COLUMNS

1- Definition:

Columns are vertical compression members which carry primarily axial compression load; the axial load may be associated with bending moments in one or two directions, as shown in Fig. 1a . They transmit loads from the upper floors to the lower levels and then to the soil through the foundations . Since columns are compression elements, failure of one column in a critical location can cause progressive collapse of adjoining floors and might lead to total collapse of the entire structure.

Structural column failure is of major significance in terms of economic as well as human loss.

Thus, extreme care needs to be taken in column design, with higher reserve strength than in the case of beams and other horizontal structural elements, particularly since compression failure provides little visual warning.

As will be seen in subsequent sections, the Egyptian code requires a considerably higher strength reduction factor (γ) in the design of compression members than other members subjected to flexure, shear and torsion.

The Egyptian code defines columns as :

An element used primarily to support axial loads with a height at least five time the smaller cross-sectional dimension (i.e. $h \geq 5b$) and the greater cross-sectional dimension does not exceed five times its smaller dimension (i.e. $t \leq 5b$) , as shown in Fig. 1b .

Reinforced concrete short columns do not have a tendency to buckle. Special consideration is necessary for slender (or long) columns, for which additional bending effects become significant.

2- Types of concrete columns

Columns can be classified on the basis of :

- Form and arrangement of reinforcement.
- Position of the load on the cross-section.
- The length of the column in relation to its lateral dimensions.

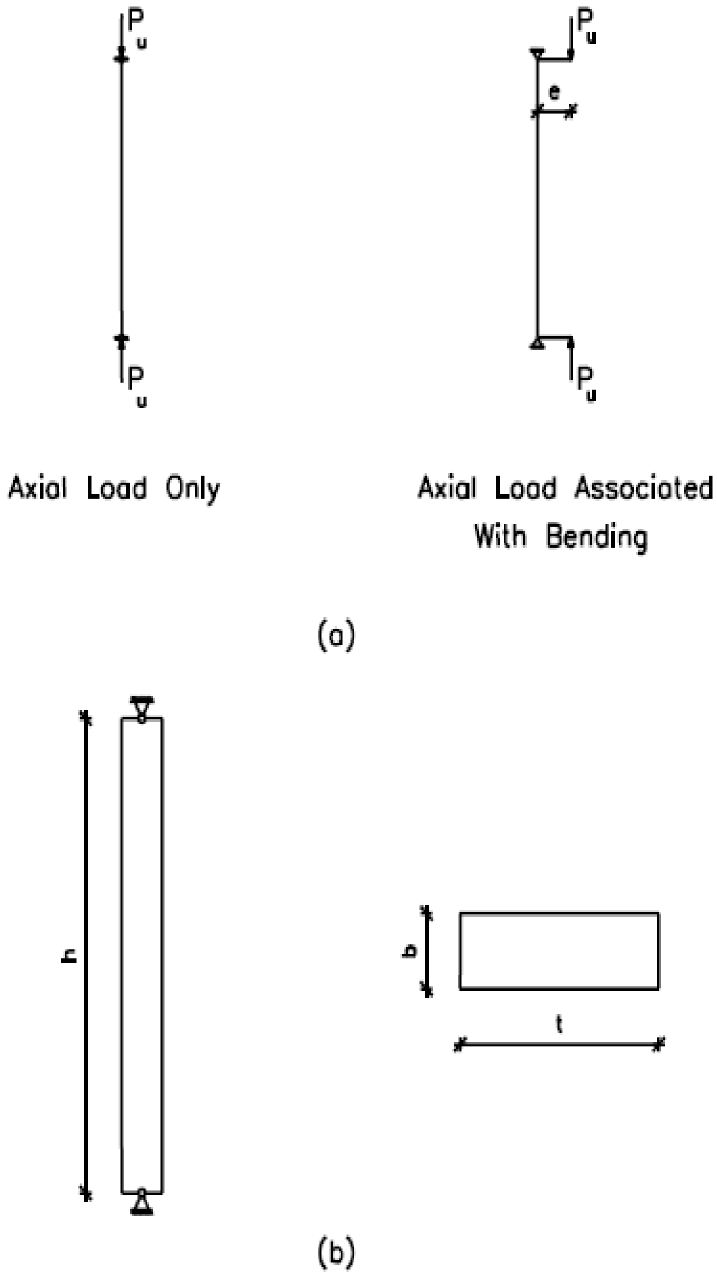


Fig. 1 Column Definition

i- Based on the form and arrangement of the reinforcement:

a) A rectangular , square or circular columns reinforced with longitudinal bars and lateral ties , Fig. 2a. At the ultimate load the concrete fails by crushing and shearing outward along inclined planes, and the longitudinal steel buckle outward between ties ,as shown, in Fig . 2b .

b) A circular columns reinforced with longitudinal reinforcement and spiral reinforcement, Fig 2c .The longitudinal steel and the concrete within the core are prevented from outward failure by the spiral. The outer shell concrete spells off when the load Pu is reached, as shown in Fig. 3 .

c) A composite columns where steel structural shapes are encased in concrete as shown in Fig. 2d .

d) A concrete-filled pipe columns is a steel shell filled with concrete as shown in Fig. 2e.

Tied columns are the most commonly used because of the lower construction cost.

Spiral columns are also used where increased ductility is needed, such as in earthquake zones. The ability of the spiral column to sustain the maximum load at excessive deformations prevents the complete collapse of the structure before total redistribution of moments and stresses is complete .The large increase in ductility (toughness) due to the effect of spiral confinement are shown in Fig. 3 .

Composite columns are only economical with relatively heavy loads .

Pipe columns are suitable in areas where minimum column dimension are preferable and loads are relatively light .

