# UNIT - IV

## DESIGN OF COMPRESSION MEMBERS

* Structural concrete members in Compression are generally referred as "columns" and "struts".

* The term column is associated with members transfering loads to the ground.

* The terms strut represents the compression members in any direction in a truss.

* Column or strut - $\frac{L_{eff}\ (\text{Effective length})}{\text{least lateral dimension}} > 3$

* Pedestal - $\frac{L_{eff}}{\text{least Lateral dimension}} < 3$

cl 25.1.1

* Axially loaded columns may fail in any of the following reasons.

(i) Pure Compression failure

(ii) Combined Compression and bending failure.

(iii) failure by elastic in-stability

* The failure modes depends primarly on the slenderness ratio of the member which inturns depends on the cross sectional dimensions, effective length and support conditions of the member

# Classification of Columns :-

(a) Based on type of reinforcement :-

* Depending on the type of reinforcement used, reinforced concrete columns are classified into three types.

(i) Tied Columns

(ii) Spiral Columns

(iii) Composite Columns.

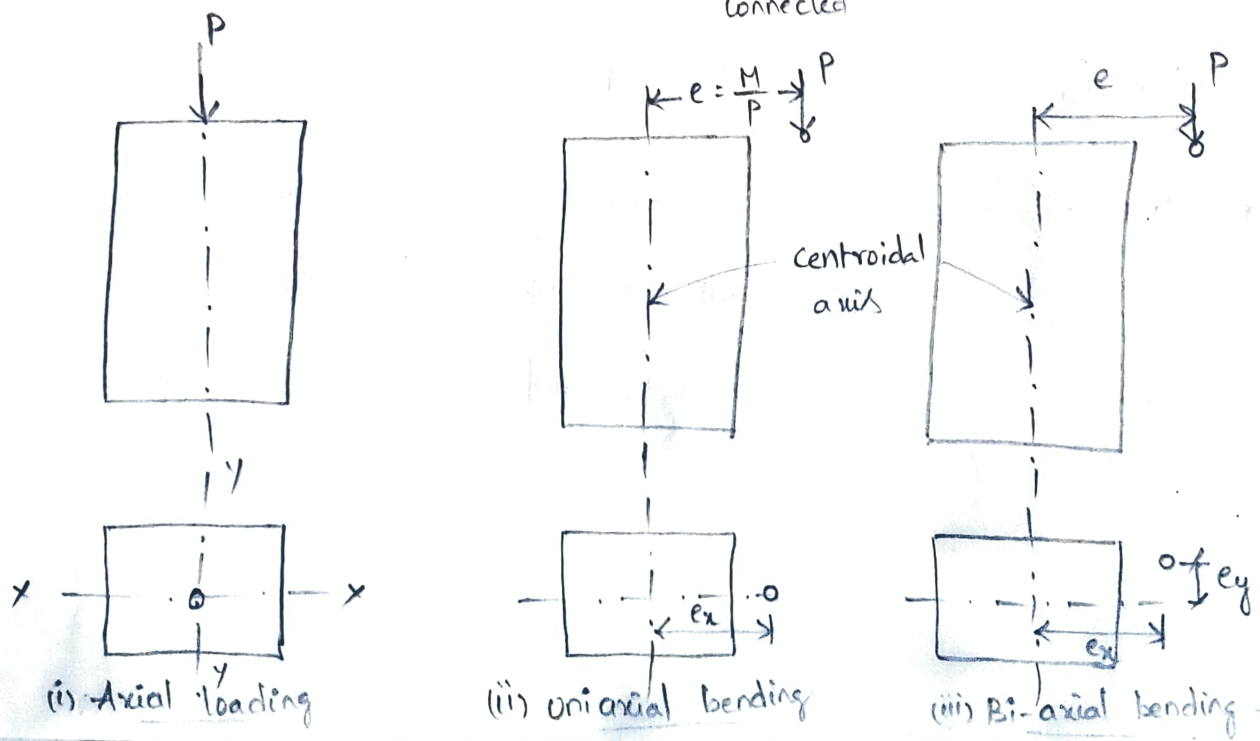
(b) Based on type of loading :-

* Depending upon the type of loading columns may be classified as

(i) Axially loaded Columns. - Interior columns of multi-storey buildings with symmetrical loads from four slabs from all sides.

(ii) Column with uni-axial bending - columns rigidly connected to beams from one side like edge column.

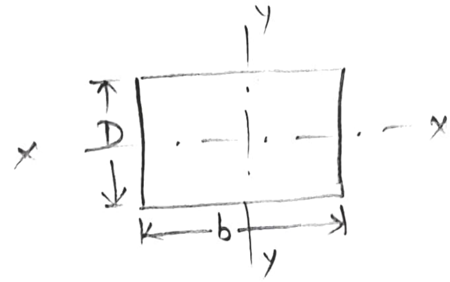
(iii) Columns with bi-axial bending - corner columns with beams rigidly connected




(i) Axial loading (ii) uni axial bending (iii) Bi-axial bending

(c) Based on slenderness ratio :-

* Depending on the slenderness ratio $\left(\frac{\text{Effective length}}{\text{least lateral dimension}}\right)$ Columns may be classified as




(i) short columns

(ii) slender columns or long columns

* As per cl 25.1.2, a column is short when $\frac{L_{ex}}{D}$, $\frac{L_{ey}}{b}$ are less than 12.

where $L_{ex}$ = Effective length in respect of major axis.

$D$ = Depth in respect of major axis.

$L_{ey}$ = Effective length in respect of minor axis

$b$ = width of the member.

