Columns

Short columns

Columns = vertical members supporting axial compression forces, bending moments and shear forces.

Vertical loads from various floors are accumulated and transmitted by columns to foundations.

Columns play a major role in structural safety.

As compression members, failure of columns is more dangerous than in beams.

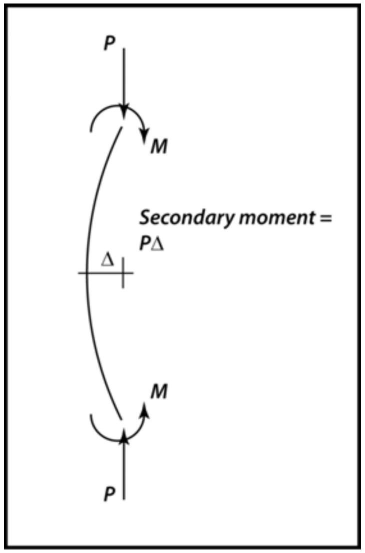
- Stability affects (buckling) must be considered for columns and compression members especially if they are slender (long)

- For majority of columns, referred to as “short columns”, slenderness effects can be neglected.

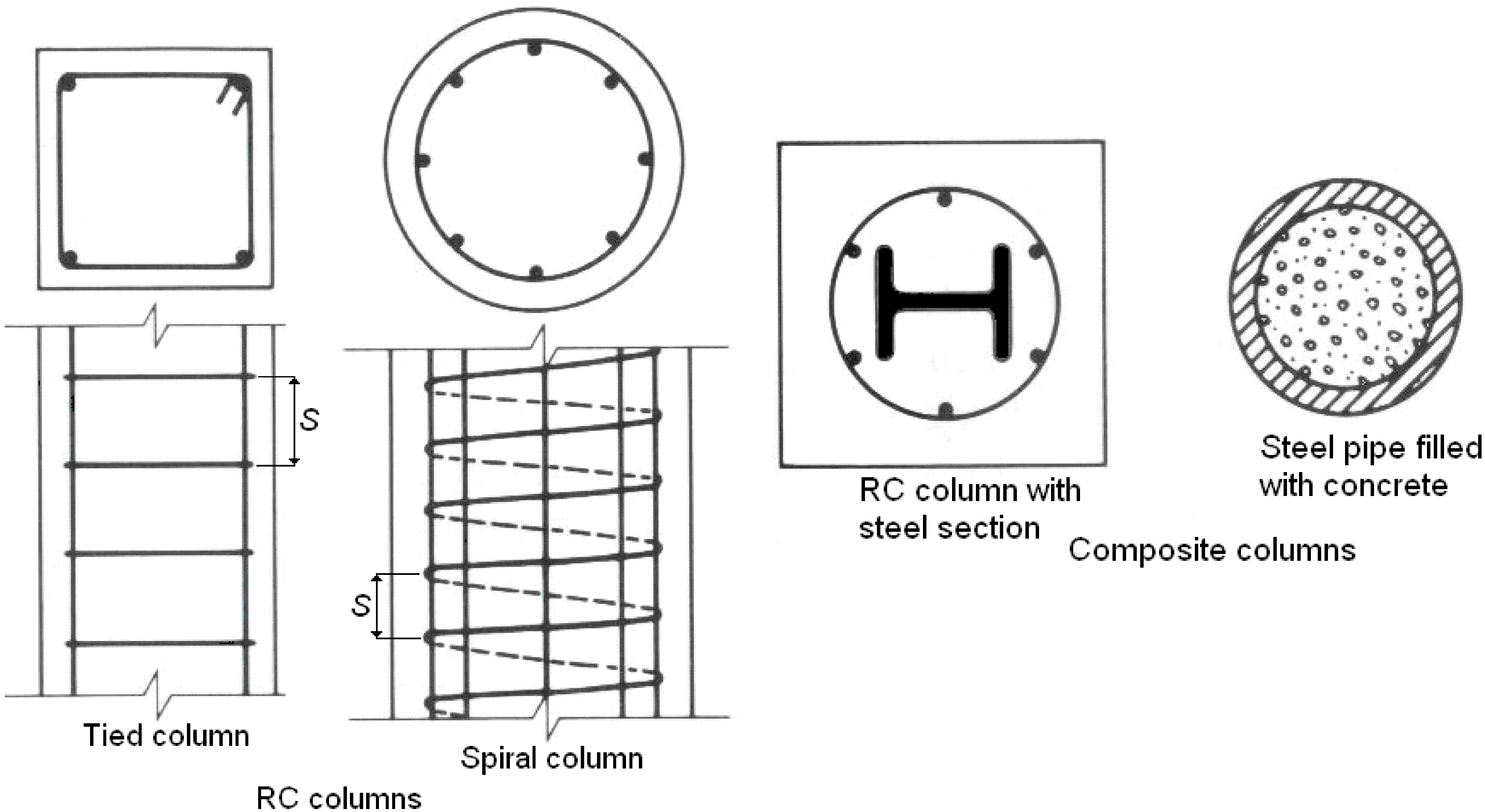
- A column is usually subjected to an axial compression force and two bending moments (biaxial bending) transmitted by beams and girders connected to it. It is also subjected to two shear forces and a torsion moment.
- The first part deals with the combination of an axial force with one moment only. Biaxial bending is studied later.