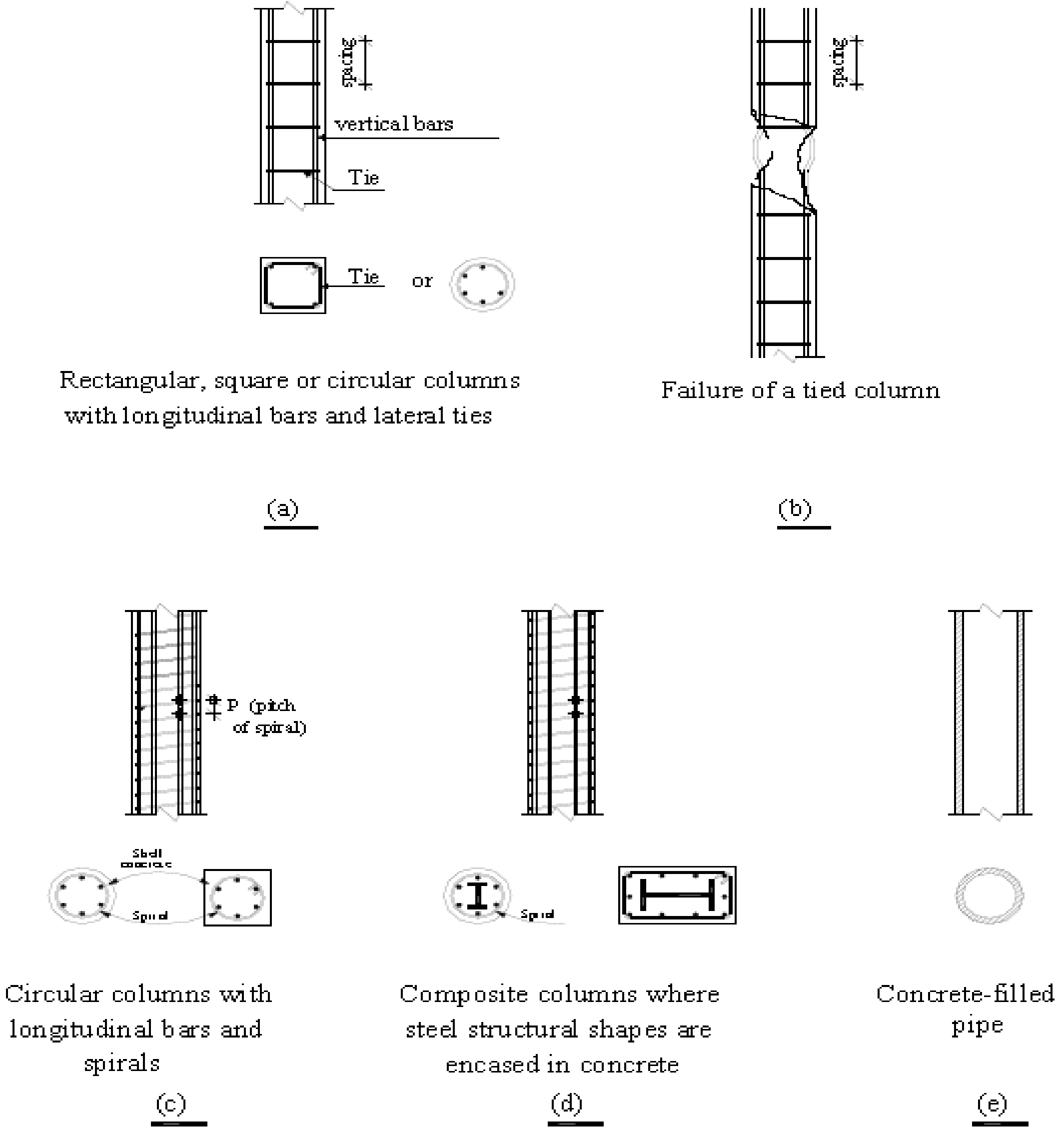


Fig. 2 Types of column based on form and arrangement of reinforcement

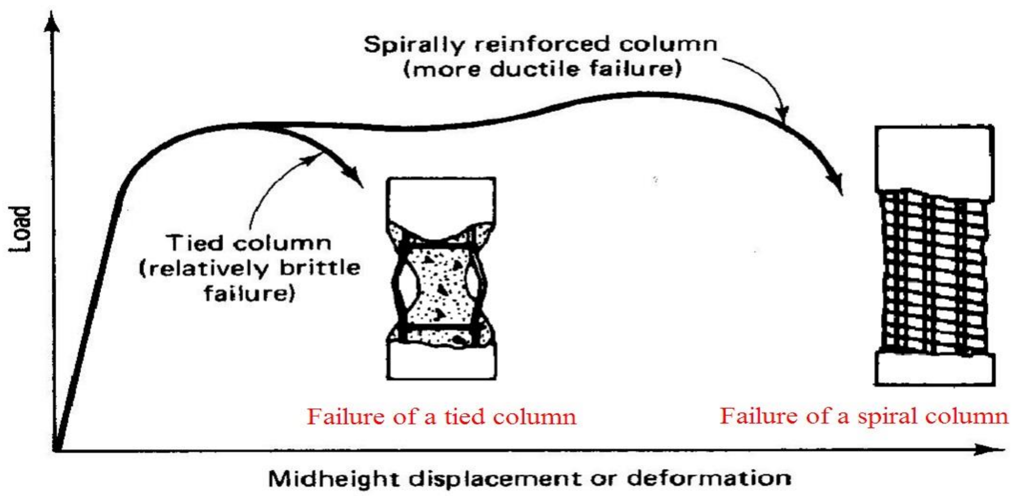


Fig. 3, comparison of load-deflection behavior between tide and spiral column

ii- Based on the position of the load on the cross-section :

a) Concentrically loaded columns carry axial load only with no bending moment (Fig. 4a) , such as in case of interior column (column c1 , Fig. 4d) .

b) Eccentrically loaded columns(Fig. 4b) are subjected to bending moment in addition to the axial force, such as in case of exterior column (column c2 , Fig .4d).

c) Biaxially loaded columns, when bending moment occurs about both, x and y axes (Fig. 4c) , such as in case of corner column (column c3, Fig. 4d) .

