	SRI VIDYA COLLEGE OF ENGINEERING & TECHNOLOGY **VIRUDHUNAGAR**	

CE6505 DESIGN OF REINFORCED CONCRETE ELEMENTS

UNIT- IV

LIMIT STATE DESIGN OF COLUMNS

QUESTIONS & ANSWERS

PART – A

1.Briefly explain the classification of columns.

Columns can be classified based on

1.Type of reinforced as

- Tied columns
- Spiral columns
- Composite columns

2.Type of loading

- Axially loaded columns
- Columns with uniaxial eccentricity
- columns with biaxial eccentricity

3. Slenderness ratio

- Short columns
- Slender or long columns

2.Briefly explain uniaxial and biaxial eccentricity.

In uniaxial eccentricity the load acts eccentric to one axis but lies on the other. These are generally encountered in case of rigid connections to beams from one side only such as edge columns. In biaxial eccentricity the load acts eccentric to both axis

3. What is the importance of slenderness ratio in columns?

IS 456-2000 code clause 25.1.2 classifies a rectangular compression member as short. When both slenderness ration's Lex/D and Lex/b are less than 12.If any of these value are more than 12, then it is termed as slender or long column.

4. What is the minimum eccentricity to be adopted while designing columns?

All columns should be designed for minimum eccentricity which (Clause 25.4) may arise due to imperfection in construction and inaccuracy in loading given by the relation,

e_{min} = (L/500+ D/30)

but not less than 20mm

Where L = Unsupported length

D = Lateral dimension in the plane of bar

5. What are the assumptions made in the design of short columns?

The main assumptions made in the limit state design of columns are

i The maximum compression strain in concrete in axial compression is 0.002.

ii Plane sections remain plane in compression

iii The design stress strain curve of steel compression is taken as the same in tension

6.Write the expression for the ultimate loade bearing capacity of a compression

$Pu = 0.4f_{ck} .f_y+(0.6f_y – 0.4f_{ck})A_{sc}$

Where

Pu – Axial ultimate load on member

Fck – Characteristic compressive strength of concrete

Ac – Area of concrete

fy- Characteristic strength of compression reinforcement.

Asc – Area of longitudinal reinforcement.

7. What are the points to be considered while designing longitudinal reinforcement for columns.

i Minimum diameter of bars is 12mm

ii Minimum area of steel for longitudinal reinforcement = 0.8% of area of concrete

iii Maximum area of steel for longitudinal reinforcement = 0.6% of area of concrete

iv Minimum number of bars 9longitudinal) in rectangular column shall be 4 and 6 in circular columns

8. What are the factors to be considered while selecting pitch and diameter of lateral ties for columns?

Pitch of the transverse reinforcement should be least of the following distance

i The least lateral dimension of the compression member

ii 16 times the smallest diameter of the longitudinal reinforcement bar to be tied

iii 48 times the diameter of the traverse reinforcement

Diameter of the ties shall not be less than ¼ of the diameter of the largest bar and in no case less than 5m

9. What are the factors to be considered while selecting pitch and diameter of helical reinforcement for columns?

Pitch : Helical reinforcement shall be of regular formation with the turns of the helix spaced evenly and its ends shall be anchored properly by providing one and a half extra turns of the spiral bar.

Where an increased load on the column on the strength of the helical reinforcement is allowed for the pitch of the helical turs shall be

i Not more than 75mm

ii Not more than $1/6^{th}$ of the core diameter of column

iii Not less than 25mm

iv Not less than 3 times the diameter of steel bar forming the helix.

Diameter The diameter of helix shall not be less than $1/4^{th}$ of diameter of largest bar and in case be less than 5mm.

10. What are braced and unbraced columns?

In most of the cases, columns are also subjected to horizontal loads like wind, earthquake etc in addition to vertical loads. If lateral supports are provided at the ends of the columns, the lateral supports. Such columns an called braced columns. In other columns where lateral loads are to be resisted to be resisted by columns themselves are called unbraced columns.