Primary and Secondary Moments

- The moment caused by applied loads, joint rotations etc. is called primary moments.
- When a column is subjected to primary moments, the axis of the member will deflect laterally.
- This cause additional moments equal to the PΔ that applies to the column. These moments are called secondary moments.



- **Types of columns:**
- Most of RC columns are either tied (more than 90 %) or spiral (5 to 10 %). Special composite columns are sometimes used.



Tied columns

In tied columns which may be of any shape, independent ties are used.

All reinforcing bars must be enclosed by lateral ties

Tie spacing requirement is the smallest of the following three values:

$$S = \mathrm{Min}\left(16d_b, 48d_s, \mathrm{Min}(b, h)\right)$$

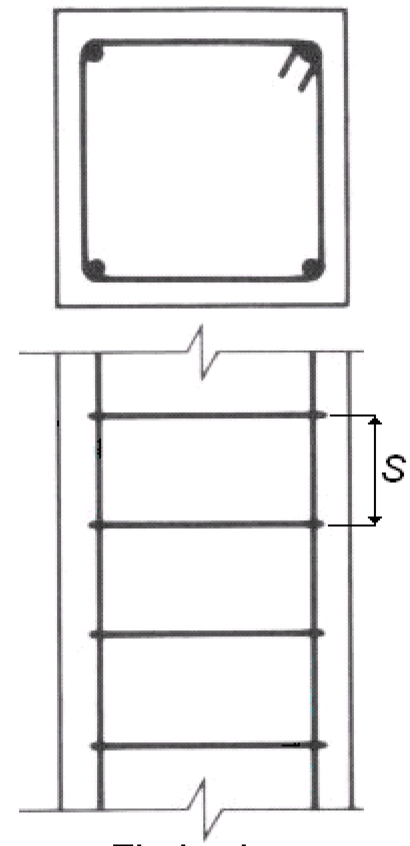
With: d_b = main bar diameter,

d_s = tie (stirrup) diameter

(b, h) = section dimensions.

The role of ties is:

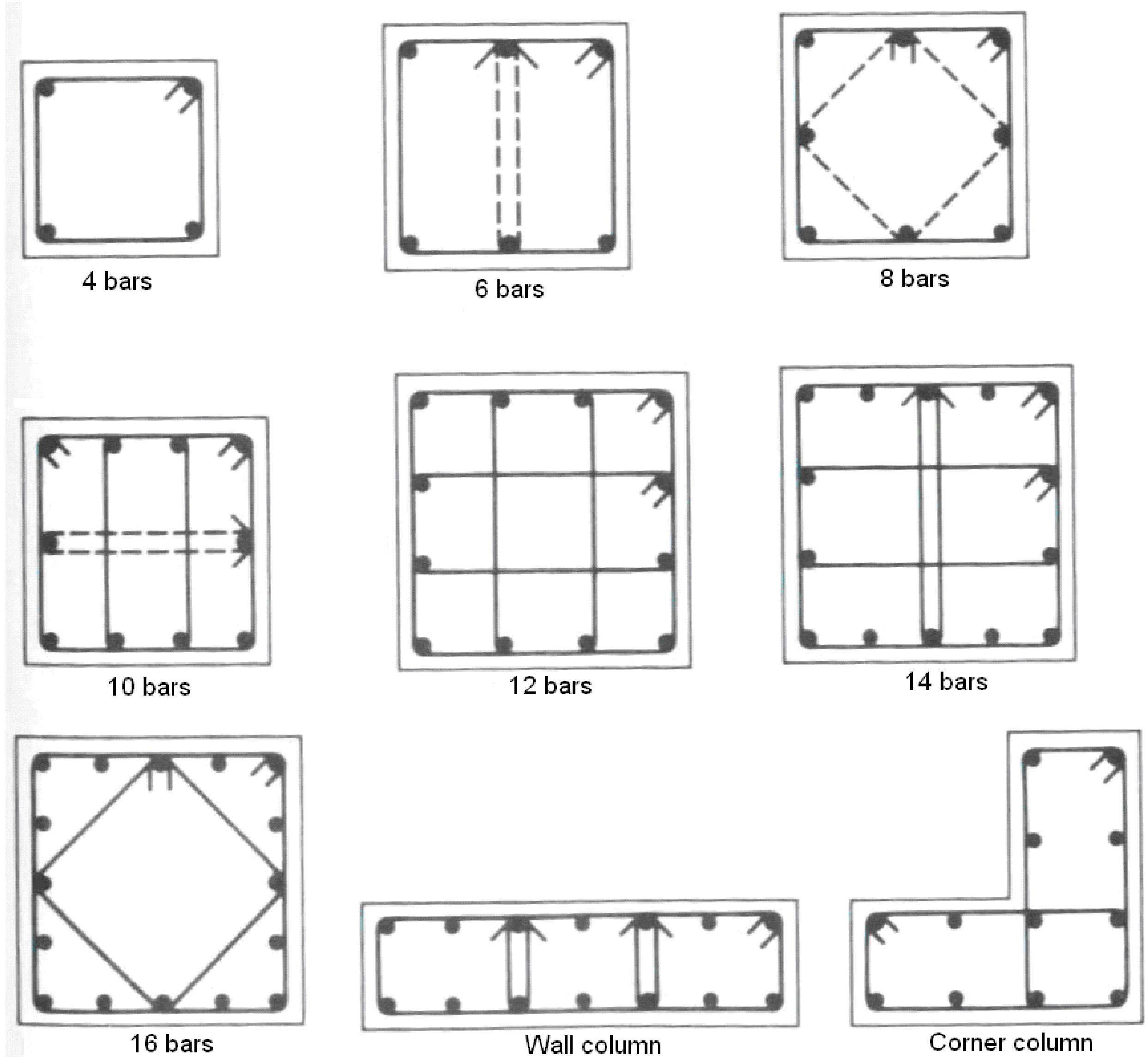
1. Hold and restrain main bars from buckling
2. Hold steel cage during construction
3. May confine concrete and provide ductility
4. Serve as shear reinforcement



Tied column

- Tie diameter d_s should be at least 10 mm if longitudinal bars have 32 mm diameter or smaller.
- For higher bar diameters, d_s should be at least 12 mm.
- The minimum number of bars in columns and compression members is four for rectangular or circular ties and three for triangular ties.
- The maximum angle in a tie is 135^o
- Maximum distance between untied bar and tied one = 150 mm
- First tie at a distance of half spacing above slab and above footing.
- Last tie at a distance of half spacing below lowest reinforcement bar of slab.

Typical tied column sections



Spiral columns

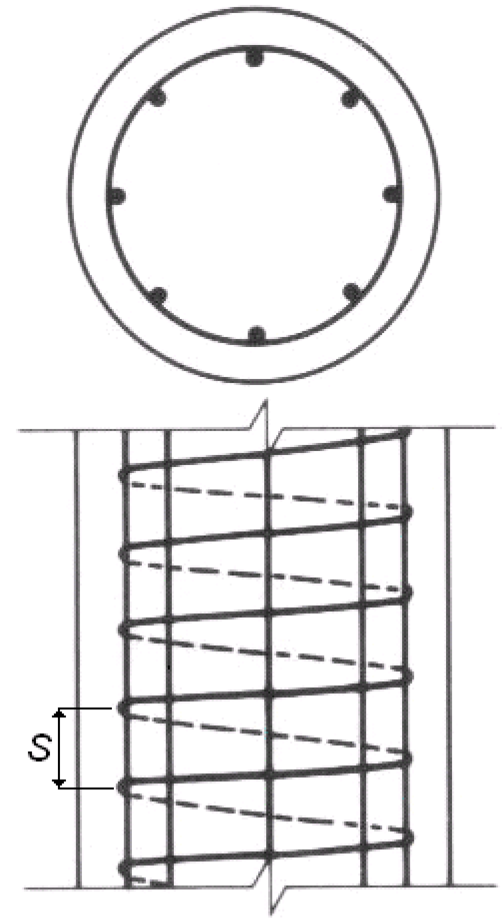
Spiral columns are usually circular

Continuous spiral plays same role as ties and provides lateral confinement opposing lateral expansion and thus improving column ductility