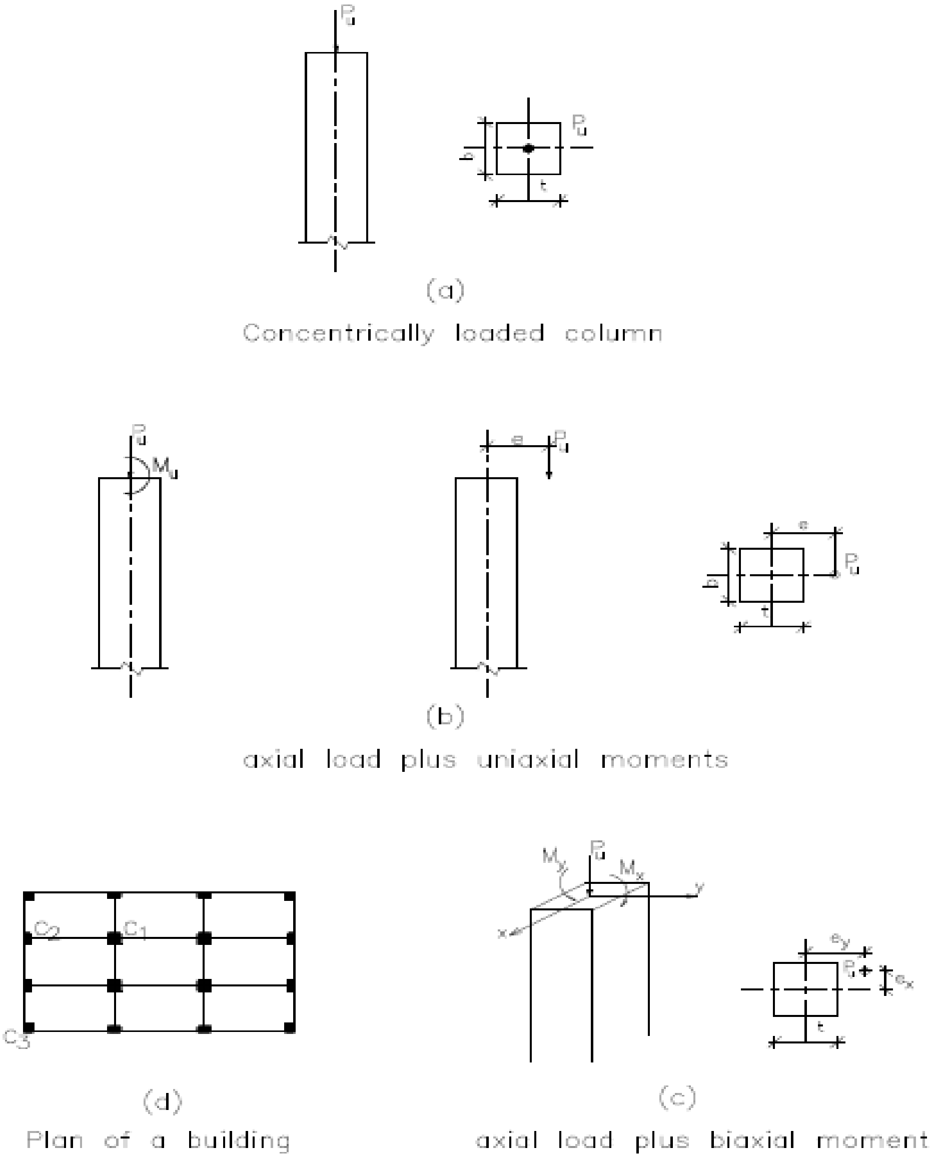


Fig.4 Types of columns based on the position of the load on the cross-section

iii- Based on the type of failure :

Failure of columns could occur as a result of material failure by initial yielding of the steel at the tension face or initial crushing of the concrete at the compression face or by loss of lateral structural stability (buckling).

a) If column fails due to material failure, it is classified as a short column.

b) As the length of the column increases, the probability that failure will occur due to buckling also increases. Therefore, the transition from the short column (material failure) to the long column (failure due to buckling) is defined by the ratio of the effective length , (k Ho) , to the radius of gyration , (i) , (λi = kHo / i), in addition to the bracing conduction of the column.

The height (Ho) is the unsupported length of the column and k is a factor that depend on end conditions of the column and whether it is braced or unbraced, (kHo / i or He /i is called the slenderness ratio) .

3- Code requirements for column reinforcement

The Egyptian code- 2001 gives the following provisions:

a) Concrete dimensions :

1- Minimum dimensions of a column are 200 × 200 mm for rectangular section, and the column diameter shall not be less than 200 mm for circular section.

2- Minimum dimensions of column supporting flat slab are 300x300 mm.

b) Longitudinal reinforcement: contributes to resistance of axial force and bending moment as will be shown later . Art. 6.4.7. specifies that :

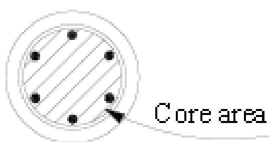
1- Minimum reinforcement:

1-1 **Tied column :**

Gross area required for the section. In a compression member which has a larger cross section than required , the percentage shall not be less than 0.6% of the chosen area of the section .

1-2 Spiral column:

The total longitudinal reinforcement shall not be less than 1 % of the gross area and 1.2 % of the core concrete area inside the spiral.



2- Maximum reinforcement :

The total percentage of the longitudinal reinforcement shall not exceed the following values : -

4% For interior column.

5% For edge column.

6% For corner column.

3 - Columns must have one longitudinal bar at each corner.

4 - Minimum diameter of longitudinal bars is 12 mm.

5 - The minimum number of bars shall be four bars in a rectangular column and six bars in a circular column.

6 - Clear distance between longitudinal bars shall not be less than the larger diameter of longitudinal bars or 1.5 of the nominal maximum size of concrete aggregate .

7- Maximum side length of column in which only corner bars are used is 300 mm, otherwise intermediate bars are placed at maximum spacing of 250 mm. These bars must be held by special hoops if the spacing between the untied bars and those tied exceeds 150 mm, as shown in Fig. 5 .

8 - Minimum length of splices for longitudinal bars is 35 times the bar diameter with minimum of 400 mm , as shown in Fig. 6 . unless minimum larger splice length is needed for special provisions .

c) Lateral reinforcement :

1. Maximum spacing between ties is the lesser of : 15 times the diameter of the smallest longitudinal bar, or the least dimension of column but not more than 200 mm.
2. To be effective in holding the longitudinal bars in place , the ties shall be so arranged that every corner and alternate longitudinal bar shall have lateral support provided by the corner of a tie having an included angle of not more than 135^{o} and steel bars shall not be of more than 150 mm clear distance on either side from such a laterally supported bar, as shown in Fig 5 .
3. - Minimum diameter of ties (stirrups) is ¼ the diameter of the larger longitudinal bar diameter but not less than 8 mm . The minimum volume of hoops (ties or stirrups) is 0.25 % of the volume of concrete .
4. - Hoops of columns as well as spirals are to be placed also within the depth of the beams (Fig . 6) .
5. - Maximum spacing between turns of spiral (pitch) is 80 mm and the minimum spacing between turns is 30 mm.
6. - Minimum diameter of spiral is 8mm.

