FRAMED STRUCTURES

Chapter 5

Frame structures

- The distinctive characteristic of a frame is that it consists of an arrangement of **beams** and **columns** that are connected at their ends with joints and supports **slab** floors.

- Frames provide optimal planning freedom, with minimal interference of structure compared with the bearing/ shear walls system.

- Frames can extend to a large number of bays in each direction and are best planned on a rectangular column grid. However, considerable variation from these is possible although this will normally increase the cost of the structure.

Frame structures

- Structurally frames can be classified as:
  - Rigid Frame: A structure where the joints do not allow any relative rotations to occur between the ends of the attached members. However, the joints may rotate as a unit. Members are continuous through the joints. As with continuous beams, rigid-frame structures are statically indeterminate.
  - Post and Beam: A structure where the joints allow relative rotation between the ends of the attached members. To be stabilized, additional bracing elements are needed.

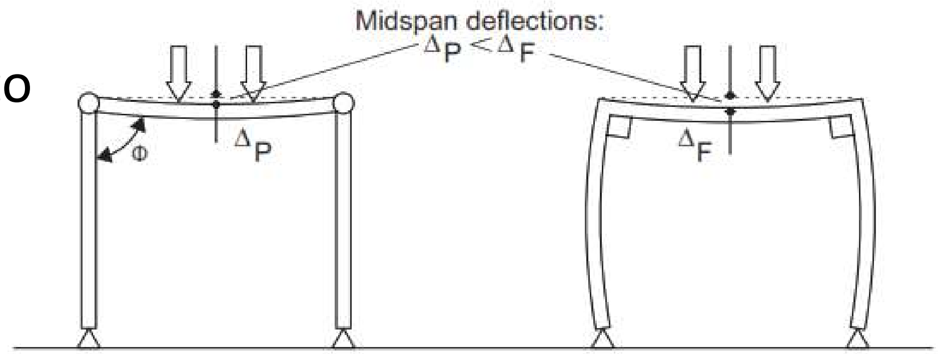
Differences between post-and-beam structures and rigid-frame structures.

Vertical loads

post-and-beam: The vertical load causes bending to develop in the beam. No moment is transferred to the columns .The columns carry only axial forces.

Rigid frame: all element are subjected to bending. Beam deflection is less. typically develop horizontal & vertical reactions

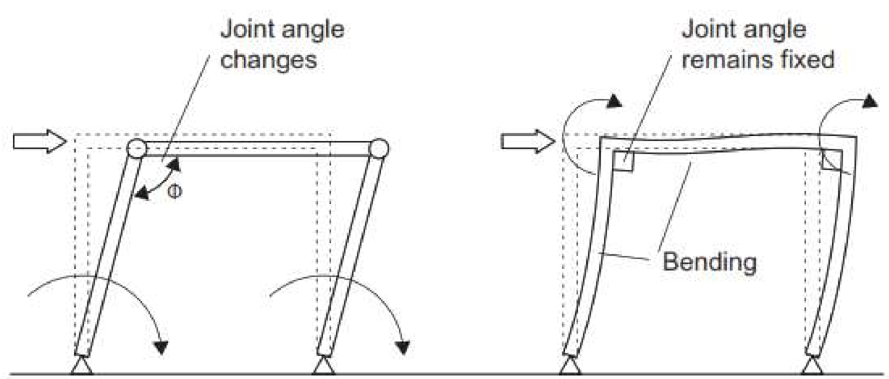
Post-and-beam Rigid Frame



Horizontal loads

post-and-beam: the structure collapse unless its stabilized.

Rigid frame: stable and all element are subjected to bending.



BEAMS

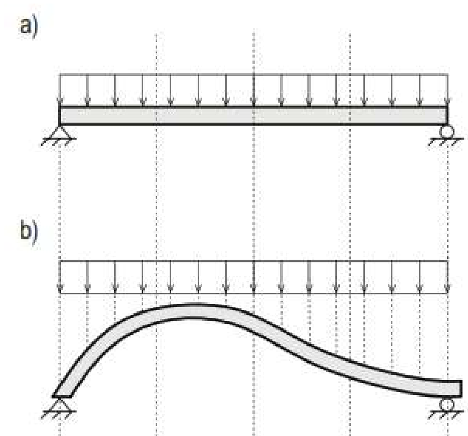
Section 5.1

Introduction

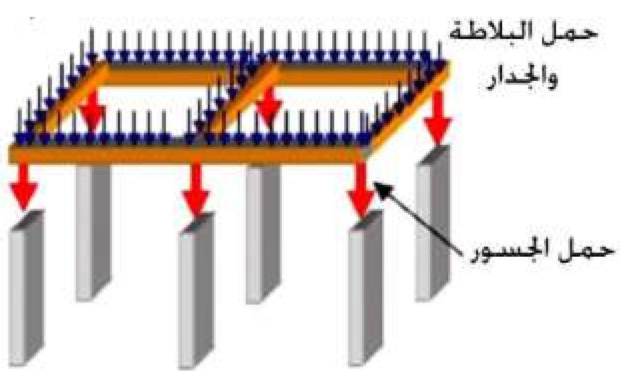
- Few structural elements are as widespread as the common beam.
- Post-and-beam systems, in which a horizontal member rests on two vertical supports, have formed the basic construction approach for much of the architecture of early and recent civilizations.
- This is partly attributable to the convenience and simplicity of the beam as an element of construction.

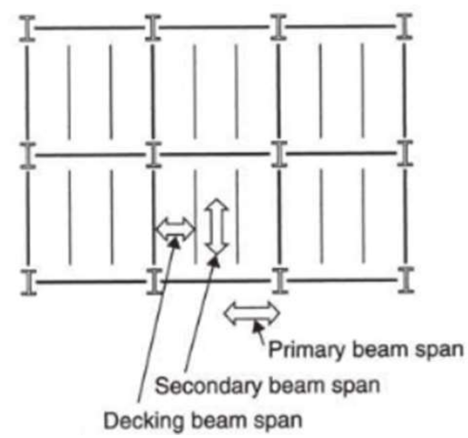
Beams - Definition

- The term beam is commonly used to describe a straight horizontal linear member (length >> other dimensions), transversely loaded, and in a state of bending.
- Some members that are curved - even in a complex way – or vertical may also be in a primary state of bending, and hence analyzed and designed as beams.

