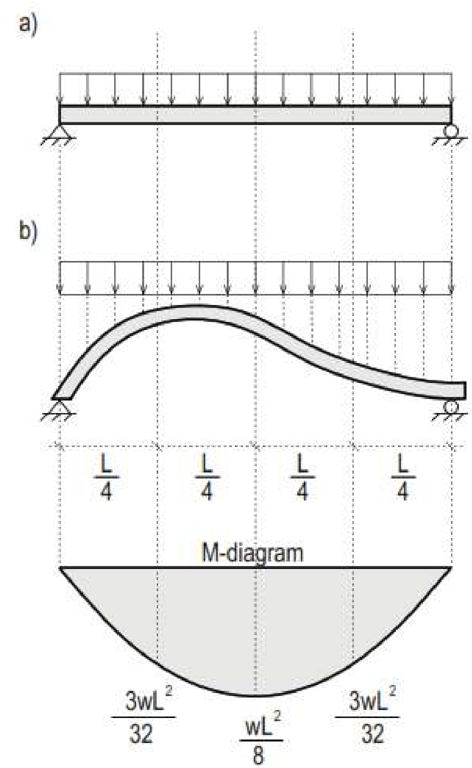
BEAMS

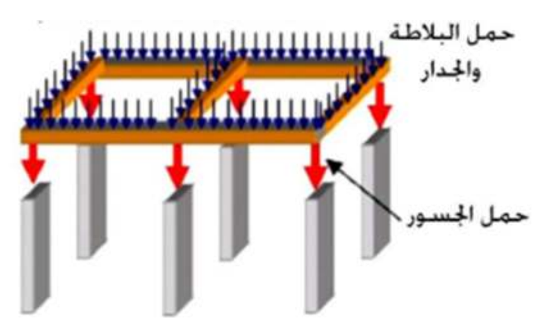
Section

3.6

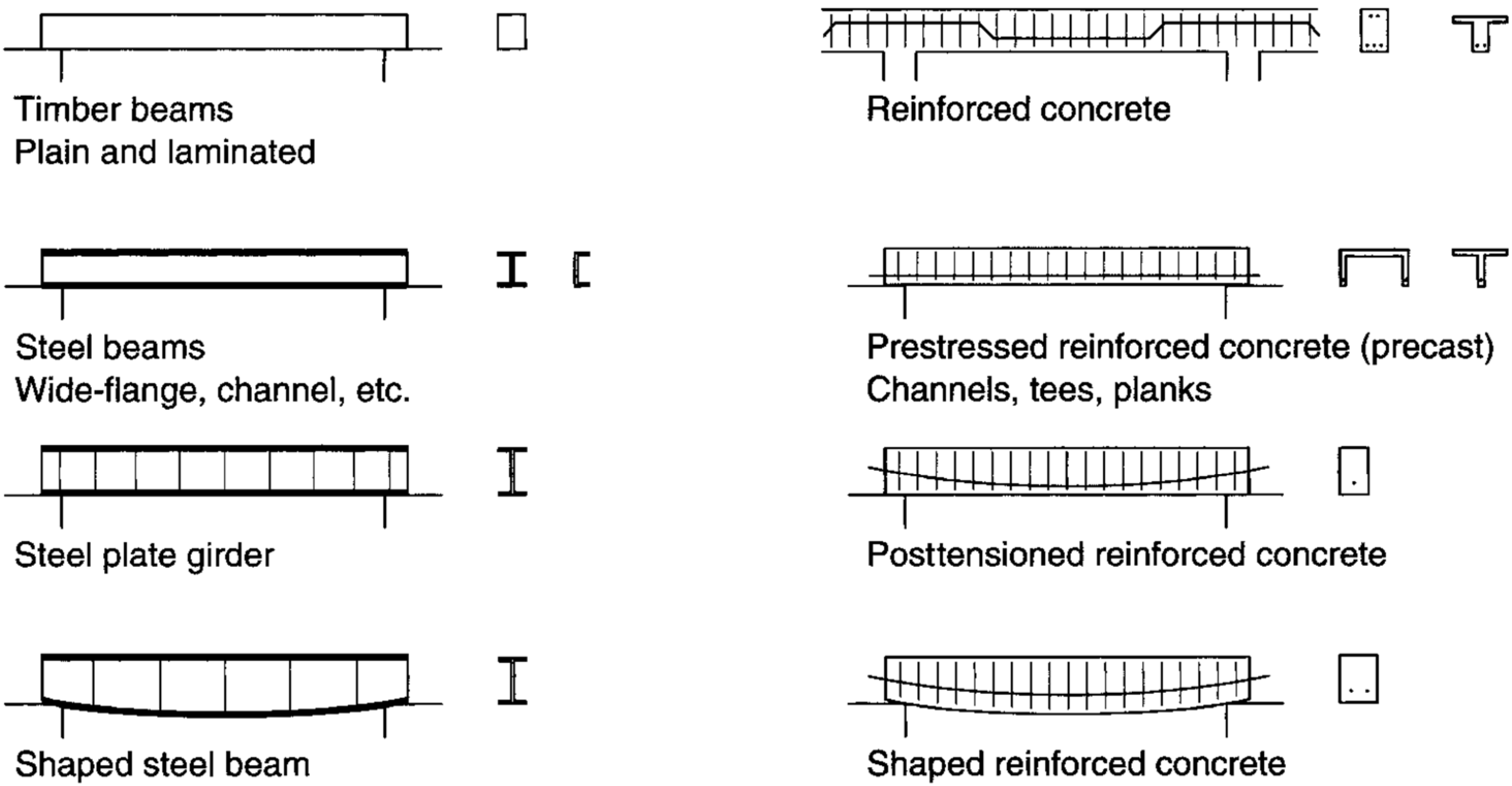
Introduction

- The term beam is commonly used to describe a straight horizontal linear member (length >> other dimensions), transversely loaded, and in a state of bending. They are the structural members that receive the slab loads and transform them into columns.
- Some members that are curved - even in a complex way - may also be in a primary state of bending, and hence analyzed and designed as beams.
- Few structural elements are as widespread as the common beam. This is partly attributable to the convenience and simplicity of the beam as an element of construction.





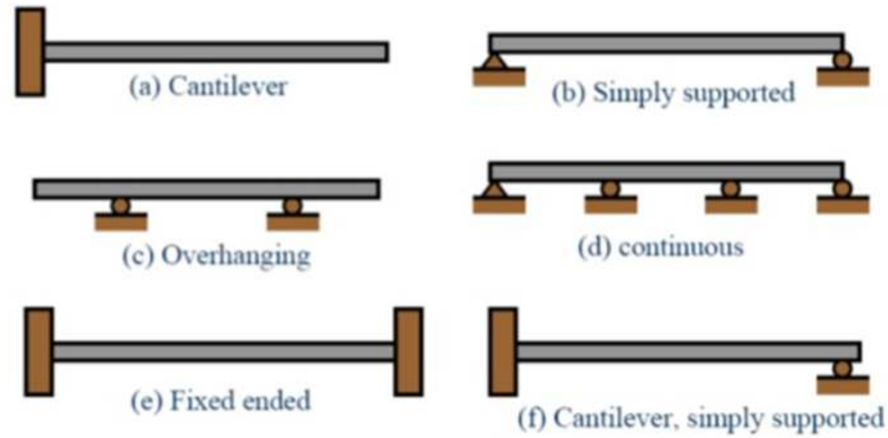
Beams Classification

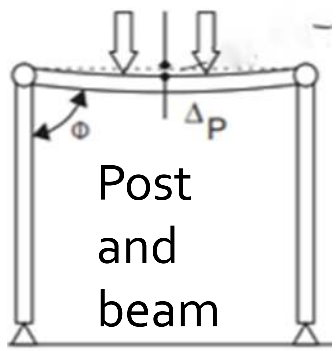


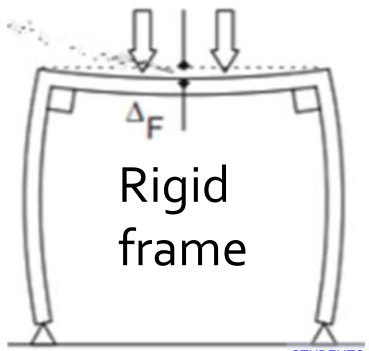
Beams can be made from different materials in several longitudinal and cross-section shapes.

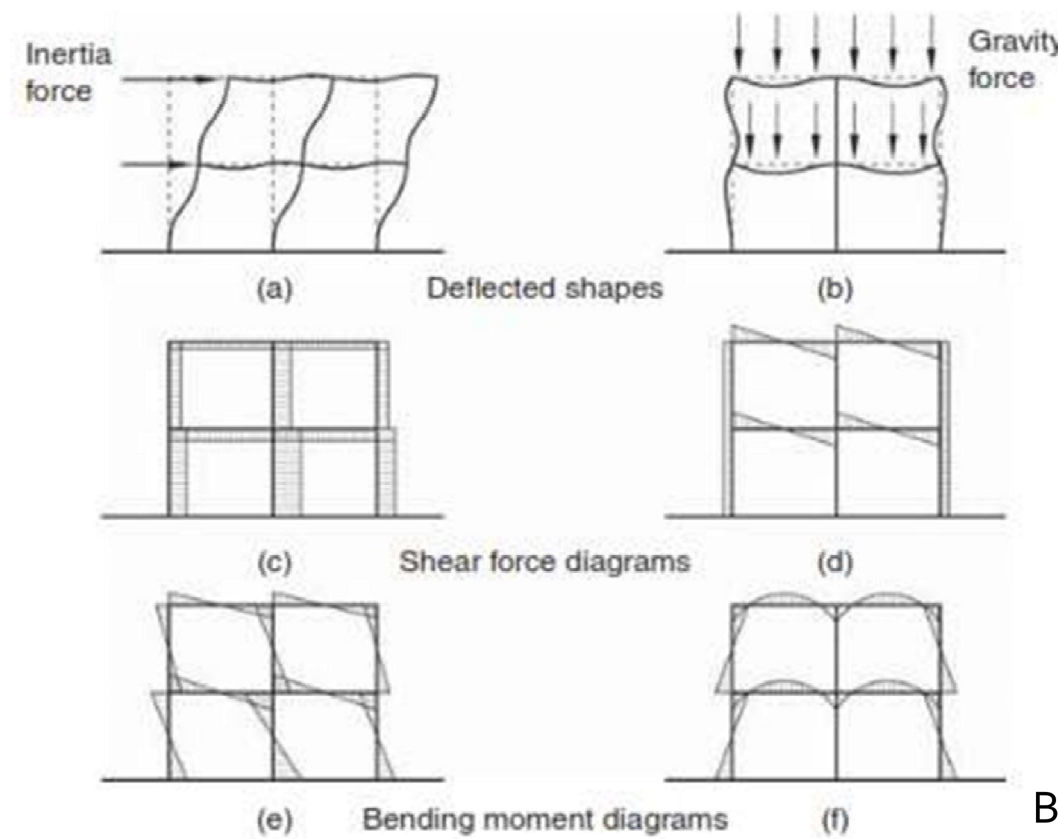
Beams Classification

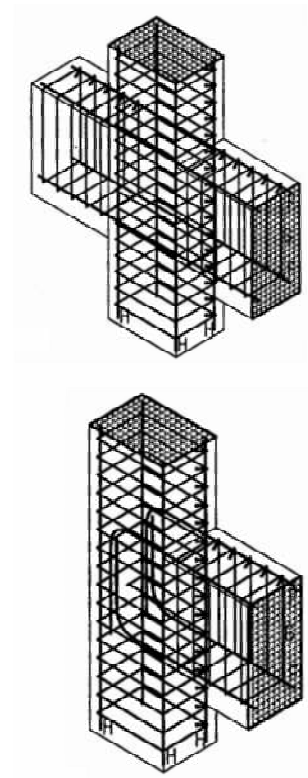
- Beams can be classification based on support conditions as shown.
- Beams can be part of a rigid frame as shown below.





