1.7 Prestressing Steel

This section covers the following topics.

- Forms of Prestressing Steel
- Types of Prestressing Steel
- Properties of Prestressing Steel
- Codal Provisions of Steel

1.7.1 Forms of Prestressing Steel

The development of prestressed concrete was influenced by the invention of high strength steel. It is an alloy of iron, carbon, manganese and optional materials. The following material describes the types and properties of prestressing steel.

In addition to prestressing steel, conventional non-prestressed reinforcement is used for flexural capacity (optional), shear capacity, temperature and shrinkage requirements. The properties of steel for non-prestressed reinforcement are not covered in this section. It is expected that the student of this course is familiar with the conventional reinforcement.

Wires

A prestressing wire is a single unit made of steel. The nominal diameters of the wires are 2.5, 3.0, 4.0, 5.0, 7.0 and 8.0 mm. The different types of wires are as follows.

1) Plain wire: No indentations on the surface.
2) Indented wire: There are circular or elliptical indentations on the surface.

Strands

A few wires are spun together in a helical form to form a prestressing strand. The different types of strands are as follows.

1) Two-wire strand: Two wires are spun together to form the strand.
2) Three-wire strand: Three wires are spun together to form the strand.
3) Seven-wire strand: In this type of strand, six wires are spun around a central wire. The central wire is larger than the other wires.

Tendons

A group of strands or wires are placed together to form a prestressing tendon. The tendons are used in post-tensioned members. The following figure shows the cross section of a typical tendon. The strands are placed in a duct which may be filled with grout after the post-tensioning operation is completed (Figure 1-7.1).

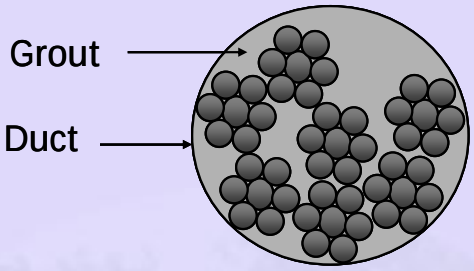

Figure 1-7.1 Cross-section of a typical tendon

Cables

A group of tendons form a prestressing cable. The cables are used in bridges.

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. Bars are available in the following sizes: 10, 12, 16, 20, 22, 25, 28 and 32 mm.

The following figure shows the different forms of prestressing steel.

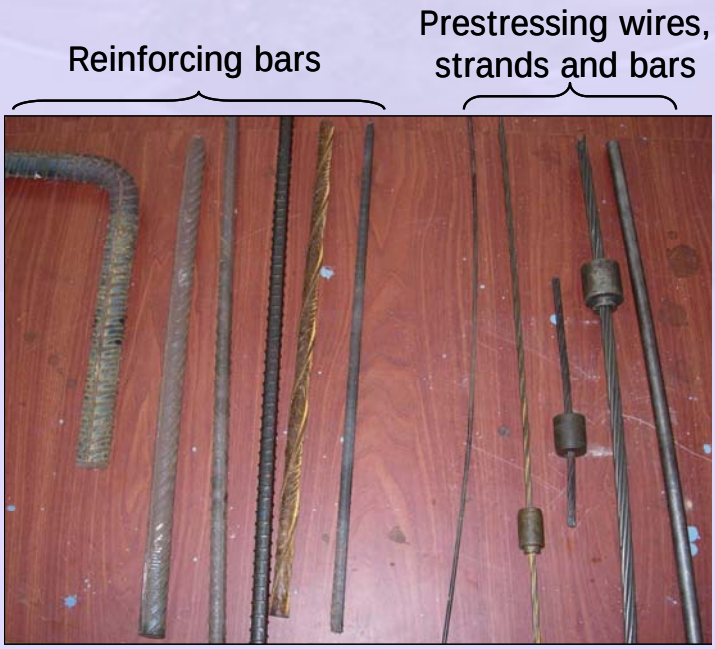

Figure 1-7.2 Forms of reinforcing and prestressing steel

1.7.2 Types of Prestressing Steel

The steel is treated to achieve the desired properties. The following are the treatment processes.

Cold working (cold drawing)

The cold working is done by rolling the bars through a series of dyes. It re-aligns the crystals and increases the strength.

Stress relieving

The stress relieving is done by heating the strand to about 350º C and cooling slowly. This reduces the plastic deformation of the steel after the onset of yielding.

Strain tempering for low relaxation

This process is done by heating the strand to about 350º C while it is under tension. This also improves the stress-strain behaviour of the steel by reducing the plastic deformation after the onset of yielding. In addition, the relaxation is reduced. The relaxation is described later.

