REINFORCED CEMENT CONCRETE

DETAILED CONTENTS

1. Introduction (04 hrs)

   1.1 Concept of Reinforced Cement Concrete (RCC)
   1.2 Reinforcement Materials:
   - Suitability of steel as reinforcing material
   - Physical properties of mild steel and HYSD/TMT steel

   1.3. Loading on structures as per IS: 875

2. Introduction to following methods of RCC design (04 hrs)
   2.1 Working stress method
   2.2 Limit state method

3. Shear and Development Length (06 hrs)

   3.1 Shear as per IS:456-2000 by working stress method
   i) Shear strength of concrete without shear reinforcement
   ii) Maximum shear stress
   iii) Shear reinforcement

4. Singly Reinforced Beam (working stress method) (10 hrs)

   4.1 Basic assumptions and stress strain curve, neutral axis, balanced, under-reinforcement and over reinforced beams, Moment of resistance for singly reinforced beam.

   4.2 Design of singly reinforced beam including sketches showing reinforcement details.

5. Concept of Limit State Method (as per IS 456:2000) (10 hrs)

- 5.1. Definitions and assumptions made in limit state of collapse (flexure)
- 5.2. Partial factor of safety for materials
- 5.3. Partial factor of safety for loads
- 5.4. Design loads
- 5.5. Stress block diagram

6. Singly Reinforced beam (12 hrs)

Theory and Design of singly reinforced beam by Limit State Method

7. Doubly Reinforced Beams (12 hrs)

Theory and design of simply supported doubly reinforced rectangular beam by Limit State Method

8. Behaviour of T beam, inverted T beam, isolated T beam and ‘L’ beams (No Numericals) (04 hrs)

9. One Way Slab (10 hrs)

Theory and design of simply supported one way slab including sketches showing reinforcement details (plan and section) by Limit State Method.

10. Two Way Slab (10 hrs)

Theory and design of two-way simply supported slab with corners free to lift, no provisions for torsional reinforcement by Limit State Method including sketches showing reinforcement details (plan and two sections)

11. Axially Loaded Column (10 hrs)

11.1 Definition and classification of columns

11.2. Effective length of column,

11.3. Specifications for longitudinal and lateral reinforcement

11.4. Design of axially loaded square, rectangular and circular (with lateral ties only) short columns by Limit State Method including sketching of reinforcement (sectional elevation and plan)

11.5 Concept of foundation: shallow and deep foundation, types and suitability of foundation (no numericals)

12. Prestressed Concrete (04 hrs)

12.1. Concept of pre-stressed concrete, advantages and disadvantages
12.2. Methods of pre-stressing

Unit- 1
INTRODUCTION

CONTENT

- Concept of Reinforced Cement Concrete (R.C.C.)
- Reinforcement Materials
- Loading on structures as per IS: 875

Concept of R.C.C.

PCC

RCC

- **<u>Plain cement concrete-</u> It is a hardened mass obtained from mixture of cement, sand, gravel and water in definite proportions.**
- Plain cement concrete (PCC) possess **high compressive** strength and very **little tensile** strength.
- To improve tensile strength of PCC, reinforcement is required which can take up tensile stresses in the structure.
- **The steel used in the form of bars to reinforce the concrete is called <u>Reinforcement.</u>**
- Steel is equally strong in tension and compression. Compressive strength of normal steel is 25 times that of cement concrete and its tensile strength is 70 times that of cement concrete.
- **The solidified composite mass of cement concrete reinforced with steel bars is known as <u>Reinforced Cement Concrete (R.C.C.)</u>**
- RCC is a versatile material which is strong in tension as well as compression

Uses of R.C.C.

RCC is used as a material for construction of the following-

- Beams, columns and slabs in residential, commercial and industrial building.
- Highways, flyover and railway bridges.
- Power plants
- Chimneys and towers
- Tunnels
- Electric poles
- Bunkers and silos

The IS code used for the design of Reinforced concrete structure is IS: 456-2000

Advantages and Disadvantages of R.C.C.

Advantages of RCC

- **Strength**: RCC has very good strength in tension and compression.
- **Durability**: RCC structures are durable and can last even upto 100 years
- **Economy**: RCC is cheap in long run as its maintenance cost is very low.
- **Fire resistance**: RCC structures are more fire resistant than any other construction material.
- **Aesthetics:** RCC structures give good aesthetic appearance.

Disadvantages of RCC

- RCC structures are **heavier** than other structural materials.
- The **initial cost** of RCC work is **high**.
- **Skilled labour is required** for construction of RCC structures.
- RCC structures **take time to attain its full strength**.

Grades of Cement and Concrete

The Bureau of Indian Standard has classified **Ordinary Portland cement (OPC) in three grades:**

- 33 Grade
- 43 Grade
- 53 Grade

- In India, cement is supplied in bags of **50kg** and its volume is 34.5 litres.
- **Concrete is graded on the basis of its compressive strength into fifteen grades.**

IS 456 : 2000

Table 2 Grades of Concrete

(*Clause* 6.1, 9.2.2, 15.1.1 *and* 36.1)

Group	Grade Designation	Specified Characteristic Compressive Strength of 150 mm Cube at 28 Days in N/mm²
(1)	(2)	(3)
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

Grades of Concrete

- **Concrete grades** are expressed by **letter 'M' followed by number**.
- The letter 'M' refers to mix and the number represents characteristic compressive strength (f_{ck}) of 150 mm concrete cube in N/mm^2

Minimum grades of concrete for various structure:

- For RCC- M20
- For post-tensioned prestressed concrete- M30
- For pre-tensioned prestressed concrete- M40

Concrete grades lower than **M20** should not be used for RCC work as per IS- 456-2000

Reinforcing Materials

Reinforced Materials- the material which develops a good bond with concrete to increase its tensile strength is called reinforced material.

Characteristics of reinforced Material:

- It should have **high tensile strength**.
- It should be **cheap and easily available in market.**
- It should be **durable.**
- It should be **easy to cut, bend and join**.
- It should have **high modulus of elasticity**.

Unit weight of Reinforced Cement Concrete is 25kN/m^3

Steel as Reinforcing Material

Steel is used as reinforcing material due to the following reasons:

- It develops very good bond with concrete.
- Steel is very strong in tension, compression, shear and torsion.
- Steel is easily available throughout India.
- Steel has long life.
- Steel is a ductile material.
- Steel bars can be cut, bend, weld or lift easily.