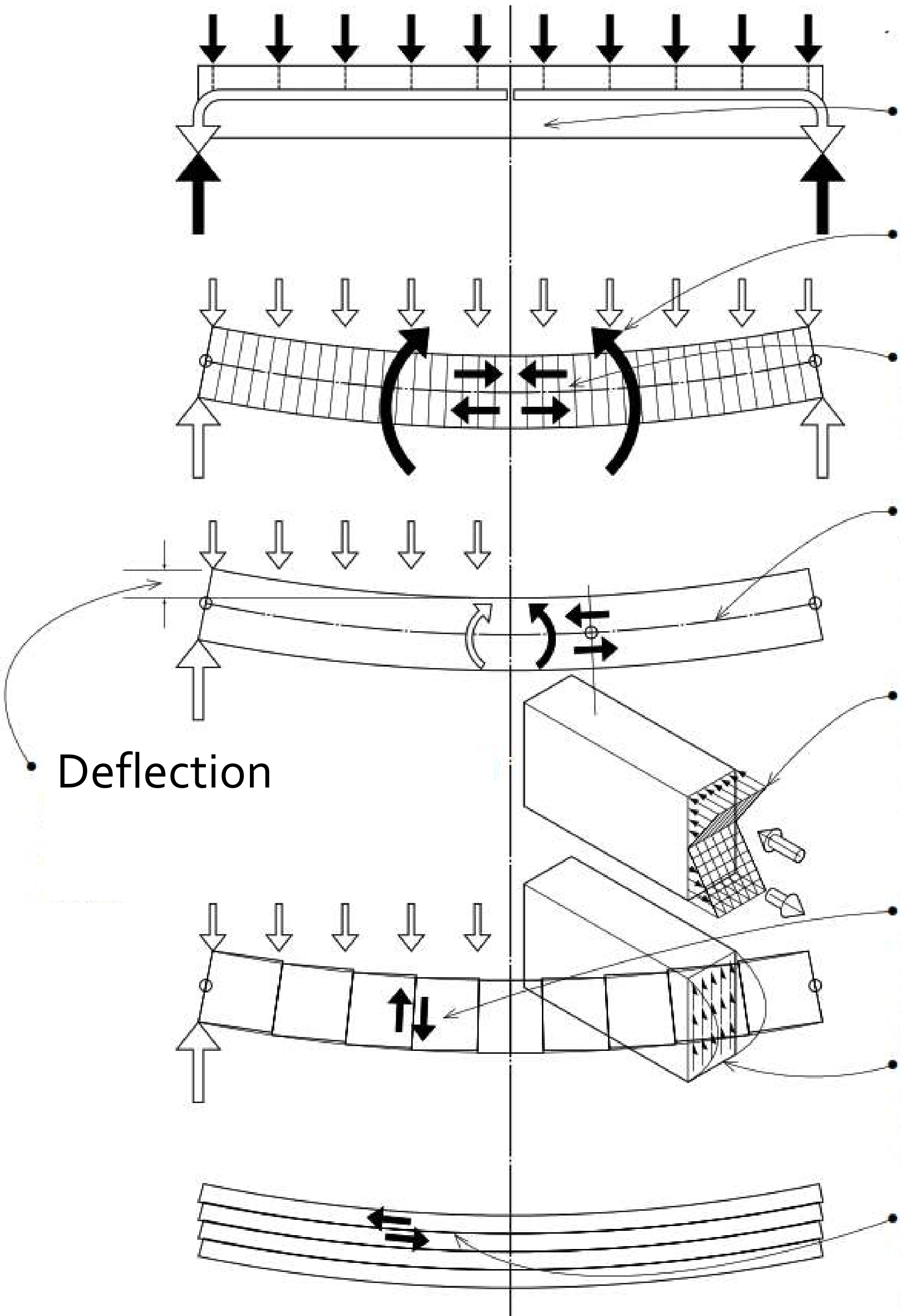






Beam – Column Joint

Beam Terminology



Span refers to the extent of space between two supports of a structure.

Bending moment is an external moment tending to cause a structure to rotate.

Resisting moment is an internal moment equal and opposite to a bending moment.

The neutral axis is an imaginary line passing through the centroid. subject to bending, along which no bending stresses occur.

Bending stress is a combination of compressive and tensile stresses developed at a cross-section

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.

Beam Design

<u>Primary Design Variables</u>

- Span.
- Loading types and magnitudes.
- Materials.
- Cross-sectional sizing and shaping (including variations along member lengths).
- Assembly or fabrication techniques.

<u>Design Criteria</u>

- Strength - safety
- Stiffness – serviceability.
- Economy.
- Depth.
- Appearance.

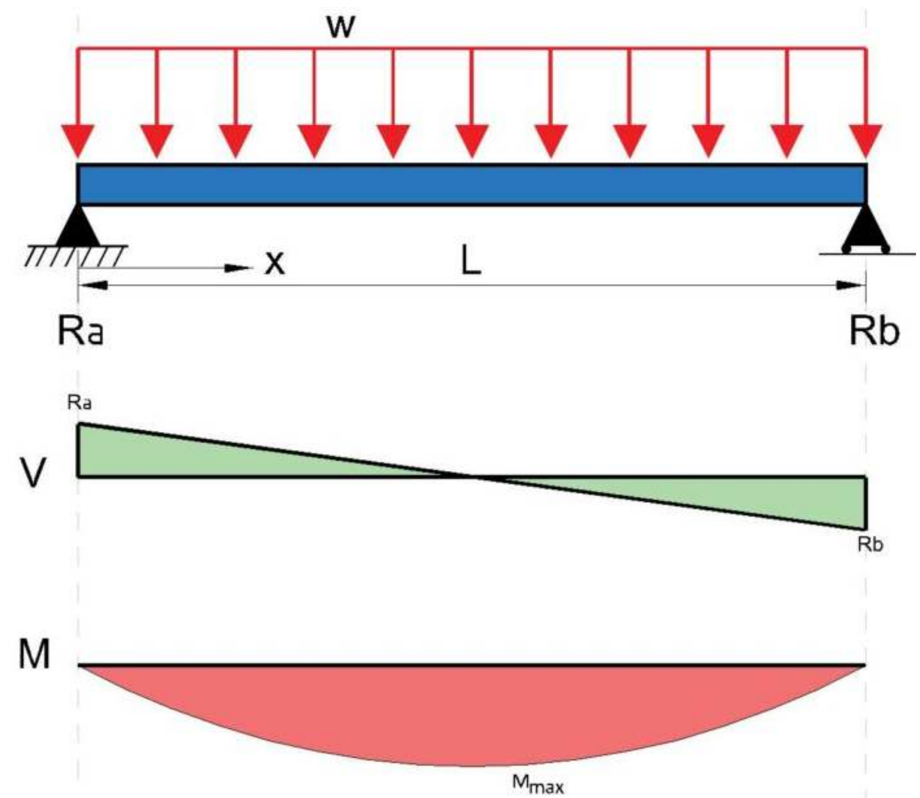
<u>Strength and stiffness.</u> Beams must be sized and shaped so that they are sufficiently strong to carry applied loadings without undue material distress or deformations.

Beam Design

Effect of span

- 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.



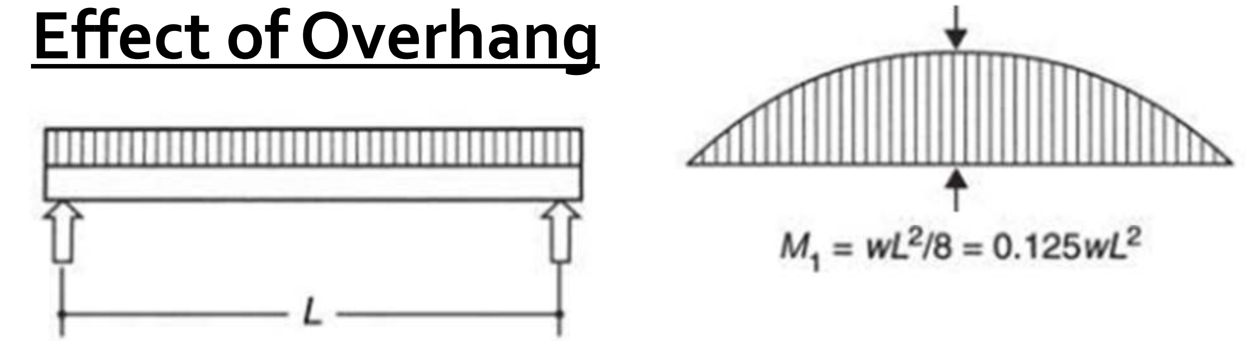
$$M_{max} = \frac{wL^2}{8}$$

$$V_{max} = \frac{wL}{2}$$

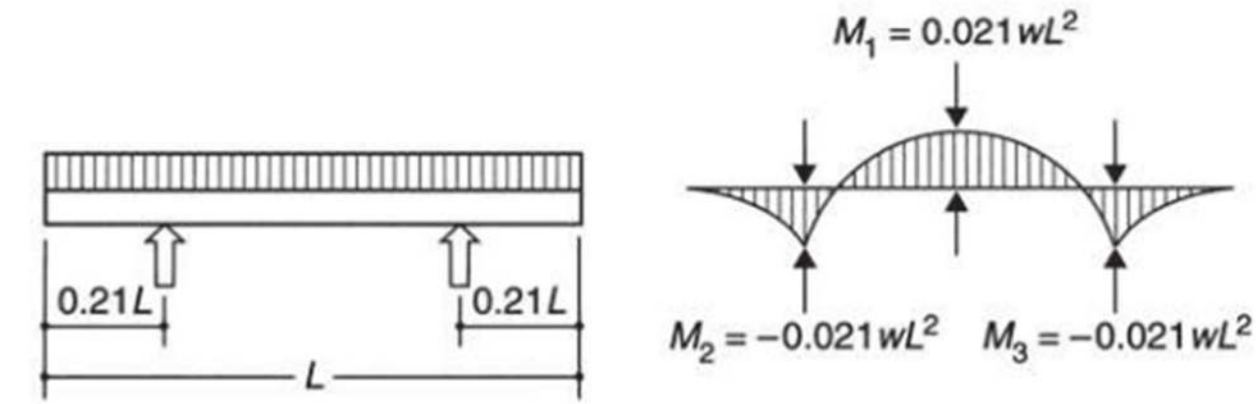
$$\Delta_{max} = \frac{5wL^4}{384EI}$$

Beam Design

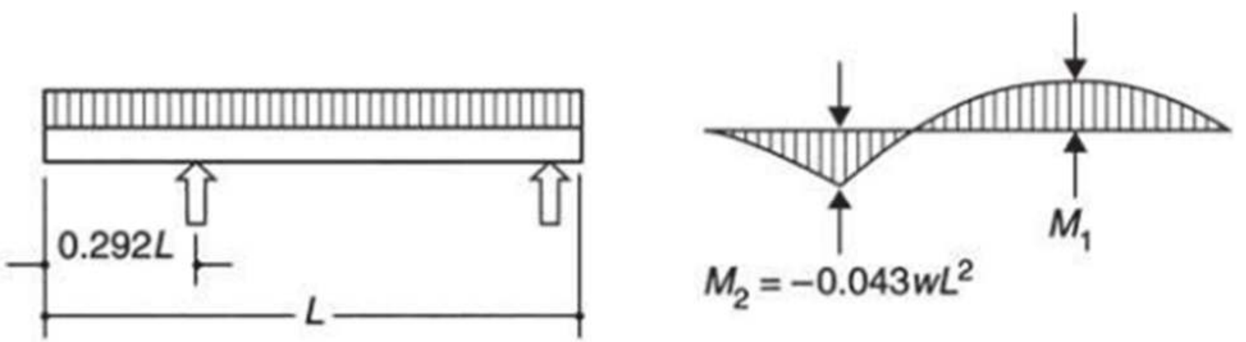
Effect of Overhang



(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.