* If $\frac{L_{ex}}{D}$ and $\frac{L_{ey}}{b}$ is equal to (or) greater than 12, then it is termed as slender (or) long column

Effective length of columns :- (Table 28, Pg 94)

* Effective length of column depends on the unsupported length (distance between lateral connections) and the boundary conditions at the ends of columns due to the conditions of the framing beams and other members.

$$L_{eff} = K \times L$$

where, $L$ = unsupported length & $K$ = effective length ratio.

**Minimum eccentricities :-** ( Pg 42 , cl 25.4)

For $\frac{l_{ex}}{D} = 12 \Rightarrow l_{ex} = L = 12D$

$\Rightarrow e_{min} = \frac{12D}{500} + \frac{D}{30} = 0.0573D = 0.05D$

$$e_{min} = \left( \frac{L}{500} + \frac{D}{30} \right)$$ , which is not less than 20 mm.
or 20mm - which is greater

$e_{min} \not> 0.05D$ (or) $0.05B$.

## Design of short Columns under axial Compression :-

**Assumptions :-**

* In addition to assumptions in flexure (cl 38.1(a) to (e), Pg 69)

(i) The ~~Com~~ Maximum Compressive strain in Concrete in axial Compression is taken as 0.002

(ii) The maximum Compressive strain at extremely Compressed fibre in Concrete subjected to axial Compression and bending and when there is no tension, shall be $0.0035 - 0.75 \times \epsilon_c$

$\epsilon_c$ = strain at the least Compressed extreme fibre.

* The design strength of short column is expressed as

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$ - Applicable only when $e_{min}$ get satisfies.

where, $P_u$ = axial load on the member

$A_c$ = Area of Concrete = $A_g - A_{sc}$

$A_{sc}$ = Area of longitudinal reinforcement

$A_g$ = Gross Sectional area

$$\therefore P_u = 0.4 f_{ck} (A_g - A_{sc}) + 0.67 f_y A_{sc}$$

$$= 0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck}) A_{sc}$$

* Short column with helical reinforcement have increased ductility prior to collapse and hence the code permits 5% increase in load carrying capacity of spiral columns.

* However, the ratio of the volume of helical reinforcement to the volume of core shall not be less than $0.36\left(\frac{A_g}{A_c}-1\right)\frac{f_{ck}}{f_y}$

$$\therefore \frac{V_{hs}}{V_c} = 0.36\left(\frac{A_g}{A_c}-1\right)\frac{f_{ck}}{f_y}.$$

Requirements of reinforcement :- (Pg 48, cl 26.5.3)

Main reinforcement :-

(i) The cross sectional area of longitudinal reinforcement, shall be not less than 0.8% and not more than 6% of gross c/s area of column

(ii) The bars shall not be less than 12 mm in diameter.

(iii) Spacing of longitudinal bars measured along the periphery of the column shall not exceed 300mm.

Transverse reinforcement :-

(i) Tie diameter should not less than 1/4 × largest dia used. and should not be greater than 16mm.

(ii) Tie spacing should be least of

(a) Least lateral dimension

(b) 16 × smaller diameter of longitudinal reinforcement.

(c) 300 mm

1. A square axially loaded column 450 x 450 mm in size, reinforced with 8 bars of 18 mm diameter. The effective length of column is 4.5m. The lateral ties of 6 mm diameter has been provided at appropriate spacing. Determine the load carrying capacity of column using $M_{20}$ grade concrete and $Fe_{415}$ steel.

Sol:- Given data :-

Size of column = 450 x 450 mm

Effective length, $L_{eff}$ = 4.5m

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

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

$A_{sc} = 8 \times \pi/4 \times 18^2 = 2036\, mm^2$

$$\frac{L_{ex}}{B} = \frac{L_{ex}}{D} = \frac{4500}{450} = 10 < 12$$

Hence the column is designed as a short column.

Minimum eccentricity :-

$$e_{x\,min} = e_{y\,min} = \frac{L}{500} + \frac{B}{30}$$

$$= \frac{4500}{500} + \frac{450}{30} = 24 > 20\, mm$$

Hence the codal formula for short column is applicable.

$$P_u = 0.4\, f_{ck}\, A_g + (0.67\, f_y - 0.4\, f_{ck})\, A_{sc}$$

$\therefore P_u = 0.4 \times 20 \times (450 \times 450) + (0.67 \times 415 - 0.4 \times 20) \times 2036$

$= \underline{2169.82 \text{ kN}}$

2. A circular ~~reinforced~~ column of 450 mm diameter and effective length of 4.5 m and reinforced with 8 bars of 18 mm diameter as longitudinal reinforcement. Determine the ultimate load carrying capacity of the column. Helical bars of 8 mm diameter are provided at a pitch of 60 mm. Use $M_{20}$ grade concrete and Fe 415 grade steel.

Sol:- Given data :-

Diameter of column = 450 mm

Effective length of column = 4.5 m

$A_{sc} = 8 \times \pi/4 \times 18^2 = 2036 \text{ mm}^2$

$$\frac{L_{ex}}{D} = \frac{4500}{450} = 10 < 12$$

Hence the column is short column.

Minimum eccentricity, $e_{min} = \frac{L}{500} + \frac{D}{30} = \frac{4500}{500} + \frac{450}{30} = 24 > 20 \text{mm}.$

Hence the codal formula for short column is applicable.

$$P_u = 1.05\left[0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck}) A_{sc}\right]$$

$$= 1.05\left[0.4 \times 20 \times \pi/4 \times 450^2 + (0.67 \times 415 - 0.4 \times 20) \times 2036\right]$$

$= \underline{1913.44 \text{ KN}}.$

3) Design the reinforcement in a column of size 400 x 600mm, subjected to an axial working load of 2000 kN. The column has unsupported length of 3m and is braced against side sway in both directions. Adopt $M_{20}$ and $Fe_{415}$ materials.