Forms of steel reinforcement- Mild steel bars, HYSD bars

Properties of mild steel bars:

- The mild steel bars are plain round and hot rolled bars
- These bars can be easily bent and weldable.
- Mild steel bars give sufficient warning time before failure.
- Mild steel has a definite yield point.

HYSD Bars

High Yield Strength Deformed (HYSD) Bars- These bars are produced by subjecting mild steel bars to cold working by tensioning and twisting.

Properties of HYSD bars:

- HYSD bars **require less length of overlap** and hence are economical.
- These bars have **high tensile strength**.
- These bars **do not need hooks or bends at the ends due to increased bond strength**.

HYSD bars are also called by the trade name **TOR steel.**

TOR steel is deformed bars with increased tensile strength, yield stress and bond strength.

Loading on Structures

Various types of loads likely to act on a structure are:

- Dead loads
- Live loads
- Wind loads
- Snow loads
- Seismic loads

Dead loads- Dead loads are due to self weight of the structure. These are **permanent loads** which are always present. This include self weight of wall, floors, beams, columns etc.

Live loads- these loads are **temporarily** placed on the structure e.g. loads of people, furniture, machines etc. These loads keep changing from time to time.

Unit- 2 Introduction to methods of RCC design

CONTENT

- **Working Stress Method (WSM)**
- **Limit State Method (LSM)**

Methods of RCC design

Various methods used for design of RCC structures-

- Working stress method
- Limit state method

Working stress method (WSM)

- **Working stress method** is the oldest one.
- This method is based on linear elastic theory and assumes that both steel and concrete are elastic and obey Hooke's Law.
- This method is also known as '**Elastic method of design**' or '**Modular ratio method**'.
- This method is referred as '**Deterministic**' because it is assumed that loads, permissible stress and factor of safety are known accurately.

Factor of safety for different materials-

- **F.O.S. for steel = 1.78**
- **F.O.S. for concrete = 3**

Drawbacks of Working Stress Method

Following are main drawbacks of working stress method of design:

- This method assumes that both concrete and steel are elastic which is not true.
- This method uses factor of safety for stresses.
- This method does not account for shrinkage and creep.
- This method does not use any factor of safety with respect to loads.
- This method is uneconomical.

Limit state method (LSM)

This is the most rational method which is based on safety at ultimate loads and serviceability at working loads.

The important limit states which are to be considered in design are-

- **Limit state of collapse**
- **Limit state of serviceability**

Unit- 3
SHEAR AND DEVELOPMENT LENGTH

CONTENT

- Shear as per IS: 456-2000 by working stress method
- Shear strength of concrete without shear reinforcement
- Maximum shear stress
- Shear reinforcement

Shear stress

- **Stress** is defined as total force applied per unit area.
- **Nominal shear stress-** shear force per unit cross-sectional area of a beam at any section is known as nominal shear stress.

$$T_v = V/bd$$

where T_v = Nominal shear stress

V = shear force in the beam at critical section

b = breadth of the beam

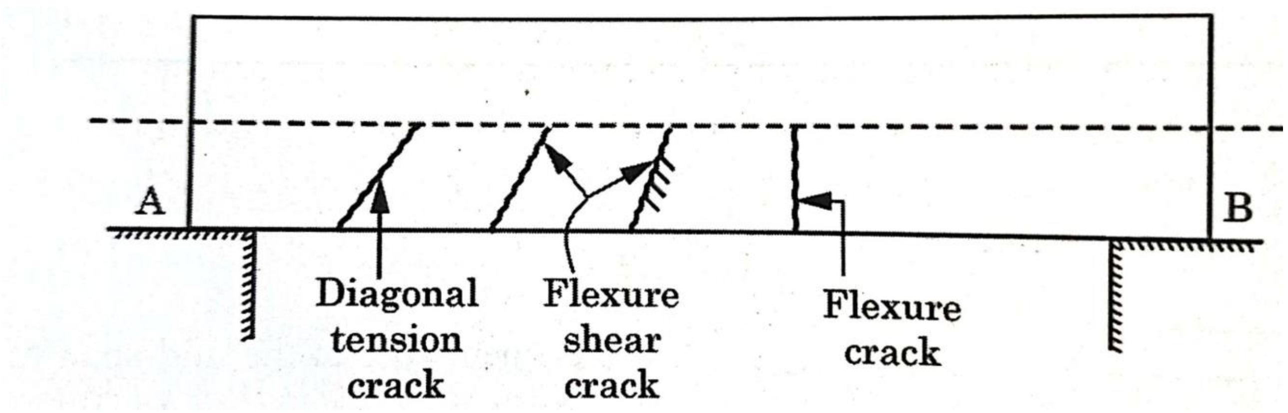
d = effective depth of beam

The shear strength of concrete depends upon the following factors-

- **Grade of concrete:** higher the grade of concrete, higher is the shear strength of concrete.
- **Percentage of Tensile Reinforcement:** the shear strength of a reinforced concrete beam increases with the percentage of tensile reinforcement.

Crack pattern for simply supported beam

The crack pattern for a simply supported beam is shown as-



- At or **near mid-span**, cracks are **vertical** (Flexural cracks)
- At or **near supports**, cracks are **inclined at 45⁰** (diagonal tension crack)
- In **between the supports and mid-span**, cracks are **inclined at 45⁰ to 90⁰** gradually (flexural shear cracks)

Shear reinforcement

Shear reinforcement is designed to resist shear forces in excess of the shear strength of concrete.

- When the nominal shear stress (T_v) exceeds the shear strength of concrete (T_c), shear reinforcement is to be provided.
- When the nominal shear stress exceeds the maximum shear stress (T_v -$T_{c\ max.}$), the section is to be redesigned.
- When the nominal shear stress (T_v) is less than or equal to shear strength of concrete (T_c), there is no need to provide shear reinforcement.