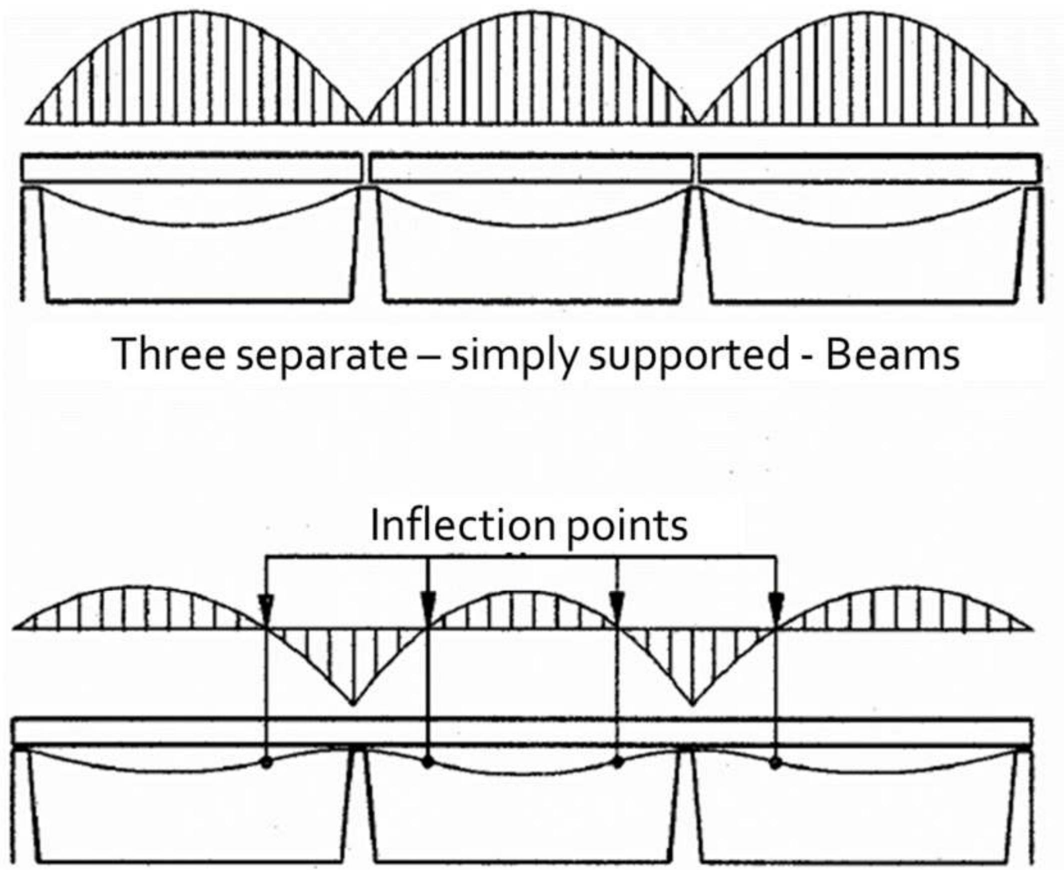


(c) Optimum support locations—one support location variable: Instead of moving in both supports, only one can be moved and a balance between positive and negative moments achieved (note that $M_1 = M_2 < wL^2/8$) and material savings can still result.

Beam Design

Effect of 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.

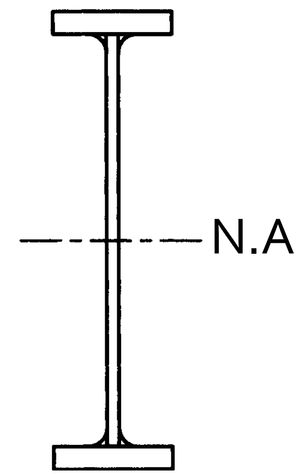


- However, continuous beams are sensitive to deferential support settlement which can lead to failure.

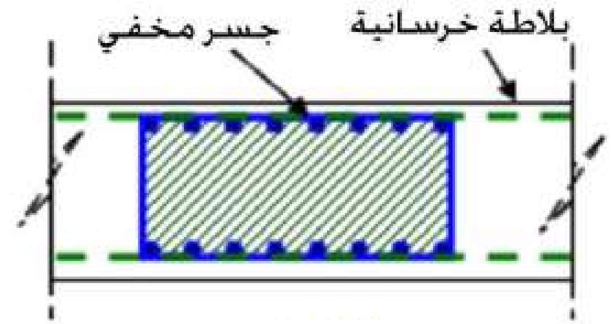
Beam Design

Cross-sectional shape

- The moment of inertia (I) or the section modulus (S) is of primary importance in beam design including bending capacity and deflection .
- I is directly related to the section depth and geometry. Accordingly to design an efficient beam cross-section, material is removed away from the neutral axis to maximize the moment of inertia of the cross-section and hence its resistance to bending.

