Structural Design-1 (TH-)
4th semester
Civil Engg.

Design of Axially loaded Columns and Footings (LSM)

* Assumptions in limit state of collapse in Compression :-

The following assumptions are made for the limit state of collapse in compression :-

1- Plane sections normal to the axis remain plane after bending.

2- The relationship between stress - strain distribution in concrete shall be assumed to be parabolic.

3 - The tensile strength of the concrete is ignored.

4- The stress in the reinforcement are derived from the representative stress - strain curve for the type of steel used.

5- The maximum compressive strain in concrete in axial compression is taken as 0.002.

* Column :-

Column or compression member is define as the member which supports or resists the axial compression load and its length should be atleast 3 times its least lateral dimension.

* Classification of columns :-

i) The columns in a building are classified as

(a) Braced columns

(b) unbraced columns

(a) Braced columns :- In braced frames, the lateral loads like wind, earthquake, etc are resisted by some special arrangements like shear walls, bracing or special supports.

(b) Unbraced columns :- In unbraced frames no special bracing systems are provided to resist horizontal forces.

2) The columns in the given floor in the given direction are classified as :-

(a) No - sway column (b) Sway column

(a) No - sway column :- The columns of the floor having limited value of the sway are called no-sway columns.

→ For no-sway columns, the effective length is always less than or equal to its actual unsupported length.

(b) Sway columns :- For sway columns, the effective length is always greater than its actual unsupported length.

3) According to the type of reinforcement and lateral restraint provided, the columns are classified as :-

(a) Tied columns

(b) Spiral columns

(c) Composite columns

(a) Tied columns :- Tied column where the transverse ties are used as lateral restraint.

(b) Spiral columns :- When continuous bar or heavy wire is wrapped around the longitudinal bars in the form of a helical spiral, the column is referred to as a spiral column.

(c) Composite columns :- Instead of longitudinal steel bars, if the column is reinforced with structural steel shapes is known as composite column.

4) Under the action of a compressive load, all columns have a tendency to buckle and this buckling effect shall be considet in the design.

(a) Short columns (b) Long columns

(a) Short columns :- Short columns are those which fail due to material failure.

→ Short columns do have buckling effect, but of a limited value.

(b) Long Columns :- Long columns are those which fail due to material failure and also due to buckling.

→ The buckling effect may have a predominant value.

* Slenderness ratio :- It is defined as the ratio of effective length of a column to its least lateral dimension.

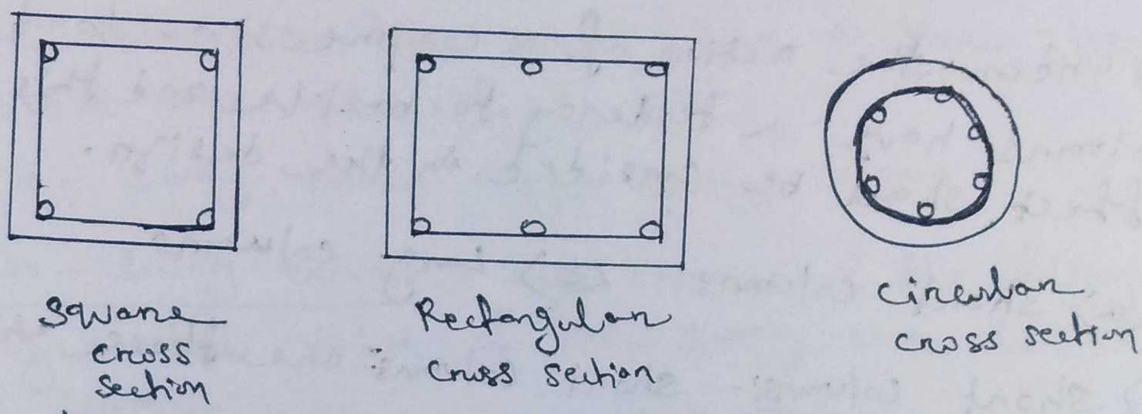
i.e $(r) = \frac{l_{eff}}{D}$

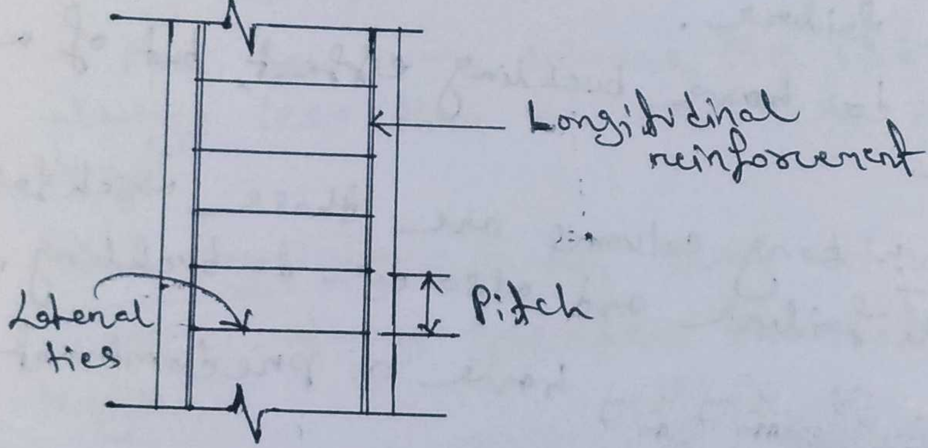
where,

r = Slenderness ratio
l_{eff} = Effective length of the column
D = Least lateral dimension of the column

