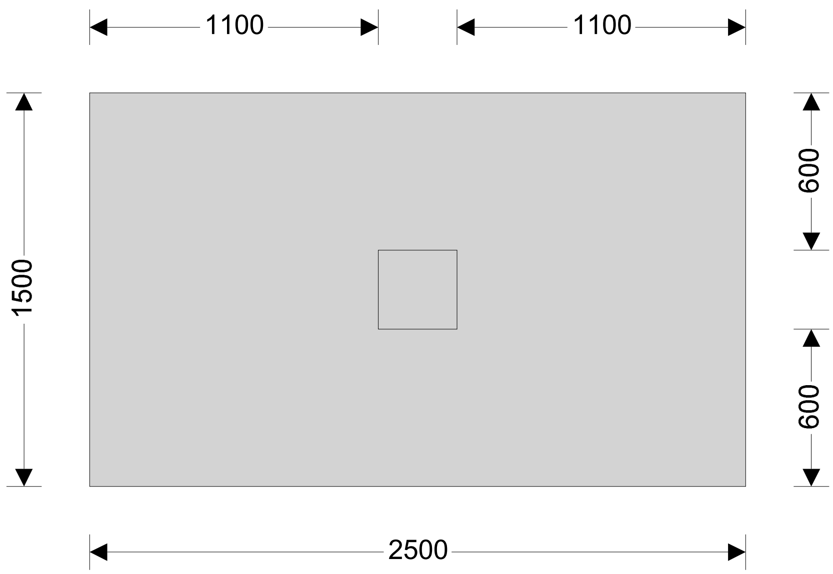
PAD FOOTING ANALYSIS AND DESIGN (BS8110-1:1997)



Pad footing details

Length of pad footing; L = **2500** mm

Width of pad footing; B = **1500** mm

Area of pad footing; $A = L \times B$ = **3.750** m^2

Depth of pad footing; h = **400** mm

Depth of soil over pad footing; h_{soil} = **200** mm

Density of concrete; ρ_{conc} = **23.6** kN/m^3

Column details

Column base length; l_A = **300** mm

Column base width; b_A = **300** mm

Column eccentricity in x; e_{PxA} = **0** mm

Column eccentricity in y; e_{PyA} = **0** mm

Soil details

Dense, moderately graded, sub-angular, gravel

Mobilisation factor; m= ;**1.5**;

Density of soil; ρ_{soil} = **20.0** kN/m^3

Design shear strength; ϕ' = **25.0** deg

Design base friction; δ = **19.3** deg

Allowable bearing pressure; $P_{bearing}$ = **200** kN/m^2

Axial loading on column

Dead axial load on column; P_{GA} = **200.0** kN

Imposed axial load on column; P_{QA} = **165.0** kN

Wind axial load on column; P_{WA} = **0.0** kN

Total axial load on column; P_A = **365.0** kN

Foundation loads

Dead surcharge load; F_{Gsur} = **0.000** kN/m^2

Imposed surcharge load; F_{Qsur} = **0.000** kN/m^2

Pad footing self weight; $F_{swt} = h \times \rho_{conc}$ = **9.440** kN/m^2

Soil self weight; $F_{soil} = h_{soil} \times \rho_{soil}$ = **4.000** kN/m^2

Total foundation load; $F = A \times (F_{Gsur} + F_{Qsur} + F_{swt} + F_{soil})$ = **50.4** kN

