2.3 Losses in Prestress (Part III)

This section covers the following topics.

- Creep of Concrete
- Shrinkage of Concrete
- Relaxation of Steel
- Total Time Dependent Losses

2.3.1 Creep of Concrete

Creep of concrete is defined as the increase in deformation with time under constant load. Due to the creep of concrete, the prestress in the tendon is reduced with time.

The creep of concrete is explained in Section 1.6, Concrete (Part II). Here, the information is summarised. For stress in concrete less than one-third of the characteristic strength, the ultimate creep strain ($\varepsilon_{cr,ult}$) is found to be proportional to the elastic strain (ε_{el}). The ratio of the ultimate creep strain to the elastic strain is defined as the ultimate creep coefficient or simply creep coefficient θ.

The ultimate creep strain is then given as follows.

$$\varepsilon_{cr,ult} = \theta \varepsilon_{el} \qquad \textbf{(2-3.1)}$$

IS:1343 - 1980 gives guidelines to estimate the ultimate creep strain in **Section 5.2.5**. It is a simplified estimate where only one factor has been considered. The factor is age of loading of the prestressed concrete structure. The creep coefficient θ is provided for three values of age of loading.

Curing the concrete adequately and delaying the application of load provide long term benefits with regards to durability, loss of prestress and deflection. In special situations detailed calculations may be necessary to monitor creep strain with time. Specialised literature or international codes can provide guidelines for such calculations.

The loss in prestress (Δf_p) due to creep is given as follows.

$$\Delta f_p = E_p \, \varepsilon_{cr,\,ult} \qquad \textbf{(2-3.2)}$$

Here, E_p is the modulus of the prestressing steel.

The following considerations are applicable for calculating the loss of prestress due to creep.

1) The creep is due to the sustained (permanently applied) loads only. Temporary loads are not considered in the calculation of creep.
2) Since the prestress may vary along the length of the member, an average value of the prestress can be considered.
3) The prestress changes due to creep and the creep is related to the instantaneous prestress. To consider this interaction, the calculation of creep can be iterated over small time steps.

2.3.2 Shrinkage of Concrete

Shrinkage of concrete is defined as the contraction due to loss of moisture. Due to the shrinkage of concrete, the prestress in the tendon is reduced with time. The shrinkage of concrete was explained in details in the Section 1.6, Concrete (Part II).

IS:1343 - 1980 gives guidelines to estimate the shrinkage strain in **Section 5.2.4**. It is a simplified estimate of the ultimate shrinkage strain (ε_{sh}). Curing the concrete adequately and delaying the application of load provide long term benefits with regards to durability and loss of prestress. In special situations detailed calculations may be necessary to monitor shrinkage strain with time. Specialised literature or international codes can provide guidelines for such calculations.

The loss in prestress (Δf_p) due to shrinkage is given as follows.

$$\Delta f_p = E_p \, \varepsilon_{sh} \qquad \textbf{(2-3.3)}$$

Here, E_p is the modulus of the prestressing steel.

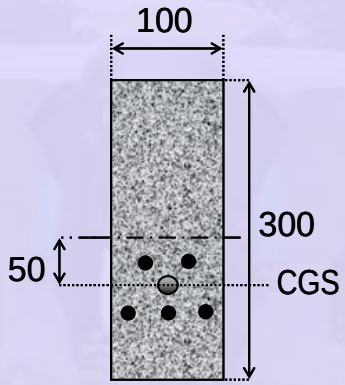
2.3.3 Relaxation of Steel

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. The relaxation depends on the type of steel, initial prestress (f_{pi}) and the temperature. To

calculate the drop (or loss) in prestress (Δf_p), the recommendations of **IS:1343 - 1980** can be followed in absence of test data.

Example 2-3.1

A concrete beam of dimension 100 mm × 300 mm is post-tensioned with 5 straight wires of 7mm diameter. The average prestress after short-term losses is $0.7f_{pk}$ = 1200 N/mm^2 and the age of loading is given as 28 days. Given that E_p = 200 × 103 MPa, E_c = 35000 MPa, find out the losses of prestress due to creep, shrinkage and relaxation. Neglect the weight of the beam in the computation of the stresses.