when the slenderness ratio for a column is less than or equal to 12, then a column is known as short column. when the slenderness ratio is greater than 12, then the column is known as long column.

*** Shape of column :-** The column is generally of various types but we use the rectangular column, square column, & circular column.





*** Pitch :-** It is the centre to centre distance between two lateral ties which is uniform throughout the length of the column. The pitch should not be exceed :-

a) The least lateral dimension of the column.

b) 16 times the diameter of main or longitudinal bar

c) 300 mm

* **Lateral ties :-** It is the shear reinforcement provided in a column section which provides or gives a rectangular to the longitudinal reinforcement and gives proper position to the longitudinal reinforcement. The diameter of lateral ties should not be less than $\frac{1}{4}$th of the diameter of longitudinal bar or 6mm.

* **Longitudinal reinforcement :-**

(i) The minimum area of longitudinal reinforcement should not be less than 0.8 % of the gross cross-sectional area of the column.

(ii) The maximum area of longitudinal bar should not exceed 6 % of the gross cross-sectional area of the column.

(iii) But we generally provide 1% of the gross cross-sectional area as the longitudinal reinforcement.

(iv) The diameter of longitudinal reinforcement should not be less than 12mm.

(v) The minimum number of longitudinal reinforcement should not be less than 4 no.s for square or rectangular columns and should not be less than 6 no.s for circular columns.

(vi) The spacing should not be greater than 300 mm for longitudinal reinforcement in a column.

* **Axially loaded column :-** When the load is applied on the neutral axis of a column, it is called axially loaded column.

→ As the load is on the neutral axis there is no bending in a column, but actually in there is no perfect axial loaded column. So the code provide a minimum eccentricity i.e

$$e_{min} \geq \frac{L}{500} + \frac{D}{30} = 20mm$$

where,

e_{min} = minimum eccentricity

L = Unsupported length or clear length of the column.

D = Least lateral dimension of the column.

* Designing formula :-

when,

$e_{min} \leq 0.05D$,

Then, $P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

where,

P_u = Factored axial load.

A_c = Area of concrete in column section

A_{sc} = Area of reinforcement in column section.

f_{ck} = characteristic compressive strength of concrete

f_y = characteristic strength of reinforcement

If $e_{min} > 0.05D$,

$$P_u = 0.4 f_{ck}\left(A_g - \frac{P A_g}{100}\right) + 0.67 f_y \frac{P A_g}{100}$$

where,

P = Percentage of reinforcement

A_g = Gross area of section

Q-1 A short column of size 230mm x 350mm is subjected to a factored load of 1500 KN. If the unsupported length of the column is 3.2m, find out design moments due to minimum eccentricity.

Given Data :-

$b = 230mm$

$D = 350mm$

$P_u = 1500 KN$

$L = 3.2m$

$= 3200mm$

Sol^n

Minimum eccentricity about x axis,

$$e_x = \frac{L}{500} + \frac{D}{30}$$

$$= \frac{3200}{500} + \frac{350}{30}$$

$$= 6.4 + 11.67$$

$$= 18.07 mm < 20mm$$

$\therefore e_x = 20mm$

$0.05D = 0.05 \times 350$

$= 17.5mm < e_x$

Minimum eccentricity about y axis,

$$e_y = \frac{L}{500} + \frac{b}{30}$$

$$= \frac{3200}{500} + \frac{230}{30}$$

$$= 6.4 + 7.67$$

$$= 14.07 mm < 20mm$$

$\therefore e_y = 20mm$

$0.05b = 0.05 \times 230$
$= 11.5 mm < e_y$

$M_{ux} = M_{uy} = P_u \times 20 mm$
$= 1500 \times 0.02$
$= 30 KNm$

Design the column for,

$P_u = 1500 KN$
$M_{ux} = 30 KNm$
$M_{uy} = 30 KNm$

(Ans)

Q-2 A short R.C.C column of size 450mm x 450mm has to carry an axial factored load of 1500KN. Assume $e_{min} < 0.05D$. Design the column using M20 grade concrete and HYSD reinforcement of grade Fe415.