Horizontal loading on column base

Dead horizontal load in x direction; H_{GxA} = **20.0** kN

Imposed horizontal load in x direction; H_{QxA} = **15.0** kN

Wind horizontal load in x direction; H_{WxA} = **0.0** kN

Total horizontal load in x direction; H_{xA} = **35.0** kN

Dead horizontal load in y direction; H_{GyA} = **5.0** kN

Imposed horizontal load in y direction; H_{QyA} = **5.0** kN

Wind horizontal load in y direction; H_{WyA} = **0.0** kN

Total horizontal load in y direction; H_{yA} = **10.0** kN

Moment on column base

Dead moment on column in x direction; M_{GxA} = **15.000** kNm

Imposed moment on column in x direction; M_{QxA} = **10.000** kNm

Wind moment on column in x direction; M_{WxA} = **0.000** kNm

Total moment on column in x direction; M_{xA} = **25.000** kNm

Dead moment on column in y direction; M_{GyA} = **25.000** kNm

Imposed moment on column in y direction; M_{QyA} = **30.000** kNm

Wind moment on column in y direction; M_{WyA} = **0.000** kNm

Total moment on column in y direction; M_{yA} = **55.000** kNm

Check stability against sliding

Resistance to sliding due to base friction

$H_{friction} = \max([P_{GA} + (F_{Gsur} + F_{swt} + F_{soil}) \times A], 0 \text{ kN}) \times \tan(\delta)$ = **87.7** kN

Passive pressure coefficient; $K_p = (1 + \sin(\phi')) / (1 - \sin(\phi'))$ = **2.464**

Stability against sliding in x direction

Passive resistance of soil in x direction; $H_{xpas} = 0.5 \times K_p \times (h^2 + 2 \times h \times h_{soil}) \times B \times \rho_{soil}$ = **11.8** kN

Total resistance to sliding in x direction; $H_{xres} = H_{friction} + H_{xpas}$ = **99.5** kN

PASS - Resistance to sliding is greater than horizontal load in x direction

Stability against sliding in y direction

Passive resistance of soil in y direction; $H_{ypas} = 0.5 \times K_p \times (h^2 + 2 \times h \times h_{soil}) \times L \times \rho_{soil}$ = **19.7** kN

Total resistance to sliding in y direction; $H_{yres} = H_{friction} + H_{ypas}$ = **107.4** kN

PASS - Resistance to sliding is greater than horizontal load in y direction

Check stability against overturning in x direction

Total overturning moment; $M_{xOT} = M_{xA} + H_{xA} \times h$ = **39.000** kNm

Restoring moment in x direction

Foundation loading; $M_{xsur} = A \times (F_{Gsur} + F_{swt} + F_{soil}) \times L / 2$ = **63.000** kNm

Axial loading on column; $M_{xaxial} = (P_{GA}) \times (L / 2 - e_{PxA})$ = **250.000** kNm

Total restoring moment; $M_{xres} = M_{xsur} + M_{xaxial}$ = **313.000** kNm

PASS - Restoring moment is greater than overturning moment in x direction

Check stability against overturning in y direction

Total overturning moment; $M_{yOT} = M_{yA} + H_{yA} \times h$ = **59.000** kNm

Restoring moment in y direction

Foundation loading; $M_{ysur} = A \times (F_{Gsur} + F_{swt} + F_{soil}) \times B / 2$ = **37.800** kNm

Axial loading on column; $M_{yaxial} = (P_{GA}) \times (B / 2 - e_{PyA})$ = **150.000** kNm

Total restoring moment; $M_{yres} = M_{ysur} + M_{yaxial}$ = **187.800** kNm

PASS - Restoring moment is greater than overturning moment in y direction

Calculate pad base reaction

Total base reaction; $T = F + P_A$ = **415.4** kN

Eccentricity of base reaction in x; $e_{Tx} = (P_A \times e_{PxA} + M_{xA} + H_{xA} \times h) / T$ = **94** mm

Eccentricity of base reaction in y; $e_{Ty} = (P_A \times e_{PyA} + M_{yA} + H_{yA} \times h) / T$ = **142** mm

Check pad base reaction eccentricity

$abs(e_{Tx}) / L + abs(e_{Ty}) / B$ = **0.132**

Base reaction acts within combined middle third of base

Calculate pad base pressures

$q_1 = T / A - 6 \times T \times e_{Tx} / (L \times A) - 6 \times T \times e_{Ty} / (B \times A)$ = **22.880** kN/m^2

