MODULE -1

Introduction and Analysis of Members: Concept of Prestressing - Types of Prestressing - Advantages - Limitations –Prestressing systems - Anchoring devices - Materials - Mechanical Properties of high strength concrete - high strength steel - Stress-Strain curve for High strength concrete. Analysis of members at transfer - Stress concept - Comparison of behavior of reinforced concrete and prestressed concrete - Force concept - Load balancing concept - Kern point -Pressure line **10 Hours**

1**. Introduction This section covers the following topics.**

- Basic Concept
- Early Attempts of Prestressing
- Brief History
- Development of Building Materials

Basic Concept A prestressed concrete structure is different from a conventional reinforced concrete structure due to the application of an initial load on the structure prior to its use. The initial load or 'prestress' is applied to enable the structure to counteract the stresses arising during its service period. The prestressing of a structure is not the only instance of prestressing. The concept of prestressing existed before the applications in concrete. Two examples of prestressing before the development of prestressed concrete are provided. Force-fitting of metal bands on wooden barrels The metal bands induce a state of initial hoop compression, to counteract the hoop tension caused by filling of liquid in the barrels.

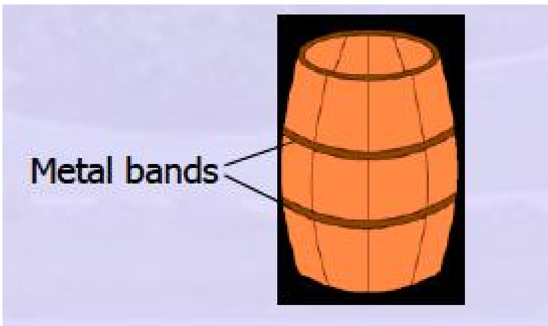

Figure 1-1.1 Force-fitting of metal bands on wooden barrels

Pre-tensioning the spokes in a bicycle wheel

The pre-tension of a spoke in a bicycle wheel is applied to such an extent that there will always be a residual tension in the spoke.

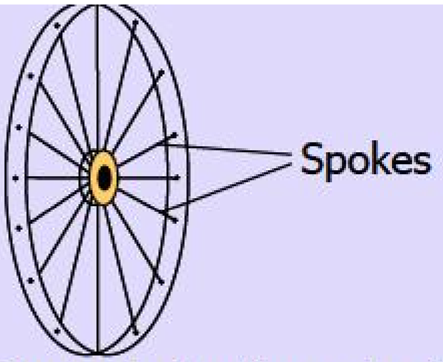

Figure 1-1.2 Pre-tensioning the spokes in a bicycle wheel

For concrete, internal stresses are induced (usually, by means of tensioned steel) for the following reasons.

- The tensile strength of concrete is only about 8% to 14% of its compressive strength.
- Cracks tend to develop at early stages of loading in flexural members such as beams and slabs.
- To prevent such cracks, compressive force can be suitably applied in the perpendicular direction.
- Prestressing enhances the bending, shear and torsional capacities of the flexural members.
- In pipes and liquid storage tanks, the hoop tensile stresses can be effectively counteracted by circular prestressing.

1.1.2 Early Attempts of Prestressing

Prestressing of structures was introduced in late nineteenth century. The following sketch explains the application of prestress.

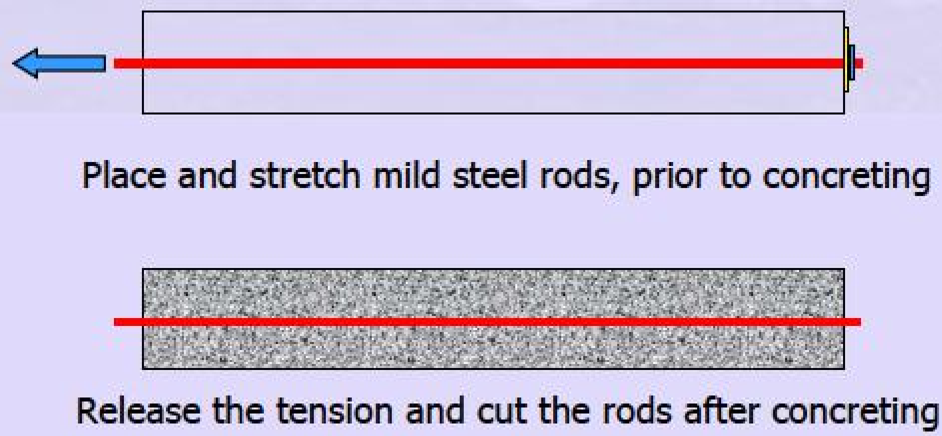

Figure 1-1.3 Prestressing of concrete beams by mild steel rods

Mild steel rods are stretched and concrete is poured around them. After hardening of concrete, the tension in the rods is released. The rods will try to regain their original length, but this is prevented by the surrounding concrete to which the steel is bonded. Thus, the concrete is now effectively in a state of pre-compression. It is capable of counteracting tensile stress, such as arising from the load shown in the following sketch.

