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UGC - Autonomous Institute
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# DEPARTMENT OF
# CIVIL ENGINEERING

# Lecture Notes
# on
# 23CE703 - Prestressed Concrete

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**UNIT I**

**INTRODUCTION**

**1.1 Definition of Prestress:**

Prestress is defined as a method of applying pre-compression to control the stresses resulting due to external loads below the neutral axis of the beam tension developed due to external load which is more than the permissible limits of the plain concrete. The pre-compression applied (may be axial or eccentric) will induce the compressive stress below the neutral axis or as a whole of the beam c/s. Resulting either no tension or compression.

## Basic 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

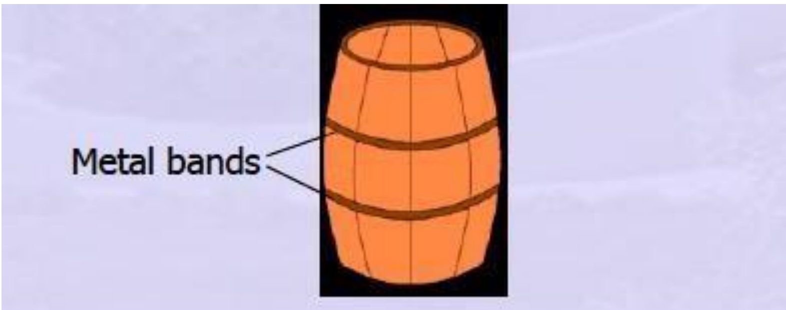
1. Tendon: A stretched element used in a concrete member of structure to impart prestress to the concrete.
2. Anchorage: A device generally used to enable the tendon to impart and maintain prestress in concrete.
3. Pre-tensioning: A method of prestressing concrete in which the tendons are tensioned before 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.

## 1.2 History and development of prestress of PSC:

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**

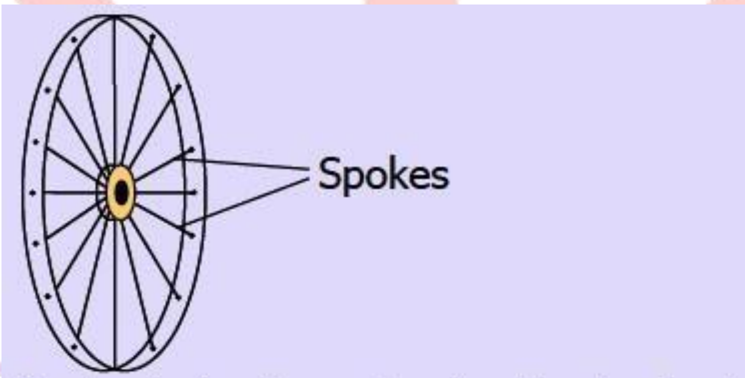
The metal bands induce a state of initial hoop compression, to counteract the hoop tension caused by filling of liquid in the barrels.




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.




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.

# 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.

# 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.

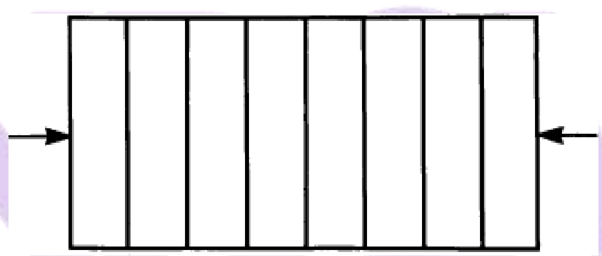
Unbonded tendon

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.