$q_2 = T / A - 6 \times T \times e_{Tx} / (L \times A) + 6 \times T \times e_{Ty} / (B \times A)$ = **148.747** kN/m^2

$q_3 = T / A + 6 \times T \times e_{Tx} / (L \times A) - 6 \times T \times e_{Ty} / (B \times A)$ = **72.800** kN/m^2

$q_4 = T / A + 6 \times T \times e_{Tx} / (L \times A) + 6 \times T \times e_{Ty} / (B \times A)$ = **198.667** kN/m^2

Minimum base pressure; $q_{min} = min(q_1, q_2, q_3, q_4)$ = **22.880** kN/m^2

Maximum base pressure; $q_{max} = max(q_1, q_2, q_3, q_4)$ = **198.667** kN/m^2

PASS - Maximum base pressure is less than allowable bearing pressure

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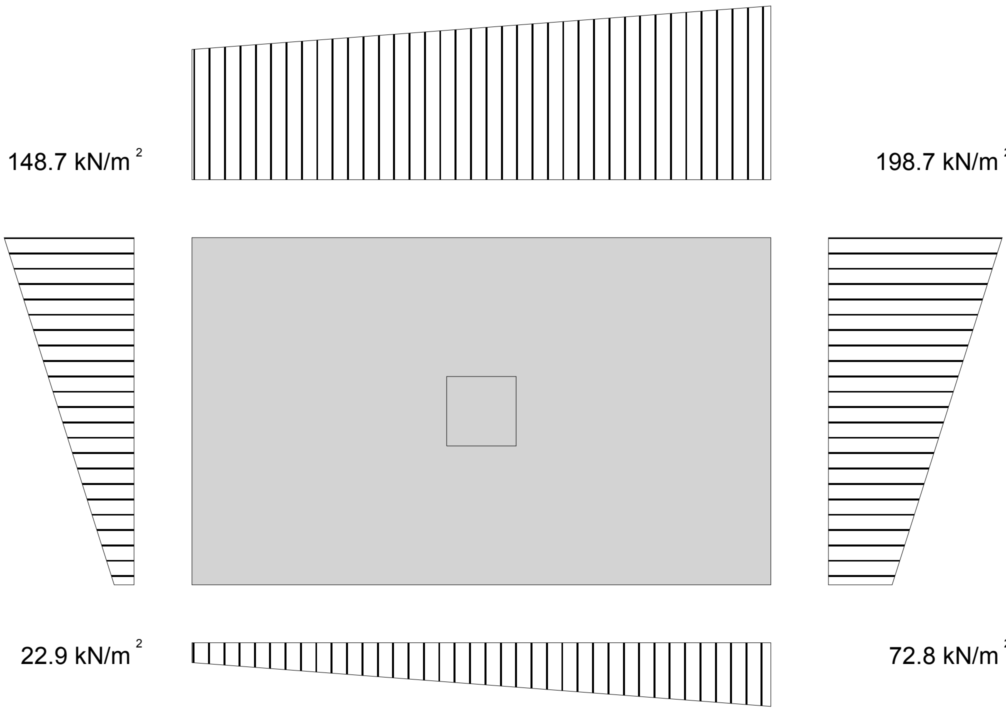


Partial safety factors for loads

Partial safety factor for dead loads; γ_{fG} = **1.40**

Partial safety factor for imposed loads; γ_{fQ} = **1.60**

Partial safety factor for wind loads; γ_{fW} = **0.00**

Ultimate axial loading on column

Ultimate axial load on column; $P_{uA} = P_{GA} \times \gamma_{fG} + P_{QA} \times \gamma_{fQ} + P_{WA} \times \gamma_{fW}$ = **544.0** kN

Ultimate foundation loads

Ultimate foundation load; $F_u = A \times [(F_{Gsur} + F_{swt} + F_{soil}) \times \gamma_{fG} + F_{Qsur} \times \gamma_{fQ}]$ = **70.6** kN