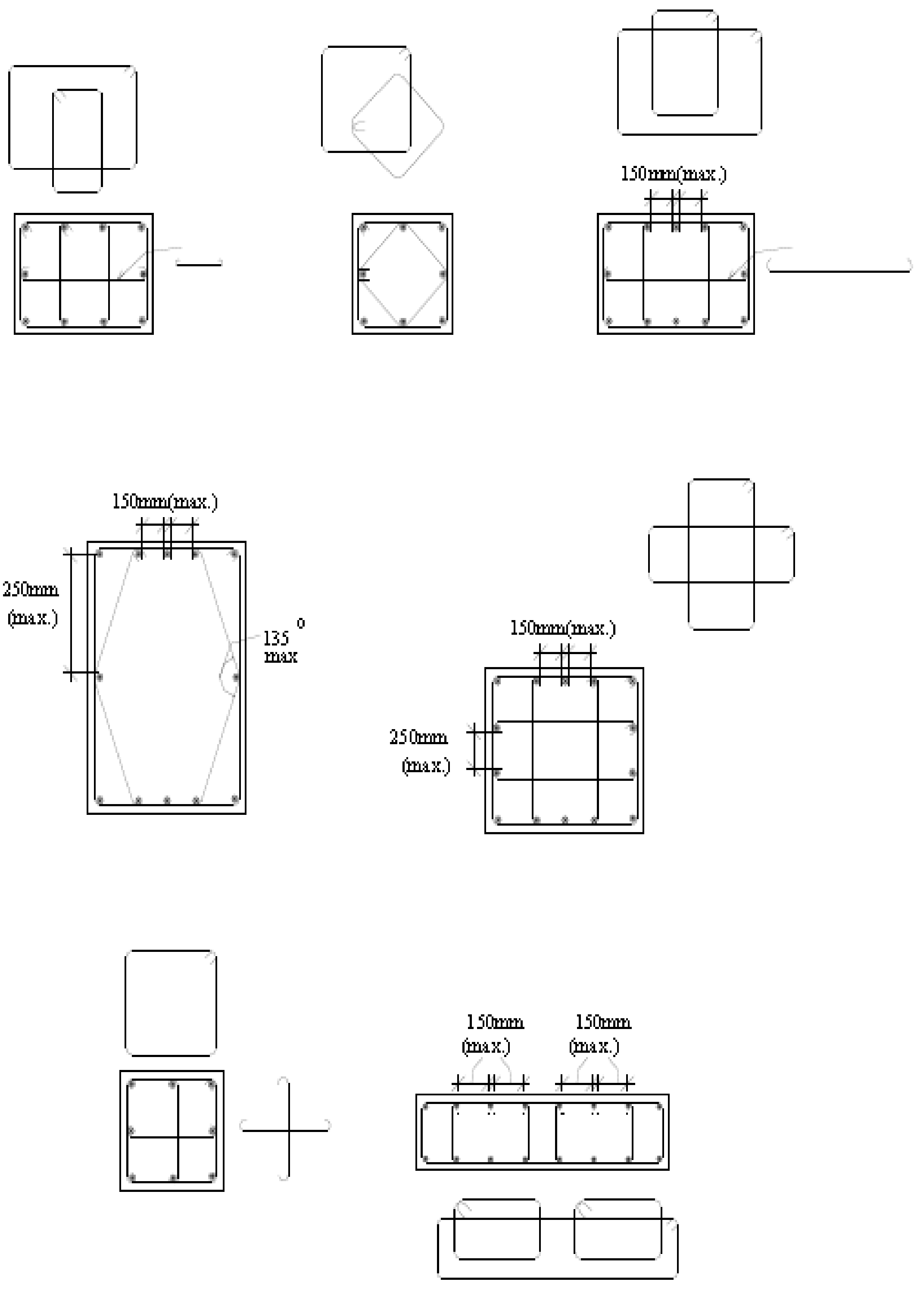
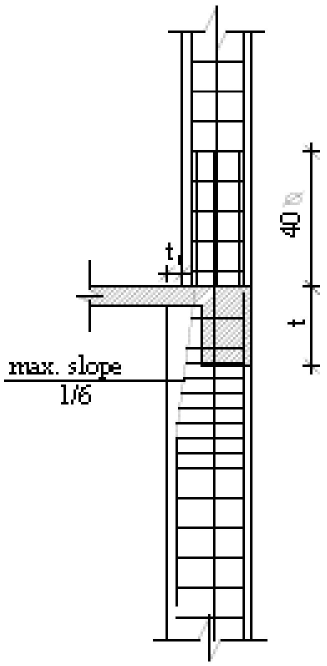
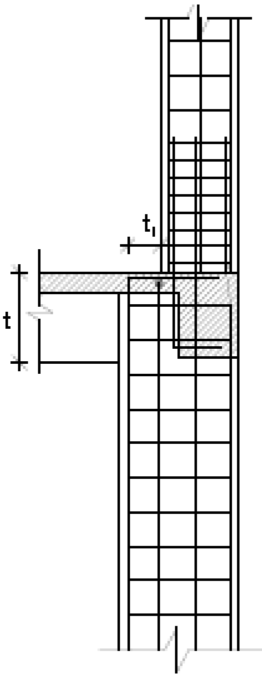


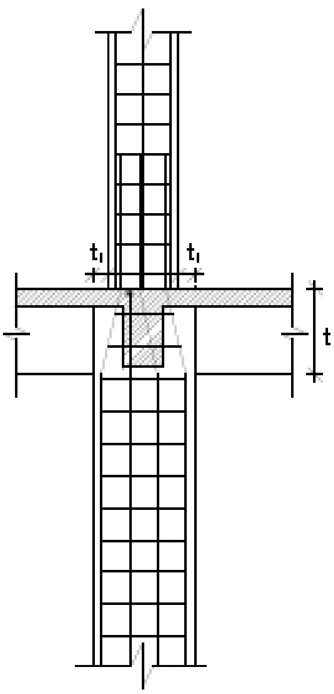
Fig.5 Standard column ties for tied rectangular columns



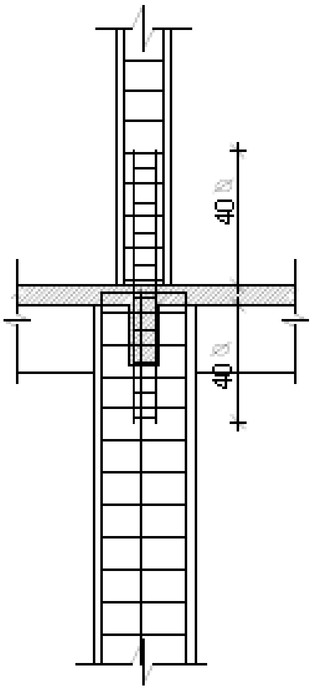
(a)
Slope ≤ 1:6
$t > 6t_1$



(b)
Slope > 1:6
$t < 6t_1$



(c)
Slope ≤ 1:6
$t > 6t_1$



(d)
Slope > 1:6

Fig.6b Details of column connection between floors

d- Minimum load eccentricity

It is highly improbable to attain zero eccentricity in actual structures. Eccentricities could easily develop because of factors such as slight inaccuracies in the layout of columns and unsymmetrical loading due to the difference in thickness of the slabs in adjacent spans or imperfections in the alignment : Hence the Egyptian code requires a minimum eccentricity estimated as the greater values of 5 % of the thickness of the column in the direction perpendicular to its axis of bending or 20 mm.

e- Design of Short Columns

The strength of columns is evaluated on the basis of the following principles:

1 - A linear strain distribution exists across the thickness of the column.

