CHAPTER 12

Foundation

CONTENTS

12. Foundation

12.1 Introduction:

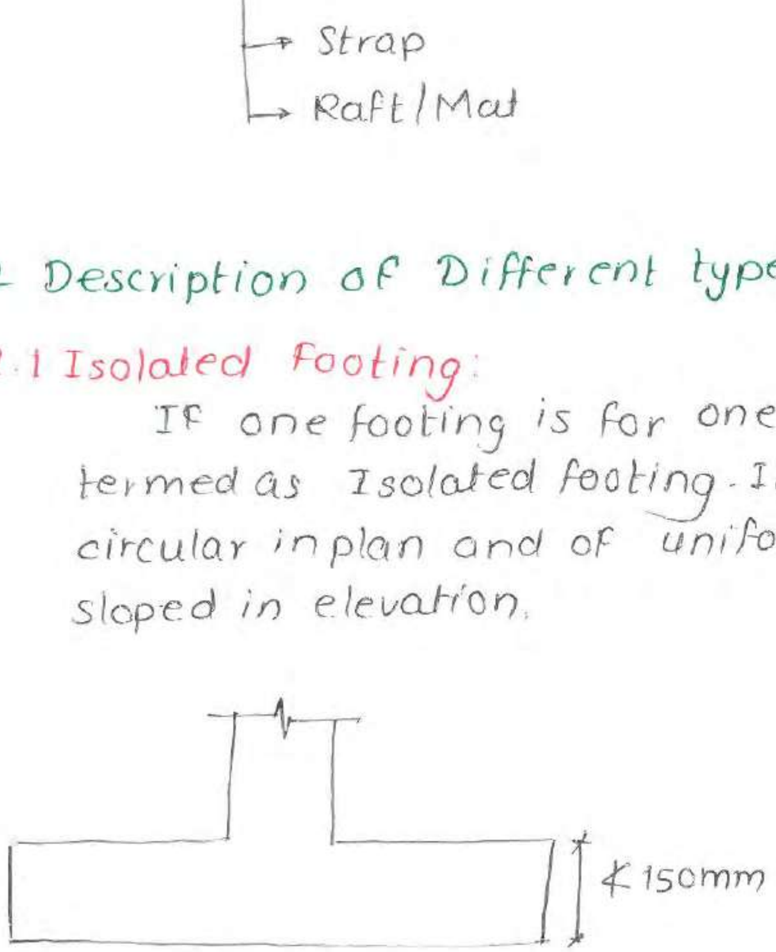
Foundation is a structural element below ground level that transfers load of superstructure to the soil safely.

Foundation
- Shallow (footing)
  - Isolated
  - Combined
  - Strap
  - Raft/Mat
- Deep
  - Pile
  - Well

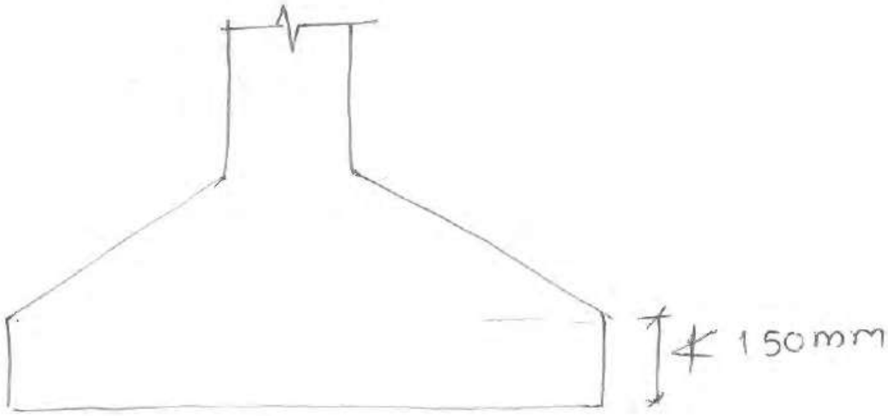
12.2 Description of Different types of footing.

12.2.1 Isolated Footing:

If one footing is for one column/wall then it is termed as Isolated footing. It may be square, rectangular, circular in plan and of uniform thickness, stepped or sloped in elevation.



(a)



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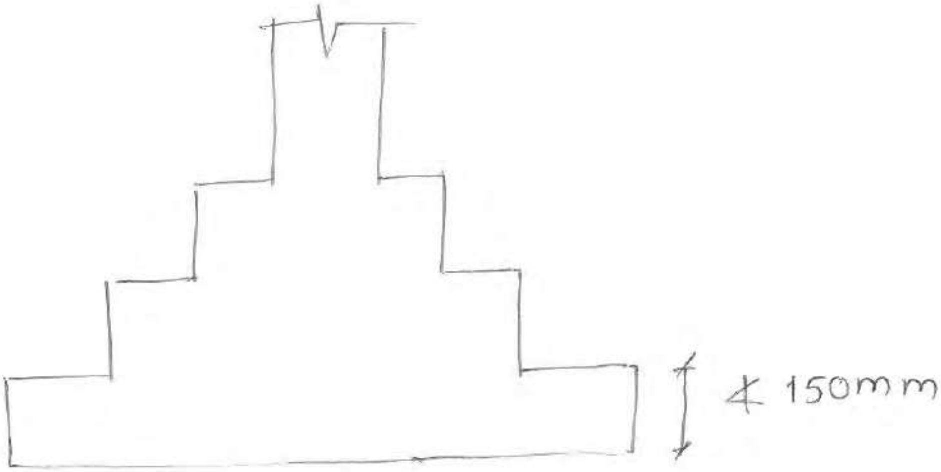

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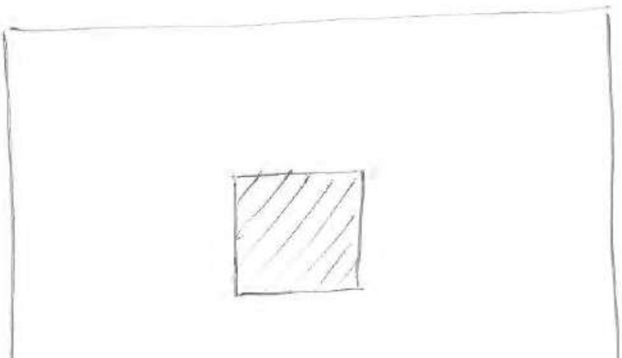