Spiral pitch *S* ranges from 40 to 85 mm

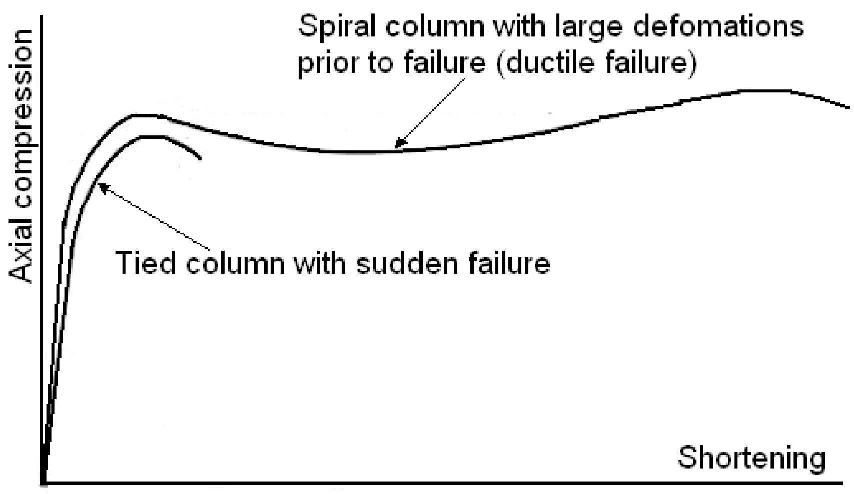
Spiral columns are used in regions with high seismic activity. Spiral column ductility improves the structure capacity in absorbing seismic energy and resisting seismic forces.

Spirals may be used for any section shape but are effective for circular shapes only.



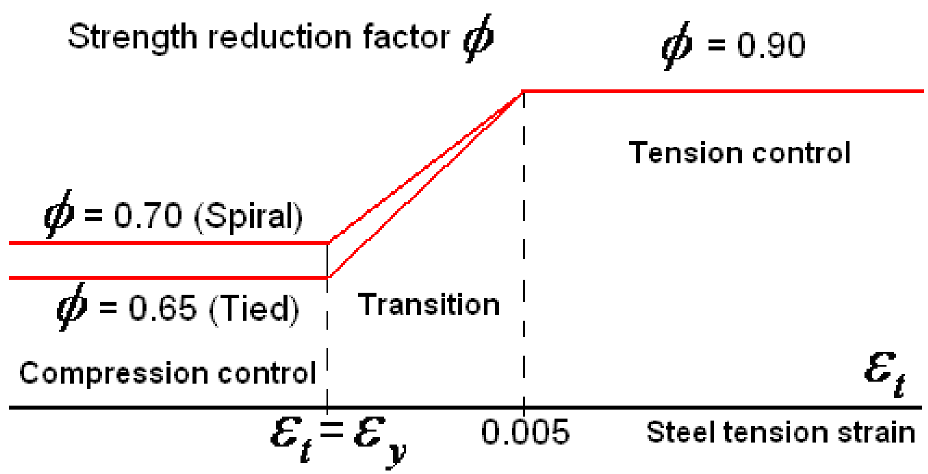
Spiral column

- Figure highlights behavioral difference between tied and spiral columns. Tied columns have brittle failures. Spiral columns develop large deformations prior to failure
- Improved behavior of spiral columns justifies use of higher strength reduction factor in compression (0.70) as compared to tied columns (0.65)



Strength reduction factor for columns

- Columns are compression members but may be subjected to axial tension resulting from lateral loading (wind, earthquake). Column section may vary from compression-controlled case to tension-controlled one, with linear transition zone in between
- Strength reduction factor depends on steel tension strain



Longitudinal reinforcement in columns

- The percentage of reinforcement of columns is expressed as the ratio of the total steel area with respect to the full concrete gross section $\rho_t = \frac{A_{st}}{A_g}$

- The ACI / SBC limits (minimum and maximum) for this percentage are 1% and 8%.
- In practice, because of bar splicing (usually located at the top of each floor), it is recommended not to exceed 4 % for longitudinal reinforcement

- **Strength of columns in axial compression**
- Under pure axial compression (with no bending), the nominal (ultimate) column strength is obtained from the combination of concrete strength and steel strength as follows:

$$P_0 = 0.85 f_c^{'}\left(A_g - A_{st}\right) + f_y A_{st}$$

Where $\left(A_g - A_{st}\right)$ is the net concrete area.