Solution

Area of concrete $A = 100 \times 300$

$= 30000$ mm^2

Moment of inertia of beam section

$I = 100 \times 300^3 / 12$

$= 225 \times 10^6$ mm^4

Area of prestressing wires $A_p = 5 \times (\pi/4) \times 7^2$

$= 192.42$ mm^2

Prestressing force after short-term losses

$P_0 = A_p.f_{p0}$

$= 192.4 \times 1200$

$= 230880$ N

Modular ratio $m = E_p / E_c$

$= 2 \times 10^5 / 35 \times 10^3$

$= 5.71$

Stress in concrete at the level of CGS

$$f_c = -\frac{P_0}{A} - \frac{P_0 e}{I} e$$

$$= -\frac{230880}{3 \times 10^4} - \frac{230880}{225 \times 10^6} \times 50^2$$

$= -7.69 - 2.56$

$= -10.25 \text{ N/mm}^2$

Loss of prestress due to creep

$(\Delta f_p)_{cr} = E_p \varepsilon_{cr,\,ult}$

$= E_p \theta \varepsilon_{el}$

$= E_p \theta (f_c / E_c)$

$= m \theta f_c$

$= 5.71 \times 10.25 \times 1.6$

$= 93.64 \text{ N / mm}^2$

Here, $\theta = 1.6$ for loading at 28 days, from **Table 2c-1 (Clause 5.2.5.1, IS:1343 - 1980).**

Shrinkage strain from **Clause 5.2.4.1, IS:1343 - 1980**

$\varepsilon_{sh} = 0.0002 / \log_{10}(t + 2)$

$= 0.0002 / \log_{10}(28 + 2)$

$= 1.354 \times 10^{-4}$

Loss of prestress due to shrinkage

$(\Delta f_p)_{sh} = E_p \varepsilon_{sh}$

$= 2 \times 10^5 \times 1.354 \times 10^{-4}$

$= 27.08 \text{ N/mm}^2$

From **Table 2c-2 (Table 4, IS:1343 - 1980)**

Loss of prestress due to relaxation

$$(\Delta f_p)_{rl} = 70.0 \text{ N/mm}^2$$

Loss of prestressing force $= \Delta f_p \, A_p$

Therefore,

Loss of prestressing force due to creep $= 93.64 \times 192.42$

$= 18018$ N

Loss of prestressing force due to shrinkage

$= 27.08 \times 192.42$

$= 5211$ N

Loss of prestressing force due to relaxation

$= 70 \times 192.42$

$= 13469$ N

Total long-term loss of prestressing force (neglecting the interaction of the losses and prestressing force)

$= 18018 + 5211 + 13469$

$= 36698$ N

Percentage loss of prestress $= 36698 / 230880 \times 100\%$

$= 15.9$ %

2.3.4 Total Time-dependent Loss

The losses of prestress due to creep and shrinkage of concrete and the relaxation of the steel are all time-dependent and inter-related to each other. If the losses are calculated separately and added, the calculated total time-dependent loss is over-estimated. To consider the inter-relationship of the cause and effect, the calculation can be done for discrete time steps. The results at the end of each time step are used for the next time step. This step-by-step procedure was suggested by the Precast / Prestressed

Concrete Institute (PCI) committee and is called the **General method** (Reference: *PCI Committee, "Recommendations for Estimating Prestress Losses", PCI Journal, PCI, Vol. 20, No. 4, July-August 1975, pp. 43-75*).

In the PCI step-by-step procedure, a minimum of four time steps are considered in the service life of a prestressed member. The following table provides the definitions of the time steps (Table 2-3.3).

Table 2-3.3 Time steps in the step-by-step procedure

Step	Beginning	End
1	Pre-tension: Anchorage of steel Post-tension: End of curing	Age of prestressing
2	End of Step 1	30 days after prestressing or when subjected to superimposed load
3	End of Step 2	1 year of service
4	End of Step 3	End of service life

The step-by-step procedure can be implemented by a computer program, where the number of time steps can be increased.

There are also approximate methods to calculate lump sum estimates of the total loss. Since these estimates are not given in **IS:1343 - 1980**, they are not mentioned here.