Analysis of Losses in Post-Tensioned Prestressed Concrete Beams

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ABSTRACT

Prestressing is the process of introducing internal stresses in the member to counteract the tensile stresses resulting from external loads during the service period. It is done to increase the members' strength and durability and control the members' cracking and deflection. As prestress introduced into concrete does not remain same due to the losses of prestress occurs immediately and during the lifetime of the member. The prestress losses result into reduction in strength and serviceability of prestressed concrete members. These prestress losses are divided into 2 categories, immediate losses and time-dependent losses. The loss of prestress due to friction, anchorage slip and elastic shortening comes under immediate losses whereas the loss of prestress due to creep, shrinkage of concrete and relaxation of steel comes under time-dependent losses. The purpose of this paper is to study and evaluate prestress losses in post-tensioned prestressed concrete beams using IS code 1343:2012. Total 6 beams are used for comparative analysis of prestress losses in prestressed concrete beams. The beams having rectangular cross-section of 100 mm wide and 150 mm deep with span of 1200 mm. Out of 6 beams, 3 beams are provided with single strand comprising of 3 wires of diameter 3 mm and other 3 beams are provided with double strands comprising of 3 wires each with diameter of 3 mm. The profile of strand is parabolic in nature with eccentricity of 50 mm. The conclusion based on the measurement findings shows that percentage loss of initial prestressing force is in between 20 % to 26 % prestressed concrete beams. Moreover, the efficiency of single reinforced prestressed concrete beam is more than double reinforced prestressed concrete beams.

Keywords: Prestressed Concrete, Creep, Shrinkage, Losses of Prestress

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1. INTRODUCTION

Prestressed concrete is a particular form of reinforced concrete. Prestressing involves the application of an initial compressive load to the structure to reduce or eliminate the internal tensile force and, thereby, control or eliminate cracking. It has long been recognized that the prestress introduced into concrete, does not remain constant but decreases gradually with the progress of time. In a pretensioned concrete, the loss of prestress is due to elastic shortening, friction, anchorage slip, creep, shrinkage and relaxation of steel. The losses are classified into immediate losses and time-dependent losses. Loss of prestress due to friction comes under immediate loss in prestress concrete.

It is due to the friction between tendons and material surrounding the tendon. Loss of prestress depends upon the cable profile of tendon and duct. In case of straight tendon, the effect of friction is based on length of tendon whereas in case of curved tendon, the loss of friction depends upon the curvature of duct and also the frictional coefficient between the duct and tendon. Loss of prestress due to friction occurs only in post tensioned beams. Loss of prestress due to anchorage slip is an immediate loss in prestress concrete. The slip occurs during the jacking process of transferring prestress to concrete. The anchorage slip depends upon the type of wedges and initial stress in tendon. The loss of prestress due to anchorage slip happens in post tensioned beams. Loss of prestress due to creep in concrete is a time-dependent loss in prestress concrete. It is due to deformation of concrete due to sustained compressive stresses. The creep in concrete member depends upon the loading and its time interval on the member. Loss of prestress due to shrinkage in concrete is a time-dependent loss in prestress concrete. It is due to reduction in volume of concrete with respect to time. Shrinkage of concrete depends only on the interval of time and the moisture conditions, but is independent of the stresses in the member due to loads. Loss of prestress due to relaxation of steel is a time-dependent loss in prestress concrete. It is due to the reduction of stresses in steel with respect to time at constant strain. It generally depends upon the type of steel, age of member, initial stress in steel and type of exposure.

2. NUMERICAL STUDY

The cross section of beam is 100 mm wide and 150 mm deep. The length of beam is 1200 mm. Total 6 beams are used for prestress losses analysis. The Prestressing strand is made up of 3 high tensioned wires of size 3mm each. The beams are divided into 2 categories on basis of number of strands placed in the beams. There are 3 beams with single strand and 3 beams with double strands. The cable profile is parabolic in nature with maximum eccentricity of 50 mm at mid-span of beam and minimum eccentricity of 0 at supports of beam