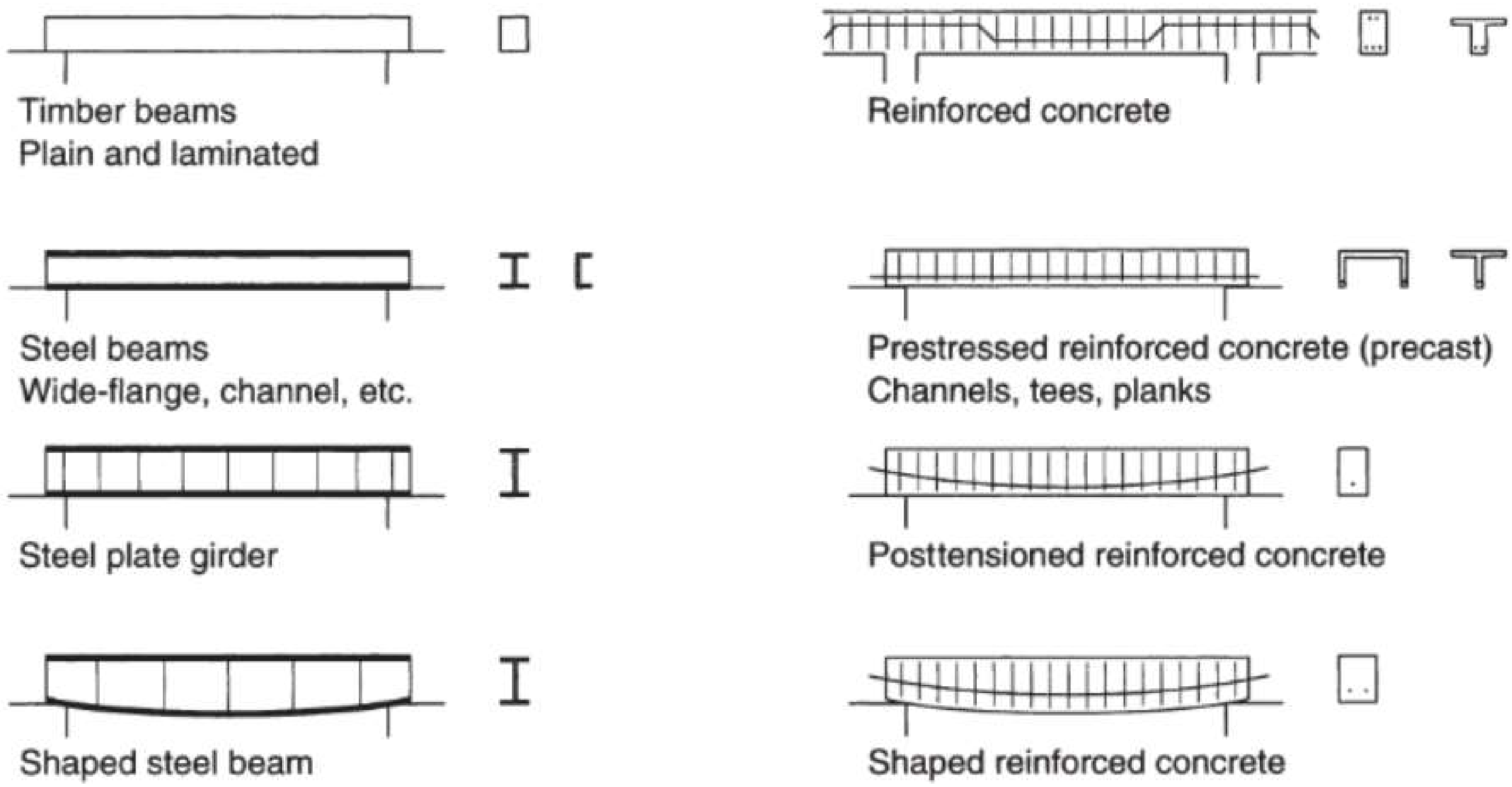


- Beams are the structural members that receive the slab loads and transform them into columns.

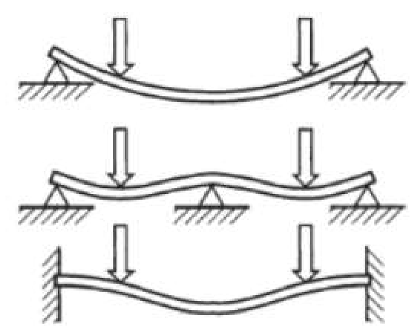




Beams Classification



Beams are classified based on (1) materials (timber, steel, concrete); (2) cross-section (rectangular, I, C, T and shaped); (3) support condition (simple, continuous, fixed).



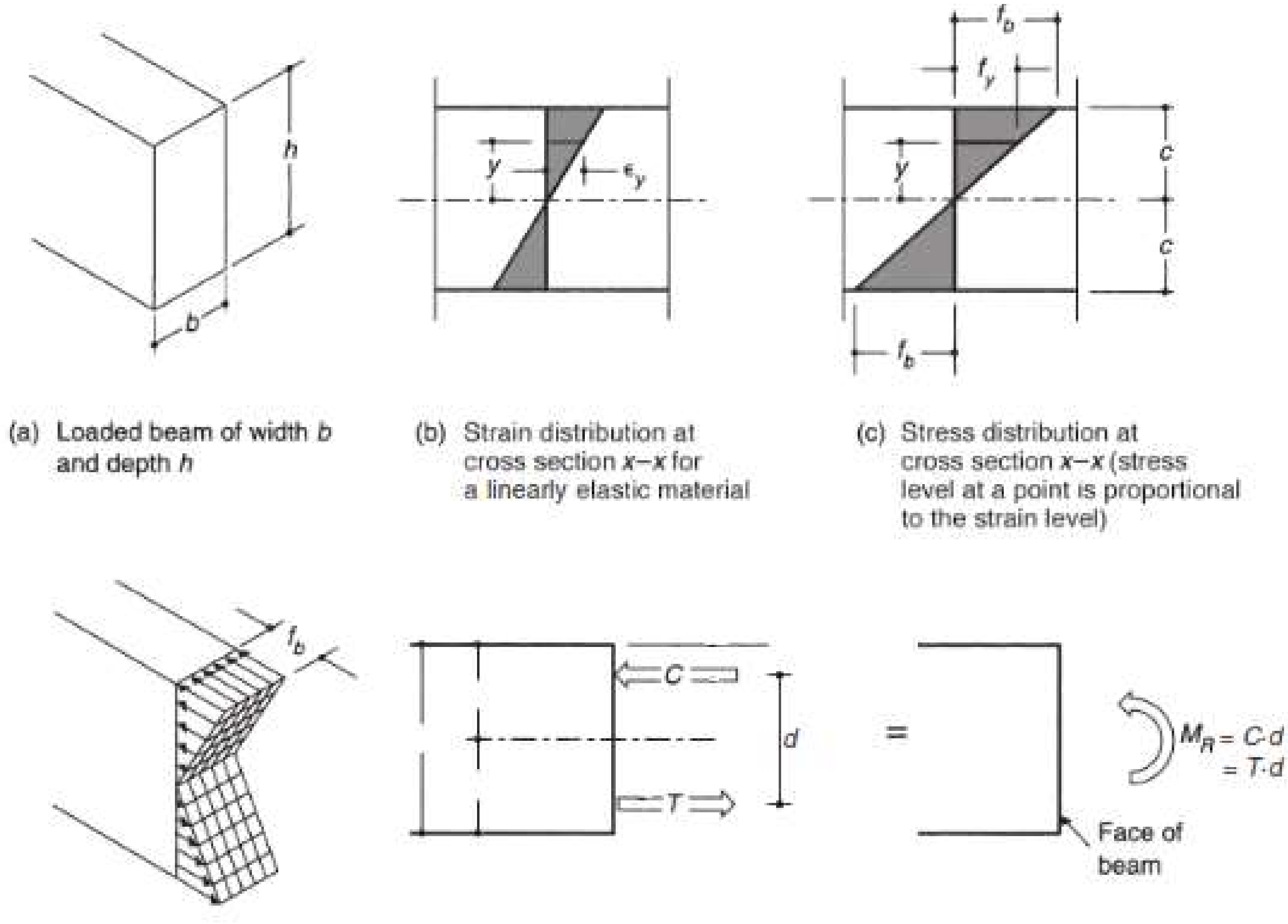
Bending stress – steel beam

According to the elastic beam theory, the bending stress (f_b) along the beam depth is

$$f_b = \frac{My}{I}, and$$

$$f_{bmax} = \frac{MC}{I}$$

I : the section's second moment of area (moment of inertia)



(a) Loaded beam of width b and depth h

(b) Strain distribution at cross section $x-x$ for a linearly elastic material

(c) Stress distribution at cross section $x-x$ (stress level at a point is proportional to the strain level)