IS:1343 - 1980 specifies the material properties of steel in **Section 4.5**. The following types of steel are allowed.

1) Plain cold drawn stress relieved wire conforming to **IS:1785, Part 1**, *Specification for Plain Hard Drawn Steel Wire for Prestressed Concrete, Part I Cold Drawn Stress Relieved Wire*.
2) Plain as-drawn wire conforming to **IS:1785, Part 2**, *Specification for Plain Hard Drawn Steel Wire for Prestressed Concrete, Part II As Drawn Wire.*
3) Indented cold drawn wire conforming to **IS:6003**, *Specification for Indented Wire for Prestressed Concrete.*
4) High tensile steel bar conforming to **IS:2090**, *Specification for High Tensile Steel Bars used in Prestressed Concrete.*
5) Uncoated stress relieved strand conforming to **IS:6006**. *Specification for Uncoated Stress Relieved Strand for Prestressed Concrete.*

1.7.3 Properties of Prestressing Steel

The steel in prestressed applications has to be of good quality. It requires the following attributes.

1) High strength
2) Adequate ductility
3) Bendability, which is required at the harping points and near the anchorage
4) High bond, required for pre-tensioned members
5) Low relaxation to reduce losses
6) Minimum corrosion.

Strength of Prestressing Steel

The tensile strength of prestressing steel is given in terms of the characteristic tensile strength (f_{pk}).

The characteristic strength is defined as the ultimate tensile strength of the coupon specimens below which not more than 5% of the test results are expected to fall.

The ultimate tensile strength of a coupon specimen is determined by a testing machine according to **IS:1521 - 1972**, *Method for Tensile Testing of Steel Wire*. The following figure shows a test setup.

(a) Test set-up

(b) Failure of a strand

Figure 1-7.3 Testing of tensile strength of prestressing strand

The minimum tensile strengths for different types of wires as specified by the codes are reproduced.

Table 1-7.1 Cold Drawn Stress-Relieved Wires (**IS: 1785 Part 1**)

Nominal Diameter (mm)	2.50	3.00	4.00	5.00	7.00	8.00
Minimum Tensile Strength f_{pk} (N/mm^2)	2010	1865	1715	1570	1470	1375

The proof stress (defined later) should not be less than 85% of the specified tensile strength.

Table 1-7.2 As-Drawn wire (**IS: 1785 Part 2**)

Nominal Diameter (mm)	3.00	4.00	5.00
Minimum Tensile Strength f_{pk} (N/mm^2)	1765	1715	1570

The proof stress should not be less than 75% of the specified tensile strength.

Table 1-7.3 Indented wire (**IS: 6003**)

Nominal Diameter (mm)	3.00	4.00	5.00
Minimum Tensile Strength f_{pk} (N/mm^2)	1865	1715	1570

The proof stress should not be less than 85% of the specified tensile strength.

For high tensile steel bars (**IS: 2090**), the minimum tensile strength is 980 N/mm^2. The proof stress should not be less than 80% of the specified tensile strength.

Stiffness of Prestressing Steel

The stiffness of prestressing steel is given by the initial modulus of elasticity. The modulus of elasticity depends on the form of prestressing steel (wires or strands or bars).

IS:1343 - 1980 provides the following guidelines which can be used in absence of test data.

Table 1-7.4 Modulus of elasticity (**IS: 1343 - 1980**)

Type of steel	Modulus of elasticity
Cold-drawn wires	210 kN/mm^2
High tensile steel bars	200 kN/mm^2
Strands	195 kN/mm^2

Allowable Stress in Prestressing Steel

As per **Clause 18.5.1**, the maximum tensile stress during prestressing (f_{pi}) shall not exceed 80% of the characteristic strength.

$$f_{pi} \leq 0.8 f_{pk} \qquad \textbf{(1-7.1)}$$

There is no upper limit for the stress at transfer (after short term losses) or for the effective prestress (after long term losses).

Stress-Strain Curves for Prestressing Steel

The stress versus strain behaviour of prestressing steel under uniaxial tension is initially linear (stress is proportional to strain) and elastic (strain is recovered at unloading).

Beyond about 70% of the ultimate strength the behaviour becomes nonlinear and inelastic. There is no defined yield point.

The yield point is defined in terms of the proof stress or a specified yield strain. **IS:1343 - 1980** recommends the yield point at 0.2% proof stress. This stress corresponds to an inelastic strain of 0.002. This is shown in the following figure.