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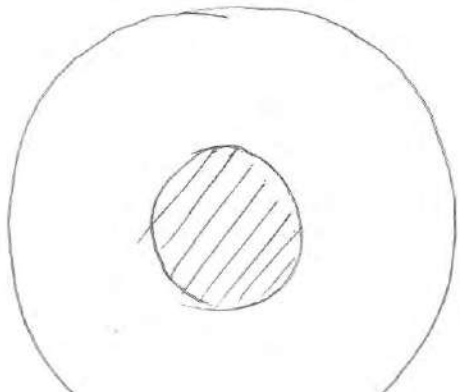
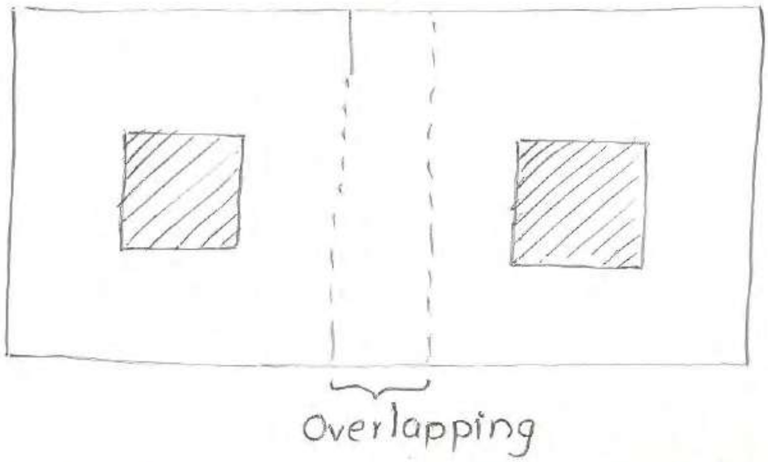


(e)

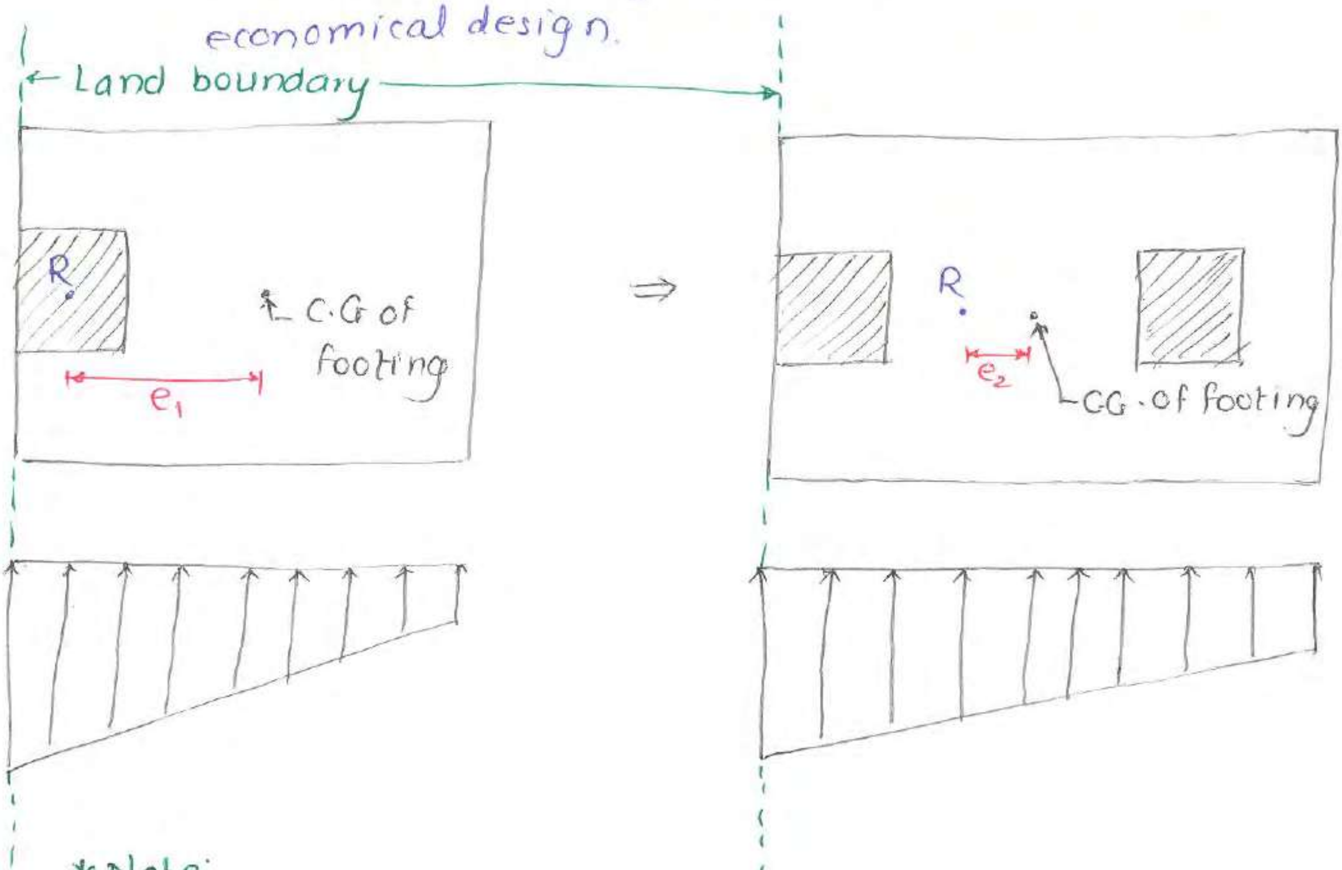
12.2.2 Combined Footing

It is provided in following two cases:

Case I: If columns are closely spaced and their isolated footings are overlapping then combined footing is preferable.



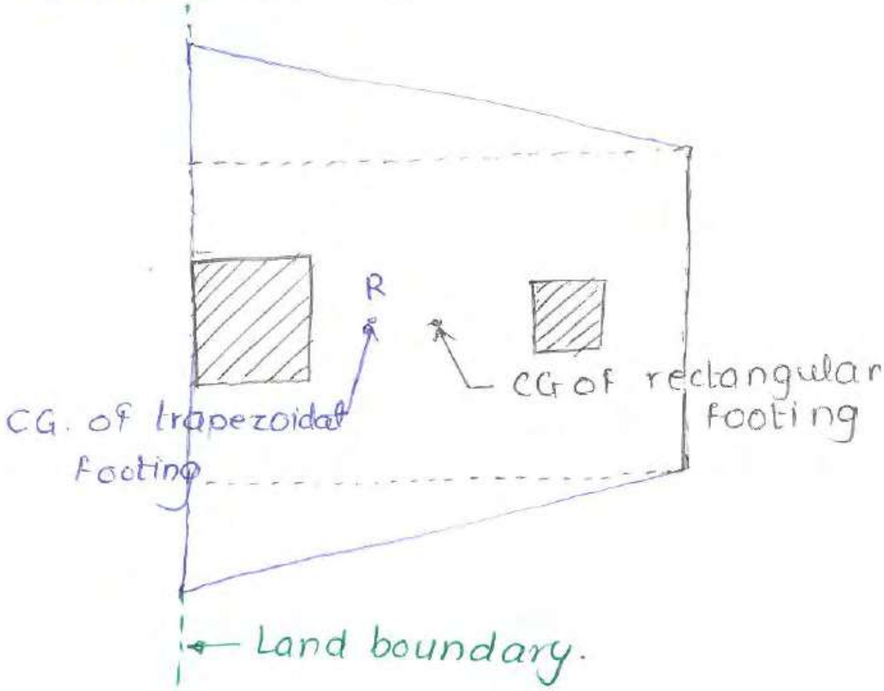
Case II: If column is placed at land boundary then its isolated footing is combined with isolated footing of other column to get desired pressure distribution for economical design.