Sol:- Given data :-

Size of Column = 400 x 600 mm

working load, P = 2000 kN

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

$f_y = 415 N/mm^2$

$l = 3m$

Boundary Condition : Braced against side sway in both directions (Hinged)

$K = 1$

Effective length = KL = 3m

$$\frac{L_{ex}}{D} = \frac{3000}{600} = 5 < 12$$

$$\frac{L_{ey}}{B} = \frac{3000}{400} = 7.5 < 12$$

Hence the column is designed as a short column.

Minimum eccentricity :-

$$e_{x\,min} = \frac{L}{500} + \frac{D}{30} = \frac{3000}{500} + \frac{600}{30} = 26 > 20mm.$$

$$e_{y\,min} = \frac{L}{500} + \frac{B}{30} = \frac{3000}{500} + \frac{400}{30} = 19.33 < 20mm.$$

$0.05\ D_x = 0.05 \times 600 = 30\,mm > e_{xmin}$

$0.05\ D_y = 0.05 \times 400 = 20\,mm > e_{ymin}$.

Hence the codal formula for short column is applicable.

$P_u = 1.5 \times 2000 = 3000\,kN$.

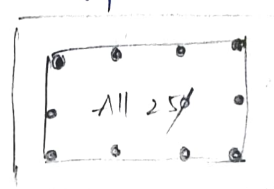
<u>Longitudinal reinforcement</u> :-

$$P_u = 0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck}) A_{sc}$$

$$3000 \times 10^3 = 0.4 \times 20 \times (400 \times 600) + (0.67 \times 415 - 0.4 \times 20) A_{sc}$$

$$A_{sc} = 4000\,mm^2$$

Assume 25 mm dia bars, No. of bars $= \dfrac{4000}{\pi/4 \times 25^2} = 8.14 \simeq 10$ bars.



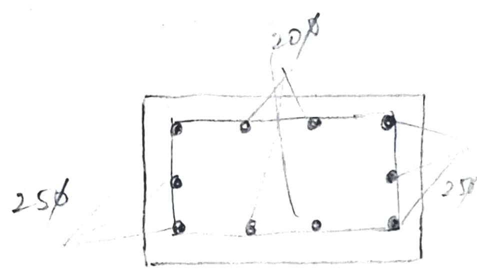

(or)

any one can be used.

Assume 6 no's of 25 mm diameter

$A_{sc1} = \pi/4 \times 25^2 \times 6 = 2945\,mm^2$

$A_{sc2} = 4000 - 2945 = 1055\,mm^2$




Assume 4 no's of 20mm diameter

$A_{sc2} = 4 \times \pi/4 \times 20^2 = 1256\,mm^2$

Minimum area of steel, $A_{st\,min} = 0.8\%$ Gross c/s area

$$= \frac{0.8}{100} \times 400 \times 600 = 1920\,mm^2 \nless 4000\,mm^2.$$

Transverse reinforcement :-

(i) Tie diameter should not be less than $\frac{1}{4} \times$ large dia used.

$\therefore$ Minimum Tie diameter $= \frac{1}{4} \times 25 = 6.25\,mm$

(ii) Tie diameter should not be greater than 16mm.

Hence provide 8mm diameter ties.

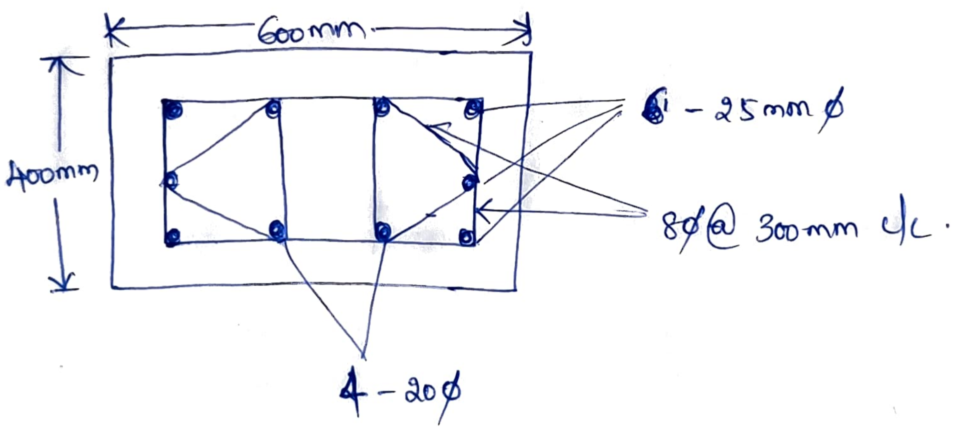
Tie spacing :-

(a) Least lateral dimension = 400mm

(b) 16 × Smaller diameter of longitudinal reinforcement

$= 16 \times 20 = 320\,mm$.

Hence provide 8mm dia lateral ties @ 300 mm c/c.




Reinforcement Details

④ Design a circular column of 400 mm diameter with helical reinforcement to support a factored load of 1500 KN. The column has a unsupported length of 3m and is braced against side sway. Use $M_{20}$ and $Fe_{415}$ materials.

sol:- Given data:-

$P_u = 1500$ KN

effective length factor $= 1$ ( For column braced against side sway)

unsupported length $= 3$ m

Effective length $= 1 \times 3 = 3$m

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

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

$$\frac{L_{ex}}{D} = \frac{3000}{400} = 7.5 < 12$$

Hence the column is a short column.

minimum eccentricity, $e_{min} = \frac{L}{500} + \frac{D}{30}$

$$= \frac{3000}{500} + \frac{400}{30} = 19.33 \ngtr 20mm$$

$0.05 D = 0.05 \times 400 = 20$ mm $> e_{min}$.

Hence, the code formula for axially loaded column can be used.