# 1.3 Basic Principle of Prestressing

Basic Example

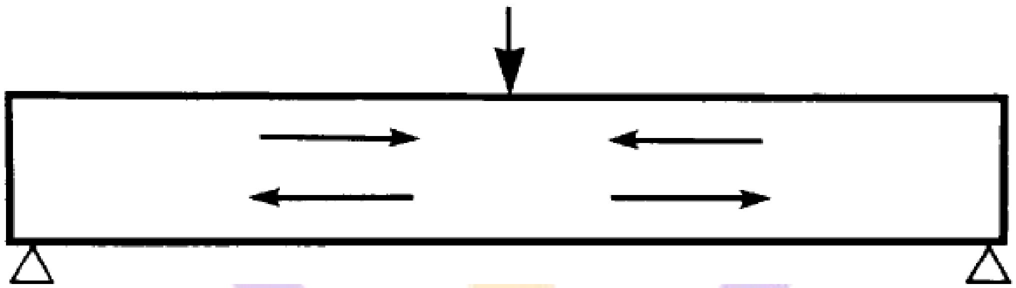
The classic everyday example of prestressing is this: a row of books can be lifted by squeezing the ends together:

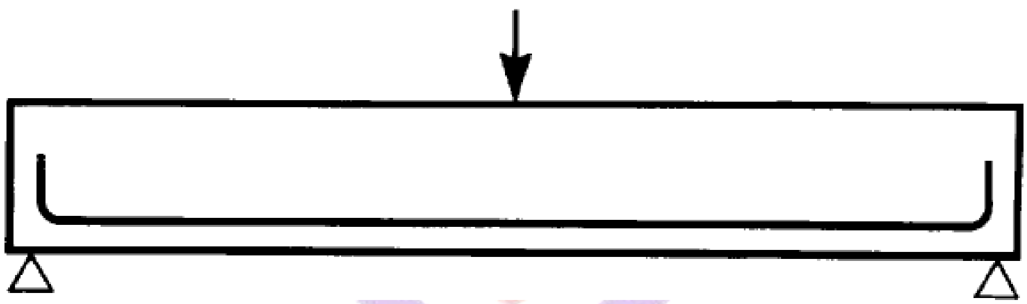


The structural explanation is that the row of books has zero tensile capacity. Therefore the 'beam' of books cannot even carry its self weight. To overcome this we provide an external initial stress (the prestress) which compresses the books together. Now they can only separate if the tensile stress induced by the self weight of the books is greater than the compressive prestress introduced.

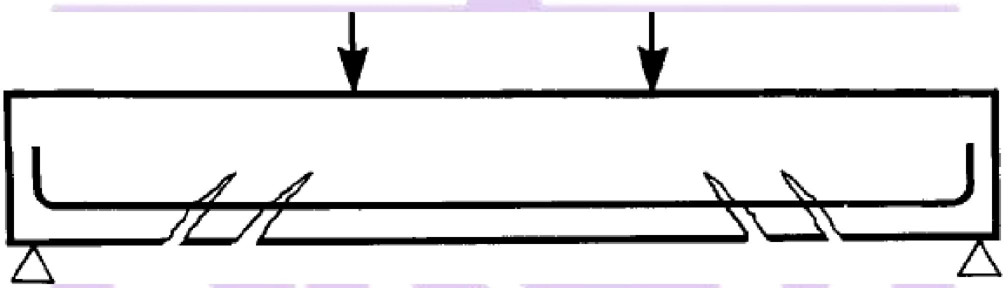
Concrete

Concrete is very strong in compression but weak in tension. In an ordinary concrete beam the tensile stress at the bottom are taken by standard steel reinforcement:





But we still get cracking, which is due to both bending and shear:



In prestressed concrete, because the prestressing keeps the concrete in compression, no cracking occurs. This is often preferable where durability is a concern.

## 1.4 Advantages of Prestressed Concrete

1. The use of high strength concrete and steel in prestressed members results in lighter and slender members than is possible with RC members.

