Reinforced Concrete Column

Course title : Reinforced Concrete-II
Course Code : CE 3217
Credit Hrs : 03

Outline

- Two way slabs
- Columns
- Retaining walls

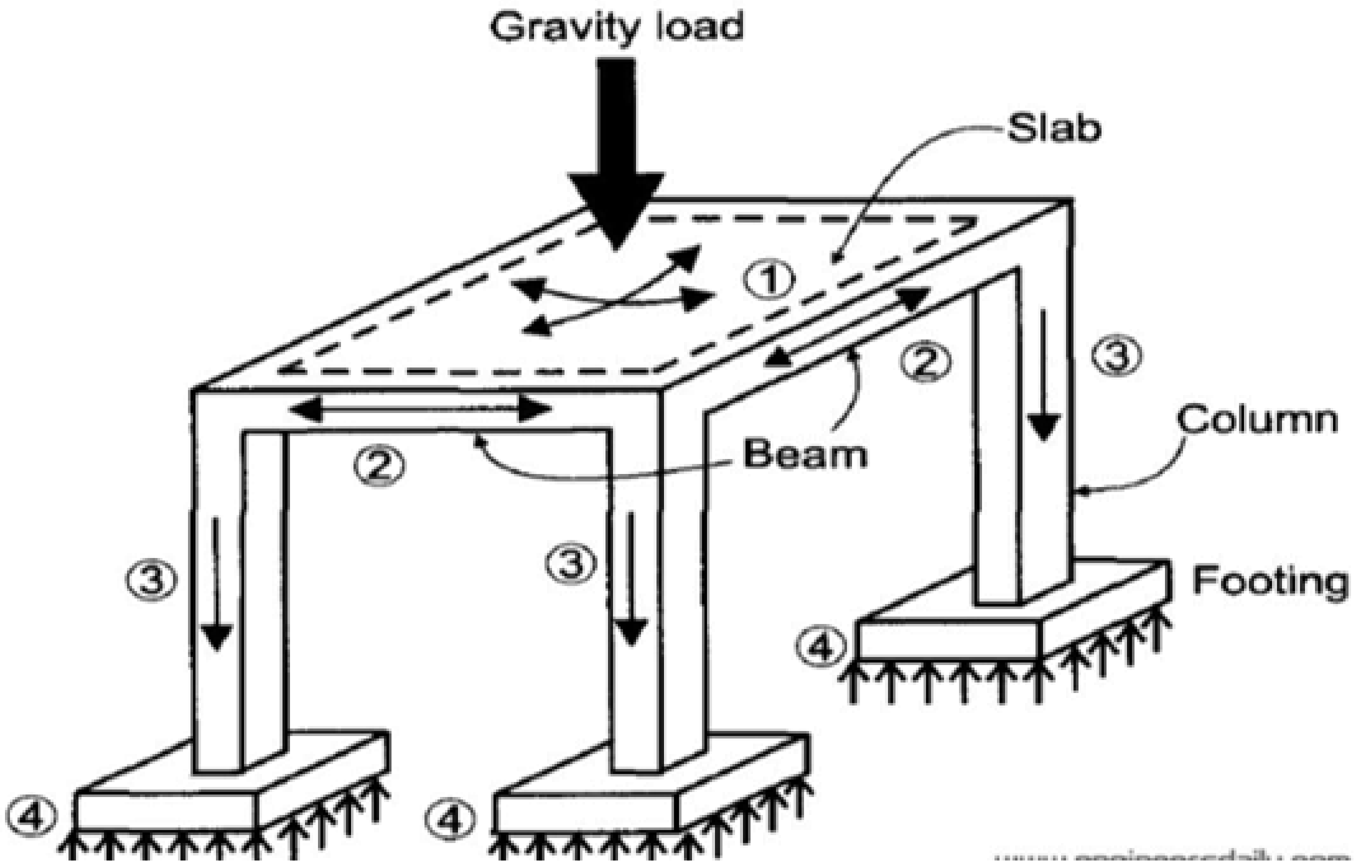
Text Books

- Design of concrete structures 13th edition by Arthur H. Nilson
- Design of concrete structures 7th edition by Arthur H. Nilson

Introduction

- Columns are members used primarily to **support axial compressive loads** and
- Have a **ratio of height to the least lateral dimension of 3** or greater.

Introduction



Introduction

- In reinforced concrete buildings, concrete beams, floors, and columns are cast monolithically, causing some moments in the columns due to end restraint.

- Moreover, perfect vertical alignment of columns in a multistory building is not possible, causing loads to be eccentric relative to the center of columns.

- The eccentric loads will cause moments in columns.

Introduction

Therefore, a column subjected to pure axial loads does not exist in concrete buildings.

However, it can be assumed that axially loaded columns are those with relatively small eccentricity, e, of about 0.1h or less,

Where, h is the total depth of the column and
e is the eccentric distance from the center of the column.

Because concrete has a high compressive strength and is an inexpensive material, it can be used in the design of compression members economically.

TYPES OF COLUMNS

Columns may be classified based on the following different categories:

1. **Based on loading**, columns may be classified as follows:

   a. Axially loaded columns,
   b. Eccentrically loaded columns,
   c. Biaxially loaded columns.

TYPES OF COLUMNS

2. **Based on length,** columns may be classified as follows:

a. **Short columns,** where the column's failure is due to the crushing of concrete or the yielding of the steel bars under the full load capacity of the column.

b. **Long columns,** where buckling effect and slenderness ratio must be taken into consideration in the design, thus reducing the load capacity of the column relative to that of a short column.

TYPES OF COLUMNS

3. **Based on the shape of the cross-section,**

- square,
- rectangular,
- round,
- L-shaped,
- octagonal, or
- any desired shape with an adequate side width or dimensions.

TYPES OF COLUMNS

4. Based on column ties, columns may be classified as follows:

a. Tied columns containing steel ties to confine the main longitudinal bars in the columns. Ties are normally spaced uniformly along the height of the column.

b. Spiral columns containing spirals (spring-type reinforcement) to hold the main longitu- dinal reinforcement and to help increase the column ductility before failure. In general, ties and spirals prevent the slender, highly stressed longitudinal bars from buckling and bursting the concrete cover.