Ultimate horizontal loading on column

Ultimate horizontal load in x direction; $H_{xuA} = H_{GxA} \times \gamma_{fG} + H_{QxA} \times \gamma_{fQ} + H_{WxA} \times \gamma_{fW}$ = **52.0** kN

Ultimate horizontal load in y direction; $H_{yuA} = H_{GyA} \times \gamma_{fG} + H_{QyA} \times \gamma_{fQ} + H_{WyA} \times \gamma_{fW}$ = **15.0** kN

Ultimate moment on column

Ultimate moment on column in x direction; $M_{xuA} = M_{GxA} \times \gamma_{fG} + M_{QxA} \times \gamma_{fQ} + M_{WxA} \times \gamma_{fW}$ = **37.000** kNm

Ultimate moment on column in y direction; $M_{yuA} = M_{GyA} \times \gamma_{fG} + M_{QyA} \times \gamma_{fQ} + M_{WyA} \times \gamma_{fW}$ = **83.000** kNm

Calculate ultimate pad base reaction

Ultimate base reaction; $T_u = F_u + P_{uA} =$ **614.6** kN

Eccentricity of ultimate base reaction in x; $e_{Txu} = (P_{uA} \times e_{PxA} + M_{xuA} + H_{xuA} \times h) / T_u =$ **94** mm

Eccentricity of ultimate base reaction in y; $e_{Tyu} = (P_{uA} \times e_{PyA} + M_{yuA} + H_{yuA} \times h) / T_u =$ **145** mm

Calculate ultimate pad base pressures

$q_{1u} = T_u/A - 6 \times T_u \times e_{Txu}/(L \times A) - 6 \times T_u \times e_{Tyu}/(B \times A) =$ **31.957** kN/m^2

$q_{2u} = T_u/A - 6 \times T_u \times e_{Txu}/(L \times A) + 6 \times T_u \times e_{Tyu}/(B \times A) =$ **221.824** kN/m^2

$q_{3u} = T_u/A + 6 \times T_u \times e_{Txu}/(L \times A) - 6 \times T_u \times e_{Tyu}/(B \times A) =$ **105.941** kN/m^2

$q_{4u} = T_u/A + 6 \times T_u \times e_{Txu}/(L \times A) + 6 \times T_u \times e_{Tyu}/(B \times A) =$ **295.808** kN/m^2

Minimum ultimate base pressure; $q_{minu} = \min(q_{1u}, q_{2u}, q_{3u}, q_{4u}) =$ **31.957** kN/m^2

Maximum ultimate base pressure; $q_{maxu} = \max(q_{1u}, q_{2u}, q_{3u}, q_{4u}) =$ **295.808** kN/m^2

Calculate rate of change of base pressure in x direction

Left hand base reaction; $f_{uL} = (q_{1u} + q_{2u}) \times B / 2 =$ **190.336** kN/m

Right hand base reaction; $f_{uR} = (q_{3u} + q_{4u}) \times B / 2 =$ **301.312** kN/m

Length of base reaction; $L_x = L =$ **2500** mm

Rate of change of base pressure; $C_x = (f_{uR} - f_{uL}) / L_x =$ **44.390** kN/m/m

Calculate pad lengths in x direction

Left hand length; $L_L = L / 2 + e_{PxA} =$ **1250** mm

Right hand length; $L_R = L / 2 - e_{PxA} =$ **1250** mm

Calculate ultimate moments in x direction

Ultimate moment in x direction; $M_x = f_{uL} \times L_L^2/2 + C_x \times L_L^3/6 - F_u \times L_L^2/(2 \times L) + H_{xuA} \times h + M_{xuA}$ = **198.900** kNm

Calculate rate of change of base pressure in y direction

Top edge base reaction; $f_{uT} = (q_{2u} + q_{4u}) \times L / 2 =$ **647.040** kN/m