2. In fully prestressed members the member is free from tensile stresses under working loads, thus whole of the section is effective.
3. In prestressed members, dead loads may be counter-balanced by eccentric prestressing.
4. Prestressed concrete member possess better resistance to shear forces due to effect of compressive stresses presence or eccentric cable profile.
5. Use of high strength concrete and freedom from cracks, contribute to improve durability under aggressive environmental conditions.
6. Long span structures are possible so that saving in weight is significant & thus it will be economic.
7. Factory products are possible.
8. Prestressed members are tested before use.
9. Prestressed concrete structure deflects appreciably before ultimate failure, thus giving ample warning before collapse.
10. Fatigue strength is better due to small variations in prestressing steel, recommended to dynamically loaded structures.

## Limitations of Prestressed Concrete

1. The availability of experienced builders is scanty.
2. Initial equipment cost is very high.
3. Availability of experienced engineers is scanty.
4. Prestressed sections are brittle
5. Prestressed concrete sections are less fire resistant.

## 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

- Reduction of steel corrosion
  - ➢ Increase in durability.
- Full section is utilized
  - ➢ Higher moment of inertia (higher stiffness)
  - ➢ Less deformations (improved serviceability).
- Increase in shear capacity.
- Suitable for use in pressure vessels, liquid retaining structures.
- Improved performance (resilience) under dynamic and fatigue loading.

## 2) High span-to-depth ratios

Larger spans possible with prestressing (bridges, buildings with large column-free spaces)
Typical values of span-to-depth ratios in slabs are given below.

| | |
|---|---|
| Non-prestressed slab | 28:1 |
| Prestressed slab | 45:1 |

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

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

## 3) Suitable for precast construction

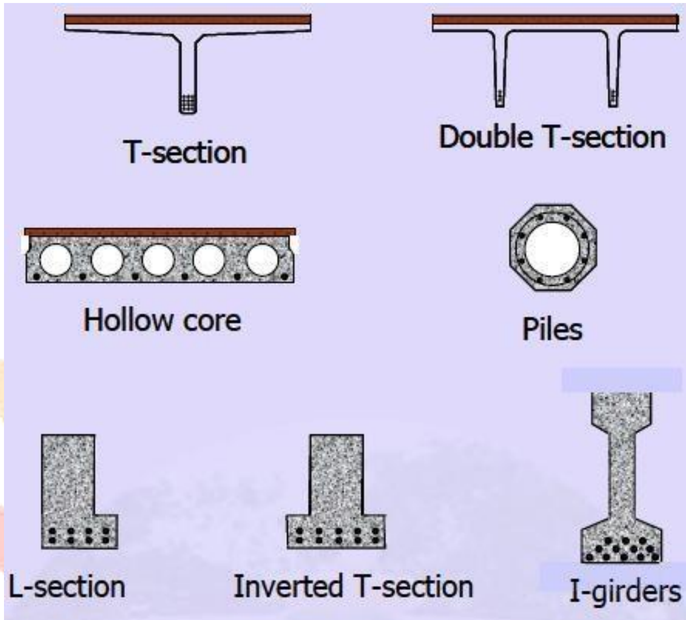
The advantages of precast construction are as follows.

• Rapid construction
• Better quality control
• Reduced maintenance
• Suitable for repetitive construction
• Multiple use of formwork

⇒ Reduction of formwork

• Availability of standard shapes.

The following figure shows the common types of precast sections.




## Limitations of Prestressing

Although prestressing has advantages, some aspects need to be carefully addressed.

- 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.

## 1.5 Methods 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.

## ➢ 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.

Electrical Prestressing

In this type of prestressing, the steel wires are electrically heated and anchored before placing concrete in the moulds. This type of prestressing is also known as thermo-electric prestressing.