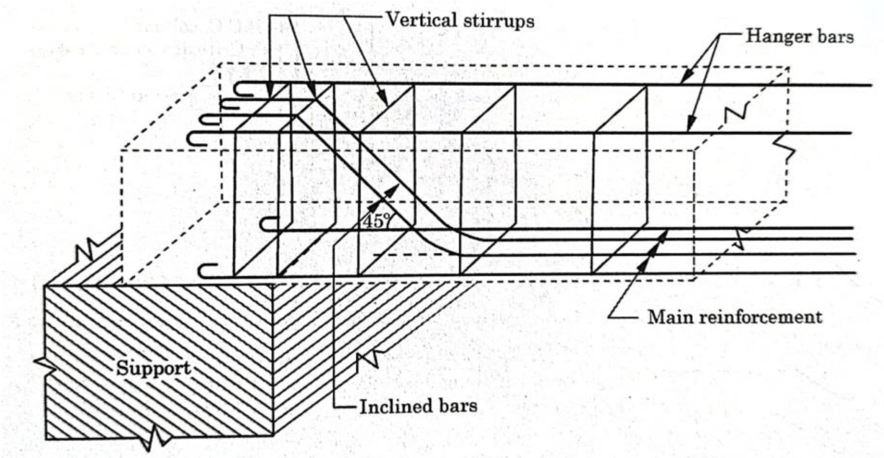


Fig. 4.3 : Arrangement of Shear Reinforcement

Nominal Shear Reinforcement

Reasons for providing minimum shear reinforcement (nominal shear reinforcement)

- It confines the concrete and hence increases its strength
- It holds the reinforcement in place while pouring concrete
- It acts as effective tie for the compression steel
- It prevents brittle shear failure caused due to lack of shear reinforcement
- It prevents the failure of beam caused by cracks

Types of Shear Reinforcement

Different types of Shear reinforcement are:

- Vertical stirrups only
- Bent-up bars inclined at an angle at right angles to the plane of diagonal tension.
- Combination of bent up bars along with vertical stirrups.

(*b*) **Bent up bars along with vertical stirrups :**

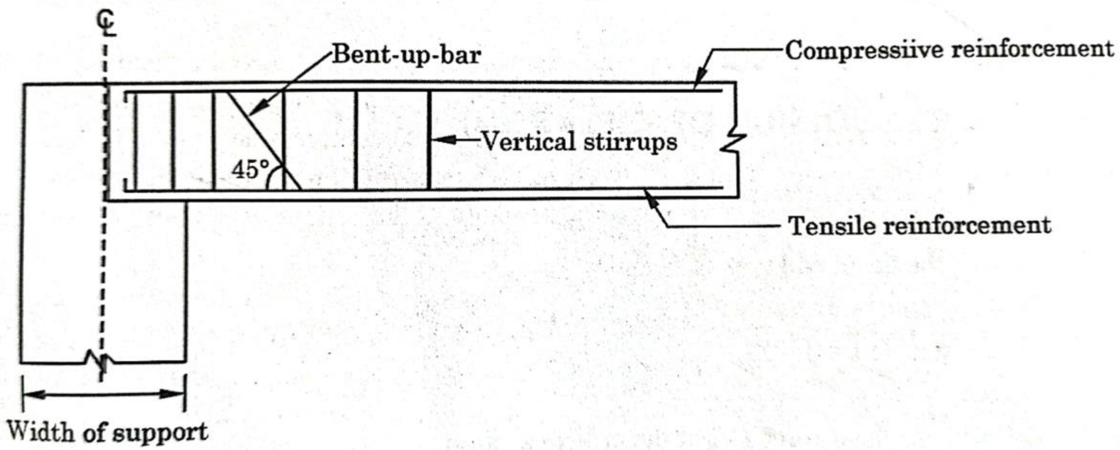


Fig. 4.7 : Combination of bent up bars and vertical stirrups

Vertical Stirrups

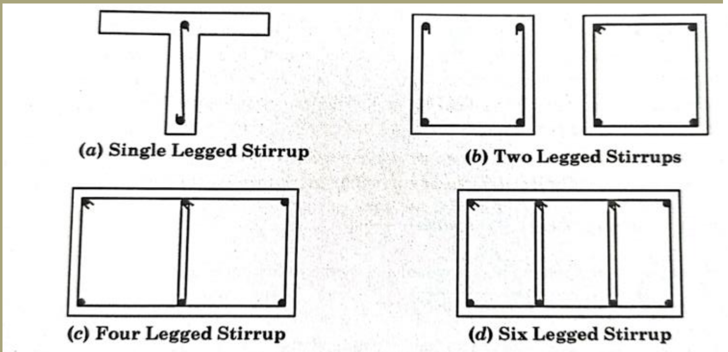


Fig. 4.6 : Vertical Stirrups

Vertical stirrups

Function:

- Vertical stirrups tie the longitudinal reinforcement into the mass of concrete
- Vertical stirrups reinforce the beam transversely against diagonal cracking
- Due to the vertical stirrups, the growth of diagonal cracks is restricted.

Spacing of stirrups

- **Maximum spacing** of vertical stirrups shall be least **0.75d or 300mm**
- The spacing of vertical stirrups **near the supports** is **minimum**

Bond between steel and concrete

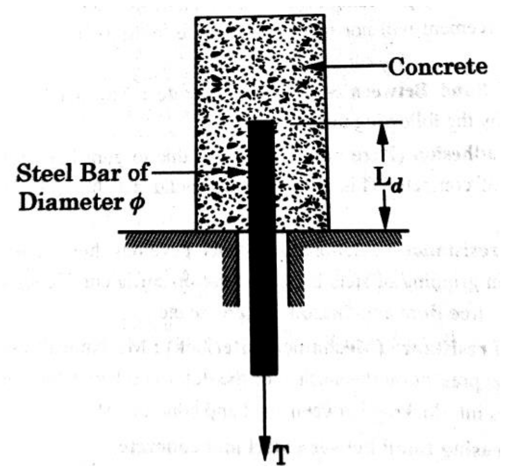
Methods of increasing Bond between steel and concrete:

- By using rich mix of concrete
- By adequate compaction of concrete
- By sufficient curing of concrete
- By providing sufficient cover to reinforcement
- By using deformed or twisted bars
- By providing sufficient length of embedment

Development length and Curtailment of bars

<u>Development length</u>

- Development length is defined as the minimum length of bar which must be embedded in concrete beyond any section to develop its full strength
- Development length is denoted by 'L_d' and is expressed in terms of the diameter of the reinforcing bar.

