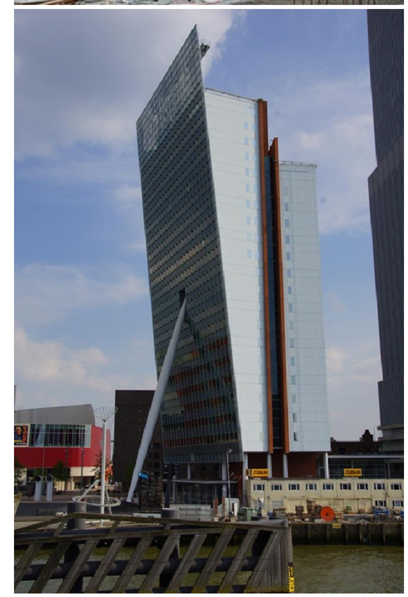
COLUMNS

Section 5.2

Columns – Definition & Materials

- **Definition**. Typically, columns are vertical structural elements that support loads from the floors and roof slabs and transfer these loads to the footings. Strictly speaking, columns need not be only vertical. Rather, they are rigid linear elements that can be inclined in any direction, but to which loads are applied solely at member ends.



- **Material.** Common column materials are:
  - Stones or block (Pillars)
  - Timber
  - Steel
  - Concrete

Columns designed to carry significant loads are made of structural steel , reinforced concrete or both (composite).

Inclined Columns

Centra at Metropark employs an asymmetrical tree column and full floor-to-ceiling trusses, 6 m deep and spanning 36m.

KPN Telecom Building, Rotterdam

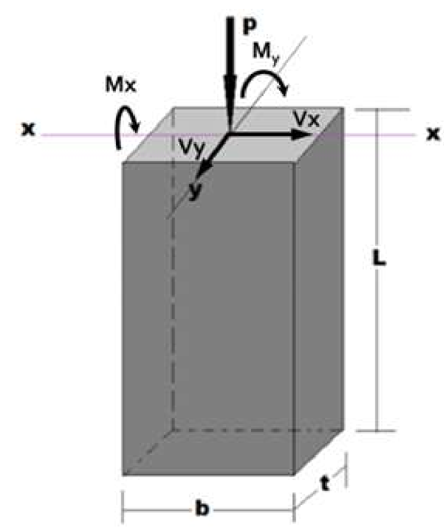
Column Stresses & Capacity

Column strength

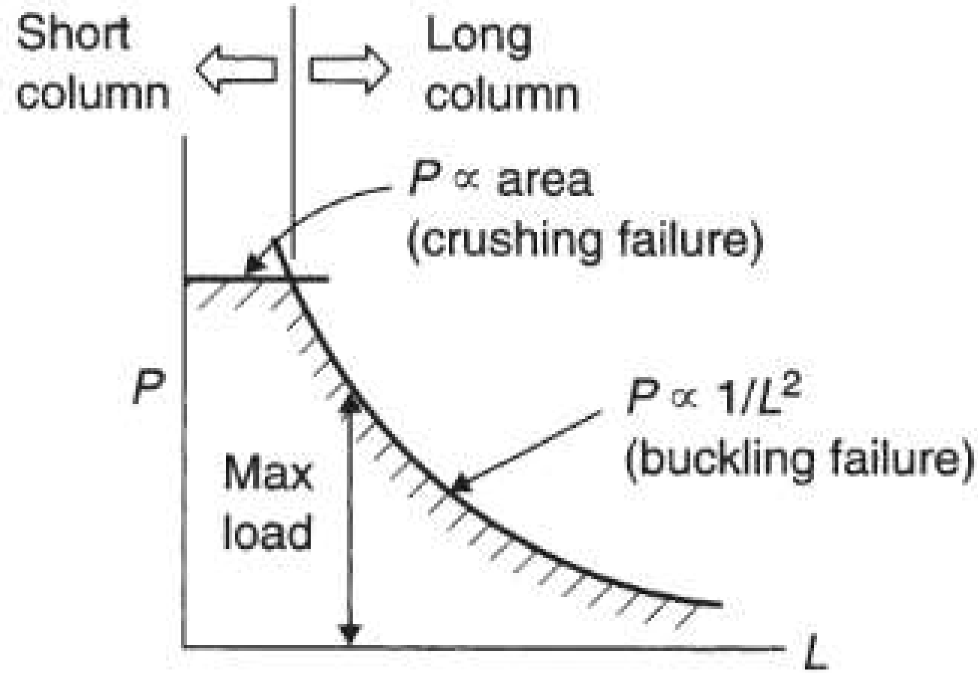
- Typically, in a post-and-beam arrangement, columns are designed primarily to carry vertical loads, making axial stress the predominant type of stress. However, if columns are part of moment-resisting frames, particularly those subjected to lateral loads, they can also experience uniaxial bending, biaxial bending, and shear forces, in addition to axial loads. Therefore, columns must be designed to safely resist all applied loads.