Chemical prestressing

Chemical prestressing is done using expanding cement. Prestressing can be applied bY embedding steel in concrete made of expanding cement. Steel is elongated by the expansion of the concrete and thus gets prestressed. Steel in turn produces compressive stress in concrete

## ➢ 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.

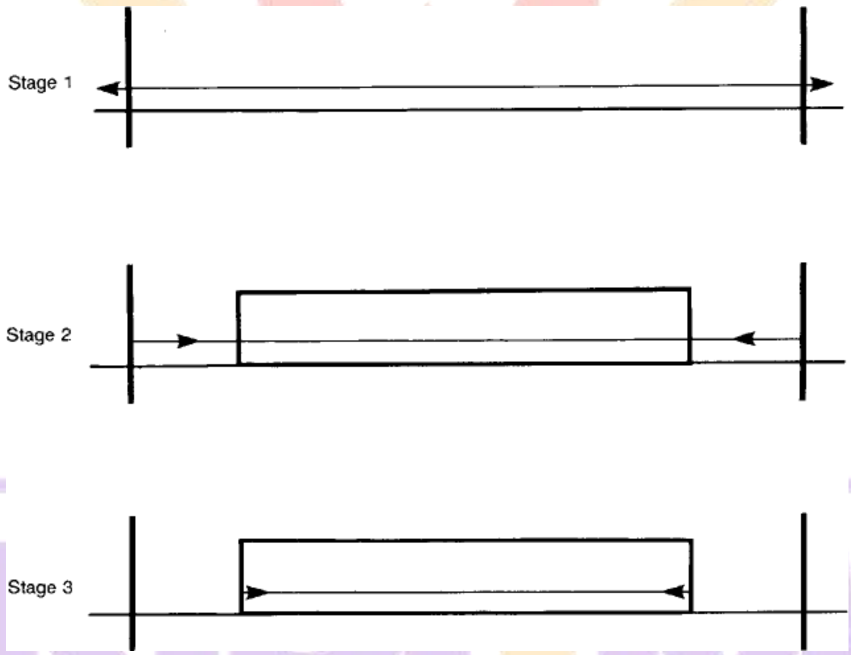
Internal Prestressing

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.

## ➢ Pre-tensioning or Post-tensioning

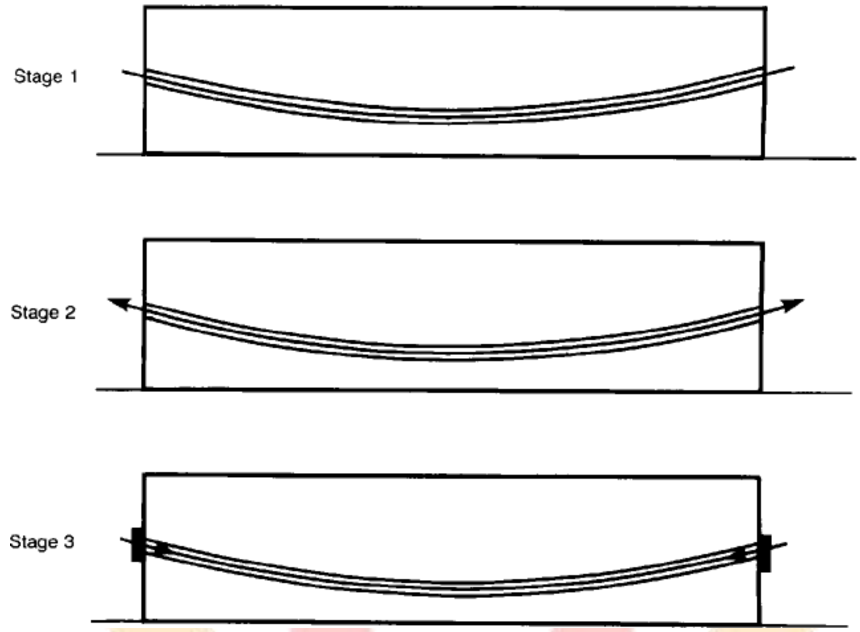
Pre-tensioning

The tension is applied to the tendons before casting of the concrete. The pre-compression is transmitted from steel to concrete through bond over the transmission length near the ends. In Stage 1 the wires or strands are stressed; in Stage 2 the concrete is cast around the stressed wires/strands; and in Stage 3 the prestressed in transferred from the external anchorages to the concrete, once it has sufficient strength:




Post-tensioning

The tension is applied to the tendons (located in a duct) after hardening of the concrete. The pre-compression is transmitted from steel to concrete by the anchorage device (at the end blocks). In this method, the concrete has already set but has ducts cast into it. The strands or tendons are fed through the ducts (Stage 1) then tensioned (Stage 2) and then anchored to the concrete (Stage 3):




## ➢ Linear or Circular Prestressing

Linear Prestressing

When the prestressed members are straight or flat, in the direction of prestressing, the prestressing is called linear prestressing. For example, prestressing of beams, piles, poles and slabs. The profile of the prestressing tendon may be curved. The following figure shows linearly prestressed railway sleepers.

Circular Prestressing

When the prestressed members are curved, in the direction of prestressing, the prestressing is called circular prestressing. For example, circumferential prestressing of tanks, silos, pipes and similar structures. The following figure shows the containment structure for a nuclear reactor which is circularly prestressed.

## Full, Limited or Partial Prestressing

Full Prestressing

When the level of prestressing is such that no tensile stress is allowed in concrete under service loads, it is called Full Prestressing (Type 1, as per **IS:1343 - 1980**).

Limited Prestressing

When the level of prestressing is such that the tensile stress under service loads is within the cracking stress of concrete, it is called Limited Prestressing (Type 2).

Partial Prestressing

When the level of prestressing is such that under tensile stresses due to service loads, the crack width is within the allowable limit, it is called Partial Prestressing (Type 3).

## Uniaxial, Biaxial or Multiaxial Prestressing

Uniaxial Prestressing

When the prestressing tendons are parallel to one axis, it is called Uniaxial Prestressing. For example, longitudinal prestressing of beams.

Biaxial Prestressing

When there are prestressing tendons parallel to two axes, it is called Biaxial Prestressing.

Multiaxial Prestressing

When the prestressing tendons are parallel to more than two axes, it is called Multiaxial Prestressing. For example, prestressing of domes.



## 1.6 High strength concrete and high tensile steel their characteristics Materials for

## **prestress concrete members**:

1. **Cement:** The cement used should be any of the following:

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

2. **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 is prescribed for the durability requirement. The water content should be as low as possible.

3. **Steel**: - High tensile steel , tendons , strands or cables.

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

a) Plain hard-drawn steel wire conforming to IS1785 (Part-I & Part-III)
b) Cold drawn indented wire conforming to IS6003
c) High tensile steel wire bar conforming to IS2090
d) 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 whichever 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. Further creep &

shrinkage losses are minimum with high-grade concrete.
Generally minimum M30 grade concrete is used for post-tensioned & M40 grade concrete is

used for pretensioned members.

The losses in prestress members due to various reasons are generally in the range of 250 $N/mm^2$ to 400 $N/mm^2$. If mild steel or deformed steel is used the residual stresses after losses is either zero or negligible. Hence high tensile steel wires are used which varies from 1600 to 2000 $N/mm^2$.

## Differences of Prestressed Concrete over Reinforced Concrete:

1. 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 depend upon the external loads. *i.e.*, no external load, no stress in steel.
2. 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.
3. Prestress concrete has more shear resistance, whereas shear resistance of R.C.C is less.
4. In prestress concrete members, deflections are less because the eccentric prestressing force will induce couple which will cause upward deflections, where as in R.C.C., deflections are more.
5. In prestress concrete fatigue resistance is more compare to R.C.C. because in R.C.C. stress in steel is external load dependent where as in P.S.C member it is load independent.
6. Prestress concrete is more durable as high grade of concrete is used which are more dense in nature. R.C.C. is less durable.
7. In prestress concrete dimensions is less because external stresses are counterbalance by the internal stress induced by prestress. Therefore reactions on column & footing are less as a whole the quantity of concrete is reduced by 30% and steel reduced by about 60 to 70%. R.C.C. is uneconomical for long span because in R.C.C. dimension of sections are large requiring more concrete & steel. Moreover as self-weight increases more reactions acted

on columns & footings, which requires higher sizes.