For circular column having helical reinforcement,

$$P_u = 1.05 \left[ 0.4 \, f_{ck} \, A_g + (0.67 \, f_y - 0.4 \, f_{ck}) A_{sc} \right]$$

$$1500 \times 10^3 = 1.05 \left[ 0.4 \times 20 \times \pi/4 \times 400^2 + (0.67 \times 415 - 0.4 \times 20) A_{sc} \right]$$

$A_{sc} = 1567 \text{ mm}^2$

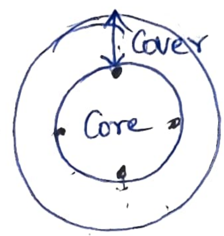
$A_{sc\,min} = \frac{0.8}{100} \times \pi/4 \times 400^2 = 1005 \text{ mm}^2$

For circular column the minimum number of bars are 6.

$\pi/4 \times \phi^2 \times 6 = 1567$

$\Rightarrow \phi = 18.23 \simeq 20 \text{ mm}$

$\therefore$ Provide 6 no's of 20mm diameter as longitudinal reinforcement.




Helical reinforcement :-

$$\frac{V_{hs}}{V_c} = 0.36 \left(\frac{A_g}{A_c} - 1\right) \frac{f_{ck}}{f_y}$$

Assuming the clear cover of 40mm over spirals.

Core diameter $= 400 - 2 \times 40 = 320$ mm.

$A_c = \pi/4 \times 320^2 - (\pi/4 \times 20^2 \times 6) = 78549.2 \text{ mm}^2$

$V_c = A_c \times 1000 = 78549.2 \times 10^3 \text{ mm}^3$ (Assume unit length)

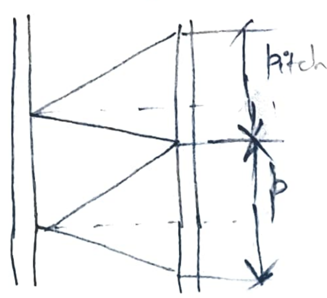
Gross area of Section, $A_g = \pi/4 \times 400^2 = 125680 \text{ mm}^2$

Use 8mm diameter, helical spirals at a pitch 'p' mm.

The volume of helical spirals per metre length is given by

$$V_{hs} = \underbrace{\pi \times (400 - 80 - 8)}_{\text{Perimeter}} \times \underbrace{\pi/4 \times 8^2}_{\text{Area}} \times \frac{1000}{p} \leftarrow \text{1m length}$$

$$= \frac{49.27 \times 10^6}{p} \text{ mm}^3/\text{m}$$



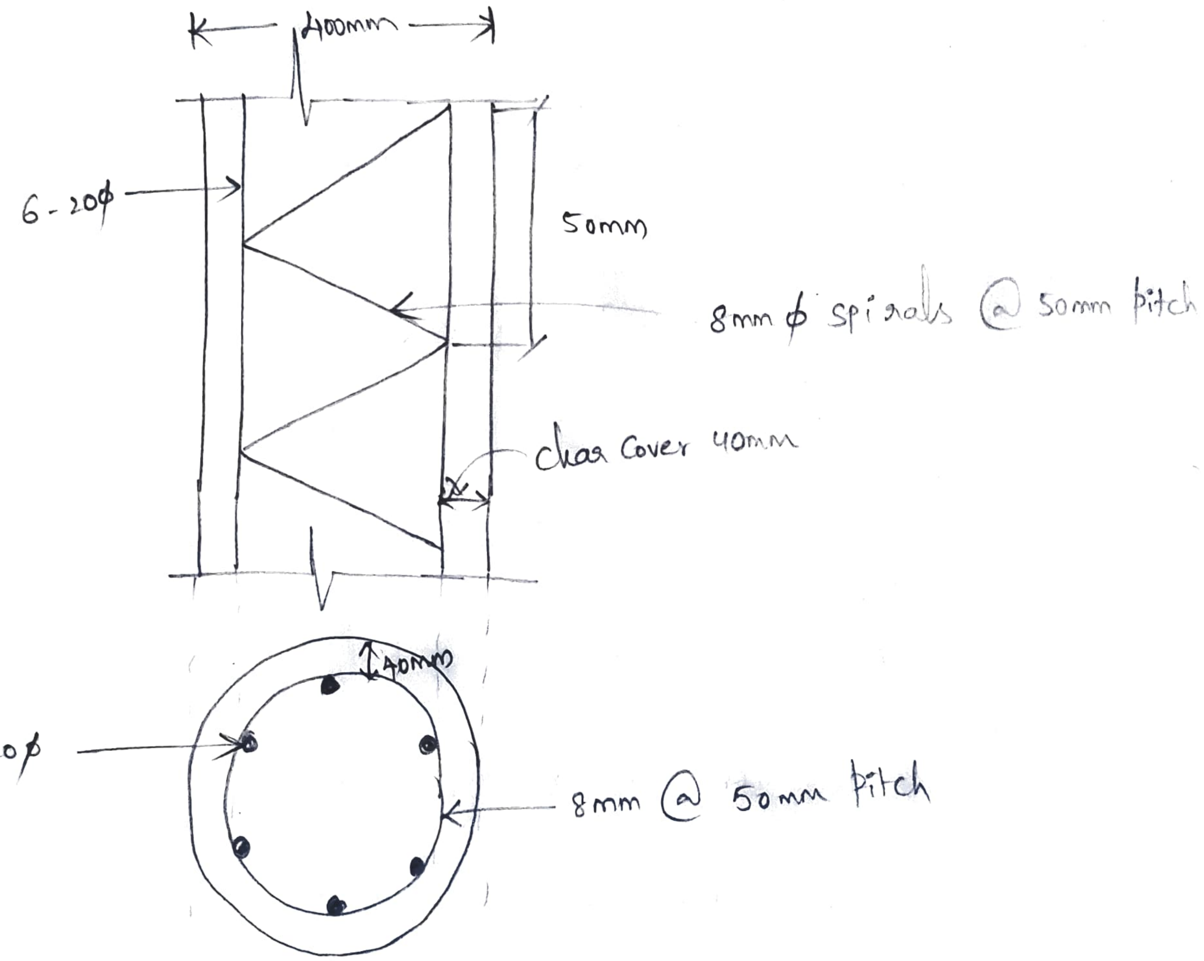
$$\therefore \frac{\left(\frac{49.27 \times 10^6}{p}\right)}{78549.2 \times 10^3} = 0.36\left(\frac{125680}{78549.3} - 1\right) \times \frac{20}{415}$$