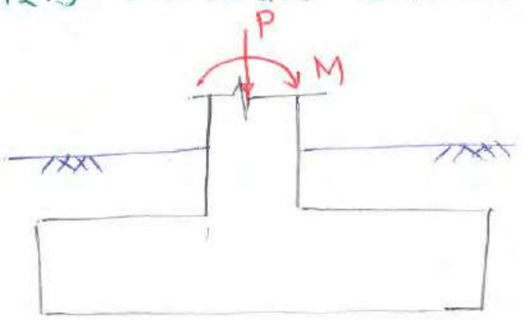
* Note:

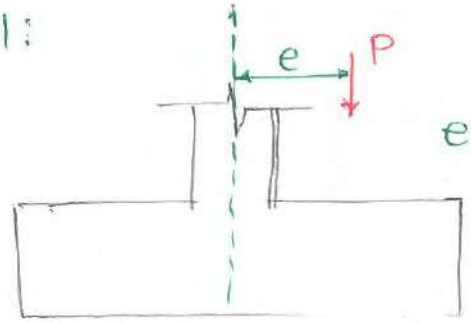
- For uniform pressure on soil below footing, resultant of all loads must pass through C.G. of plan area of footing.

- If two unequally loaded columns are supported by a footing and lengthe of footing is restricted then trapezoidal footing is provided for uniform pressure distribution on soil.

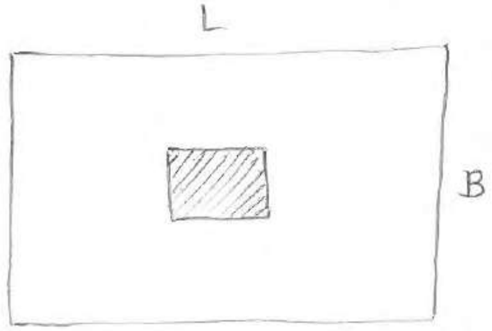


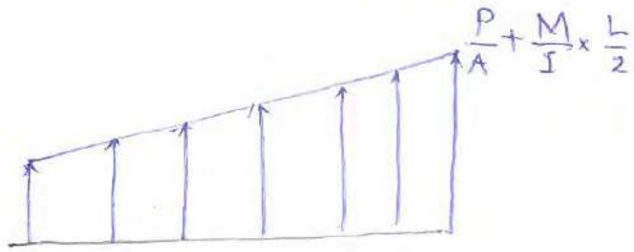
12.3 Pressure Distribution of Soil:

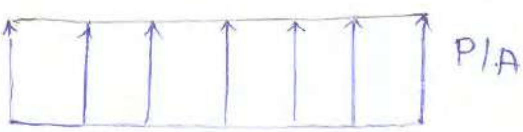


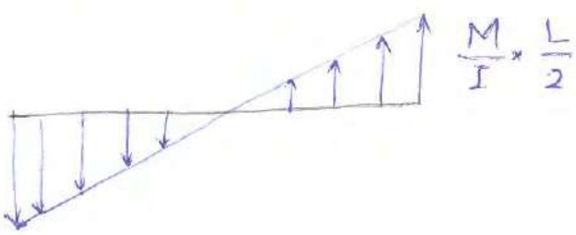


$$e = \frac{M}{P}$$









For just zero pressure one one extreme fibre

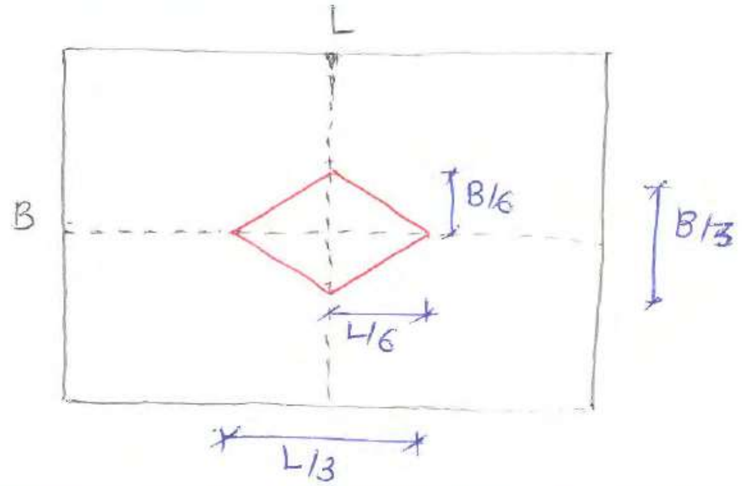
$$\frac{P}{A} - \frac{M}{I}\times\frac{L}{2} = 0$$

$$\Rightarrow \frac{P}{LB} - \frac{Pe}{\frac{BL^3}{12}}\times\frac{L}{2} = 0$$

$$\Rightarrow \boxed{e = \frac{L}{6}}$$

* Conclusion:

For non-zero upward pressure from soil (no lifting cond^n) resultant must pass through middle third of plan area. This is also called as Middle Third Rule.



Ex. Calculate maximum and minimum pressure exerted by soil on footing base of plan area (3×4) m. This footing is supporting axial load 2000 kN and moment 400 kN m about shorter side, at its base.