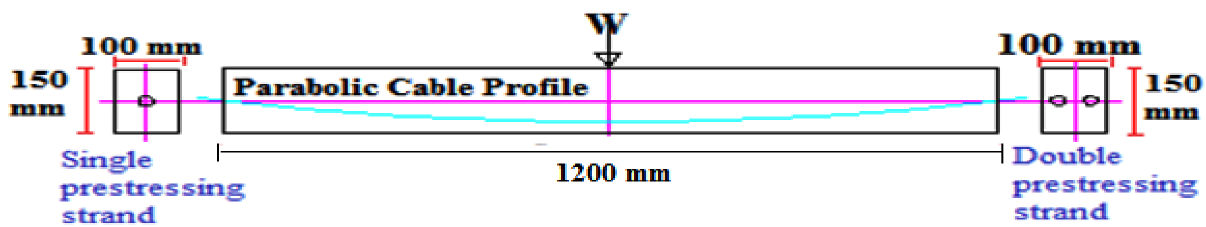

Fig 1: Cross-Sectional Details of Beams

The date available for the prestressed concrete beams,

- Characteristic concrete cube strength, f_c = 35 N/mm^2
- Length of Beam, L= 1200 mm; Width= 100 mm; Depth, D= 150 mm
- Area of concrete section, A = 15000 mm$^{2;}$ Area of steel, A_s = 21.2 mm^2
- Eccentricity, e = 50 mm (at midspan); 0 mm (at support)
- Modulus of Elasticity of Steel, Es = 2×10^5 MPa
- Modulus of Elasticity of Concrete = 2×10^4 MPa
- Modular Ratio, m = 10
- Section modulus at top fiber, Vt = 75 mm
- Section Modulus at Bottom fiber, Vb = 75 mm
- Second moment of area, I = 28.125×10^6 mm^4
- Self-weight of beam = 0.375 kN/m
- Max. Bending Moment at mid-span = 0.0675 kN-m

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Table 1: Computational Details for Beams

Name of BEAMS	Prestressing Force (kN)	No. of Strand	Area of concrete mm^2	Area of Steel mm^2	Stress in Tendons N/mm2	Stress in Concrete N/mm2	Second modulus $I=bd^3/12$
P-1	36.10	1	15000	21.2	1702.80	5.48	28.125×10^6
Q-1	37.30	1	15000	21.2	1759.40	5.67	28.125×10^6
R-1	38.20	1	15000	21.2	1801.80	5.81	28.125×10^6
P-2	60.00	2	15000	42.4	1415.10	9.21	28.125×10^6
Q-2	62.20	2	15000	42.4	1466.98	9.55	28.125×10^6
R-2	64.40	2	15000	42.4	1518.86	9.90	28.125×10^6

Fig 2: Prestressed concrete beams

Prestress loss due to friction in the cable duct are calculated using following expression,

$$P_L = P_i\,[\,1- (k.x - \mu.\alpha)]$$

The coefficient of wobble effect, k is taken as 15×10^{-4} for normal conditions. The frictional coefficient is taken as 0.3 as per IS Code 1343-2012. The commulative angle, α depends upon the jacking style, for both side jacking simultaneously it is taken as 4e/L.

The value k depends on the type of jacking style. If the jacking is done from both ends simultaneously than the maximum effect or loss of prestress due to friction will take place at mid-span, Therefore, the value of k is taken as L/2.

Prestress loss due to anchorage slip in post tensioned prestressed concrete beams is shown as,

$$P_L = (\delta l/ L)\, Es$$

Anchorage slip, δl is taken as 0.75 mm. The magnitude of slip depends upon the type of wedge and the stress in the wires. This loss of prestress occurs only in post-tensioned members as no anchorages are used in pre-tensioned members.

Loss of prestress due to creep in post-tensioned prestressed concrete beam, as follow,

$$P_L = \varphi \times m \times f_c$$

The Creep coefficient, φ is taken as 1 and modular ratio, m is 10. To evaluate the stress in concrete at level of tendon, the following equation is used,

$$f_{c=} [(P/A) + (P.e^{e}/I) – (M.e/I)]$$

The loss of prestress due to creep of concrete is obtained as the product of the modulus of elasticity of the prestressing steel and the ultimate creep strain of the concrete fibre integrated along the line of center of gravity of the prestressing steel over its entire length.

Loss of prestress in post-tensioned prestressed concrete beam due to shrinkage of concrete

$$\epsilon_s = 0.0002/ \text{Log}_{10}\ (\boldsymbol{t} + 2)$$

The age of concrete at transfer in t days and shrinkage of concrete shall be the product of the modulus of elasticity of steel and the shrinkage strain of concrete.

Loss of prestress in post-tensioned prestressed concrete beam due to relaxation of steel. The relaxation losses in prestressing steels vary with type of steel, initial prestress, age, and temperature and, therefore, shall be determined from experiments. It is taken as 3% of initial stress.

3. RESULTS

The total losses calculated for the post-tensioning prestressed concrete beams using IS Code 11343:2012 are shown in table 2. The amount of prestress left in the post tensioned beams is shown in figure 3. The percentage prestress loss is higher in post tensioned beams having double strands than post tensioned beams having single strand, as shown in table 3.