TYPES OF COLUMNS

5. Based on frame bracing,

columns may be part of a frame that is braced against sidesway or unbraced against sidesway. Bracing may be achieved by using shear walls or bracings in the building frame. In braced frames, columns resist mainly gravity loads, and shear walls resist lateral loads and wind loads.

In unbraced frames, columns resist both gravity and lateral loads, which reduce the load capacity of the columns.

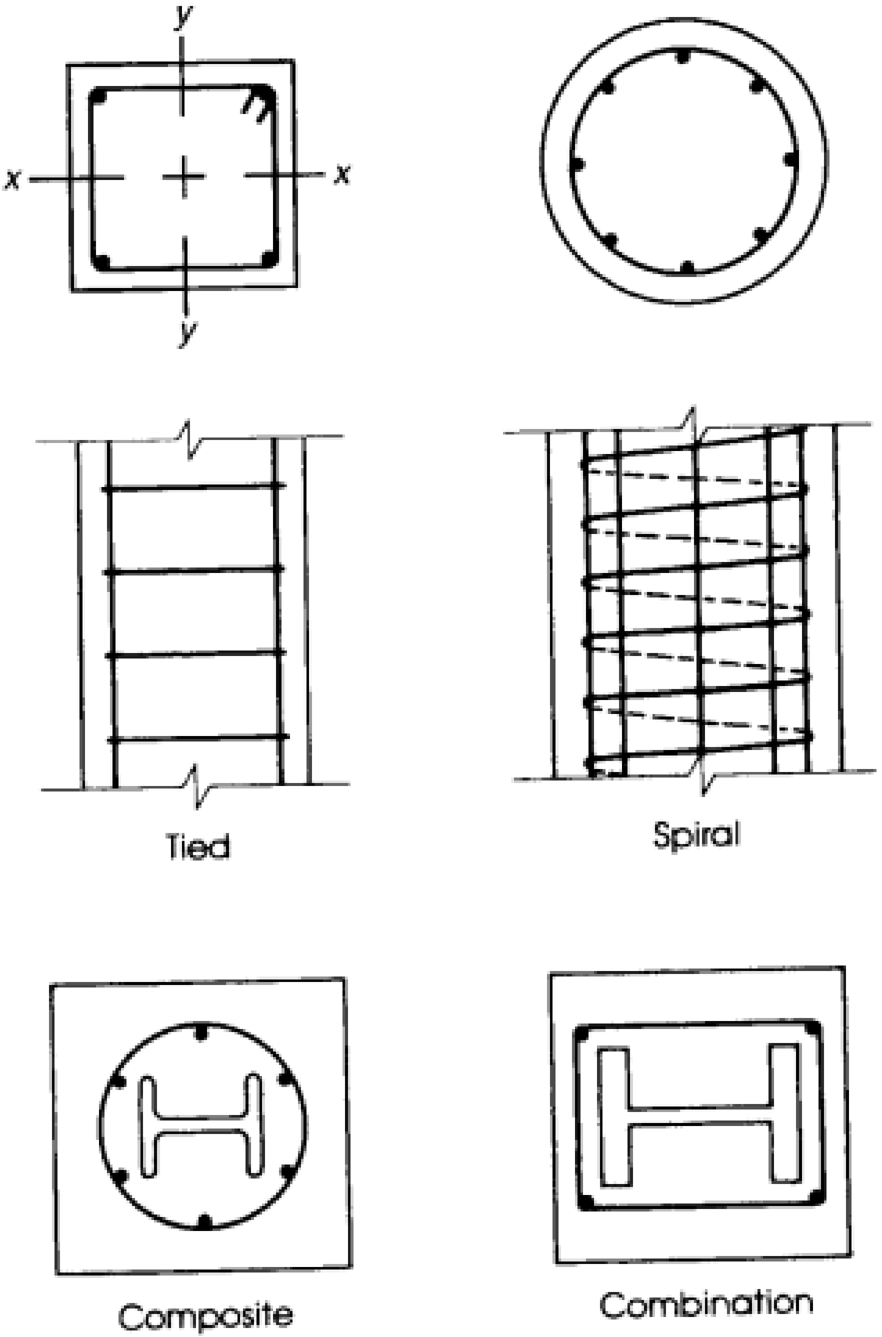
TYPES OF COLUMNS

6. Based on materials, columns may be

- Reinforced,
- Prestressed,
- Composite (containing rolled steel sections such as I-sections), or
- A combination of rolled steel sections and reinforcing bars.

Concrete columns reinforced with longitudinal reinforcing bars are the most common type used in concrete buildings.

TYPES OF COLUMNS



Why Reinforcement ?

In members that sustain chiefly or exclusively axial compression loads, such as building columns. it is economical to make the concrete carry most of the load. Still, some steel reinforcement is always provided for various reasons, For