⇒

$$\sigma_{max/min} = \frac{P}{A} \pm \frac{M}{I} \cdot \frac{L}{2}$$

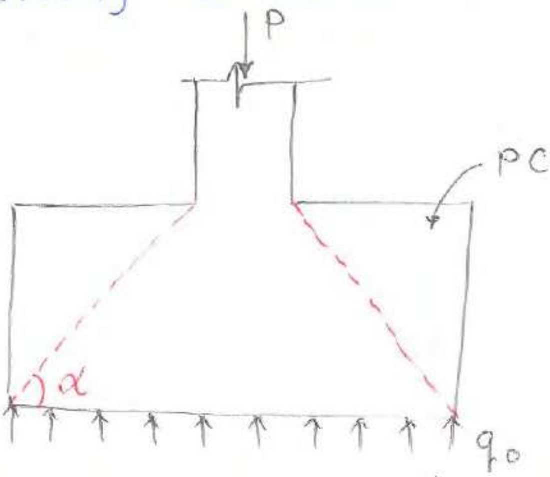
$$= \frac{2000}{3\times4} \pm \frac{400}{\frac{3\times4^3}{12}} \times \frac{4}{2}$$

$$\sigma_{max} = 216.67 \ kN/m^2$$

$$\sigma_{min} = 116.67 \ kN/m^2$$

12.4 Codal Provisions:

- Minimum slab thickness is 150mm.
- Minimum nominal cover 50mm
- Dimension of footing of PCC should be such that following condition must be satisfied,

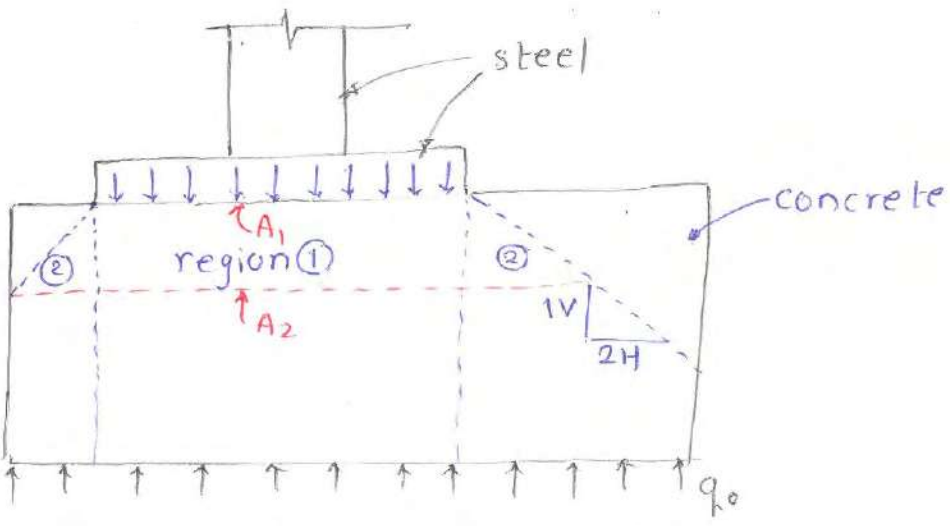


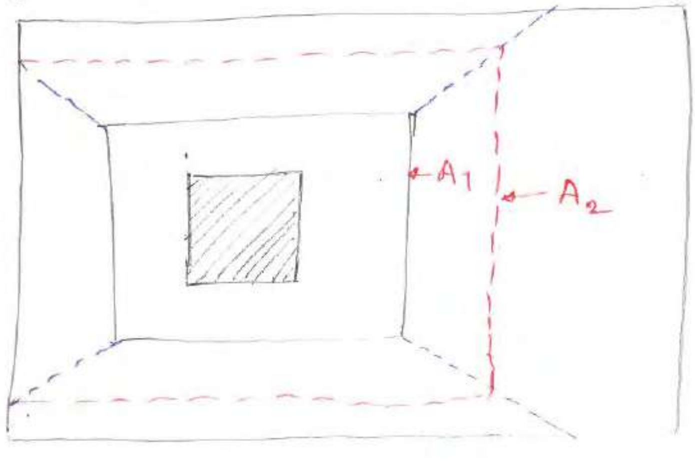
$$\tan\alpha \nless 0.9\sqrt{\frac{100 q_0}{f_{ck}}+1}$$

- Maximum bearing strength of concrete is

$$0.45 f_{ck}\sqrt{\frac{A_2}{A_1}}$$

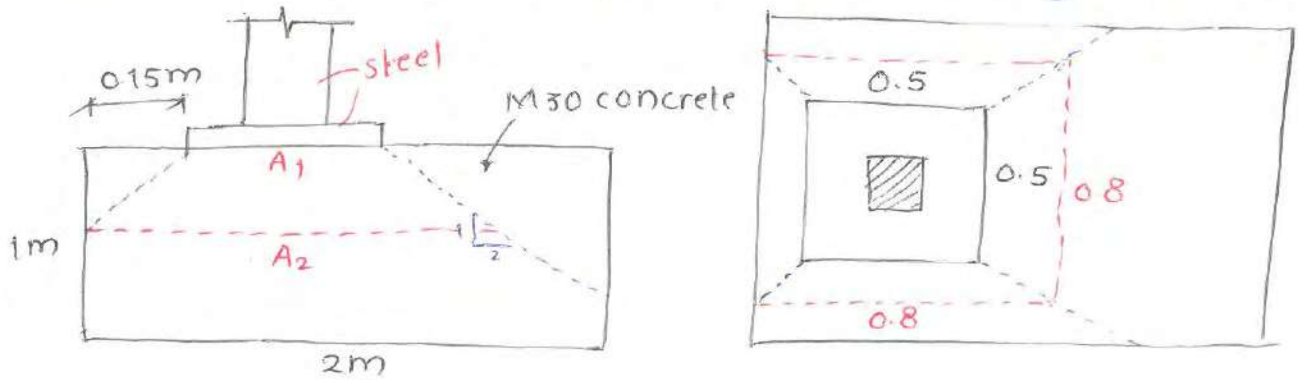
where, $\sqrt{\frac{A_2}{A_1}} \ngtr 2$





Bearing strength of concrete is enhanced by $\sqrt{\frac{A_2}{A_1}}$ because concrete of region ① is confined by concrete of region ②.

Ex. Calculate bearing strength of concrete for given case.



$$\Rightarrow \sqrt{\frac{A_2}{A_1}} = \sqrt{\frac{0.8 \times 0.8}{0.5 \times 0.5}} = 1.6$$

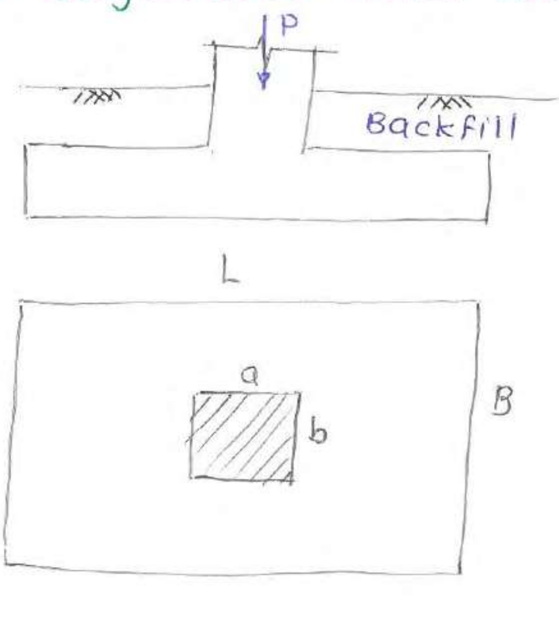
$$f_{br} = 0.45 f_{ck} \sqrt{\frac{A_2}{A_1}} = 0.45 \times 30 \times 1.6$$

$$\Rightarrow f_{br} = 21.6 \text{ N/mm}^2$$

12.5 Design of Rectangular Isolated footing of uniform thickness subjected to Axial Load:

L>B

a>b



Step 1: Take working axial load

Step 2: Take safe bearing capacity (SBC) of soil

Step 3: Take self weight of footing and backfill as 10% of axial working load. (based on experience)