## 1.6 Systems of Prestressing

In concrete structures, prestress is introduced by stretching steel wire and anchoring them against concrete. Therefore, the prestressing systems should comprise essentially a method of stretching the steel and a method of anchoring it to the concrete. Different systems are adopted for pre-tensioning and post tensioning.

## Pre-tensioning Systems:

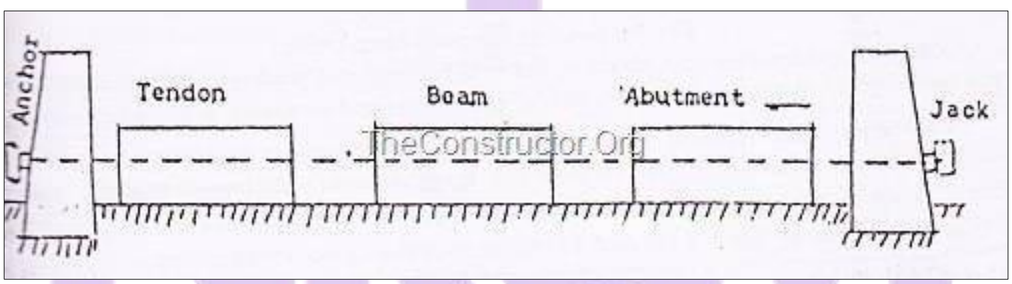
**Hoyer system** or long line method is often adopted in pre-tensioning. Two bulk heads or abutments independently anchored to the ground are provided several meters apart, say, 100m.

wires are stretched between the bulkheads. Moulds are placed enclosing the wires. Concrete is placed surrounding the wires. With this Hoyer system, several members can be produced along one line. This method is economical and is used in almost all pre-tensioning factories. For tensioning, a hydraulic jack is used. Wires are gripped at the bulkheads, using split-cone wedges. These wedges are made from tapered conical pins. Flat surface of the pin carries serrations to grip the wire (fig.)

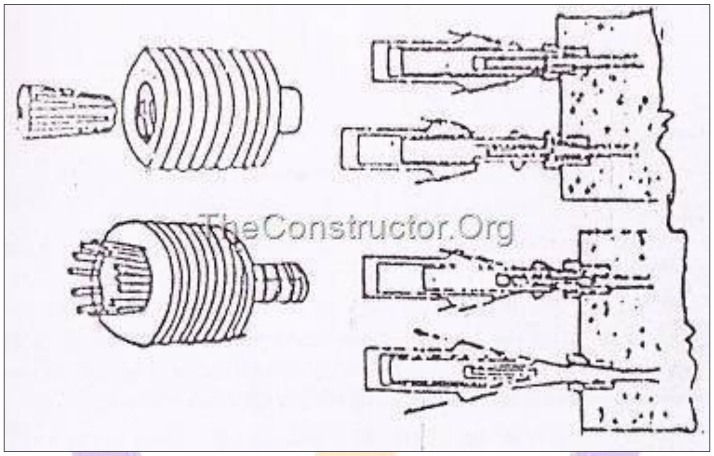
There is another pre-tensioning method known as **Shorer system**. In this system a central tube of high strength steel carries the prestress from surrounding wires and the entire assembly is placed in position and concreted. After the concrete has attained sufficient strength, the tube is removed and the prestress is transferred to concrete through bond. The hole left by the tube is grouted.

The advantage in pre-tensioning system is that there is no expenditure on end anchorages and on rubber core or metal sheath required for post-tensioning system. There is greater certainty about the prestressing force. In post-tensioned members certainty of the force depends on the two end anchorages.

Disadvantages in this system are that the end abutments should be very strong and are provided only in pre-cast factories. This naturally limits the size of the member as large sizes are difficult to transport from factory to the site of construction. Loss is more in pre-tensioned members.