Column Stability

- The column's geometric configuration — including its cross-sectional dimensions, height, and end conditions — can significantly affect its load-bearing capacity as buckling may occur due to the applied axial load before material failure.

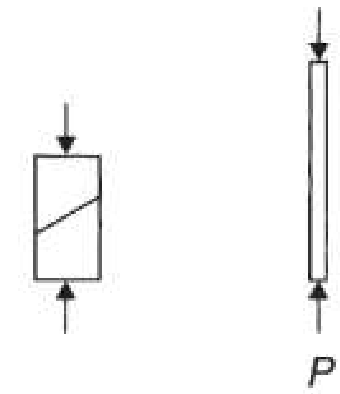


Column Stresses & Capacity

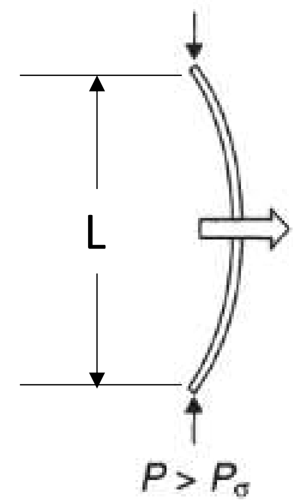


Capacity of axially loaded column

Crushing failure



Buckling failure



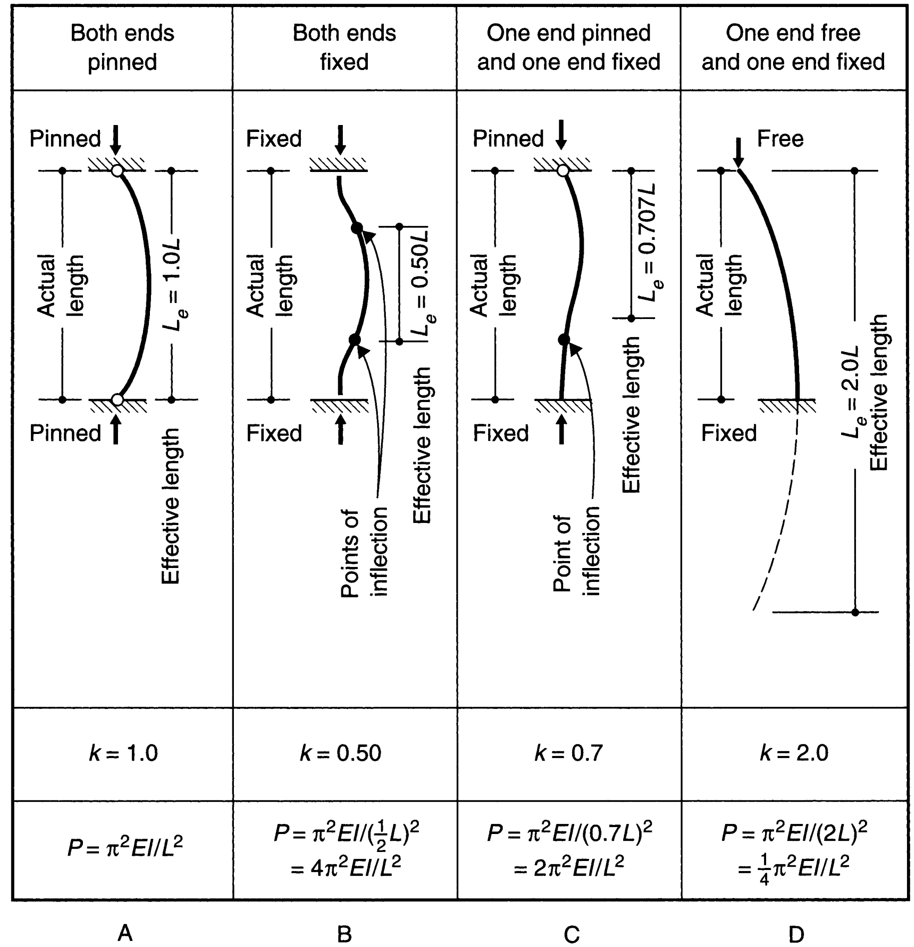
The differentiation between short and long columns is based on the slenderness ratio which is a function of the column height, end conditions, and cross-sectional properties.