2 - There is no slippage between the concrete and steel (i.e. the strain in steel and in the adjoining concrete is the same).

3 - The maximum allowable concrete strain at failure = 0.002 mm/mm

4 - The tensile resistance of the concrete is neglected.

For Axially loaded column :

Consider a column of cross - sectional area Ac with width b and total depth t , reinforced with a total area of steel Asc on all faces of the column , as shown in Fig. 7 . The maximum axial load capacity of the column can be obtained by adding the contribution of the concrete, which is (A_c *$0.67f_{cu}/\gamma_c$) and the contribution of the steel, which is ($A_{sc} f_y/\gamma_s$) where Asc is total steel area = As + As' . Thus the axial load capacity (Pu) can be expressed as :

$$P_u = A_c \frac{0.67 \ f_{cu}}{\gamma_c} + A_{sc} \frac{f_y}{\gamma_s} \qquad (1)$$

Egyptian code - 2001 gives:

$$\gamma_c = 1.75 - 0.5 \frac{e}{t} \geq 1.5 \qquad \text{and} \qquad \gamma_s = 1.36 - 0.43 \frac{e}{t} \geq 1.15$$

where $e/t \geq 0.05$

It should be noted that the axial load causes uniform compression throughout the cross section .Consequently, at failure, the strain and stress will be uniform across the cross section , as shown in Fig .7 . Substituting by, $\gamma c = 1.75$ and $\gamma s = 1.36$. Eq. (1) becomes,

$Pu = 0.38 \ Ac \ fcu + 0.74 \ Asc \ f y$ (2)

A minimum eccentricity of load of (0.05 t) reduces the values of Pu by about 10% , thus, the maximum axial load capacity of columns can be taken as ,

$Pu = 0.35A_c f_{cu} + 0.67 \ A_{sc} f_y$ (3)

Where, Ac is the area of the concrete section, Asc is the area of the longitudinal reinforcement . Equation 3 is applicable to columns provided with lateral ties (stirrups) .

Similarly, the ultimate design load for columns provided by spiral reinforcement is given by the lesser value of the following :

$Pu = 0.35\ A_k\ f_{cu} + 0.67 A_{sc}\ f_y + 1.38\ V_{sp}\ f_{yp}$ (4)

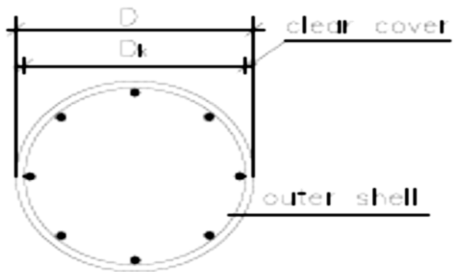
$Pu = 0.4\ A_c\ f_{cu} + 0.76\ Asc\ f y$ (5)

Where, $V_{sp} = \pi\ A_{sp}\ D_k / p$

$\mu sp = V_{sp}/A_k \geq \mu_{sp\ (min.)}$ and

$$\mu_{sp(min.)} = 0.36 \left(\frac{f_{cu}}{f_{yp}}\right)\left(\frac{A_c}{A_k} - 1\right) \quad (6)$$

A_k = area of core of spirally reinforced column measured to the outside diameter of spiral. $=\pi\ D_k^2 / 4$



A_c = gross area of section = $\pi\ D^2 / 4$

D_k = diameter of the cross-sectional core.

V_{sp} = volume of spiral reinforcement in one spiral's pitch (p).

f_{yp} = characteristic yield stress of spiral reinforcement .

p = Pitch of spiral (center to center spacing of the spiral reinforcement) .

μ_{sp} = volume of spiral reinforcement to total volume of core.

A_{sp} = cross sectional area of spiral reinforcement.

Equation 6 , based on evaluation of extensive test results , provides the minimum volume ratio for the spirals to contribute to the column strength by confining concrete inside the core, increasing its strength and strain capacity which are combined to produce a much more gradual failure as compared to failure of tied columns. In the case of tied columns or columns with a volume of spirals less than that given by Eq. (6) failure is rather abrupt and is manifested by a simultaneous crushing of the concrete spalling of the outer shell and buckling of the longitudinal bars . Columns with a spiral volume not less than that given by

Eq. (6) fail in a more gradual manner after spalling of the outer shell since the confining action of the spirals do not become significant before that stage, (Fig. 3) .