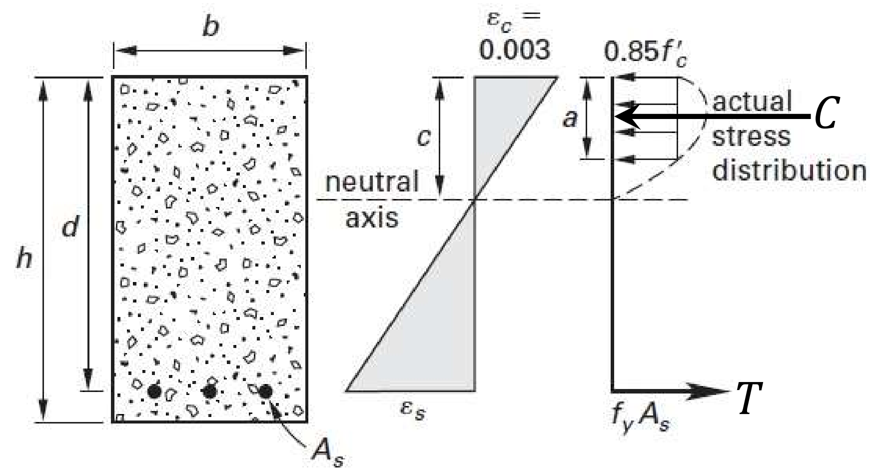
(d) Stress f_b at extreme fiber [$f_b = Mc/I$]

(e) Bending stresses acting over the face of the cross section produce equivalent forces

(f) Equivalent moment

Bending stress – concrete beam

- Assuming tension steel yield and crushing of the concrete above the neutral axis and applying equilibrium



$$\sum F_{horizantal} = C - T = 0 \rightarrow C = T$$

$$0.85 f_c' ba = A_s f_y \longrightarrow a = \frac{A_s f_y}{0.85 f_c' b}$$

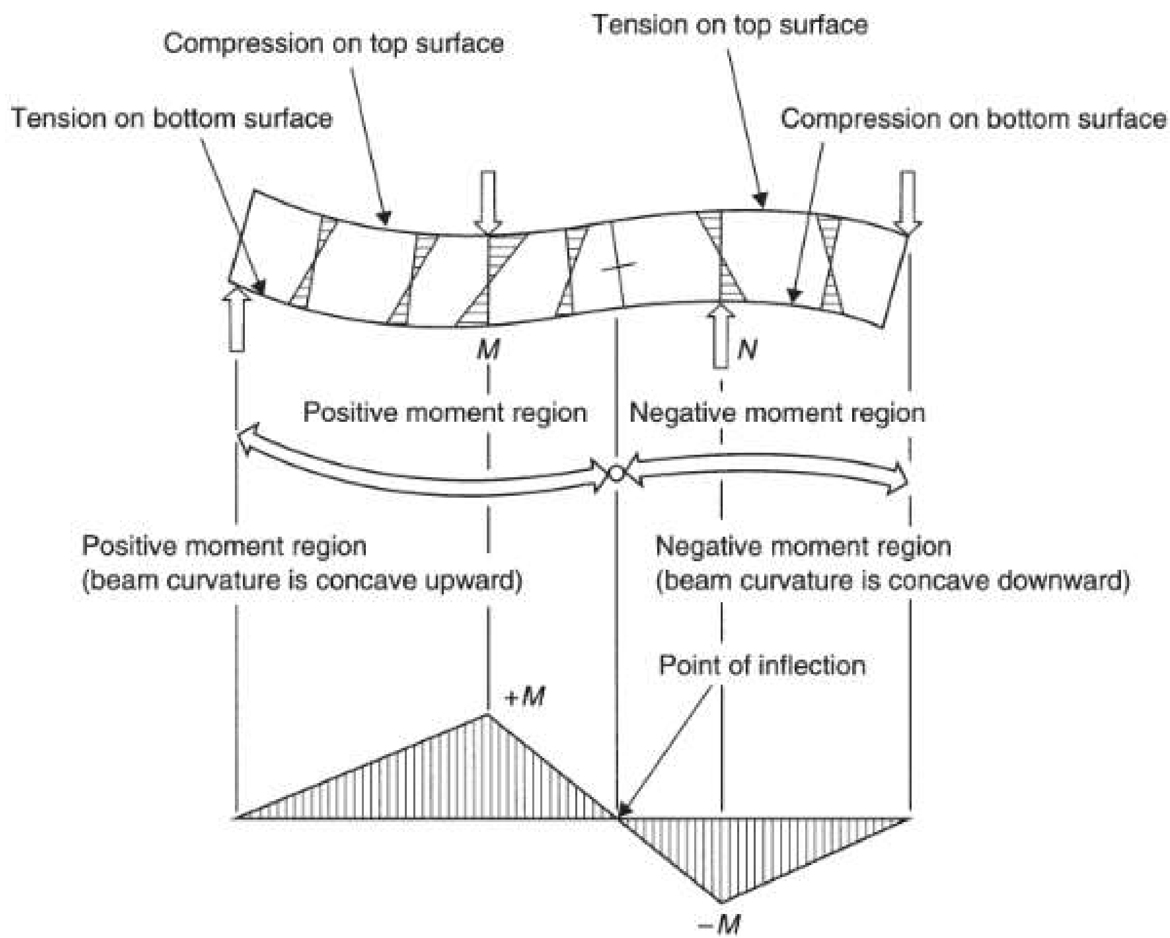
- The resultant compression force in the concrete, C, forms a couple with the resultant tension force of the steel , T. So

$$M_n = T\left(d - \frac{a}{2}\right) \longrightarrow \quad M_n = A_s f_y \left(d - \frac{a}{2}\right)$$

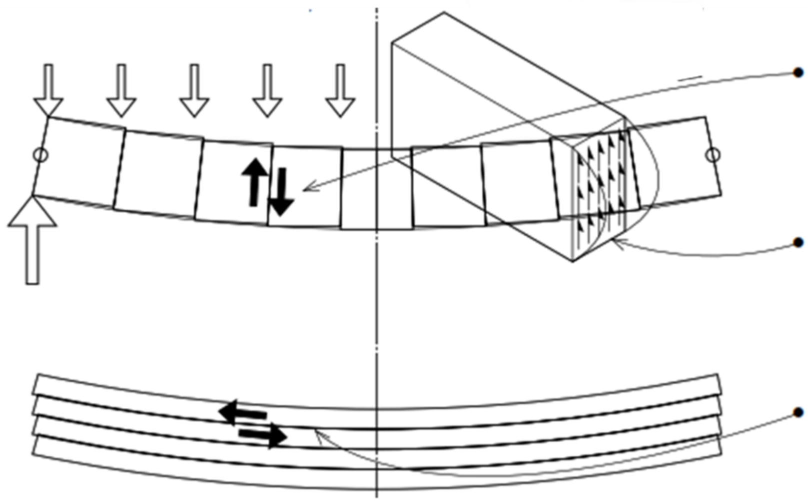
M_n: moment capacity of the beam

Bending stress variations

Because bending stresses are directly dependent on bending moments, it follows that bending stress magnitudes vary along the length of a beam as described by the moment diagram in the Figure.



