UNIT - V

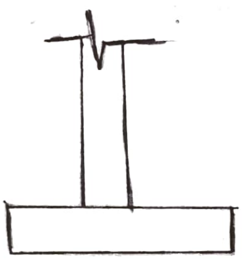
Design of foundations

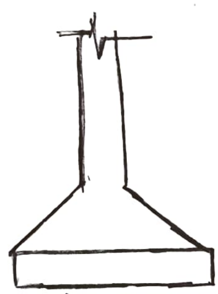
* Foundations may be broadly classified into two types.
  (i) shallow foundations
  (ii) Deep foundations

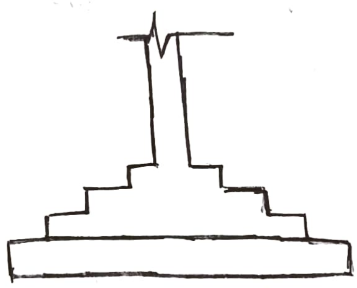
* According to Terzaghi a foundation is shallow, if its depth is equal to (or) less than the width.

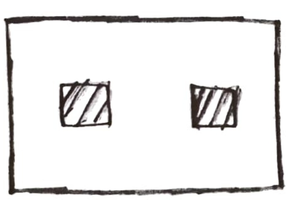
* In case of deep foundation, the depth is greater than the width of the foundation.

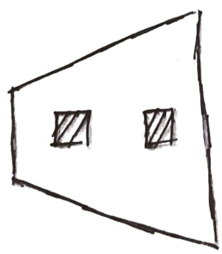
Various types of shallow footings:-

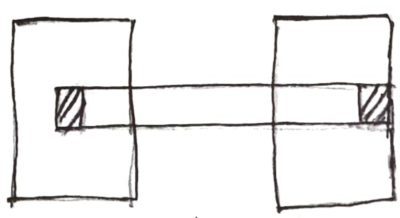

Simple spread footing

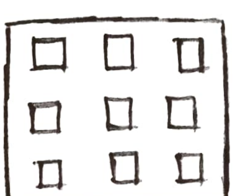

Sloped footing

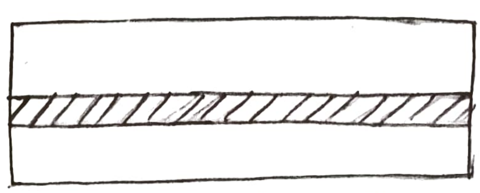

Stepped footing


Combined rectangular footing


Combined trapezoidal footing


Strap footing


Mat foundation


Foundation for wall

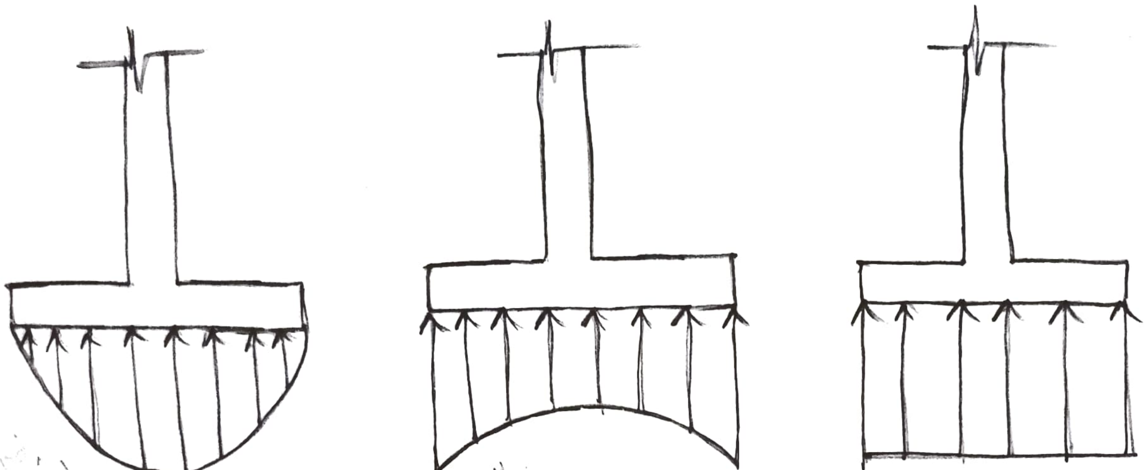
Types of Deep foundations :-

(1) Pier foundation

(2) Pile foundation

(3) Well foundation.

Pressure distribution beneath footings :-



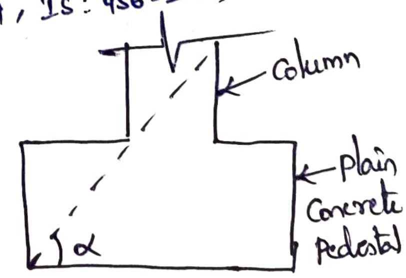
eg: sand, Gravel — Cohessionless Soils

eg: clay, silt — Cohessive soil

Uniform pressure distribution

Indian standard Code recommendation for Design of footings :-

(i) Thickness at the edge of the footing :- (Pg 64, IS : 456-2000)



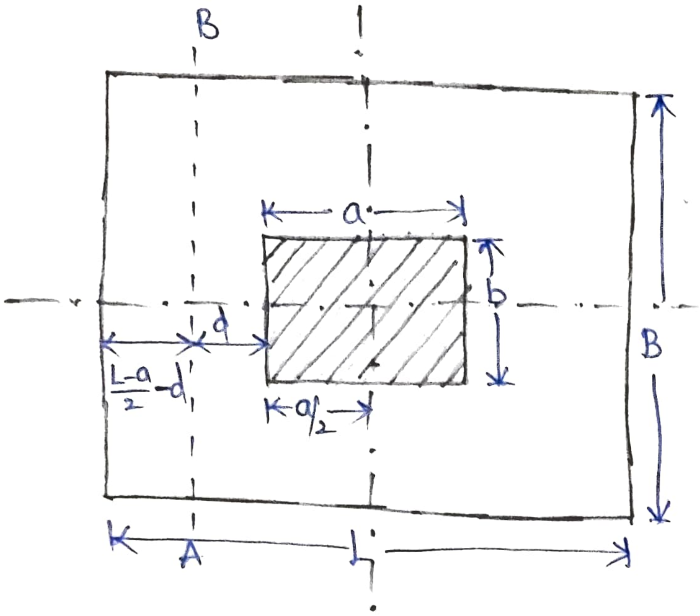
* In reinforced and plain Concrete footings, the thickness at the edge shall not be less than 150mm for footings on soils, nor less than 300mm above the tops of Piles for footings on piles.

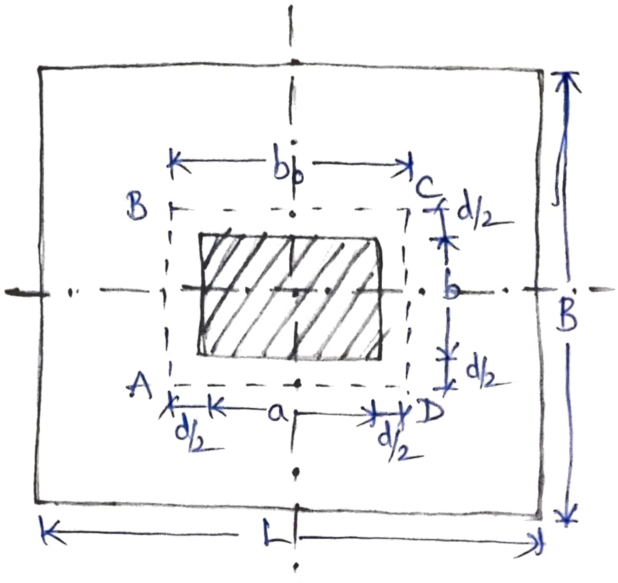
$$\tan\alpha \nless 0.9\sqrt{\frac{100\, q_0}{f_{ck}}+1}$$

where, q_0 = Maximum bearing pressure at the base of the pedestal.

f_{ck} = characteristic Compressive strength of Concrete.