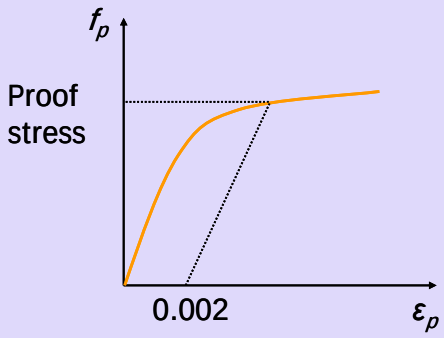

Figure 1-7.4 Proof stress corresponds to inelastic strain of 0.002

The characteristic stress-strain curves are given in **Figure 5** of **IS:1343 - 1980**. The stress corresponding to a strain can be found out by using these curves as shown next.

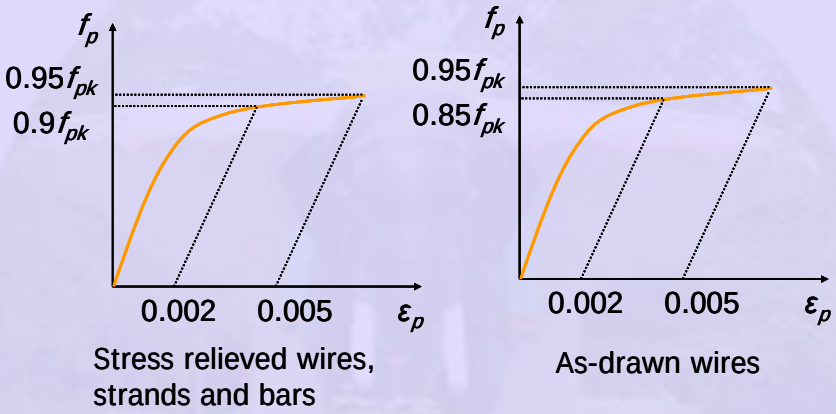

Figure 1-7.5 Characteristic stress-strain curves for prestressing steel (**Figure 5, IS:1343 - 1980**)

The stress-strain curves are influenced by the treatment processes. The following figure shows the variation in the 0.2% proof stress for wires under different treatment processes.

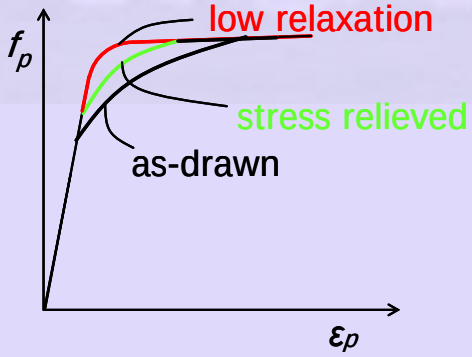

Figure 1-7.6 Variation in the 0.2% proof stress for wires under different treatment processes

The design stress-strain curves are calculated by dividing the stress beyond $0.8f_{pk}$ by a material safety factor γ_m =1.15. The following figure shows the characteristic and design stress-strain curves.

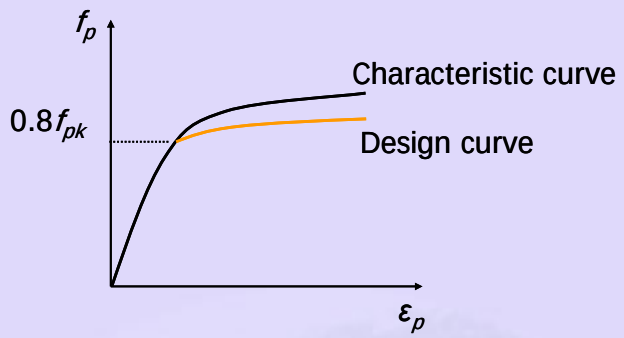

Figure 1-7.7 Characteristic and design stress-strain curves for prestressing steel

Relaxation of Steel

Relaxation of steel is defined as the decrease in stress with time under constant strain. Due to the relaxation of steel, the prestress in the tendon is reduced with time. Hence, the study of relaxation is important in prestressed concrete to calculate the loss in prestress.

The relaxation depends on the type of steel, initial prestress and the temperature. The following figure shows the effect of relaxation due to different types of loading conditions.