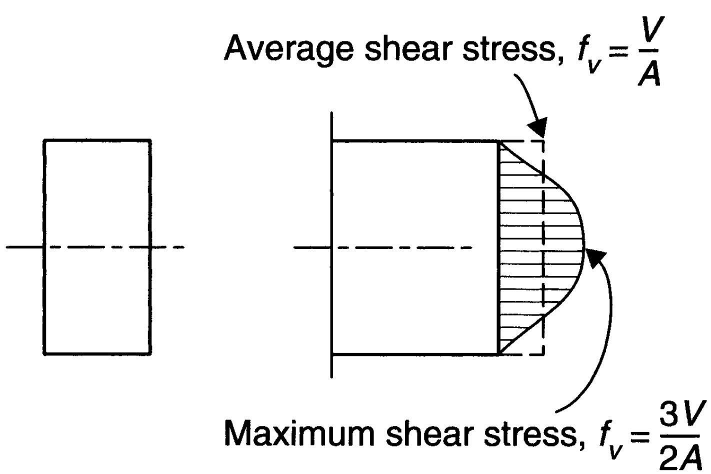
Sheer stress

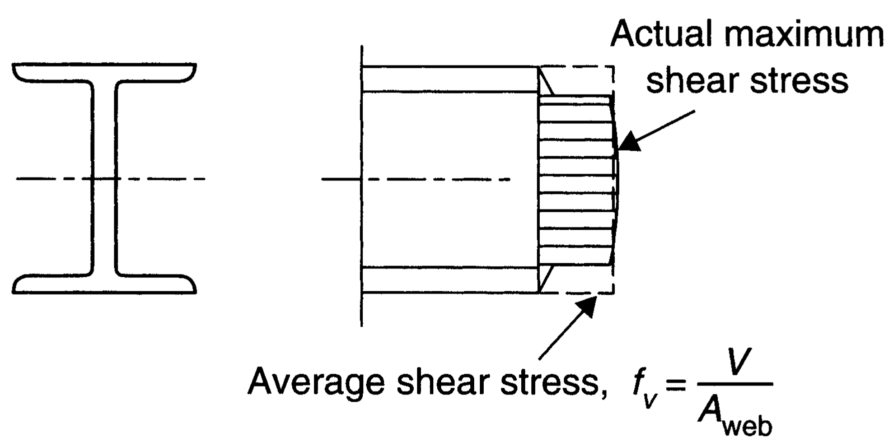


Vertical shearing stress - resist transverse shear, having a maximum value at the neutral axis and decreasing nonlinearly toward the outer faces.

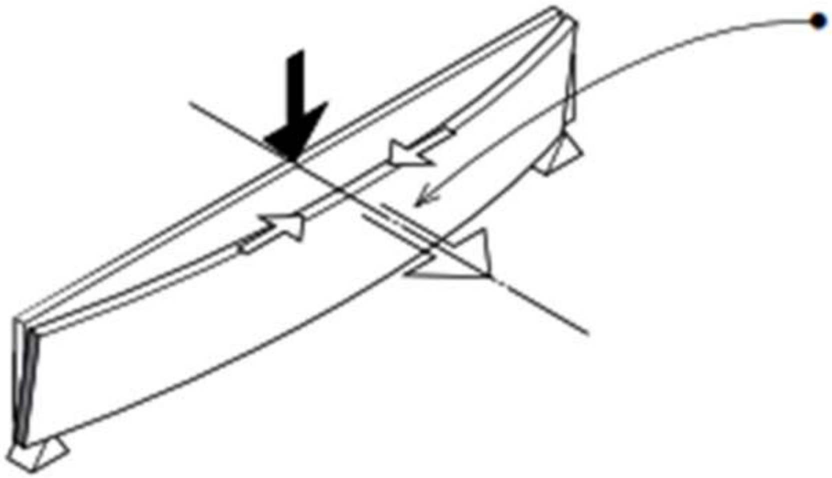
Transverse shear

Horizontal shearing stress is developed along horizontal planes of a beam under transverse loading, equal at any point to the vertical shear.





Lateral Buckling of Beams



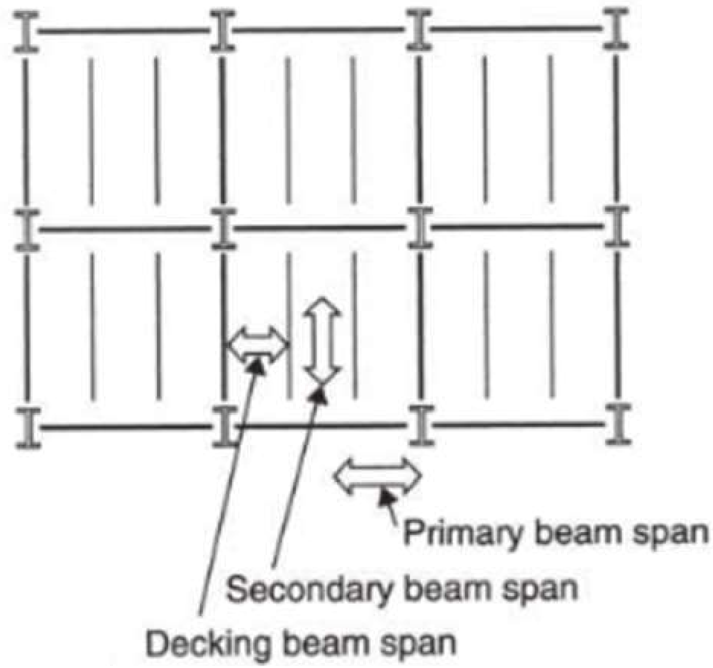
- Lateral buckling can be induced in a structural member by compressive stresses acting on a slender portion insufficiently rigid in the lateral direction. Particularly important in steel construction.

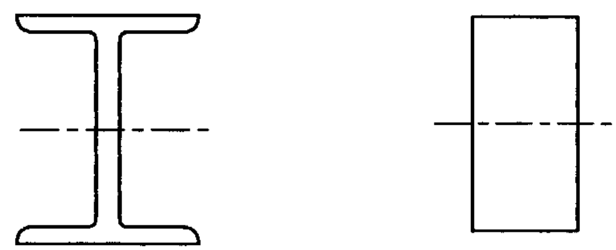
- Increasing the beam width—or in the case of a steel beam, the flange width—increases the beam's resistance to lateral buckling.
- Another alternative is to provide lateral support as shown.

Beams Design

<u>Primary variables in designing beams include:</u>

- Span.
- Member spacings.
- Loading types and magnitudes.
- Types of materials.
- Cross-sectional sizing and shaping (including variations along member lengths).
- Assembly or fabrication techniques.





Design Criteria

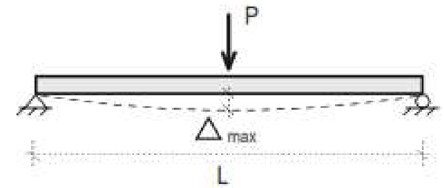
Beams design criteria include

- Strength and stiffness (safety and serviceability). Beams must be sized and shaped so that they are sufficiently strong to carry applied loadings without undue material distress or deformations.
- Economy and appearance.

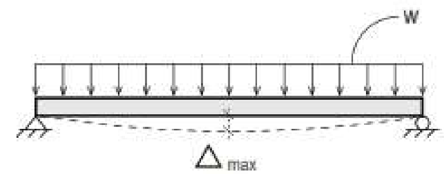
Beams Design

Effect of the beam span on the beam stresses and deformation

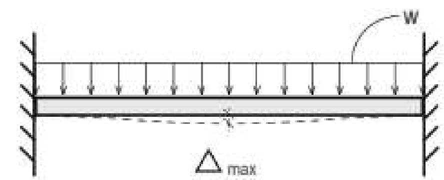
- For a beam of constant cross-section loaded with a uniformly distributed load (w), if the span is doubled deflection increases 16 times, the bending four times, but shear would only double.
- Thus, for long bending members deflection usually governs; for medium span bending governs, yet for very short ones, shear governs.