UNIT 4

LIMIT STATE DESIGN OF COLUMNS

PROBLEM 1

Design an axially loaded tied column 400 mm × 400 mm pinned at both ends with an unsupported length of 3m to carry a factored load of 2300 kN. Use M20 grade concrete and Fe-415 grade steel. **(Anna Univ. Nov/Dec. 2007)**

Solution

(i) Given Data

Unsupported Length, $L_0 = 3$ m

Pin – jointed, *i.e.*, effectively held in position at both ends but not restrained against rotation . Hence effective length } $L_{ef} = L_0 = 3.0$ m

Size of column 400 mm × 400 mm

Factored load = 2300 kN; $f_c = 20$ N/mm^2 and $f_y = 415$ N/mm^2

(ii) Slenderness Ratio

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

Hence the column is designed as a short column

(iii) Minimum Eccentricity

$$e_{min} = \frac{L}{500} + \frac{D}{30} = \frac{3000}{500} + \frac{400}{30} = 19.33 < 20 \text{ mm}$$

also $0.05 \times D = 0.05 \times 400 = 20$ mm

Hence the eccentricity condition is satisfied

(iv) Main Reinforcement

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

$$2300 \times 10^3 = [\{ 0.4 \times 20 \times (400^2) \} + \{ (0.67 \times 415 - 0.4 \times 20) A_{sc} \}]$$

$$2300 \times 10^3 = 1280000 - 270.05 A_{sc}$$

$$A_{sc} = 3777 \text{ mm}^2$$

$$\text{Percentage steel, } p = \frac{3777}{400^2} \times 100 = 2.36\%$$

This is more than 0.8% and less than 6%. Hence area of main reinforcement is satisfactory. Provide 8 bars of 25 mm dia ($A_{sc} = 3925 \text{ mm}^2$) at a spacing of $\left(\frac{400-40-40-25}{2} = 147.5 \text{ mm}\right)$ 147.5 mm with a cover of 40 mm.

(iv) Lateral Steel

$$\text{Diameter of link} \nless \frac{25}{4} - 6 \text{ mm}$$

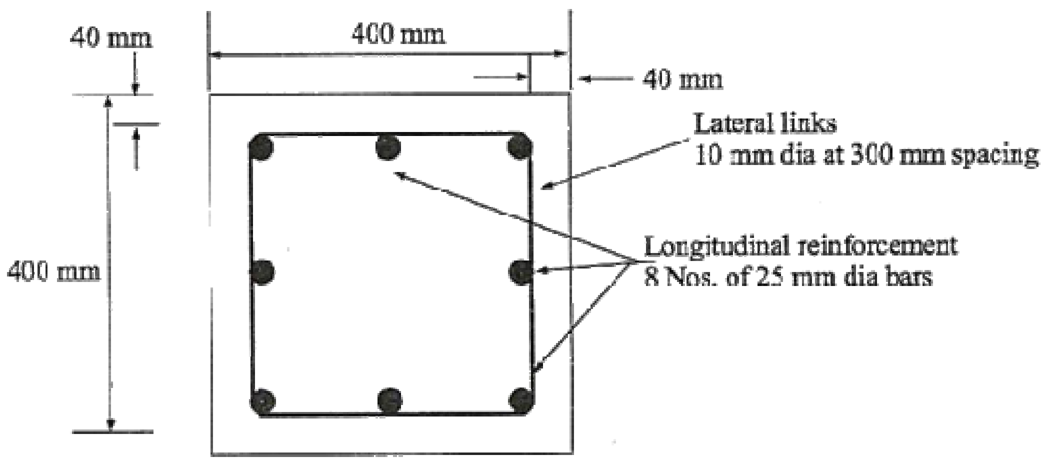
Adopt 10 mm dia. bars with spacing, at the least of

(a) dimension of column = 400 mm

(b) 16 times dia of longitudinal steel $= 16 \times 25 = 400$ mm

(c) 300 mm

Adopt 300 mm spacing.



PROBLEM 2

Design the required reinforcements in a column of 400 mm × 600 mm size subjected to a characteristic axial load of 2000 kN. The column has an unsupported length of 3 m and is braced against the sidesway in both dimensions. Use M20 concrete and Fe-415 steel.