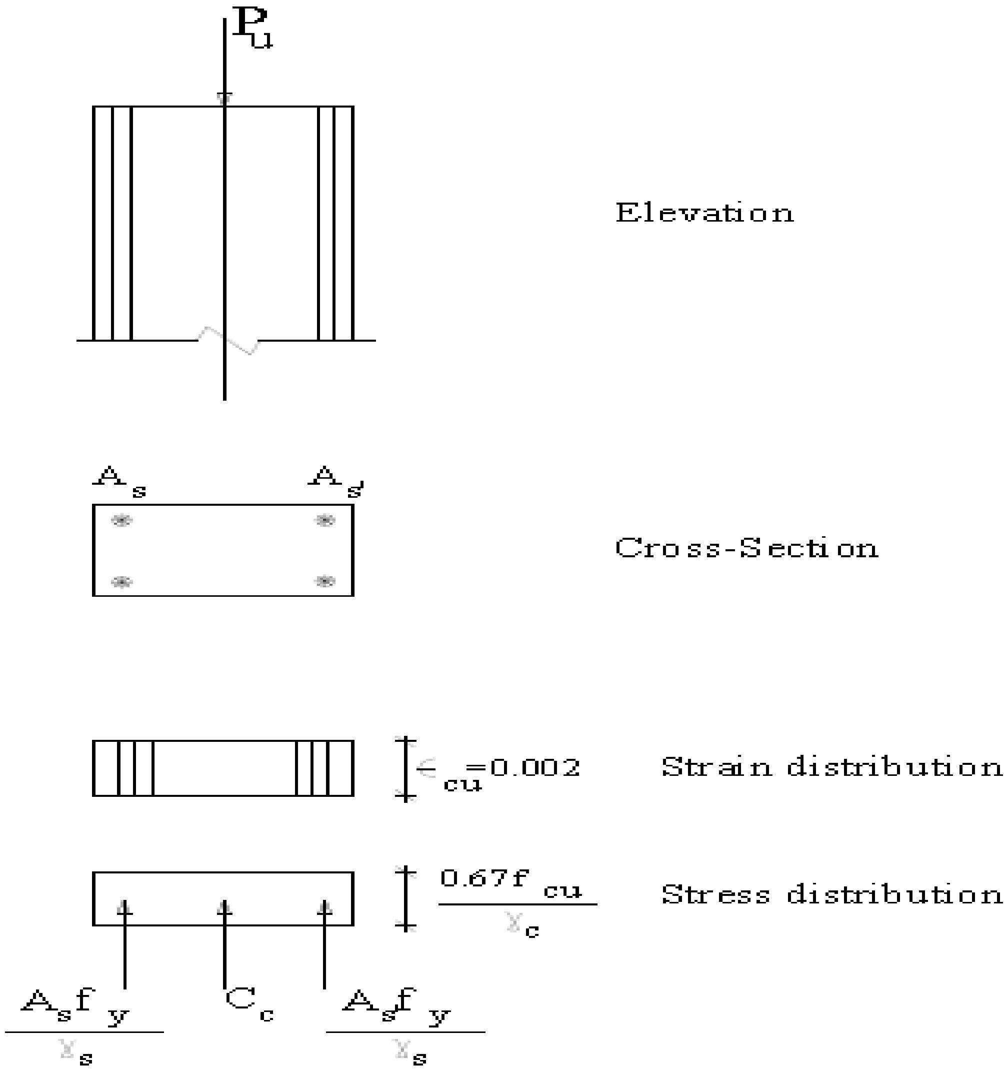


Fig.7 Axially loaded column

Design steps of short tied column

$$P_{U.L.} = 0.35\, A_c\, F_{cu} + 0.67\, A_s\, F_y$$

Ac & As unknown.

1. Assume steel ratio (μ) = (0.8-1)% ,
   As = (0.008 – 0.01) Ac
2. Get Ac = b x t
3. Get As
4. Get No. and diameter of the steel bars
5. Check stirrups

$$n \times A_{sp} \times primeter \geq 2.5 \times b \times t \quad (mm^3)$$

----- Ø -----

Number

- اقل عدد من الاسياخ فى العمود المستطيل هو ٤
- اقل عدد من الاسياخ فى العمود الدائرى هو ٦
- اسياخ الحديد توجد فى المحيط الخارجى فقط .
- اذا كان العمود مربع نختار عدد الاسياخ يقبل القسمة على ٤
- اكبر مسافة بين سيخين متتاليين = ٢٥سم
- يجب ان يكون عدد الاسيا خ زوجى و ان تكون الاسياخ متماثلة حول المحورين .

Diameter

- اقل قطر للسيخ = ١٢ مم
- اكبر قطر للسيخ =٢٥ مم
- ممكن استخدام قطرين مختلفين فى العمود بشرط ان يكون متتاليان فى الجدول كما ١٦ و ١٨ مم مثلا ان الاسياخ الاكبر توضع فى الاركان

Example 1 :

A short tied column is subjected to axial load only. The cross-sectional dimensions are 300 mm x 600 mm and is reinforced with 4 Φ 25 on each of the two faces as shown .

Calculate the maximum ultimate load can be carried .

Given : *fcu* = 25 Mpa , *f y* = 360 Mpa

Solution :

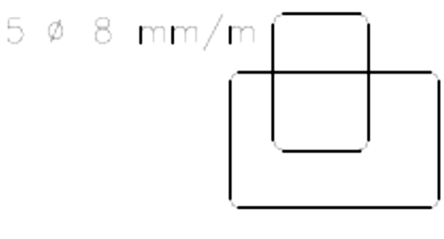
A_{sc} = 8 x 491.0 = 3928.0 mm2

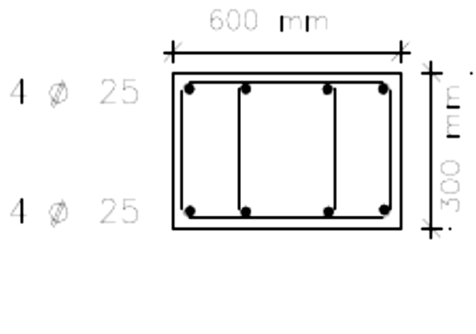
A_c= 300 x 600 = 180000 mm2

Using Eq . 3 yields

Pu = 0.35 (180000) (25) + 0.67 (3928.0) (360)

= 1575.0 + 947.4 = 2522.4 kN





Example 2 :

Design a short column subject to the given service load :

PD.L. = 1343 kN , PL.L. = 700 kN

fcu = 25 Mpa , *f y* = 360 Mpa.

Solution:

Longitudinal reinforcement :

Pu = 1.4 PD.L. + 1.6 PL.L. = 3000 kN , and

Pu = 0.35 Ac *fcu* + 0.67 Asc *f y*

3000 x1000 = 0.35 Ac (25) + 0.67 Asc (360)

assume μ = *Asc/Ac* = 1 %

300,0000 = Ac (0.35 x 25 + 0.67 x 1 / 100 x 360) = 11.16 Ac

∴ Ac = 268769 mm^2.

use b x t = 300 x 900 ∴ Asc = 300 ×900× 1 /100 = 2700 mm^2,

use (14 Φ 16)

Lateral ties :

Provide φ 8mm, spacing is the least of :

15 x Φ = 240 mm. or

b= 300 mm. or

200 mm.

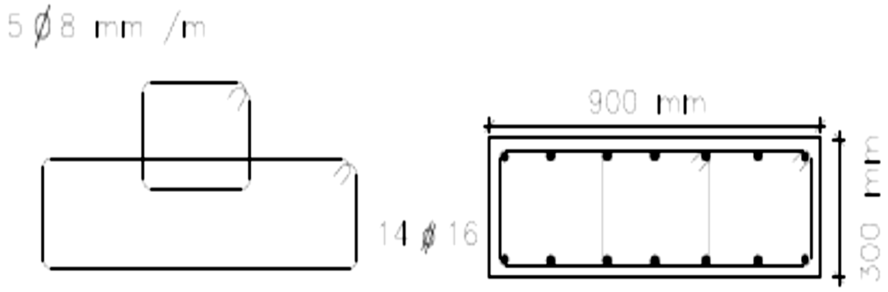
choose 5 φ 8 mm/m

Check

Minimum volume of stirrups = 0.25 ×900 × 300 × 1000/100 = 675000 mm^3.

Actual volume of stirrups = 50.2 × 2 ((250 + 850) + (250 + 300)) × 5

= 828300 mm3 > min. vol.