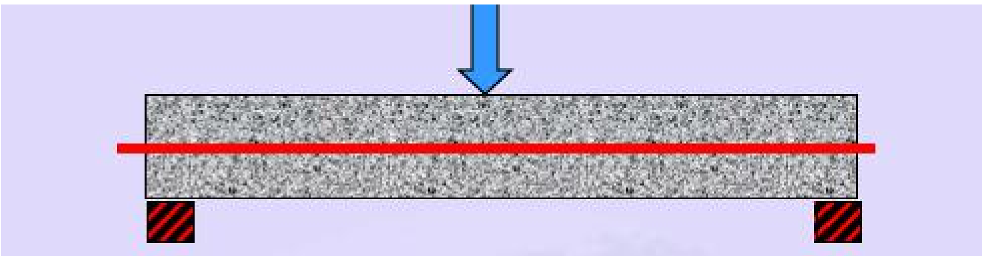

Figure 1-1.4 A prestressed beam under an external load

But, the early attempts of prestressing were not completely successful. It was observed that the effect of prestress reduced with time. The load resisting capacities of the members were limited. Under sustained loads, the members were found to fail. This was due to the following reason.

Concrete shrinks with time. Moreover under sustained load, the strain in concrete increases with increase in time. This is known as creep strain. The reduction in length due to **creep** and **shrinkage** is also applicable to the embedded steel, resulting in significant loss in the tensile strain.

In the early applications, the strength of the mild steel and the strain during prestressing were less. The residual strain and hence, the residual prestress was only about 10% of the initial value. The following sketches explain the phenomena.