Step 4: Calculate plan area required for footing base slab.

$$A_{req} = \frac{P + 0.1P}{SBC}$$

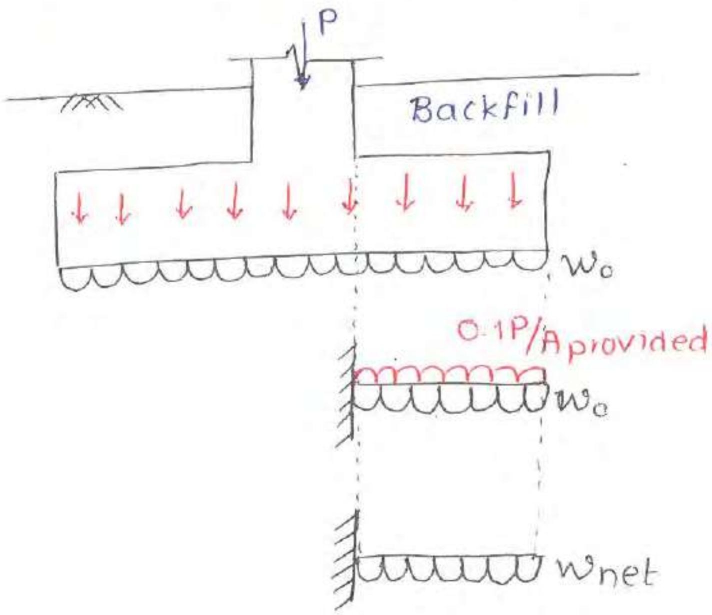
Step 5: Provide dimension of footing in such a way that overhang on both sides of column should be approximately equal.

$$A_{provided} \geq A_{required}$$

Step 6: Calculate upward soil pressure on base slab.

$$w_0 = \frac{P + 0.1P}{A_{provided}} \leq SBC$$

Step 7: Calculate net upward pressure for design of base slab.



$$w_{net} = w_0 - \frac{0.1P}{A_{provided}}$$

$$= \frac{P + 0.1P}{A_{prov.}} - \frac{0.1P}{A_{prov.}}$$

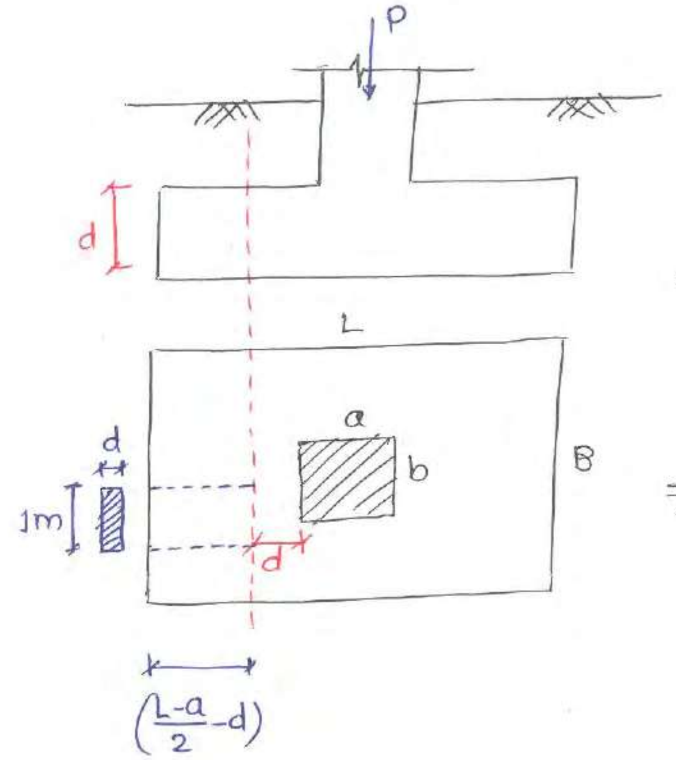
$$w_{net} = \frac{P}{A_{provided}}$$

Step 8: Calculate factored Net upward pressure.

$$w_u = 1.5\, w_{net}$$

Step 9: Design for one way shear.

Critical section for one way shear is at a distance 'd' from face of column/wall.



Oneway shear stress $\leq k\,\tau_c$

$$\Rightarrow \frac{\text{Load on strip}}{\text{Resisting area}} \leq k\,\tau_c$$

$$\Rightarrow \frac{w_u\left[\left(\frac{L-a}{2}-d\right)\times 1\right]}{1\times d} \leq k\,\tau_c$$

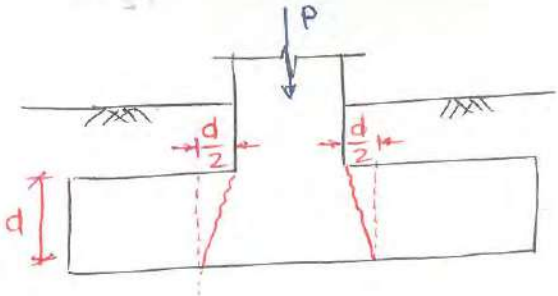
Above expression is used to calculate 'd' required to prevent one way shear failure.

*** Note:**

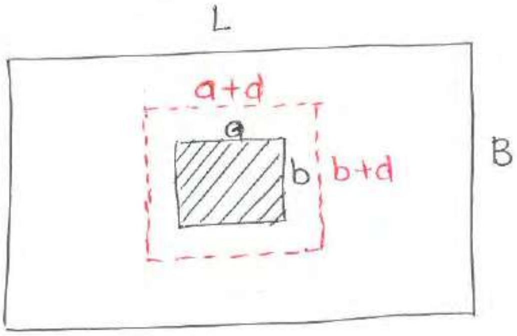
For preliminary design, considering $k=1$ and τ_c corresponding to 0.2% of longitudinal tension reinforcement.