Typical Pre-tensioning Bed



Some Typical Wire Gripping System

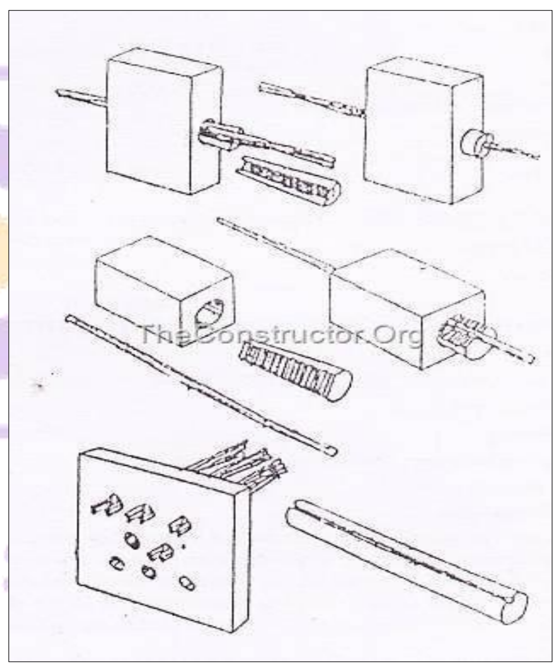
## **Post Tensioning Systems:**

A metal tube or a flexible hose following intended profile is placed inside the mould and concrete is laid. Flexible hose is then removed leaving a duct inside the member. Steel cable is inserted in the duct. The cable is anchored at one end of the member and stretched using a hydraulic jack at the other end. After stretching the cable is anchored at the other end also. Therefore post tensioning system consists of end anchorages and jacks. The popular post-tensioning systems are the following:

- Freyssinet system
- Magnel Blaton system
- Gifford-Udall system
- Lee-McCall system

1. Freyssinet System:

Freyssinet system was introduced by the French Engineer Freyssinet and it was the first method to be introduced. High strength steel wires of 5mm or 7mm diameter, numbering 8 or 12 or 16 or 24 are grouped into a cable with a helical spring inside. Spring keeps proper spacing for the wire. Cable is inserted in the duct.



Freyssinet system of Post-tensioning

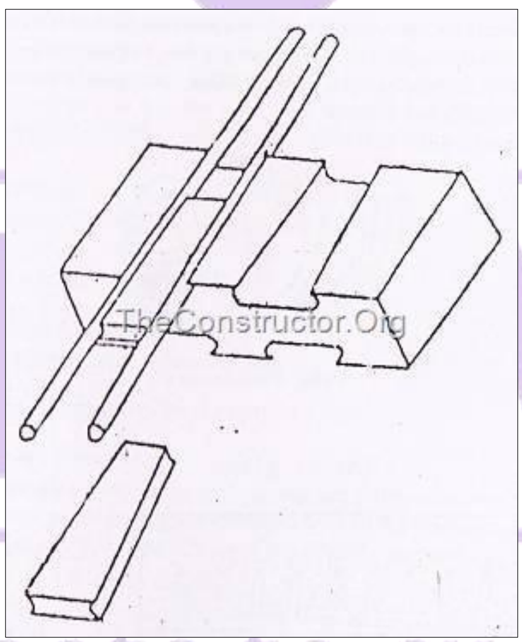
Anchorage device consists of a concrete cylinder with a concentric conical hole and corrugations on its surface, and a conical plug carrying grooves on its surface. Steel wires are carried along these grooves at the ends. Concrete cylinder is heavily reinforced. Members are fabricated with the cylinder placed in position. Wires are pulled by Freyssinet double acting jacks which can pull through suitable grooves all the wires in the cable at a time. One end of the wires is anchored and the other end is pulled till the wires are stretched to the required length. An inner piston in the jack then pushes the plug into the cylinder to grip the wires.

