1.1 Introduction

This section covers the following topics.

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

1.1.1 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.

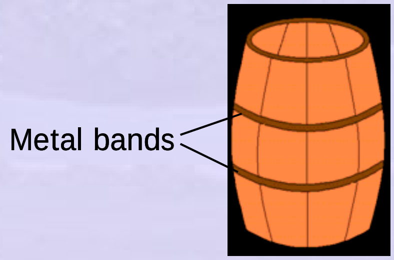


Figure 1-1.1 Force-fitting of metal bands on wooden barrels

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.

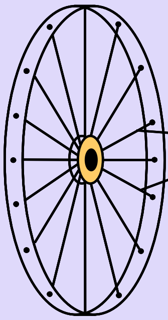


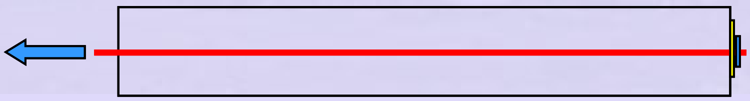
Figure 1-1.2 Pre-tensioning the spokes in a bicycle wheel

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.



Place and stretch mild steel rods, prior to concreting

Release the tension and cut the rods after concreting

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.

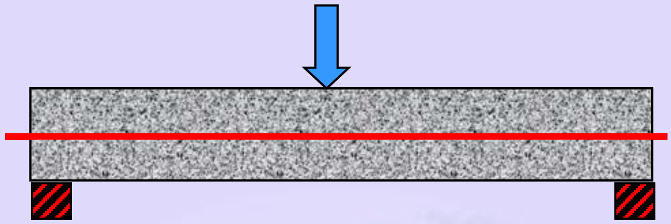
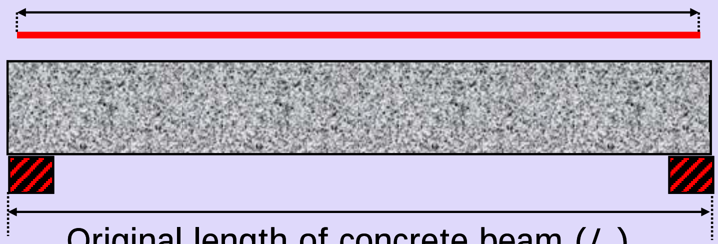


Figure 1-1.4 A prestressed beam under an external load

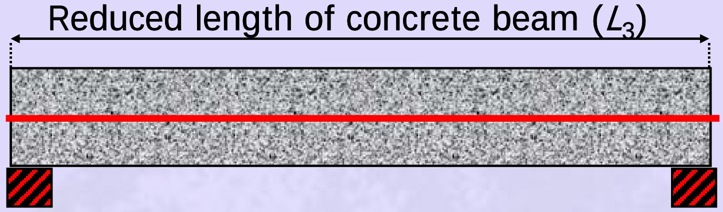
But, the early attempts of prestressing were not completely successful. It was observed that the effect of prestress reduced with time. The load resisting capacities of the members were limited. Under sustained loads, the members were found to fail. This was due to the following reason.

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.

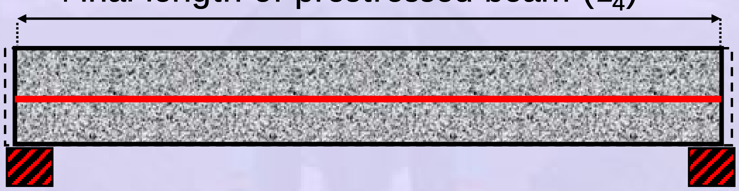
In the early applications, the strength of the mild steel and the strain during prestressing were less. The residual strain and hence, the residual prestress was only about 10% of the initial value. The following sketches explain the phenomena.



a) Beam before applying prestress



b) Beam at transfer of prestress



c) Beam after long-term losses of prestress

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.

1.1.3 Brief History

Before the development of prestressed concrete, two significant developments of reinforced concrete are the invention of Portland cement and introduction of steel in concrete. These are also mentioned as the part of the history. The key developments are mentioned next to the corresponding year.

1824 Aspdin, J., (England)

Obtained a patent for the manufacture of Portland cement.

1857 Monier, J., (France)

Introduced steel wires in concrete to make flower pots, pipes, arches and slabs.

The following events were significant in the development of prestressed concrete.

1886 Jackson, P. H., (USA)

Introduced the concept of tightening steel tie rods in artificial stone and concrete arches.

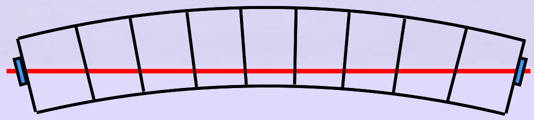


Figure 1-1.6 Steel tie rods in arches

1888 Doehring, C. E. W., (Germany)

Manufactured concrete slabs and small beams with embedded tensioned steel.

