CHAPTER 10

Compression Member

CONTENTS

10. Compression Member

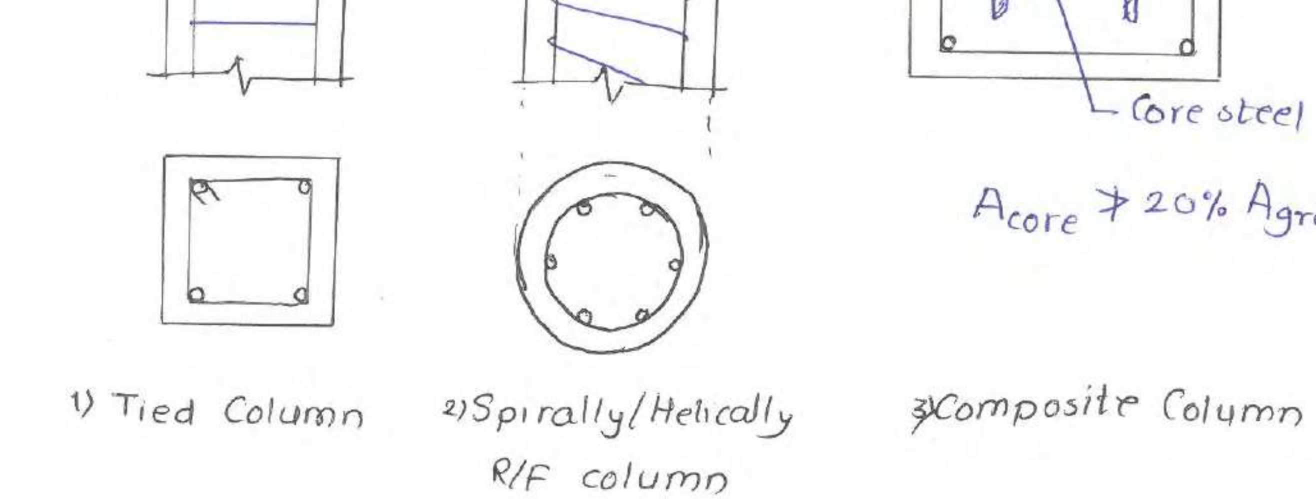
10.1 Introduction:

Compression member is a structural member which is primarily subjected to axial compression. If orientation is vertical then termed as column otherwise strut.

10.2 Classification of Column:

10.2.1 Based on Type of Steel:

1) Tied Column.
2) Spirally / Helically reinforced column.
3) Composite column.



1) Tied Column 2) Spirally/Helically R/F column 3) Composite Column

10.2.2 Based on Type of Loading.

1) Concentrically Loaded:

Load is placed at C.G. of section.

2) Axially Loaded:

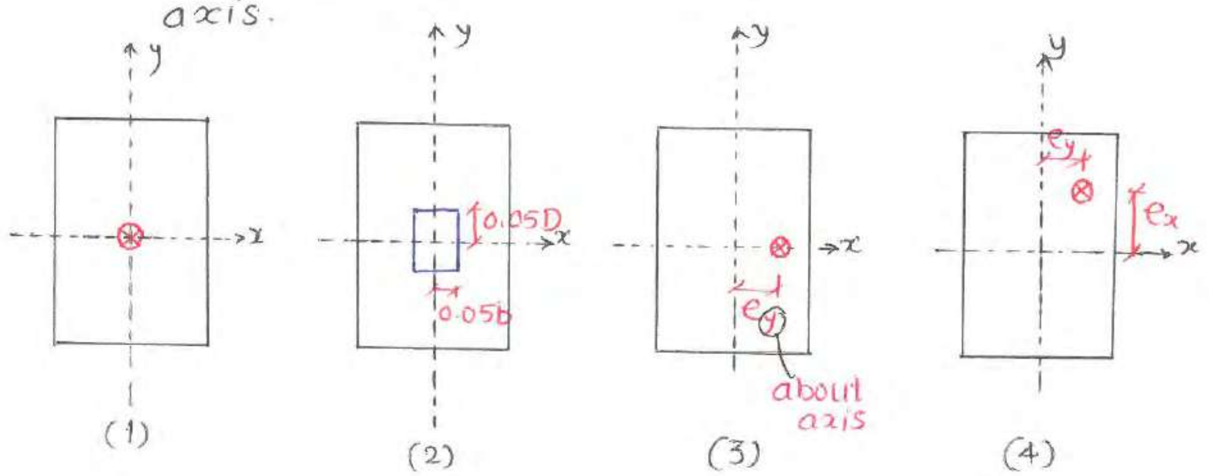
Load is placed at an eccentricity within 5% of lateral dimension.

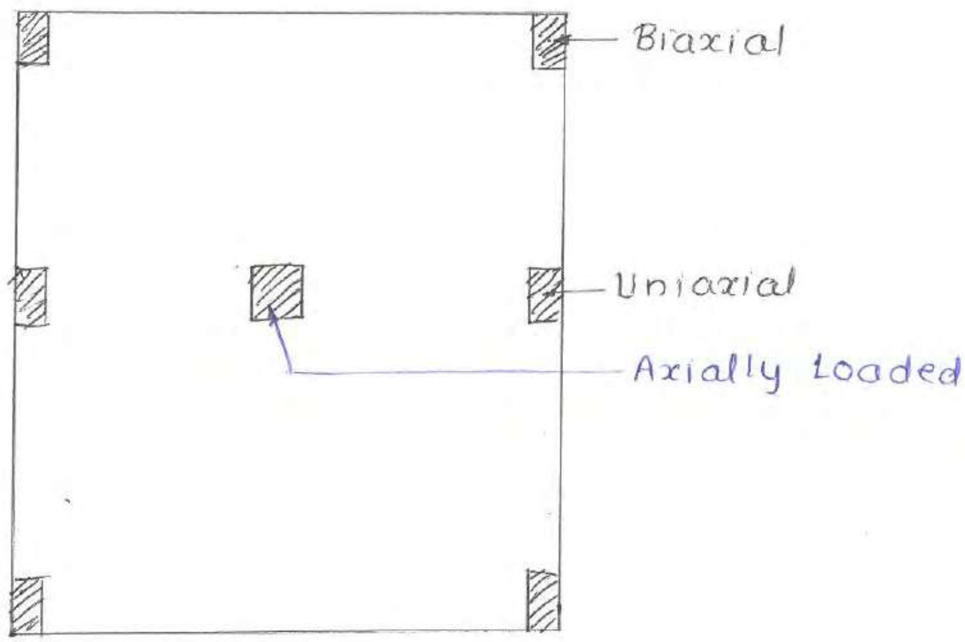
3) Axial Load with uniaxial moment:

Load is placed at an eccentricity about 1 axis only.

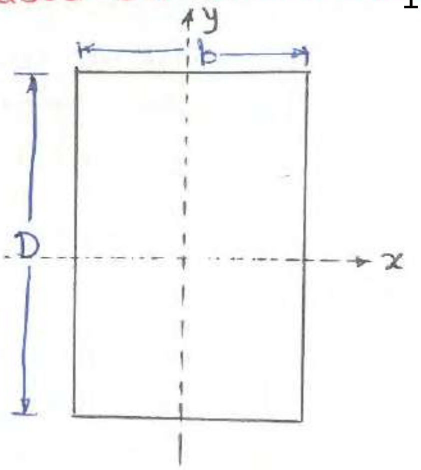
4) Axial load with Biaxial Moment:

Load is placed at an eccentricity about both axis.