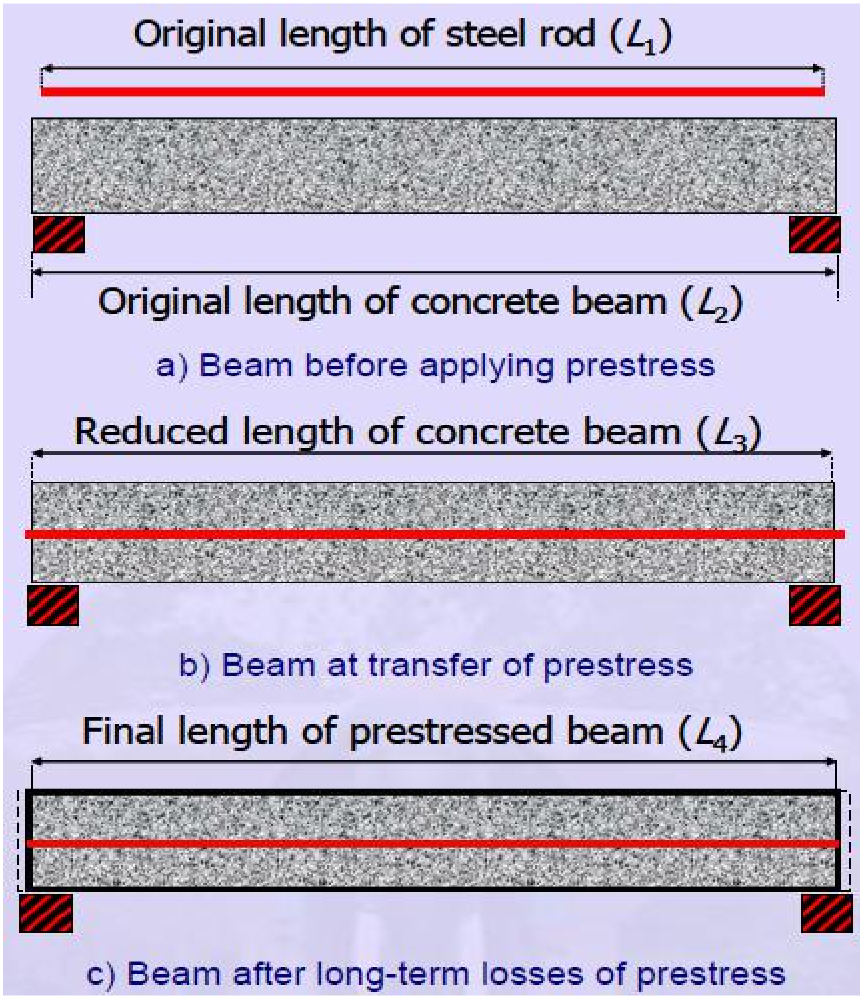

Figure 1-1.5 Variation of length in a prestressed beam

The residual strain in steel = original tensile strain in steel – compressive strains corresponding to short-term and long-term losses.
Original tensile strain in steel = $(L_2 - L_1)/L_1$
Compressive strain due to elastic shortening of beam = $(L_2 - L_3)/L_1$
(short-term loss in prestress)
Compressive strain due to creep and shrinkage = $(L_3 - L_4)/L_1$
(long-term losses in prestress)
Therefore, residual strain in steel = $(L_4 - L_1)/L_1$

The maximum original tensile strain in mild steel = Allowable stress / elastic modulus
$= 140 \text{ MPa} / 2\times10^5 \text{ MPa}$
$= 0.0007$

The total loss in strain due to elastic shortening, creep and shrinkage was also close to 0.0007. Thus, the residual strain was negligible.
The solution to increase the residual strain and the effective prestress are as follows.

- Adopt **high strength steel** with much higher original strain. This leads to the scope of high prestressing force.
- Adopt **high strength concrete** to withstand the high prestressing force.

Advantages and Types of Prestressing
This section covers the following topics.

- Definitions
- Advantages of Prestressing
- Limitations of Prestressing
- Types of Prestressing

1.2.1 Definitions
The terms commonly used in prestressed concrete are explained. The terms are placed in groups as per usage.

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.

The different types of prestressing steel are further explained in Section 1.7, Prestressing Steel.

Nature of Concrete-Steel Interface

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.

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

The prestressing of concrete has several advantages as compared to traditional reinforced concrete (RC) without prestressing. A fully prestressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete.

The following text broadly mentions the advantages of a prestressed concrete member with an equivalent RC member. For each effect, the benefits are listed.

1) Section remains uncracked under service loads

1. Reduction of steel corrosion
2. Increase in durability.
3. Full section is utilised
4. Higher moment of inertia (higher stiffness)
5. Less deformations (improved serviceability)
6. Increase in shear capacity.
7. Suitable for use in pressure vessels, liquid retaining structures.
8. Improved performance (resilience) under dynamic and fatigue loading

For the same span, less depth compared to RC member.

- Reduction in self-weight
- More aesthetic appeal due to slender sections
- More economical sections.

Types of Prestressing

Prestressing of concrete can be classified in several ways. The following classifications are discussed.

Source of prestressing force

This classification is based on the method by which the prestressing force is generated. There are four sources of prestressing force: Mechanical, hydraulic, electrical and chemical.

External or internal prestressing

This classification is based on the location of the prestressing tendon with respect to the concrete section.

Pre-tensioning or post-tensioning

This is the most important classification and is based on the sequence of casting the concrete and applying tension to the tendons.

Linear or circular prestressing

This classification is based on the shape of the member prestressed.

Full, limited or partial prestressing

Based on the amount of prestressing force, three types of prestressing are defined. **Uniaxial, biaxial or multi-axial prestressing**

As the names suggest, the classification is based on the directions of prestressing a member. The individual types of prestressing are explained next.

Source of Prestressing Force

Hydraulic Prestressing

This is the simplest type of prestressing, producing large prestressing forces. The hydraulic jack used for the tensioning of tendons, comprises of calibrated pressure gauges which directly indicate the magnitude of force developed during the tensioning.

Mechanical Prestressing

In this type of prestressing, the devices includes weights with or without lever transmission, geared transmission in conjunction with pulley blocks, screw jacks with or without gear drives and wire-winding machines. This type of prestressing is adopted for mass scale production.

External or Internal Prestressing

External Prestressing

When the prestressing is achieved by elements located outside the concrete, it is called external prestressing. The tendons can lie outside the member (for example in I-girders or walls) or inside the hollow space of a box girder. This technique is adopted in bridges and strengthening of buildings. In the following figure, the box girder of a bridge is prestressed with tendons that lie outside the concrete.

Internal Prestressing

When the prestressing is achieved by elements located inside the concrete member (commonly, by embedded tendons), it is called internal prestressing. Most of the applications of prestressing are internal prestressing. In the following figure, concrete will be cast around the ducts for placing the tendons.

Pre-tensioning Systems and Devices

This section covers the following topics.