(Anna Univ. Nov/Dec. 2009)

Solution

(i) Given Data

$$\text{Unsupported length, } L_0 = 3 \text{ m}$$

Braced against sidesway. Hence effective length, $L_{ef} = L_O = 3$ m

Size of the column	$= 400 \text{ mm} \times 600 \text{ mm}$
Characteristic axial load	$= 2000$ kN
Factored load	$= 1.5 \times 2000 = 3000$ kN

(ii) Slenderness Ratio

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

Hence the column is designed as a short column.

(iii) Minimum Eccentricity

$$e_{min} = \frac{L}{500} + \frac{D}{30} = \frac{3000}{500} + \frac{400}{30} = 19.33 < 20 \text{ mm}$$

also $0.05 \times D = 0.05 \times 400 = 20$ mm

Hence the eccentricity condition is satisfied.

(iv) Main Reinforcement

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

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

$$3000 \times 10^3 = 1920000 + 270.05 A_{sc}$$

$$A_{sc} = 3999 \text{ mm}^2$$

Percentage steel, $p = \frac{3999}{400 \times 600} \times 100 = 1.67\%$

This is more than 0.8% and less than 6%.

Hence area of main reinforcement is satisfactory.

Provide 8 bars of 25 mm dia and 2 bars of 16 mm diameter ($A_{sc} = 4320 \text{ mm}^2$)

(v) Lateral Steel

Diameter of link $\nless \frac{\text{Largest Dia}}{4}$, *i.e.*, $\frac{25}{4}$, *i.e.* 6 mm

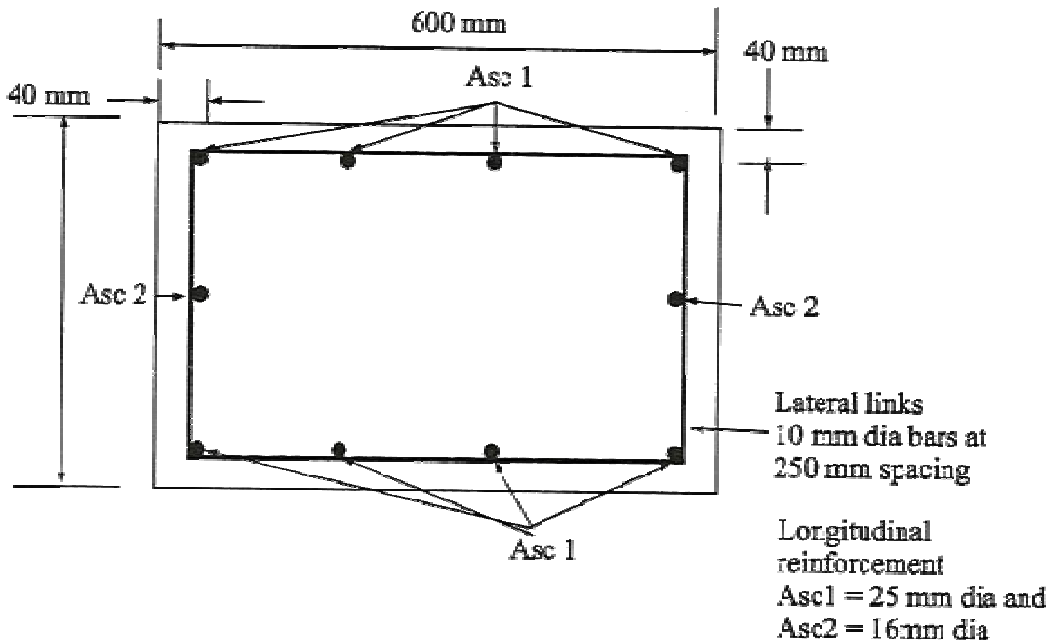
Adopt a diameter of link as 10 mm and spacing of the link not to exceed the least the following

(a) Least lateral dimension of column = 400 mm

(b) 16 times the diameter of the smallest longitudinal bar } $16 \times 16 = 256$ mm

(c) 300 mm

Adopt 250 mm spacing.