End conditions and effective length

- When the column is not pin-ended, the length L shall be modified by a factor (k) as shown in the table. The modified L is called effective length (L_e).
- So the critical load become

$$P_{cr} = \frac{\pi^2 EI}{(kL)^2}$$

- And critical stress



$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 E}{\left(kL/_r\right)^2}$$

$$\boxed{slenderness\ ratio\ (\lambda) = {kL}/_{r}}$$

$$r = \sqrt{I/_A}$$

Short Columns vs. Long Columns

- **Classification**

- The design codes classify columns as short or long based on the slenderness ratio (λ). Typical values are shown below.
  - Short Column: Low slenderness ratio (typically $\lambda < 10$–12).
  - Long Column: High slenderness ratio (typically $\lambda > 30$–50).
- The classification and the corresponding design requirements are crucial in steel structures. However, concrete columns may also need to be investigated as long or short columns, especially when used in double-volume spaces or high stories.
- Typically, a concrete rectangular column is considered long when the ratio of its height to the smallest cross-section dimension is more than 12, otherwise, it is considered short.

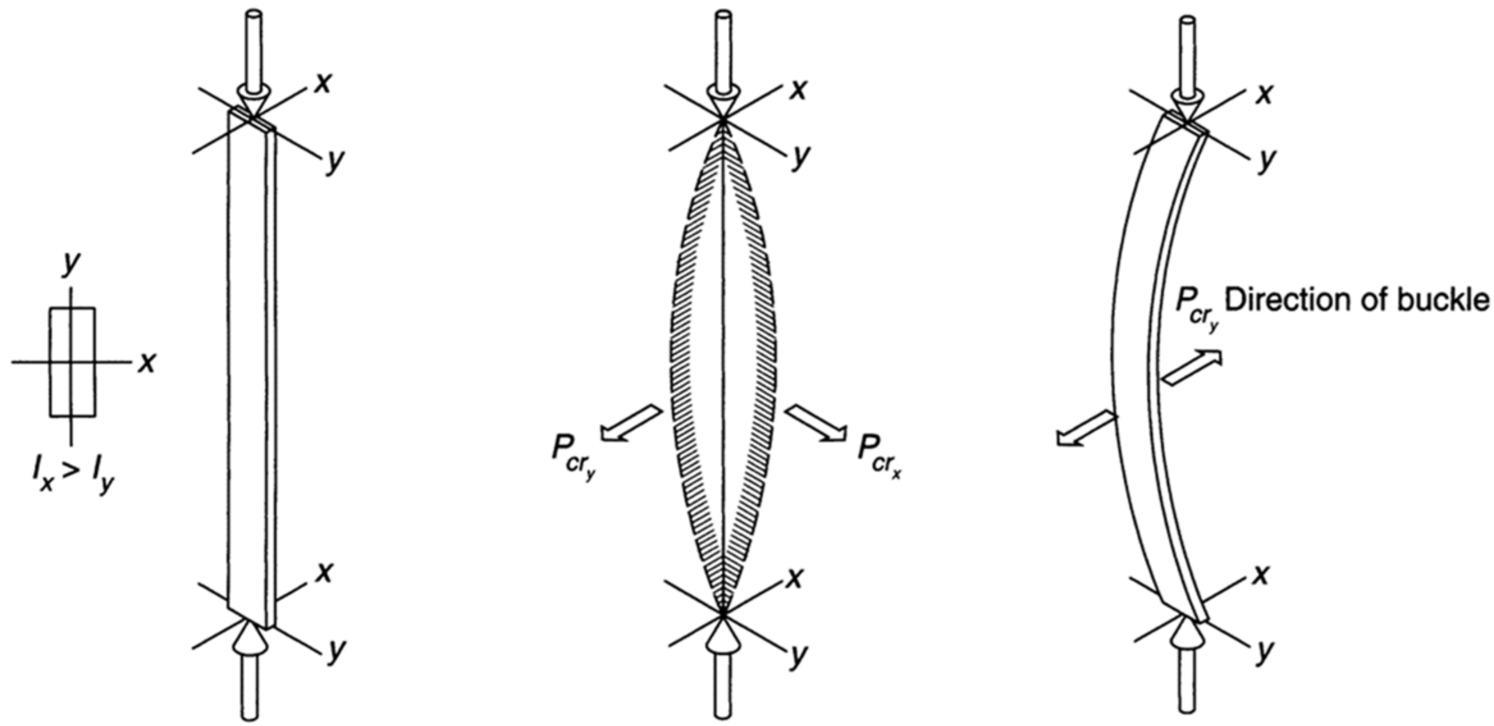
Short Columns vs. Long Columns

- **Failure Mode**. Primarily, short column fails by crushing due to direct compression or shear, while long columns tend to buckle.
- **Characteristics**

- Short columns have a high load-carrying capacity but typically fail without much warning. Their failure is primarily governed by material strength, such as concrete or steel.