Given Data:-

$b = 450 mm$
$D = 450 mm$
$P_u = 1500 KN$
$f_{ck} = 20 N/mm^2$
$f_y = 415 N/mm^2$

Soln

$A_c = b \times D - A_{sc} = 450 \times 450 - A_{sc}$

$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

$\Rightarrow 1500 \times 10^3 = 0.4 \times 20 \times (450 \times 450 - A_{sc}) + 0.67 \times 415 \times A_{sc}$

$\Rightarrow 1500 \times 10^3 = 1620000 - 8 A_{sc} + 278.05 A_{sc}$

$\Rightarrow 1500000 - 1620000 = 270.05 A_{sc}$

$\Rightarrow -120000 = 270.05 A_{sc}$

$\Rightarrow A_{sc} = -444.36 mm^2$

Negative value indicates that there is no need of providing reinforcement. However minimum reinforcement should be provided. Here it is based on concrete area required for direct load.

Area of concrete required for direct load

$$= \frac{1500 \times 10^3}{0.4 \times 20}$$

$$= 187500 \ mm^2$$

Minimum steel required

$$= \frac{0.8}{100} \times 187500 = 1500 \ mm^2$$

Provide 8-16 # $= \frac{\pi}{4} \times 16^2 \times 8$

$$= 1608.49 \ mm^2$$

$$\simeq 1608 \ mm^2$$

use 6mm φ lateral ties

spacing should be lesser of

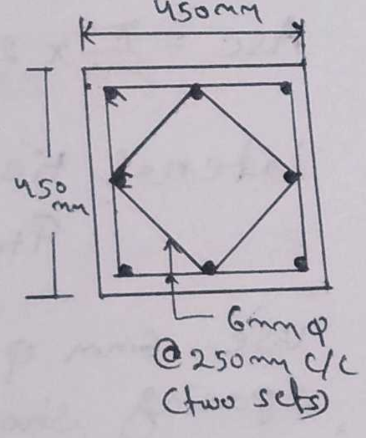
(i) 450 mm (minimum column dimension)

(ii) 16 × 16 = 256 mm (16 times φ of main bar)

(iii) 300 mm

i.e 256 mm

use 6mm φ @ 250mm c/c. Also, as the distance between corner bars exceeds 48φtr, closed double ties are used.



(Ans).

Q-3 A column with size 400mm × 500mm carries a factored axial load of 3000 KN. The column is short and having a minimum eccentricity $e_{min} < 0.05D$. Design the column. The materials are M20 grade concrete and HYSD reinforcement of grade Fe415.

Given Data:-

$b = 400mm$
$D = 500mm$
$P_u = 3000 KN$
$f_{ck} = 30 N/mm^2$
$f_y = 415 N/mm^2$

Soln

Longitudinal steel :-

$A_c = b \times D - A_{sc} = 400 \times 500 - A_{sc}$

$\therefore P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

$\Rightarrow 3000 \times 10^3 = 0.4 \times 30 \times (400 \times 500 - A_{sc}) + 0.67 \times 415 \times A_{sc}$

$\Rightarrow 3000 \times 10^3 = 2400000 - 12 A_{sc} + 278.05 A_{sc}$

$\Rightarrow 3000000 = 2400000 + 266.05 A_{sc}$

$\Rightarrow 266.05 A_{sc} = 600000$

$\Rightarrow A_{sc} = \frac{600000}{266.05} = 2255.21 mm^2$
$\simeq 2255 mm^2$

Provide 8 no. 20mm diameter bars with

$A_{sc} = \frac{\pi}{4} \times 20^2 \times 8 = 2513.27 mm^2$
$\simeq 2513 mm^2$

Lateral ties :-

$\phi_{tr} = \frac{\phi}{4} = \frac{20}{4}$
$= 5mm \nless 6mm$

use 6mm ϕ M.S ties.

spacing should not exceed.

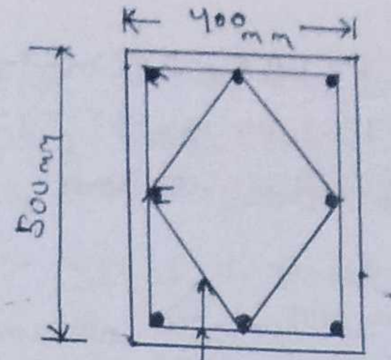
(i) 400mm (minimum column dimension)

(ii) $16 \times 20 = 320mm$ (16 times ϕ of main bars)

(iii) 300mm

i.e 300mm

Provide 6mm ϕ ties about 300mm c/c.



(Ans)

Q-4 Design a circular short column to carry an axial working load of 1200 KN. Assume $e_{min} < 0.05D$. Use lateral ties. The materials are M20 grade concrete and HYSD reinforcement of grade Fe 415.

Given Data:-

$P_u = 1200 KN$

$f_{ck} = 20 N/mm^2$

$f_y = 415 N/mm^2$

Soln

Factored load $= 1.5 \times P_u$

$= 1.5 \times 1200 = 1800 KN$

$\therefore P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

Assume minimum steel $= 0.8\%$.