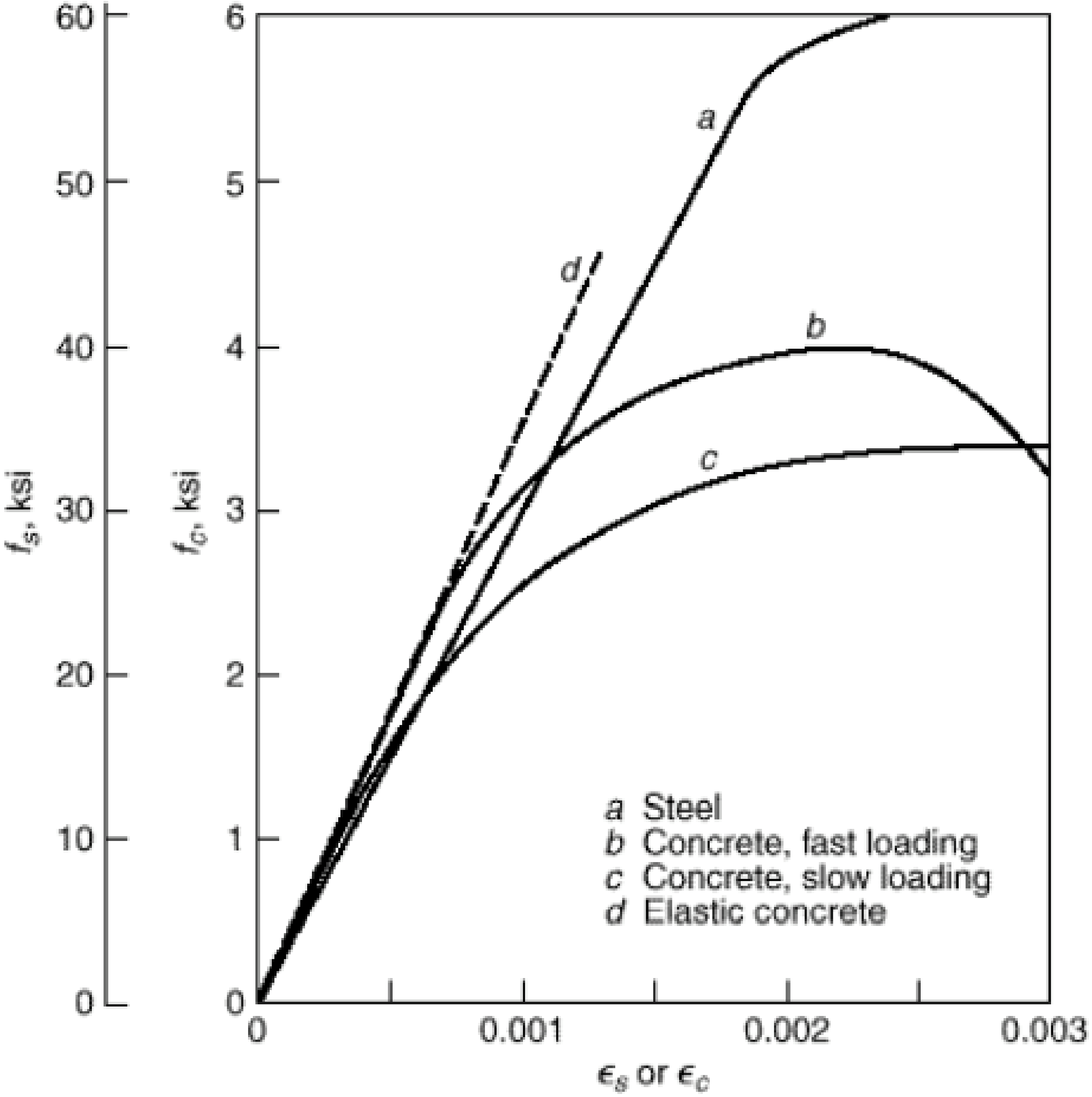
1. Very few members are truly axially loaded; steel is essential for resisting any bending that may exist.

2. If part of the total load is carried by steel with its much greater strength, the **cross-sectional dimensions of the member can be reduced.**

Stress-strain cuve

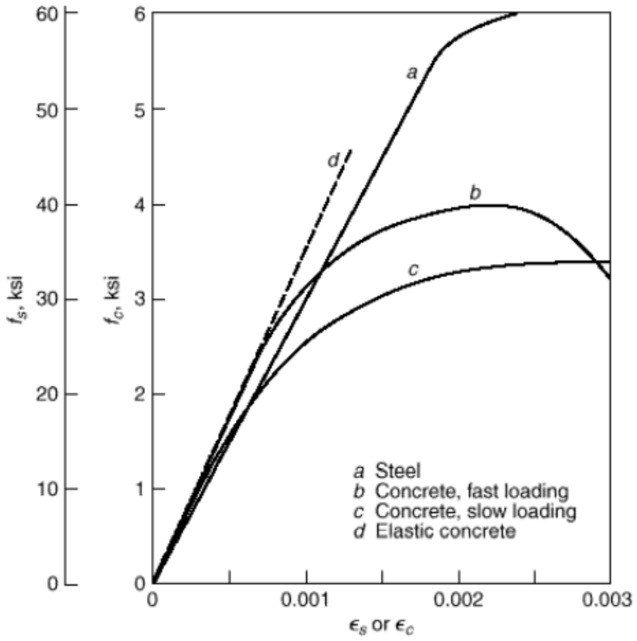
b. Cylinder test
c. Real structure

Max reliable comp. strength of concrete would be $0.85f_c'$



ELASTIC BEHAVIOR

- At low stresses, up to about ***f_c'/2 or** (**f_c'/3**) the concrete is seen to behave nearly elastically, i.e., stresses and strains are quite closely proportional, the straight line d represents this range of behavior with little error for both rates of loading.
- **The compression strain in the concrete, at any given load, is equal to the compression strain in the steel**



ELASTIC BEHAVIOR

- **The compression strain in the concrete, at any given load, is equal to the compression strain in the steel**

$$\epsilon_c = \frac{f_c}{E_c} = \epsilon_s = \frac{f_s}{E_s}$$

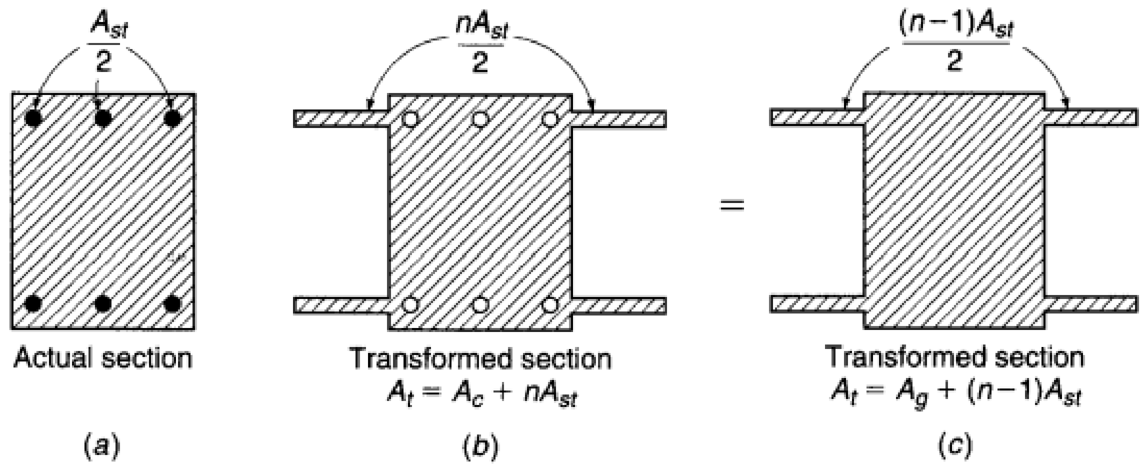
$$\gg \frac{f_c}{E_c} = \frac{f_s}{E_s}$$

$$\gg f_s = \frac{E_s}{E_c} f_c$$

$$\gg f_s = n f_c$$

Where, n is modular ratio

ELASTIC BEHAVIOR



Let,

A_g = gross area

A_c = net area of concrete, i.e„ gross area minus area occupied by reinforcing bars