1. Introduction
2. Stages of Pre-tensioning
3. Advantages of Pre-tensioning
4. Disadvantages of Pre-tensioning
5. Devices
6. Manufacturing of Pre-tensioned Railway Sleepers

1. **Introduction**

Prestressing systems have developed over the years and various companies have patented their products. Detailed information of the systems is given in the product catalogues and brochures published by companies. There are general guidelines of prestressing in **Section 12** of **IS:1343 - 1980**. The information given in this section is introductory in nature, with emphasis on the basic concepts of the systems.

The prestressing systems and devices are described for the two types of prestressing, pre-tensioning and post-tensioning, separately. This section covers pre-tensioning. Section 1.4, “Post-tensioning Systems and Devices”, covers post-tensioning. In pre-tensioning, the tension is applied to the tendons before casting of the concrete. The stages of pre-tensioning are described next.

2 Stages of Pre-tensioning

In pre-tensioning system, the high-strength steel tendons are pulled between two end abutments (also called bulkheads) prior to the casting of concrete. The abutments are fixed at the ends of a prestressing bed.

Once the concrete attains the desired strength for prestressing, the tendons are cut loose from the abutments.

The prestress is transferred to the concrete from the tendons, due to the bond between them. During the transfer of prestress, the member undergoes elastic shortening. If the tendons are located eccentrically, the member is likely to bend and deflect (camber).

The various stages of the pre-tensioning operation are summarised as follows.

1) Anchoring of tendons against the end abutments
2) Placing of jacks
3) Applying tension to the tendons
4) Casting of concrete
5) Cutting of the tendons.

During the cutting of the tendons, the prestress is transferred to the concrete with elastic shortening and camber of the member.

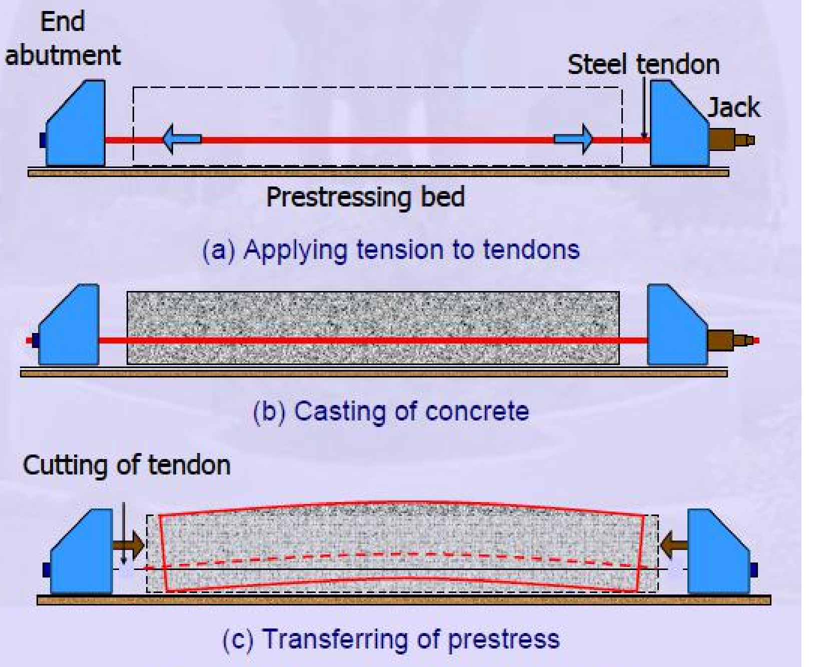

Figure1-3.1 Stages of pre-tensioning

1.3.3 Advantages of Pre-tensioning

The relative advantages of pre-tensioning as compared to post-tensioning are as follows.

• Pre-tensioning is suitable for precast members produced in bulk.

Prestressed Concrete Structures Dr. Amlan K Sengupta and Prof. Devdas Menon Indian Institute of Technology Madras

• In pre-tensioning large anchorage device is not present.

1.3.4 Disadvantages of Pre-tensioning

The relative disadvantages are as follows.

• A prestressing bed is required for the pre-tensioning operation.

• There is a waiting period in the prestressing bed, before the concrete attains sufficient strength.

• There should be good bond between concrete and steel over the transmission length.

Devices

The essential devices for pre-tensioning are as follows.

• Prestressing bed

• End abutments

• Shuttering / mould

• Jack

• Anchoring device

Analysis of Members under Flexure (Part I)

This section covers the following topics.

• Introduction

• Analyses at Transfer and at Service

Introduction

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.