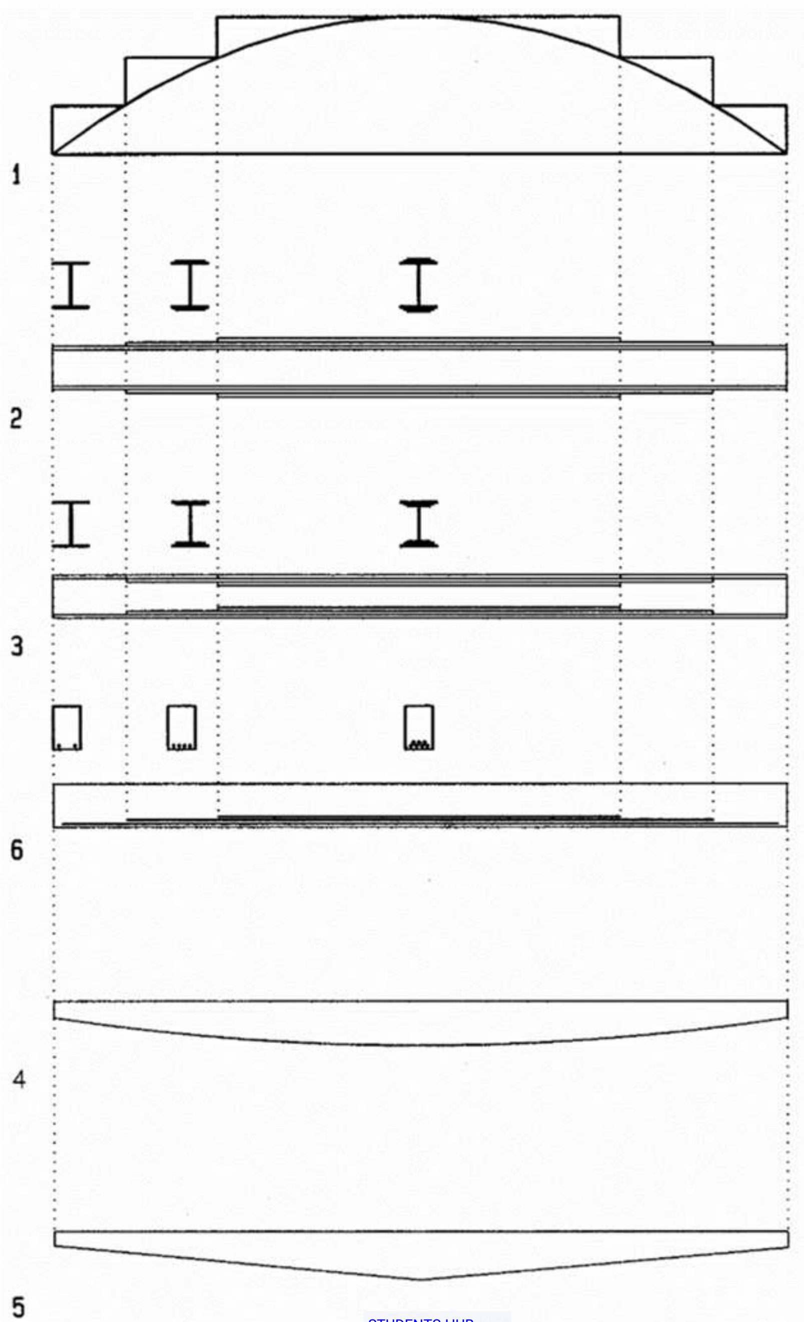


Efficient beam cross-section



Inefficient beam cross-section

Beam Design

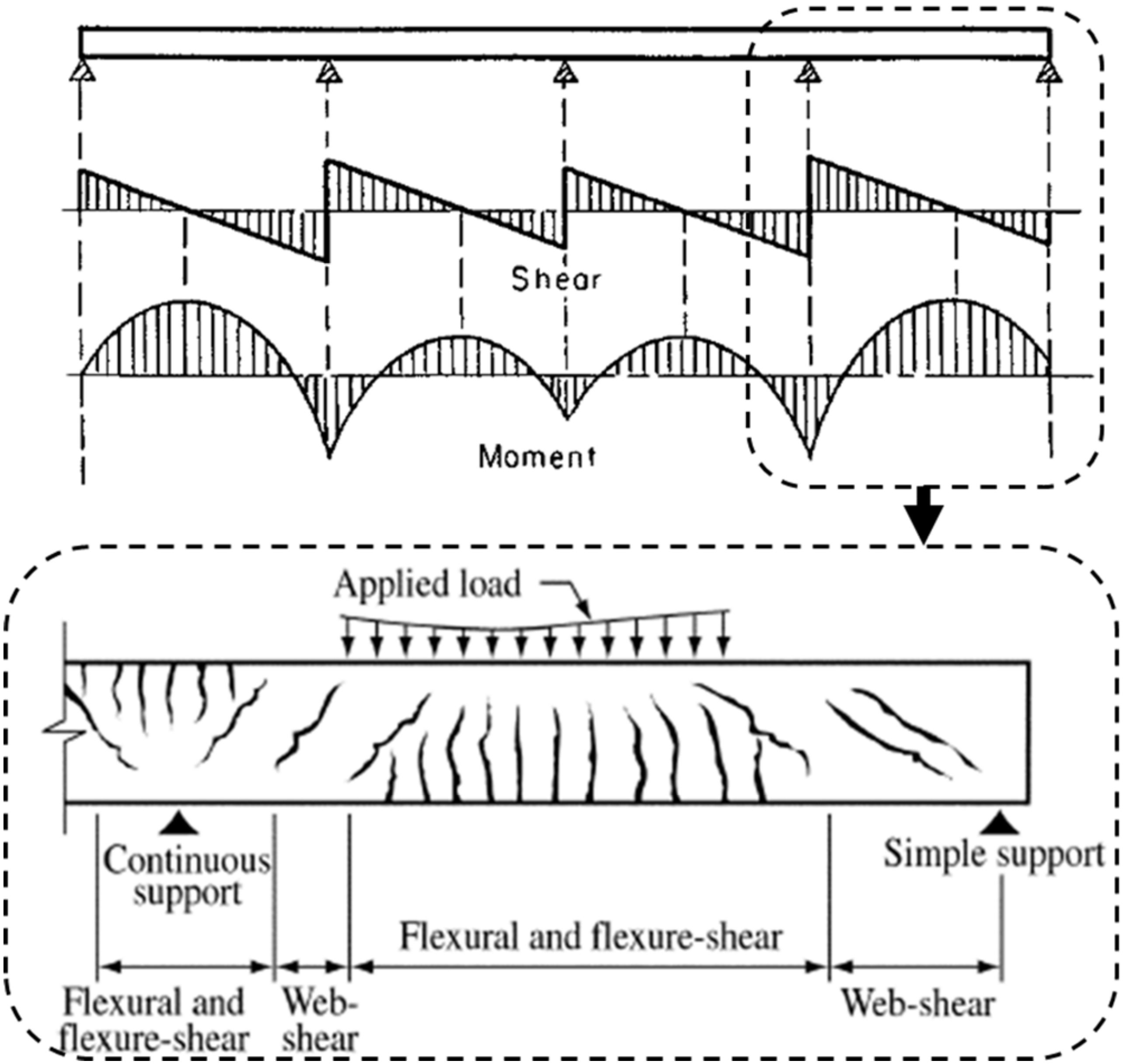


Shaping the beam along Its length

- 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

Concrete Beams

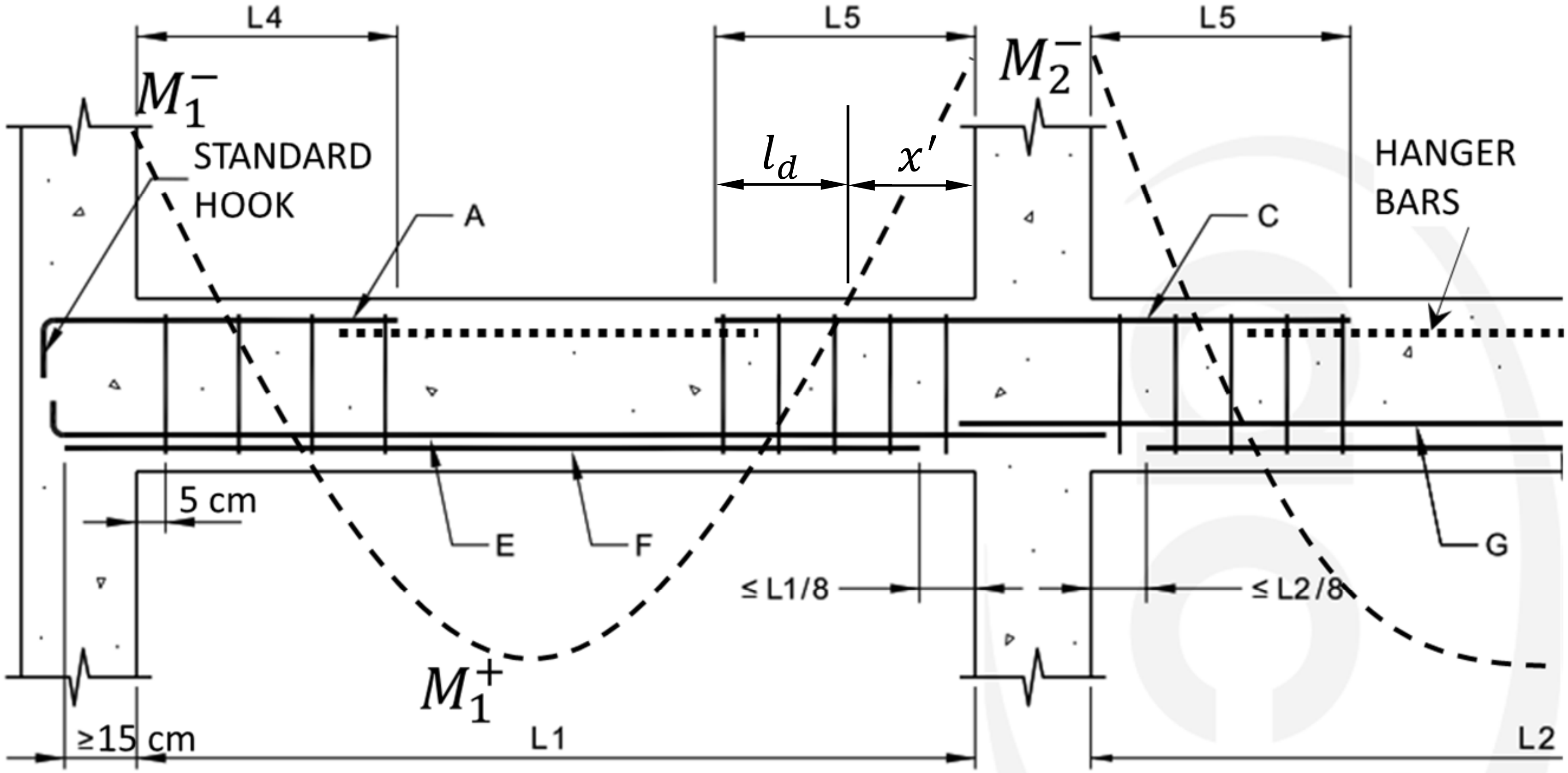
- A distributed load acting on a concrete beam will develop flexural and shear stresses in the beam that can produce the pattern of the cracks in the figure before failure due to the concrete weakness in resisting tension and shear.



Concrete Beams Reinforcement

- Accordingly, to prevent early failure and to increase the beam's capacity and ductility, concrete beams must be reinforced by:
  1. Flexural reinforcement - longitudinal bars - to resist the tension forces caused by bending moment
  2. Shear reinforcement - stirrups to resist access shear above concrete capacity.
  3. Integrity reinforcement - reinforcement detailing aims to improve the redundancy and ductility in structures.
- Additionally, beam reinforcement may include compression reinforcement to post concrete compression capacity, torsion reinforcement, hanger bars to fix stirrups and ties, and deflection reinforcement.
- Beams are designed to fail in tension, thus flexural reinforcement should be within a specific minimum and maximum ($A_{smin} \leq A_s \leq A_{smax}$).

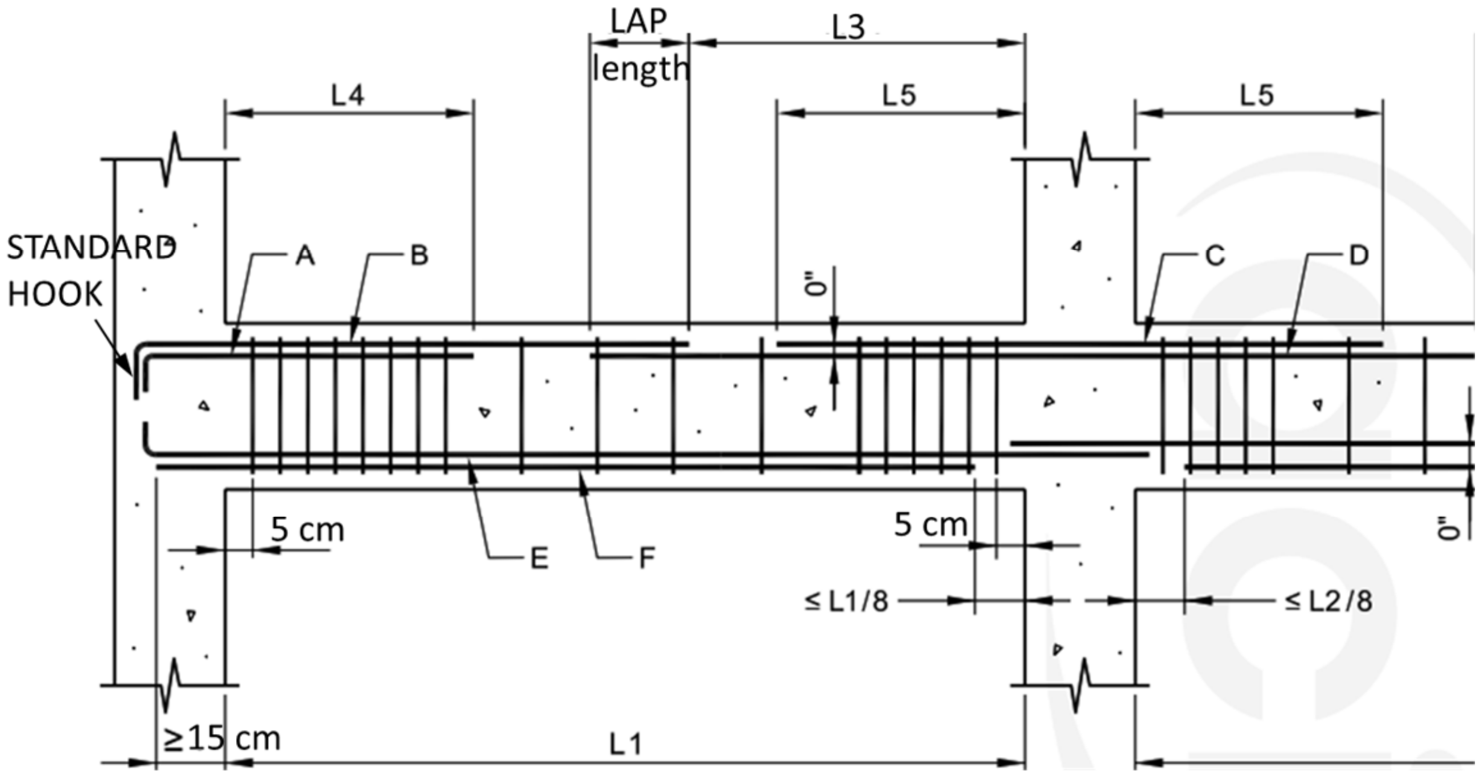
Longitudinal Reinforcement



Required Integrity Reinforcement – Other Than Perimeter Beam

- A &C = Top reinforcement according to M_1^- *and* M_2^- respectively, $\geq A_{smin}$.
- E&F = Bottom reinforcement according to $M_1^+ \geq A_{smin}$. $E \geq \frac{1}{4}(E+F)$; minimum 2 bars.
- Hanger bars to support the stirrups; at least 2 bars.
- A_{smin} = Minimum area of tension steel; l_d = Development length.

Longitudinal Reinforcement

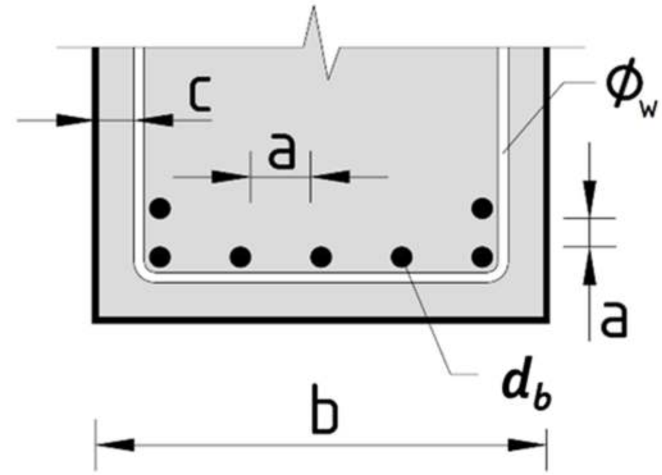


Required Integrity Reinforcement – Perimeter Beam

- A , B, C, D = Top reinforcement $(\mathrm{A}+\mathrm{B})$; $(\mathrm{C}+D) \geq A_{smin}$.
- $B \geq \frac{1}{6}(A+B)$ and $\mathrm{D} \geq \frac{1}{6}(C+D)$; minimum 2 bars
- E and F = Bottom reinforcement; $\mathrm{E}+F \geq A_{smin}$ and $\mathrm{E} \geq \frac{1}{4}(E+F)$; minimum 2 bars.
- A_{smin} = Minimum area of tension steel.