A_{st} = total area of reinforcing bars

P = axial load

Then

$$p = f_c A_c + f_s A_{st} = f_c A_c + n f_c A_{st}$$

Or

$$p = f_c (A_c + nA_{st})$$

$$p = f_c \{(A_g - A_{st}) + nA_{st}\} = f_c \{A_g + (n\text{-}1) A_{st}\}$$

ELASTIC BEHAVIOR

Nominal strength of the axially loaded concrete column can be found from

$$p_n = 0.85\, f'_c\, A_c + f_y\, A_{st}$$

$$p_n = 0.85\, f'_c\, (A_g - A_{st}) + f_y\, A_{st}$$

ELASTIC BEHAVIOR

The design strength at an axially loaded column is to be found based on Eq. ($\boldsymbol{p_n = 0.85\, f'_c\, (A_g - A_{st})\, + f_y\, A_{st}}$) with the introduction of **certain strength reduction factors**.

Why strength reduction factor of column is smaller?

- Column has a greater importance in a structure.
- A beam failure would normally affect only a local region, whereas a column failure could result in the collapse of the entire structure.

Strength reduction factor of column

Spirally reinforced columns,∅ = 0.75

Tied columns, ∅ = 0.65

Beams ∅ = 0.9

A further limitation on column strength is imposed by ACI Code to allow for accidental eccentricities of loading not considered in the analysis

This is done by imposing an upper limit on the axial load that is less than the calculated design strength.

This upper limit for spiral column is 0.85 times the design strength.

This upper limit for tied column is 0.80 times the design strength.

Strength reduction factor of column

Summary		
Columns	Strength reduction factor ∅	Upper limit of axial load, k
Spiral columns	0.75	0.85
Tied columns	0.65	0.80

According ACI code

Ultimate strength of column

∴ For spiral column, (∅=0.75)

$$\emptyset p_{n(max)} = \mathbf{0.85}\emptyset\ [\mathbf{0.85}\ f'_c\ (A_g - A_{st})\ + f_y\ A_{st}]$$

∴ For tied column, (∅=0.65)

$$\emptyset p_{n(max)} = \mathbf{0.80}\emptyset\ [\mathbf{0.85}\ f'_c\ (A_g - A_{st})\ + f_y\ A_{st}]$$

According ACI code

Problem-01

Determine the allowable design axial load on a 12-in. square, short tied column reinforced with four # 9 bars. Ties are #3 spaced at 12 in. Use f'c = 4 ksi and fy 60 ksi.

Solution steps:

Bar no.	Diameter (in.)	Cross-sectional area (in.^{2})
3	0.375	0.11
4	0.500	0.20
5	0.625	0.31
6	0.750	0.44
7	0.875	0.60
8	1.000	0.79
9	1.128	1.00
10	1.270	1.27
11	1.410	1.56
14	1.693	2.25
18	2.257	4.00

1. *Eqn.* $p_u = \emptyset p_n = k\emptyset\,[0.85\, f'_c\,(A_g - A_{st}) + f_y\, A_{st}]$

   For tied column: $\emptyset = 0.65$ & $k = 0.80$

2. *Calculate* A_g *and* A_{st} *then put value in the eqn.*

Problem-02

Determine the allowable design axial load on a 16-in. dia, short spiral column reinforced with four # 8 bars. spirals are #3 spaced at 12 in. Use f'c = 4 ksi and fy 60 ksi.

Solution steps:

1. *Eqn.* $p_u = \emptyset p_n = k\emptyset\,[0.85\, f'_c\,(A_g - A_{st}) + f_y\, A_{st}]$

   For tied column: $\emptyset = 0.75$ & $k = 0.85$

2. *Calculate* A_g *and* A_{st} *then put value in the eqn.*

Bar no.	Diameter (in.)	Cross-sectional area (in.[2])
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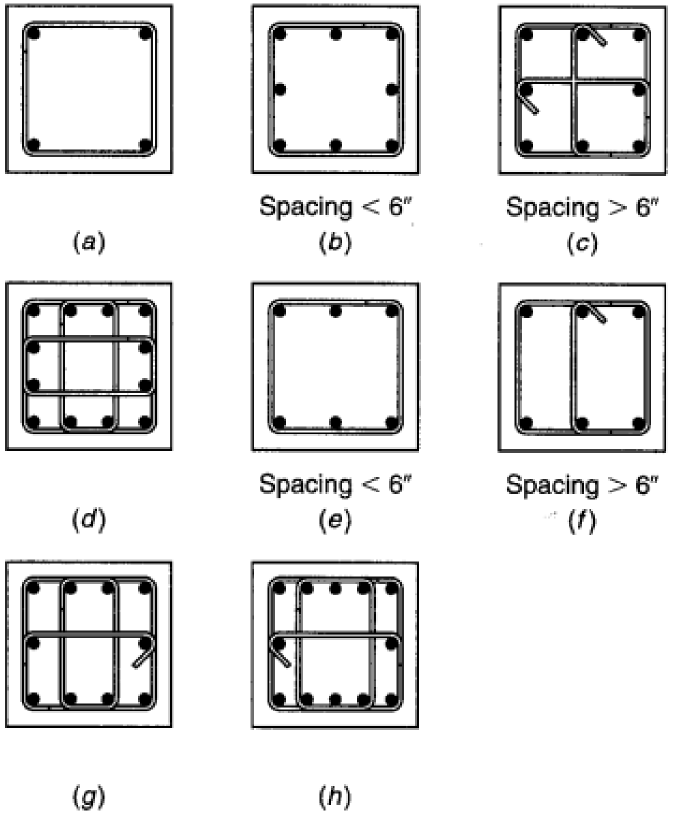
Lateral Ties