Then, $A_{sc} = 0.008 A_g$

$A_c = 0.992 A_g$

Substituting, we have

$1800 \times 10^3 = 0.4 \times 20 \times 0.992 A_g + 0.67 \times 415 \times 0.008 A_g$

$\Rightarrow 1800 \times 10^3 = 7.936 A_g + 2.224 A_g$

$\Rightarrow 1800000 = 10.16 A_g$

$\Rightarrow A_g = \frac{1800000}{10.16} = 177165.35 \, mm^2$
$\simeq 177165 \, mm^2$

If D is the diameter of the column,

$\frac{\pi}{4} D^2 = A_g$

$\Rightarrow \frac{\pi}{4} \times D^2 = 177165$

$\Rightarrow D^2 = 225573.48$

$\Rightarrow D = \sqrt{225573.48} = 474.94 \, mm$
$\simeq 475 \, mm$

Use 475mm diameter column.

$A_{sc} = 0.008 A_g$
$= 0.008 \times 177165 = 1417.32 \, mm^2$
$\simeq 1417 \, mm^2$

minimum 6 bars shall be used

∴ Provide 8 no. of 16mm diameter bars giving

$A_{sc} = \frac{\pi}{4} \times 16^2 \times 8 = 1608.49 \, mm^2$
$\simeq 1608 \, mm^2$

use 6mm φ lateral ties. Spacing shall be lesser of,

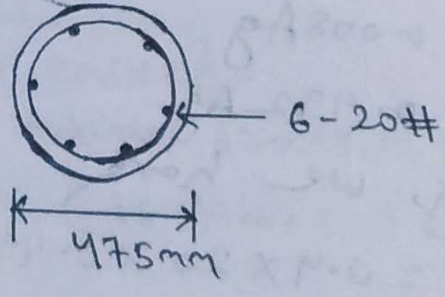
(i) 475mm (minimum lateral dimension)

(ii) $16 \times 16 = 256$ mm (16 times φ of main bar)

(iii) 300mm

i.e 256mm

use 6mm φ lateral ties @ 250mm c/c.



(Ans)

*** Foundation :-** The sub-structure which is provided to transmit the loads from the upper structure to the soil is known as the foundation.

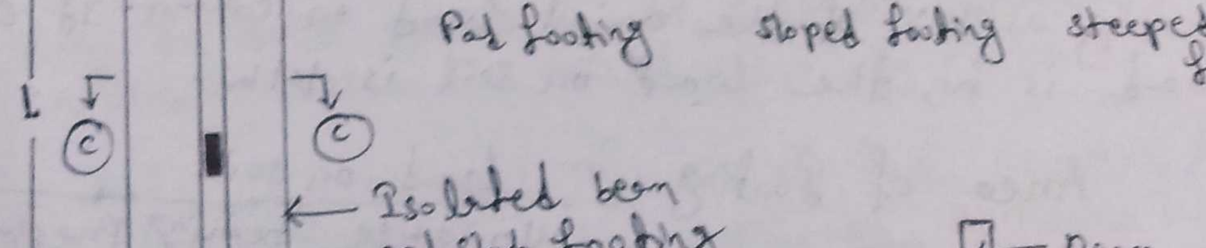
*** Footing :-** It is a part of foundation which is constructed with concrete or brickwork masonry and acts as a base to the floor columns and floor walls. The main function of footing is to transfer the vertical loads directly to the soil.

*** Types of footings :-** Some of the common footings usual in general building construction are as follows:-

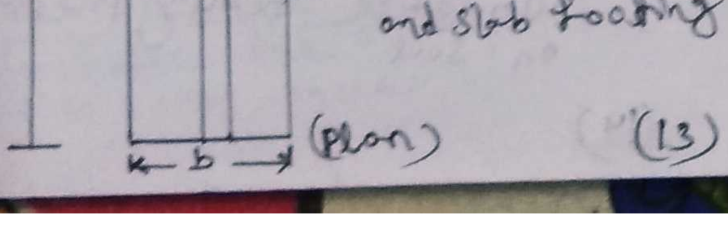
1) continuous wall footing
2) Isolated footing
3) Combined footing
4) Strap footing
5) Strip footing
6) Raft foundation
7) Pile foundation

1) Continuous wall footing :- A footing that supports a continuous long masonry or R.C.C wall is known as continuous wall footing.

2) Isolated footing :- An individual footing under a single column is known as an isolated footing. These may be pad, slopped, stepped, or with isolated beam and slab type footing.



Section B-B Pad footing | section B-B Sloped footing | section B-B steeped footing



(Plan)

(Section C-C)

3) **Combined footing** :- A footing that supports a group of column is known as combined footing. where the distance between two columns is small and if the isolated footing for these columns concide, a combined footing is used.

4) **Strap footing** :- The distance between the column is large, a strap footing is used for economy.

5) **Strip footing** :- If a number of footings in a line are to be combined, a strip footing is used.