PROBLEM 3

Determine the cross-section and reinforcement for an axially loaded column wi following data

Factored load = 2000 kN

Concrete grade = M20

Characteristic strength of steel = 415 N/mm²

Unsupported length of column = 3 m

Solution

(i) Given Data

Effective length of column, $L_{ef} = 3$ m

Factored load $= 2000$ kN

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

(ii) Slenderness Ratio

Assuming the column as short circular column with $L_{ef} = L_0$

$$\frac{L_{ef}}{D} < 12$$

i.e., Assuming $D = 400$ mm

i.e., $\frac{L_{ef}}{D} = \frac{3000}{400} = 7.5 < 12$

Hence designed as a short column.

(iii) Minimum Eccentricity

$$e_{min} = \frac{L_0}{500} + \frac{D}{30} = \frac{3000}{500} + \frac{400}{30} = 19.33 \text{ mm} < 20 \text{ mm}$$

and $0.05D = 0.05 \times 400 = 20$ mm

Hence the eccentricity is within minimum limits.

(iii) Main Reinforcement

$$(P_u)_{helical} = 1.05\,(P_u)_{ties}$$

i.e., $(P_u)_{helical} = 1.05\,[0.4 f_{ck} A_g + (0.67\,A_y - 0.4 f_{ck})\,A_{sc}]$

$$\frac{2000 \times 10^3}{1.05} = \left[\left(0.4 \times 20 \times \frac{\pi \times 400^2}{4}\right) + (0.67 \times 415 - 0.4 \times 20)\,A_{sc}\right]$$

$$1905 \times 10^3 = 1004800 + 270.05\,A_{sc}$$

$$A_{sc} = \frac{9000200}{270.05} = 3334.5\ \text{mm}^2$$

Provide 8 No. of 25 mm dia bars ($A_{sc} = 3925.04\ \text{mm}^2$)

(v) Helical Reinforcement

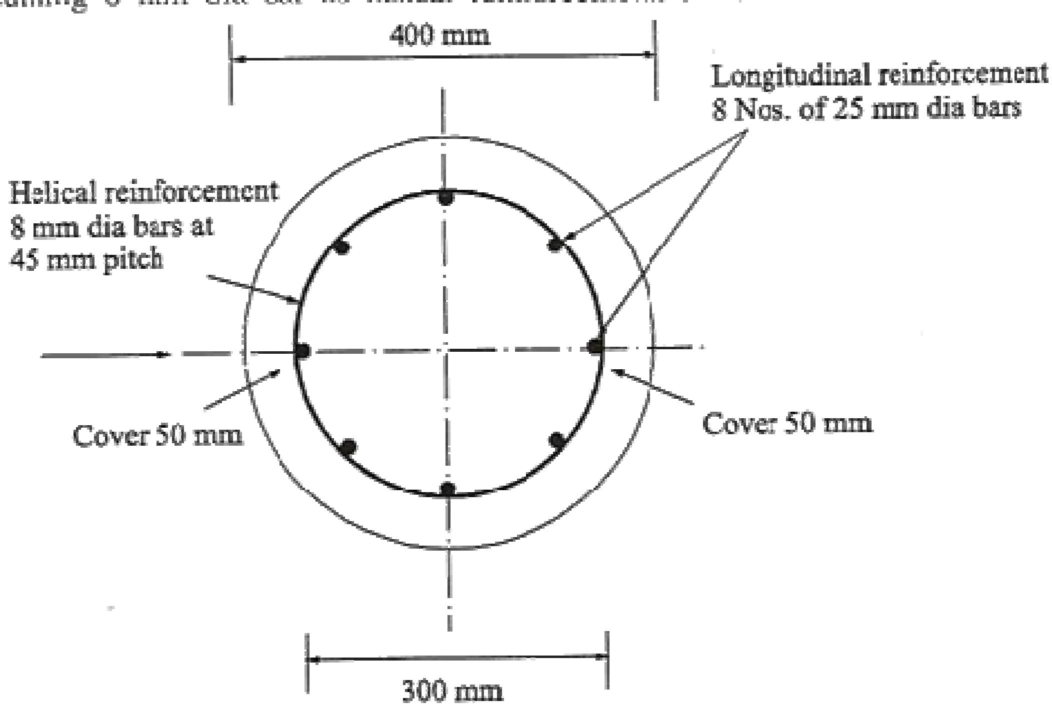
Adopting clear cover of 50 mm over spirals