10.2.3 Based on Slenderness Ratio:



$D > b$

$I_{xx} > I_{yy}$

X- axis is considered as Major axis because I_{xx} is greater

Y- axis $\longrightarrow$ Minor axis.

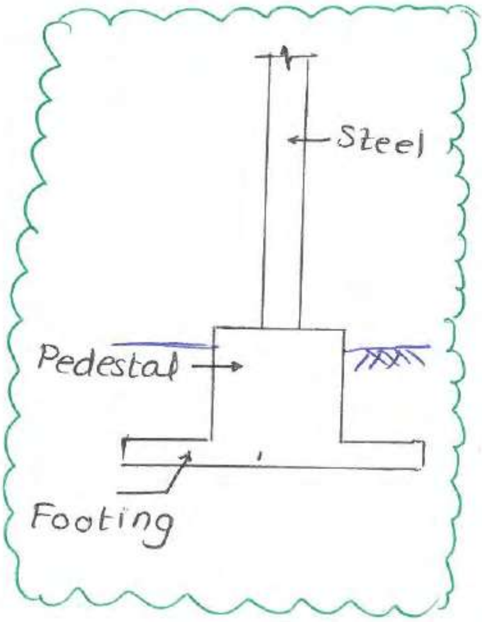
$$\text{Slenderness Ratio} = \frac{L_{eff}}{\text{Lateral Dimension}}$$

$$\lambda_x = \frac{L_{eff,x}}{D}$$

$$\lambda_y = \frac{L_{eff,y}}{b}$$

For $L_{eff,x} = L_{eff,y} = L_{eff}$.

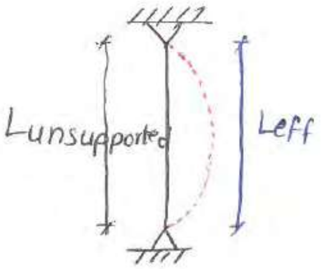
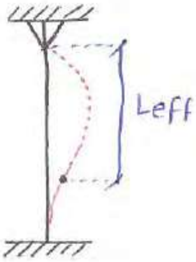
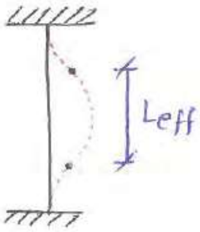
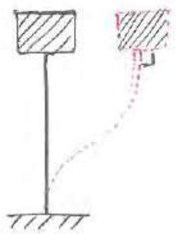
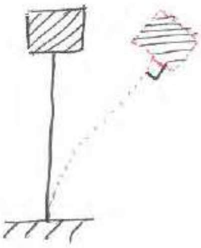
$$\lambda_{max} = \frac{L_{eff}}{\text{Least Lateral Dimension}}$$

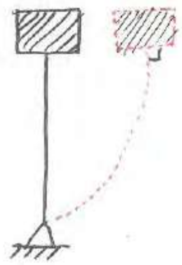


$\lambda_{max} \leq 3$	Pedestal
$3 < \lambda_{max} < 12$	Short Column
$12 \leq \lambda_{max}$	Long Column

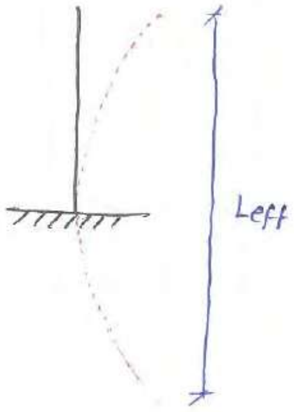
10.3 Effective Length of Column:

It is the distance between point of contraflexure or point of zero moment. In other words, length of column that effectively participates in buckling is called effective length of column.

Support Condition	Theoretical	Reccommended.
	$L_{eff} = 1.0\ L_{unsupported}$	$L_{eff} = 1.0\ L_{unsupported}$
	$L_{eff} = 0.7\ L_{unsupported}$	$L_{eff} = 0.8\ L_{unsupported}$
	$L_{eff} = 0.5\ L_{unsupported}$	$L_{eff} = 0.65\ L_{unsupported}$
	$L_{eff} = 1.0\ L_{unsupported}$	$L_{eff} = 1.2\ L_{unsupported}$
	—	$L_{eff} = 1.5\ L_{unsupported}$

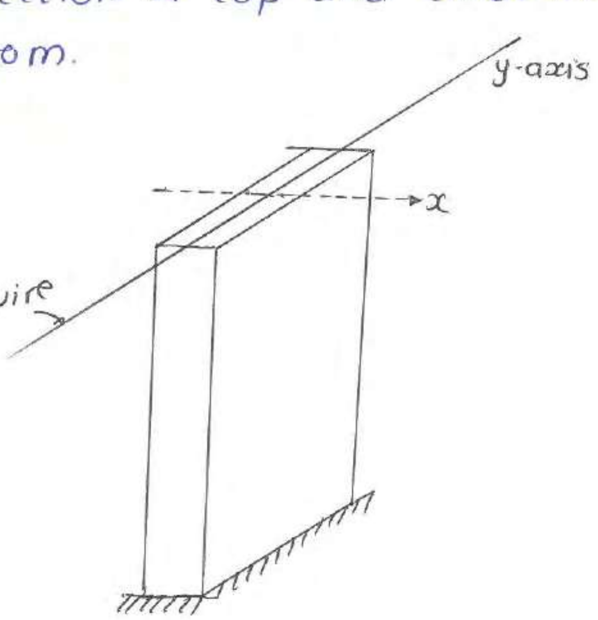


$L_{eff} = 2.0\ L_{unsupported}$ $L_{eff} = 2.0\ L_{unsupported}$.



$L_{eff} = 2.0\ L_{unsupported}$ $L_{eff} = 2.0\ L_{unsupported}$.

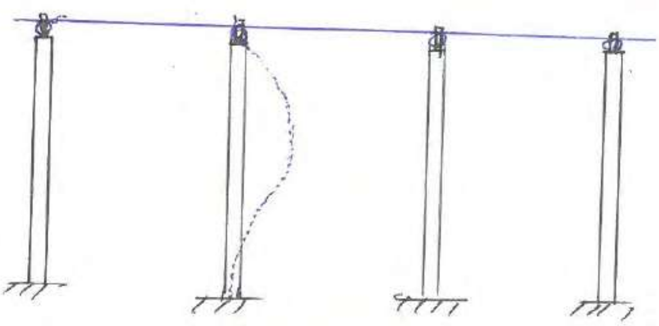
Ex. Calculate effective length of an electric pole carrying wire in one direction at top and embeded in large size foundation at bottom.



About y-axis.

$L_{eff} = 2.0L$

About x-axis



$L_{eff} = 0.8L$

* Note:-

$L_{unsupported}$ may also be different about different axes
For ex. a column supported by walls from two opposite sides has different $L_{unsupported}$ about different axes.