6) **Raft foundation** :- A single slab or a slab beam footing that covers the entire stratum beneath the entire area of the super structure is known as a mat or raft footing.

7) **Pile foundation** :- If good soil is available at a higher depth (more than 3m) below the ground level. Pile foundations are economical.

* **Isolated Footings** :-

Isolated footings are most commonly used footings for R.C.C columns because of the simplicity and economy.

* **Axially loaded Pad footing** :- The footings are designed as inverted cantilevers from column loaded with net upward soil pressure. The design Procedure is explained below :-

1) **Proportioning the size** : Assume the weight of the footing as 10% of the axial load on column. If column load is W, the load on soil is 1.1W.

$$\text{Area of footing} = \frac{\text{load on soil}}{\text{allowable bearing Pressure on soil}}$$

2) **Bendimoment** :- The greater bending moment to be used in the design of an isolated concrete footing which supports a column, pedestral or wall, shall be the moment computed by passing through a vertical section which extends completely across the footing at sections located as follows :

a) At the face of the column, pedestal or wall, for footings supporting a concrete column, pedestal or wall.

b) Half-way between the centre line and the edge of the wall, for footings under masonry wall.

c) Half-way between the face of the column or pedestal and the edge of the gusseted base for footings under gusseted bases.

3) **Nominal reinforcement** :- Nominal reinforcement equal to 0.15 % of gross cross-section area for mild steel and 0.12 % of gross-section area for HYSD bars shall be considered as minimum reinforcement.

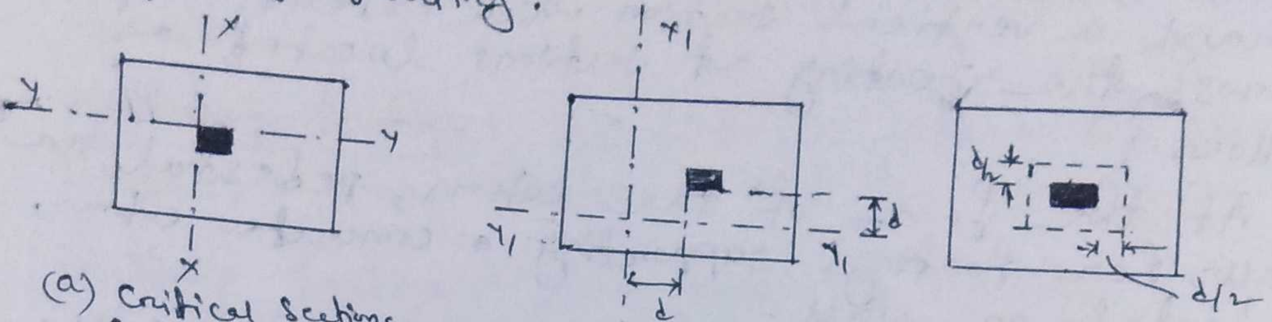
-> The spacing of these reinforcement shall not exceed 3d or 300mm whichever is smaller for main bars and 5d or 450mm whichever is smaller for secondary bar.

4) **Shear** :-

a) **one-way shear** :- The sum of the vertical forces due to soil pressure on footing outside the critical section is called one-way shear.

b) **Two-way shear** :- The sum of the vertical loads outside the appropriate perimeter is known as two-way shear.

The critical section for shear in this case is at a distance d/2 from the periphery of the column or pedestal where 'd' is the effective depth of footing.



(a) Critical sections for moment

(b) critical sections for one-way shear

(c) critical sections for two-way shear

The design of shear strength in this case shall be taken equal to $K_s \tau_c$.

where,

$K_s = (0.5 + \beta_c)$ but not greater than 1, β_c being the ratio of short side to long side of the column or pedestal

$\tau_c = 0.25\sqrt{f_{ck}}$ in limit state method design.

5) Development length :- The critical section for checking the development length in footing shall be assumed at the same planes as.

6) Deflection :- This is not important in footing & may not be checked.

7) Cover :- Clear cover to main reinforcement of the footing bars may be provided as 50mm for normal soil. Large cover is provided in footing to allow for small irregularities in the surface of the excavation and for potential contamination of the bottom layer of concrete with soil.

8) Reinforcement requirements :- The following are the general reinforcement requirements for footings :-

Bending moment :- The total tensile reinforcement shall be distributed across the corresponding resisting section as given below.

(i) In one-way reinforced footing and two-way reinforced square footing the reinforcement should be distributed uniformly across the full width of the footing.