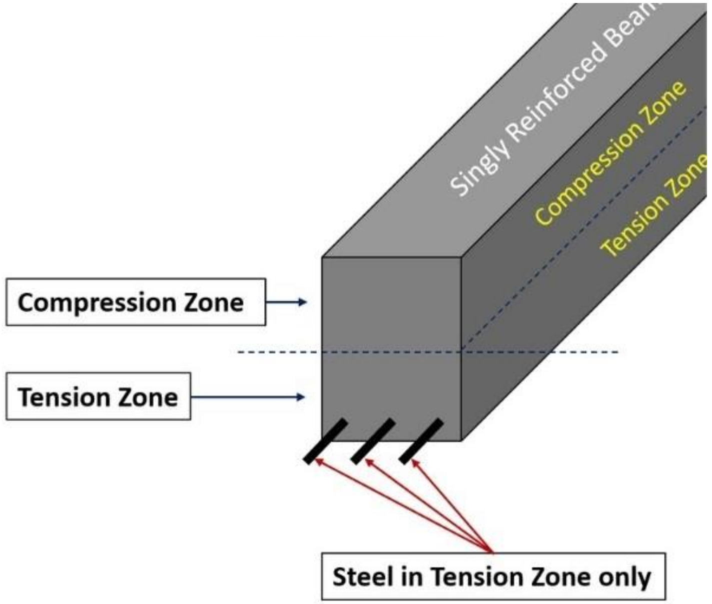


<u>Curtailment of bars</u> is a way to shorten the length of reinforcement or tensile bars are curtailed where the bending moment is minimum or zero to achieve an economical design.

Unit- 4
SINGLY REINFORCED BEAM (WSM)

CONTENT

- Basic assumptions and stress strain curve, neutral axis, balanced, under- reinforcement and over reinforced beams, Moment of resistance for singly reinforced beam
- Design of singly reinforced beam including sketches showing reinforcement details.



BEAMS

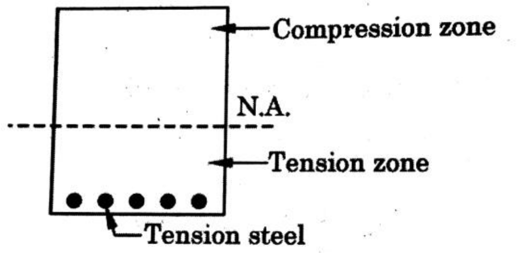


Fig. 3.1 : Section of Singly Reinforced Beam

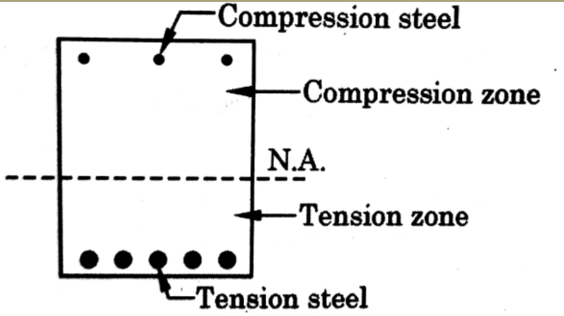


Fig. 3.2 : Section of Doubly Reinforced Beam

Beams are flexural members which are provided in the structures to resist bending, caused due to external loading.

Types of beams- there are three types of beams

- Singly reinforced rectangular beams
- Doubly reinforced rectangular beams
- Singly or doubly reinforced flanged beams (T-beams and L-beams)

Singly reinforced beams: The RCC beams in which the steel reinforcement is provided only in tension zone are known as Singly reinforced beams.

Doubly reinforced beams: The RCC beams reinforced with steel both in tension and compression zones are called Doubly reinforced beams.

Reinforcement in Beams

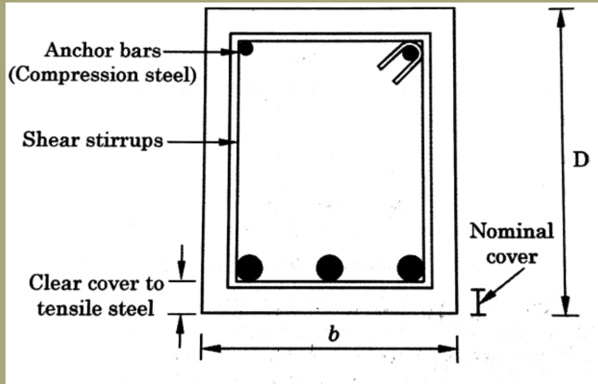


Fig. 5.5 : Nominal Covers to Reinforcement

Tension reinforcement

- **Minimum reinforcement:** the minimum area of tension reinforcement shall not be less than

  $$A_s/bd = 0.85/f_y$$

  where A_s = Minimum area of tension reinforcement
  b = Breadth of beam
  d = effective depth of beam
  f_y = characteristic strength of reinforcement

- **Maximum reinforcement:** the maximum area of tension reinforcement shall not exceed 0.04bD (4% of cross-sectional area of beam)

Compression reinforcement: the maximum area of tension reinforcement shall not exceed 0.04bD (4% of cross-sectional area of beam).

Nominal cover of reinforcement: Nominal cover is the design depth of the concrete cover to all steel reinforcements including shear stirrups or column ties. It shall not be less than the diameter of the bar in any case.

Modular ratio Neutral axis and Lever arm

Modular Ratio: It is defined as ratio of modulus of elasticity of steel (E_s) to that of concrete (E_c). As per IS:456-2000, the modular ratio (m) is expressed mathematically by the following relation: $\mathbf{m = 280/3\sigma_{cbc}}$

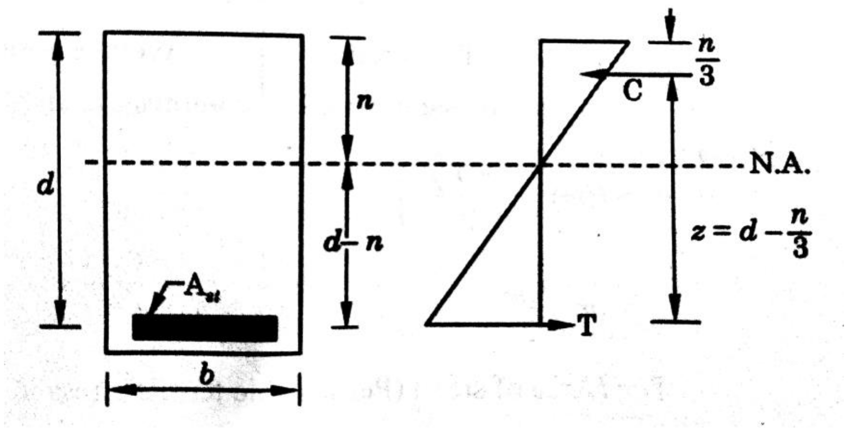
where σ_{cbc} is permissible compressive stress in concrete in bending

- **Modular ratio used for compression steel shall be 1.5m**

Neutral axis (N.A.): Neutral axis is the axis at which the stresses are zero in the section and it divides the cross-section into a tension and a compression zone.