10.4 Codal Provisions:

10.4.1 Maximum Permissible Length:

- Laterally restrained at ends

$$L_{unsupported} \ngtr 60b$$

- Laterally not-restrained at ends

$$L_{unsupported} \ngtr \frac{100b^2}{D}$$

10.4.2 Minimum Eccentricity:

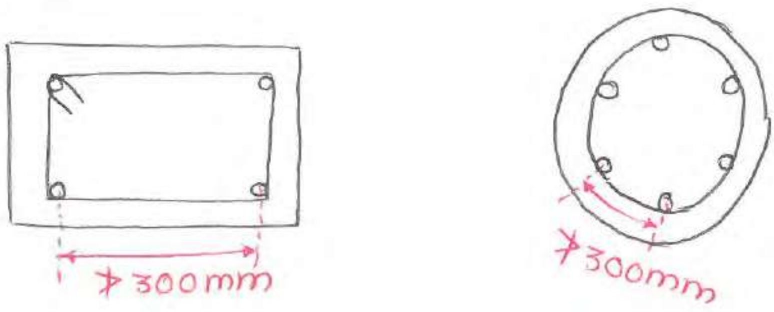
Every column must be designed for minimum eccentricity to account for constructional defects and material imperfection.

$$e_{min} = \text{Maximum} \begin{cases} \bullet \ \dfrac{L_{unsupported}}{500} + \dfrac{b \text{ or } D}{30} & \perp^{re} \text{ to axis} \\ \bullet \ 20\,mm \end{cases}$$

10.4.3 Longitudinal Reinforcement:

- Minimum 0.8% of gross area.
- Maximum 6% of gross area (Practically 4% due to lapping)
- Minimum dia. 12mm.
- Minimum 4 bars for rectangular column and 6 for circular column.
- Minimum nominal cover 40mm or dia. of bar whichever is greater. This can be reduced to 25mm for bar dia. 12mm and section dimension 200mm or less.

- Minimum 0.15% of gross area for pedestal
- Maximum spacing along peripheri should not exceed 300 mm.



10.4.4 Transverse Reinforcement:

- To prevent buckling of longitudinal reinforcement.
- For confinement of concrete.
- To hold longitudinal reinforcement at position.
- To enhance resistance against shear and torsion.

10.4.4.1 Lateral Ties:

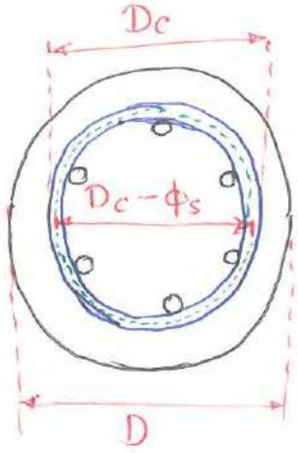
$$\phi \geq \text{Maximum} \begin{cases} \bullet\ \phi_{long,max}/4 \\ \bullet\ 6\,mm \end{cases}$$

$$S \leq \text{Minimum} \begin{cases} \bullet\ \text{Least Lateral dimension} \\ \bullet\ 16\,\phi_{long,min} \\ \bullet\ 300\,mm \end{cases}$$

10.4.4.2 Spiral / Helical Reinforcement:

- Spirally reinforced columns are more ductile and its load carrying capacity is 5% higher than column with lateral ties.
- Concrete of spirally reinforced column is subjected to triaxial compression.
- A column is considered as spirally reinforced if following condition is satisfied.

$$\frac{\text{Volume of spiral R/F}}{\text{Volume of core}} \geq \frac{0.36 f_{ck}}{f_y}\left(\frac{A_g}{A_c} - 1\right)$$



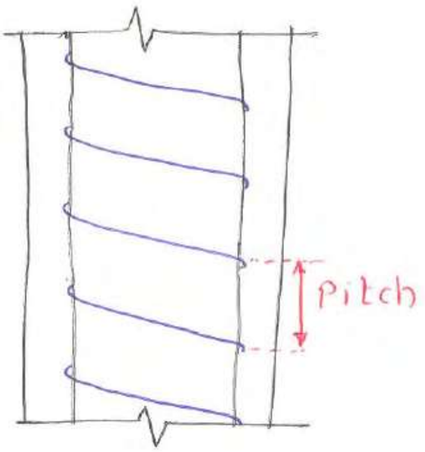
$D_c = D - 2 \times \text{clear cover}$

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

$A_c = \frac{\pi}{4} D_c^2$

Volume of spiral per pitch

$= \frac{\pi}{4} \phi_s^2 \times \pi (D - \phi_s)$

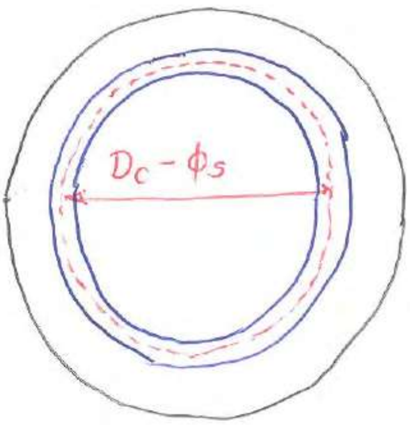


Volume of core per pitch

$= \frac{\pi}{4} D_c^2 \times \text{pitch}$

$\phi_s \geq$ maximum $\begin{cases} \bullet\ \phi_{long,max}/4 \\ \bullet\ 6\,mm \end{cases}$

S/pitch $\leq$ Minimum $\begin{cases} \bullet\ 75\,mm \\ \bullet\ D_c/6 \end{cases}$



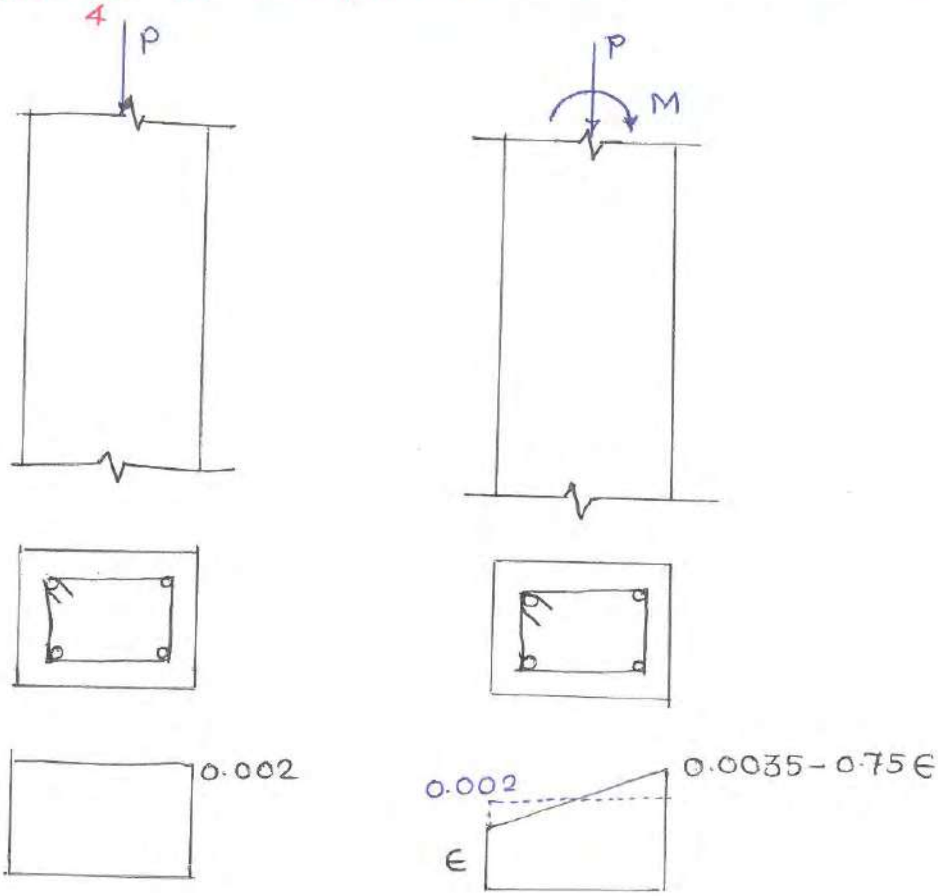
S/pitch $\geq$ Maximum $\begin{cases} \bullet\ 25\,mm \\ \bullet\ 3\phi_s \end{cases}$