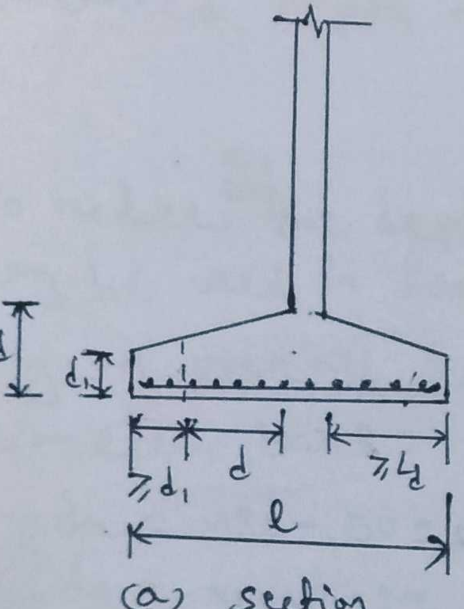
(ii) In two-way reinforced rectangular footing, the reinforcement in the long direction shall be distributed uniformly across the full width of footing.

uniformly distributed across the central band:

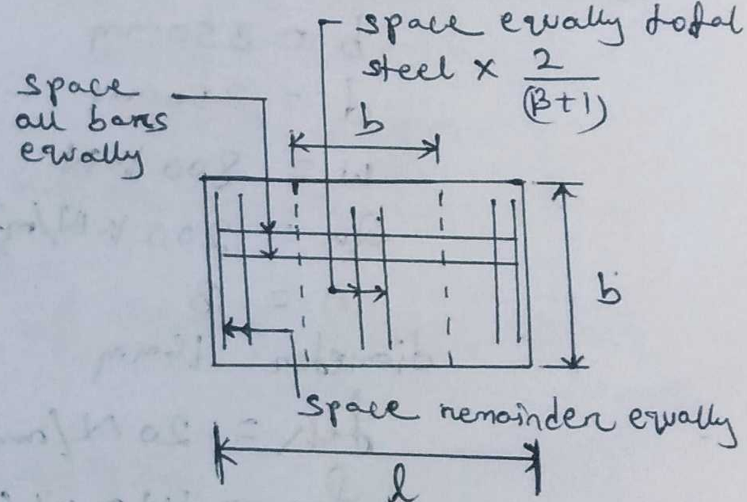
$$\frac{\text{reinforcement in central band width}}{\text{total reinforcement in short direction}} = \frac{2}{\beta + 1}$$

where,

β = The ratio of the long side to the short side of the footing.



(a) section



(b) Plan

Shear force :- One way shear check is made at distance d from the face of the column. From this point the bar must extend upto a minimum distance of d_1, where, d_1 is the effective depth of footing at a critical section for checking one-way shear.

Development length :- From the point of maximum bending moment the bar must extend in both directions for a length equal to its development length. Mild steel reinforcement is provided with U bend anchorage while HYSD reinforcement is provided without end anchorage.

9) Weight of the footing :- After completing the design self-weight of footing is found which shall be comparable with that of the assumed one.

Q-1 An R.C.C column of size 350 mm x 350mm reinforced with 8 no. of 16mm diameter bars carries a characteristic load of 800 kN. The allowable bearing pressure on soil is 200 kN/m². Design an isolated square pad footing. The materials are grade M20 concrete and HYSD reinforcement of grade Fe415 for both, the column and the footing.

Given Data :-

$b = 350mm$

$d = 350mm$

$W = 800 \, kN$

$Q_a = 200 \, kN/m^2$

$n = 8$

diameter = 16mm

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

$f_y = 415 \, N/mm^2$

Soln

(a) Size of footing :

Load on column = 800 kN

Assume dead load on footing = 80 kN (10% of column load)

Total load on soil = 880 kN

Area of footing required = $\frac{880}{200}$

$= 4.4 m^2$

Adopt 2.1m x 2.1m footing,

Area (A) = $4.41 m^2$

(b) Net upward Pressure :

Net factored upward pressure = $\frac{1.5 \times w}{2.1 \times 2.1}$

$= \frac{1.5 \times 800}{2.1 \times 2.1}$

$= 272.1 \ kN/m^2$

(c) Moment steel :

Net cantilever = $\frac{2100 - 350}{2}$

= 875mm

$M_{ux} = M_{uy} = \frac{0.875^2}{2} \times 272.1 \times 2.1$

$= 218.74 \ kNm$

Balanced depth required = $\sqrt{\frac{218.74 \times 10^6}{2100 \times 2.76}}$

= 194.26 mm

To reduce the depth, higher grade concrete may be used in footing.

Try an overall depth of 480mm. Assume 12mm diameter bars.