One way shear:-





Two way shear:-

Two way shear

$$\tau_v \le k_s \tau_c$$

$$\tau_v = \frac{V_u}{bd}$$

$$= \frac{V_u}{[2\times(a+d) + 2\times(b+d)]\times d}$$

$$k_s = (0.5+\beta_c) \not> 1$$

$$\beta_c = \frac{b}{a} = \frac{\text{shorter side of column}}{\text{Longer side of column}}$$

$$\tau_c = 0.25\sqrt{f_{ck}}$$

Isolated footing of uniform depth:-

* The total area at the base of such footing is determined from the safe bearing capacity of soil.
* The depth of footing is determined from the bending moment considerations and from punching shear.

$$A = \frac{w + w'}{q_o}$$

where, w = Weight transfered from Column

w' = Self weight of footing (Assumed as 10% of the load Coming from the column)

q_o = Safe bearing capacity of soil.

A = Area of footing at base

Net upward pressure, $p_o = \frac{w}{A} = \frac{w q_o}{w + w'}$

Square footing :-

$$\text{Moment, } M = \frac{p_o B}{8} (B - b)^2 \times 10^6 \text{ N mm}$$

$$= \frac{p_o B}{8} (B - b)^2 \text{ kN m}$$

$$M_u = 1.5 M$$

where, B = width of footing

b = width of column

Assuming Fe 415 reinforcement, $d = \sqrt{\frac{M_u}{0.138 f_{ck} b}}$

Depth from shear :-

$$\tau_v \leq k_s \tau_c$$

$$\tau_v = \frac{V_u}{bd} = \frac{V_u}{[4(b+d)] \times d}$$

$$\tau_c = 0.25 \sqrt{f_{ck}}$$

A minimum thickness of 150 mm should be provided.

Reinforcement :-

$$M_u = 0.87 f_y A_{st} d \left[1 - \frac{f_y A_{st}}{f_{ck} bd}\right]$$

check for development length :-

$$\text{Development length, } L_d = \frac{\phi \sigma_{st}}{4 \tau_{bd}}$$

Design of continuous footing :-

* Concrete footing under Masonary wall :-

$$B = \frac{W + W'}{q_0}$$

$$p_0 = \text{Net upward pressure} = \frac{W}{B}$$

$$\text{Moment, } M = \frac{p_0}{8} (B-b) \times (B - b/4) \times 10^6 \text{ N mm}$$

$$M_u = 1.5 M$$

$$\text{Depth, } d = \sqrt{M_u / 0.138 f_{ck} b}$$

$$\text{For } A_{st},\ M_u = 0.87 f_y A_{st} d \left(1 - \frac{f_y A_{st}}{f_{ck} bd}\right)$$

In addition to this longitudinal reinforcement is provided at 0.15% of gross c/s area of footing for mild steel bars and 0.12% of gross c/s area for HYSD bars.

* check the footing for shear.

1) Design an isolated footing of uniform thickness of a R.C. column bearing a vertical load of 600 kN and having a base of size 500 x 500mm. The safe bearing capacity of soil is 120 kN/m². Use M_{20} and Fe 415 materials.

Sol:- Given data :-

Vertical load, $P = 600$ kN

size of base $= 500 \times 500$ mm

Safe bearing capacity $= 120$ kN/m² $= q_o$

$f_{ck} = 20$ N/mm²

$f_y = 415$ N/mm²

Size of the footing :-

Area of footing, $A = \dfrac{w + w'}{q_o}$

w' = Self weight of footing = 10% load coming from column

$= \dfrac{10}{100} \times 600 = 60$ kN

$\therefore A = \dfrac{600 + 60}{120} = 5.5\,m^2$

Assume a square footing,

$B = D = \sqrt{5.5} = 2.34$ m

$\therefore$ Provide a square footing of size 2.4 x 2.4 m.

Net upward pressure, $p_o = \dfrac{W}{A} = \dfrac{600}{2.4^2}$

$= 104.16$ kN/m²

Design of Section :-

(a) Depth on the basis of bending moment Consideration :-

The maximum bending moment acts at the face of the column and its magnitude is given by

$$M = \frac{p_o}{8} \times B \times (B-b)^2 \times 10^6 \text{ N mm}$$

$$= \frac{104.16}{8} \times 2.4 \; (2.4-0.5)^2 \times 10^6$$

$$= 112.8 \text{ KNm}$$

$$M_u = 1.5 \times 112.8 = 169.2 \text{ KNm}$$

$$M_u = 0.138 \, f_{ck} \, B d^2$$

$$169.2 \times 10^6 = 0.138 \times 20 \times 2400 \times d^2$$

$$\Rightarrow d = 159.82 \text{ mm} \simeq 160 \text{ mm}$$

$$D = 160 + 60 = 220 \text{ mm}$$ (Assume clear cover = 60 mm)

(b) Depth on the basis of one way shear :-

For one way shear, the critical section is located at a distance 'd' from the face of the column. where shear force 'V' is given by

$$V = p_o \times B\left[\tfrac{1}{2}(B-b) - d\right]$$

$$= 104.16 \times 2.4 \left[\tfrac{1}{2}(2.4-0.5) - \frac{d}{1000}\right]$$

$$= 237.48 - 0.25d$$

$$V_u = 1.5\left[237.48 - 0.25d\right] = 356.22 - 0.375d$$

Nominal shear stress, $\tau_v = \frac{V_u}{Bd}$

$$= \frac{(356.22 - 0.375d) \times 10^3}{2.4 \times d/1000}$$

$$= \frac{148.425 \times 10^3}{d} - 156.25$$

$D = 200\ mm \rightarrow K = 1.2$

$D = 225\ mm \rightarrow K = 1.15$

$D = 220\ mm \rightarrow K = 1.2 - \frac{1.2 - 1.15}{225 - 200}(220 - 200)$

$$= 1.16$$

For an under reinforced section, assuming $P_t = 0.3\%$

For M_{20} grade concrete,

$P_t = 0.25 \rightarrow \tau_c = 0.36\ N/mm^2$

$P_t = 0.50 \rightarrow \tau_c = 0.48\ N/mm^2$

For $P_t = 0.3$, $\tau_c = 0.36 + \frac{0.48 - 0.36}{0.5 - 0.25}(0.3 - 0.25)$

$$= 0.384\ N/mm^2$$

$K_s \tau_c = 1.16 \times 0.384 = 0.445\ N/mm^2$

$\tau_v = K_s \tau_c$

$$\left[\frac{148.425 \times 10^3}{d} - 156.25\right] = 0.445 \times 10^{+3}$$

$d = 247.1\ mm$

$\simeq 250mm.$

(C) Depth from two way shear :- (or) check for two way shear:-

Assume effective depth, $d = 250$ mm.