10.5 Assumptions:

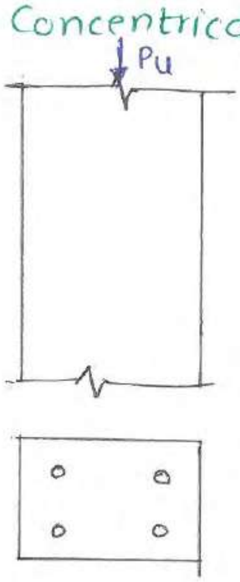
1. Assumption 1 to 5 of limit state of collapse of flexure are applicable for compression member also.

2. For axially loaded column, maximum compressive strain in all fibres is limited to 0.002.

3. For column subjected to axial load with bending and entire section is under compression, maximum strain in concrete is limited to $0.0035 - \frac{3}{4}^{th}$ of compressive strain of least comp. fibre.



10.6 Concentrically loaded Short Column.



$$P_u = P_{uR}$$
$$= P_c + P_s$$
$$= f_c \cdot A_c + f_{sc} \cdot A_{sc}$$
$$= f_c (A_g - A_{sc}) + f_{sc} \cdot A_{sc}$$
$$P_u = f_c A_g + (f_{sc} - f_c) \cdot A_{sc}$$

At strain 0.002:-

$$f_c = 0.45 f_{ck}$$

$$f_{sc} = 0.87 f_y \quad (Fe250)$$

$$0.79 f_y \quad (Fe415)$$

$$0.745 f_y \quad (Fe500)$$

Now,

$$P_u = 0.45 f_{ck} \cdot A_g + (0.75 f_y - 0.45 f_{ck}) A_{sc}$$

For spiral R/F

$$P_u = 1.05 \left[0.45 f_{ck} \cdot A_g + (0.75 f_y - 0.45 f_{ck}) A_{sc} \right]$$

Ex. A RCC short column of size 450 x 450 mm is reinforced with 4-20φ of Fe 415. calculate concentric working load carrying capacity of column by ignoring reduction of concrete area due to presence of steel. M20 concrete.

⇒ ~~Alex~~

$$P_u = 0.45 f_{ck} \cdot A_g + 0.75 f_y \cdot A_{sc}$$

$$= 0.45 \times 20 \times 450 \times 450 + 0.75 \times 415 \times 4 \times \frac{\pi}{4} \times 20^2$$

$$P_u = 2213.63 \text{ kN}$$

$$\text{Working Load} = \frac{P_u}{1.5} = \frac{2213.63}{1.5} = 1475.75 \text{ kN.}$$

10.7 Axially Loaded Short Column:

It is obtained by reducing load carrying capacity of concentrically loaded column by approximately 10% to account for eccentricity of load within 5% of lateral dimension.

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

For spiral R/F

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

Ex. Calculate axial load carrying capacity of section 500 x 600mm reinforced with 8-20ϕ of Fe 415. M20 concrete.

⇒

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

$$= 0.4 \times 20 \times 500 \times 600$$

$$P_u = 3078.78 \text{ kN}$$

10.8 Design of Axially Loaded Short Column:

1. Section size is given and steel is to be designed.
2. Section size and steel both are to be designed.

Ex. Design the reinforcement of a spirally reinforced column of dia. 450mm. It is subjected to factored axial load 3000kN $L_{unsupported}$ 3.4m, pinned supported at both ends M25. Fe 415, Mild exposure.

⇒

Slenderness Ratio, $\lambda = \dfrac{L_{eff}}{D} = \dfrac{3.4 \times 10^3}{450}$

$$\lambda = 7.55 < 12$$

so, column is short

$$e_{min} = \text{Maximum} \begin{cases} \cdot\ \dfrac{L_{unsupported}}{500} + \dfrac{D}{30} = \dfrac{3.4 \times 10^3}{500} + \dfrac{450}{30} = 21.8\text{mm} \\ \cdot\ 20 \end{cases}$$

$$e_{min} = 21.8\text{mm} \quad < 0.05D\ (22.5\text{mm})$$

So, column is axially loaded.

Now,

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

$$3000 \times 10^3 = 1.05 \left[\left(0.4 \times 25 \times \frac{\pi}{4} \times 450^2\right) + (0.65 \times 415 - 0.4 \times 25) \times A_{sc} \right]$$

$$A_{sc} = 4725.65 \text{ mm}^2$$

Providing $6 - 32\phi$

Transverse reinforcement:

$$\phi_s \geq \text{Maximum} \begin{cases} \cdot\ \phi_{long,max}/4 = \frac{32}{4} = 8mm \\ \cdot\ 6\ mm \end{cases}$$

Assuming $\phi_s = 8mm$

$D_c = D - 2 \times \text{clear cover}$

$= 450 - 2 \times 40$

$D_c = 370\ mm$

Now,

$$\frac{\text{Volume of spiral per pitch}}{\text{Volume of core per pitch}} \geq \frac{0.36 f_{ck}}{f_y}\left(\frac{A_g}{A_c} - 1\right)$$

$$\frac{\frac{\pi}{4} \times \phi_s^2 \times \pi (\cancel{\phi} D_c - \phi_s)}{\frac{\pi}{4} \times D_c^2 \times \text{pitch}} \geq \frac{0.36 f_{ck}}{f_y}\left(\frac{\pi/4\ D^2}{\pi/4\ D_c^2} - 1\right)$$

$$\frac{8^2 \times \pi \times (370 - 8)}{370^2 \times \text{Pitch}} \geq \frac{0.36 \times 25}{415} \times \left(\frac{450^2}{370^2} - 1\right)$$

Pitch ≤ 51.17 mm

Dia should be such that this value must be more than 25mm

$$\text{S/ pitch} \leq \text{Minimum} \begin{cases} \cdot\ 75\ mm \\ \cdot\ \frac{D_c}{6} = \frac{370}{6} = 61.66\ mm \end{cases}$$

$$\text{S/ pitch} \geq \text{Maximum} \begin{cases} \cdot\ 25\ mm \\ \cdot\ 3\phi_s = 3 \times 8 = 24\ mm \end{cases}$$

Providing spiral of 8ϕ @ 50mm c/c

Ex. Design rectangular section of column subjected to factored axial load 4000kN. $L_{unsupported} = 3.4\,m$, pin connected at one end and fixed at another end, Fe415 and M20.