$d_x = 480 - 50 - 6 = 424$ mm

$d_y = 424 - 12 = 412$ mm (second layer)

$\frac{M_u}{bd^2} = \frac{218.74 \times 10^6}{2100 \times 412 \times 412}$

$= 0.614$

$P_t = 0.177$

$$A_{st} = \frac{0.177}{100} \times 2100 \times 412$$
$$= 1531.40 \text{ mm}^2$$
$$\simeq 1531 \text{ mm}^2$$

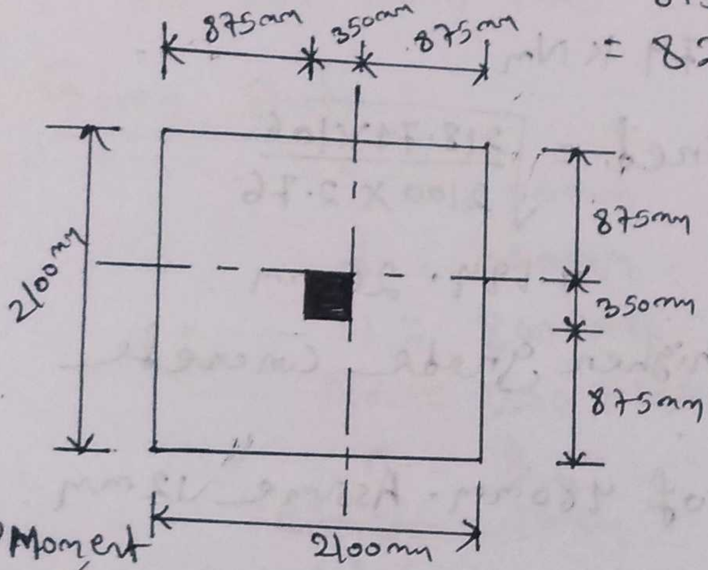
Minimum steel $= \frac{0.12}{100} \times 2100 \times 500$
$$= 1260 \text{ mm}^2$$

Provide 14 no. of 12mm diameter bars = 1582 mm² on both the direction.

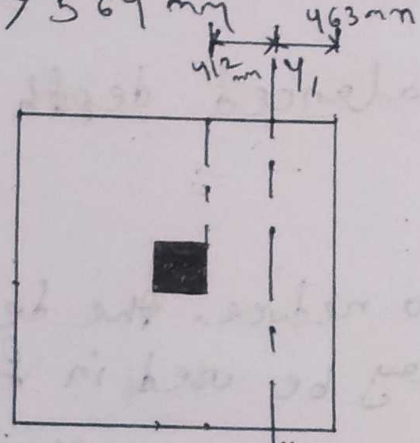
d) Development length :-

Development length $= 47\phi$
$= 47 \times 12$
$= 564$ mm

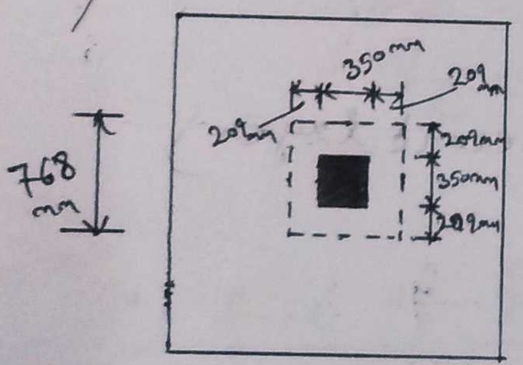
Available anchorage referring,
$= 875 - 50$
$= 825 \text{ mm} > 564 \text{ mm}$



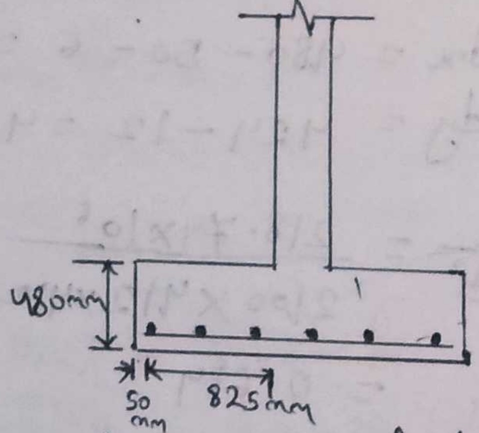
(a) Moment



(b) one - way shear



(c) Two - way shear



(d) Development length

e) one - way shear :-

shear at 412 mm from face of the column

$= 0.463 \times 2.1 \times 272.1$

$= 264.56$ KN

$\tau_v = \frac{264.56 \times 10^3}{2100 \times 412}$

$= 0.306$ N/mm² ..... (ok)

The bars extend $= 463 - 30$

$= 433$ mm i.e more than d, beyond the critical section. Therefore, the steel is effective in increasing the shear stress.

$\frac{100 A_s}{bd} = \frac{100 \times 1582}{2100 \times 412}$

$= 0.183$

$\therefore \tau_c = 0.306$ N/mm²

f) Two - way shear :-

This is checked at d/2 from the face of the column.