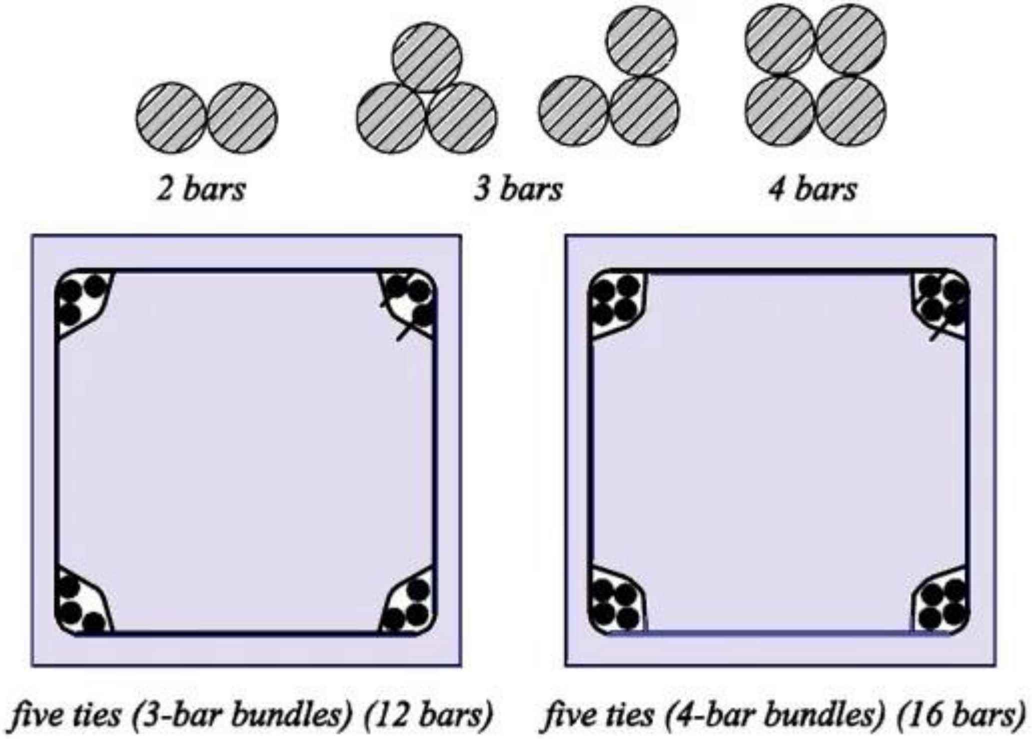
- Bending moments are large → much of the longitudinal steel at the faces of highest compression or tension

- Heavily loaded columns → large steel percentages,
  - large number of bars,
  - each of them positioned and held individually by ties



Lateral Ties

- Large steel percentages and consequent ties may cause steel congestion which leads to difficulties in placing the concrete.
- In such cases, bundled bars are frequently employed



Function of Lateral Ties & Spirals

- **To hold the longitudinal bars** in position in the forms while the concrete is being placed.

For this purpose, longitudinal and transverse steel is wired together to form cages, which are then moved into the forms and properly positioned before placing the concrete.

- To prevent the highly stressed, slender longitudinal bars **from buckling outward by bursting the thin concrete cover**.

Function of Lateral Ties & Spirals

- The **spacing must be sufficiently small** to prevent buckling between ties and that, in any tie plane.

- A **sufficient number of ties** must be provided to position and hold all bars.

Bar arrangement Rule [ACI Code 7.10.5]

- All bars of tied columns shall be enclosed by lateral ties, least No. 3 (10 mm) for longitudinal bars up to NO. 10 (32mm).

- At least No. 4 (13 mm) in size for Nos. 11, 14, and 18 (36, 43, and 57 mm) and bundled longitudinal bars.

Steel Requirement [ACI Code 10.9.1]

- The **minimum longitudinal steel** percentage is **1%,** and
- The **maximum** percentage is **8%** of the gross area of the section

  - e.g. 1% of $A_g < \rho < 8\% A_g$

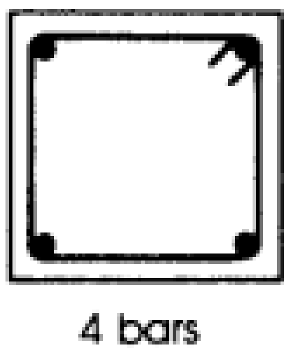
Steel Requirement [ACI Code 10.9.1]

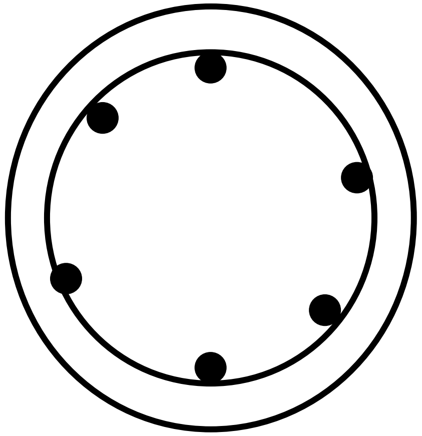
- Minimum reinforcement is necessary to provide resistance to
  - bending, which may exist, and
  - to reduce the effects of creep and shrinkage of the concrete under sustained compressive stresses.

- Practically, it is very difficult to fit more than 8% of steel reinforcement into a column and maintain sufficient space for concrete to flow between bars.

Steel Requirement [ACI Code 10.9.2]

- **At least four** bars are required for **tied circular and rectangular** members and
- **six bars** are needed for **circular members** enclosed by spirals





Steel Requirement [ACI Code 10.9.2]

- For other shapes,
    - **one bar** should be provided at **each corner**, and
    - **proper lateral reinforcement** must be provided.

- For tied triangular columns, **at least three bars** are required.
- Bars shall not be located at a distance greater than 6in. clear on either side from a laterally supported bar.

- The **minimum concrete cover** in columns is **1.5 in**.