Bottom edge base reaction; $f_{uB} = (q_{1u} + q_{3u}) \times L / 2 =$ **172.373** kN/m

Length of base reaction; $L_y = B =$ **1500** mm

Rate of change of base pressure; $C_y = (f_{uB} - f_{uT}) / L_y =$ **-316.444** kN/m/m

Calculate pad lengths in y direction

Top length; $L_T = B / 2 - e_{PyA} =$ **750** mm

Bottom length; $L_B = B / 2 + e_{PyA} =$ **750** mm

Calculate ultimate moments in y direction

Ultimate moment in y direction; $M_y = f_{uT} \times L_T^2/2 + C_y \times L_T^3/6 - F_u \times L_T^2/(2 \times B) =$ **146.500** kNm

Material details

Characteristic strength of concrete; $f_{cu} =$ **30** N/mm^2

Characteristic strength of reinforcement; f_y = **500** N/mm^2

Characteristic strength of shear reinforcement; f_{yv} = **500** N/mm^2

Nominal cover to reinforcement; c_{nom} = **30** mm

Moment design in x direction

Diameter of tension reinforcement; ϕ_{xB} = **12** mm

Depth of tension reinforcement; $d_x = h - c_{nom} - \phi_{xB} / 2$ = **364** mm

Design formula for rectangular beams (cl 3.4.4.4)

$K_x = M_x / (B \times d_x^2 \times f_{cu})$ = **0.033**

$K_x' = 0.156$

$K_x < K_x'$ compression reinforcement is not required

Lever arm; $z_x = d_x \times \min([0.5 + \sqrt{(0.25 - K_x / 0.9)}], 0.95)$ = **346** mm

Area of tension reinforcement required; $A_{s\_x\_req} = M_x / (0.87 \times f_y \times z_x)$ = **1322** mm^2

Minimum area of tension reinforcement; $A_{s\_x\_min} = 0.0013 \times B \times h$ = **780** mm^2

Tension reinforcement provided; **12 No. 12 dia. bars bottom (125 centres)**

Area of tension reinforcement provided; $A_{s\_xB\_prov} = N_{xB} \times \pi \times \phi_{xB}^2 / 4$ = **1357** mm^2

PASS - Tension reinforcement provided exceeds tension reinforcement required

Moment design in y direction

Diameter of tension reinforcement; ϕ_{yB} = **12** mm

Depth of tension reinforcement; $d_y = h - c_{nom} - \phi_{xB} - \phi_{yB} / 2$ = **352** mm

Design formula for rectangular beams (cl 3.4.4.4)

$K_y = M_y / (L \times d_y^2 \times f_{cu})$ = **0.016**

$K_y' = 0.156$

$K_y < K_y'$ compression reinforcement is not required

Lever arm; $z_y = d_y \times \min([0.5 + \sqrt{(0.25 - K_y / 0.9)}], 0.95)$ = **334** mm

Area of tension reinforcement required; $A_{s\_y\_req} = M_y / (0.87 \times f_y \times z_y)$ = **1007** mm^2

Minimum area of tension reinforcement; $A_{s\_y\_min} = 0.0013 \times L \times h$ = **1300** mm^2

Tension reinforcement provided; **13 No. 12 dia. bars bottom (200 centres)**

Area of tension reinforcement provided; $A_{s\_yB\_prov} = N_{yB} \times \pi \times \phi_{yB}^2 / 4$ = **1470** mm^2

PASS - Tension reinforcement provided exceeds tension reinforcement required

Calculate ultimate shear force at d from right face of column

Ultimate pressure for shear; $q_{su} = (q_{1u} + C_x \times (L / 2 + e_{PxA} + l_A / 2 + d_x) / B + q_{4u}) / 2$

q_{su} = **189.984** kN/m^2

Area loaded for shear; $A_s = B \times \min(3 \times (L / 2 - e_{Tx}), L / 2 - e_{PxA} - l_A / 2 - d_x)$ = **1.104** m^2