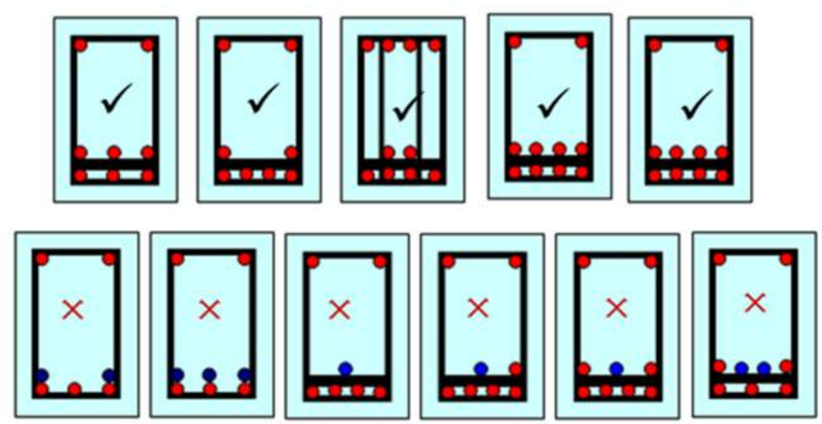
Longitudinal Reinforcement

- **The minimum clear spacing** between parallel bars in a layer (a) shall be at least the greatest of d_b, $4/3(d_{agg})$, and 25 mm, where d_{agg} is the maximum aggregate size .



- In addition to the general rules, 75 mm spacing is required in some locations to ensure sufficient space for inserting the vibrator.

- Where parallel reinforcement is placed in two or more layers, bars in the upper layers shall be placed directly above bars in the bottom layer with clear distance between layers not less than 25 mm.



Longitudinal Reinforcement

Maximum bar spacing: the maximum spacing between longitudinal reinforcing bars in tension shall not exceed specified limits to control crack width in beams. For reasons of durability and appearance, many fine cracks are preferable to a few wide cracks.

Maximum bar spacing for crack control

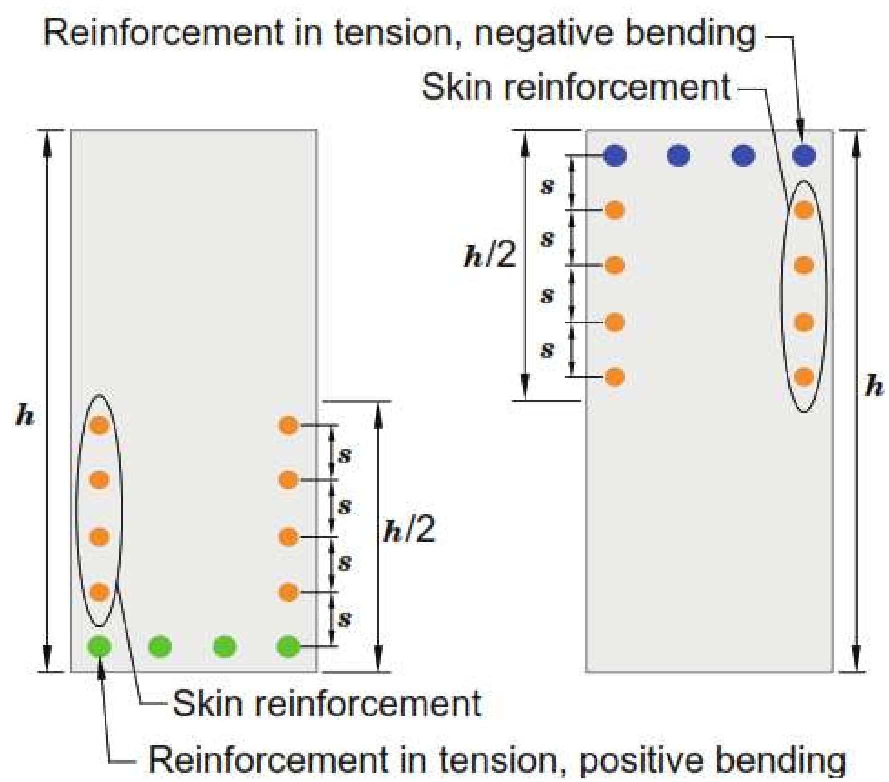
Steel stress (N/mm^2)	Maximum bar spacing (mm)	
	$w_k = 0.4$ mm	$w_k = 0.3$ mm
160	300	300
200	300	250
240	250	200
280	200	150
320	150	100
360	100	50

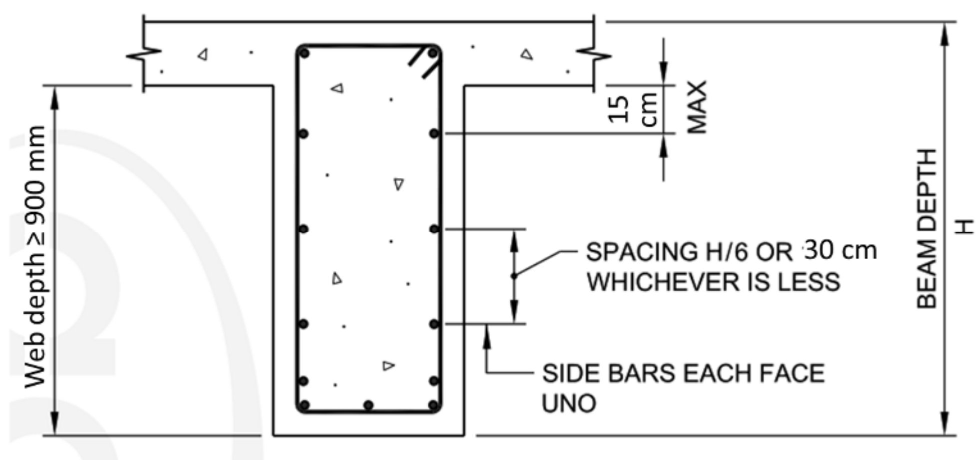
Longitudinal Reinforcement

Skin Reinforcement

- Beams with **h** exceeding 900 mm, longitudinal skin reinforcement shall be uniformly distributed on both side faces of the beam for a distance h/2 from the tension face to control cracking in the web.

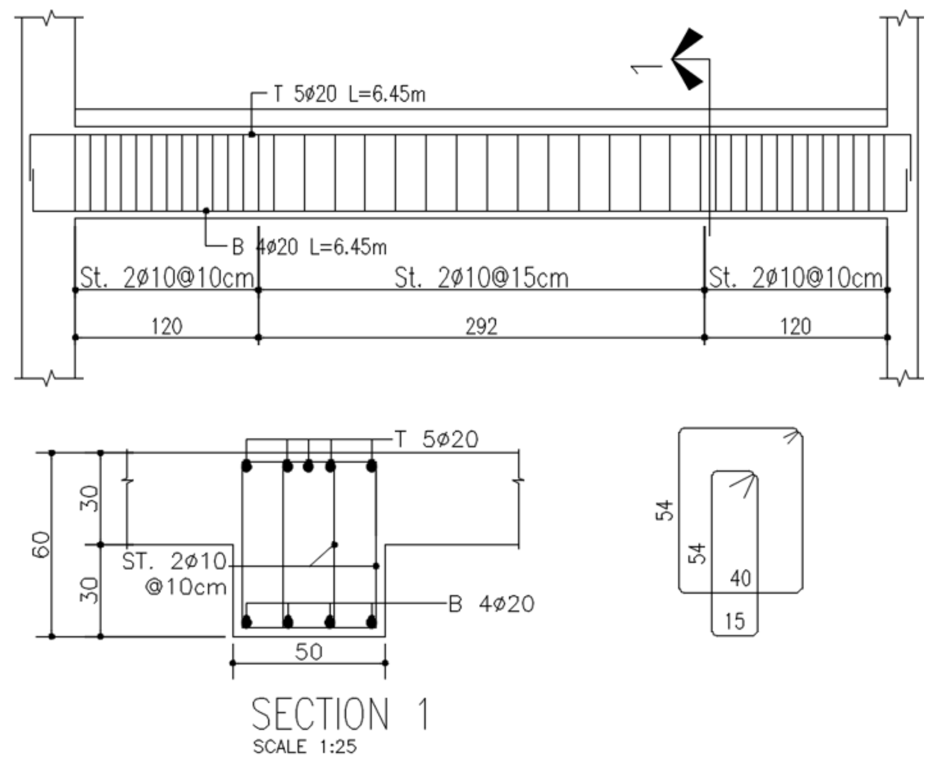
- Bar sizes No. 10 to No. 16, with a minimum area of 210 mm² per meter of depth, are typically provided.





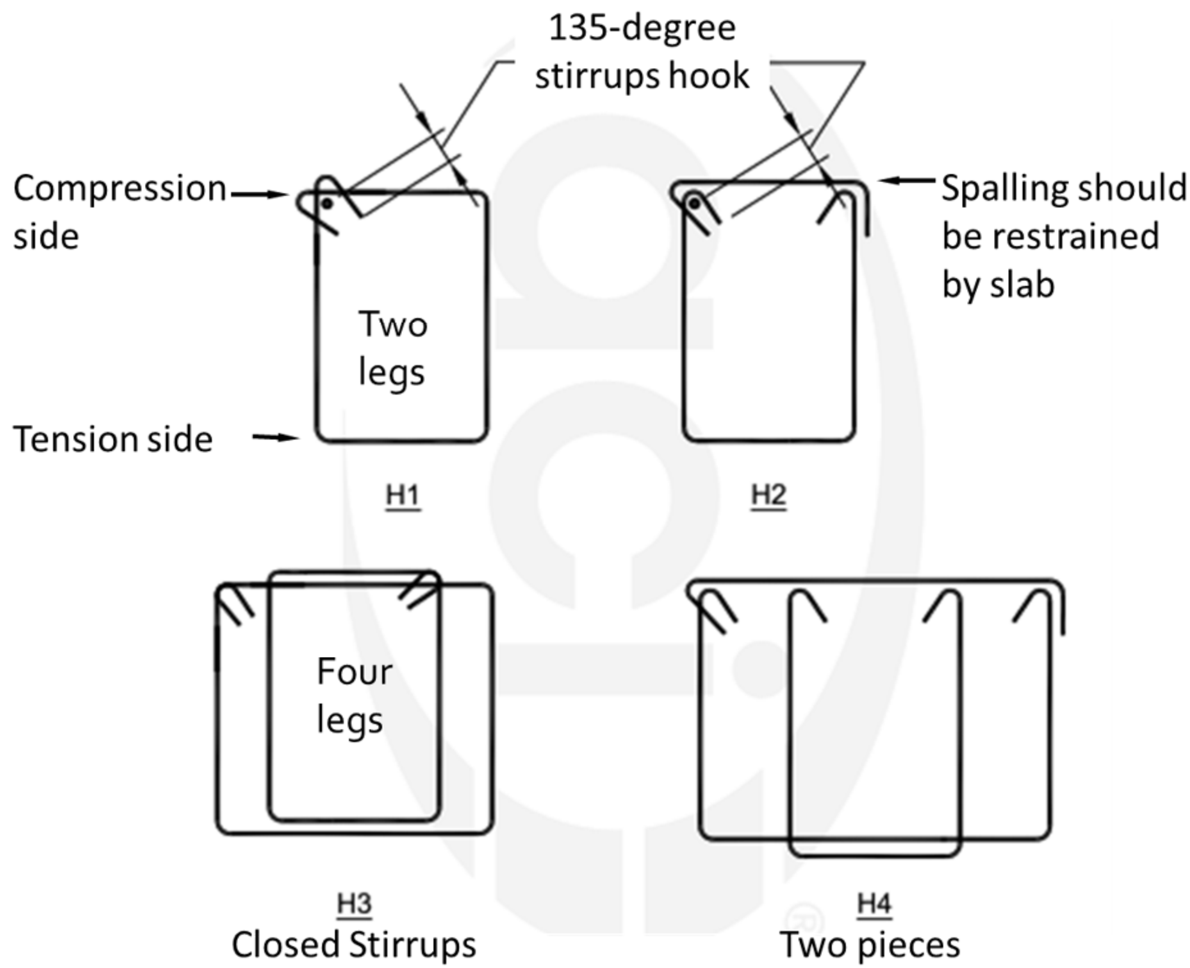
Shear Reinforcement

- Shear reinforcement can be provided using stirrups, hoops, or longitudinal bent bars.
- Stirrups (the most common reinforcement) consist of deformed bars, either single-leg or bent into L, U, or rectangular shapes and located perpendicular to, or at an angle to, longitudinal reinforcement. They are used to resist torsion in addition to shear.
- **Shear design output**
  - Stirrups type, bar diameter, and anchorage requirements.
  - Stirrups spacing through the beam length.
  - Stirrups number of leges and legs spacing