⇒ In general, 1-2% of gross area is provided as longitudinal reinforcement. Considering 1.5% as longitudinal R/F for this problem.

Section size is required to classify column as axially loaded short column. Since section size is not known so assuming column as axially loaded short column.

Step 1: Gross area:

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

$$4000 \times 10^3 = 0.4 \times 20 \times A_g + (0.67 \times 415 - 0.4 \times 20) \times \frac{1.5}{100} \times A_g$$

$$\Rightarrow A_g = 331929.54\,mm$$

Assuming $D/b = 1.25$ (Preferably 1 to 3)

$$bD = A_g$$

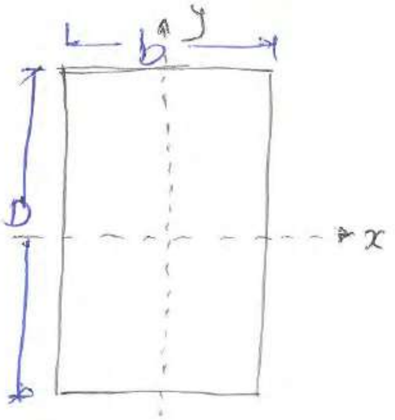
$$b \times 1.25b = A_g$$

$$b = 515.31\,mm$$

Section size smaller than this value results into higher % of steel.

Assuming $b = 500\,mm$

$$D = 1.25b = 1.25 \times 500 = 625\,mm.$$



Slenderness ratio :-

$$\lambda = \frac{L_{eff}}{b}$$

$$= \frac{0.8 \times 3.4 \times 10^3}{500}$$

$$\lambda = 5.44 < 12$$

So column is short.

$$e_{min,x} = \text{Maximum} \begin{cases} \cdot \dfrac{L_{unsupported}}{500} + \dfrac{D}{30} \\ \cdot 20mm. \end{cases}$$

$$= \text{Maximum} \begin{cases} \cdot \dfrac{3.4 \times 10^3}{500} + \dfrac{625}{30} = 27.63mm. \\ \cdot 20mm \end{cases}$$

$e_{min,x} = 27.63\ mm < 0.05D\ (31.25mm)$

$$e_{min,y} = \text{Maximum} \begin{cases} \cdot \dfrac{L_{unsupported}}{500} + \dfrac{b}{30} \\ \cdot 20\ mm \end{cases}$$

$$= \text{Maximum} \begin{cases} \cdot \dfrac{3.4 \times 10^3}{500} + \dfrac{500}{30} = 23.46 \\ \cdot 20\ mm \end{cases}$$

$e_{min,y} = 23.467 < 0.05b\ (25mm)$

So column is axially loaded.

Now,

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

$$4000 \times 10^3 = 0.4 \times 20 \times 500 \times 625 + (0.67 \times 415 - 0.4 \times 20) \times A_{sc}$$

$$\Rightarrow \quad A_{sc} = 5554.52\ mm^2$$

Atleast 3-bars on each face (total 8-bars) are required to satisfy maximum spacing criteria.(300mm)

$\Rightarrow$ Providing $4\text{-}32\phi + 2\text{-}28\phi$

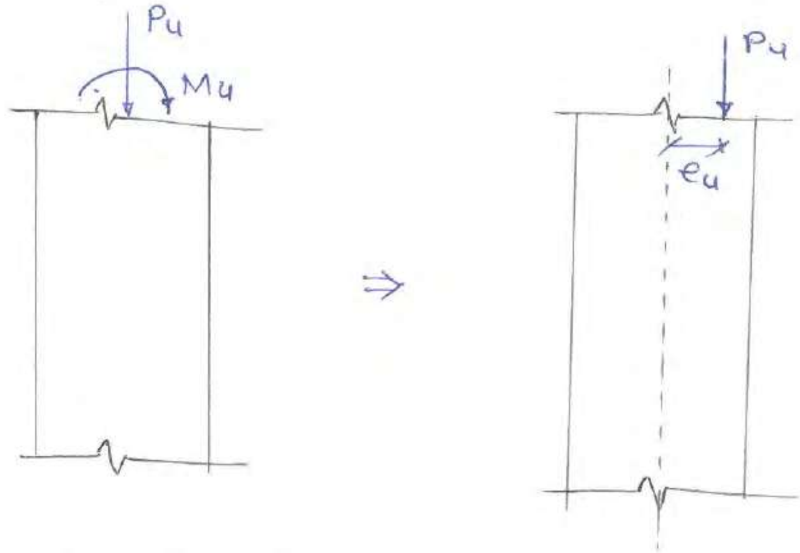
Transverse R/F

$$\phi \geq \text{Maximum} \begin{cases} \cdot \phi_{long,max}/4 = \dfrac{32}{4} = 8mm \\ \cdot 6mm \end{cases}$$

$$S/pitch \leq \text{Minimum} \begin{cases} \cdot \text{Least lateral dimension} = 500mm \\ \cdot 16\ \phi_{long,min} = 16 \times 28 = 448mm. \\ \cdot 300\ mm \end{cases}$$

Providing 8ϕ @ 300 mm c/c.

10.9 Short Column Subjected to Axial Load with Uni-axial Moment.

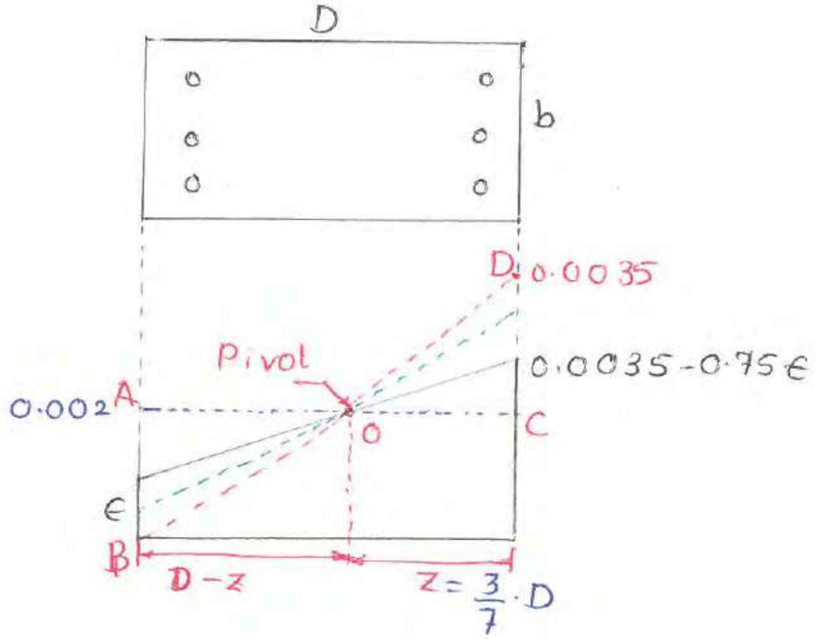


$$e_u = \frac{M_u}{P_u}$$

Step 1: Load carrying capacity of section means maximum applied load must be equal to resistance of section.

$$P_u = P_{uR} \qquad \text{or} \qquad P_u = P_{uR}$$
$$M_u = M_{uR} \qquad\qquad\quad e_u = e_{uR}$$

Step 2: To calculate P_{uR} and e_{uR}, failure criteria should be known. IS456 provides failure criteria for column subjected to axial load with uniaxial moment as given below



$$\frac{OA}{AB} = \frac{OC}{CD}$$

$$\Rightarrow \frac{D-z}{0.002} = \frac{z}{0.0035-0.002}$$

$$z = \frac{3}{7} D$$

In above strain diagram, different values of ϵ represents different failure strain profile. This is possible because a column fails with multiple load combinations of P_u and M_u.

