INSTITUTE OF AERONAUTICAL ENGINEERING

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PRESTRESSED CONCRETE STRUCTURES

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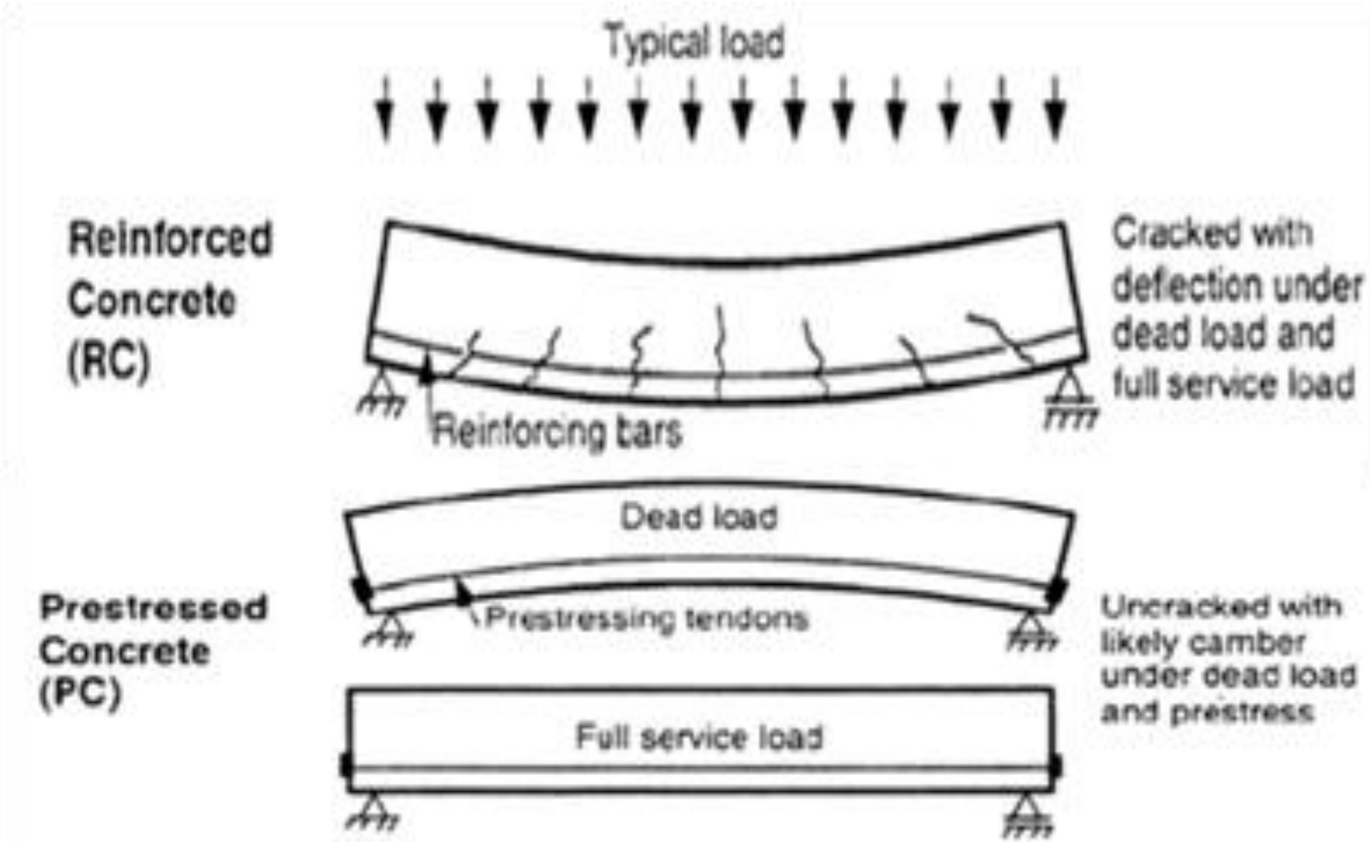
UNIT-I

INTRODUCTION

Definition of Prestress

Internal stresses are induced in a member to counteract the external stresses which are developed due to the external loads or service loads

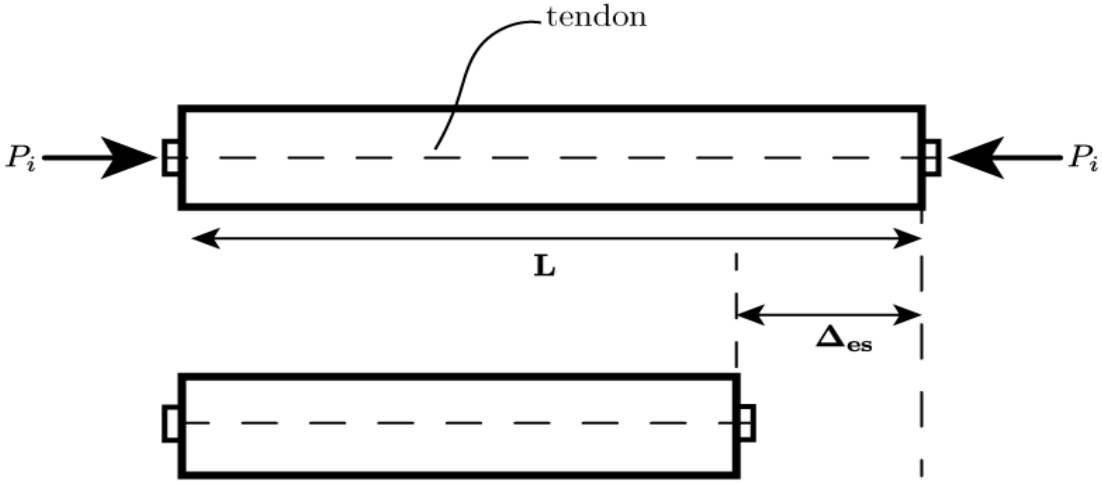

Typical load
Reinforced Concrete (RC)
Cracked with deflection under dead load and full service load
Reinforcing bars
Dead load
Prestressed Concrete (PC)
Prestressing tendons
Uncracked with likely camber under dead load and prestress
Full service load

Concept:

- Prestressed concrete is basically concrete in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting from the external loads are counteracted to a desired degree.

Terminology

- **1. Tendon**: A stretched element used in a concrete member of structure to impart prestress to the concrete.



- **2**. **Anchorage**: A device generally used to enable the tendon to impart and maintain prestress in concrete.

3. **Pretensioning**: A method of prestressing concrete in which the tendons are tensioned before the concrete is placed. In this method, the concrete is introduced by bond between steel & concrete.

4. **Post-tensioning**: A method of prestressing concrete by tensioning the tendons against hardened concrete. In this method, the prestress is imparted to concrete by bearing.

Materials for prestress concrete members

Cement:

The cement used should be any of the following

- Ordinary Portland cement conforming to IS269
- Portland slag cement conforming to IS455. But the slag content should not be more than 50%.
- Rapid hardening Portland cement conforming to IS8041.
- High strength ordinary Portland cement conforming to IS8112.

Concrete:

- Prestress concrete requires concrete, which has a high compressive strength reasonably early age with comparatively higher tensile strength than ordinary concrete.
- The concrete for the members shall be air-entrained concrete composed of Portland cement, fine and coarse aggregates, admixtures and water.
- The air-entraining feature may be obtained by the use of either air-entraining Portland cement or an approved air-entraining admixture.

- The entrained air content shall be not less than 4 percent or more than 6 percent.
- Minimum cement content of 300 to 360 kg/m^3 is prescribed for the durability requirement.
- The water content should be as low as possible

Steel

- High tensile steel , tendons , strands or cables

The steel used in prestress shall be any one of the following:-

- Plain hard-drawn steel wire conforming to IS1785 (Part-I & Part-III)
- Cold drawn indented wire conforming to IS6003
- High tensile steel wire bar conforming to IS2090
- Uncoated stress relived strand conforming to IS6006

High strength steel contains:

- 0.7 to 0.8% carbons,
- 0.6% manganese,
- 0.1% silica

Durability, Fire Resistance & Cover Requirements For P.S.C Members:-

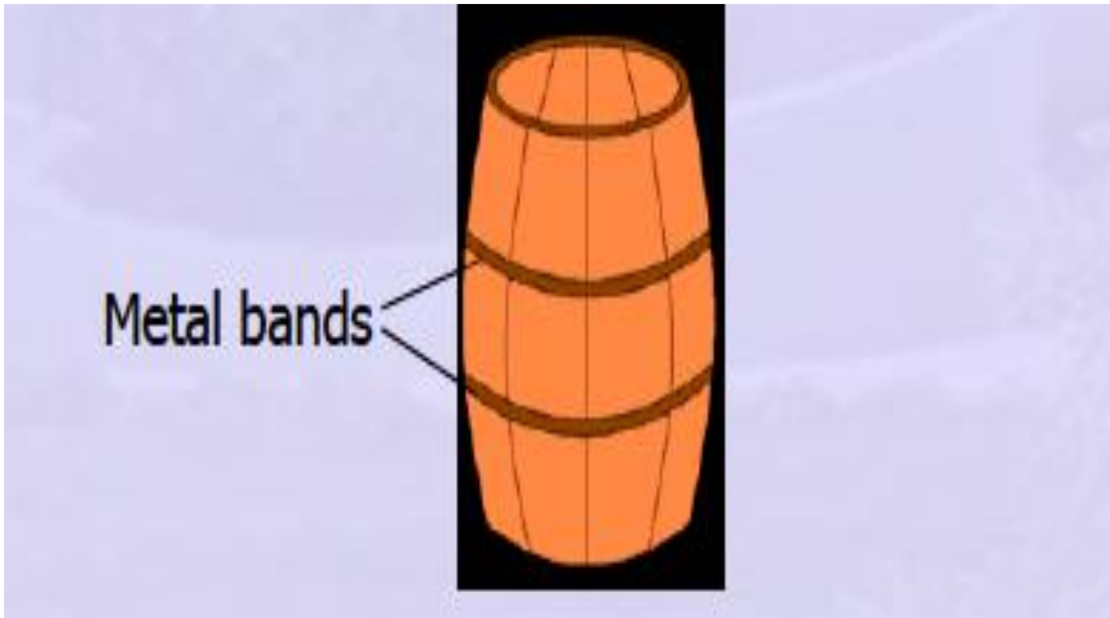
According to IS: 1343-1980

- 20 mm cover for pretensioned members
- 30 mm or size of the cable which ever is bigger for post tensioned members.
- If the prestress members are exposed to an aggressive environment, these covers are increased by another 10 mm.

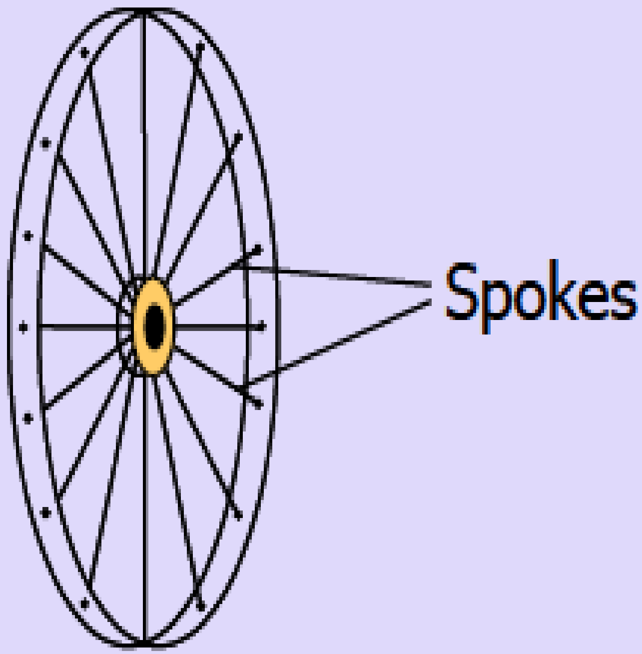
Necessity of high grade of concrete & steel

- Higher the grade of concrete higher the bond strength which is vital in pretensioned concrete, Also higher bearing strength which is vital in post-tensioned concrete.
- Generally minimum M30 grade concrete is used for post-tensioned & M40 grade concrete is used for pretensioned members

History and development of prestress of PSC



Force-fitting of metal bands on wooden barrels



Pre-tensioning the spokes in a bicycle wheel

Forms of Prestressing Steel

- **Wires**: Prestressing wire is a single unit made of steel.
- **Strands**: Two, three or seven wires are wound to form a prestressing strand.
- **Tendon**: A group of strands or wires are wound to form a prestressing tendon.
- **Cable**: A group of tendons form a prestressing cable.
- **Bars**: A tendon can be made up of a single steel bar. The diameter of a bar is much larger than that of a wire.

Bonded tendon

- When there is adequate bond between the prestressing tendon and concrete, it is called a bonded tendon. Pre-tensioned and grouted post-tensioned tendons are bonded tendons.

Unbonded tendon

- When there is no bond between the prestressing tendon and concrete, it is called unbonded tendon. When grout is not applied after post-tensioning, the tendon is an unbonded tendon.

Stages of Loading

- The analysis of prestressed members can be different for the different stages of loading. The stages of loading are as follows.

- **1) Initial:** It can be subdivided into two stages.

  a) During tensioning of steel

  b) At transfer of prestress to concrete.

- **2) Intermediate:** This includes the loads during transportation of the prestressed members.

- **3) Final:** It can be subdivided into two stages.
- a) At service, during operation.
- b) At ultimate, during extreme events.

Advantages of Prestressing

- Section remains uncracked under service loads
- **High span-to-depth ratios**
- **Suitable for precast construction**

Limitations of Prestressing

- Prestressing needs skilled technology. Hence, it is not as common as reinforced concrete.
- The use of high strength materials is costly.
- There is additional cost in auxiliary equipments.
- There is need for quality control and inspection.

Types of Prestressing

- External or internal prestressing
- Pre-tensioning or post-tensioning
- Linear prestressing

Circular pre stressing

- Full, limited or partial prestressing

- Uniaxial, biaxial or multi-axial prestressing

Source of Prestressing Force

- Hydraulic Prestressing
- Electrical Prestressing
- Mechanical Prestressing

Differences of Prestressed Concrte Over Reinforced Concrete

- In prestress concrete member steel plays active role. The stress in steel prevails whether external load is there or not. But in R.C.C., steel plays a passive role. The stress in steel in R.C.C members depends upon the external loads. *i.e.*, no external load, no stress in steel.

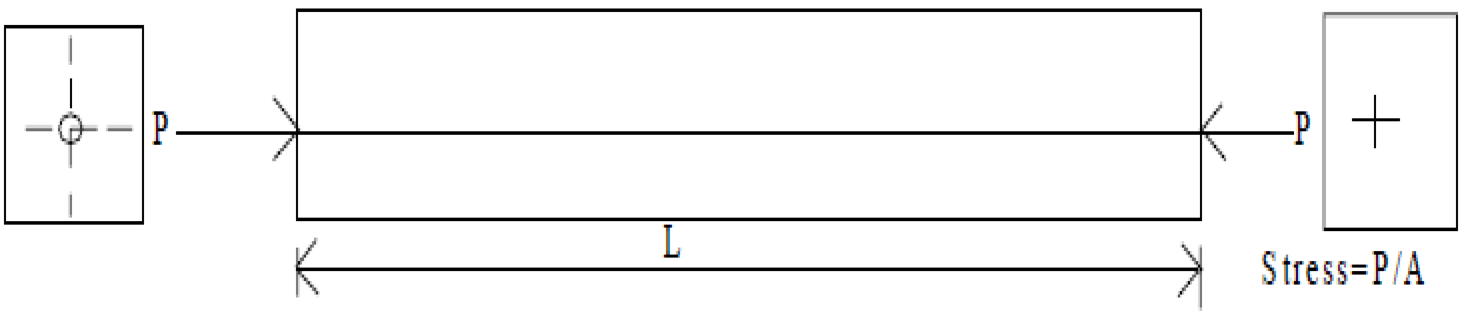
- In prestress concrete the stresses in steel is almost constant where as in R.C.C the stress in steel is variable with the lever arm.
- concrete has more shear resistance, where as shear resistance of R.C.C is less.
- In prestress concrete members, deflections are less

- In prestress concrete fatigue resistance is more compare to R.C.C
- In prestress concrete dimensions are less because external stresses are counterbalance by the internal stress induced by prestress