For two way shear, the section lies at a distance of $d/2$ from the column face. The width 'b_0' of the section, $b_0 = b + d$.

$$b_0 = 500 + 250 = 750 \text{ mm}$$

Shear force around the section, $F = P_0 (B^2 - b_0^2)$

$$= 104.16 (2.4^2 - 0.75^2)$$

$$= 541.37 \text{ kN}.$$

Factored shear force, $F_u = 1.5 \times 541.37 = 812.05$ kN

Nominal shear stress, $\tau_v = \frac{V_u}{bd} = \frac{V_u}{4 b_0 \times d}$

$$= \frac{812.05 \times 10^3}{4 \times 750 \times 250} = 1.083 \text{ N/mm}^2$$

Permissible shear stress $= K_s \tau_c$

$$K_s = (0.5 + \beta_c) \ngtr 1$$

$$\beta_c = \frac{2.4}{2.4} = 1 \qquad \left(\beta_c = \frac{\text{shorter side}}{\text{longer side}}\right)$$

$K_s = 0.5 + 1 = 1.5 > 1$, $\therefore K_s = 1$

$$\tau_c = 0.25 \sqrt{f_{ck}} = 0.25 \sqrt{20} = 1.118 \text{ N/mm}^2$$

$$K_s \tau_c = 1 \times 1.118 = 1.118 \text{ N/mm}^2$$

$\tau_v < K_s \tau_c$. Hence it is safe against two way shear.

Using effective cover of 60mm and keeping overall depth $D = 330$ mm

Effective depth, $d = 330 - 60 = 270$ mm.

In other direction, effective depth (d) = 270 − 12 = 258 mm with 12 mm dia bars in two directions.

Design of steel reinforcement :-

$$M_u = 0.87\, f_y\, A_{st}\, d \left(1 - \frac{f_y A_{st}}{f_{ck}\, b d}\right)$$

$$169.2 \times 10^6 = 0.87 \times 415 \times A_{st} \times 258 \left(1 - \frac{415\, A_{st}}{20 \times 2400 \times 258}\right)$$

$$= 93150.9\, A_{st} - 3.12\, A_{st}^2$$

$$A_{st} = 1943 \text{ mm}^2$$

$$\text{No. of bars} = \frac{1943}{\frac{\pi}{4} \times 12^2}$$ (Assume 12mm dia bars).

$$= 17.18 \cong 18 \text{ bars}.$$

Hence provide 18 No.s of 12 mm diameter bars uniformly distributed in each direction.

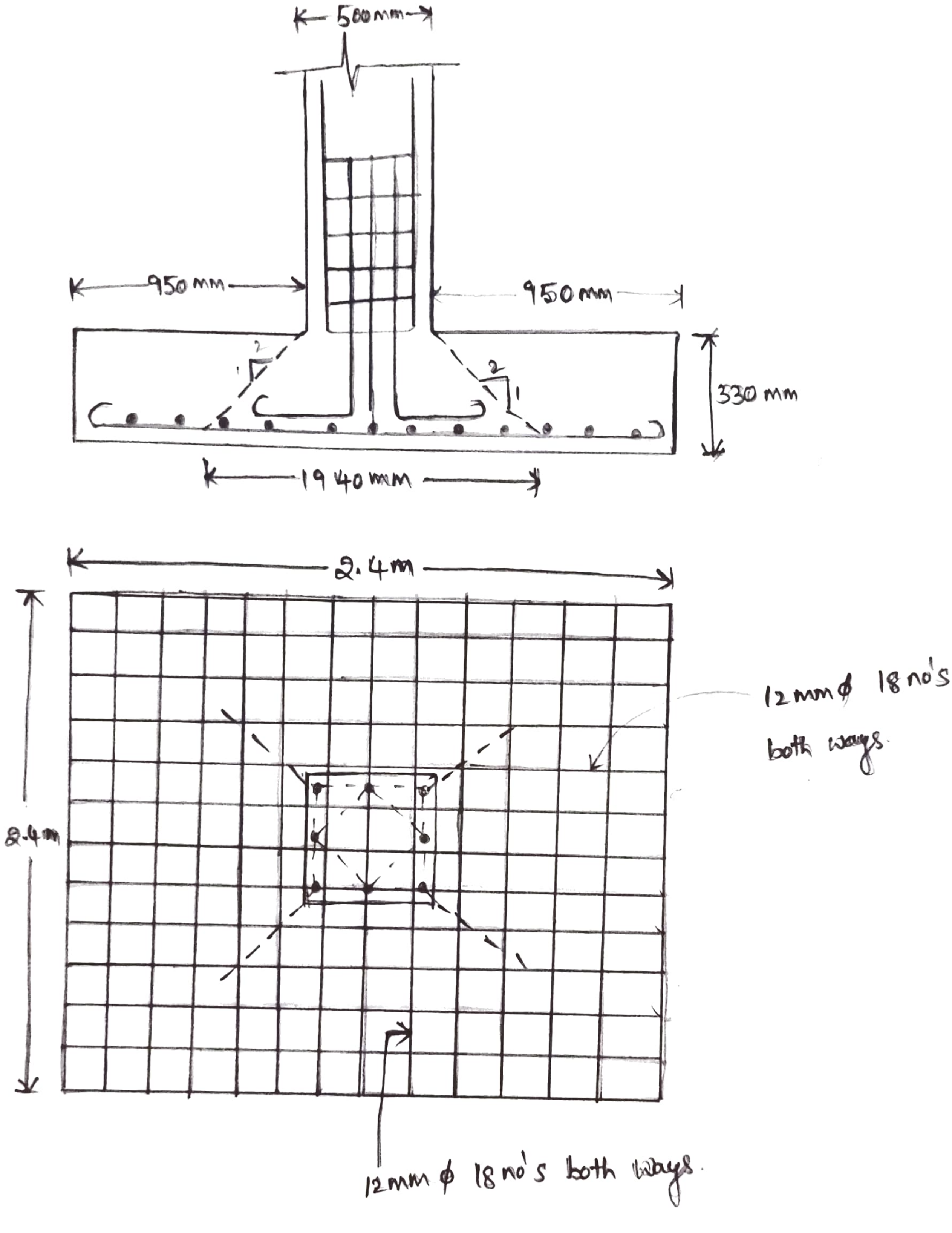
Check for development length :-

$$L_d = \frac{\phi\, \sigma_{st}}{4 \tau_{bd}} = \frac{12 \times 0.87 \times 415}{4 \times (1.2 \times 1.6)} = 564 \text{ mm}$$

Provide 60 mm side cover, length of bars available = ½ (B − b) − 60

$$= \tfrac{1}{2}(2400 - 500) - 60 = 890 \text{ mm} > L_d.$$

Hence the footing is safe in development length



Reinforcement Details

2) Design a rectangular isolated footing of uniform thickness of R.C column bearing a vertical load of 600 KN and having a base of size 400 x 600 mm. The safe bearing capacity of soil is 120 KN/m². Use M_{20} and Fe_{415} materials.

Sol:- Given data :-

Vertical load = 600 KN.