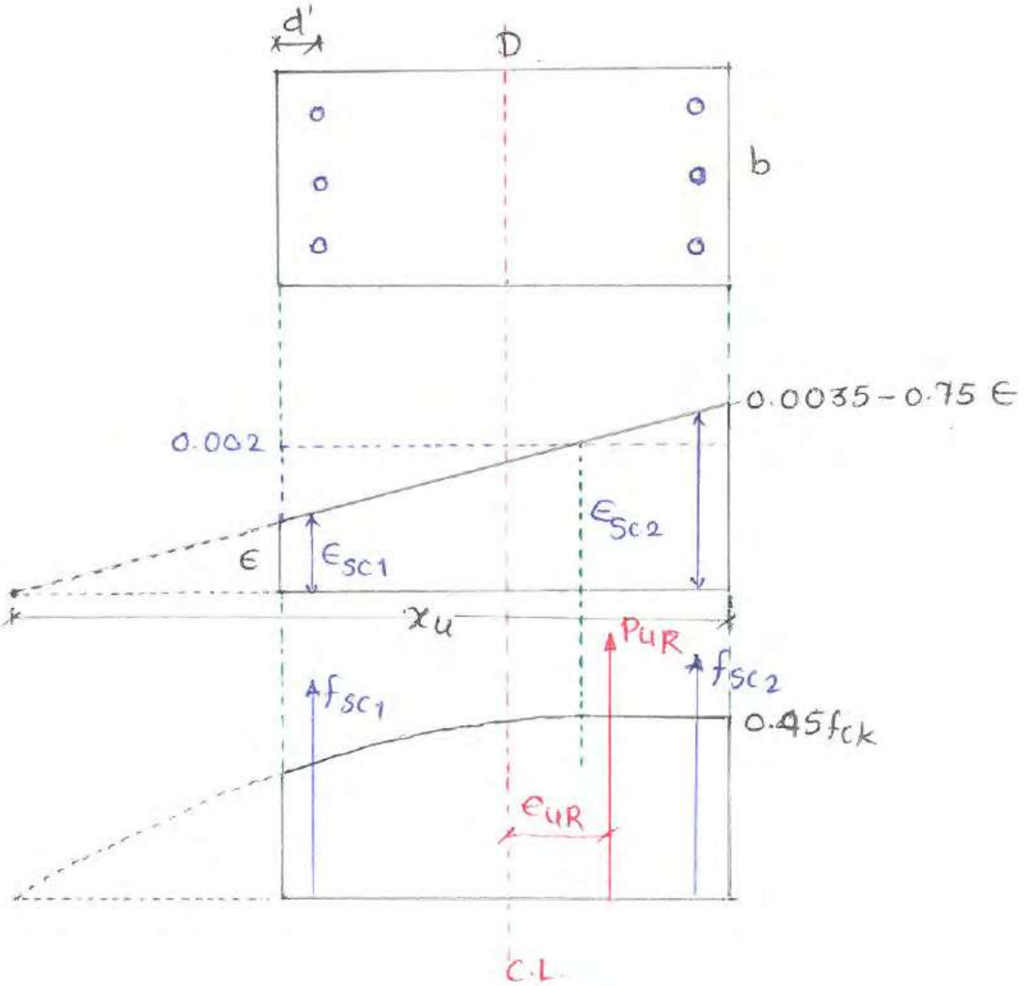
$P_u = 5000\,kN$ & $M_u = 1500\,kNm$

$P_u = 4000\,kN$ & $M_u = 2000\,kNm$

$P_u = 6000\,kN$ & $M_u = 1000\,kN\cdot m$

All are representing different failure strain profiles

Step 3: Resistance of section corresponding to failure strain profile is calculated as follows.



P_u & M_u ← P_u & e_u ← P_{uR} & e_{uR} ← Stress block f_{sc_1} & f_{sc_2} ← failure Strain diagram ϵ_{sc1} & ϵ_{sc2} ← ϵ ← x_u

from above sequence, it is clear that different positions of x_u represents different load carrying capacity of section. (P_u and M_u)

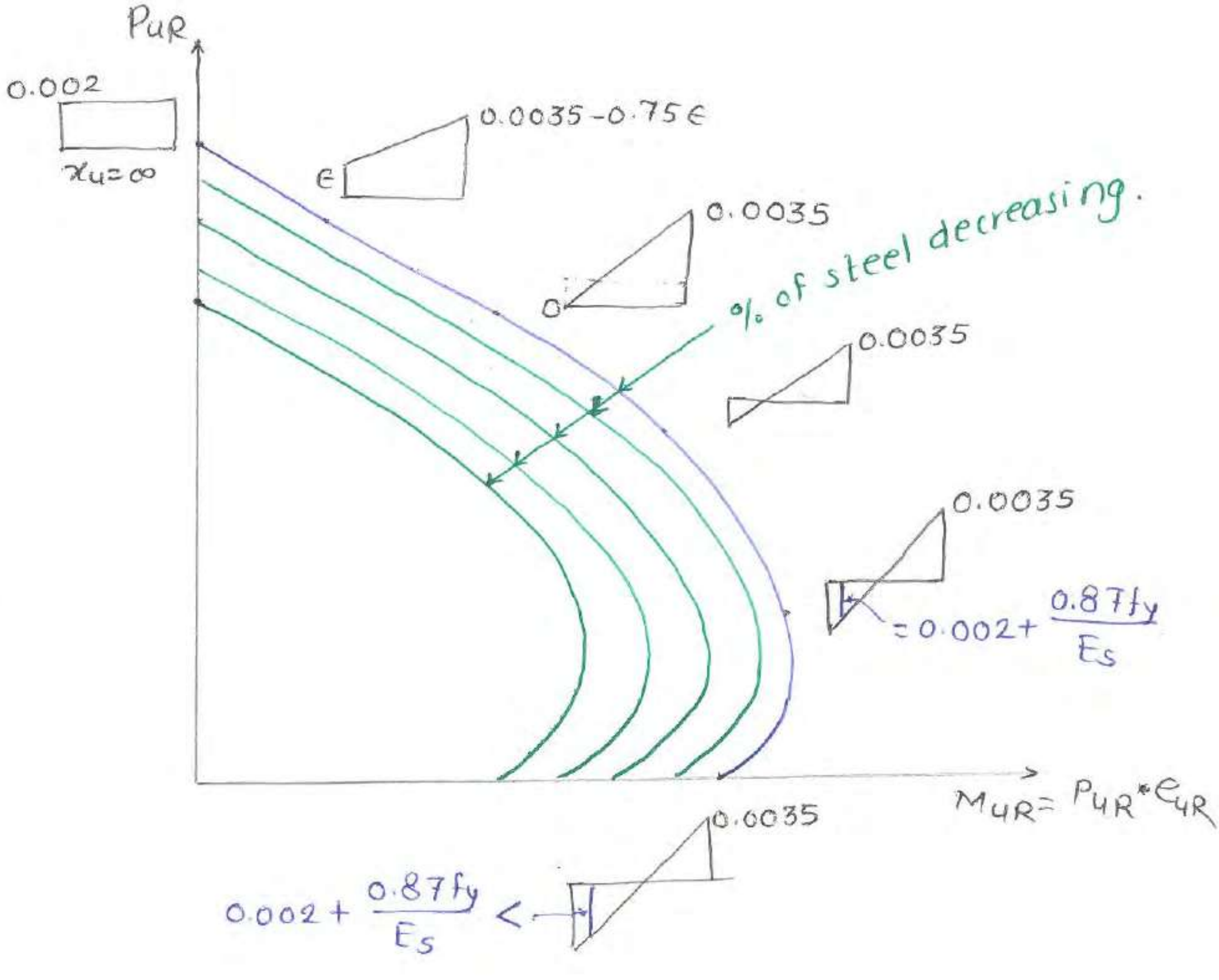
In above sequence, P_u and ~~Mu~~ ~~e_u~~ M_u cannot be represented in terms of x_u because f_{sc} and ϵ_{sc} are not interrelated by any mathematical function.