Analysis of Prestress Member

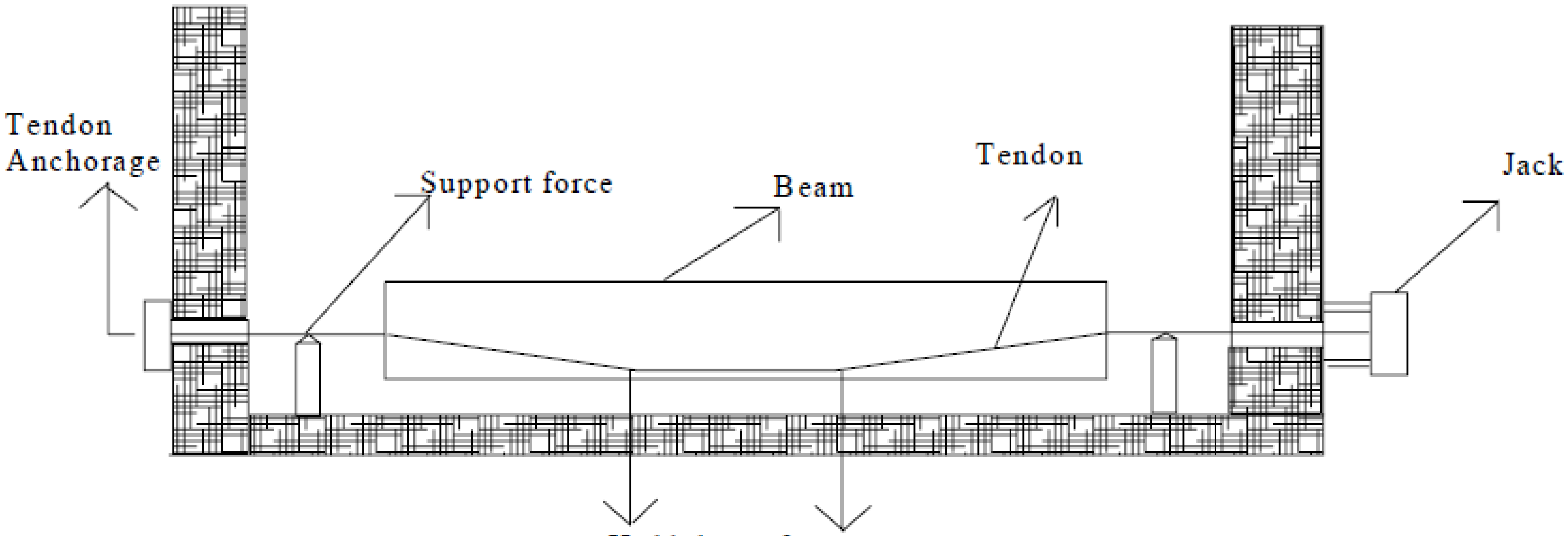
- **Basic assumption:**
- 1. Concrete is a homogenous material.
- 2. Within the range of working stress, both concrete & steel behave elastically, not withstanding the small amount of creep, which occurs in both the materials under the sustained loading.
- 3. A plane section before bending is assumed to remain plane even after bending, which implies a linear strain distribution across the depth of the member

Concentric tendon

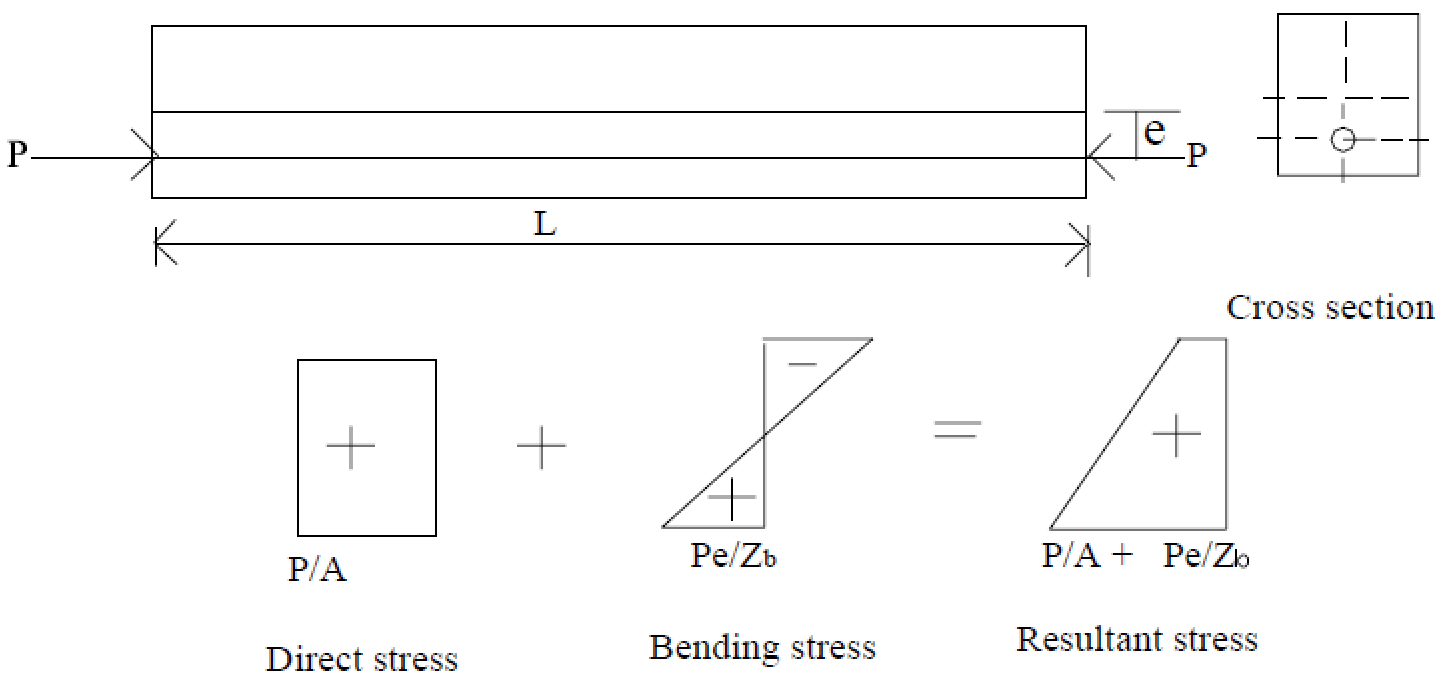


Concentric prestressing

Eccentric tendon



Beam with bend tendon


P
e
P
L
Cross section
P/A
Pe/Zb
P/A + Pe/Zb
Direct stress
Bending stress
Resultant stress

UNIT-II

LOSSES OF PRE-STRESS

- Pre stress does not remain constant with time
- Even during prestressing of tendons and transfer of prestress there is a drop in pre stress from the initially applied stress

Reduction of prestress is nothing but the **loss** in prestress

Loss of prestress is classified into two types

- Short-Term or Immediate Losses

- Long-Term or Time Dependent Losses

- Immediate losses occur during prestressing of tendons, and transfer of prestress to concrete member

- **Time dependent losses** occur during service life of structure

Immediate Losses include

- **Elastic Shortening** of Concrete

f_c → Prestress in concrete at the level of steel

E_s → Modulus of elasticity of steel

E_c → Modulus of elasticity of concrete

α_e → Modular ratio

$$\text{Strain in concrete at the level of steel} = \frac{f_c}{E_c}$$

$$\text{Stress in steel corresponding to this strain} = \frac{f_c}{E_c} E_s$$

- **Slip** at anchorages immediately after prestressing

- The magnitude of loss of stress due to the slip in anchorage is computed as follows: -
- If Δ slip of anchorage, in mm
- *L* -Length of the cable, in mm
- *A*-Cross-sectional area of the cable in mm^2
- E_s - Modulus of elasticity of steel in N/mm^2

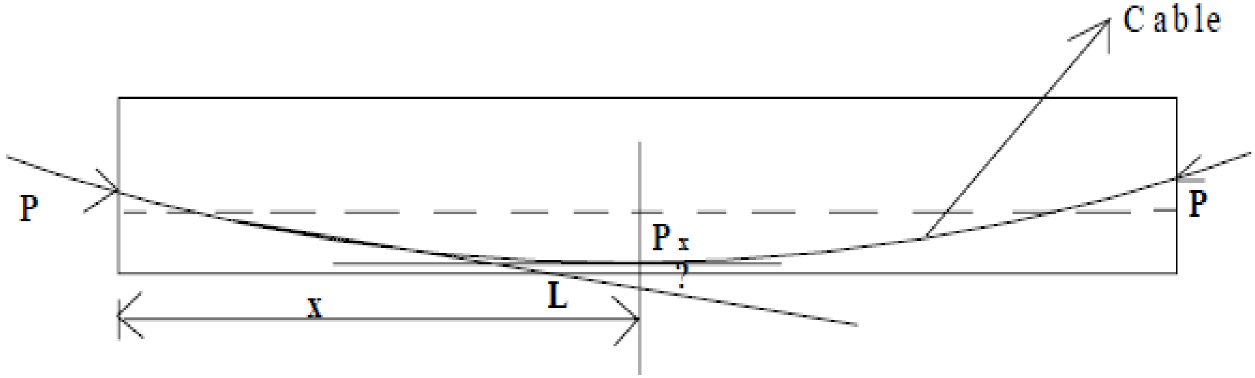
P -Prestressing force in the cable, in N

$\Delta = PL / A E_s$

- Hence, Loss of stress due to anchorage slip=

$$\frac{P}{A} = \frac{E_s \Delta}{L};$$

- **Friction** between tendon and tendon duct, and wobble Effect



$$P_x = P_o e^{-(\mu\alpha + kx)}$$

Where,

P_o -The Prestressing force at the jacking end.