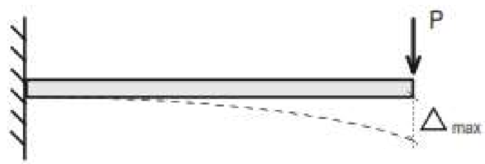
$$\Delta = \frac{PL^3}{48EI}$$



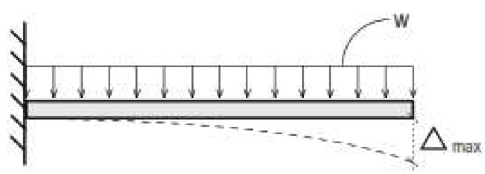
$$\Delta = \frac{5wL^4}{384EI}$$



$$\Delta = \frac{wL^4}{384EI}$$



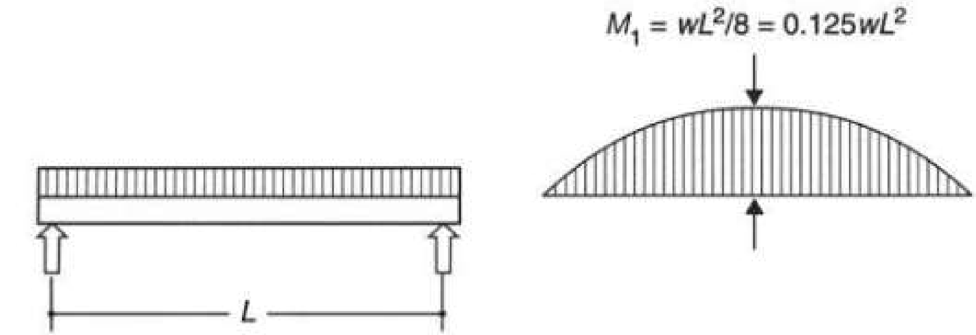
$$\Delta = \frac{PL^3}{3EI}$$



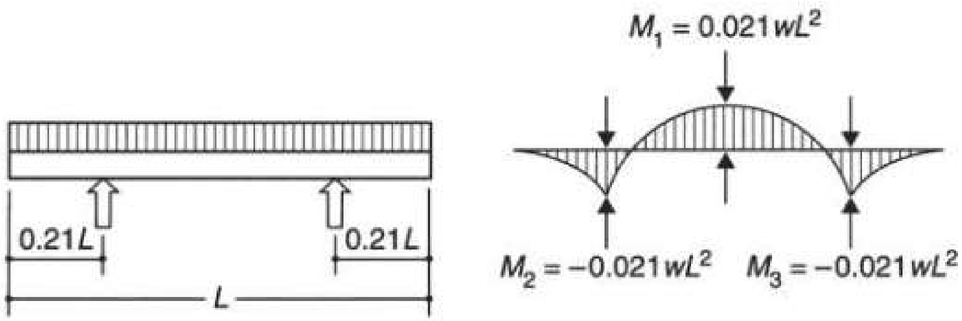
$$\Delta = \frac{wL^4}{8EI}$$

Beams Efficiency Improvement

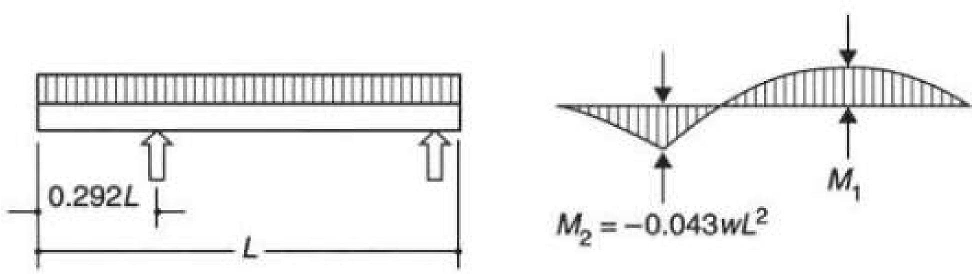
Locating supports to minimize design moments in beams.



(a) Simply supported beam carrying uniformly distributed load: The beam must be designed for a moment of $wL^2/8$.



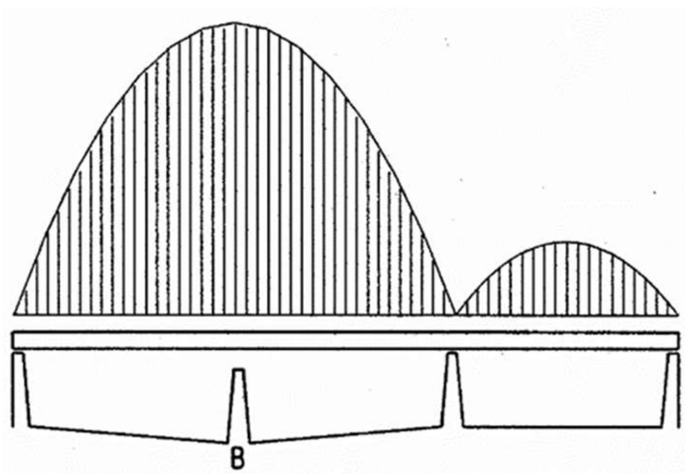
(b) Optimum support locations—both support locations variable: By moving in both supports, a certain amount of the positive moment present can be made equal to the negative moment present; thus, the beam can be designed for a $0.021wL^2$ moment rather than a $wL^2/8$ (or $0.125\ wL^2$) moment. Significant material savings result.



(c) Optimum support locations—one support location variable: Instead of moving in both supports, only one can be moved and a balance between positive and negative moments achieved (note that $M_1 = M_2 < wL^2/8$) and material savings can still result.

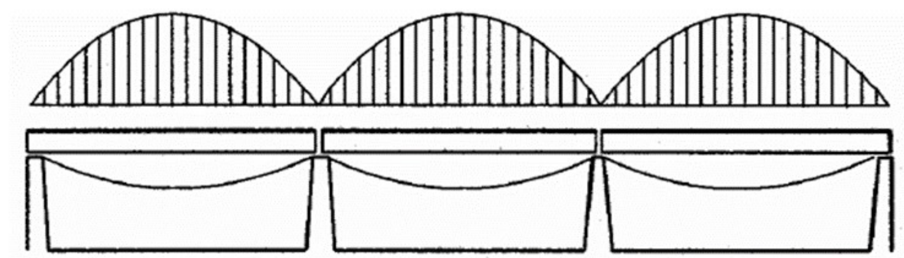
Beams Efficiency Improvement

Beams Continuity. Continuous beams extending over more than two supports develop greater rigidity and smaller moments than a series of simple beams having similar spans and loading. However, continuous beams are sensitive to deferential support settlement which can lead to failure due to moment increase resulting from support settlement.

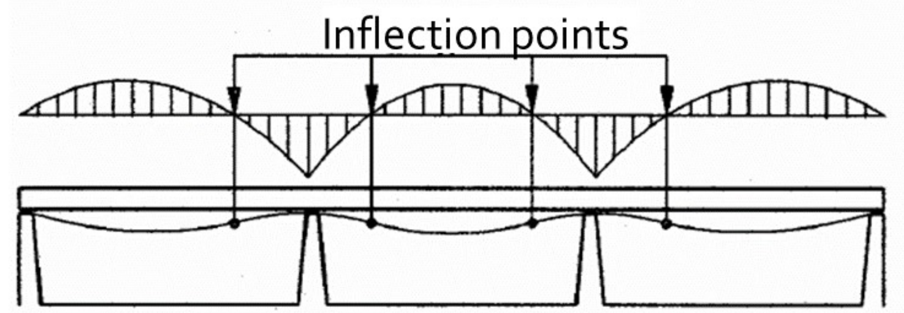


Moment increase due to support settlement at B.