- Long columns have a lower load-carrying capacity compared to short columns of the same cross-sectional area. They fail primarily due to instability (buckling) rather than material strength.

Columns Buckling

- For a specific column, the capacity is determined using the minimum moment of inertia of the section.



(a) The moment of inertia about x is greater than about y.

(b) The load required to cause buckling around y is less than load required to cause buckling around x

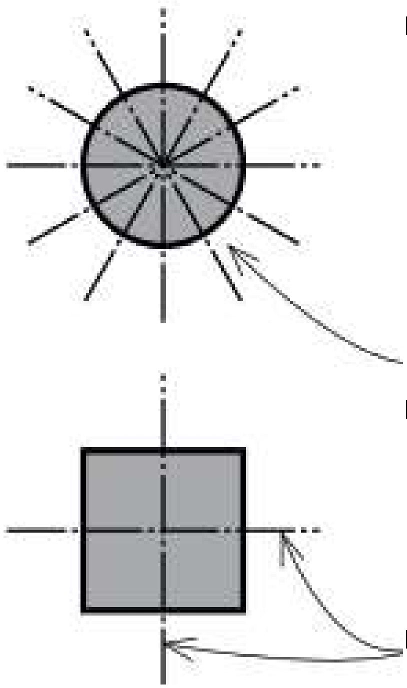
(c) Consequently, the column will buckle at $P_{cr_y} = \pi^2 EI_y/L^2$ in the mode Shown.

Improving Columns Capacity

Column capacity to resist buckling can be achieved through:

- Using efficient Cross-section and cross-section improvement.
- Longitudinal section improvement
- Bracing

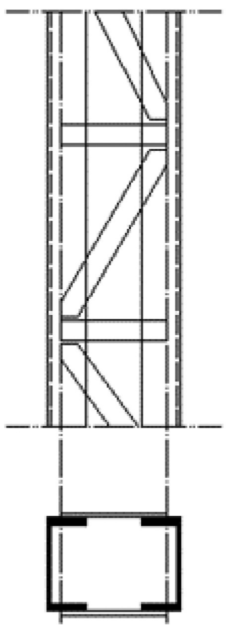
The shape of the cross-section



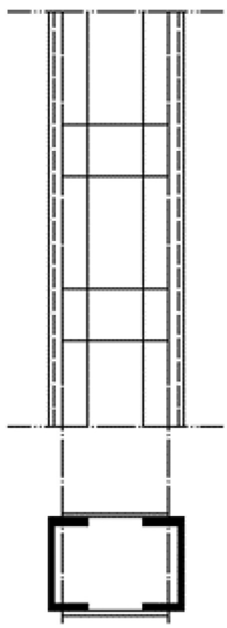
- In general, the most efficient column cross sections for axial loads are those having an equal radius of gyration about the x- and y-axes. Both axes are equivalent and thus result in the same slenderness ratio for the column.
- A circular cross-section possesses an unlimited number of axes, all being equal. None is weaker or stronger than the others.
- A square cross-section has the same radius of gyration and slenderness ratio about the x- and y-axes and so buckling could result about either axis.

- In contrast, a rectangular cross-section has two different radii of gyration. The smaller radius of gyration about its weaker axis produces a larger slenderness ratio, resulting in a smaller axial load capacity.