Here, $d_x = 424$ mm, $d_y = 412$ mm

$d_{avg} = d = 0.5\,(424 + 412) = 418$ mm

$V_u = (2.1^2 - 0.768^2) \times 272.1$

$= 1039.46$ KN $\simeq 1040$ KN

$d = 418$ mm

$b = 4 \times 768$

$= 3072$ mm

$\tau_v = \frac{1040 \times 10^3}{3072 \times 412} = 0.821$ N/mm²

Design shear strength $= K_s \tau_c$

where, $K_s = (0.5 + \beta_c)$

$\beta = \frac{\text{short side of column}}{\text{long side of column}}$

$= \frac{1}{1} = 1$

$k_s = (0.5 + 1) = 1.5$

$k_s \ngtr 1$

$k_s = 1$

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

$= 0.25\sqrt{20} = 1.12\ N/mm^2$

$k_s \tau_c = 1 \times 1.12 = 1.12\ N/mm^2$

$\tau_v < k_s \tau_c$ ...... (ok)

g) Spacing of bars :-

$\text{spacing of bars} = \frac{2100 - 100 - 12}{13}$

$= 152.92\ mm$

$< 3 \times 432 (= 1296\ mm)$ or $300\ mm$

h) Transfer of load from column to footing :-

At the base of the column,

allowable bearing force $= 0.45 \times 20 \times 350 \times 350 \times 10^{-3}$

$= 1102.5\ kN < 1200\ kN$

Dowels are required

Force in dowel bars $= 1200 - 1102.5$

$= 97.5\ kN$

At the top of footing

$A_1 = 2.1 \times 2.1 = 4.41\ m^2$

$A_1 = (0.35 + 4 \times 0.48)(0.35 + 4 \times 0.48)$

$= 5.15\ m^2$ whichever is small

i.e $4.41\ m^2$

$A_2 = 0.35 \times 0.35$

$= 0.1225\ m^2$

$\sqrt{\frac{A_1}{A_2}} = 6 \not> 2$, therefore use 2.

Allowable bearing force $= 2 \times (0.45 \times 20) \times 350 \times 350 \times 10^{-3}$

$= 2205 \text{ KN}$

Dowel area $= \frac{97.5 \times 10^3}{0.75 \times 415}$

$= 313.25 \text{ mm}^2 \simeq 313 \text{ mm}^2$

Minimum dowel area $= \frac{0.5}{100} \times 350 \times 350$

$= 612.5 \text{ mm}^2$

use 8-16# column bars as dowel bars.

Dowel length in footing $= D + 450$

$= 950 \text{mm}$

Extend column bars for 950mm in footing.

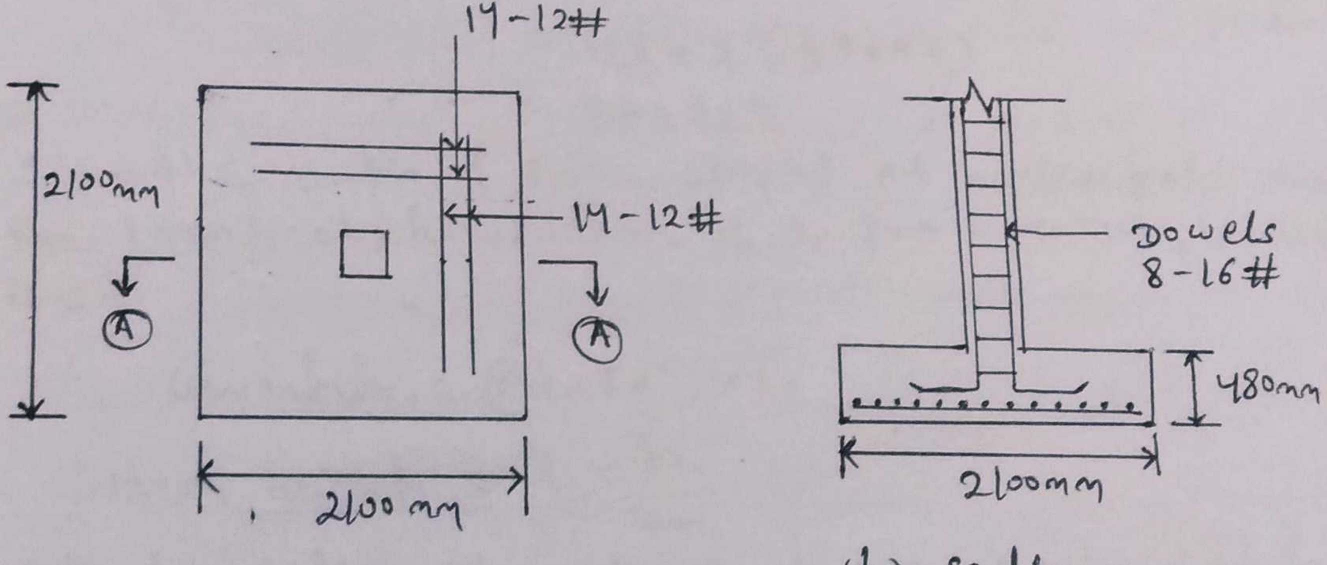
(i) Weight of base :-

weight $= 2.1^2 \times 0.48 \times 25$

$= 52.92 \text{ KN} < 80 \text{ KN}$ (OK)

(j) sketch :-

Designed footing



(a) Plan

(b) section A-A

(Ans)