M - Coefficient of friction between cable and duct

A - The cumulative angle in radians through the tangent to the cable profile has turned between any two points under consideration.

k- Friction coefficient for wave effect.

The IS code recommends the following value for *k*

k = 0.15 per 100 m for normal condition

= 1.5 per 100 m for thin walled ducts where heavy vibration are encountered and in other adverse conditions.

Time Dependent Losses include

Creep

The loss of stress in steel due to creep of concrete = $\varepsilon_{cc} f_c E_s$

Where, ε_{cc} → Ultimate creep strain for a sustained unit stress.

f_c → Compressive stress in concrete at the level of steel

E_s → Modulus of elasticity of steel

2. Creep Coefficient Method

$$\text{Creep coefficient} = \frac{Creep\ \ strain}{Elastic\ \ strain} = \frac{\varepsilon_c}{\varepsilon_e}$$

$$\text{Therefore, loss of stress in steel} = \varepsilon_c E_s = \phi \varepsilon_e E_s = \phi \left(\frac{f_c}{E_c} \right) E_s = \phi f_c \alpha_e$$

Where, ϕ → Creep Coefficient

ε_c → Creep strain

ε_e → Elastic strain

α_e → Modular ratio

f_c → Stress in concrete

E_c → Modulus of elasticity of concrete

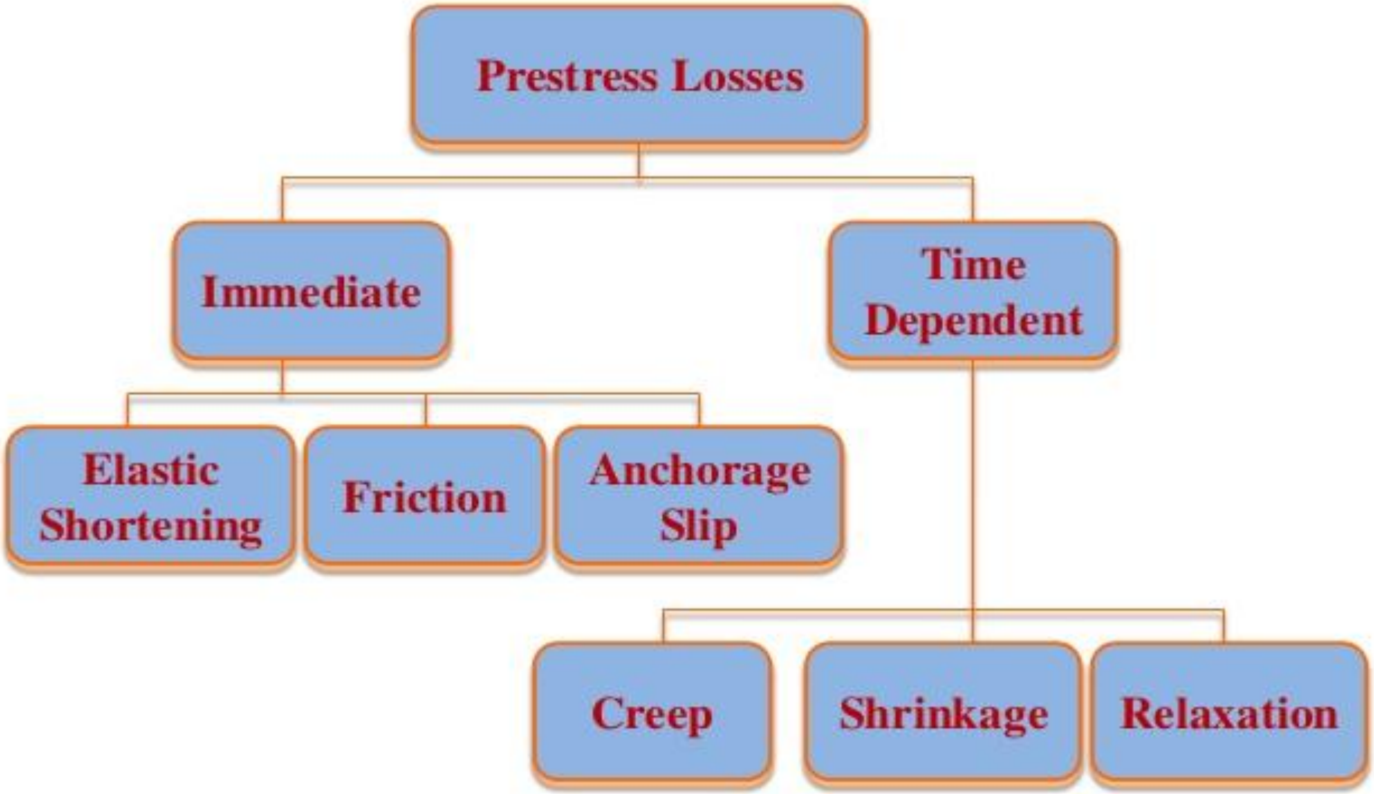
E_s → Modulus of elasticity of steel

Relaxation of pre-stressing steel

Most of the codes provide for the loss of stress due to relaxation of steel as a percentage of initial stress in steel. The BIS recommends a value varying from 0 to 90 N/mm^2 for stress in wires varying from

$$0.5 f_{pu} \text{ to } 0.8 f_{pu}$$

Where, f_{pu} → Characteristic strength of pre-stressing tendon.


Prestress Losses
Immediate
Time Dependent
Elastic Shortening
Friction
Anchorage Slip
Creep
Shrinkage
Relaxation

UNIT -III

FLEXURE

Similar to members under axial load, the analysis of members under flexure refers to the evaluation of the following.

- 1) Permissible prestress based on allowable stresses at transfer.
- 2) Stresses under service loads. These are compared with allowable stresses under service conditions.

- 3) Ultimate strength. This is compared with the demand under factored loads.
- 4) The entire load versus deformation behaviour

Assumptions

- The analysis of members under flexure considers the following.
- Plane sections remain plane till failure (known as Bernoulli's hypothesis).
- Perfect bond between concrete and prestressing steel for bonded tendons.

Principles of Mechanics

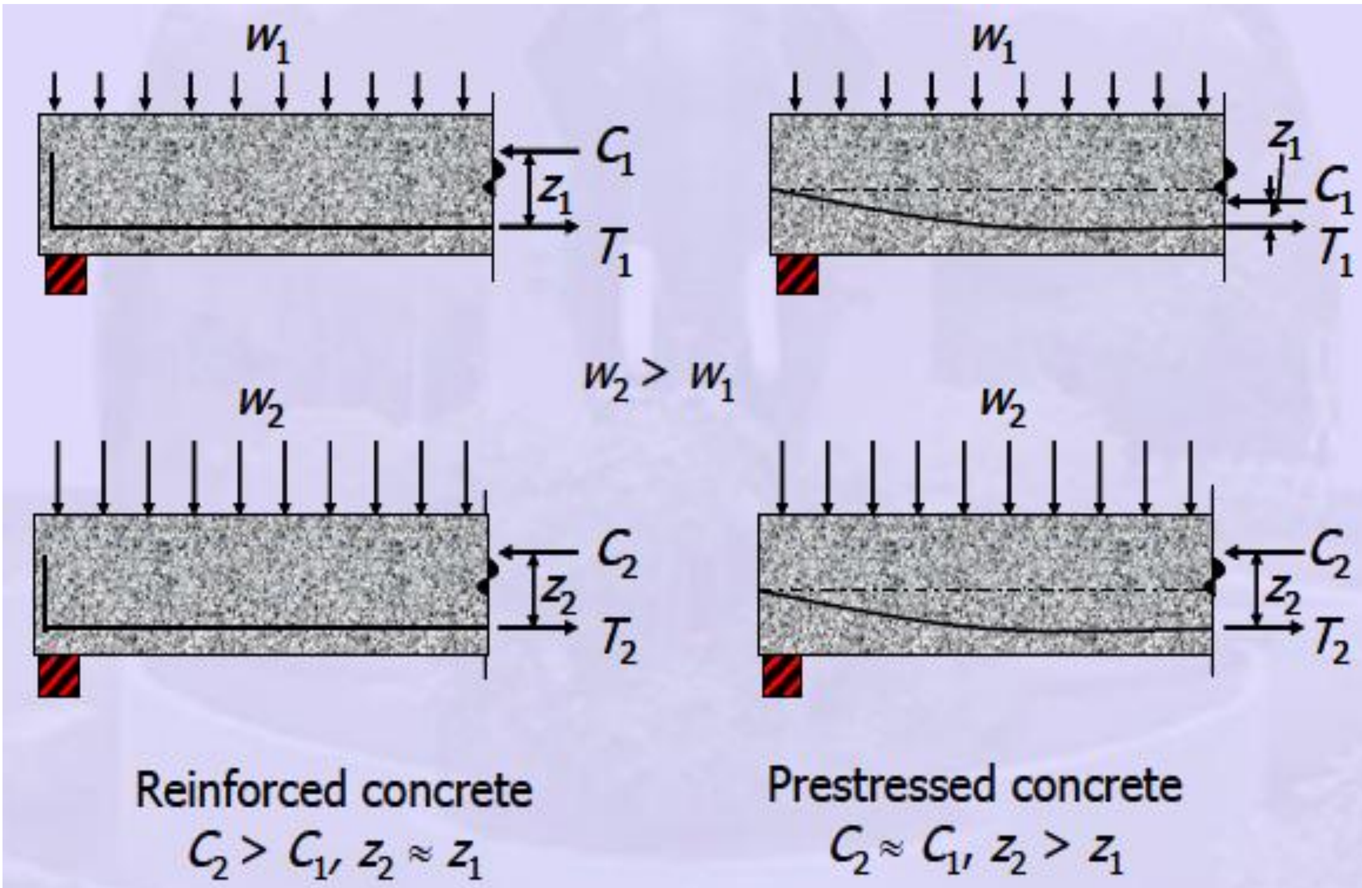
The analysis involves three principles of mechanics.