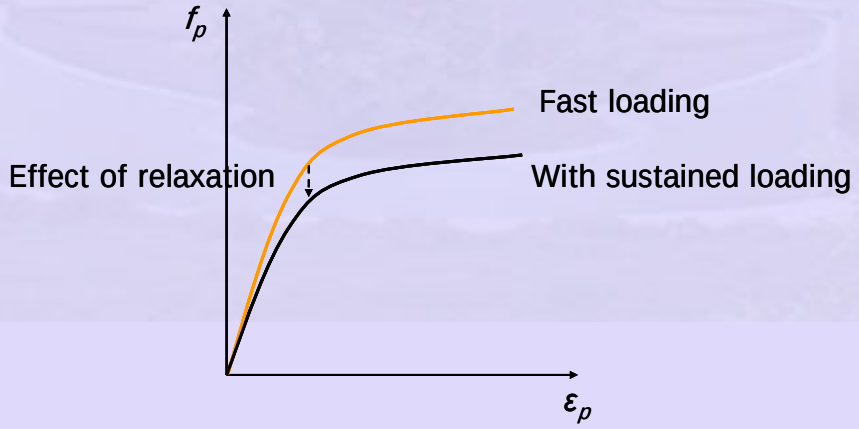

Figure 1-7.8 Effect of relaxation due to different types of loading conditions

The following figure shows the variation of stress with time for different levels of prestressing. Here, the instantaneous stress (f_p) is normalised with respect to the initial prestressing (f_{pi}) in the ordinate. The curves are for different values of f_{pi}/f_{py}, where f_{py} is the yield stress.

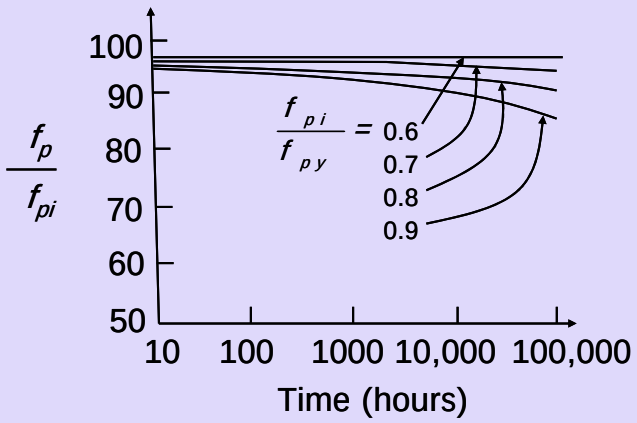

Figure 1-7.9 Variation of stress with time for different levels of prestressing

It can be observed that there is significant relaxation loss when the applied stress is more than 70% of the yield stress.

The following photos show the test set-up for relaxation test.

(a) Test of a single wire strand

(b) Test of a seven-wire strand

Figure 1-7.10 Set-up for relaxation test

The upper limits of relaxation loss are specified as follows.

Table 1-7.5 Relaxation losses at 1000 hours (**IS:1785, IS:6003, IS:6006, IS:2090**)

Cold drawn stress-relieved wires	5% of initial prestress
Indented wires	5% of initial prestress
Stress-relieved strand	5% of initial prestress
Bars	49 N/mm^2

In absence of test data, **IS:1343 - 1980** recommends the following estimates of relaxation losses.

Table 1-7.6 Relaxation losses at 1000 hours at 27°C

Initial Stress	Relaxation Loss (N/mm^2)
$0.5f_{pk}$	0
$0.6f_{pk}$	35
$0.7f_{pk}$	70
$0.8f_{pk}$	90

Fatigue

Under repeated dynamic loads the strength of a member may reduce with the number of cycles of applied load. The reduction in strength is referred to as fatigue.

In prestressed applications, the fatigue is negligible in members that do not crack under service loads. If a member cracks, fatigue may be a concern due to high stress in the steel at the location of cracks.

Specimens are tested under 2 x 10^6 cycles of load to observe the fatigue. For steel, fatigue tests are conducted to develop the stress versus number of cycles for failure (S-N) diagram. Under a limiting value of stress, the specimen can withstand infinite number of cycles. This limit is known as the endurance limit.

The prestressed member is designed such that the stress in the steel due to service loads remains under the endurance limit. The following photo shows a set-up for fatigue testing of strands.

Figure 1-7.11 Set-up for fatigue testing of strands

Durability

Prestressing steel is susceptible to stress corrosion and hydrogen embrittlement in aggressive environments. Hence, prestressing steel needs to be adequately protected.

For bonded tendons, the alkaline environment of the grout provides adequate protection. For unbonded tendons, corrosion protection is provided by one or more of the following methods.

1) Epoxy coating
2) Mastic wrap (grease impregnated tape)
3) Galvanized bars
4) Encasing in tubes.

1.7.4 Codal Provisions of Steel

The following topics are covered in **IS:1343 - 1980** under the respective sections. These provisions are not duplicated here.

Table 1-7.7 Topics and sections

Assembly of prestressing and reinforcing steel	Section 11
Prestressing	Section 12