- However because of possible accidental eccentricities and resulting accidental bending, SBC and ACI codes reduce this nominal capacity as: $P_{n(\max)} = \alpha P_0$

where α is a reduction factor. α = 0.80 for tied columns

α = 0.85 for spiral columns

- The design axial compression force is therefore:

$$\phi P_{n(\max)} = \begin{cases} 0.65\,x\,0.80 P_0 = 0.52\left[0.85 f_c^{'}\left(A_g - A_{st}\right) + f_y A_{st}\right]: \textbf{Tied column} \\ 0.70\,x\,0.85 P_0 = 0.595\left[0.85 f_c^{'}\left(A_g - A_{st}\right) + f_y A_{st}\right]: \textbf{Spiral column} \end{cases}$$

- **Column tension strength**
- Only steel resists tension. The nominal and design tension strengths are then:

$P_{nt} = -f_y A_{st}$ $\quad\quad$ $\phi P_{nt} = -0.90 f_y A_{st}$ (Tension is negative)

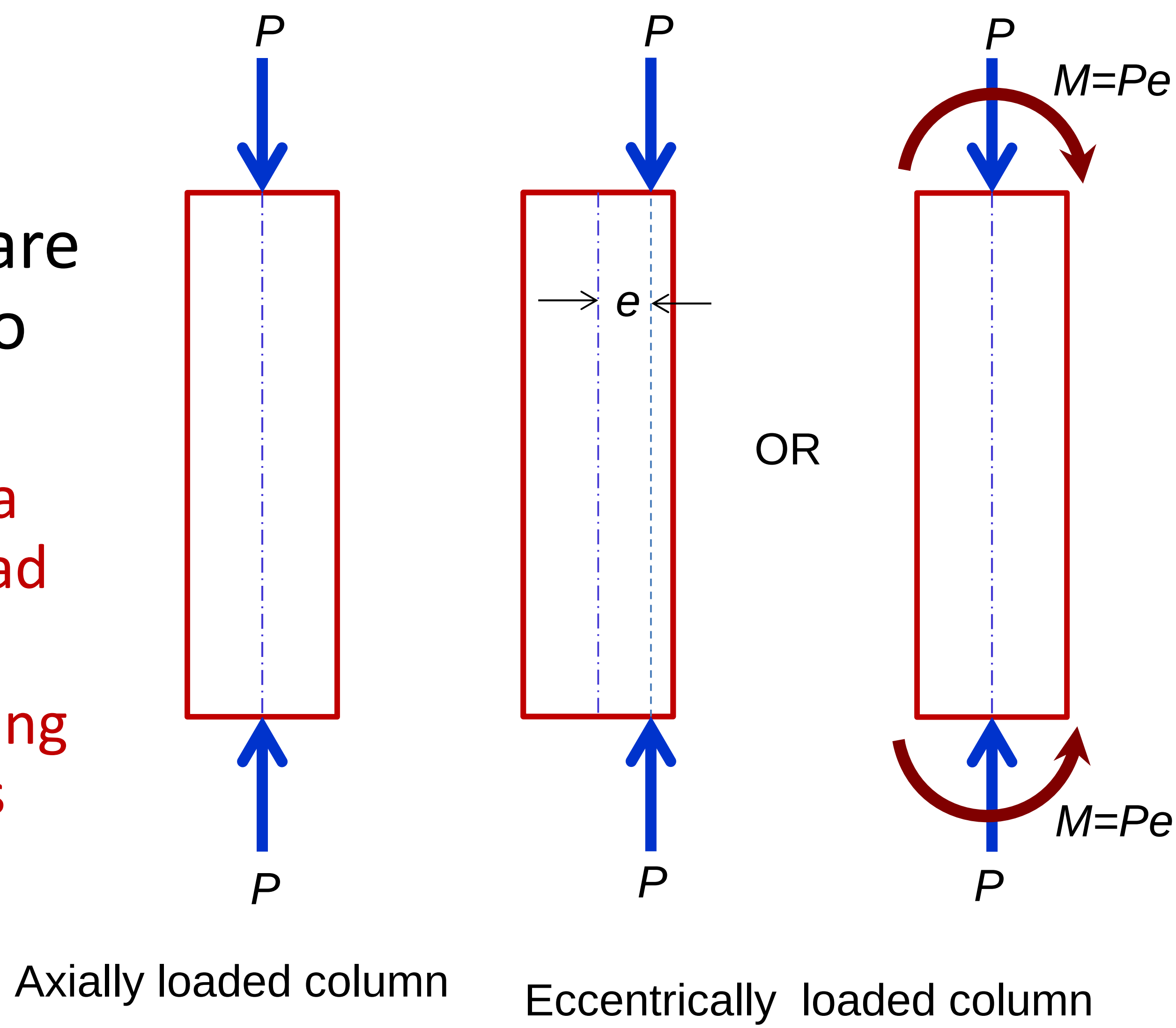
- **Concrete shear strength for columns**
- The concrete shear strength is increased by the axial compression force:

$$V_c = \left(1 + \frac{P_u}{14A_g}\right)\frac{\sqrt{f_c^{'}}}{6} b_w d$$

- if $0.5\phi V_c \le V_u$ then ties must be designed for shear.

Design of Short Columns

- Reinforced Concrete (RC) short columns are divided into two categories:
  - Columns with a purely Axial load (no moment)
  - Columns carrying eccentric loads



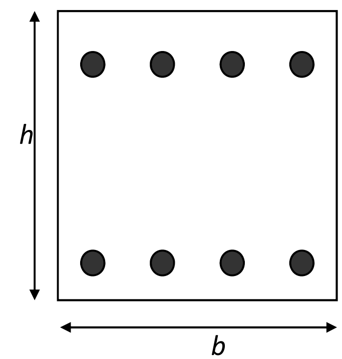
- **Design of concrete section**
- If unknown the concrete gross section may be determined using axial force only with a reduction factor to account for bending and by considering an initial value of steel ratio from 1 to 2 %. The minimum gross section is:
- Tied column: $A_{g(trial)} \geq \frac{P_u}{0.40(f_c^{'} + f_y \rho_t)}$
- Spiral column: $A_{g(trial)} \geq \frac{P_u}{0.50(f_c^{'} + f_y \rho_t)}$
- This approximate section design must then be followed by a check taking into account the bending moment as shown in the next example.

- **Example: Design of a tied column for given loading**
- Design the section and reinforcement of a tied column to support an axial load of $P_u = 1550\ kN$
- Material data is: $f_c^{'} = 20\,MPa$ $f_y = 420\,MPa$
- **a/ Select trial section and trial steel ratio:**
- We select a trial steel ratio of 0.02 (2 %).
- For a tied column: $A_{g(trial)} \geq \dfrac{P_u}{0.40(f_c^{'} + f_y \rho_t)}$ $A_{g(trial)} \geq \dfrac{1550.10^3}{0.40(20 + 420\,x\,0.02)} = 136443.7\,mm^2$
- This gives a 370-mm square column. We must however take a greater dimension to allow for the bending moment. We take a 400-mm square column. *b* = *h* = 400 mm

- **b/ Select reinforcement**

$$A_{st} = \rho_t A_g = 0.02\,x\,400\,x\,400 = 3200.0\,mm^2$$

- One bar area for 25 mm diameter is: $A_b = \dfrac{\pi\,x\,25^2}{4} = 490.88\,mm^2$
- Required number of bars is 7 but we must use an even number to obtain symmetrical steel.
- Use eight bars of 25 mm diameter (four bars in each layer).
- Total steel area is then: $A_{st} = 3927.0\,mm^2$
- We use two layers only, to optimize steel resistance as the column may be subjected to one bending moment only.



- **c/ Check maximum compression capacity**
- We must have: $P_u \le \phi P_{n(\max)}$
- For a tied column: $\phi P_{n(\max)} = 0.65\, x\, 0.80\, x\, P_0 = 0.65\left[0.80\left(0.85 f_c^{'}\left(A_g - A_{st}\right) + f_y A_{st}\right)\right]$
- We find $\phi P_{n(\max)} = 2237342\, N = 2237.342\, kN$
- which is much greater than P_u .