Core diameter $= [400 - (2 \times 50)] = 300$ mm

Pitch is determined from the expression

$$s - \frac{11.1 \times a \times D_k \times f_y}{(D^2 - D_k^2)\,f_{ck}}$$

Assuming 8 mm dia bar as helical reinforcement, $a = 50.24\ \text{mm}^2$



$$s = \frac{11.1 \times 50.24 \times 300 \times 415}{(400^2 - 300^2)\, 20}$$

$$= 49.6 \text{ mm} \approx 45 \text{ mm}$$

As per code

(i) Spacing not more than 75 mm

(ii) Spacing not more than (core diameter ÷6) $\frac{300}{6} = 50$ mm

(iii) Spacing not less than 25 mm

(iv) Spacing to be greater than 3 times dia of helical reinforcement $= 3 \times 8 = 24$ mm

Hence a pitch of 45 mm is provided. The cross-section of the column is shown

PROBLEM 4

Design the reinforcements in a circular column of diameter 350 mm with helical reinforcement of 8 mm diameter to support a factored load of 1400 kN. The column has an unsupported length of 3.5 m and is braced against sidesway. Adopt M20 grade concrete and Fe-415 steel bars. **(Anna Univ. May/June 2012)**

Solution

(i) Given Data

Length of the column, $L_0 = 3.5$ m

Diameter, $D = 350$ mm

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

Factored load $= 1400$ kN

Effective length, $L_{ef} = L_0 = 3.5$ m

(ii) Slenderness Ratio

$$\frac{L_{ef}}{D} = \frac{3500}{350} = 10 < 12$$

Hence the column is designed as a short column.

(iii) Minimum Eccentricity

$$e_{min} = \frac{L}{500} + \frac{D}{30} = \frac{3500}{500} + \frac{350}{30} = 18.67 \text{ mm} < 20 \text{ mm}$$

and also $\quad 0.05\,D = 0.05 \times 350 = 17.5 < 20$ mm

Hence eccentricity condition is satisfied.

(iv) Main Reinforcement

$$(P_u)_{\text{helical}} = 1.05\,(P_u)_{\text{ties}}$$

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

$$1400 \times 10^3 = 1.05\left[\frac{0.4 \times 20 \times \pi \times 350^2}{4} + (0.67 \times 415 - 0.4 \times 20)\,A_{sc}\right]$$

$$1333.3 \times 10^3 = 769300 + 270.05\,A_{sc}$$

$$A_{sc} = 2088.5 \text{ mm}^2$$

$$p = \frac{2088.5}{\pi \times (350)^2/4} \times 100 = 2.17\%$$

Hence the requirement of main reinforcement is satisfactory as it is more than 0.8% and less than 6%

Provide 8 bars of 20 mm diameter ($A_{sc} = 25/2$ mm^2)

Helical reinforcement is provided as 8 mm dia bars.

Let cover be 50 mm and $a = \dfrac{\pi \times 8^2}{4} = 50.24$ mm^2

Spacing, $s = \dfrac{11.1\,a\,D_k f_y}{(D^2 - D_k^2) f_{ck}}$

$$\frac{11.1 \times 50.24 \times 250 \times 415}{(350^2 - 250^2) \times 20} = 48.2 \text{ mm}$$

Spacing should comply with the following specifications.

(i) < 75 mm

(ii) $< \dfrac{\text{core diameter}}{6} = \dfrac{250}{6} = -\,41.67$ mm

(iii) > 25 mm

(iv) $> 3 \times$ dia of helical reinforcement $= 3 \times 8 = 24$ m.

Adopt 40 mm spacing

PROBLEM 5

A column of size 300 mm × 400 mm has effective length of 3.6 m and is subjected to a factored load of 1100 kN and a factored moment of 150 kNm about the major axis. Design the column using M25 concrete and Fe-415 steel. Adopt limit state method.