Column dimensions = 400 x 600 mm

Safe bearing capacity, q_0 = 120 KN/m²

$f_{ck} = 20\ N/mm^2$, $f_y = 415\ N/mm^2$

Size of footing :-

$$\text{Area} = \frac{w + w'}{q_0} = \frac{600 + \frac{10}{100} \times 600}{120} = 5.5\ m^2$$

Let the ratio of $\frac{B}{L} = \frac{400}{600} = \frac{2}{3}$

$$B = 2/3\ L$$

$$L \times B = 5.5\ m^2 \Rightarrow L \times 2/3\ L = 5.5$$

$$\Rightarrow L = 2.87 \cong 2.9\ m$$

$$B = 2/3\ L = 1.93\ m.$$

Provide a footing of size 2m x 3m.

Net upward pressure, $p_0 = \frac{W}{A} = \frac{600}{2 \times 3} = 100\ KN/m^2$

Design of the section :-

Depth on the basis of bending moment consideration :-

$$M_1 = \frac{P_o \times B}{8}(L-a)^2$$

$$= \frac{100 \times 2}{8}(3-0.6)^2 = 144 \text{ KNm}$$

$$M_{1u} = 1.5 \times 144 = 216 \text{ KNm}.$$

$$M_2 = \frac{P_o \times L}{8}(B-b)^2$$

$$= \frac{100 \times 3}{8}(2-0.4)^2 = 96 \text{ KNm}$$

$$M_{2u} = 1.5 \times 96 = 144 \text{ KNm}.$$

$$M_u = 0.138 f_{ck} B d^2$$

$$216 \times 10^6 = 0.138 \times 20 \times 2000 \times d^2$$

$$d = 197.8 \simeq 200 \text{mm}.$$

Overall depth, $D = 200 + 60 = 260 \text{mm}$

Provide uniform thickness over the entire footing.

Depth on the basis of one-way shear :-

Shear force, $V = P_o \times B \left(L/2 - a/2 - d \right)$

$$= 100 \times 10^3 \times 2 \left(3/2 - \frac{0.6}{2} - d/1000 \right) \text{ N/m}$$

$$V = 240 \times 10^3 - 0.2 d \times 10^3$$

$$V_u = 1.5 \left[240 \times 10^3 - 0.2 d \times 10^3 \right]$$

$$\tau_v = \frac{V_u}{Bd} = \frac{(240 \times 10^3 - 200d)\,1.5}{2 \times d/1000} = \frac{180 \times 10^6}{d} - 150 \times 10^3$$

Assuming the section as under reinforced section, $p_t = 0.3\%$

$\tau_c = 0.384\ N/mm^2$ for M_{20} grade concrete.

$D = 250mm \rightarrow k = 1.1$

$D = 260mm,\ k = 1.08$

$D = 275\ mm \rightarrow k = 1.05$

$K\tau_c = 1.08 \times 0.384 = 0.41\ N/mm^2 = 0.41 \times 10^6\ N/m^2$

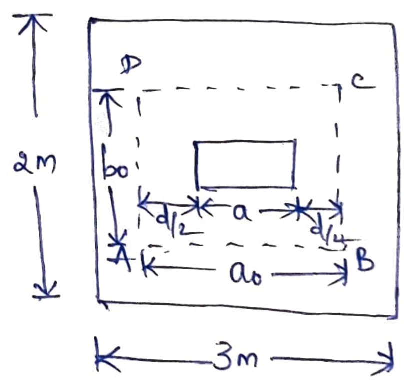
$\tau_v = K\tau_c$

$$\frac{180 \times 10^6}{d} - 150 \times 10^3 = 0.41 \times 10^6$$

$d = 319.4\ mm$

Adopt effective depth of 340 mm.

<u>check for two way shear</u> :-



Perimeter of punching shear

$= 2 \times [(a+d)+(b+d)]$

$= 2 \times [(0.6+0.34)+(0.4+0.34)]$

$= 3.36\ m$

Area of punching shear ABCD $= (0.6+0.34) * (0.4+0.34) = 0.6956\ m^2$

$V_u = 1.5 \times p_o$ ($L \times B$ - Area of punching shear)

$= 1.5 \times 100\ (3 \times 2 - 0.6956)$

$= 795.66$ kN.

$$\tau_v = \frac{V_u}{Bd} = \frac{V_u}{(2 \times a_o + 2b_o) \times d} = \frac{795.66 \times 10^3}{(3.36 \times 1000) \times 340} = 0.696\ N/mm^2$$

$K_s = (0.5 + \beta_c) \not> 1$

$\beta_c = \frac{400}{600} = 0.67$

$K_s = 1.167 > 1 \quad \therefore K_s = 1$

$\tau_c = 0.25\sqrt{f_{ck}} = 1.118 \ N/mm^2$

$K_s \tau_c = 1.118 \ N/mm^2$

$\tau_v < K_s \tau_c$

Hence safe in two way shear

Thus, the effective depth, $d = 340mm$ is safe.

Keep overall depth $D = 420mm$, $d = 420 - 60 = 360mm$ in one direction and $d = 360 - 12 = 348\ mm$ in other direction by using 12mm dia bars.

Reinforcement :-

$M_{1u} = 0.87 f_y A_{st} d \left(1 - \frac{f_y A_{st}}{f_{ck} b d}\right)$

$216 \times 10^6 = 0.87 \times 415 \times A_{st_1} \times 360 \left(1 - \frac{415 A_{st_1}}{20 \times 2000 \times 360}\right)$

$= 129978 A_{st_1} - 3.745 A_{st_1}^2$

$A_{st_1} = 1752\ mm^2$

The diameter of bar = 12 mm

$\therefore$ No. of bars $= \frac{1752}{\pi/4 \times 12^2} = 15.49 \simeq 16$ No's.

$\therefore$ Provide 16 no's of 12 mm diameter.

$$M_{2u} = 144 \times 10^6 = 0.87 \times 415\, A_{st_2} \times 348 \left(1 - \frac{415\, A_{st_2}}{20 \times 2000 \times 348}\right)$$

$$= 125645.4\, A_{st_2} - 3.745\, A_{st_2}$$

$$A_{st_2} = 1188 \text{ mm}^2$$

Assume 12mm dia bars.

$$\text{No. of bars} = \frac{1188}{\pi/4 \times 12^2} = 10.5 \simeq 11 \text{ bars.}$$

$\therefore$ Provide 11 bars of 12 mm diameter.

Check for development length :-

$$L_d = \frac{\phi\, \sigma_{st}}{4\, \tau_{bd}} = \frac{12 \times 0.87 \times 415}{4 \times (1.2 \times 1.6)} = 564.14 \text{ mm}$$

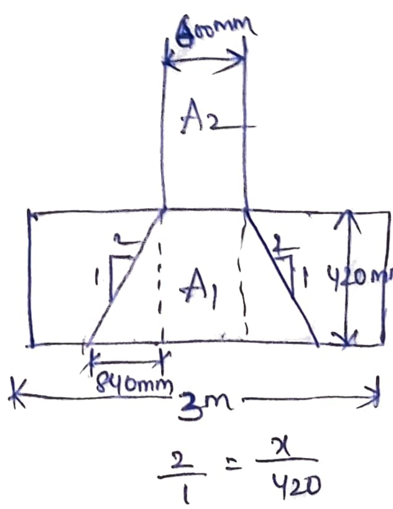
Using 60mm side cover, length available $= \frac{1}{2}(B-b) - 60$

$$= \frac{1}{2}(2000 - 400) - 60 = 740\text{mm} > L_d$$

Hence safe in development length.