Shear Reinforcement

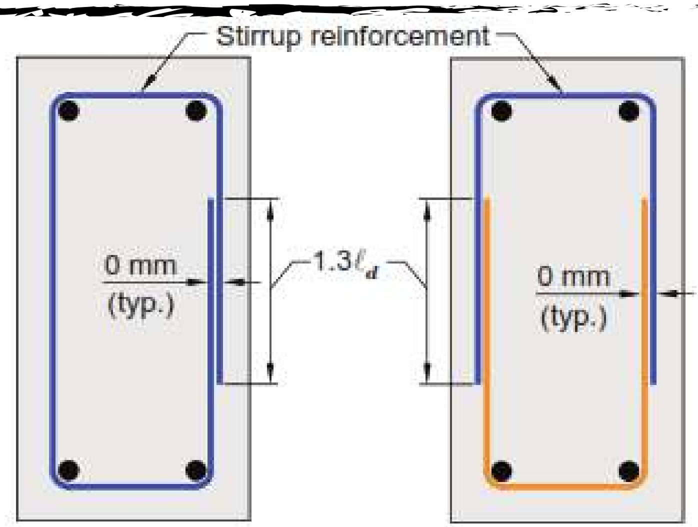
- Stirrups should extend as close to the compression and tension surfaces of the member as cover requirements and proximity of other reinforcement permit, and are to be anchored at both ends.



- Stirrups used for torsion or integrity reinforcement can be either closed stirrups placed perpendicular to the beam axis, or can be made up of two pieces of reinforcement as shown.

Shear Reinforcement

- Except where used for torsion or integrity reinforcement, closed stirrups are permitted to be made using pairs of U-stirrups spliced to form a closed unit where lap lengths are at least $1.3\ell_d$.
- Based on shear stress, design codes indicate limits for a minimum shear reinforcement and maximum spacing of stirrups along the length and across the width of the beam.



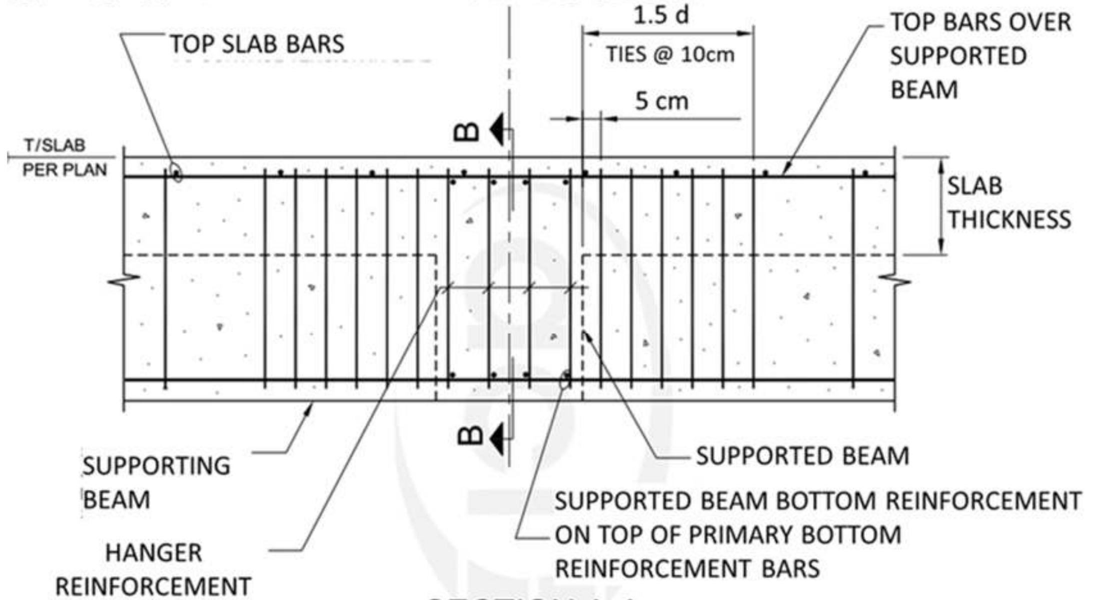
Required V_s		Maximum *s*, mm			
		Nonprestressed beam		Prestressed beam	
		Along length	Across width	Along length	Across width
$\leq 0.33\sqrt{f'_c} b_w d$	Lesser of:	$d/2$	d	$3h/4$	$3h/2$
		600			
$> 0.33\sqrt{f'_c} b_w d$	Lesser of:	$d/4$	$d/2$	$3h/8$	$3h/4$
		300			

Reduced stirrup spacing across the beam width enhance shear capacity.

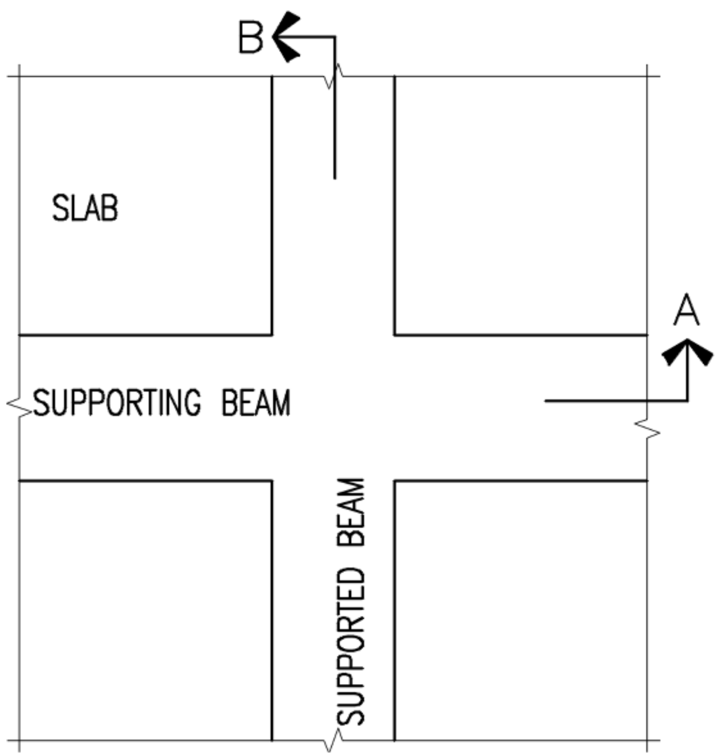
- **Tie bar diameter.** At least Φ10 for enclosing bars Φ32 or smaller, and Φ12 for enclosing bars Φ36 or larger and bundled longitudinal bars.

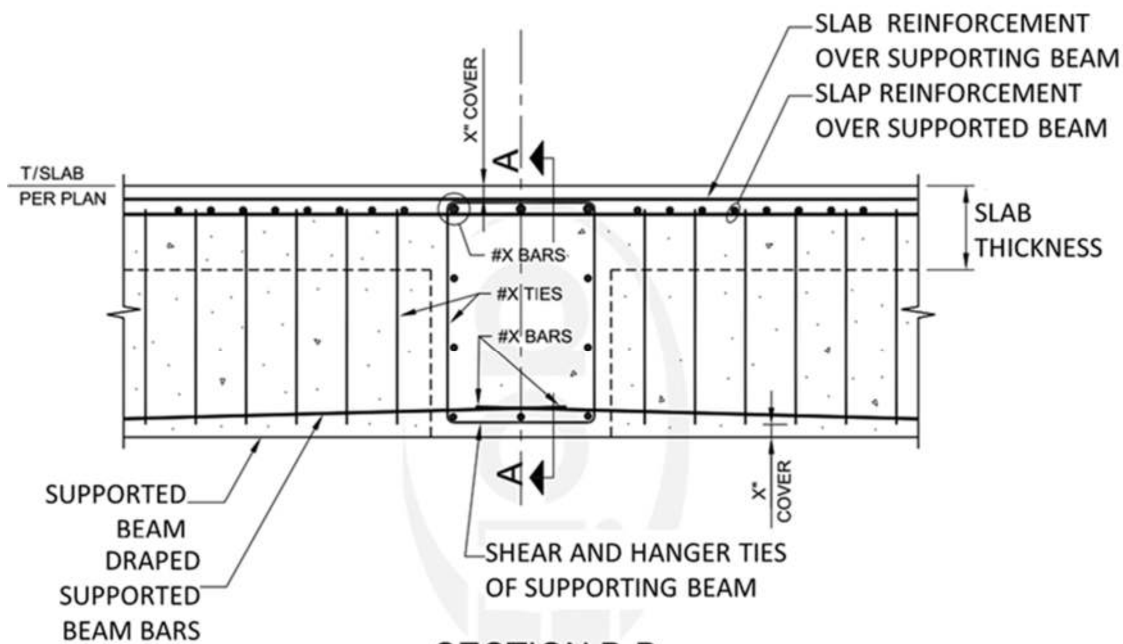
Issues In Beams Detailing

Reinforcement details of crossing beams - a supported beam cast monolithically with a supporting beam.