The neutral axis of a balanced section beam is known as critical neutral axis (n_c)

Lever Arm: Lever arm may be defined as the distance between the resultant compressive force and tensile force. It is denoted by 'z'.



Moment of Resistance

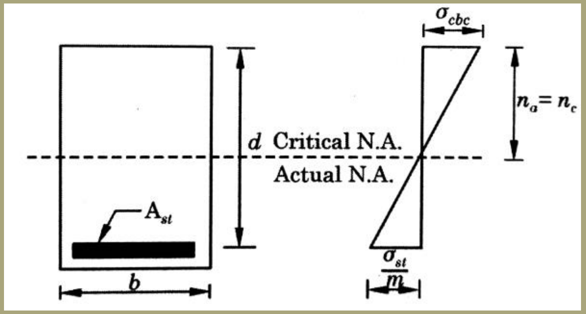
Moment of Resistance (Resisting Moment)
Moment of resistance of a beam may be defined as the resistance offered by a beam to the bending moments developed at the section. It is denoted by 'M_r'.

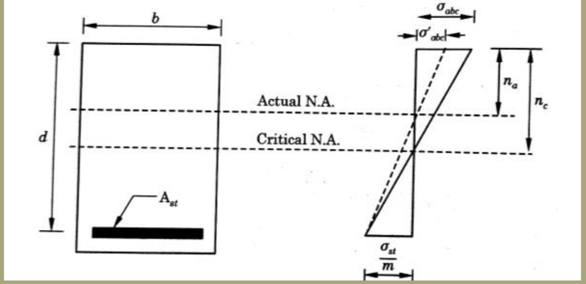
Steps for calculating the moment of resistance of beam are:

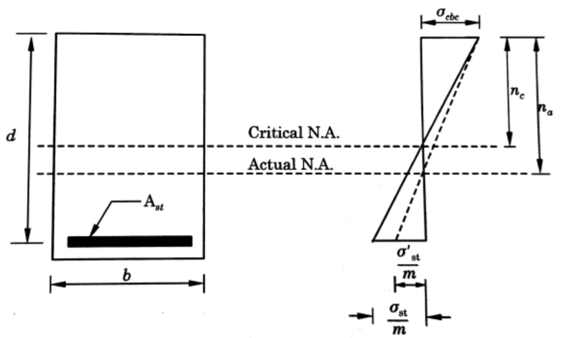
- First step is to find the critical neutral axis (n_c).
- Then, find the depth of actual neutral axis (n_a).
- Final step is to compare n_a and n_c
  i. if $n_a = n_c$, then the moment of resistance can be calculated by formula $$M_r = A_{st}\sigma_{st}\left(d - \frac{n_a}{3}\right)$$
  ii. If $n_a < n_c$, then the moment of resistance can be calculated by formula $$M_r = A_{st}\sigma_{st}\left(d - \frac{n_a}{3}\right)$$
  iii. If $n_a > n_c$, then the moment of resistance can be calculated by formula $$M_r = bn_a\frac{\sigma_{cbc}}{2}\left(d - \frac{n_a}{3}\right)$$

where, area of tensile steel (A_{st})
maximum permissible stresses in concrete and steel (σ_{cbc} and σ_{st})

Types of Beam Sections







Beam sections are classified in the following types:

- **Balanced section:** a balanced section is that in which the compressive stress in concrete and tensile stress reach their maximum permissible values at the same time. Balanced section is also known as critical section.

Formula of **neutral axis for balance beam section n_c = kd**, where 'k' is neutral axis constant and 'd' is effective depth of beam.

- **Unbalanced section:** the RCC section in which the area of steel provided is either less or more than that required for a balanced section is known as unbalanced section.

Unbalanced section is of two types-

a) **Under- reinforced section:** the RCC section in which the area of steel provided is less than required for a balanced section is known as under-reinforced section. Hence, $n_a < n_c$ in under-reinforced section.

b) **Over-reinforced section:** the RCC section in which the area of steel provided is more than that required for a balanced section is known as over-reinforced section. Hence, $n_a > n_c$ in over-reinforced section.

Failure of an over-reinforced section is brittle.

Difference between under-reinforced and over-reinforced section

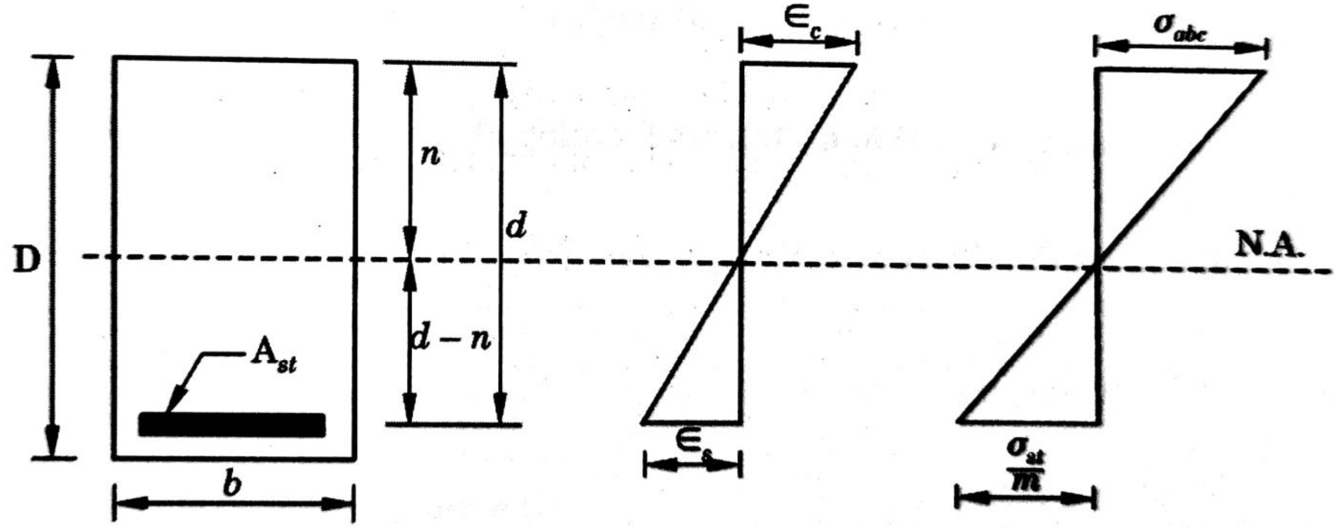
Difference between under-reinforced section and over-reinforced section