Discontinuous beams



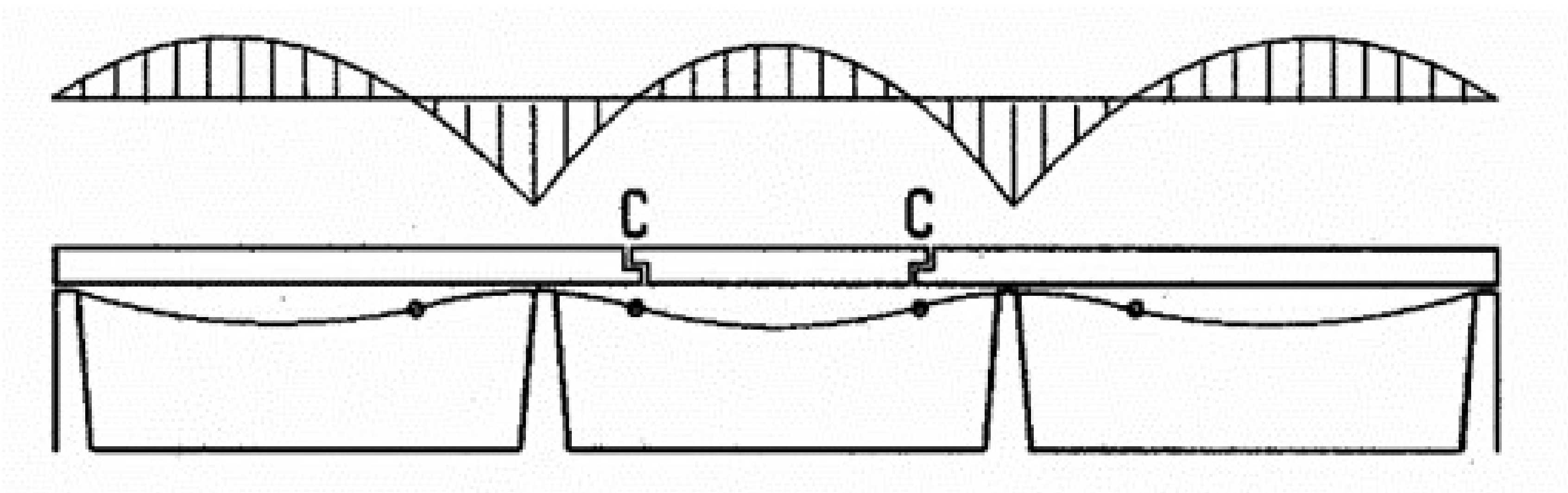
Continuous beam



Beams Efficiency Improvement

Gerber beam

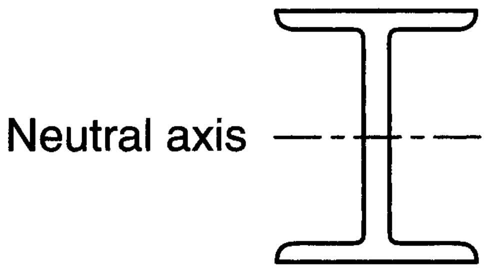
The Gerber beam has hinges at inflection points to reduce bending moments, takes advantage of continuity, and allows settlements without secondary stresses.



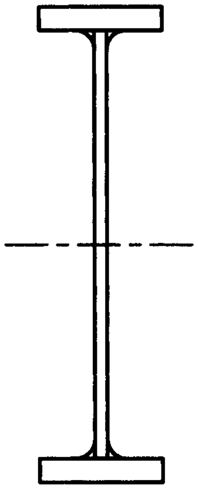
Beams Efficiency Improvement

Beam Cross-section

- The moment of inertia (I) or the section modulus (S) is of primary importance in beam design. I is directly related to the section depth and geometry.



(a) Steel wide-flange beam.



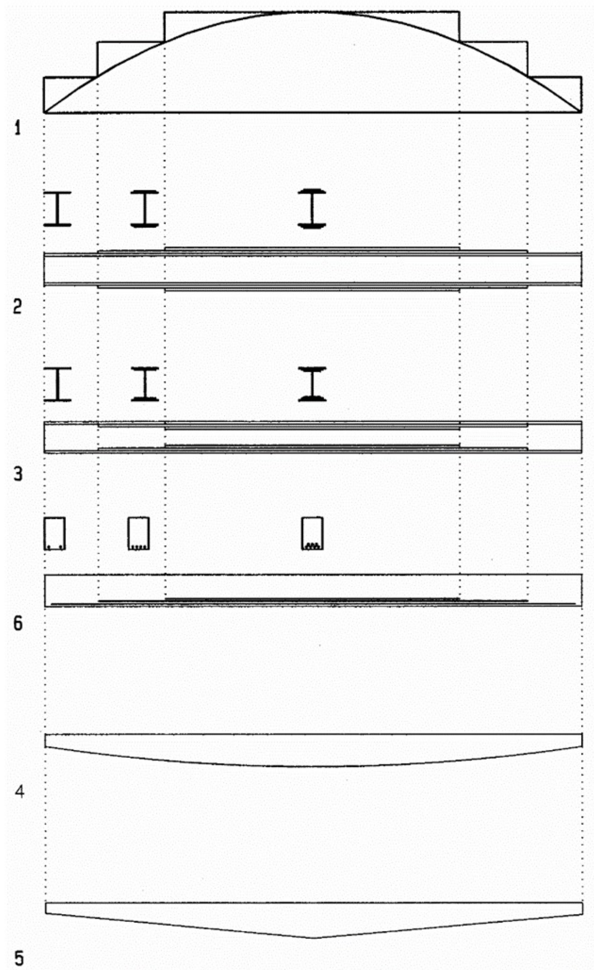
(b) Plate girder

Efficient beam cross-sectional shapes. Material is removed from the neutral axis to maximize the moment of inertia of the cross-section and hence its resistance to bending.

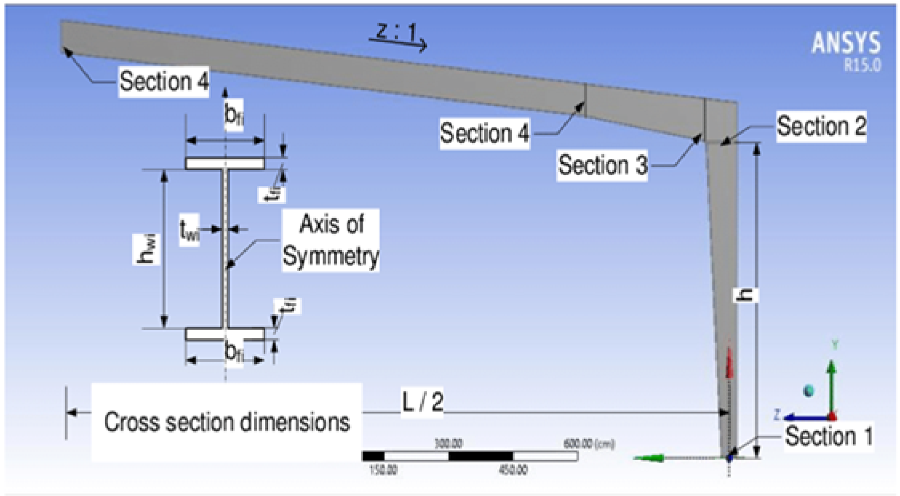
Beams Efficiency Improvement

<u>Shaping a Beam along Its length.</u> Optimizing long-span girders can save scares resources. The following are a few conceptual options to optimize girders.