SECTION A-A





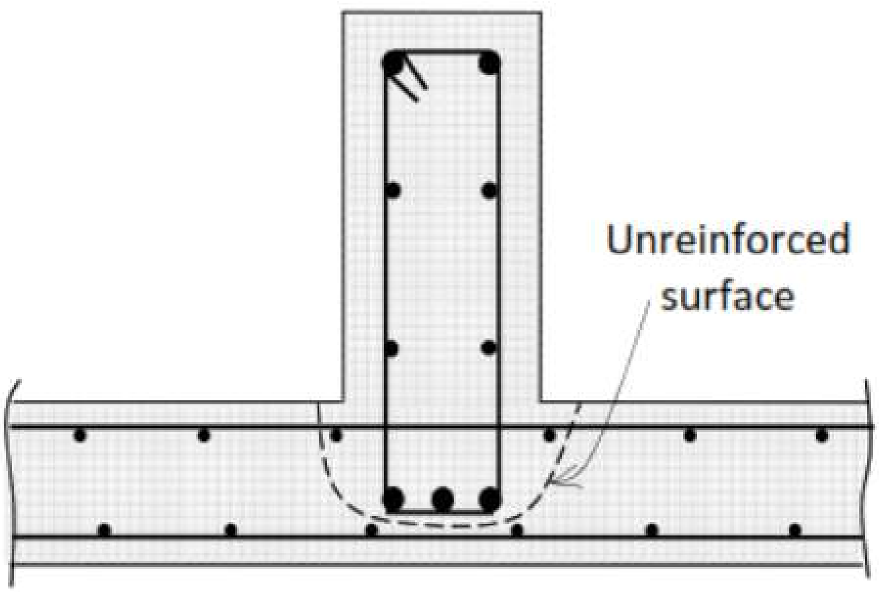
SECTION B-B

ISSUES IN BEAMS DETAILING

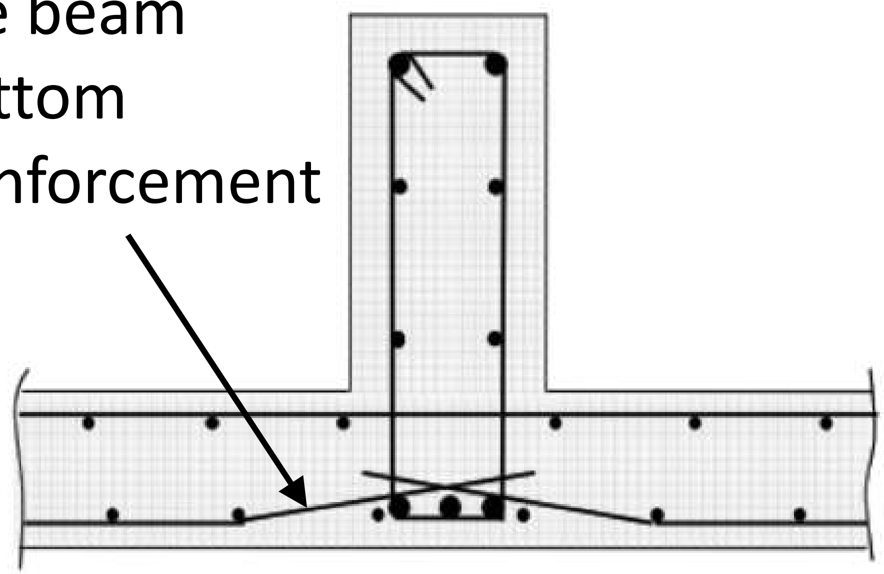
Inverted beam (Slab supported by upturned beam)

Reaction from the slab must be carried in tension up to the top of the inverted beam.

Slab bottom bars should be draped above the beam bottom reinforcement



(a) Incorrect detail

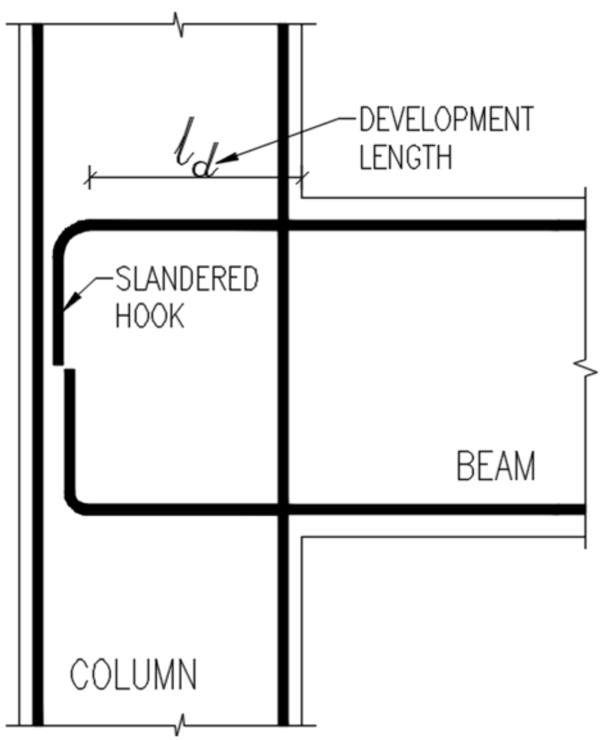


(b) Correct detail

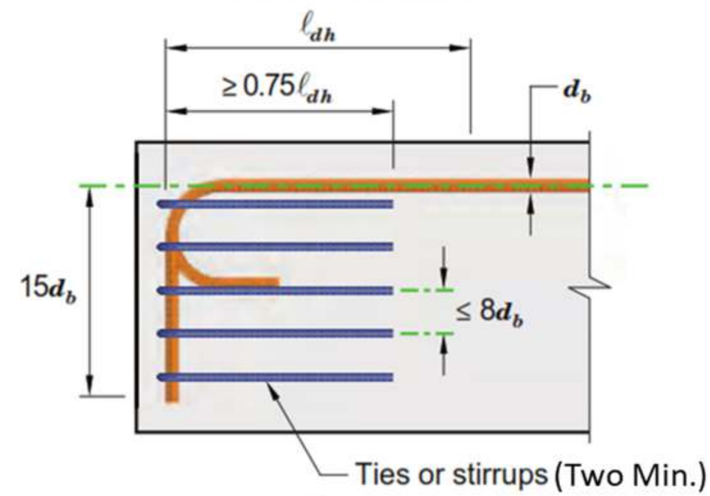
ISSUES IN BEAMS DETAILING

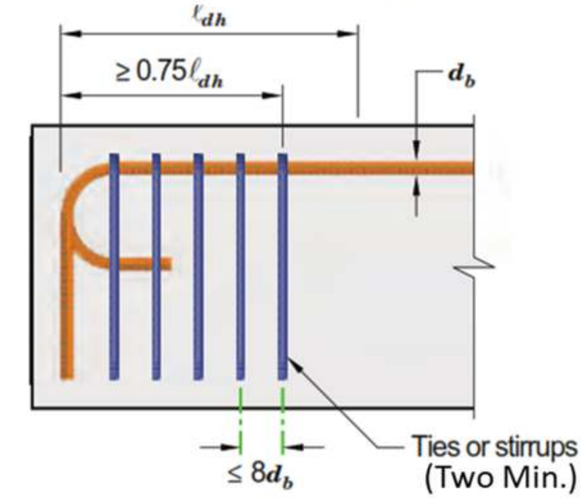
Development of standard hooks in tension (anchorage of beam top reinforcement into the end supporting column)

- Negative moment reinforcement in a beam shall be anchored in the supporting column as shown bellow or by mechanical anchorage.



- Its recommended to enclose the hook by confining reinforcement placed parallel or perpendicular to the bar being developed>





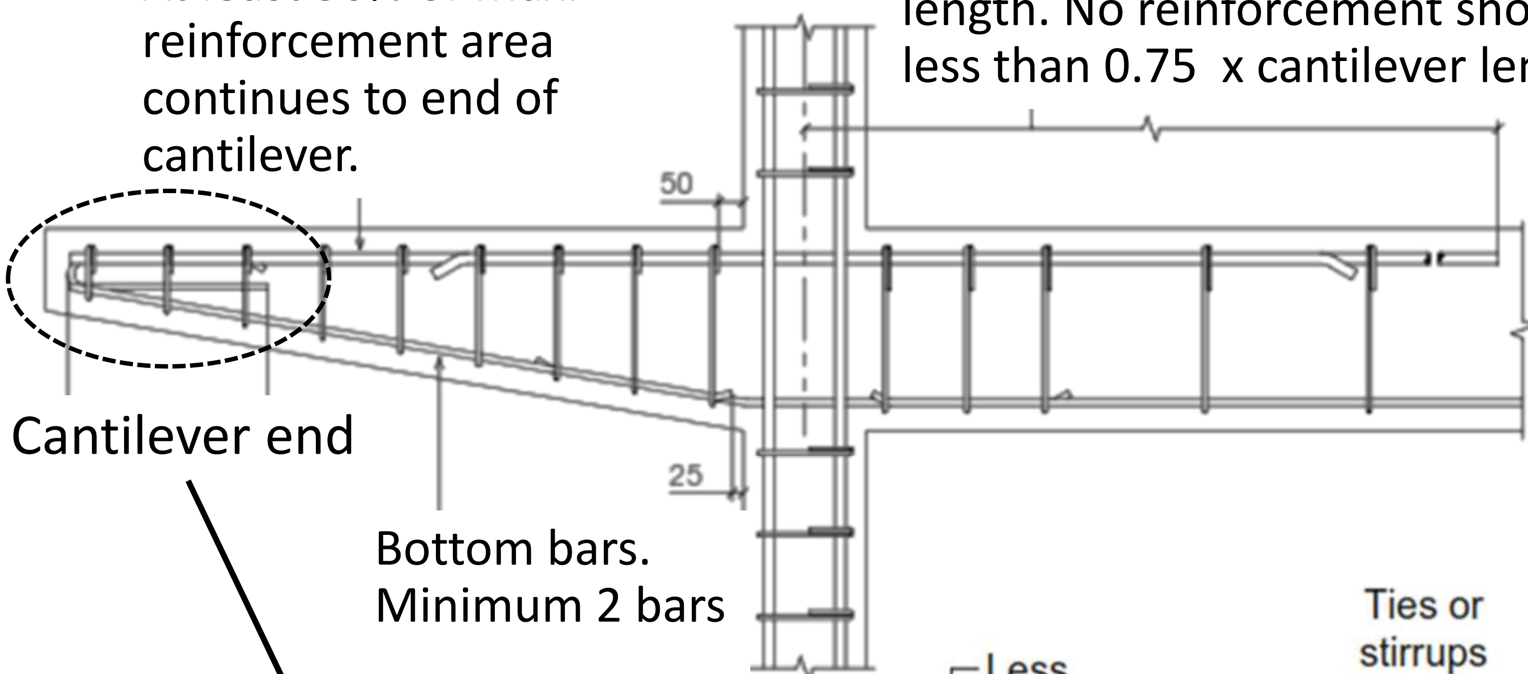
Confining reinforcement

ISSUES IN BEAMS DETAILING

Typical Detailing of Cantilever

At least 50% of cantilever bars should be anchored a distance of 1.5 x cantilever length. No reinforcement should be stopped less than 0.75 x cantilever length

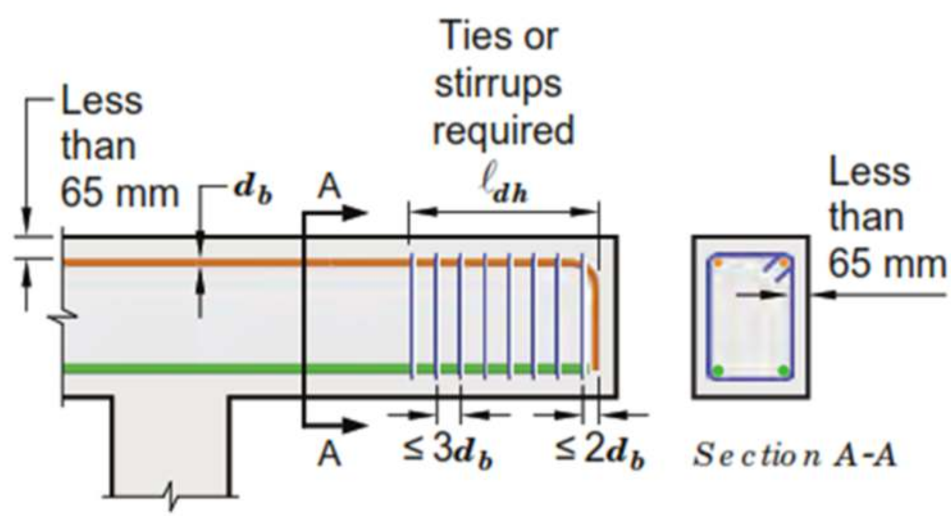
At least 50% of Max. reinforcement area continues to end of cantilever.