Check for transfer of load at base :-

$\sqrt{\frac{A_1}{A_2}} \not> 2$, A_2 = area of column base



$A_2 = 400 \times 600 = 240000 \text{ mm}^2$

Assuming the slope as 2 : 1

$$\frac{2}{1} = \frac{x}{420}$$

$$x = 840 \text{ mm.}$$

$A_1 = \cancel{\frac{1}{2}(a+b) \times h}\ (600 + 2 \times 2 \times 420) \times$

$= \cancel{\frac{1}{2}(600 + 2280) \times 420}\ (400 + 2 \times 2 \times 420)$

$= \cancel{604800 \text{ mm}^2}\ 4742400 \text{ mm}^2$

$$\sqrt{\frac{A_1}{A_2}} = \sqrt{\frac{4742400}{240000}} = 4.44 \not< 2 \Rightarrow \sqrt{A_1/A_2} = 2$$

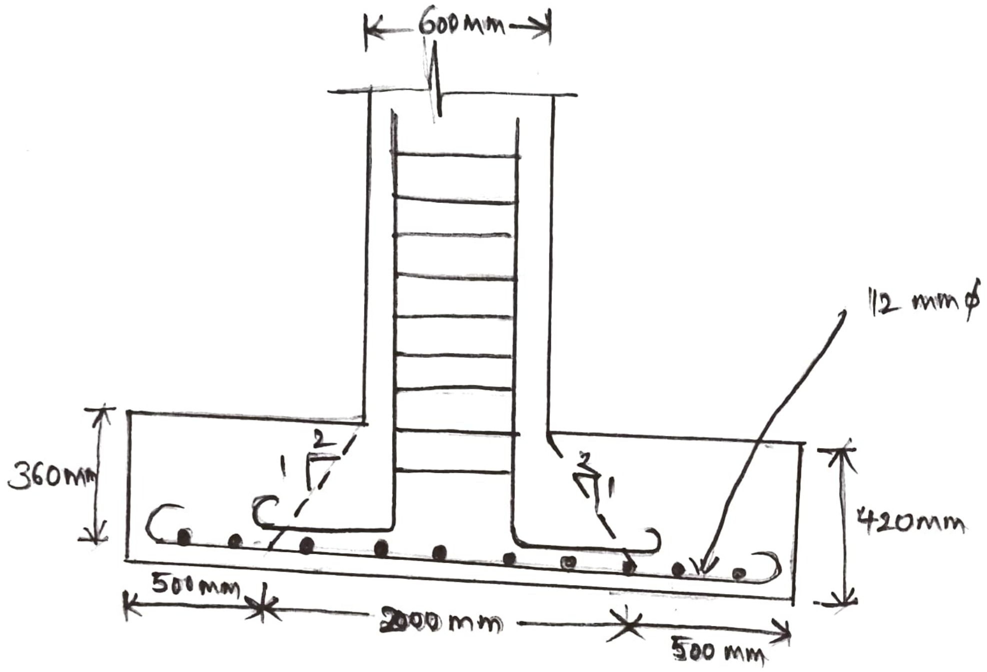
Permissible bearing stress $= 0.45\, f_{ck} \sqrt{\frac{A_1}{A_2}}$

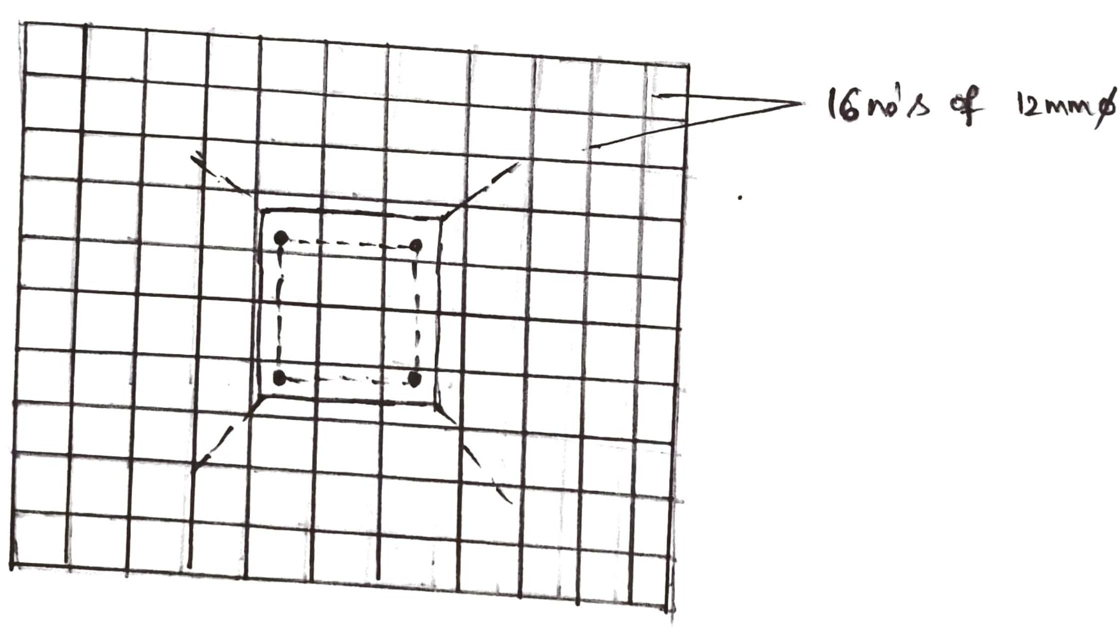
$$= 0.45 \times 20 \times \cancel{1.58}\ 2 = \cancel{14.28}\ 18\ N/mm^2$$

Actual bearing stress $= 1.5 \times \frac{P}{A} = \frac{1.5 \times 600 \times 10^3}{400 \times 600} = 3.75\ N/mm^2$

$< \cancel{14.28}\ 18\ N/mm^2$

Hence, it is safe in transfer of load.





Plan

Reinforcement Details

3) Design an isolated Square sloped footing for a column 500 x 500 mm, transmitting an axial load of 1200 KN. The column is reinforced with 8no's of 20 mm diameter. The Safe bearing capacity of soil is 120 KN/m^2. Use M_{20} and Fe_{415} materials.