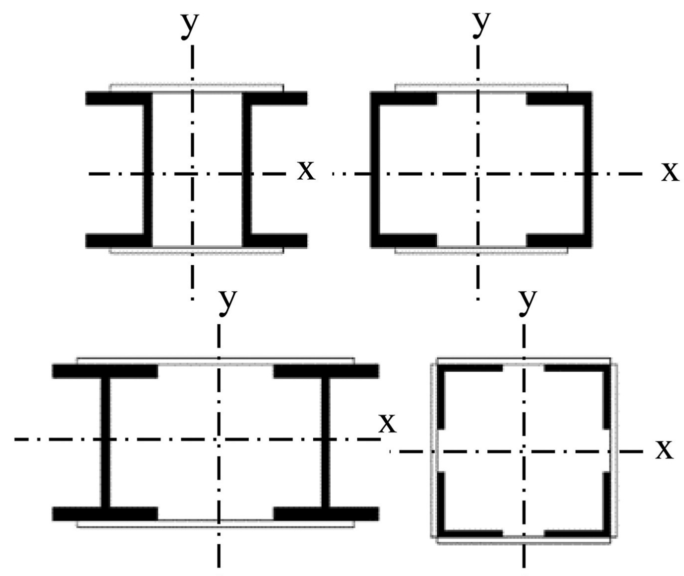
Cross-section Improvement



Laced column



Battened column



Cross sections

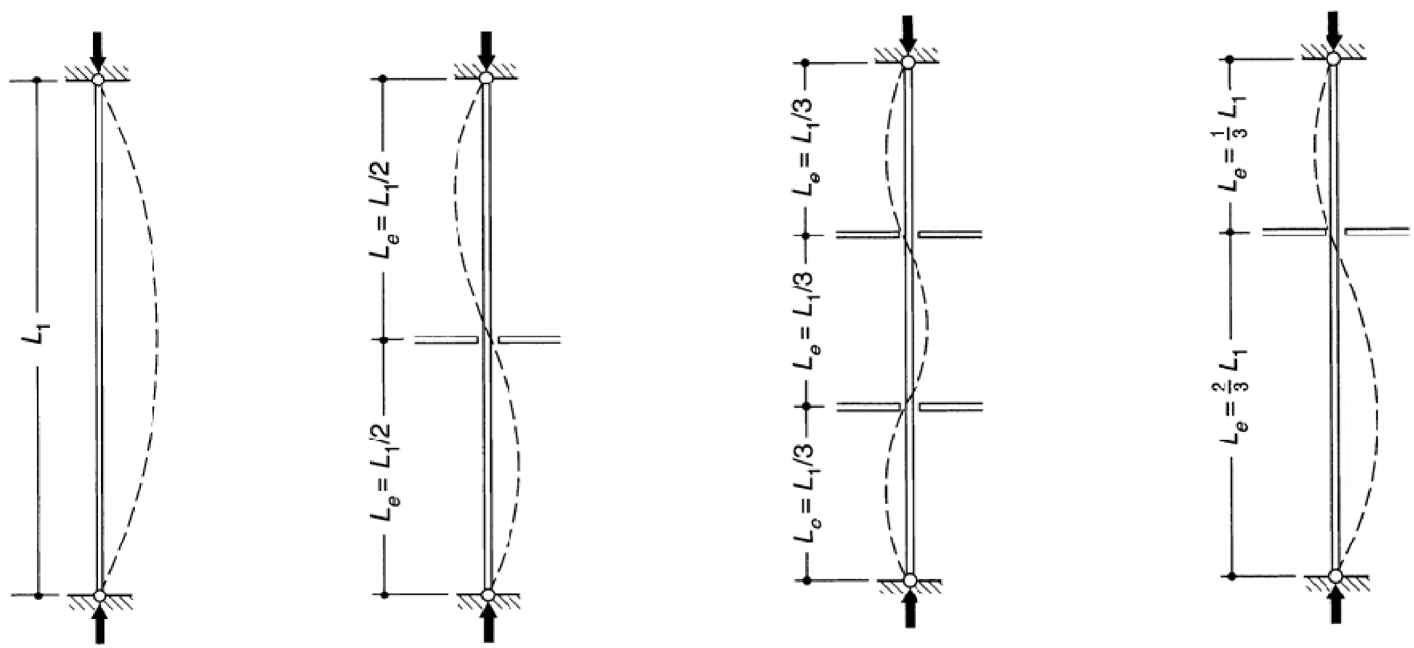
For a given amount of material, arranging the cross-section so that the material is removed as far from the centroidal axis as feasible will result in higher inertia and radius of gyration. This, in turn, will decrease the slenderness ratio and, thus, increase the column capacity to resist buckling.

