \]

Minimum curtailment length in y-direction;

\[ l_{int\_y} = \text{Max}(r + 12 \times D, 0.25 \times \text{Span}_y) = 1841 \text{ mm} \]

**Corner column**

Radius of yield line;

\[ r = (l_x \times l_y / \pi)^{1/2} \times ((0.45 \times \text{Span}_x + e_x) \times (0.45 \times \text{Span}_y + e_y) / (l_x \times l_y))^{1/2} \]

\[ r = 863 \text{ mm} \]

Minimum curtailment length in x-direction;

\[ l_{corner\_x} = \text{Max}(r + 12 \times D, 0.2 \times \text{Span}_x) = 1440 \text{ mm} \]


Minimum curtailment length in y-direction; \( l_{\text{corner,}y} = \max(r + 12 \times D, 0.2 \times \text{Span}_y) = 1440 \text{ mm} \)

**Edge columns**

Radius of yield line in x-direction; \( r = (l_1 \times l_2 / \pi)^{1/2} \times (0.45 \times \text{Span}_x + e_x) \times (1.05 \times \text{Span}_y) / (l_1 \times l_2) \)

Minimum curtailment length in x-direction; \( l_{\text{edge,}x} = \max(r + 12 \times D, 0.2 \times \text{Span}_x) = 1440 \text{ mm} \)

Radius of yield line in y-direction; \( r = (l_1 \times l_2 / \pi)^{1/2} \times (0.45 \times \text{Span}_y + e_y) \times (1.05 \times \text{Span}_x) / (l_1 \times l_2) \)

Minimum curtailment length in y-direction; \( l_{\text{edge,}y} = \max(r + 12 \times D, 0.2 \times \text{Span}_y) = 1440 \text{ mm} \)
When the effective span in the x direction, $L_x$, is greater than the effective span in the y direction, $L_y$, the reinforcement in the outer layer is assumed to be that in the x direction otherwise it is assumed to be that in the y direction.
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REINFORCEMENT KEY

a = 20 dia bars @ 150 centres - (2094 mm²/m);
b = 16 dia bars @ 200 centres - (1005 mm²/m);
c = 20 dia bars @ 200 centres - (1570 mm²/m);
d = 16 dia bars @ 200 centres - (1005 mm²/m);
e = 20 dia bars @ 125 centres - (2513 mm²/m);
f = 20 dia bars @ 200 centres - (1570 mm²/m);
g = 20 dia bars @ 150 centres - (2094 mm²/m);
h = 20 dia bars @ 200 centres - (1570 mm²/m);
j = 20 dia bars @ 150 centres - (2094 mm²/m);
k = 20 dia bars @ 200 centres - (1570 mm²/m);
l = 20 dia bars @ 150 centres - (2094 mm²/m);
m = 20 dia bars @ 200 centres - (1570 mm²/m);
n = 16 dia bars @ 150 centres - (1340 mm²/m);
p = 16 dia bars @ 175 centres - (1148 mm²/m);
q = 16 dia bars @ 150 centres - (1340 mm²/m);
r = 16 dia bars @ 175 centres - (1148 mm²/m);
s = 16 dia bars @ 200 centres - (1005 mm²/m)

Distribution bars = 12 dia bars @ 300 centres - (377 mm²/m)

Shear reinforcement is required - Refer to output above for details.