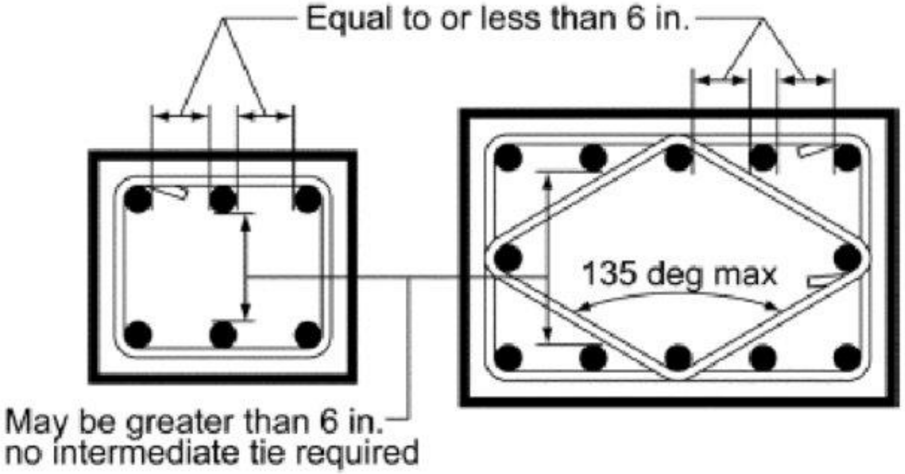
Bar arrangement Rule [ACI Code 7.10.5]

- The spacing of the ties shall not exceed
    - 16 x diameters of longitudinal bars,
    - 48 x diameters of tie bars,
    - Nor the least dimension of the column.

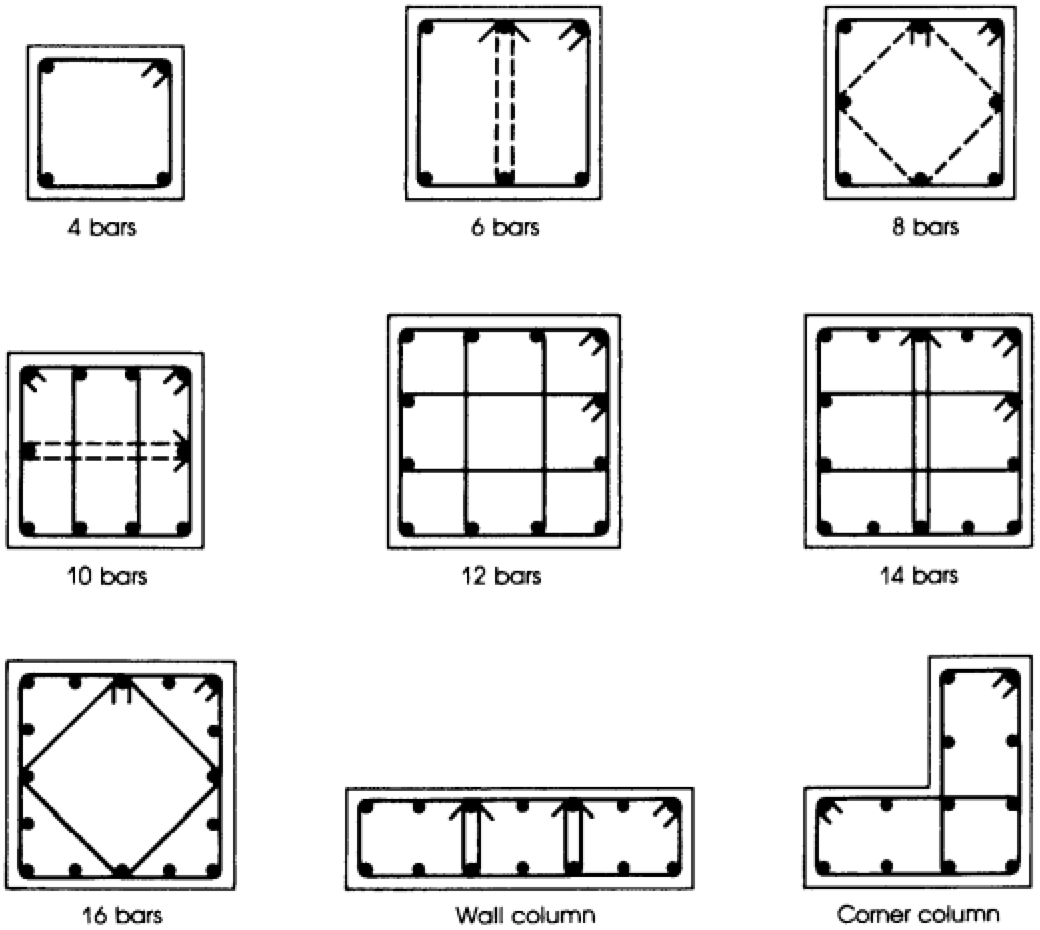
Bar arrangement Rule [ACI Code 7.10.5]

- 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°

- No bar shall be farther than 6 in. clear on either side from such a laterally supported bar.



Bar arrangement Rule [ACI Code 7.10.5]

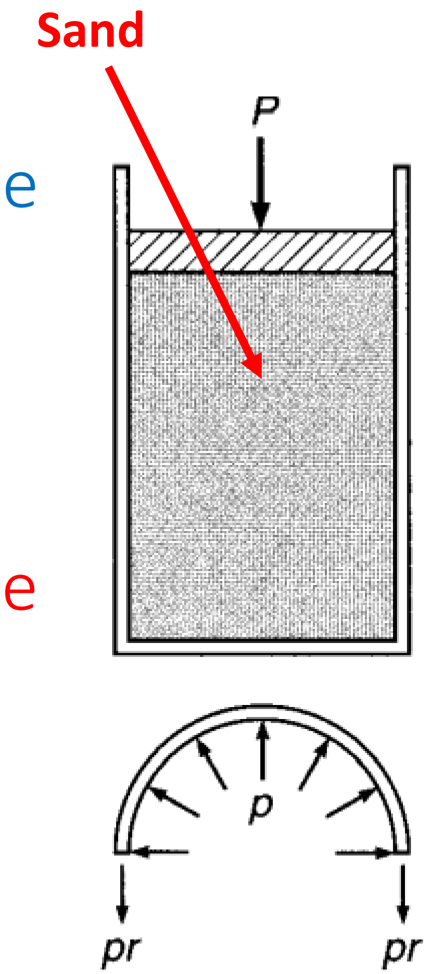


Bar arrangement Rule [ACI Code 7.10.5]

- Spirals shall consist of a continuous bar or wire not less than 3/8 “ diameter,
- The clear spacing between turns of the spiral must not exceed 3 in.
- Not be less than 1 in