$$\Rightarrow p = 60.28 \text{ mm}$$

(i) $p < 75\text{mm}$ (or) $\frac{\text{Core diameter}}{6} = \frac{320}{6} = 53.33 \text{ mm}$

(ii) $p > 25\text{mm}$ (or) $3 \times$ diameter of helix $= 3 \times 8 = 24$ mm

Hence provide 8mm dia spirals at a pitch of 50mm.




Reinforcement Details.

5) Design a Square reinforced Concrete column to carry an axial load of 1200 KN including dead load, live load and self weight of the column shall remain Continuous through a reinforced beam and slab at both ends. Use M20 and Fe415 materials. The height of column is 6m.

Sol:- Given data :-

Axial load = 1200 KN

$l = 6m$

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

$f_y = 415\ N/mm^2$

Boundary condition : The columns are supported by beams i.e The columns are fixed

$K = 0.65$

effective length, $L_{eff} = 0.65 \times 6 = 3.9m$

Factored load on column $= 1.5 \times 1200 = 1800$ KN.

Step-1!- c/s dimensions of column (or) size of column:-

Let the percentage of steel for the longitudinal reinforcement be 1% of gross c/s area. (i.e $A_{sc} = 1\%\ A_g$)

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

$$= 0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck}) A_{sc}$$

$$= 0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck}) \frac{1}{100} A_g$$

$$= A_g \left[0.4 f_{ck} + (0.67 f_y - 0.4 f_{ck})/100\right]$$

$$1800 \times 10^3 = A_g \left[0.4 \times 20 + (0.67 \times 415 - 0.4 \times 20) \frac{1}{100}\right]$$

$$\Rightarrow A_g = 168216.43 \text{ mm}^2$$

$$D = b = \sqrt{A_g} = \sqrt{168216.43}$$ (Assume a Square Column $b = D$)

$$b = D = 410.14 \text{ mm}$$

$\therefore$ Provide a Square Column of Size 450mm x 450mm.

$$\text{Slenderness ratio} = \frac{L_{ef}}{D} = \frac{3900}{450} = 8.67 < 12$$

Hence, it is a short Column.

Minimum eccentricity,

$$e_{min} = \frac{L}{500} + \frac{b}{30}$$

$$= \frac{3900}{500} + \frac{450}{30} = 22.8 > 20$$

Longitudinal reinforcement, $A_{sc} = 1\% \, bD$

$$= \frac{1}{100} \times 450 \times 450 = 2025 \text{ mm}^2$$

Use 22 mm diameter bars, No. of bars, $n = \dfrac{2025}{\frac{\pi}{4} \times 22^2}$

$$= 5.32 \simeq 6 \text{ bars.}$$

$\therefore$ Provide 6 bars of 22 mm diameter.

Lateral ties (or) Transverse reinforcement :-

$$\text{Tie diameter} = \frac{1}{4} \times \text{largest bar diameter}$$

$$= \frac{1}{4} \times 22 = 5.5 \text{ mm.}$$

Tie diameter < 16 mm

∴ Provide 6mm diameter lateral ties.