Sol:- Given data :-

Size of Column = 500 x 500 mm

Axial load = 1200 KN = P

Safe bearing capacity, q_o = 120 KN/m^2

Size of footing :-

$$Area = \frac{w + w'}{q_o} = \frac{1200 + \frac{10}{100} \times 1200}{120} = 11 \ m^2$$

It is a square footing, $B = D = \sqrt{11} = 3.316m$

Provide a footing of size 3.4 x 3.4m.

$$\text{Net upward pressure, } p_o = \frac{P}{A} = \frac{1200}{3.4 \times 3.4}$$

$$= 103.8 \ KN/m^2 = 104 \ KN/m^2$$

Design of the footing (Depth) :-

Based on bending moment Consideration :-

$$M = \frac{p_o B}{8}(B-b)^2$$

$$= \frac{104 \times 3.4}{8}(3.4 - 0.5)^2 = 372 \ KNm$$

$$M_u = 1.5 \times 372 = 558 \ KNm$$

$$M_u = 0.138\, f_{ck}\, B d^2$$

$$d = \sqrt{\frac{M_u}{0.138\, f_{ck}\, B}} = \sqrt{\frac{558 \times 10^6}{0.138 \times 20 \times 3400}}$$

$$= 243.8 \simeq 250\,mm.$$

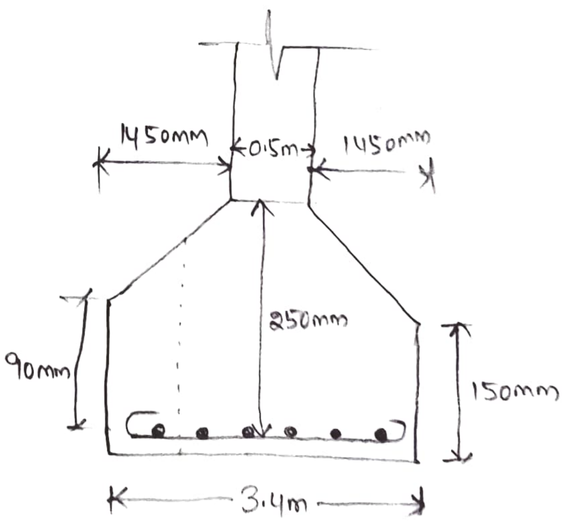
Let us adopt $D = 250 + 60 = 310\,mm$ using an effective cover of 60mm

Effective depth $d = 250\,mm$ for lower layer and $250 - 12 = 238\,mm$ for the upper layer of reinforcement.

At the end provide $D = 150\,mm$. So that available effective depth $= 150 - 60 = 90\,mm$ for the lower layer and $90 - 12 = 78\,mm$ for upper layer.

Check for one way shear :-

One way shear occurs at a distance of $d = 250\,mm$ from the face of the column.

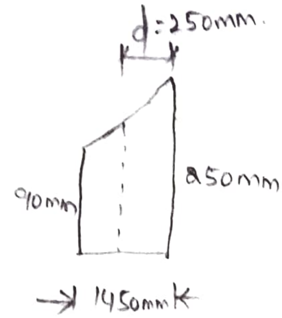


$$V = p_0 B \left(\frac{B-b}{2} - d\right)$$

$$= 104 \times 3.4 \left(\frac{3.4 - 0.5}{2} - 0.25\right)$$

$$= 424.32 \simeq 425\,KN.$$

$$V_u = 1.5 \times 425 = 637.5\,KN.$$



Effective depth at a distance of 'd' from face of Column $= 90 + \frac{250 - 90}{1450 - 0}(1450 - 250 - 0)$

$$d_x = 222.41\,mm.$$

$0 \rightarrow 90\,mm$

$1450 - 250 \rightarrow ?$

$1450 \rightarrow 250\,mm$

Nominal shear stress, $\tau_v = \dfrac{V_u}{b d_x}$

$$= \frac{637.5 \times 10^3}{3400 \times 222.41} = 0.843\ N/mm^2$$

Assuming an under reinforced section with $p_t = 0.3\%$

$\tau_c = 0.384\ N/mm^2$

$\tau_v > \tau_c$ - Hence the Section depth has to be revised.

Assume $d = 700mm$.

(Either assume a value of 'd' (or) equate τ_c and τ_v, calculate d_x and 'd')

$$V_u = 1.5\left[104 \times 3.4 \times \left(\frac{3.4-0.5}{2} - 0.7\right)\right]$$

$= 397.8$ KN. $\simeq 398$ KN

Effective depth, $d_x = 90 + \dfrac{700-90}{1450-0}(1450-700-0)$

$= 405.51$ mm.

Nominal shear stress, $\tau_v = \dfrac{398 \times 10^3}{3400 \times 405.51} = 0.288\ N/mm^2$

$\tau_v < \tau_c$.

Hence the footing is Safe in one way shear.

<u>check for two way shear</u>:-

Perimeter $= 4b_0 = 4 \times (500+700) = 4800$ mm

Area of Punching shear $= (500+700) \times (500+700)$

$= 1440000\ mm^2 = 1.44\ m^2$

$V_u =$ ~~p_0~~ $1.5\,[p_0\,(B \times B -$ Area of Punching shear$)]$

$= 1.5\left[104 \times (3.4^2 - 1.44)\right] =$ ~~1052.48~~

$= \underline{1578.7}$ KN

Two way shear occurs at a distance of $d/2$ from column face.

Nominal shear stress, $\tau_v = \frac{V_u}{bd}$

$0 \rightarrow 90$

$\frac{1450-700}{2} \rightarrow ? = 552.7$ mm

$1450 \rightarrow 700$mm

$= \frac{1578.72 \times 10^3}{\cancel{45}\overset{34}{}00 \times 552.75} = 0.84 \text{ N/mm}^2$

$K = 1$

$K\tau_c = 0.25\sqrt{f_{ck}} = 1.118 \text{ N/mm}^2$

$\tau_v < K\tau_c$

Hence the footing is safe in two way shear.

Design of steel reinforcement :-

$M_u = 0.87 f_y A_{st} d \left(1 - \frac{f_y A_{st}}{f_{ck} bd}\right)$

$558 \times 10^6 = 0.87 \times 415 \times A_{st} \times 700 \left(1 - \frac{415 A_{st}}{20 \times 3400 \times 700}\right)$

$= 252735 A_{st} - 2.2 A_{st}^2$

$A_{st} = 2251.99 \text{ mm}^2$

Assuming 12 mm dia bars, No. of bars $= \frac{2251.99}{\pi/4 \times 12^2} = 19.9 \simeq 20$ bars

$\therefore$ Provide 20 bars of 12 mm diameter.

Check for development length :-

$L_d = \frac{\phi \sigma_{st}}{4 \tau_{bd}} = \frac{12 \times 0.87 \times 415}{4 \times 1.2 \times 1.6} = 564.1$ mm

Allowable length $= \frac{1}{2}(B-b) - 60$

$= \frac{1}{2}(3.4 - 0.5) - \frac{60}{1000} = 1.39 \text{ m} > L_d$

Hence Safe.

Check for transfer of load at column base :-

$$\sqrt{\frac{A_1}{A_2}} > 2$$

$$A_1 = \left[500 + 2\times(2\times760)\right]^2 = 12531600 \text{ mm}^2$$

$$A_2 = 500\times500 = 250000 \text{ mm}^2$$

$$\therefore \sqrt{\frac{A_1}{A_2}} = \sqrt{\frac{12531600}{250000}} = 7.08 > 2$$

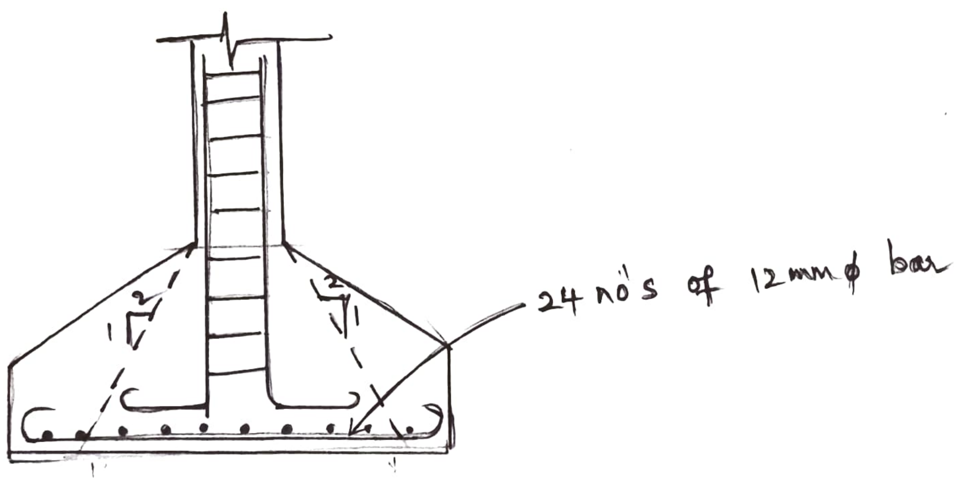
So adopt maximum value of '2'