Cantilever end

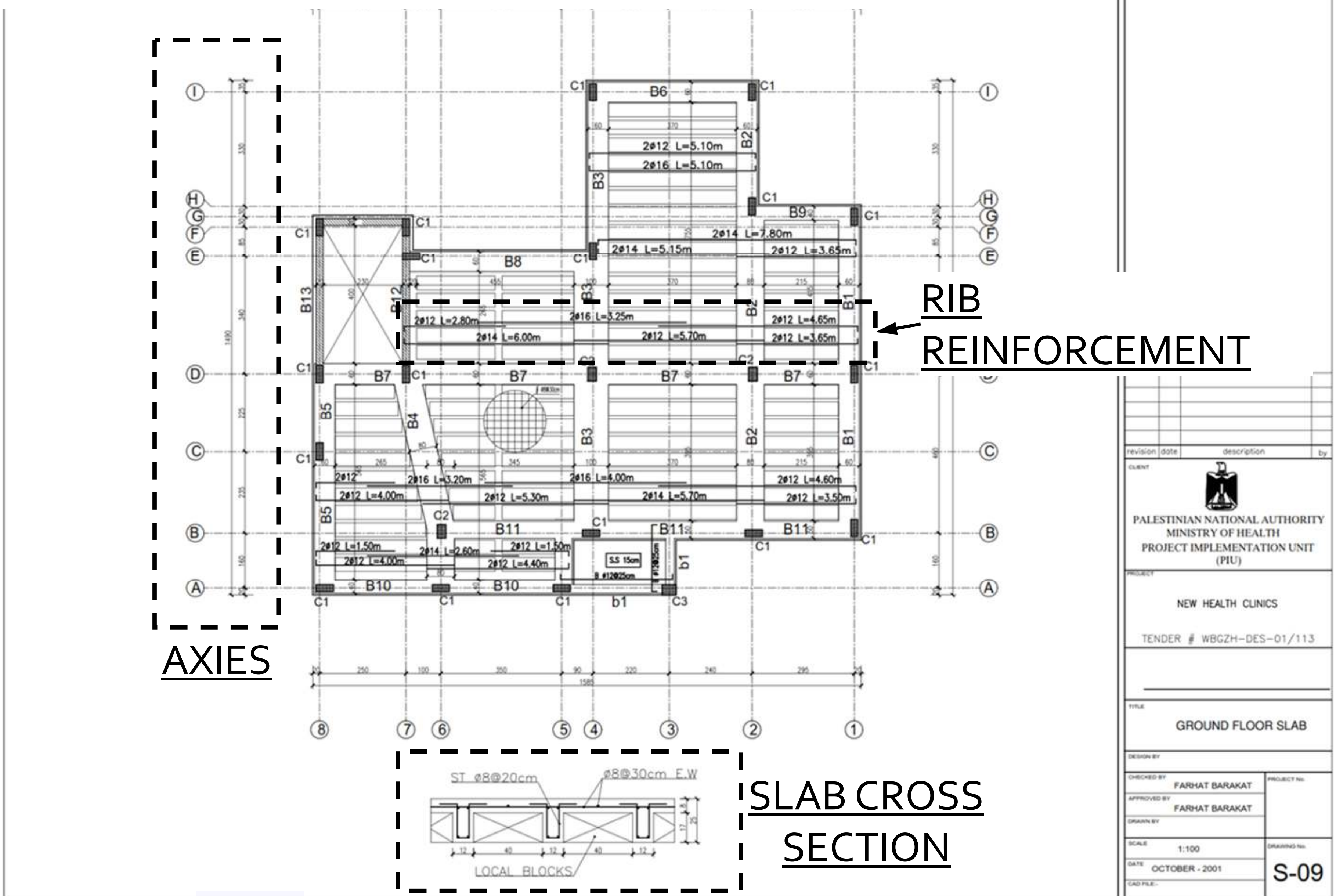
Bottom bars.
Minimum 2 bars

Standard hook 180 or 90° with ties when upper and side cover is less than 65 mm



BEAMS DRAWINGS – FLOOR PLAN

The drawing illustrates the followings



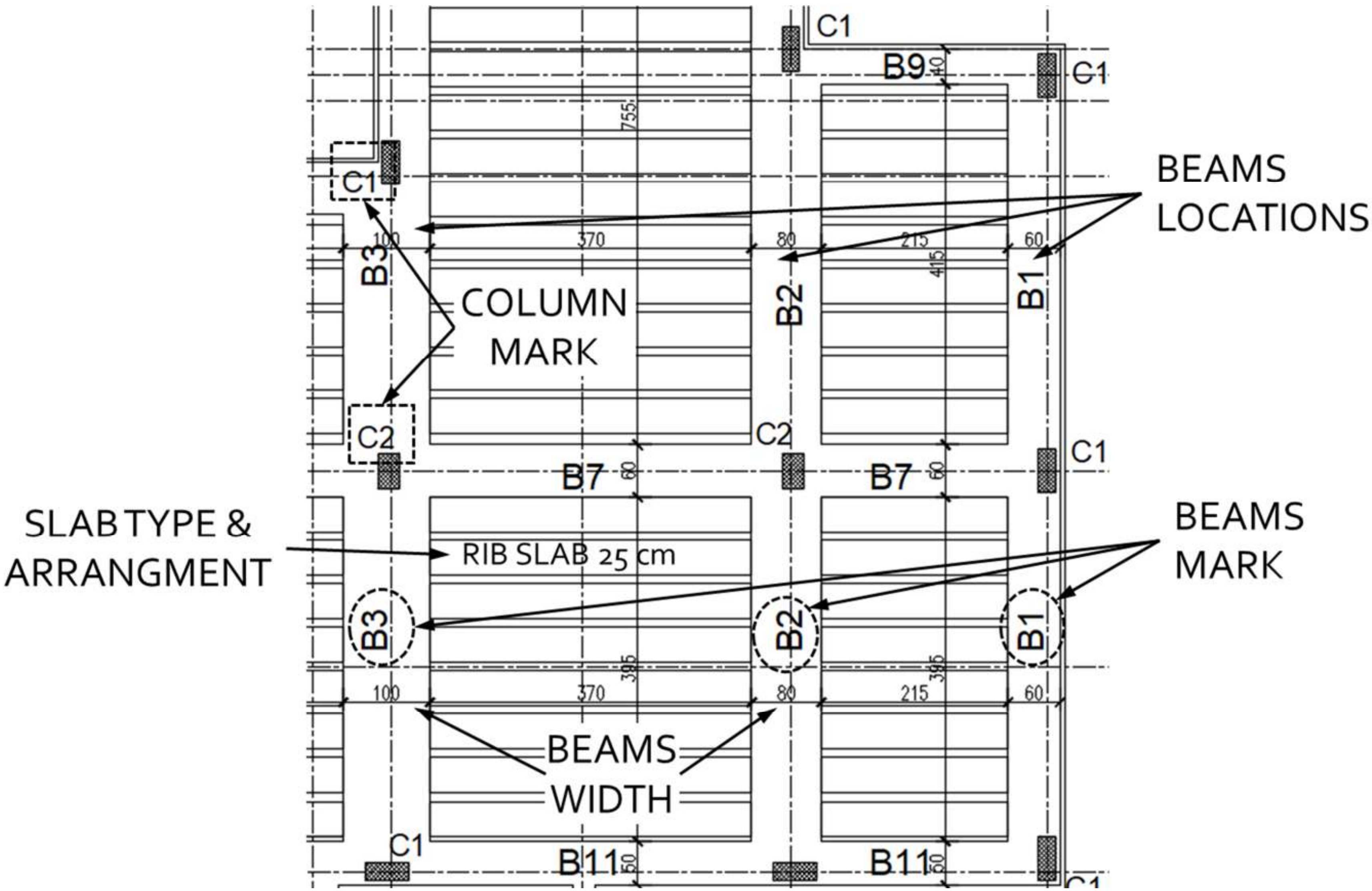
RIB REINFORCEMENT

AXIES

SLAB CROSS SECTION

FLOOR PLAN

The drawing illustrates the following

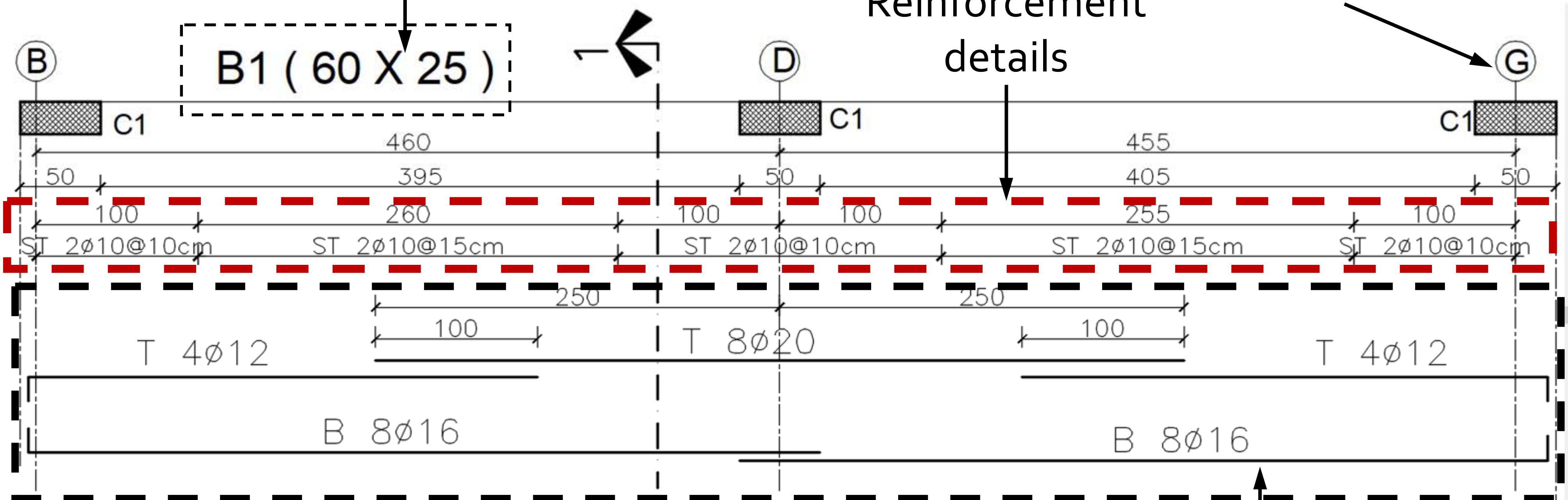


BEAMS DETAILS

Beam mark & dimensions (Width x Depth)

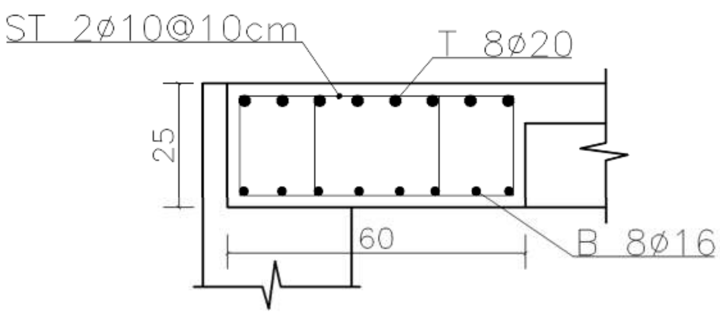
Shear Reinforcement details

Column axis



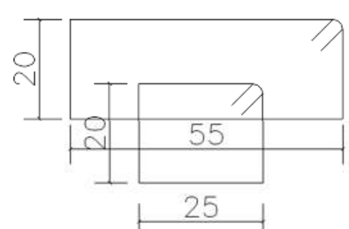
Flexural and integrity reinforcement details; include

- Number of bars and bars diameter.
- Length of bars
- Splices details - location and length.



SECTION - 1 - (B1)

Scale 1 : 20



Stirrups details

BEAMS DETAILS