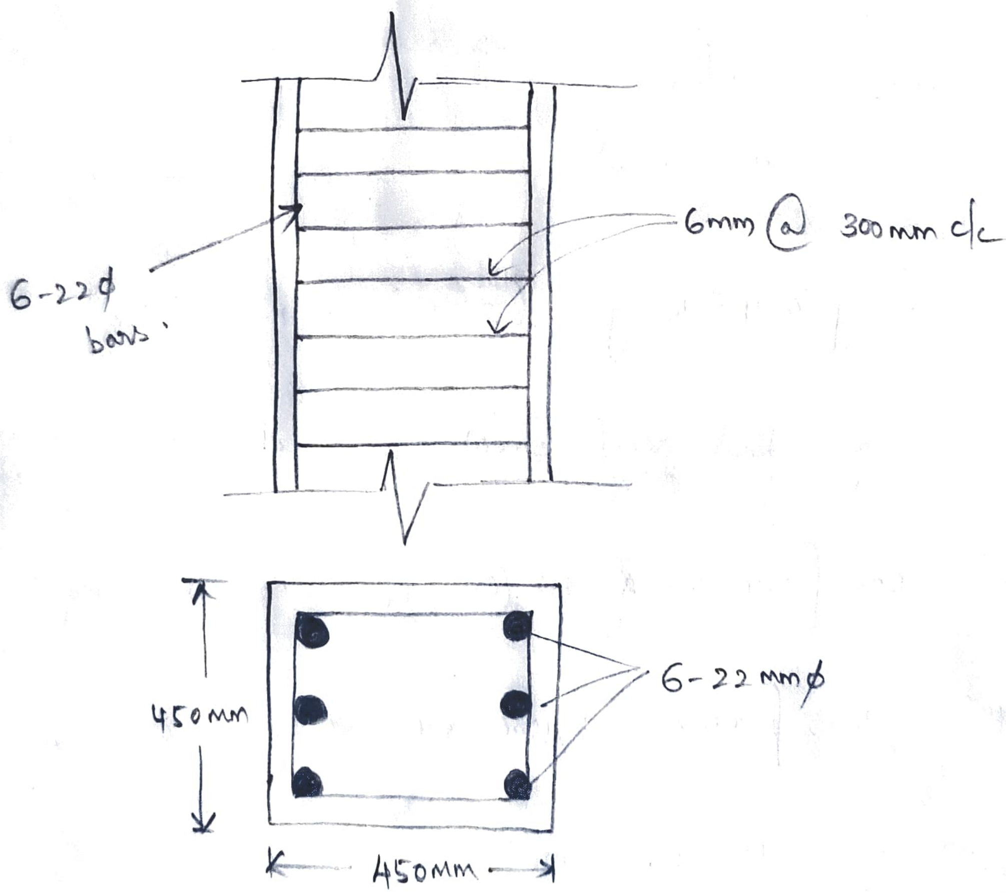
Pitch (or) Tie spacing :-

(a) Least lateral dimension = 450mm

(b) 16 x dia of smallest bar = 16×22 = 352 mm

(c) 300 mm

Use 6mm dia lateral ties @ 300 mm c/c.




Reinforcement Details

6) Design a spiral column subjected to a factored load of 2000 KN. The column has unsupported length of 3m and is braced against side sway. Use $M_{25}$ and $Fe_{415}$ materials.

Sol:- Given data :-

$P_u = 2000$ KN

$L = 3m$

Condition : braced against side sway (i.e $k = 1$)

$L_{eff} = 1 \times 3 = 3m$

$f_{ck} = 25 \ N/mm^2$

$f_y = 415 \ N/mm^2$

$$P_u = 1.05\left[0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck}) A_{sc}\right]$$

Assume longitudinal reinforcement as 1% of gross c/s area.

$$= 1.05\left[0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck})\frac{1}{100} A_g\right]$$

$$2000 \times 10^3 = 1.05\left[0.4 \times 25 + (0.67 \times 415 - 0.4 \times 25)1/100\right] A_g$$

$$\Rightarrow A_g = 150211.89 \ mm^2$$

$$\pi/4 \ d^2 = 150211.89$$

$$\Rightarrow d = 437.32 \ mm$$

Adopt 450 mm diameter column.

Slenderness ratio $= \dfrac{L_{eff}}{D} = \dfrac{3000}{450} = 6.67 < 12$

Hence it is a short column.

Minimum eccentricity, $e_{min} = \frac{L}{500} + \frac{D}{30}$

$= \frac{3000}{500} + \frac{450}{30} = 21 > 20\ mm.$

Longitudinal reinforcement, $A_{sc} = \frac{1}{100} \times \pi/4 \times 450^2$

$= 1590.43\ mm^2$

Assume 6 bars.

$6 \times \pi/4 \times d^2 = 1590.43$

$\Rightarrow d = 18.37mm \simeq 20\ mm.$

Provide 6 no's of 20 mm diameter bars as longitudinal reinforcement

Helical reinforcement :-

$$\frac{V_{ns}}{V_c} > 0.36 \left(\frac{A_g}{A_c} - 1\right) \frac{f_{ck}}{f_y}$$

Assuming the clear cover as 40mm,

The core diameter $= 450 - 2 \times 40 = 370\ mm.$

Area of Core $= \pi/4 \times 370^2 - A_{sc\ prov}$

$= \pi/4 \times 370^2 - 6 \times \pi/4 \times 20^2$

$= 105649.75\ mm^2$

volume of the core per 1m length, $V_c = 105649.75 \times 1000$

$= 105.65 \times 10^6\ mm^3$

Gross area, $A_g = \pi/4 \times 450^2$

$= 159.043 \times 10^3\ mm^2$

Use 8 mm diameter helical spirals at a pitch 'p' mm, the volume of helical reinforcement per metre length is given by

$$V_{hs} = \pi \times (450 - 8 - 80) \times \pi/4 \times 8^2 \times \frac{1000}{p}$$