2. Magnel Blaton system:

In Freyssinet system several wires are stretched at a time. In Magnel Blaton system, two wires are stretched at a time. This method was introduced by a famous engineer, Prof. Magnel of

Belgium. In this system, the anchorage device consists of sandwich plate having grooves to hold the wires and wedges which are also grooved. Each plate carries eight wires. Between the two ends the spacing of the wires is maintained by spacers. Wires of 5mm or 7mm are adopted.

Cables consist of wires in multiples of 8 wires. Cables with as much as 64 wires are also used under special conditions. A specially deviced jack pulls two wires at a time and anchors them. The wires with the sandwich plate using tapered wedge are shown in fig.




Anchorage of Magnel System

3. Gifford Udall System:

This system originated in Great Britain, is widely used in India. This is a single wire system.

Each wire is stressed independently using a double acting jack. Any number of wires can be grouped together to form a cable in this system. There are two types of anchorage device in this system.

a) Tube anchorages
b) Plate anchorages

Tube anchorage consists of a bearing plate, anchor wedges and anchor grips. Anchor plate may be square or circular and have 8 or 12 tapered holes to accommodate the individual prestressing wires. These wires are locked into the tapered holes by means of anchor wedges. In addition, grout entry hole is also provided in the bearing plate for grouting. Anchor wedges are split cone wedges carrying serrations on its flat surface. There is a tube unit which is a fabricated steel component incorporating a thrust plate, a steel tube with a surrounding helix. This unit is attached to the end shutters and forms an efficient cast-in component of the anchorage.

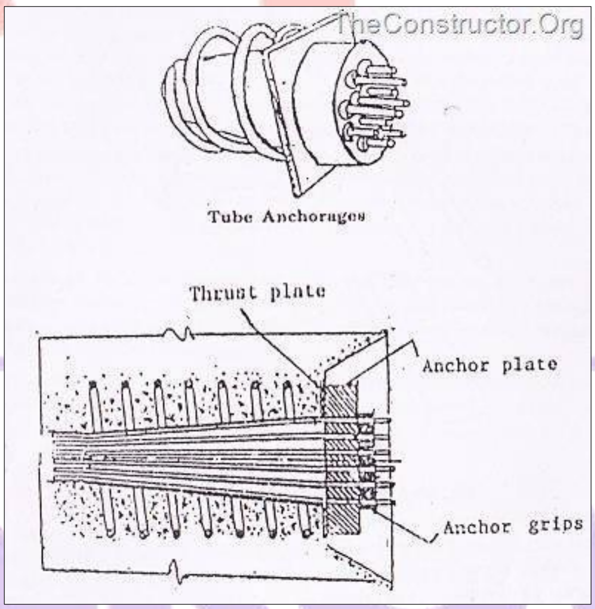
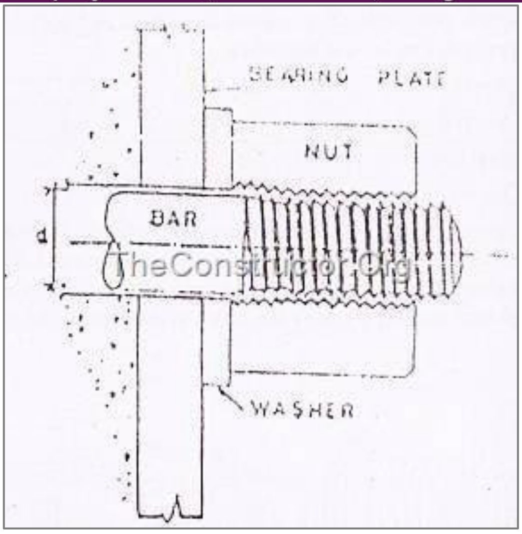



Plate Anchorage

4. Lee McCall System:

This method is used to prestress steel bars. The diameter of the bar is between 12 and 28mm. bars provided with threads at the ends are inserted in the performed ducts. After stretching the bars to the required length, they are tightened using nuts against bearing plates provided at the end sections of the member (fig.).




End Anchorage for Lee McCall System