The analyses at transfer and under service loads are presented in this section. The analysis for the ultimate strength is presented separately in Section 3.4, Analysis of Member under Flexure (Part III). The evaluation of the load versus deformation behaviour is required in special type of analysis. This analysis will not be covered in this section.

Assumptions

The analysis of members under flexure considers the following.

1) Plane sections remain plane till failure (known as Bernoulli's hypothesis).

2) Perfect bond between concrete and prestressing steel for bonded tendons.

Principles of Mechanics

The analysis involves three principles of mechanics.

1) **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.

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

3) **Constitutive** relationships relating the stresses and the strains in the materials.

Variation of Internal Forces

In reinforced concrete members under flexure, the values of compression in concrete (*C*) and tension in the steel (*T*) increase with increasing external load. The change in the lever arm (*z*) is not large.

In prestressed concrete members under flexure, at transfer of prestress *C* is located close to *T*. The couple of *C* and *T* balance only the self weight. At service loads, *C* shifts up and the lever arm (*z*) gets large. The variation of *C* or *T* is not appreciable.

The following figure explains this difference schematically for a simply supported beam under uniform load.

The analyses at transfer and under service loads are similar. Hence, they are presented together. A prestressed member usually remains uncracked under service loads. The concrete and steel are treated as elastic materials. The principle of superposition is applied. The increase in stress in the prestressing steel due to bending is neglected.

There are three approaches to analyse a prestressed member at transfer and under service loads. These approaches are based on the following concepts.

a) Based on stress concept.

b) Based on force concept.

c) Based on load balancing concept.

The following material explains the three concepts.

Based on Stress Concept

In the approach based on stress concept, the stresses at the edges of the section under the internal forces in concrete are calculated. The stress concept is used to compare the calculated stresses with the allowable stresses.

The following figure shows a simply supported beam under a uniformly distributed load (UDL) and prestressed with constant eccentricity (*e*) along its length

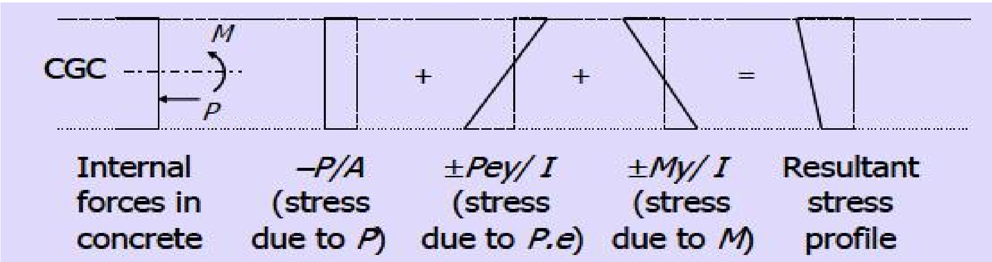

Figure 3-2.3 Stress profiles at a section due to internal forces

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

Based on Force Concept

The approach based on force concept is analogous to the study of reinforced concrete. The tension in prestressing steel (*T*) and the resultant compression in concrete (*C*) are considered to balance the external loads. This approach is used to determine the dimensions of a section and to check the service load capacity. Of course, the stresses in concrete calculated by this approach are same as those calculated based on stress concept. The stresses at the extreme edges are compared with the allowable stresses

Based on Load Balancing Concept

The approach based on load balancing concept is used for a member with curved or harped tendons and in the analysis of indeterminate continuous beams. The moment, upward thrust and upward deflection (camber) due to the prestress in the tendons are calculated. The upward thrust balances part of the superimposed load

Example 1

A concrete beam prestressed with a parabolic tendon is shown in the figure. The prestressing force applied is 1620 kN. The uniformly distributed load includes the self weight. Compute the extreme fibre stress at the mid-span by applying the three concepts. Draw the stress distribution across the section at mid-span.

Solution

a) Stress concept

Area of concrete, $A = 500 \times 750$

$= 375{,}000\ mm^2$

Moment of inertia, $I = (500 \times 750^3) / 12$

$= 1.758 \times 10^{10}\ mm^4$

Bending moment at mid-span, $M = (45 \times 7.32) / 8$

$= 299.7$ kNm

Top fibre stress (C ,T) = - 4.32 + 5.01- 6.39 = - 5.7 N/mm

Bottom fibre stress (C, T) = -4.32 - 5.01+ 6.39 = -2.9 N/mm

Lever arm $z = M / P$

$= 299.7 \times 10^3 / 1620$

= 185 mm

Eccentricity of C $e_c = z - e$

= 185 – 145

= 40 mm