Example 3 :(from design of reinforced concrete structures book)

Design a tied column that is subjected to the following axial compression loads

P_{DL} = 1057 kN
P_{LL} = 400 kN

The material properties are as follows:

f_{cu} = 35 N/mm^2
f_y =400 N/mm^2

Solution

Step 1: Calculate column dimension

Calculate the ultimate load

$$P_u = 1.4\ P_{DL} + 1.6\ P_{LL} = 1.4 \times 1057 + 1.6 \times 400 = 2119.8\ kN$$

Assume A_{sc}= $0.01\ A_c$

$$P_u = A_c (0.35\ f_{cu} + 0.0067\ f_y\ )$$

$$2119.8 \times 1000 = A_c (0.35 \times 35 + 0.0067 \times 400\ )$$

Ac = 141982 mm^2

Assume column width b of 250 mm, then column thickness t equals

$$t = \frac{A_c}{b} = \frac{141982}{250} = 568\ mm$$

t= 600 mm

Step 2: Calculate reinforcement area

$$A_{sc} = 0.01\ A_c, required > 0.006\ A_c, chosen$$

$$A_{sc} = 0.01 \times 141982 = (1419\ mm^2) > 0.006\ (250 \times 600) \quad o.k.$$

Choose 8 Φ 16 (1608 mm^2)

Step 3: Calculate stirrups

Chose stirrup diameter of 8 mm (>16/4) and spacing of 200 mm <(16 x 15)

Choose 5 ϕ 8 /m'

Assume concrete cover of 25 mm from each side, the dimensions of the stirrups equal:

Stirrup A (200 x 550) Stirrup B (200 x 250)

The perimeter of the center line of the stirrups

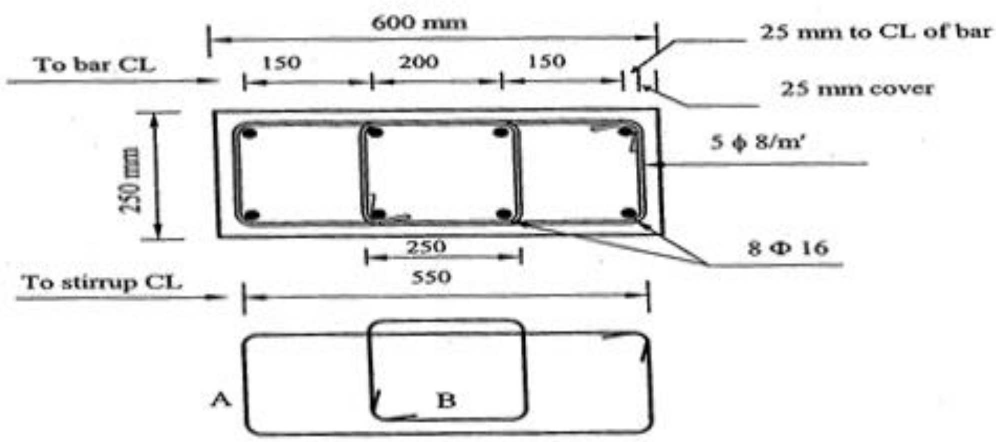
$$p = 2 \times (200 + 550) + 2 \times (200 + 250) = 2400\ mm$$

The volume of the stirrups in 1 meter equals

Noting that we have 5 stirrups per meter and A_{sp} for ϕ 8mm =50 mm^2

$$V_{s,min} = 2.5 \times 250 \times 600 = 375 \times 10^3\ mm^3$$

$$V_s = n \times A_{sp} \times p = 5 \times 50 \times 2400 = 600 \times 10^3 mm^3 > V_{s\,min} \ldots\ldots o.k$$



Example 4 :(from design of reinforced concrete structures book)

Calculate the maximum and the minimum loads that an interior column can carry according the following data:
Column cross section (250 mm x 800 mm)
f_{cu} = 30 N/mm^2
f_y =360 N/mm^2

Solution

Since the column dimensions, material properties are given, the only variable is the reinforcement area.

The maximum area steel for interior column is 4% thus A_{sc} equals

$$A_{sc,max} = \frac{4}{100} \times 250 \times 800 = 8000\ mm^2 \qquad \rightarrow (18\ \Phi\ 25)$$

$$P_u = 0.35\ f_{cu}\ A_c + 0.67\ f_y\ A_{sc}$$

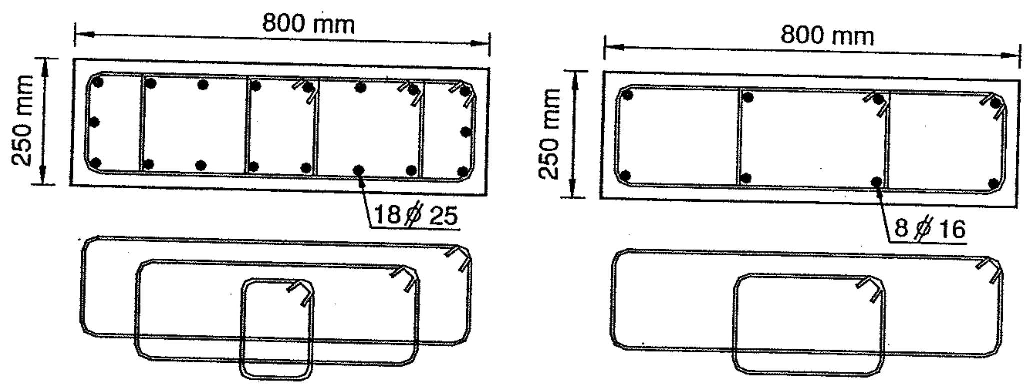
$$P_{u,max} = \frac{1}{1000}\{0.35 \times 30 \times 250 \times 800 + 0.67 \times 360 \times 8000\} = 4029.6\ kN$$

The minimum area of steel for a column is 0.8% of the required area

$$A_{sc,min} = \frac{0.8}{100} \times 250 \times 800 = 1600 mm^2 \qquad \rightarrow (8\ \Phi\ 16)$$

$$P_u = 0.35\ f_{cu}\ A_c + 0.67\ f_y\ A_{sc}$$

$$P_{u,min} = \frac{1}{1000}\{0.35 \times 30 \times 250 \times 800 + 0.67 \times 360 \times 1600\} = 2485.92\ kN$$



Column with maximum reinforcement   Column with minimum reinforcement

Design Steps

1. Assume $A_{sc}= 0.01\ A_c$
2. Solve the first equation to find A_c

   Calculate $P_u = 1.4 P_{DL} + 1.6 P_{LL}$

   $P_u = A_c (0.4\ f_{cu} + 0.0076\ f_y)$

3. Solve the second equation to get V_{sp}

   $P_u = 0.35 f_{cu}\ A_k + 0.67 f_y\ A_{sc} + 1.38 \times f_{yp}\ V_{sp}$

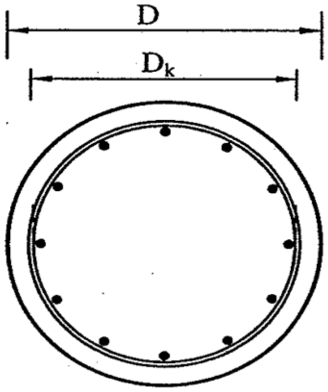
   if V_{sp} =-ve use $V_{sp,min}$

4. check $V_{sp,min}$

   $$V_{sp,\min} = 0.36\left(\frac{f_{cu}}{f_{yp}}\right)[A_c - A_k]$$

5. calculate the pitch *(p)* using

   $$p = \frac{\pi\ A_{sp}\ D_k}{V_{sp}}$$



if $p > 80$ mm use $p = 80$ mm

if $p < 30$ mm increase spiral area (A_{sp}) and recalculate p

Example 5 :

Design a circular column with spiral reinforcement subjected to the same loads as in example 2 . f_{yp} = 240 Mpa.