Step 10: Design for punching / two way shear:

Critical section for punching shear is at a distance $d/2$ from face of column.



$$\text{2-way shear stress} \leq k_\beta \, 0.25\sqrt{f_{ck}}$$

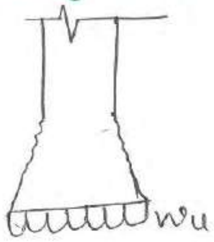


$$\Rightarrow \frac{\text{Punching SF}}{\text{Resisting area}} \leq k_\beta \, 0.25\sqrt{f_{ck}}$$

$$\Rightarrow \frac{P_u - W_u\left[(a+d)(b+d)\right]}{2\left[(a+d)+(b+d)\right] d} \leq k_\beta \, 0.25\sqrt{f_{ck}}$$

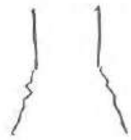
where, k_β = Minimum $\begin{cases} \cdot\ 0.5 + b/a \\ \cdot\ 1 \end{cases}$

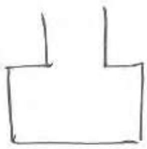
Punching SF :



Punching SF $= P_u - W_u\left[(a+d)(b+d)\right]$

where,
$P_u = 1.5\,P$





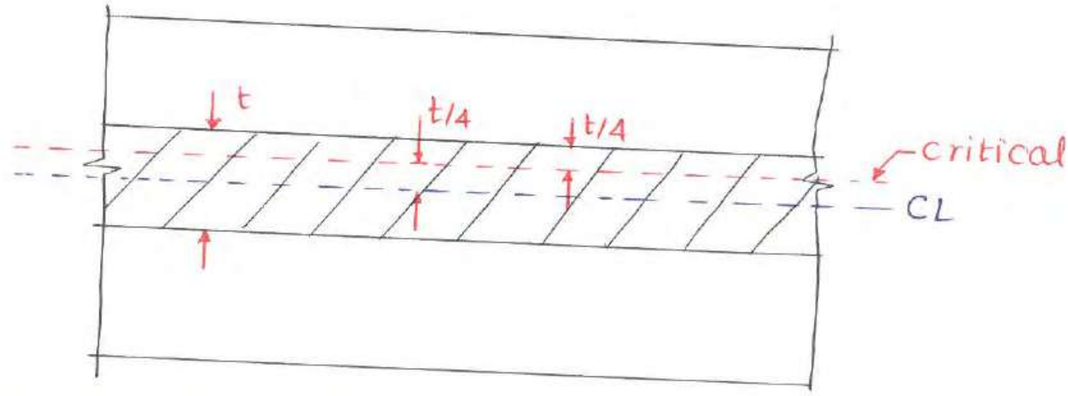
*** Note :**
If footing fails in punching shear then depth is sufficiently increased and only step 10 is repeated.

Step11: Design for bending

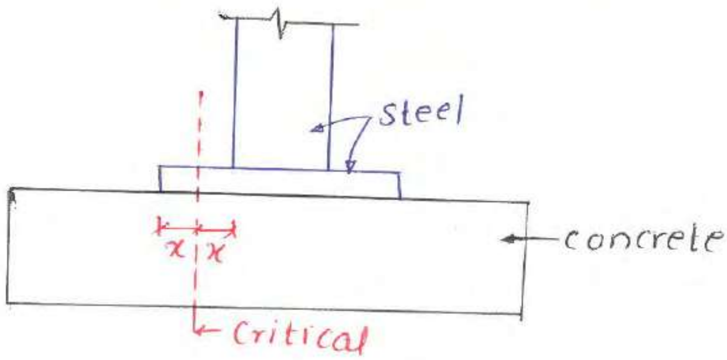
Critical section:

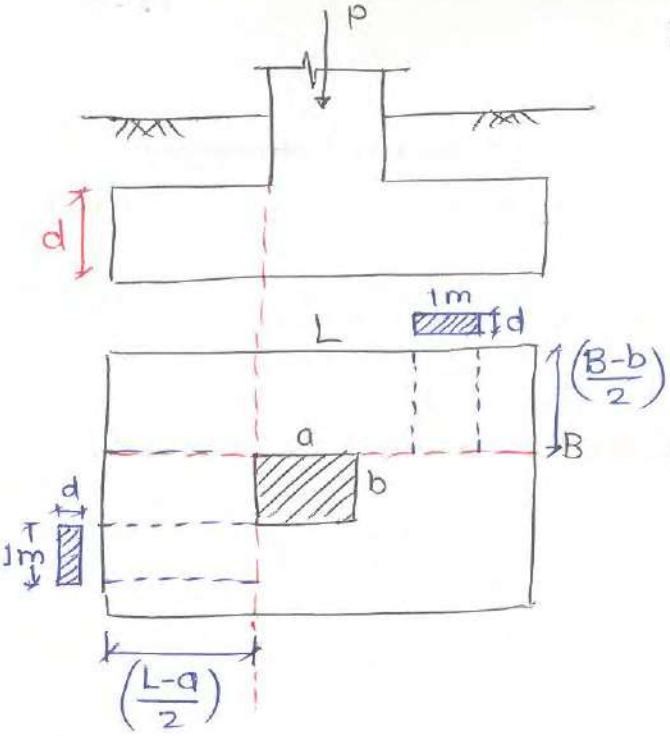
1. If concrete slab is supporting monolithically casted column/ wall then critical section is at the face of column/wall.

2. If concrete slab is supporting masonary wall then critical section is at the mid of centre line of wall and face of wall.



3. If footing slab is supporting a steel column with gusset plate then critical section is at the mid of face of column and edge of gusset plate.





For longer Overhang:

$$BM_{max} = \frac{w_u \left(\frac{L-a}{2}\right)^2}{2}$$

If $BM_{max} \leq M_{u,lim}$ then

$$A_{st} = \frac{0.5 f_{ck} b' d}{f_y}\left[1 - \sqrt{1 - \frac{4.6\, BM_{max}}{f_{ck} b' d^2}}\right]$$

$\nless A_{st,min}$ of slab

where,
$b' = 1000mm$.

For shorter overhang:

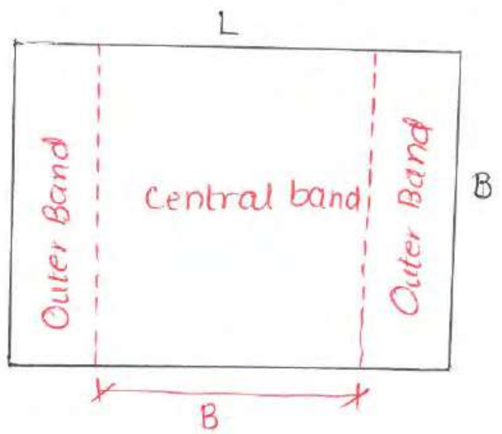
$$BM_{max} = \frac{w_u \left(\frac{B-b}{2}\right)^2}{2}$$

If $BM_{max} \leq M_{u,lim}$ then,

$$A_{st} = \frac{0.5 f_{ck} b' d}{f_y}\left[1 - \sqrt{1 - \frac{4.6\, BM_{max}}{f_{ck} b' d^2}}\right] \nless A_{st,min} \text{ of slab}$$

where, $b' = 1000mm$

Step 12: Reinforcement Detailing:



n_T = Total no. of bars along shorter side

n_c = No. of bars along shorter side in central band

$$n_c = n_T \left(\frac{2}{1 + L/B}\right)$$

Ex. Design an isolated footing of uniform thickness for column of section sizes (300 × 500) mm. Column is subjected to factored axial load 1800 kN. SBC = 130 kN/m², M25, Fe415. effective cover 75 mm.