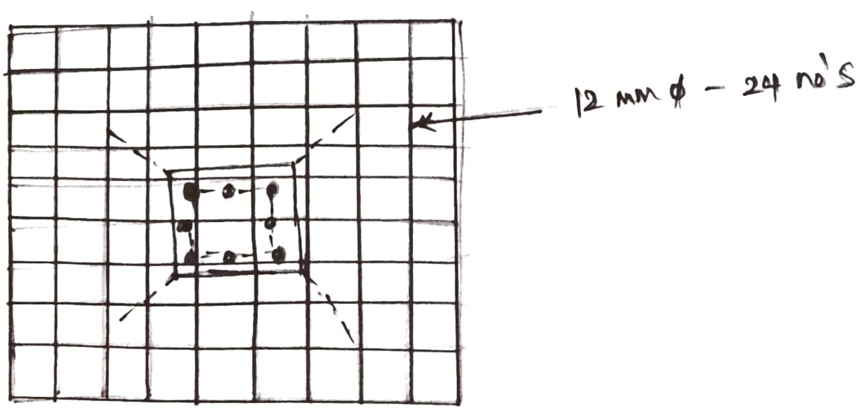
$$\text{Permissible bearing stress} = 0.45 f_{ck}\sqrt{\frac{A_1}{A_2}}$$

$$= 0.45\times20\times2 = 18 \text{ N/mm}^2$$

$$\text{Allowable bearing stress} = 1.5\times\frac{1200\times10^3}{500\times500} = 7.2 \text{ N/mm}^2 < 18 \text{ N/mm}^2$$

Hence safe.





Reinforcement Details

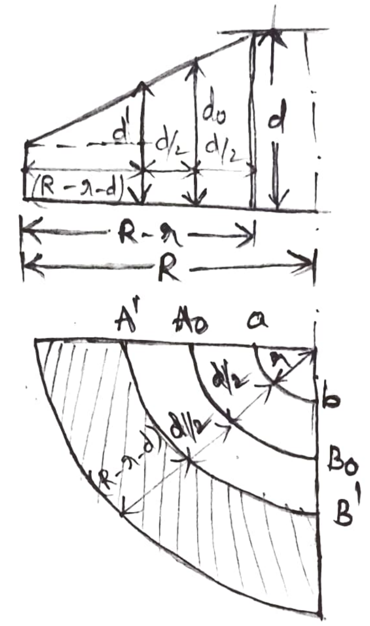
4) Design a footing for circular column 560 mm diameter, transmitting an axial load of 1200 KN. The column is reinforced with 8 bars of 10mm diameter. The safe bearing capacity of soil is 120 KN/m². Use M20 Concrete and Fe 415 steel.

Sol:- Given data :-

Size of Column = 560mm ϕ

Axial load = 1200 KN.

Safe bearing capacity, $q_0 = 120\ KN/m^2$.



Size of footing :-

$$\text{Area} = \frac{W+W'}{q_0} = \frac{1200 + \frac{10}{100}\times 1200}{120} = 11\ m^2$$

$$\text{Area} = \frac{\pi}{4} d^2 = \pi r^2$$

$$\Rightarrow r = \sqrt{A/\pi} = \sqrt{11/\pi} = 1.87m$$

Adopt radius R = 1.9m or diameter = 3.8m at base.

Radius of column r = 280mm = 0.28 m

$$\text{Net upward Pressure, } p_0 = \frac{W}{\pi R^2} = \frac{1200}{\pi \times 1.9^2} = 106\ KN/m^2.$$

Design of footing :-

upward force on one quadrant of footing = $p_0 \frac{\pi}{4}(R^2 - r^2)$

Distance of C.G of shaded area from the face of the column

$$= \frac{0.2}{R+r}(3R^2 - 2Rr - 2r^2)$$

Bending moment at the face of the column is given by

$$M = p_o \, \pi/4 \, (R^2 - r^2) \times \frac{0.2}{R+r} (3R^2 - 2Rr - 2r^2)$$

$$= p_o \times \frac{\pi}{20} (R-r)(3R^2 - 2Rr - 2r^2)$$

$$= 106 \times \frac{\pi}{20} (1.9 - 0.28) \left[3 \times 1.9^2 - 2 \times 1.9 \times 0.28 - 2 \times 0.28^2\right]$$

$= \cancel{2.592}$ 259.2 kNm.

Breadth 'b' of quadrant $= \frac{\pi r}{2} = \frac{\pi \times 280}{2} = 440$ mm.

$$M_u = 0.138 f_{ck} b d^2$$

$$d = \sqrt{\frac{259.2 \times 10^6}{0.138 \times 20 \times 440}} = 462 \text{ mm}$$

Let us keep D = 700mm with 60mm effective cover,

d = 640mm for outer layer

d = 640 − 12 ~~for~~ = 628mm for inner layer.

Design for shear :-

The depth above, from bending compression should be adequate from shear point of view. Circular footings are checked for two way shear (Punching shear) at a circular critical section distant d/2 (= 320mm) away from the face of the column.

$$\therefore r_o = r + d/2 = 280 + 320 = 600 \text{ mm}$$

Punching shear, $F_u = 1.5 \, p_o \, \pi (R^2 - r_o^2)$

$\therefore$ $F_u = 1.5 \times 106 \times \pi \left[1.9^2 - 0.6^2\right] = \cancel{16}\ 1623.4$ kN.

In circular columns, $\dfrac{F_u}{2\pi r_o d_o} \leq 0.25\sqrt{f_{ck}}$

$$\Rightarrow d_o = \frac{F_u}{2\pi r_o \times 0.25\sqrt{f_{ck}}} = \frac{1623.4 \times 10^3}{2\pi \times 600 \times 0.25\sqrt{20}} \simeq 386\text{mm}.$$

Let the effective depth, d_1 at the outer edge be 140mm. Then the available depth d_o at the critical plane corresponding to $d = 640$mm is given by,

$$d_o = d_1 + \frac{d - d_1}{R - r}\left(R - r - d/2\right)$$

$$= 140 + \frac{640 - 140}{1900 - 280}\left(1900 - 280 - 640/2\right) = 541\text{mm}. > 386\text{mm}.$$

This depth is more than the depth obtained from punching shear.