Ultimate shear force; $V_{su} = A_s \times (q_{su} - F_u / A)$ = **188.970** kN

Shear stresses at d from right face of column (cl 3.5.5.2)

Design shear stress; $v_{su} = V_{su} / (B \times d_x)$ = **0.346** N/mm^2

From BS 8110:Part 1:1997 - Table 3.8

Design concrete shear stress; v_c = $\underline{\mathbf{0.432}}$ N/mm^2

Allowable design shear stress; $v_{max} = \min(0.8N/mm^2 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5\ N/mm^2)$ = $\underline{\mathbf{4.382}}$ N/mm^2

PASS - $v_{su} < v_c$ - No shear reinforcement required

Calculate ultimate punching shear force at face of column

Ultimate pressure for punching shear; $q_{puA} = q_{1u}+[(L/2+e_{PxA}-l_A/2)+(l_A)/2]\times C_x/B-[(B/2+e_{PyA}-b_A/2)+(b_A)/2]\times C_y/L$

q_{puA} = $\underline{\mathbf{163.883}}$ kN/m^2

Average effective depth of reinforcement; $d = (d_x + d_y) / 2$ = $\underline{\mathbf{358}}$ mm

Area loaded for punching shear at column; $A_{pA} = (l_A)\times(b_A)$ = $\underline{\mathbf{0.090}}$ m^2

Length of punching shear perimeter; $u_{pA} = 2\times(l_A)+2\times(b_A)$ = $\underline{\mathbf{1200}}$ mm

Ultimate shear force at shear perimeter; $V_{puA} = P_{uA} + (F_u / A - q_{puA}) \times A_{pA}$ = $\underline{\mathbf{530.944}}$ kN

Effective shear force at shear perimeter; $V_{puAeff} = V_{puA}\times[1+1.5\times abs(M_{xuA})/(V_{puA}\times(b_A))+1.5\times abs(M_{yuA})/(V_{puA}\times(l_A))]$ = $\underline{\mathbf{1130.944}}$ kN

Punching shear stresses at face of column (cl 3.7.7.2)

Design shear stress; $v_{puA} = V_{puAeff} / (u_{pA} \times d)$ = $\underline{\mathbf{2.633}}$ N/mm^2

Allowable design shear stress; $v_{max} = \min(0.8N/mm^2 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5\ N/mm^2)$ = $\underline{\mathbf{4.382}}$ N/mm^2

PASS - Design shear stress is less than allowable design shear stress

Calculate ultimate punching shear force at perimeter of 1.5 d from face of column

Ultimate pressure for punching shear; $q_{puA1.5d} = q_{1u}+[(L/2+e_{PxA}-l_A/2-1.5\times d)+(l_A+2\times 1.5\times d)/2]\times C_x/B-[B/2]\times C_y/L$

$q_{puA1.5d}$ = $\underline{\mathbf{163.883}}$ kN/m^2

Average effective depth of reinforcement; $d = (d_x + d_y) / 2$ = $\underline{\mathbf{358}}$ mm

Area loaded for punching shear at column; $A_{pA1.5d} = (l_A+2\times 1.5\times d)\times B$ = $\underline{\mathbf{2.061}}$ m^2

Length of punching shear perimeter; $u_{pA1.5d} = 2\times B$ = $\underline{\mathbf{3000}}$ mm

Ultimate shear force at shear perimeter; $V_{puA1.5d} = P_{uA} + (F_u / A - q_{puA1.5d}) \times A_{pA1.5d}$ = $\underline{\mathbf{245.018}}$ kN

Effective shear force at shear perimeter; $V_{puA1.5deff} = V_{puA1.5d} \times 1.25$ = $\underline{\mathbf{306.272}}$ kN

Punching shear stresses at perimeter of 1.5 d from face of column (cl 3.7.7.2)