- 2 and 3: Steel girder with plates welded on top of flanges for increased resistance
- 6: Reinforced concrete girder with reinforcing bars staggered.
- 4: Girder of parabolic shape, following the bending moment distribution
- 5: Tapered Girder, approximating bending moment distribution



Shaping a Beam along Its length

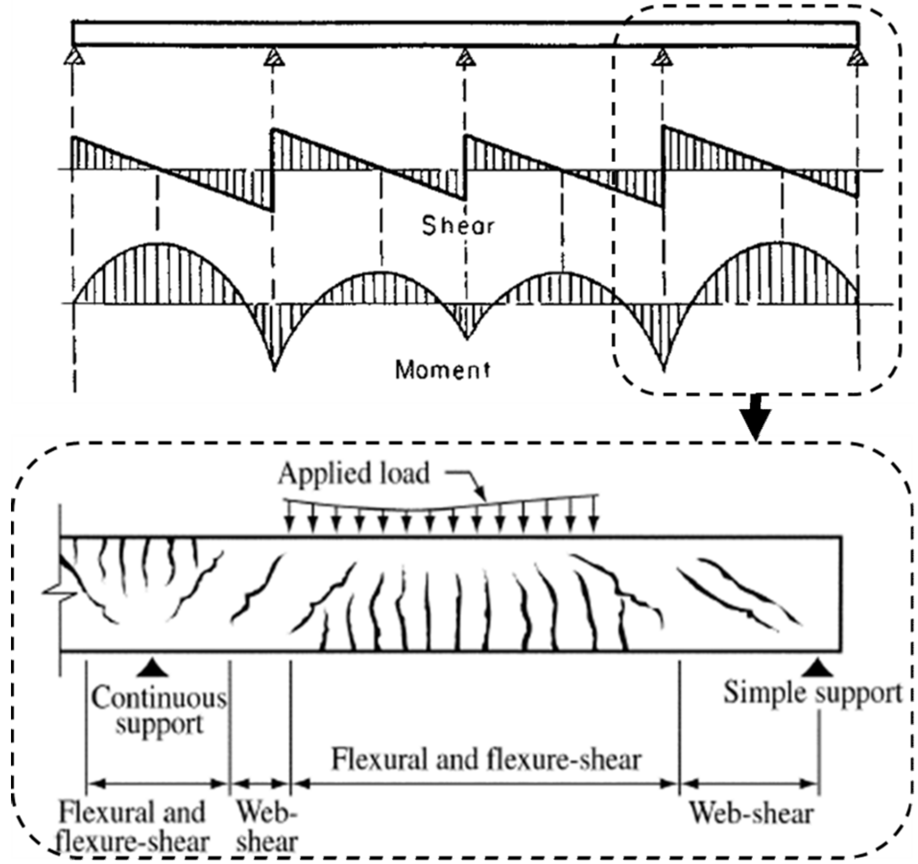


Typical Beam Span and Depth Range

- Initial sizing of the beam depth is about L/8 for cantilever beams to L/21 for continuous beams.
- The normal span range for reinforced concrete beams is 4.5 to 10 m. Spans of up to 20 m are occasionally used but depths of around 1.5 m are required for this span, and a large volume of concrete is therefore involved. Spans greater than 20 m are possible but other types of structure will normally perform better.
- Beams made of steel can be used for long spans. Shown in the photo, a 61.5m single-span steel girder is believed to be the longest ever in the UK.

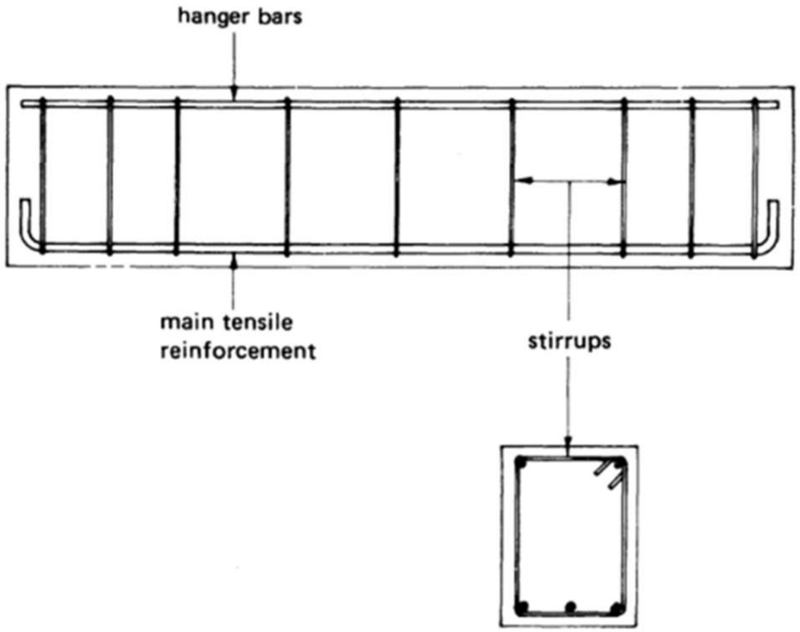
Concrete Beams

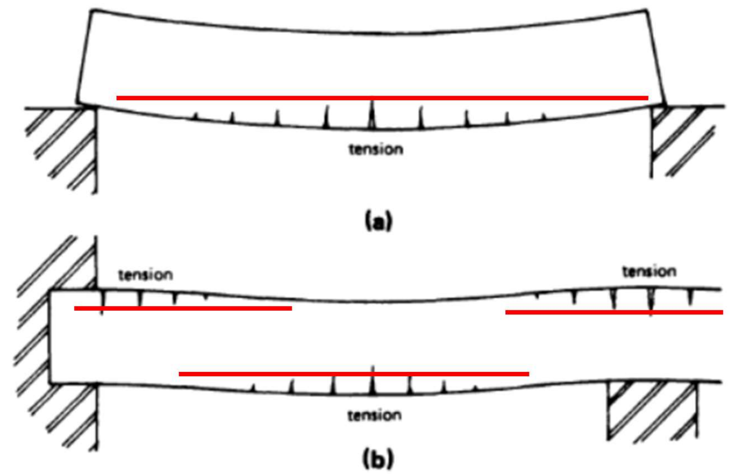
- As concrete is weak in tension, a concrete beam subjected to a distributed load will show the pattern of cracks shown in the figure due to the moment and shear stresses before failure.
- Accordingly, flexural reinforcement in the form of straight bars crossing the flexural cracks is needed to resist the moment on the tension side.



- Additional reinforcement shaped as vertical ties (stirrups) shall be installed to resist the shear stress.