Structural effect of a spiral

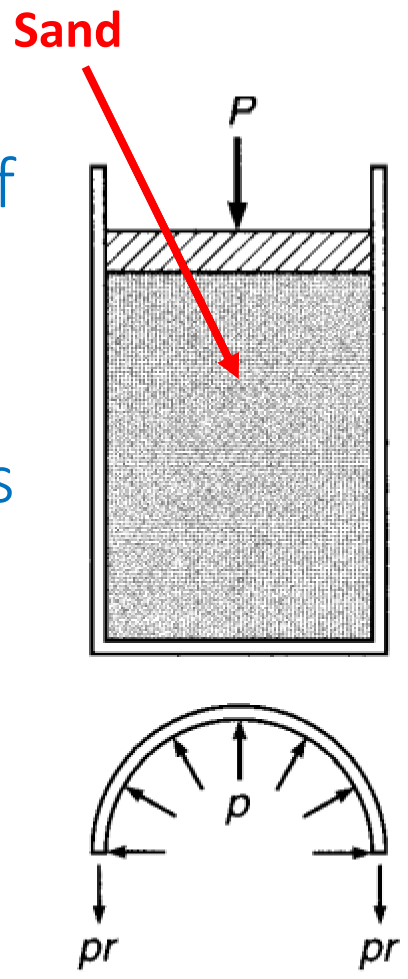
- Lateral pressure is exerted by the sand causes **hoop tension** in the wall.
- The load can be increased until the drum burst .
- Longitudinal shortening and laterally expansion occurs.
- A closely spaced spiral confining the column counteracts the expansion, as did the steel drum in the model.



Structural effect of a spiral

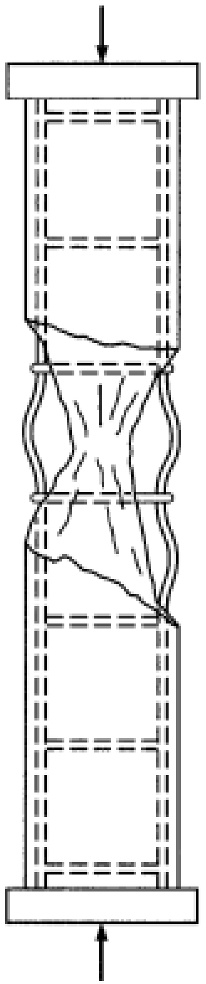
- This causes hoop tension in the spiral, while the carrying capacity of the confined concrete in the core is greatly increased.

- Failure occurs only when the spiral steel yields, which greatly reduces its confining effect, or when it fractures.



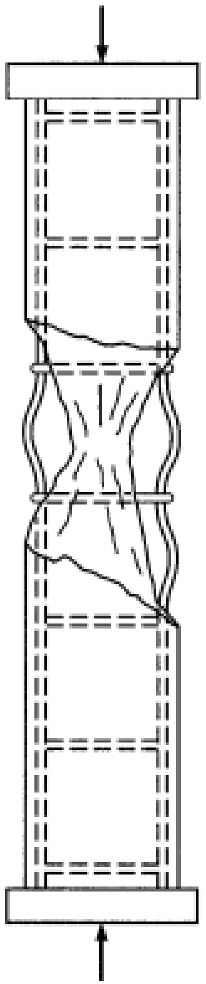
Behavior of tied vs spiral column

- At P_n load the concrete in tied column fails by crushing and shearing outward along inclined planes.
- And the longitudinal steel by buckling outward between ties.
- In a spirally reinforced column at same load is, the longitudinal steel and the concrete within the core are prevented from moving outward by the spiral.



Behavior of tied vs spiral column

- The concrete in the outer shell, not being so confined does fail.
- i.e., the outer **shell spalls off** When the load P_n, is reached.

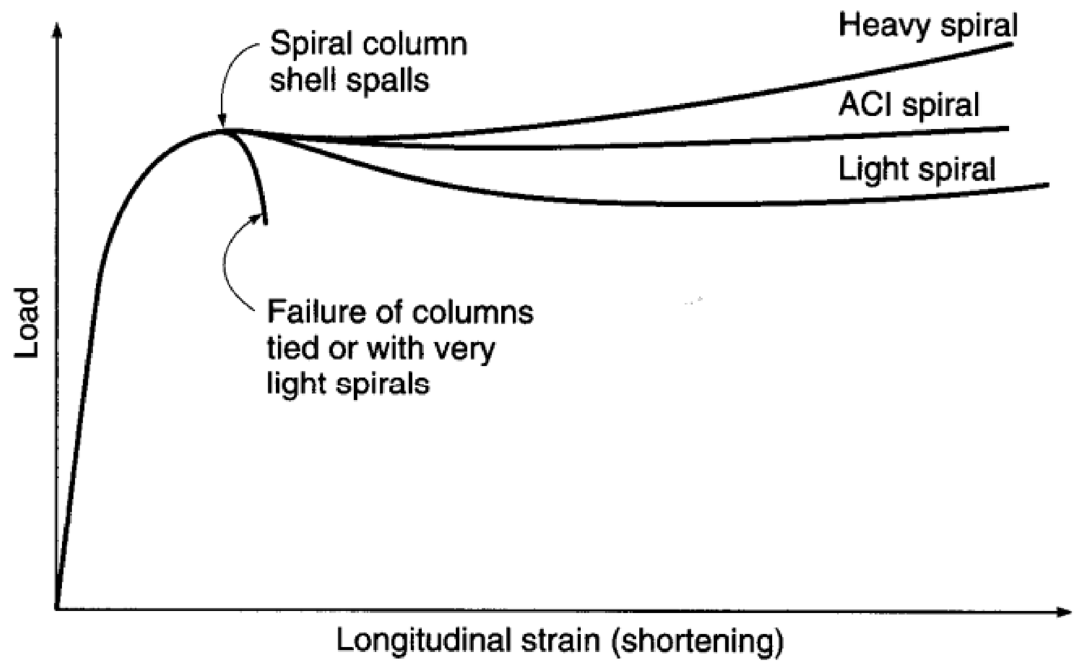


Behavior of tied vs spiral column

- In contrast to the practice, any excess capacity beyond the spalling load of the shell is wasted the member. although not actually failed, would no longer be considered serviceable.
- For this reason, the **ACI Code provides a minimum spiral reinforcement** of such an amount that its contribution to the carrying capacity is just slightly larger than that of the concrete in the shell.