Solution :

Design of longitudinal reinforcement :

Pu = 0.4 *fc u* Ac + 0.76 Asc *f y*

$$assume\quad \mu = \frac{A_{sc}}{A_c} = 1\%$$

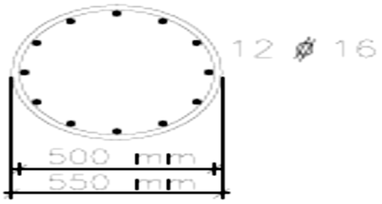
$$\therefore 300{,}0000 = A_c\left(0.4\times25 + 0.76\times\frac{1}{100}\times360\right)$$

$$\therefore A_c = \frac{300{,}0000}{12.736} = 235553\,mm^2$$

use D = 550 mm , D_k = 500 mm

$$A_{sc} = \frac{\pi(550)^2}{4} \times \frac{1}{100} = 2375.8 mm^2$$

use (12 Φ 16)



Design of spiral reinforcement :

$$P_u = 0.35 f_{cu} A_k + 0.67 A_{sc} f_y + 1.38 V_{sp} f_{yp}$$

$$A_k = \frac{\pi(500)^2}{4} = 196350 mm^2$$

$$f_{yp} = 240 Mpa, \phi = 8mm (mild\ steel)$$

$$\therefore 300,0000 = 0.35(25)(196350) + 0.67(2412)(360) + 1.38 V_{sp}(240)$$

$$\therefore V_{sp} = 2114.0$$

$$V_{sp\min} = \mu_{sp\min} * A_k$$

$$\mu_{sp(\min)} = 0.36 \left(\frac{f_{cu}}{f_{yp}}\right) \left(\frac{A_c}{A_k} - 1\right)$$

$$= 0.36\left(\frac{25}{240}\right)\left(\frac{237582}{196350} - 1\right) = 7.874 \times 10^{-3}$$

$$V_{sp\min} = 7.874 x 10^{-3} x 196350 = 1546.05$$

$$V_{sp} \succ V_{sp\min}$$

$$\therefore V_{sp} = 2114.0$$

$$V_{sp} = \frac{\pi A_{sp} D_k}{p}$$

$$2114.0 = \frac{\pi(50.3)(500)}{p}$$

$$p = 37.3mm \therefore 30mm \prec p \prec 80mm$$

$$let\ p = 30\ mm$$

Example 6 :

A round spirally reinforced column has an overall diameter of 600 mm . The concrete cover to the spiral reinforcement is 40 mm . The spiral bar is 10 mm. Concrete *fcu* = 30 Mpa and steel *f y* = 360 Mpa , *f yp* = 240 Mpa . It is required to :

a) Determine the center to center spacings of the spiral bars (pitch) .

b) What is the maximum number of Φ 22 longitudinal bars that can be used in that column to satisfy requirements for percentage of longitudinal reinforcement and clear distance between longitudinal bars (assume corner column and nominal maximum size of aggregate is 25mm).

c) Determine the minimum longitudinal reinforcement to be used to satisfy code limitations for longitudinal reinforcement .

Solution :

a) D = 600 mm

$$A_c = \frac{\pi D^2}{4} = 282743 mm^2$$

$$D_k = (600 - 2(40)) = 520 mm$$

$$A_k = \frac{\pi D_k^2}{4} = 212361 mm^2$$

$$A_{sp} = 78.5 mm^2$$

<u>To satisfy minimum spiral volume requirement :</u>

From Eq. 6

$$\mu_{sp} = \frac{\pi A_{sp} D_k}{p \cdot A_k} = 0.36 \left(\frac{f_{cu}}{f_{yp}}\right) \left(\frac{A_c}{A_k} - 1\right)$$

$$\pi \left(\frac{78.5}{212361}\right) \left(\frac{520}{p}\right) = 0.36 \left(\frac{30}{240}\right) \left(\frac{282743}{212361} - 1\right) = 0.0149$$

$$\therefore p = 40.5 mm, \; 30 mm \prec p \prec 80 mm \qquad \text{o.k.}$$

b) Maximum total area of longitudinal bars

$$Max. A_{st} = 0.06 A_c = 0.06 \left(\frac{\pi x 600^2}{4}\right) = 16964.6 mm^2$$

with Φ 22 , diameter of circle through centers of bars :

$$D_s = D - 2(\text{cover}) - 2(spiral\,diameters) - bar\,diameter$$

$$= 600 - 2(40) - 2(10) - 22 = 478 mm$$

Accurding to the Egyptian code (Art . 7 . 3. 3) , minimum clear spacing between bars are the largest of :

$$1\frac{1}{2}(25) = 37.5 mm \quad \text{or}$$

$$\Phi_{max.} = 22\, mm$$

least center to center of Φ 22 mm bars = 37.5 + 22 = 59.5 mm

∴ Maximum number of Φ 22 mm bars to satisfy clear

$$spacing\,requirement = \frac{\pi D_s}{59.5} = \frac{\pi (478)}{59.5} = 25.2 \text{ bars}$$

Say 25 bars , providing an area A_{st} = 25 (380) = 9500 mm^2 < max. A_{st} = 16964 mm^2

Therefore the maximum longitudinal reinforcement to be used in 600 mm diameter column is 25 Φ 22 bars.

$$c)\ Minimum A_{st} = 0.01 A_c = 0.01\left(\frac{\pi x 600^2}{4}\right) = 2827 mm^2\ or$$

$$= 0.012 A_k = 0.012\left(\frac{\pi x 520^2}{4}\right) = 2548 mm^2$$

According to Art. 6.4.7, minimum number of bars to be used in circular reinforced compression members = 6, use 8 Φ 22 providing A_{st} = 3041 mm^2