$$P_u \,\&\, M_u \neq f(x_u)$$

because

$$f_{sc} \neq f(\epsilon_{sc})$$

Step 4: To overcome above problem, capacity of section [(P_{uR} & e_{uR}) or (P_{uR} & M_{uR})] is calculated corresponding to different positions of NA. and they are represented in the form of graph. This graphical representation is called as Interaction Curve.



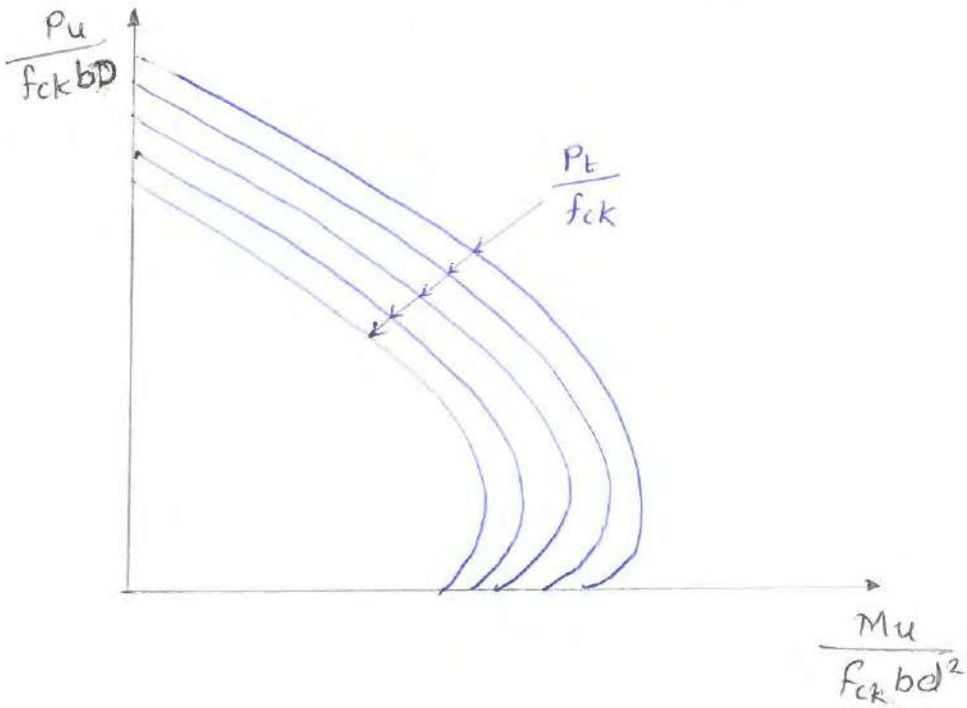
To draw above interaction diagram, following quantities are required.

1. Grade of concrete
2. Grade of Steel
3. Section size (b and D both)
4. Shape of section (Rectangular & circular)
5. $\frac{d'}{D}$ ratio
6. Arrangement of Reinforcement

Equally distibuted on 2-face & 4-face

7. Area of longitudinal steel & % of longitudinal steel. If % of longitudinal steel is changed then similar interaction curves are obtained.

Step 5: Above interaction diagram can carry limited load combinations. Since, load combinations could be infinite so dimensionless interaction diagram is plated to cater infinite load combinations.



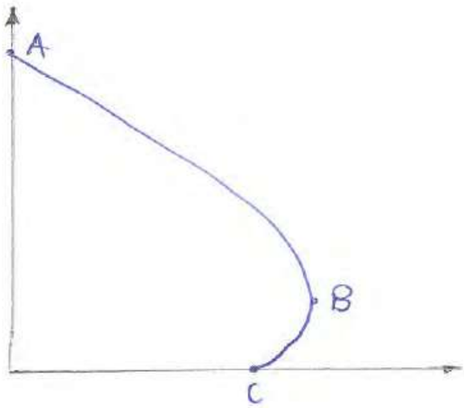
To draw dimensionless interaction diagram, following quantities are required:

1. Grade of Steel
2. Shape of section
3. $\frac{d'}{D}$ ratio
4. Arrangement of Reinforcement.
5. % of reinforcement.

Interaction Diagram (SP16)

- Rectangular
  - 2-face
  - 4-face
    - Fe 250
    - Fe 415
      - $\frac{d'}{D}$: 0.05, 0.1, 0.15, 0.2
    - Fe 500
- Circular

10.9.1 Important Points about Interaction Diagram:



- Point B represents balanced failure of section.
- Portion AB represents compression failure because concrete attains its permissible value before yielding of steel
- Portion BC represents tension failure because concrete attains its permissible value after yielding of steel.
- Any load combination falling within interaction curve is safe for section

10.9.2 Design Steps :

Step 1: Calculate design axial load and uniaxial moment (P_u and M_u)

Step 2: Assume any suitable value of b, D, $\frac{d'}{D}$ ratio, arrangement of reinforcement. f_{ck} and f_y are given

Step 3: Calculate $\frac{P_u}{f_{ck} b D}$ and $\frac{M_u}{f_{ck} b D^2}$

Step 4: Select suitable interaction chart from SP 16 corresponding to shape of ~~concrete~~ section, arrangement of reinforcement, grade of steel and $\frac{d'}{D}$ ratio