- **Equilibrium** of internal forces with the external loads. The compression in concrete (*C*) is equal to the tension in the tendon (*T*). The couple of C and T are equal to the moment due to external loads.

Compatibility of the strains in concrete and in steel for bonded tendons. Theformulation also involves the first assumption of plane section remaining plane after bending. For unbonded tendons, the compatibility is in terms of deformation.

- **Constitutive** relationships relating the stresses and the strains in the materials

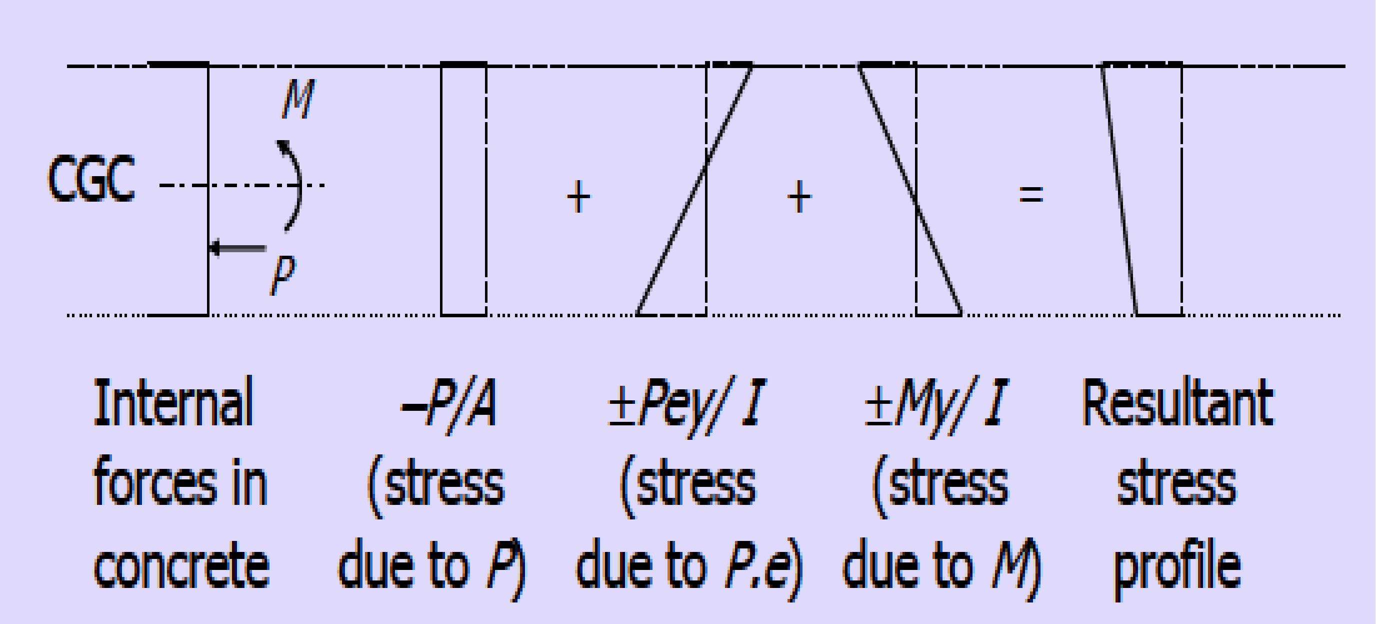
Variation of Internal Forces



Analysis at Transfer and at Service

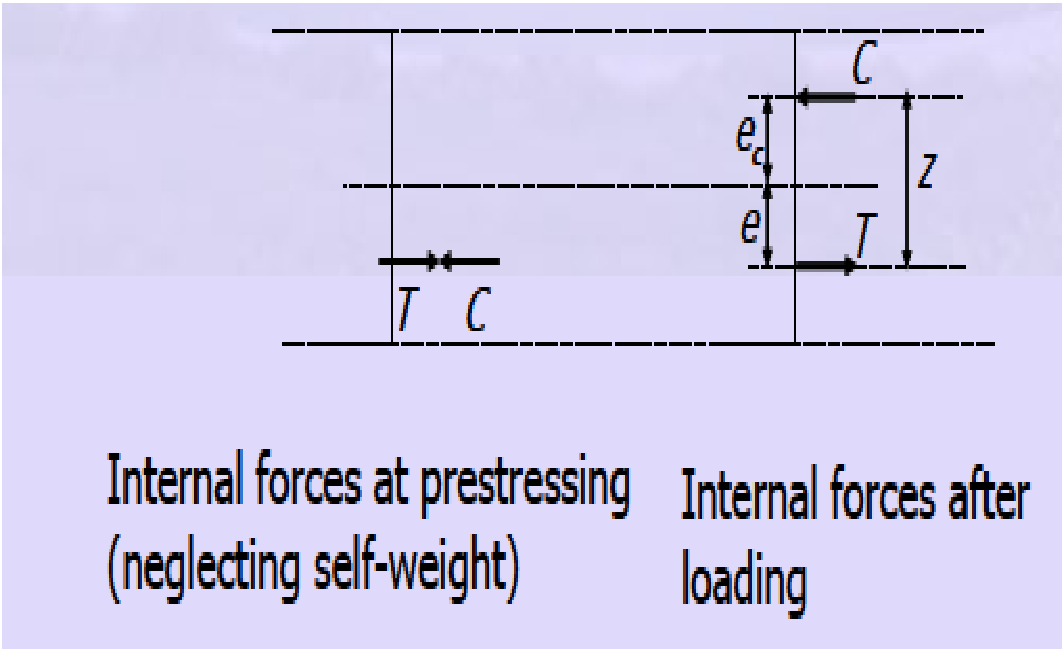
- Based on stress concept.
- Based on force concept.
- Based on load balancing concept.