Sr. No.	Parameter	Under-reinforced	Over-reinforced
1.	Actual stress in steel (σ_{st})	equal to maximum permissible	less than the maximum permissible
2.	Actual stress in concrete (σ_{cbc})	less than maximum permissible	equal to maximum permissible
3.	Depth of actual neutral axis	$n_a < n_c$	$n_a > n_c$
4.	Percentage of steel	less than the balanced section. Hence economical.	more than the balanced section. Hence uneconomical.
5.	Moment of resistance (M_r)	less than the balanced section.	more than the balanced section.
6.	Formula for calculating M.O.R.	$M_r = \sigma_{st} A_{st} \left(d - \frac{n_a}{3}\right)$	$M_r = \frac{1}{2} \sigma_{cbc}\, b n_a \left(d - \frac{n_a}{3}\right)$
7.	Type of failure	ductile failure, sufficient warning before collapse.	brittle failure, sudden collapse.

Stress- Strain diagram

Stress diagram: As per assumption in the elastic theory, the stress-strain relationship is linear for steel and concrete. So, the stress diagram is a straight line with value zero at neutral axis and varying linearly with the distance.

Strain diagram: the strain in any layer is proportional to its distance from the neutral axis.



(a) Section of a Beam (b) Strain Diagram (c) Stress Diagram

Assumptions in the theory of Simple Bending

The elastic theory of bending is based on the following assumptions for design of R.C.C. structures:

- At any cross-section, plane sections before bending remain plane after bending.
- All tensile stresses are taken up by reinforcement and none by concrete.
- The stress-strain relationship of steel and concrete, under working loads, is a straight line.
- The modular ratio (m) has the value $280/3\sigma_{cbc}$
- The modulus of elasticity of steel and modulus of elasticity of concrete are constant.
- There is a perfect bond between steel and concrete.
- There are no initial stresses in steel and concrete.
- Concrete area in tension zone is assumed to be ineffective and steel area is assumed to be concentrated at the centroid of steel area.

Design of Singly Reinforced Beam (WSM)

- An RCC beam 300mm x 600mm (effective) is reinforced with 6-25mm dia longitudinal tensile steel bars. It is subjected to a shear force of 150kN. Take m=13.33Find whether shear reinforcement is required for the beam using M20 grade concrete and Fe 415 steel.
- Find the moment of resistance of an RCC beam 300mm x 600mm (effective) reinforced with 3 bars of 20mm diameter. The permissible stress in steel and concrete are not to exceed 140 N/mm^2 and 7 N/mm^2 respectively. Take m = 13.33
- An RCC beam 300mm x 600mm (effective) is reinforced with 4 bars of 25mm diameter. The beam is subjected to a bending moment of 120kNm. Find the stresses developed in steel and concrete. Take m = 13.33

Unit- 5
Concept of Limit State Method

CONTENT

- Definitions and assumptions made in limit state of collapse.
- Partial factor of safety for materials and loads
- Design loads
- Stress block diagram

Concept of Limit State Method

Limit State- the acceptable limit for the safety and serviceability requirements before failure occurs is called a 'limit state'.

The important limit states which are considered in design are:

- **Limit state of collapse**
- **Limit state of serviceability**

Limit state of collapse- it is also known as ultimate limit state as it corresponds to the maximum load carrying capacity.

Limit state of serviceability- this limit state is introduced to prevent excessive deflection and cracking. It ensures the satisfactory performance of the structure at working loads.

The two important limit states of serviceability are:

- Limit state of deflection
- Limit state of collapse

Comparison between WSM and LSM

Comparison between Working Stress Method and Limit State Method

Working Stress Method (WSM)	Limit State Method (LSM)
1. This method is based on the elastic theory which assumes that concrete and steel are elastic and the stress strain curve is linear for both materials.	1. This method is based on non-linear stress distribution taking inelastic strain into consideration.
2. This method is based on the behaviour of structure under service load (working loads).	2. In this method the structure is designed on the basis of most critical limit state and checked for other limit states.
3. This method assumes that all the loads, permissible stresses and factor of safety are known. So it is called deterministic method.	3. This method is known as non-deterministic because loads and stresses are predicted based upon experience and field data.
4. In this method the factor of safety are applied to the yield stresses to get permissible (working) stresses. No factor of safety is used for loads.	4. In this method partial safety factors are applied to stress as well as to working loads to get design stresses and design loads respectively.
5. In this method safety against ultimate, loads, is not known.	5. It satisfies all the limit states of collapse and serviceability.
6. This method gives thicker sections and higher quantities of steel reinforcement, therefore, is uneconomical.	6. This method is more economical as it gives thinner sections and requires lesser quantities of steel reinforcement as compared to WSM.

Characteristic Strength and Characteristic Load

Characteristic Strength: the term 'characteristic strength' means that value of the strength of the material below which not more than 5 percent of the test results are expected to fall.

Characteristic strength of concrete (f_{ck}) is defined as the compressive strength of 150mm cube at 28 days expressed in N/mm^2 below which not more than 5% of the test results are expected to fall.

Characteristic strength of Steel (f_y) is defined as that value of yield stress below which not more than 5% of the test results are expected to fall.

Characteristic Load: characteristic load is that value of load which has a 95% probability of not being exceeded during the life of the structure.

Factor of safety

Factor of Safety- Factor of Safety is the ratio of the load or stress that a system can withstand before failure to the actual applied load or stress.

Factor of Safety= Ultimate Load (Strength)/Allowable Load (Stress)

Partial Safety Factors

There are two partial safety factors-

- **Partial Safety Factor for Strength of Materials-** the partial safety factor for strength of materials is the factor by which the characteristic strength of the material is divided to get the design values for materials. It is denoted by γ_m.
- **Partial Safety Factor for Loads-** the partial safety factor for the loads is the factor by which the characteristic loads are multiplied to get the design values for loads. It is denoted by γ_f.