Take value of $\frac{P_t}{f_{ck}}$ from selected interaction chart corresponding to $\frac{P_u}{f_{ck} b D}$ and $\frac{M_u}{f_{ck} b d^2}$

*Note:

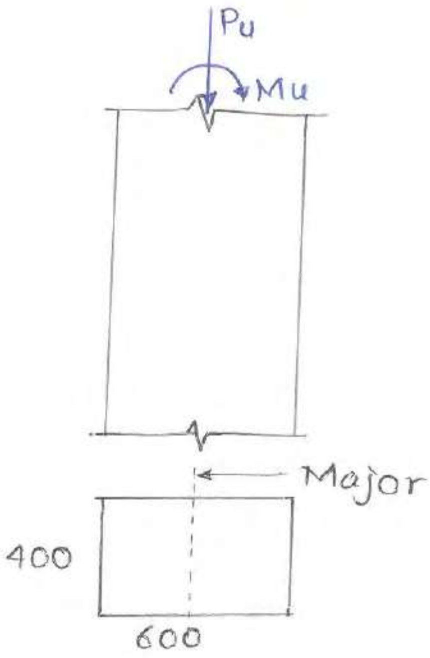
If not able to find any suitable point on interaction chart then revise data of step 2.

Step 5: Calculate area of longitudinal steel from $\frac{P_t}{f_{ck}}$ of previous step.

Step 6: Provide area of longitudinal steel in the form of bars as per interaction diagram used.

Step 7: Provide transverse reinforcement.

Ex Design the reinforcement of RCC short column of section size 400 x 600 mm. It is subjected to factored axial load 1400 kN and moment 280 kN·m about major axis. M20, Fe 415, effective cover 60 mm.



⇒

Step 1: $P_u = 1400 \text{ kN}$

$M_u = 280 \text{ kN·m}$

Step 2: $b = 400 \text{ mm}$

$D = 600 \text{ mm}$

$\frac{d'}{D} = \frac{60}{600} = 0.1$

4-face

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

$f_y = 415 \text{ N/mm}^2$

Step 3: $\frac{P_u}{f_{ck} b D} = 0.29$

$\frac{M_u}{f_{ck} b D^2} = 0.1$

Step 4: Chart 44 ..... (From SP16, rectangular 4-face, Fe 415, $\frac{d'}{D} = 0.1$)

$\frac{P_t}{f_{ck}} = 0.08$ .... (Chart 44, $\frac{P_u}{f_{ck} b D} = 0.29$, $\frac{M_u}{f_{ck} b D^2} = 0.1$)

Step 5: $\frac{P_t}{f_{ck}} = 0.08$

$P_t = 0.08 \times 20 = 1.6$

$\frac{A_{sc}}{bD} \times 100 = 1.6$

$A_{sc} = \frac{1.6 \times 400 \times 600}{100}$

$A_{sc} = 3840 \text{ mm}^2$

Atleast 3 bars on each face (total 8 bars) are required for equal distribution on all 4-faces and to satisfy maximum spacing criteria along periphery. (300 mm)

Providing 4-32ϕ + 4-16ϕ

Step 6: Transverse reinforcement

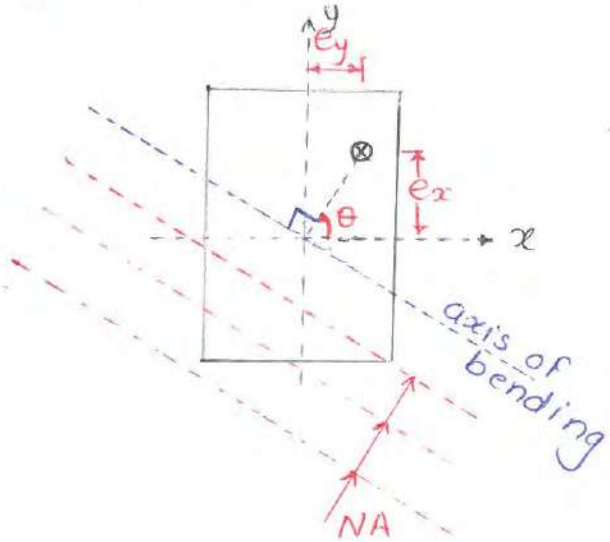
$$\phi \geq \text{Maximum} \begin{cases} \bullet\ \phi_{long.max}/4 = \frac{32}{4} = 8mm \\ \bullet\ 6mm \end{cases}$$

$$s \leq \text{Minimum} \begin{cases} \bullet\ \text{Least lateral dimension} = 400mm \\ \bullet\ 16\,\phi_{long.min} = 16 \times 16 = 256\ mm \\ \bullet\ 300mm \end{cases}$$

Providing 8ϕ @ 250 mm c/c

10.10 Short Column subjected to axial load with Biaxial Moment:

P_u, M_{ux}, M_{uy}.



- Axis of bending is perpendicular to line joining CG and point of application of load
- All NA are inclined and parallel to axis of bending
- Slope of axis of bending $= \theta + \pi/2$

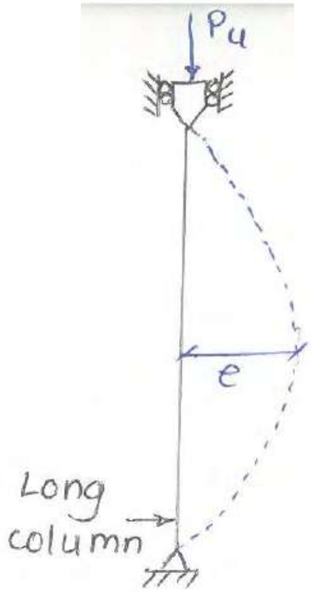
Where, $\tan\theta = \frac{e_x}{e_y}$

10.11 Long / Slender Column:

Long columns are also designed as short column with some additional moment to account for slenderness of column.

Due to slenderness, member may be subjected to additional moment $P_u \cdot e$.

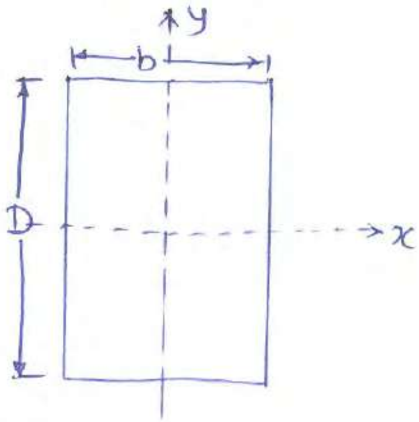
IS 456 provides standard expression for this additional moment



$$M_{ax} = \frac{P_u D}{2000}\left(\frac{L_{eff.x}}{D}\right)^2$$

$$M_{ay} = \frac{P_u b}{2000}\left(\frac{L_{eff.y}}{b}\right)^2$$

Now, column is designed as short column subjected to P_u, M_{ax}, and M_{ay}.



Ex. What is the minimum size of a square column for being axially loaded?

⇒ For being axially loaded,

$$(e_{min})_{min} \leq 0.05\,D$$

$$20 \leq 0.05D$$

$$\Rightarrow D \geqslant 400\text{mm}.$$

..... Chapter 10 Ends Here...