Based on Stress Concept



$$f = -\frac{P}{A} \pm \frac{Pey}{I} \pm \frac{My}{I}$$

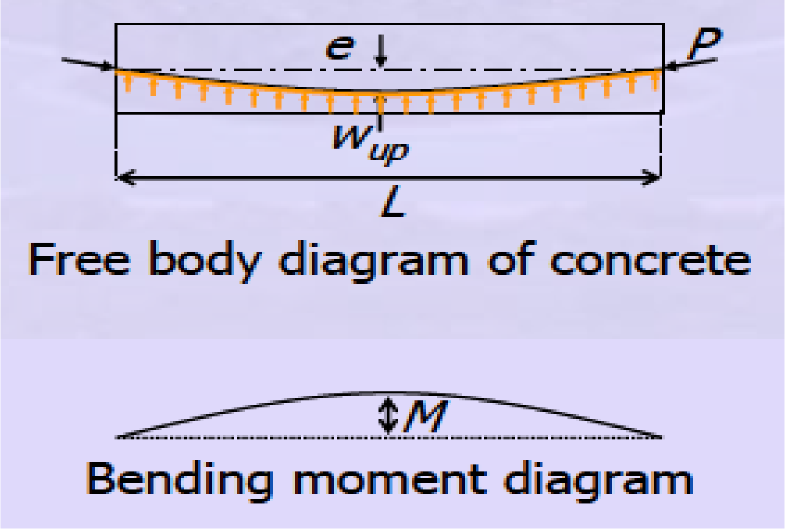
Based on Force Concept



$$f = -\frac{P}{A} \pm \frac{Pey}{I} \pm \frac{My}{I}$$

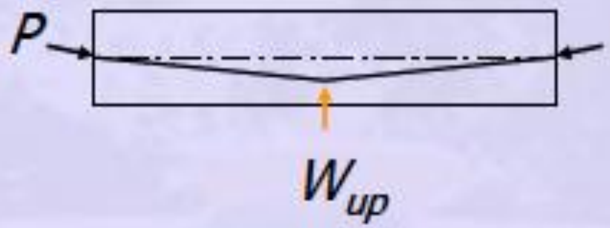
Based on Load Balancing Concept

a) For a Parabolic Tendon



$$M = \frac{w_{up} L^2}{8}$$

b) For Singly Harped Tendon



Free body diagram of concrete

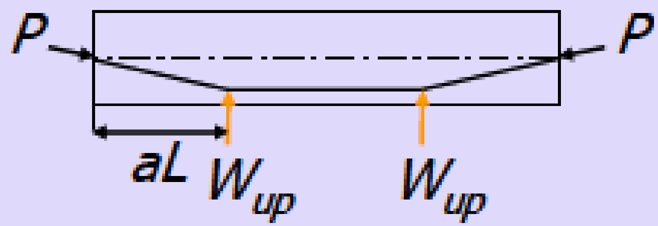
Bending moment diagram

$$M = \frac{W_{up}L}{4} = Pe$$

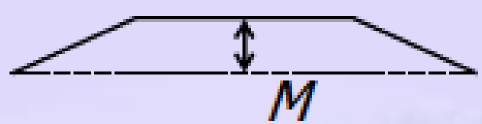
$$W_{up} = \frac{4Pe}{L}$$

$$\Delta = \frac{W_{up}L^3}{48EI}$$

- c) … on



Free body diagram of concrete



Bending moment diagram

$$M = W_{up} aL = Pe$$

$$W_{up} = \frac{Pe}{aL}$$

$$\Delta = \frac{a\left(3 - 4a^2\right) W_{up} L^3}{24EI}$$

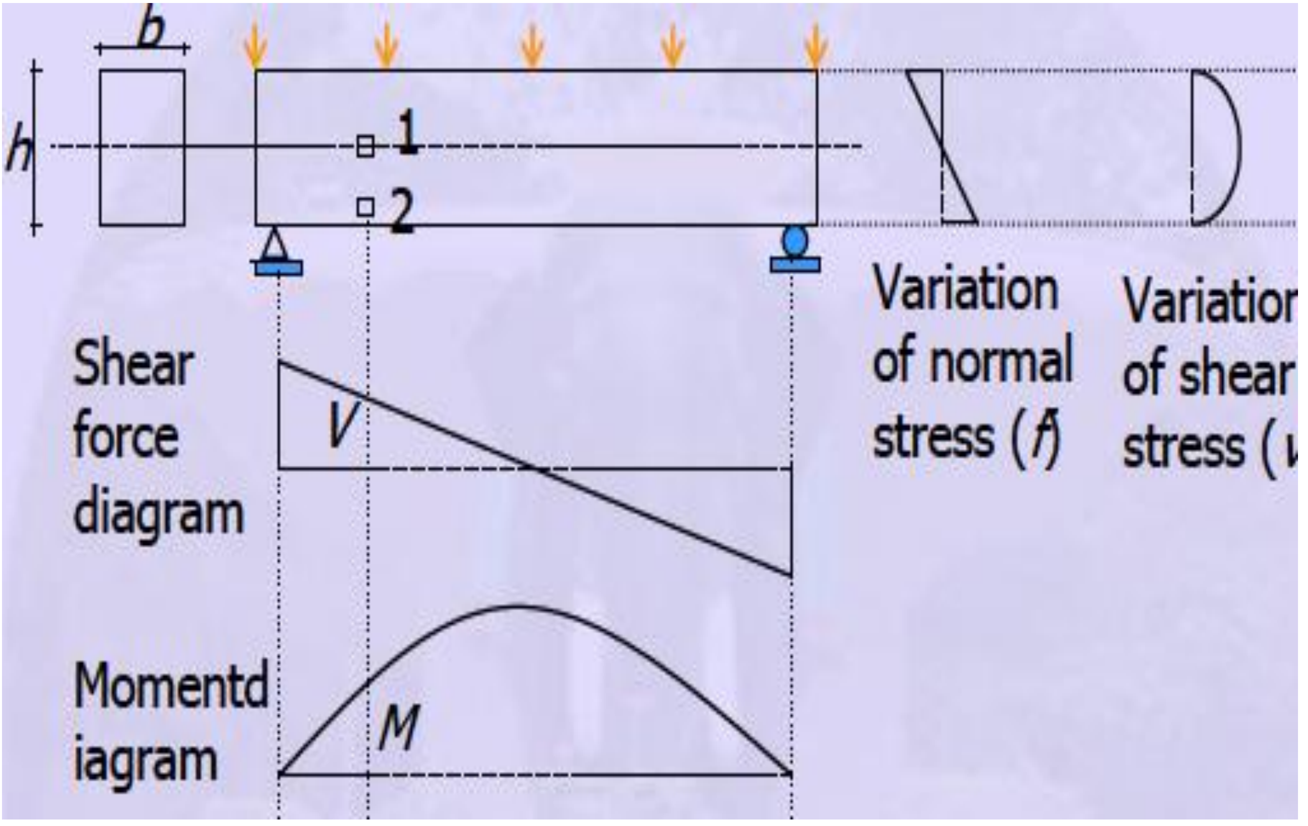
Analysis for Shear

Introduction:

- The analysis of reinforced concrete and prestressed concrete members for shear is more difficult compared to the analyses for axial load or flexure.

- The analysis for axial load and flexure are based on the following principles of mechanics.
- 1) **Equilibrium** of internal and external forces
- 2) **Compatibility** of strains in concrete and steel
- 3) **Constitutive relationships** of materials.

Stresses in an Uncracked Beam



Variations of forces and stresses in a simply supported beam

UNIT-IV

TRANSFER OF PRESTRESS IN PRETENSIONED MEMBERS

pre-tensioned Members

- The stretched tendons transfer the prestress to the concrete leading to a self equilibrating system.

- For a pre-tensioned member, usually there is no anchorage device at the ends.

End of pre-tensioned railway sleepers

- For a pre-tensioned member the prestress is transferred by the **bond** between the concrete and the tendons.

There are three mechanisms in the bond.

- 1) Adhesion between concrete and steel
- 2) Mechanical bond at the concrete and steel interface
- Friction in presence of transverse compression.

Transmission Length

- There are several factors that influence the transmission length. These are as follows.

➢ Type of tendon

wire, strand or bar

➢ Size of tendon

- Stress in tendon

- Surface deformations of the tendon
  - Plain, indented, twisted or deformed

- Strength of concrete at transfer

- Pace of cutting of tendons
    - Abrupt flame cutting or slow release of jack
- Presence of confining reinforcement
- Effect of creep

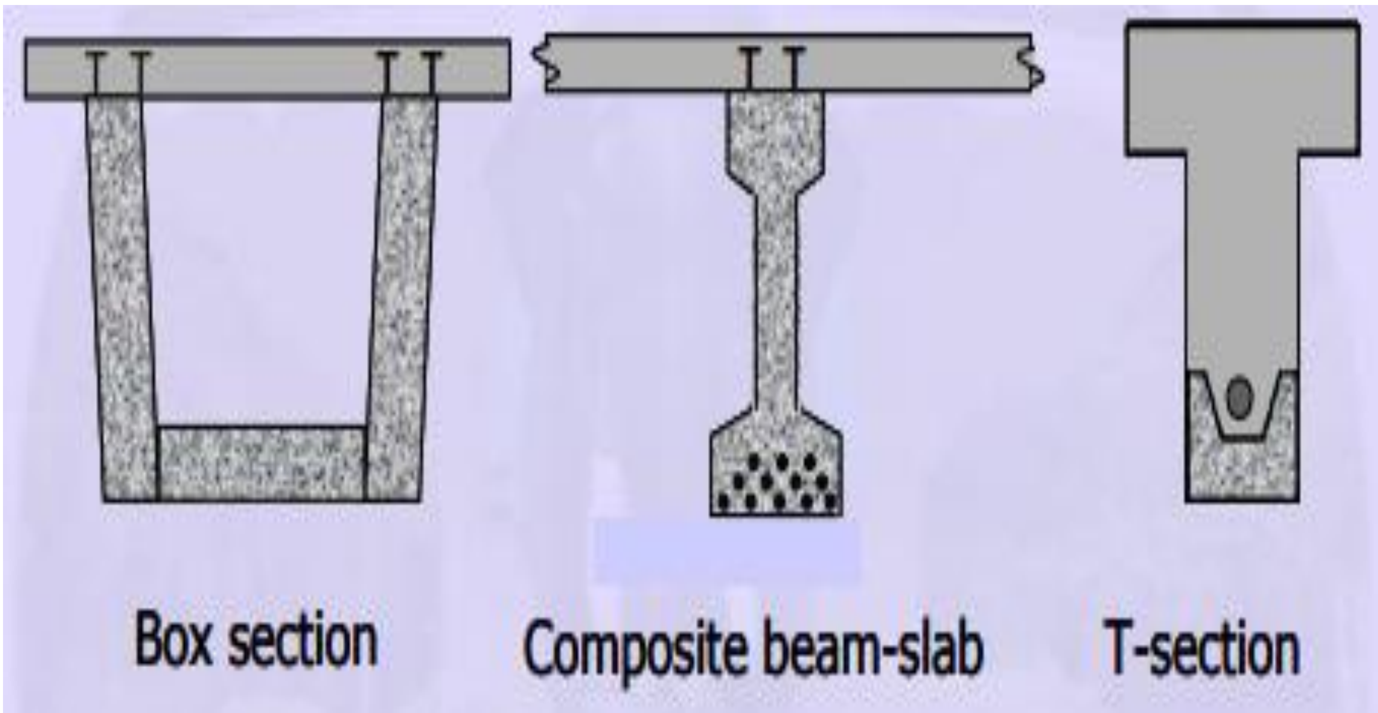
- Compaction of concrete
- Amount of concrete cover