Longitudinal section Improvement

Columns can be shaped to address issues of buckling. Larger sections at the mid-point provide better stiffness, while the tapering toward the supports makes the element appear visually lighter.

Bracing

To reduce column lengths and increase their load-carrying capacities, columns are frequently braced at one or more points along their length. The bracing can be part of the structural framework for the rest of the building, which also serves other functions.



$P_1 = \pi^2 EI/L_1^2$ (a) No bracing

$P_2 = \pi^2 EI/(L_1/2)^2 = 4P_1$ (b) Midheight bracing

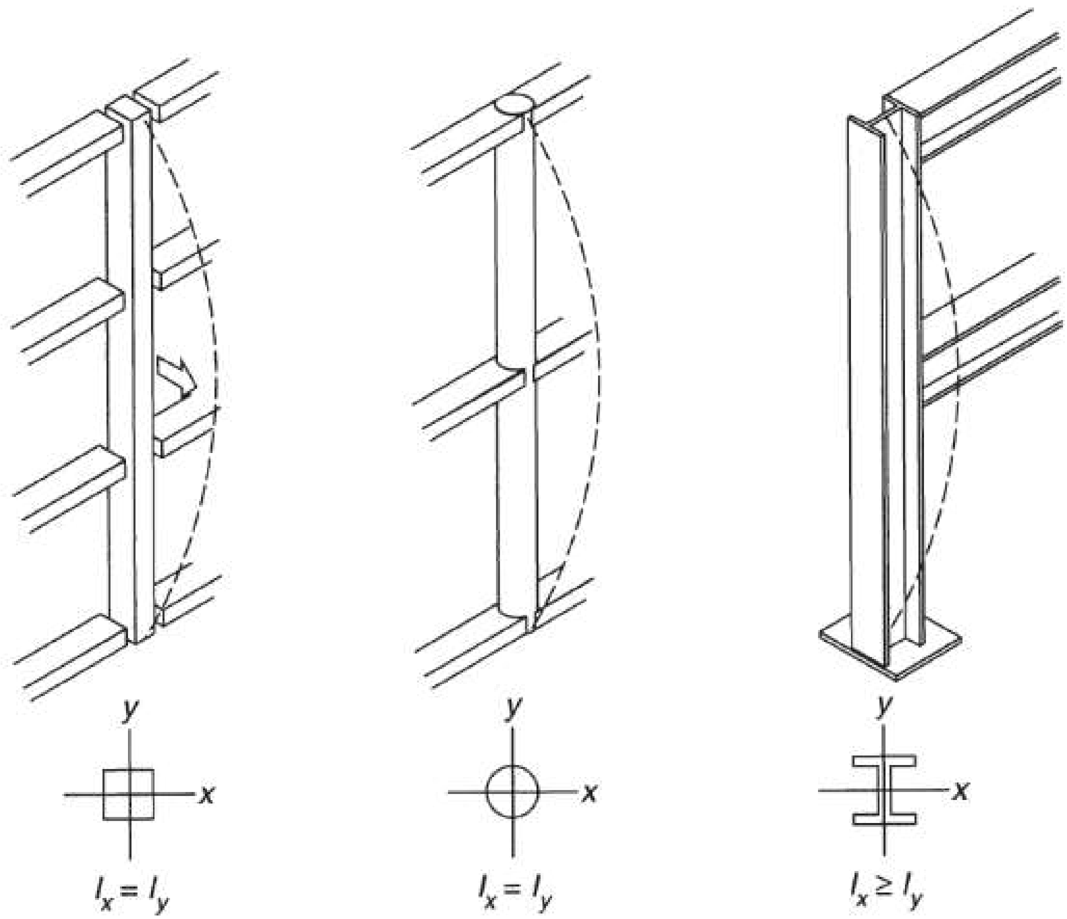
$P_3 = \pi^2 EI/(L_1/3)^2 = 9P_1$ (c) Third-point bracing

$P_4 = \pi^2 EI/(\frac{2}{3} L_1)^2 = \frac{9}{4} P_1$ (d) Asymmetric bracing

Bracing

- **Ineffective use of bracing.** Columns always buckle in the mode associated with the highest slenderness ratio (L/ r).