Table 2: Loss of Prestress in Beams due to various factors

Name of Beams	Initial Prestress N/mm^2	Loss due to Friction	Loss due to Anchorage slip	Loss due to Creep	Loss due to Shrinkage	Loss due to steel Relaxation	Total Loss of Prestress N/mm^2
P-1	1702.80	85.14	125	54.8	40	51.06	356.00
Q-1	1759.40	87.97	125	55.9	40	52.78	361.65
R-1	1801.80	90.09	125	58.2	40	54.05	367.34
P-2	1415.10	70.75	125	92.1	40	42.45	370.30
Q-2	1466.98	73.35	125	95.5	40	44.00	377.85
R-2	1518.90	75.94	125	99.0	40	45.56	385.50

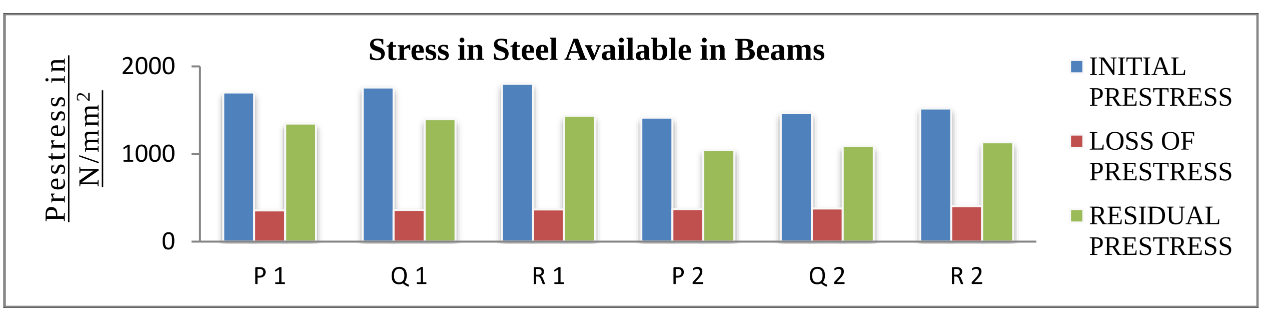

Fig 3: Initial Prestress, Loss of Prestress and Residual Prestress in Steel wires

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Table 3: Remaining Prestressing Force in Beams and Percentage loss of Prestress in Beams

Name of Beams	Applied Prestressing Force in kN	Initial Prestress in N/mm^2	Total Loss of Prestress in N/mm^2	Residual Prestress in N/mm^2	Remaining Prestressing Force in kN	Percentage Loss of Prestress %
P-1	36.10	1702.80	356.00	1346.80	28.55	20.90
Q-1	37.30	1759.40	361.65	1397.75	29.63	20.55
R-1	38.20	1801.80	367.34	1434.46	30.41	20.38
P-2	60.00	1415.10	370.30	1044.80	44.29	26.16
Q-2	62.20	1466.98	377.85	1089.13	46.17	25.75
R-2	64.40	1518.90	385.50	1133.40	48.05	25.38