Beam Reinforcement

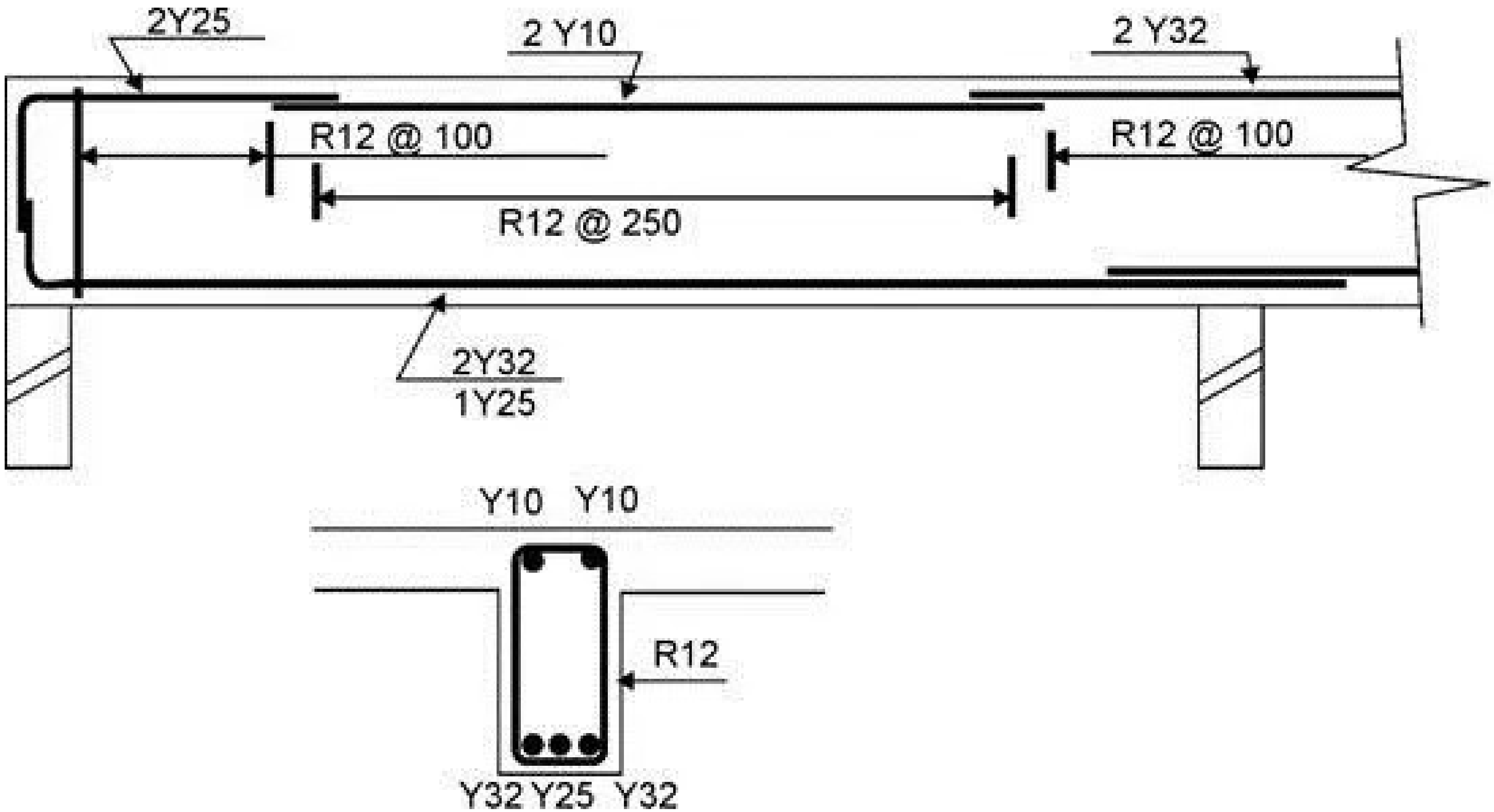




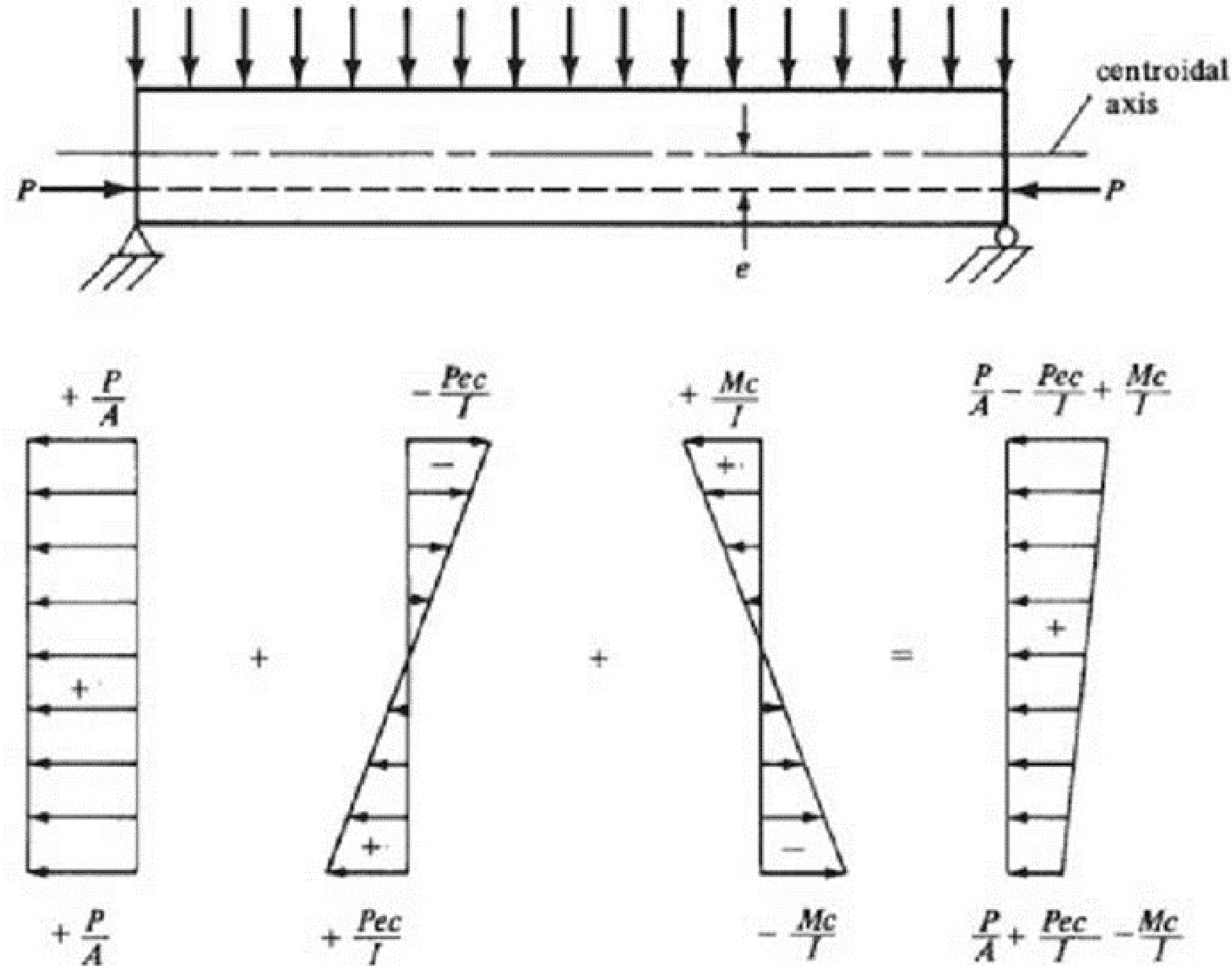
- Main Reinforcement – Tension & Compression.
- Shear Reinforcement
- Deflection control Reinforcement.
- Crack control Reinforcement
- Ductility Reinforcement
- Hanger Bars

The main flexural Reinforcement is located at the tension sides of the beam.

Typical continuous Beam Reinforcement



Prestressed Beams - Concept



Prestressed Beams

T, Y, I, and hollow sections can be produced easily in prestressed concrete.

Prestressed Beams