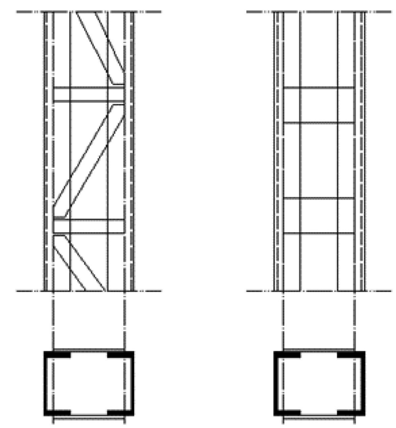
- The corresponding buckling loads relate to an unbraced or unsupported column length of L are the same as if the columns were not braced at all.



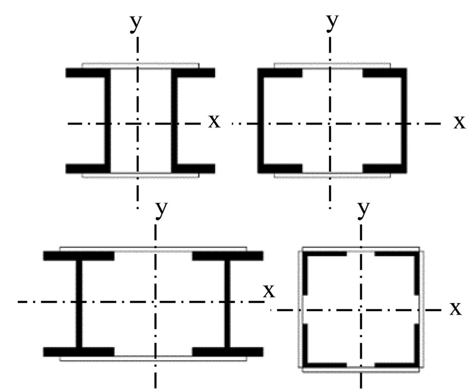
Steel Columns

- Steel columns are fabricated:

1. Utilizing the standard structural steel sections such as H, I, tubes, or pipe sections.
2. Developing a built–up section by jointing several structural sections, as shown in the figure, or welding steel plates to the desired shape.

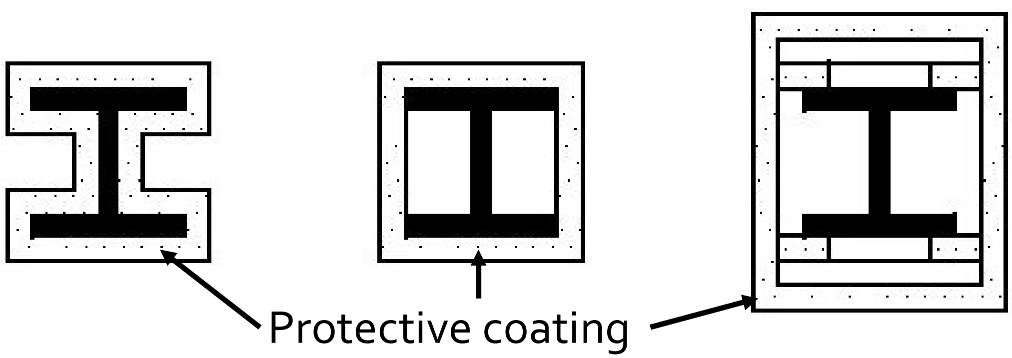


Laced column Battened column



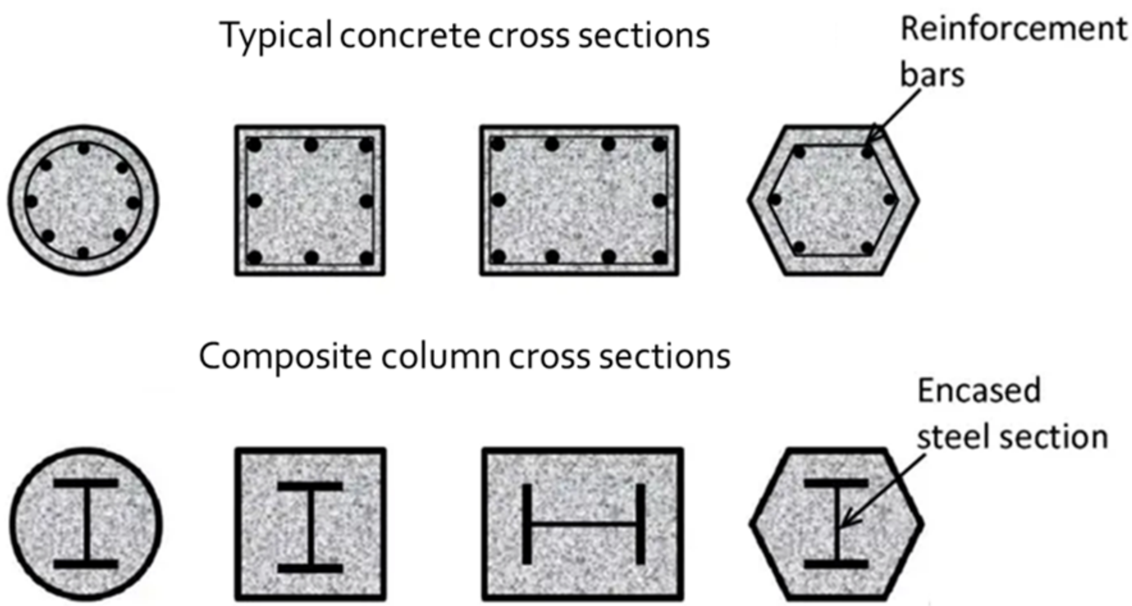
Cross sections

- In addition to buckling, steel is sensitive to temperature, so all structure steel members shall be fireproofed, as shown below.