⇒

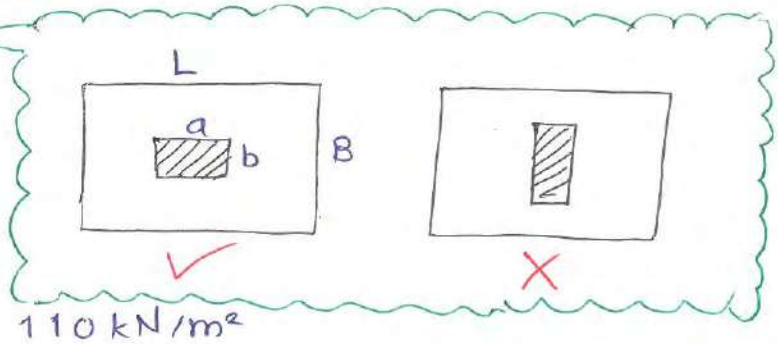
Step 1: $P = \frac{P_u}{1.5} = \frac{1800}{1.5} = 1200\ kN$

Step 2: $SBC = 130\ kN/m^2$

Step 3: Self wt. $= 0.1P = 120\ kN$

Step 4: $A_{req} = \frac{P + 0.1P}{SBC} = \frac{1200 + 120}{130} = 10.15\ m^2$

Step 5: Providing 3 × 4 m



Step 6: $w_o = \frac{P + 0.1P}{A_{provided}}$

$$= \frac{1200 + 120}{12} = 110\ kN/m^2$$

Step 7: $w_{net} = \frac{P}{A_{provided}} = \frac{1200}{3 \times 4} = 100\ kN/m^2$

Step 8: $w_u = 1.5 w_{net} = 150\ kN/m^2$

Step 9: One way shear

$$\tau_c = 0.32\ N/mm^2$$

$$= 320\ kN/m^2$$

Now, One way shear stress $\leq k\tau_c$

$$\frac{w_u\left[\left(\frac{L-a}{2} - d\right) \times 1\right]}{1 \times d} \leq k\tau_c$$

$$\frac{150\left[\left(\frac{4-0.5}{2} - d\right) \times 1\right]}{1 \times d} \leq 1 \times 320$$

$$d \geq 0.558\ m$$

$$d \geq 558\ mm$$

Providing $d = 600\,mm$

$$D = d + \text{effective cover} = 600+75$$

$$D = 675\,mm$$

step 10: Two-way shear:

$$K_\beta = \text{Minimum} \begin{cases} \cdot\ 0.5 + b/a = 0.5 + 0.3/0.5 = 1.1 \\ \cdot\ 1 \end{cases}$$

$$K_\beta = 1$$

$$0.25\sqrt{f_{ck}} = 0.25\sqrt{25} = 1.25\,N/mm^2 = 1250\,kN/m^2$$

Two-way shear stress $\leq K_\beta\, 0.25\sqrt{f_{ck}}$

$$\frac{P_u - w_u\left[(a+d)(b+d)\right]}{2\left[(a+d)+(b+d)\right]\cdot d} \leq K_\beta\ 0.25\sqrt{f_{ck}}$$

$$\Rightarrow \frac{1800 - 150\left[(0.5+0.6)\ (0.3+0.6)\right]}{2\left[(0.5+0.6)+(0.3+0.6)\right]\times 0.6} \leq 1\times 1250$$

$$\Rightarrow 688.12 < 1250 \quad \text{OK}$$

Step 11: Design for Bending:

- Longer Overhang:

$$BM_{max} = \frac{w_u\left(\frac{L-a}{2}\right)^2}{2}$$

$$= \frac{150\times\left(\frac{4-0.5}{2}\right)^2}{2}$$

$$BM_{max} = 229.68\ kNm$$

$$M_{u,lim} = 0.138\, f_{ck}\, bd^2$$

$$= 0.138\times 25\times 1000\times 600^2$$

$$M_{u,lim} = 1242\ kNm$$

Since, $BM_{max} < M_{u,lim}$

$$A_{st} = \frac{0.5 f_{ck} b'd}{f_y}\left[1 - \sqrt{1 - \frac{4.6 BM_{max}}{f_{ck} b' d^2}}\right]$$

$$= \frac{0.5 \times 25 \times 1000 \times 600}{415}\left[1 - \sqrt{1 - \frac{4.6 \times 229.68 \times 10^6}{25 \times 1000 \times 600^2}}\right]$$

$A_{st} = 1093.87 mm^2$

Now,

$A_{st,min} = 0.12\% \ b'D$

$$= 0.12 \times \frac{1}{100} \times 1000 \times 675$$

$A_{st,min} = 810 mm^2$

$A_{st} = 1093.87 mm^2$

Assuming $\phi = 16 mm$

$$Spacing = \frac{1000}{No.\ of\ bars}$$

$$= \frac{1000}{A_{st} / \frac{\pi}{4}\phi^2}$$

$$= \frac{1000}{1093.87 / \frac{\pi}{4} \times 16^2}$$

Spacing = 183.80 mm

Providing 16 ϕ @ 175 mm c/c.

- Shorter Overhang:

$$BM_{max} = \frac{w_u \left(\frac{B-b}{2}\right)^2}{2}$$

$$= \frac{150 \times \left(\frac{3 - 0.3}{2}\right)^2}{2}$$

$BM_{max} = 136.68 \ kNm.$

$M_{u,lim} = 1242 \ kN\text{-}m$

Since $BM_{max} < M_{u,lim}$ so

$$A_{st} = \frac{0.5 f_{ck} b d}{f_y}\left[1 - \sqrt{1 - \frac{4.6\, BM_{max}}{f_{ck} b' d^2}}\right]$$

$$= \frac{0.5 \times 25 \times 1000 \times 600}{415}\left[1 - \sqrt{1 - \frac{4.6 \times 136.68 \times 10^6}{25 \times 1000 \times 600^2}}\right]$$