Assumptions in Limit State of Collapse in flexure

Design for the limit state of collapse in flexure (bending) shall be based on the following assumptions:

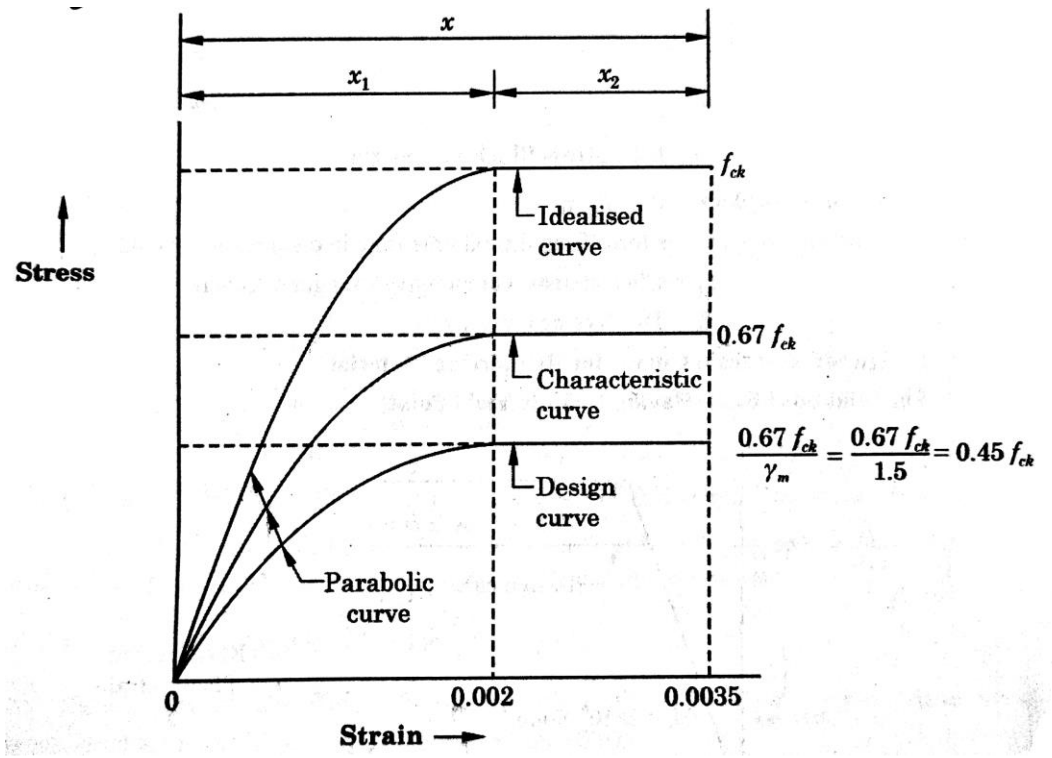
- Plane sections normal to the axis remain plane after bending.
- The maximum strain in concrete at the outermost compression fibre is taken as 0.0035 in bending.
- The relationship between the stress-strain distribution in concrete is assumed to be parabolic.
- The tensile strength of concrete is ignored.
- The stresses in the reinforcement are obtained from the stress-strain curve.
- The maximum strain in the tension reinforcement in the section at failure shall not be less than

  $f_y/1.15E_s + 0.002$ where f_y = characteristic strength of steel

  E_s = Modulus of elasticity of steel

Stress- Strain Curve

As per IS:456-2000, the characteristic and design stress-strain curve for concrete in flexural compression is shown below:



- The curve for concrete is a parabola in the initial region upto a strain of 0.002. Beyond strain, the stress remains constant until a strain of 0.0035 is reached when the concrete is said to have failed.

Unit- 6,7
Singly Reinforced and Doubly Reinforced beams

CONTENT

- Theory and design of singly reinforced beam by Limit State Method
- Theory and design of simply supported doubly reinforced beam by Limit State Method

Beams

Beams are flexural members which are provided in the structures to resist bending, caused due to external loading.

There are three types of RCC beams

I. Singly reinforced beams
II. Doubly reinforced beams
III. T-beams and L-beams

Singly reinforced beams: the RCC beams in which the steel reinforcement is provided only in tension zone, are known as Singly reinforced beams.

Simply supported beams: A simply supported beam is one that rests on two supports and is free to move horizontally.

Cantilever beams: A cantilever beam is a rigid structural element that is supported at one end and free at the other.

Continuous beams: A continuous beam is a statically indeterminate multi-span beam on hinged support. The end spans may be cantilever, may be freely supported or fixed supported.

Doubly Reinforced beams

The RCC beams reinforced with steel both in tension and compression zones are called Doubly reinforced beams.

- A doubly reinforced beam section has **moment of resistance greater than that of a balanced section**.
- In doubly reinforced beam, **compression is taken by steel and concrete.**

Conditions under which doubly reinforced beams are used:

- When depth of beam is restricted due to any constraints like availability of head room, architectural or some other reasons.
- When the member is subjected to eccentric loading
- When the member is subjected to accidental or sudden lateral loads.
- In case of continuous beams, the sections at supports are generally designed as doubly reinforced beams.

Difference between Singly reinforced and doubly reinforced beam

S.No	Singly reinforced beam	Doubly reinforced beam
1	Reinforcement bars provided only in the tension zone	Reinforcement bars are provided in both tension and compression zone
2	Steel bars in the compression zone don't participate in a moment carrying capacity	Steel bars in the compression zone participate in a moment carrying capacity
3	Concrete in the compression zone is sufficient to resist bending moment	Concrete in the compression zone is inadequate to resist bending moment, requiring additional reinforcements
4	Used in situations where the load is minimum	Used in situations where there are constraints about the cross-section, changing bending moments, and for structures with moving loads
5	Commonly used in residential buildings, small-span structures	Commonly used in High-rise buildings, bridges, industrial structures

Basic rules for Design of Beams

While designing RCC beams, the following rules as per IS:456-2000 must be kept in mind:

Effective Span: the effective span of a beam shall be as follows:

- Simply supported beam: the effective span is taken as the least of the following: (i) centre to centre distance between supports

  (ii) clear span + effective depth of beam

- Cantilever beam: the effective span of cantilever beam shall be taken as length of the overhang + ½ effective depth

- Continuous beam:

  (i) if the width of support is less than $1/12^{th}$ of the clear span

  (ii) if the width of support is greater than $1/12^{th}$ of the clear span or 600 mm whichever is less.