(Anna Univ. Nov/Dec. 2010)

Solution

(i) Given Data

Factored load = 1100 kN ; $f_{ck} = 25\ N/mm^2$

Factored moment about major axis = 150 kN.m ; $f_y = 415\ N/mm^2$

Effective length = 3.6 m Size of column : 300 mm × 400 mm

(ii) Slenderness Ratio

$$\frac{L_{ef}}{D} = \frac{3600}{400} = 9.0 < 12$$

Hence design as short column

(iii) Eccentricity

$$e_{min} = \frac{L}{500} + \frac{D}{30} = \frac{3000}{500} + \frac{400}{30} = 19.3\ mm < 20\ mm \qquad \text{(assuming } L_0 = 3.0\ m)$$

Actual eccentricity, $e = \frac{M}{P} = \frac{150 \times 10^6}{1100 \times 10^3} = 136.4\ mm > 20\ mm$

Hence to be designed for moment and compression.

(iv) Non-dimensional Parameters

$$\frac{P_u}{f_{ck}\, bD} = \frac{1100 \times 10^3}{25 \times 300 \times 400} = 0.37$$

$$\frac{M_u}{f_{ck}\, bD^2} = \frac{150 \times 10^6}{25 \times 300 \times 400^2} = 0.125$$

Assuming $\frac{d'}{D} = 0.10$; $d' = 0.10 \times 400 = 40\ mm$

(v) Steel Requirement

(a) Main Bars

From Chart 32 of SP16 (Fig.8.13) for $\frac{P_u}{f_{ck}\,bd} = 0.37$

and $\frac{M_u}{f_{ck}\,bD^2} = 0.125$, $\frac{p}{f_{ck}}$ is read as 0.085

i.e., $p = 0.085 \times f_{ck} = 0.085 \times 25 = 2.13\%$

$$A_{sc} = \frac{2.13 \times 300 \times 400}{100} = 2556 \text{ mm}^2$$

Provide 6 bars of 25 mm dia ($A_{sk} = 2943.75 \text{ mm}^2$)

Spacing $= \frac{300 - 2 \times 40}{2} = 110$ mm

(b) Lateral Links

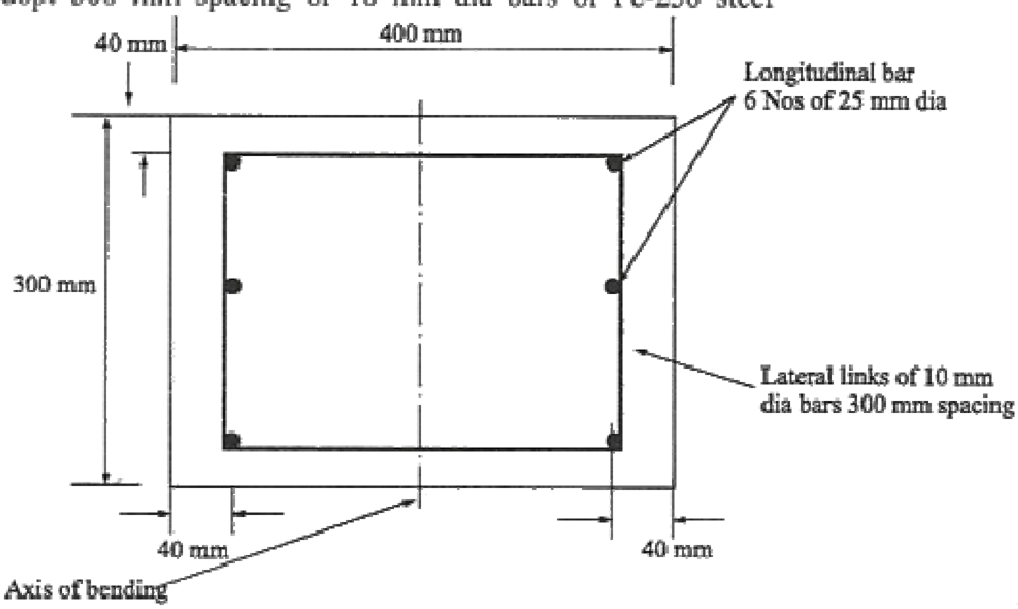
Use 10 mm dia bars. Spacing should be least of

(i) dimension of the column 300 mm / 400 mm

(ii) 16 times the diameter of longitudinal steel, *i.e.*, $16 \times 25 = 400$ mm

(iii) 300 mm

Adopt 300 mm spacing of 10 mm dia bars of Fe-250 steel



PROBLEM 6

Design the reinforcement required for a circular column of 450 mm dia subjected to a factored load of 1000 kN and a factored moment of 100 kN.m M20 grade concrete and Fe-415 steel were used. Assume d′/D = 0.10.