$A_{st} = 642.78\ mm^2 < A_{st,min}\ (810\ mm^2)$

So providing $A_{st,min}$

$A_{st} = 810\ mm^2$

Assuming $\phi = 12\ mm$

$$\text{Spacing} = \frac{1000}{\text{No. of Bars}} = \frac{1000}{A_{st} / \frac{\pi}{4} \times \phi^2}$$

$$= \frac{1000}{810 / \frac{\pi}{4} \times 12^2}$$

Spacing = 139.63 mm

Providing 12ϕ @ 125 mm c/c

Step 12: Reinforcement Detailing:

n_T = (No. of bars per meter x distance) + 1

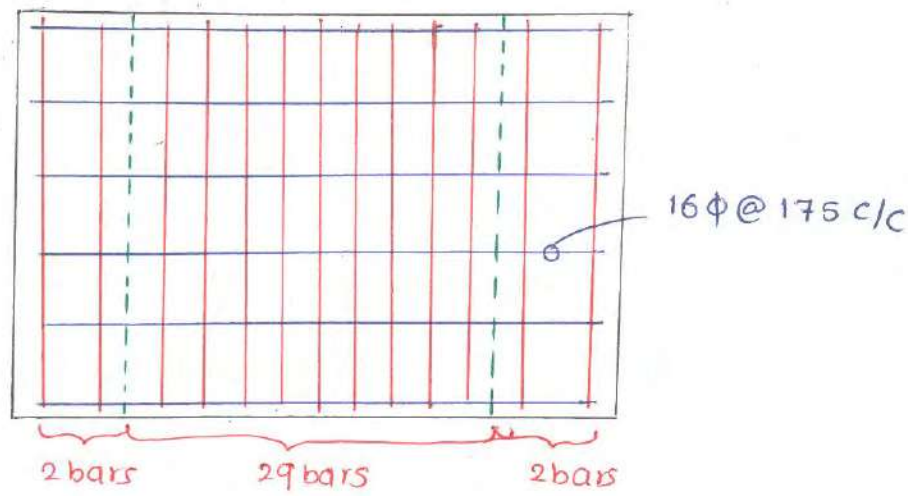
$$= \left(\frac{1000}{\text{spacing}} \times \text{distance}\right) + 1$$

$$= \left(\frac{1000}{125} \times 4\right) + 1$$

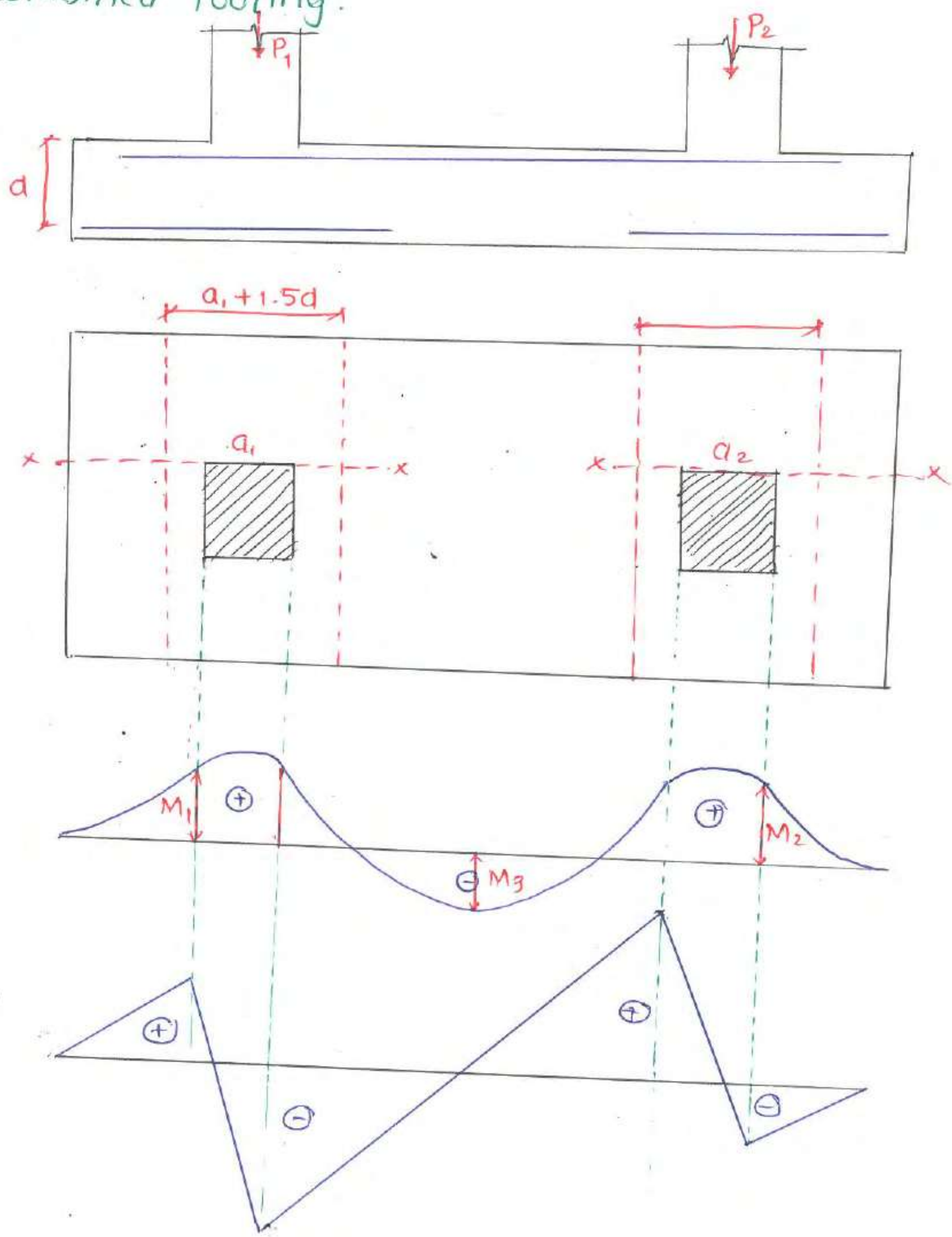
$n_T = 33$ bars

$$n_c = n_T\left(\frac{2}{1 + L/B}\right) = 33\left(\frac{2}{1 + 4/3}\right) = 28.28 \approx 29 \text{ bars}$$

$$\text{No. of bars in outer band} = \frac{n_T - n_c}{2} = \frac{33 - 29}{2} = 2 \text{ bars}$$



12.6 Combined footing:



- Design for one-way shear and way shear is same as isolated footing
- Reinforcement required for BM at x-x is provided in a strip of width $\{a_1+1.5d\}$ (similarly for $a_2+1.5d$) remaining portion is provided with nominal reinforcement along shorter side.
- Reinforcement along longer side is calculated corresponding to critical positive bending moment (M_1 and M_2) and critical negative BM (M_3)

.... Chapter 12 Ends Here...