1908 Stainer, C. R., (USA)

Recognised losses due to shrinkage and creep, and suggested retightening the rods to recover lost prestress.

1923 Emperger, F., (Austria)

Developed a method of winding and pre- tensioning high tensile steel wires around concrete pipes.

1924 Hewett, W. H., (USA)

Introduced hoop-stressed horizontal reinforcement around walls of concrete tanks through the use of turnbuckles.

Thousands of liquid storage tanks and concrete pipes were built in the two decades to follow.

1925 Dill, R. H., (USA)

Used high strength unbonded steel rods. The rods were tensioned and anchored after hardening of the concrete.

Figure 1-1.7 Portrait of Eugene Freyssinet

(Reference: Collins, M. P. and Mitchell, D.,*Prestressed Concrete Structures*)

1926 Eugene Freyssinet (France)

Used high tensile steel wires, with ultimate strength as high as 1725 MPa and yield stress over 1240 MPa. In 1939, he developed conical wedges for end anchorages for post-tensioning and developed double-acting jacks. He is often referred to as the **Father of Prestressed concrete**.

1938 Hoyer, E., (Germany)

Developed 'long line' pre-tensioning method.

1940 Magnel, G., (Belgium)

Developed an anchoring system for post-tensioning, using flat wedges.

During the Second World War, applications of prestressed and precast concrete increased rapidly. The names of a few persons involved in developing prestressed concrete are mentioned. Guyon, Y., (France) built numerous prestressed concrete bridges in western and central Europe. Abeles, P. W., (England) introduced the concept of partial prestressing. Leonhardt, F., (Germany), Mikhailor, V., (Russia) and Lin, T. Y., (USA) are famous in the field of prestressed concrete.

The International Federation for Prestressing (FIP), a professional organisation in Europe was established in 1952. The Precast/Prestressed Concrete Institute (PCI) was established in USA in 1954.

Prestressed concrete was started to be used in building frames, parking structures, stadiums, railway sleepers, transmission line poles and other types of structures and elements.

In India, the applications of prestressed concrete diversified over the years. The first prestressed concrete bridge was built in 1948 under the Assam Rail Link Project. Among bridges, the Pamban Road Bridge at Rameshwaram, Tamilnadu, remains a classic example of the use of prestressed concrete girders.

Figure 1-1.8 Pamban Road Bridge at Rameshwaram, Tamilnadu
(Reference: http://www.ramnad.tn.nic.in)

1.1.4 Development of Building Materials

The development of prestressed concrete can be studied in the perspective of traditional building materials. In the ancient period, stones and bricks were extensively used. These materials are strong in compression, but weak in tension. For tension, bamboos and coir ropes were used in bridges. Subsequently iron and steel bars were used to resist tension. These members tend to buckle under compression. Wood and structural steel members were effective both in tension and compression.

In reinforced concrete, concrete and steel are combined such that concrete resists compression and steel resists tension. This is a **passive** combination of the two materials. In prestressed concrete high strength concrete and high strength steel are combined such that the full section is effective in resisting tension and compression. This is an **active** combination of the two materials. The following sketch shows the use of the different materials with the progress of time.

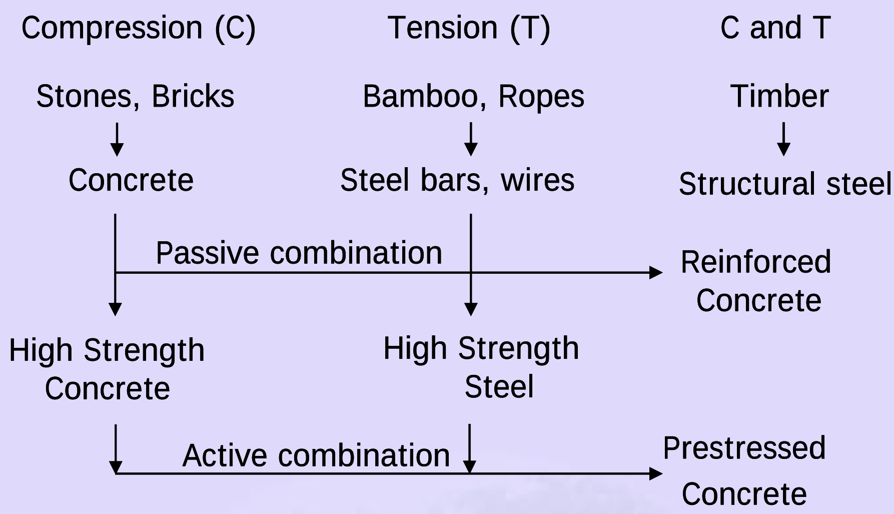


Figure 1-1.9 Development of building materials

(Reference: Lin, T. Y. and Burns, N. H., *Design of Prestressed Concrete Structures*)