<u>For one way shear</u>, the critical plane $A'B'$ lies at a radial distance 'd'' from the column face, where effective depth d' is given by

$$d' = d_1 + \frac{d - d_1}{R - r}\left(R - r - d\right)$$

$$= 140 + \frac{640 - 140}{1900 - 280}\left(1900 - 280 - 640\right) \simeq 442\text{ mm}$$

Breadth b' at this section $= \pi/2\,(r + d)$

$$= \pi/2\,(280 + 640) = 1445\text{ mm}.$$

Shear force, $V_u = 1.5\, p_o\, \pi/4\, \{R^2 - (r+d)^2\}$

$$= 1.5 \times 106 \times \pi/4\,\left(1.9^2 - (0.28 + 0.64)^2\right)$$

$$= 345.11\text{ kN}.$$

Nominal shear stress, $\tau_v = \dfrac{345.11 \times 10^3}{1445 \times 442} = 0.54\ N/mm^2$

Assuming the section as under reinforced, i.e $p_t = 0.3\%$.

critical shear stress, $\tau_c = 0.384\ N/mm^2$

with $k = 1$ for $D > 300$ mm

$\cdot K \tau_c = 0.384\ N/mm^2 > 0.54\ N/mm^2$

Hence $d = 640$ mm is ~~de~~ inadequate.

Revised $d = \dfrac{0.54}{0.384} \times 640 = 900$ mm

check again for one way shear

$$d' = 140 + \frac{900 - 140}{1900 - 280}(1900 - 280 - 900) = 477.77\ mm$$

$$b' = \pi/2\,(280 + 900) = 1853.78\ mm$$

$$V_u = 1.5 \times 106 \times \pi/4\left[1.9^2 - (0.28 + 0.9)^2\right] = 276.96\ KN.$$

$$\therefore \tau_v = \frac{276.96 \times 10^3}{1853.78 \times 477.77} = 0.312\ N/mm^2 < 0.384\ N/mm^2$$

Hence safe.

Hence keep $d = 900$mm and $D = 960$mm at the column face and $D = 200$ mm at the ends.

Design of reinforcement :-

$$M_u = 0.87 f_y A_{st} d \left(1 - \frac{f_y A_{st}}{f_{ck} b d}\right)$$

$$259.2 \times 10^6 = 0.87 \times 415 \times A_{st} \times 900 \left(1 - \frac{415 A_{st}}{20 \times 440 \times 900}\right)$$

breadth of quadrant

$$= 324945 A_{st} - 17.02 A_{st}^2$$

$$A_{st} = 834.11 \text{ mm}^2$$

Provide 12 mm dia bars, No. of bars $= \dfrac{834.11}{\pi/4 \times 12^2} = 7.3 \simeq 8$ bars.

$\therefore$ provide 8 bars of 12 mm diameter in two directions.

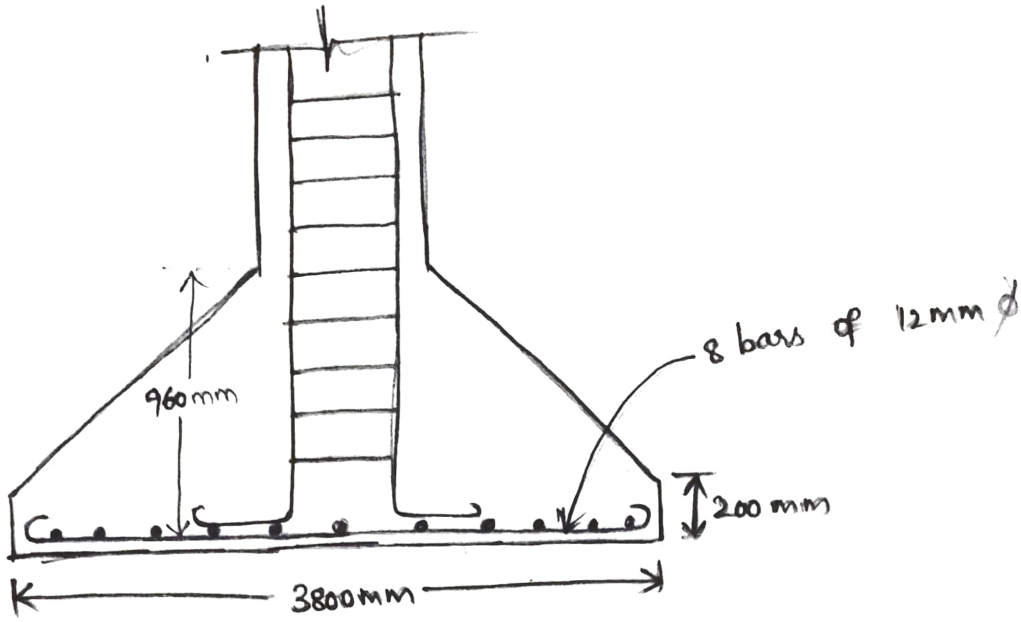
Check for development length :-

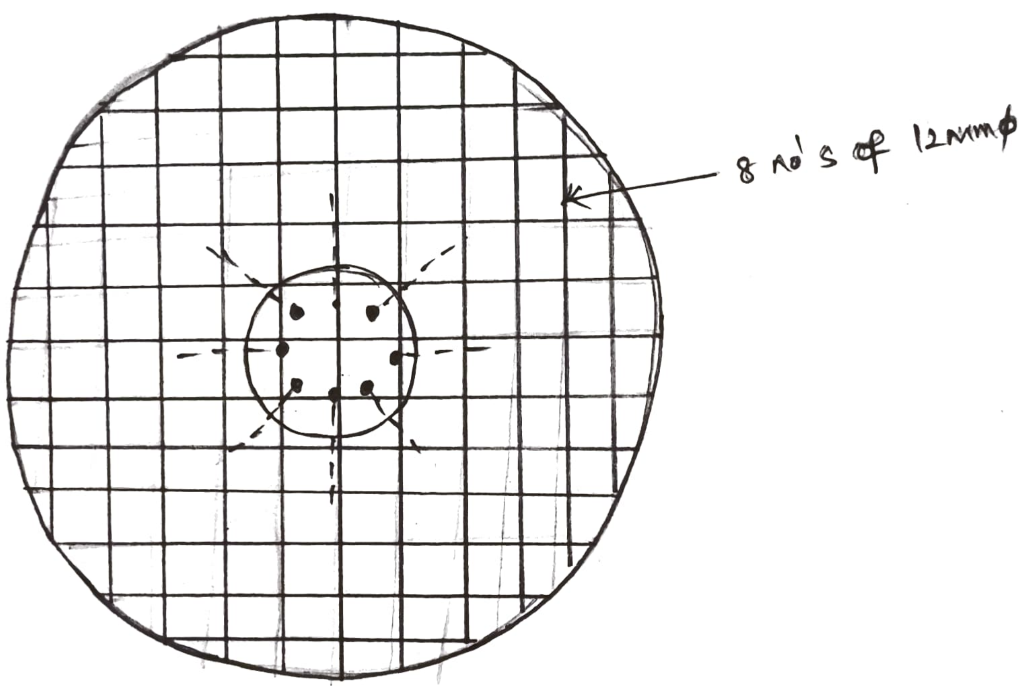
$$L_d = \frac{\phi \sigma_{st}}{4 \tau_{bd}} = \frac{12 \times 0.87 \times 415}{4 \times 1.2 \times 1.6} = 564.1 \text{ mm}$$

Available length $= (R - r) -$ side cover

$= 1900 - 280 - 60 = 1560 \text{ mm} > 564.1 \text{ mm}$

Hence the footing is safe.





Reinforcement Details