Reinforced Concrete Columns

- Concrete columns have a breadth-to-thickness ratio of less than 3 to 4. Where the ratio exceeds 4, the element is considered a wall.



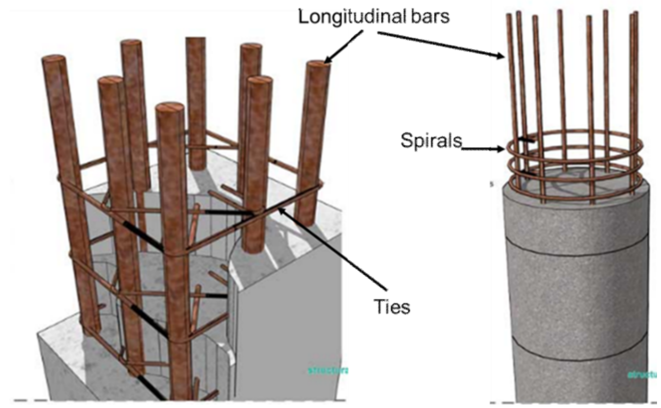
- Regarding cross-sections, they may be square, rectangular, circular, octagonal, or any of a variety of shapes in cross-section, such as T or L.

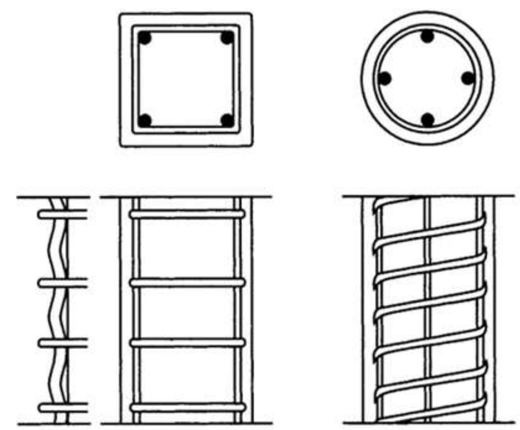
Concrete Columns Reinforcement

<u>Column Reinforcement</u>

1. Longitudinal bars - Main bars: resist compression loads and tension force due to bending.

2. Transverse reinforcement: resist shear forces, if any, and laterally support longitudinal bars to prevent buckling. These include:
   - Ties (Tied Columns)
   - Spiral (Spirally-Reinforced Columns)
   - Links





Tied column

Spirally reinforced column

- Spirals provide a confining force to the concrete core in the spiral column, thus enabling the column to sustain large deformations before the final collapse occurs.

Design and Detailing Requirements

1. **Concrete grade**: it shall be noticed that Concrete grade is important in column, detailer have to check and verify the grade that has been used by the designer. Concrete grades less than 28/35 MPa (cylinder strength/ cube strength) are not normally used.
2. **Minimum number of bars** is 4 and 6 for rectangular and circular columns respectively. The recommended minimum bar diameter is 16mm. Total number of bars shall be even to ensure symmetrical distribution to two or four sides.
3. **Minimum Cross Sectional Dimensions**: although there is no limit to column size in the code for vertical load design, it is recommended that the least dimension of the column cross section shall be $\geq$ 250mm. For practical considerations, column dimensions are taken as multiples of 5 cm.

Buckling and bracing of R.C columns

- The criteria for determining whether a column is short or long include the slenderness ratio of the column, the type of its end supports, and its support against lateral movement.
- If elements in the structure other than the column can provide the lateral support, the column is braced against lateral movement. Such elements are shear walls, elevator shafts, stairwells, and so on. A column is unbraced if it and the other columns provide the lateral support for the building.
- Unbraced columns are more prone to buckling than braced columns, and this relationship is quantified by establishing the appropriate checks. The bending moments for long columns are amplified according to the applicable codes, and then the column is designed for strength criteria only.