Behavior of tied vs spiral column

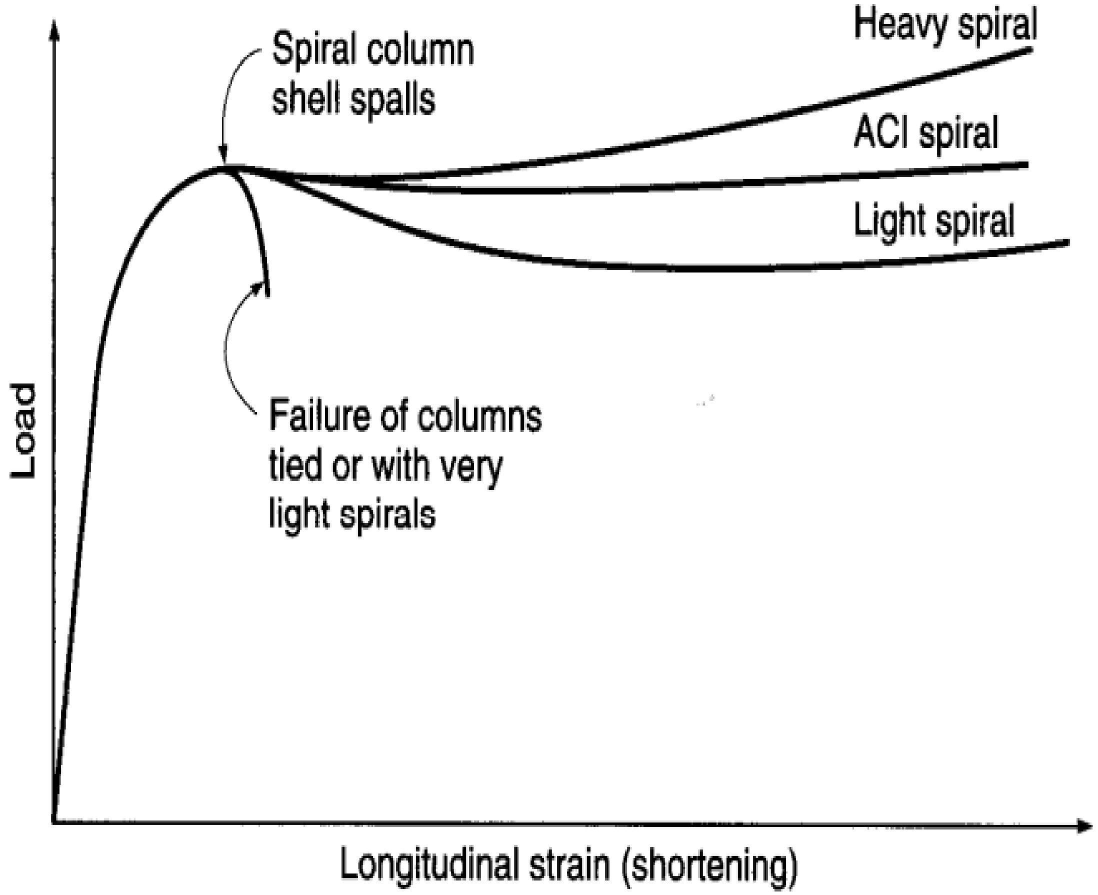
- **spalling load of a spiral column equal to the ultimate load of the tied column.**
- The failure or the tied column is abrupt and complete.
- Light spiral column has strength contribution is considerably less than the strength lost in the spalled shell.
- With a heavy spiral the reverse is true.



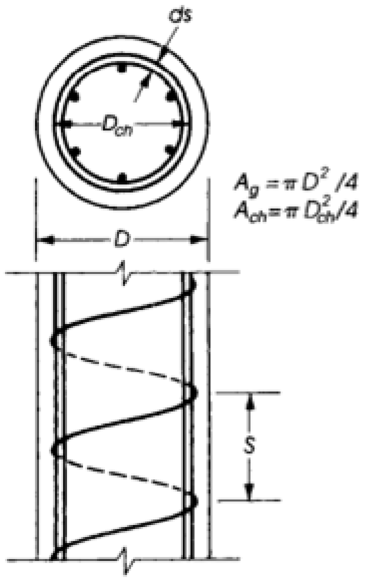
Behavior of tied vs spiral column

- The "ACI spiral," its strength contribution axial compensating for that lost in the spalled shell, **hardly increases the ultimate load**.

- However, by preventing instantaneous crushing of concrete and buckling of steel, it produces a more **gradual and ductile failure, i.e., a tougher column**.



Spiral reinforcement ratio



Strength contribution of the shell $= 0.85f'_c(A_g - A_{ch})$

Where,

- A_g is the gross concrete area and
- A_{ch} is the core area

- In spirally reinforced columns, spiral steel is at least twice as effective as longitudinal bars; therefore,

$$\text{Strength provided by spiral} = 2\rho_s f_{yt} A_{ch}$$

Where,

ρ_s is the ratio of volume of spiral reinforcement to **total volume of core.**

Spiral reinforcement ratio

- The basis for the design of the spiral is that the strength gain provided by the spiral should be at least equal to that lost when the shell spalls.

$$0.85f_c'(A_g - A_{ch}) = 2\rho_s f_{yt} A_{ch}$$

$$\rho_s = 0.425\left(\frac{A_g}{A_{ch}} - 1\right)\frac{f_c'}{f_{yt}}$$

According to the ACI Code, this result is rounded upward slightly, and ACI Code states that the ratio Of spiral reinforcement shall not be less than

$\rho_{s\ min}$

$$\rho_s = 0.45\left(\frac{A_g}{A_{ch}} - 1\right)\frac{f_c'}{f_{yt}}$$

Spiral reinforcement ratio

- The design relationship Of spirals may be obtained as follows

$$\rho_s = \pi d_c A_{sp} \frac{4}{\pi d_c^2 s}$$

$$A_{sp} = \frac{\rho_s d_c s}{4}$$

A_{sp} = cross-sectional area of spiral wire
d_c = outside diameter of spiral
s = spacing or pitch of spiral wire

$$\rho_s > \rho_{s\,min}$$