UNIT-V

COMPOSITE BEAMS

- A **composite section** in context of prestressed concrete members refers to a section with a precast member and cast-in-place (CIP) concrete. There can be several types of innovative composite sections.

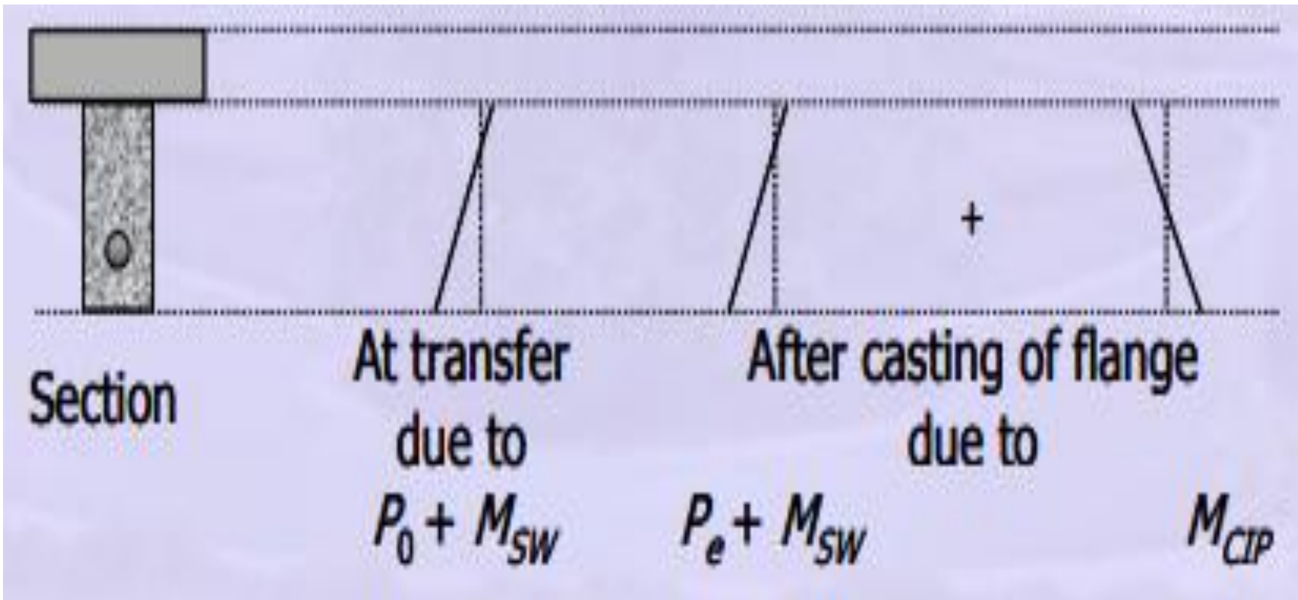
Examples of composite sections



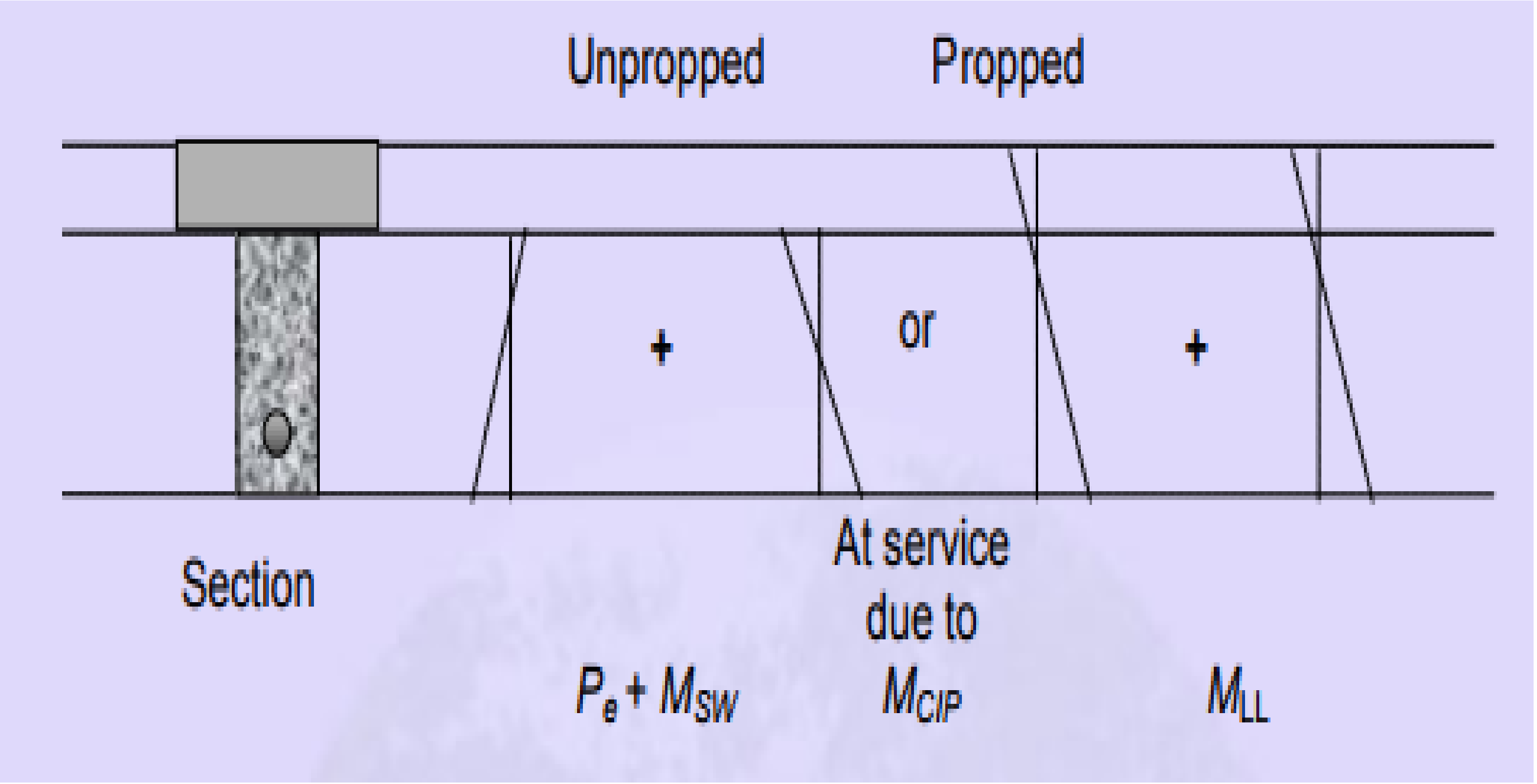
The advantages of composite construction

- Savings in form work
- Fast-track construction
- Easy to connect the members and achieve continuity

Analysis of Composite Sections



profiles for the precast web



Stress profiles for the composite section

Stress in precast web at transfer

$$f = -\frac{P_0}{A} \pm \frac{P_0 e c}{I} \pm \frac{M_{sw} c}{I}$$

Stress in precast web after casting of flange

$$f = -\frac{P_e}{A} \pm \frac{P_e ec}{I} \pm \frac{(M_{SW} + M_{CIP})c}{I}$$

- Stress in precast web at service

  For unpropped construction

$$f = -\frac{P_e}{A} \pm \frac{P_e ec}{I} \pm \frac{(M_{SW} + M_{CIP})c}{I} \pm \frac{M_{LL}c'}{I'}$$