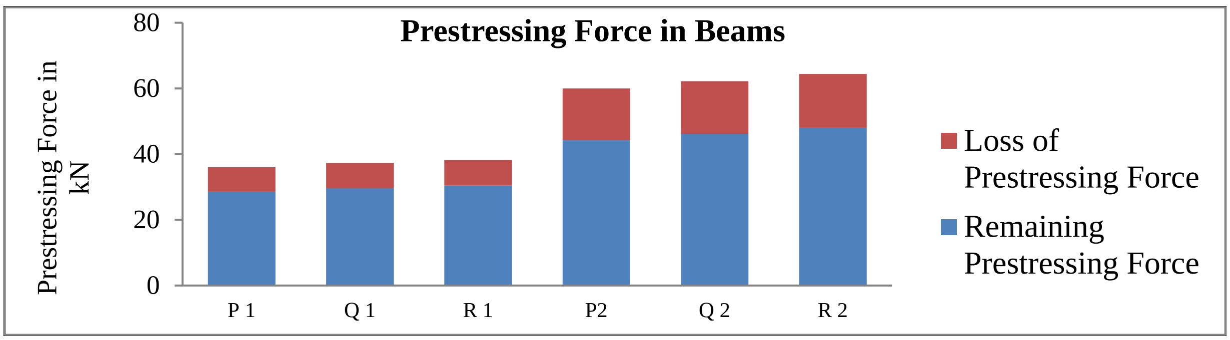

Fig 4: Initial Prestressing Force and Remaining Prestressing Force in Beams

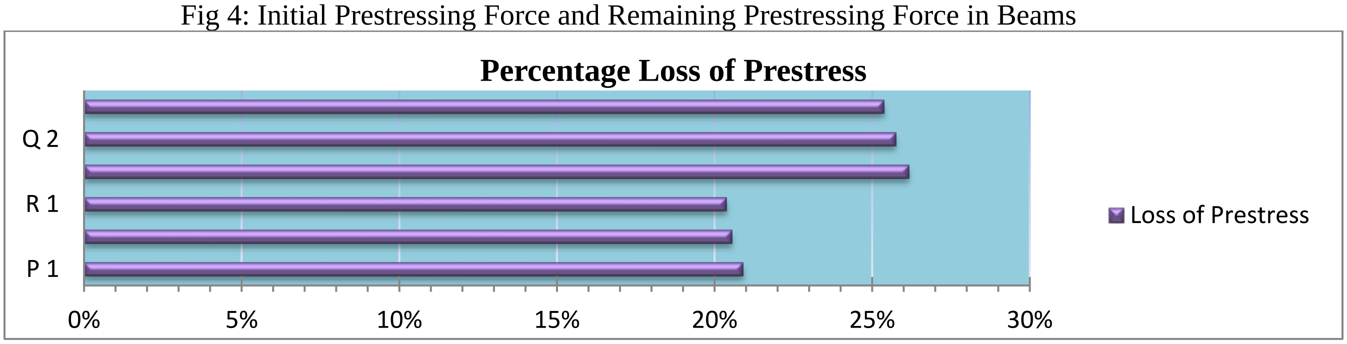

Fig 5: Percentage Loss of Prestress in Beams

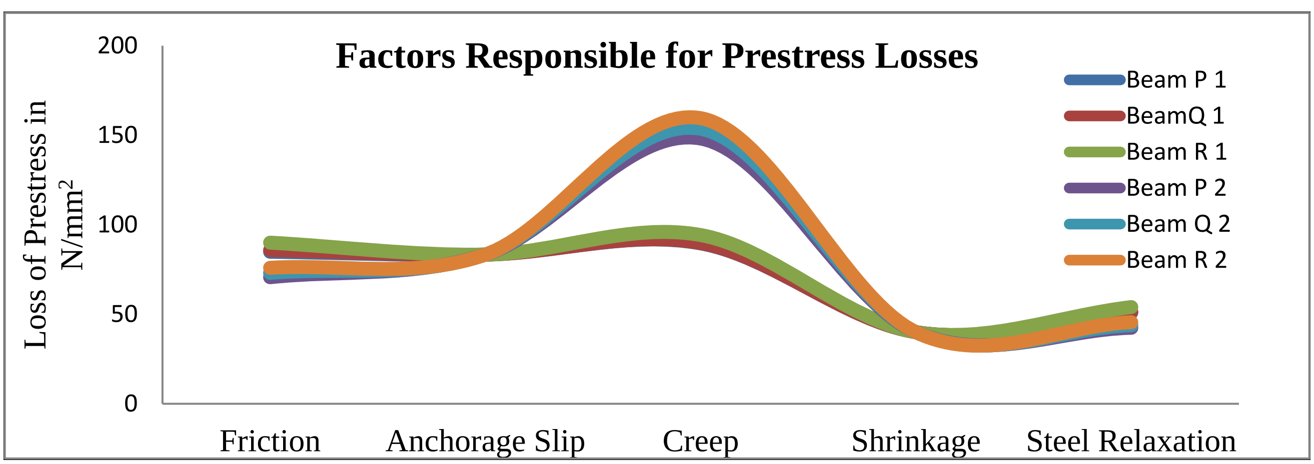

Fig 6: Comparison of Factors responsible for Losses in Prestressed Concrete Beam

4. CONCLUSION

The following points are concluded from present study,

- The maximum prestress loss in magnitude is seen in prestressed concrete beam with double prestressing strand R-2. However, the maximum percentage loss in prestress came in prestressed concrete beam with double prestressing strand P-2.
- Minimum loss of prestress loss in magnitude is seen in prestressed concrete beam with single prestressing strand P-1 whereas the maximum percentage loss of prestress came in prestressed concrete beam with single prestressing strand R-1.
- The Loss of prestress in prestressed concrete beams due to creep factor appear to be more in beams with double prestressing strands with similar cross-sectional area. However, the prestressing force is more in these beams. It gives value of creep which is independently of relative of humidity or volume to surface ratio. Rate of creep is, in turn, altered by the change in tendon stress.
- The rate of loss due to one factor, such as relaxation of tendons, is continually altered by changes in stress due to other factors such as shrinkage and creep of concrete.
- The Loss of prestress in prestressed concrete beams due to friction appear to be more in beams with double prestressing strands with similar cross-sectional area due to the effect of friction on both sides.
- If we consider that only one duct is placed in both groups so the actual effect of frictional loss is evaluated. The study suggests that more the magnitude more is the loss in prestress.
- Many of these factors are further dependent upon such uncertainties as material properties, time of loading, method of curing of concrete, environmental conditions and construction details. From above points it is therefore concluded that it is better to have one HDPE duct for cable comprising of many steel wires than multiple ducts for individual wires or group of wires.

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