Reinforcement in Beams

Tension reinforcement

- **Minimum reinforcement:** The minimum area of tension reinforcement shall be not less than that given by the following

$$\frac{A_s}{bd} = \frac{0.85}{f_y}$$

where

A_s = minimum area of tension reinforcement,

b = breadth of beam or the breadth of the web of T-beam,

d = effective depth, and

f_y = characteristic strength of reinforcement in N/mm^2.

- **Maximum reinforcement:** The maximum area of tension reinforcement shall not exceed 0.04bD (i.e. 4% of cross-sectional area of beam)

Compression reinforcement: The maximum area of compression reinforcement shall not exceed 0.04bD (i.e. 4% of the cross-sectional area of beam)

Design steps for Doubly Reinforced Beams

Design steps of doubly reinforced beams:

1. Calculate ultimate maximum bending moment (M_u)
2. Calculate limiting moment of resistance ($M_{u,\,lim}$)
3. Compare (M_u) and ($M_{u,\,lim}$)
4. Calculate area of tensile reinforcement (A_{st})
5. Calculate area of compressive reinforcement (A_{sc})
6. Check for shear at critical section
7. Check for development length

Unit- 8
T- Beams and L-Beams

CONTENT

- Behavior of T beam, inverted T beam, isolated T beam
- L beams

Concept of T beam

T-Beam

In RCC construction, when a slab along with beam are cast monolithically and beam is hanging below the slab then it is called as T- beam

The portion of slab which acts integrally with the beam is called as '**Flange**' of T-beam.

The portion of beam below the flange or slab is called as '**Web**' or '**Rib**' of the beam.

Inverted T-beam: the arrangement of T-beam in which web lies above the slab is called Inverted T-Beam.

Isolated T-beam: An Isolated T-Beam is such type of beam in which flange of T-Beam not connected with the slab. In this type of beam T-Beam and slab didn't cast at same time.

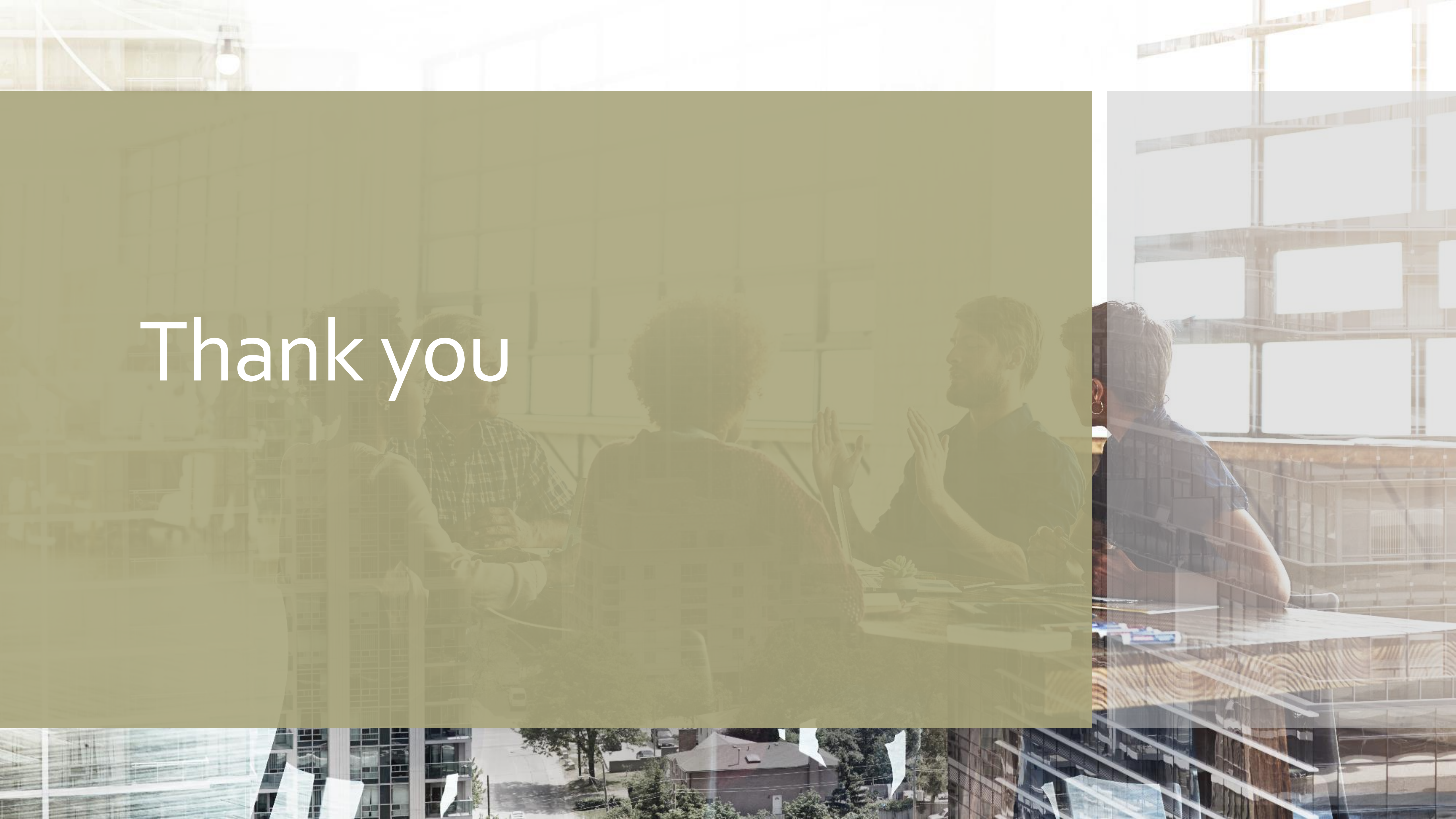
Concept of T beam

T-beam is considered better as compared to rectangular beam because:

- In rectangular RCC beam, concrete below the neutral axis does not resist any bending moment but simply holds the tensile reinforcement.
- Some portion of concrete just above the neutral axis carries only very little compressive stresses because the intensity of compressive stress there is of very small magnitude.
- Section of beam should be such that it has greater width at the top in comparison to width below neutral axis.
- Flanged beam has larger width at the top in comparison to width at bottom

Reasons for providing inverted T-beams:

- In some cases, provision of beam below the slab may be undesirable from architectural point of view or there might be the need of clear space between floor and ceiling. Hence, inverted T-beam is provided.


Thank you