For propped construction

$$f = -\frac{P_e}{A} \pm \frac{P_e e c}{I} \pm \frac{M_{SW} c}{I} \pm \frac{(M_{CIP} + M_{LL}) c'}{I'}$$

Here,

A = area of the precast web

c = distance of edge from CGC of precast web

c' = distance of edge from CGC of composite section

e = eccentricity of CGS

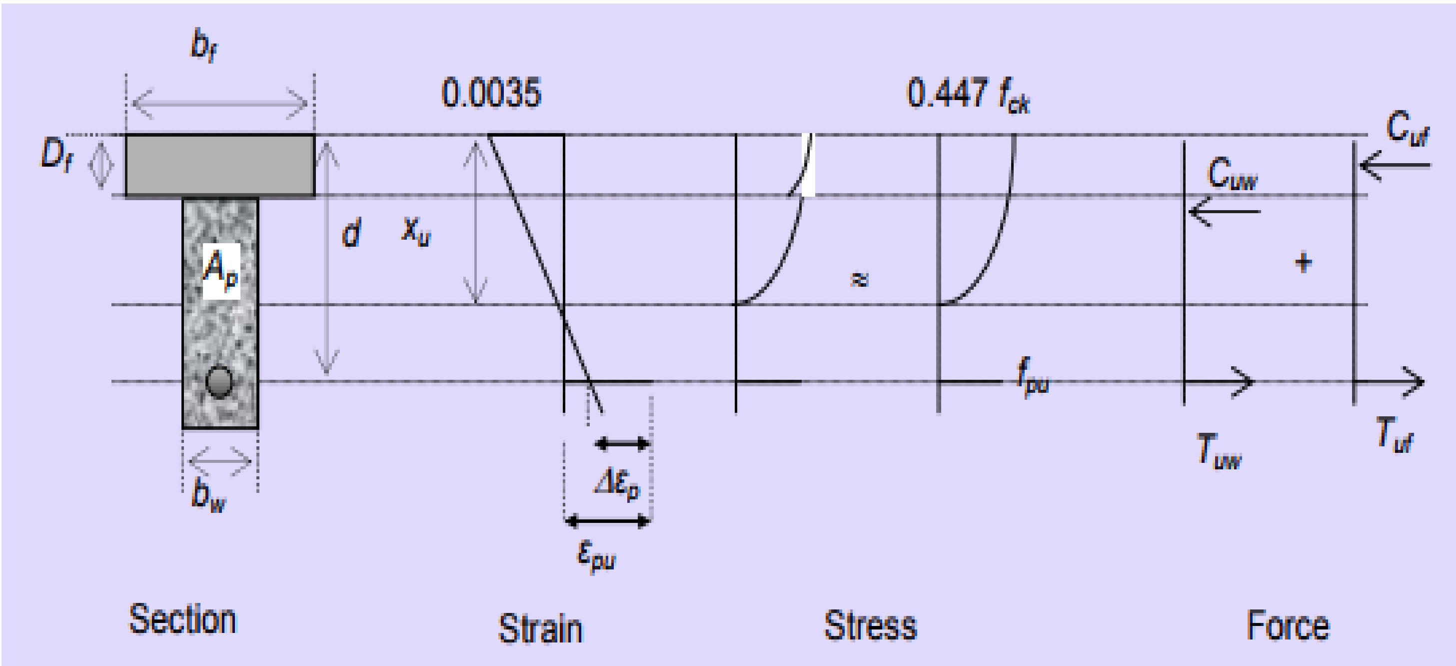
I = moment of inertia of the precast web

I' = moment of inertia of the composite section

The analysis at ultimate is simplified by the following assumptions

- The small strain discontinuity at the interface of the precast and CIP portions is ignored.
- The stress discontinuity at the interface is also ignored.

- If the CIP portion is of low grade concrete, the weaker CIP concrete is used for calculating the stress block. The strain and stress diagrams and the force couples at ultimate are shown below



Sketches for analysis at ultimate

Design of Composite Sections

Step 1. Compute e

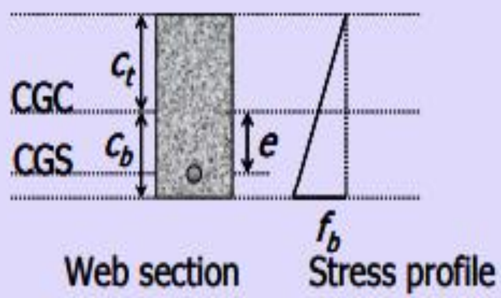


Figure 9-1.6 Stress profile for maximum eccentricity of CGS

$$e_{max} = k_b + \frac{M_{sw}}{P_0}$$

- Here, CGC = Centroid of the precast web
- k_b = Distance of the bottom kern of the precast web from CGC
- M_{sw} = Moment due to self weight of the precast web.
- P_0 = A trial prestressing force at transfer

Step 2

Compute equivalent moment for the precast web

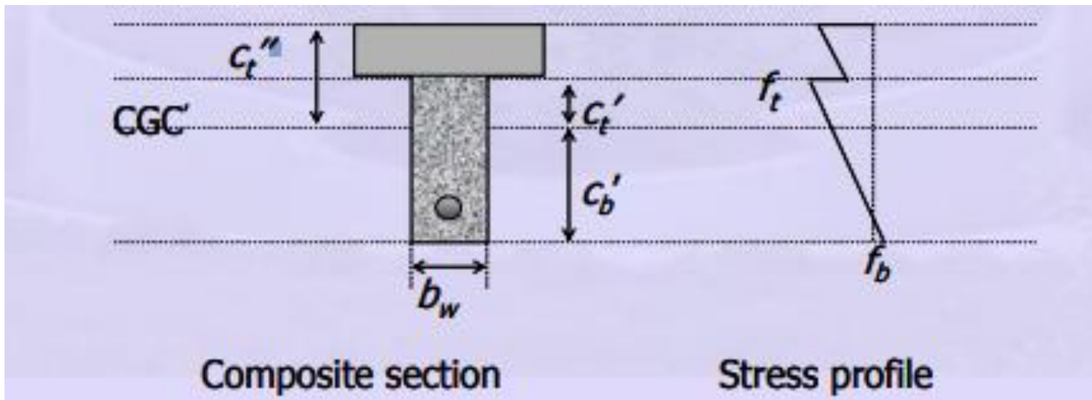


Figure 9-1.7 Stress profile for the composite section

$$f_t = \frac{M_c c_t'}{I'}$$

$$f_b = \frac{M_c c_b'}{I'}$$

Here,

- CGC’ = centroid of the composite section
- ct’ = Distance of the top of the precast web from the CGC’
- ct” = Distance of the top of the composite section from the CGC’.
- cb’ = Distance of the bottom of the precast web (or composite section) from the CGC’
- I ’ = moment of inertia for the composite section

- The following quantities are defined as the ratios of the properties of the precast web and composite section.

$$m_t = \frac{I/c_t}{I'/c_t'}$$

$$m_b = \frac{I/c_b}{I'/c_b'}$$

- Then the stresses in the extreme fibres of the precast web can be expressed in terms of mt and mb as follows.

$$f_t = \frac{m_t M_c c_t}{I} = \frac{m_t M_c}{A k_b}$$

$$f_b = \frac{m_b M_c c_b}{I} = \frac{m_b M_c}{A k_t}$$

Here, A = Area of the precast web

- k_b = Distance of the bottom kern of the precast web from CGC
- k_t = Distance of the top kern of the precast web from CGC

Step 3. Compute Pe

$$-\frac{P_e}{A}-\frac{P_e e}{Ak_t}+\frac{M_P+m_b M_c}{Ak_t}=0$$

or, $$P_e=\frac{\left(M_P+m_b M_c\right)}{e+k_t}$$

- **Step 4.** Estimate P_0

$$P_i = A_p(0.8f_{pk})$$

$$A_p = P_e / 0.7f_{pk}$$

$$e_{max} = k_b + \frac{M_{sw}}{P_0}$$

- **Step 5**. Check for the compressive stresses in the precast web.
- At transfer, the stress at the bottom is given as follows.

$$f_b = -\frac{P_0}{A} - \frac{P_0 e}{Ak_t} + \frac{M_{sw}}{Ak_t}$$

$$f_t = -\frac{P_e}{A} - \frac{P_e e}{Ak_b} + \frac{(M_P + m_t M_c)}{Ak_b}$$

- **Step 6.** Check for the compressive stress in the CIP flange.

$$f_t' = \frac{M_c c_t''}{I'}$$

The stress ft / should be limited to fcc,all , where fcc,all is the allowable compressive stress in concrete under service loads.