$$= \frac{57164748.69}{p} = \frac{57.164 \times 10^6}{p} \; mm^3/m$$

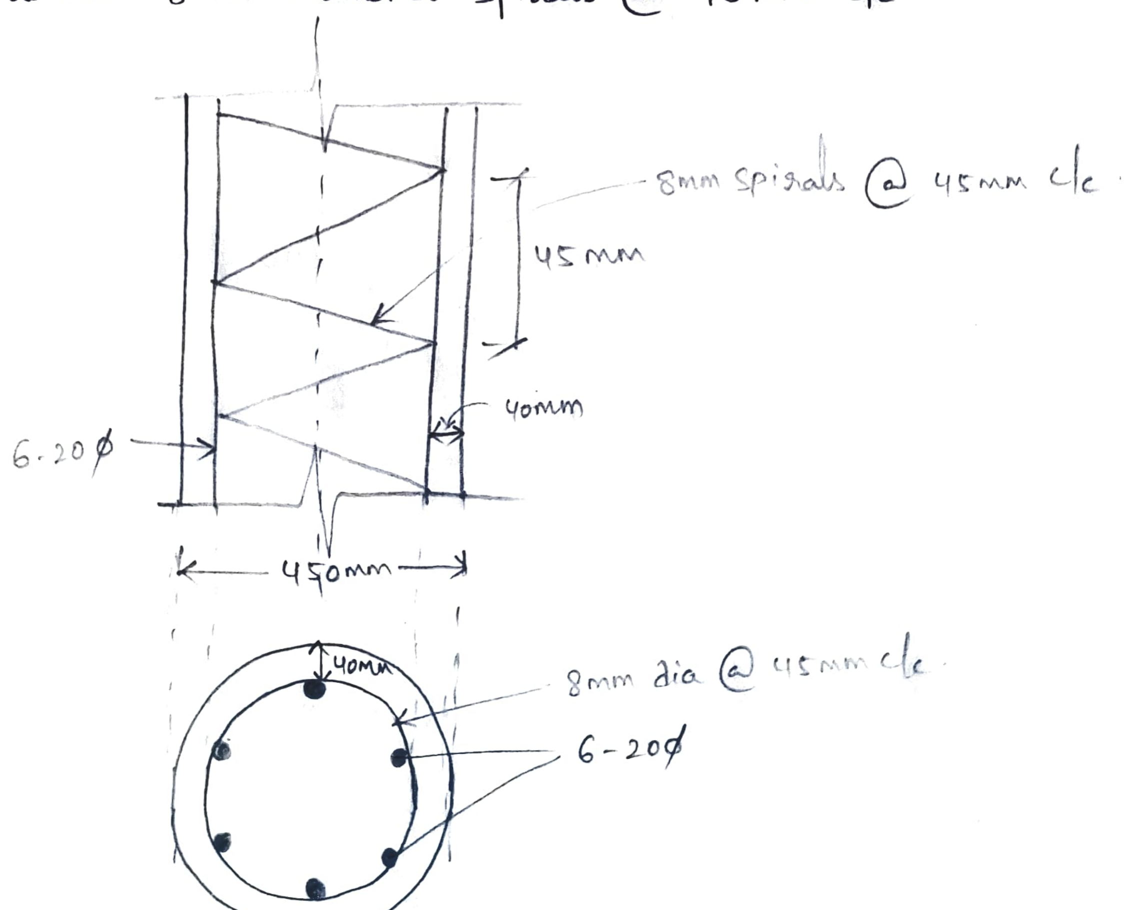
$$\frac{57.164 \times 10^6}{p \times 105.64 \times 10^6} = 0.36 \left( \frac{159.043 \times 10^3}{105649.75} - 1 \right) \frac{25}{415}$$

$$p = 49.37 \text{ mm}$$

(i) $p < 75$ mm (or) $\frac{\text{Core diameter}}{6} = \frac{370}{6} = 61.67$ mm

(ii) $p > 25$ mm (or) 3x diameter of helix $= 3 \times 8 = 24$ mm

Provide 8 mm diameter spirals @ 45mm c/c.



# Columns under axial Compression and Uni - axial bending :-

* Columns rarely subjected to pure axial loads.

* There is always some minimum eccentricity due to non homogenity of material, in accuracies in loading etc - decides many times the column is subjected to end moments on account of monolithic connection of beams and columns.

* In such a case, the column is subjected to combined action of axial load '$P_u$' and bending moment '$M_u$'. The bending moment developed by the eccentricity of application of axial load.

$$\text{Eccentricity, } e = \frac{M_u}{P_u}$$

* The behaviour of such member depends on the amount of eccentricity (or) the magnitude of the bending in relation to the axial load.

## Design of eccentrically loaded short column under uni-axial bending :-

(1) Design of column by using equations

(2) Design of column by SP-16

## Design of column by SP-16 (special publication -16) :-

Step -1 :- For bending about x-axis bisecting the depth of column.

(a) Assume the size of the column

(b) Calculate $\frac{P_u}{f_{ck} bD}$ and $\frac{M_u}{f_{ck} bD^2}$

(c) Calculate $\frac{d'}{D}$, $d'$ = effective cover.

(d) Select the appropriate chart for corresponding to $d'/D$, grade of steel, and distribution reinforcement. obtain the point of intersection

$$\frac{P_u}{f_{ck}\, bD} \text{ and } \frac{M_u}{f_{ck}\, bD^2}$$

(e) Interpolate the value of $\frac{P_t}{f_{ck}}$

(f) Calculate $A_{st}$ = Area of steel required

$$= \frac{P_t\, bD}{100} \times f_{ck}.$$

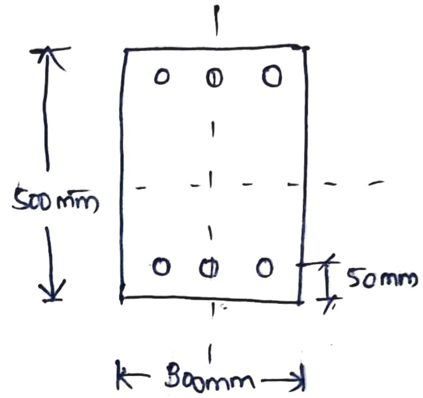
step - II :- For bending about y-axis bisecting the width of the column.

In this case, the chart to be referred is having the value of $d'/b$ and the expression $\frac{M_u}{f_{ck}\, b^2 D}$ rest of the procedure is same as bending about x-axis.

1) A short R.C Column 300mm wide and 500 mm deep is reinforced with 6 bars of 20 mm diameter, distributed equally on two short sides of column. Determine the bending moment about an axis bisecting the depth, when it is subjected to $P_u = 800$ KN. Assume $M_{20}$ grade Concrete and $Fe_{415}$ grade steel.

Sol:-

Assume $d' = 50$ mm




$D = 500$mm , $b = 300$ mm

$$d'/D = \frac{50}{500} = 0.1$$

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

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

From chart 32 of SP16, Pg 117,

$$\frac{P_u}{f_{ck}bD} = \frac{800 \times 10^3}{20 \times 300 \times 500} = 0.267$$

$$A_{st} = 6 \times \pi/4 \times 20^2 = 1885 \text{ mm}^2$$

$$p = p_t = \frac{100 A_{st}}{bD} = \frac{100 \times 1885}{300 \times 500} = 1.257$$

$$\frac{p}{f_{ck}} = \frac{1.257}{20} = 0.063$$

For $\frac{P_u}{f_{ck}bD} = 0.267$, $\frac{p}{f_{ck}} = 0.063$, we get $\frac{M_u}{f_{ck}bD^2} \simeq 0.13$

$$M_u = 0.13 f_{ck} b D^2$$

$$= 0.13 \times 20 \times 300 \times 500^2$$

$$= 195 \text{ KNm}$$

2) For the same data given in problem 1, determine the value of Pu, if Mu = 100 KNm.