Solution

(i) Given Data

$$D = 450 \text{ mm}; \quad f_{ck} = 20 \text{ N/mm}^2$$

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

Factored load, $P_u = 1000$ kN

Factored moment, $M_u = 100$ kN.m

(ii) Non-dimensional Parameters

$$\frac{P_u}{f_{ck}\,bD} = \frac{1000 \times 10^3}{20 \times 450 \times 450} = 0.246$$

$$\frac{M_u}{f_{ck}\,bD^2} = \frac{100 \times 10^6}{20 \times 450 \times 450^2} = 0.055$$

(iii) Reinforcement

(a) Main

From Chart 56 of SP16, for $\frac{P_u}{f_{ck}\,bd} = 0.246$ and

$$\frac{M_u}{f_{ck}\,bD^2} = 0.055, \frac{P}{f_{ck}} \text{ is read as } 0.05$$

$$\frac{p}{f_{ck}} = 0.05$$

$$\therefore \quad p = 0.0 \times 20 = 1.0$$

$$A_{sc} = \frac{p\,\pi D^2}{100 \times 4} = \frac{1.0 \times \pi \times 450^2}{100 \times 4} = 1589.6 \text{ mm}^2$$

Provide 8 bars of 16 mm diameter ($A_{sc} = 1607.7 \text{ mm}^2$)

(b) Lateral

$$\text{Tie diameter } \frac{16}{4} = 4 \nless 6 \text{ mm}$$

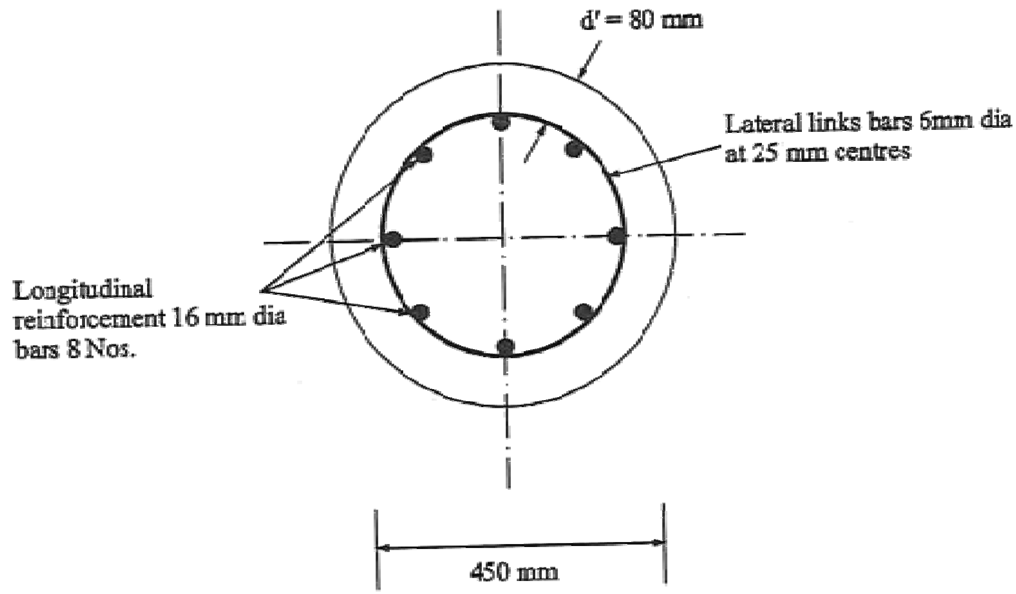
Provide 6 mm dia. ties

Spacing of ties $\nless$ 400 mm

$$16 \times 16 = 256 \text{ mm}$$

$$48 \times 6 = 288 \text{ mm}$$

Provide 6 mm dia. ties at 250 mm centres.