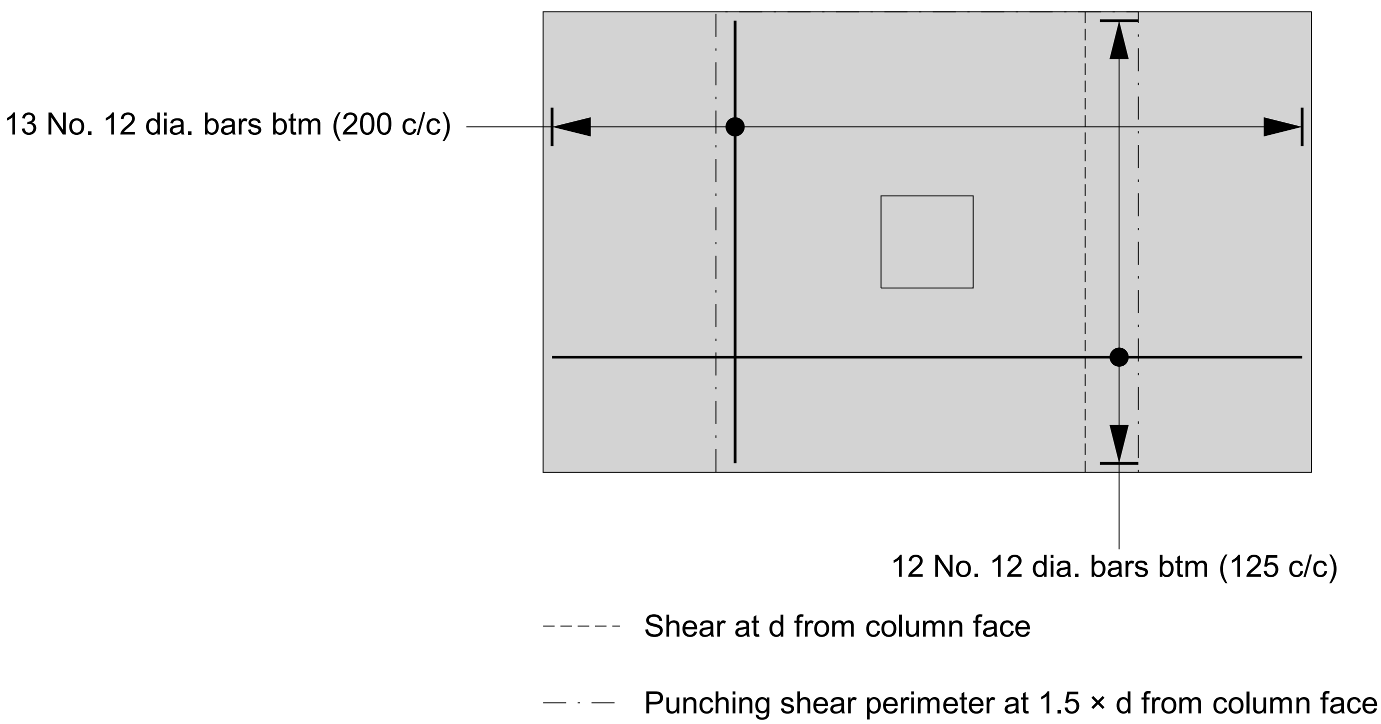
Design shear stress; $v_{puA1.5d} = V_{puA1.5deff} / (u_{pA1.5d} \times d)$ = $\underline{\mathbf{0.285}}$ N/mm^2

From BS 8110:Part 1:1997 - Table 3.8

Design concrete shear stress; v_c = $\underline{\mathbf{0.409}}$ N/mm^2

Allowable design shear stress; $v_{max} = \min(0.8N/mm^2 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5\ N/mm^2)$ = $\underline{\mathbf{4.382}}$ N/mm^2

PASS - $v_{puA1.5d} < v_c$ - No shear reinforcement required



13 No. 12 dia. bars btm (200 c/c)
12 No. 12 dia. bars btm (125 c/c)
Shear at d from column face
Punching shear perimeter at 1.5 × d from column face