Sol:-

$$\frac{M_u}{f_{ck} b D^2} = \frac{100 \times 10^6}{20 \times 300 \times 500^2} = 0.067$$

From chart 32, for $\frac{M_u}{f_{ck} b D^2} = 0.067$ and $\frac{p}{f_{ck}} = 0.063$,

$$\frac{P_u}{f_{ck} b D} = 0.49$$

$$\therefore P_u = 0.49 \times 20 \times 300 \times 500 = 1470 \text{ KN}.$$

3) Design a reinforced concrete column, 400mm square, to carry an ultimate load of 1000 KN at an eccentricity of 160mm. Use $M_{20}$ grade concrete and Fe250 grade steel.

Sol:- Assume effective cover, $d' = 40$mm

$$b = D = 400\text{mm}$$

$$\frac{d'}{D} = \frac{40}{400} = 0.1$$

$$P_u = 1000 \text{ KN}.$$

$$M_u = P_u \times e = 1000 \times 10^3 \times 160 = 160 \text{ KNm}$$

The non dimensional parameters,

$$\frac{P_u}{f_{ck} b D} = \frac{1000 \times 10^3}{20 \times 400 \times 400} = 0.3125$$

$$\frac{M_u}{f_{ck} b D^2} = \frac{160 \times 10^6}{20 \times 400 \times 400^2} = 0.125$$

Interaction diagram for $f_y = 250$ MPa, $d'/D = 0.1$ i.e chart 28 of SP-16.

For $\frac{P_u}{f_{ck} bD} = 0.3125$ and $\frac{M_u}{f_{ck} bD^2} = 0.125$,

Draw Figure?

$p/f_{ck} = 0.105$

$p = 0.105 \times 20 = 2.1 = \frac{100 A_{sc}}{bD}$

$\Rightarrow A_{sc} = \frac{2.1 \times 400 \times 400}{100} = 3360 \text{ mm}^2$

Provide 25 mm dia bars,

No. of bars $= \frac{3360}{\pi/4 \times 25^2} = 6.84 \simeq 8$ bars.

Provide 4 bars of 25 mm dia on each face.

Use 6mm dia lateral ties, at a spacing of the least of the following

(i) Least lateral dimension = 400 mm

(ii) $16 \times 25 = 400$ mm

(iii) 300 mm.

Hence provide 6mm dia lateral ties at a spacing of 250mm c/c.

4) Design a short circular column of 500mm dia. with the following data. with helical reinforcement.

Factored load = 800 KN, Factored moment = 162.5 KNm

Take $M_{20}$ Concrete Mix and Fe 415 steel.

Sol:- $\frac{P_u}{f_{ck} D^2} = \frac{800 \times 10^3}{20 \times 500^2} = 0.16$, $\frac{M_u}{f_{ck} D^3} = \frac{162.5 \times 10^6}{20 \times 500^3} = 0.065$.

According to cl 39.4 of IS Code, strength of Compression member with helical reinforcement is 1.05 times the strength of member with ties.

$$\therefore \frac{P_u}{f_{ck} D^2} = \frac{0.16}{1.05} = 0.152 , \quad \frac{M_u}{f_{ck} D^3} = \frac{0.065}{1.05} = 0.062$$

From chart 56 of SP-16, $\frac{p}{f_{ck}} = 0.045$

$$p = 0.045 \times 20 = 0.9 = \frac{100\, A_{sc}}{\pi/4\, D^2} = \frac{100 \times A_{sc}}{\pi/4 \times 500^2}$$

$$\Rightarrow A_{sc} = 1767.1 \text{ mm}^2$$

Assume 20 mm dia bars, No. of bars $= \frac{1767.1}{\pi/4 \times 20^2} = 5.62$

$\therefore$ Provide 6 no's of 20 mm dia bars.

$$A_g = \pi/4 \times 500^2 = 196349.5 \text{ mm}^2.$$

use 8 mm dia bars as helical reinforcement. and clear cover = 40mm.

Core diameter, $D_c = 500 - (2 \times 40) \cancel{+ 2 \times 8} = 420$ mm

Area of Core $= \pi/4 \times 420^2 = 138562.2 \text{ mm}^2$

~~Dia of Core upto Centre of helix =~~

Volume of helical spirals per metre length

$$V_{ns} = \pi \times (500 - 80 - 8) \times \pi/4 \times 8^2 \times \frac{1000}{s} \text{ mm}^3$$

$$V_c = 138562 \times 1000 = 138.56 \times 10^6 \text{ mm}^3$$

$$\frac{V_{ns}}{V_c} = 0.36 \left( \frac{A_g}{A_c} - 1 \right) \frac{f_{ck}}{f_y}.$$

$$\frac{\frac{65060.4 \times 10^3}{s}}{138.56 \times 10^6} = 0.36\left(\frac{196349.5}{149301} - 1\right)\frac{20}{415}$$

$$\frac{0.47}{s} = 0.01$$

$$\Rightarrow s = 47\ mm \simeq 50\ mm.$$

~~However, the pitch should not~~ be ~~more than 75mm~~, ~~nor mo~~

(i) pitch $< 75$ mm (or) $\frac{\text{Core diameter}}{6} = \frac{420}{6} = 70$ mm

(ii) pitch $> 25$mm (or) $3\times$ diameter of helix $= 24$ mm

Hence provide 8mm dia spirals at a pitch of 50mm.

Draw figure