PROBLEM 7

A short column located at the corner of a multistoried building is subjected to an axial factored load of 2000 kN together with factored moments of 75 kN.m and 60 kN.m acting in perpendicular planes. The size of the column is 450 mm × 450 mm. Design suitable reinforcements in the column section. Adopt M20 grade concrete and Fe-415 grade steel.

(Anna Univ. April/May 2008)

Solution

(i) Given Data

$b = 450$ mm ; $f_{ck} = 20$ N/mm^2

$D = 450$ mm ; $f_y = 415$ N/mm^2

$P_u = 2000$ kN

$M_{ux} = 75$ kN.mm ; $M_{uy} = 60$ kN.m

Assume $\frac{d'}{D} = 0.10$

(ii) Equivalent Moment

Reinforcement in the section is designed for the axial compressive load P_u and the equivalent moment and finally reduced for safety.

$$M_u = 1.15\sqrt{M_{ux}^2 + M_{uy}^2}$$

$$= 1.15\sqrt{75^2 + 60^2}$$

$$= 110.45 \text{ kN.m}$$

(iii) Non-dimensional Parameters

$$\left(\frac{P_u}{f_{ck}\,bD}\right) = \left(\frac{2000 \times 10^3}{20 \times 450 \times 450}\right) = 0.494$$

$$\left(\frac{M_u}{f_{ck}\,bD^2}\right) = \left(\frac{110.45 \times 10^6}{20 \times 450 \times 450^2}\right) = 0.061$$

(iv) Reinforcement

Since the column is under biaxial bending, equivalent reinforcement should be provided on all four sides. Hence using

Chart 44 of SP = 16 (for $f_y = 415\ N/mm^2$ and $d'/D = 0.10$) for $\frac{P_u}{f_{ck}\, bD} = 0.494$ and $\frac{M_u}{f_{ck}\, bD^2} = 0.061$ the $\frac{p}{f_{ck}}$ is read as 0.065

$$\therefore \quad p = 0.065\, f_{ck} = 0.065 \times 20 = 1.3\%$$

$$\therefore \quad A_{sc} = \frac{p\, bD}{100} = \frac{1.3 \times 450 \times 450}{100} = 2632.5\ mm^2$$

Provide 4 bars of 25 mm diameter and 4 bars of 16 mm diameter ($A_{sc} = 2766\ mm^2$) distributed equally on all faces with 4 bars on each face

Now $p = \frac{100 \times 2766}{450 \times 450} = 1.37\%$

$$\therefore \quad \frac{p}{f_{ck}} = \frac{1.37}{20} = 0.068$$

Again using Chart 44 of SP-16, for $\frac{p}{f_{ck}} = 0.068$ and $\frac{P_u}{f_{ck}\, bD} = 0.494$, the value of $M_{ux1}/f_{ck}\, bD^2$ is found as 0.065

$$\therefore \quad M_{ux1} = (0.065 \times 20 \times 450 \times 450^2) \times 10^{-6} = 118.5\ kN.m$$

Because of symmetry

$$M_{ux1} = M_{uy1} = 118.5\ kN.m$$

$$P_{uz} = [0.45\, f_{ck} A_c + 0.75\, f_y A_{sc}]$$

$$= [0.45 \times 20\, (450^2 - 1708) + 0.75 \times 415 \times 1708] \times 10^{-3}$$

$$= 2323.4\ kN$$

$$\therefore \quad \left(\frac{P_u}{P_{uz}}\right) = \frac{2000}{2323.4} = 0.86$$

From Fig.8.18 for $\frac{P_u}{P_{uz}} = 0.86$, α_n is read as 2.0

(iv) *Check for Safety Under Biaxial Bending*

$$\left[\left(\frac{M_{ux}}{M_{ux1}}\right)^{\alpha_n} + \left(\frac{M_{uy}}{M_{y1}}\right)^{\alpha_n}\right] \leq 1$$

$$\left[\left(\frac{75}{118.5}\right)^2 + \left(\frac{60}{118.5}\right)^2\right] = 0.401 + 0.226$$

$$= 0.657 \leq 1$$

Hence the section is safe against biaxial bending.