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USE OF PRESTRESS CONCRETE

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I. INTRODUCTION

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. Pretensioning: 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.

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^3 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 which ever 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.

II. ADVANTAGE 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 posses 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.

III. DISADVANTAGES 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.

IV. CLASSIFICATIONS AND TYPES

Prestressed concrete structures can be classified in a number of ways depending upon the feature of designs and constructions.

1.Pre-tensioning: In which the tendons are tensioned before the concrete is placed, tendons are temporarily anchored and tensioned and the prestress is transferred to the concrete after it is hardened.

2.Post-tensioning: In which the tendon is tensioned after concrete has hardened. Tendons are placed in sheathing at suitable places in the member before casting and later after hardening of concrete.

The various methods by which pre-compression are imparted to concrete are classified as follows:

1. Generation of compressive force between the structural elements and its abutments using flat jack.
2. Development of hoop compression in cylindrically shaped structures by circumferential wire.
3. Use of longitudinally tensioned steel embedded in concrete or housed in ducts.
4. Use of principle of distortion of a statically indeterminate structure either by displacement or by rotation of one part relative to the remainder.
5. Use of deflected structural steel sections embedded in concrete until the hardening of the latter.
6. Development of limited tension in steel and compression in concrete by using expanding cements.

V. TENSIONING DEVICES

The various types devices used for tensioning steel are grouped under four principal categories, viz.

1. Mechanical devices: The mechanical devices generally used include weights with or without lever transmission, geared transmission in conjunction with pulley blocks, screw jacks with or without gear devices and wire-winding machines. These devices are employed mainly for prestressing structural concrete components produced on a mass scale in factory.
2. Hydraulic devices: These are simplest means for producing large prestressing force, extensively used as tensioning devices.
3. Electrical devices: The wires are electrically heated and anchored before placing concrete in the mould. This method is often referred to as thermo-prestressing and used for tensioning of steel wires and deformed bars.

4. Chemical devices: Expanding cements are used and the degree of expansion is controlled by varying the curing condition. Since the expansive action of cement while setting is restrained, it induces tensile forces in tendons and compressive stresses in concrete.

VI. PRESTRESSING SYSTEM

1. Pretensioning system:

In the pre-tensioning systems, the tendons are first tensioned between rigid anchor-blocks cast on the ground or in a column or unit –mould types pretensioning bed, prior to the casting of concrete in the mould. The tendons comprising individual wires or strands are stretched with constant eccentricity or a variable eccentricity with tendon anchorage at one end and jacks at the other.

With the forms in place, the concrete is cast around the stressed tendon. The system is shown in Fig. 1 below.

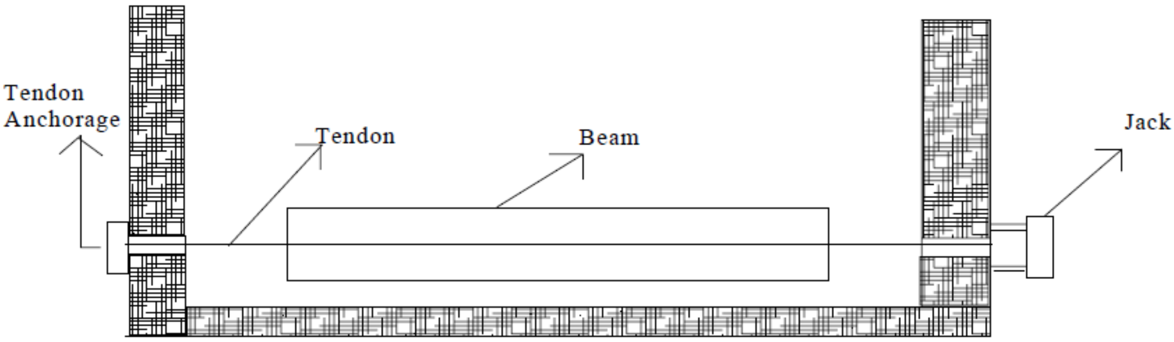


Fig. 1 Prestressing system

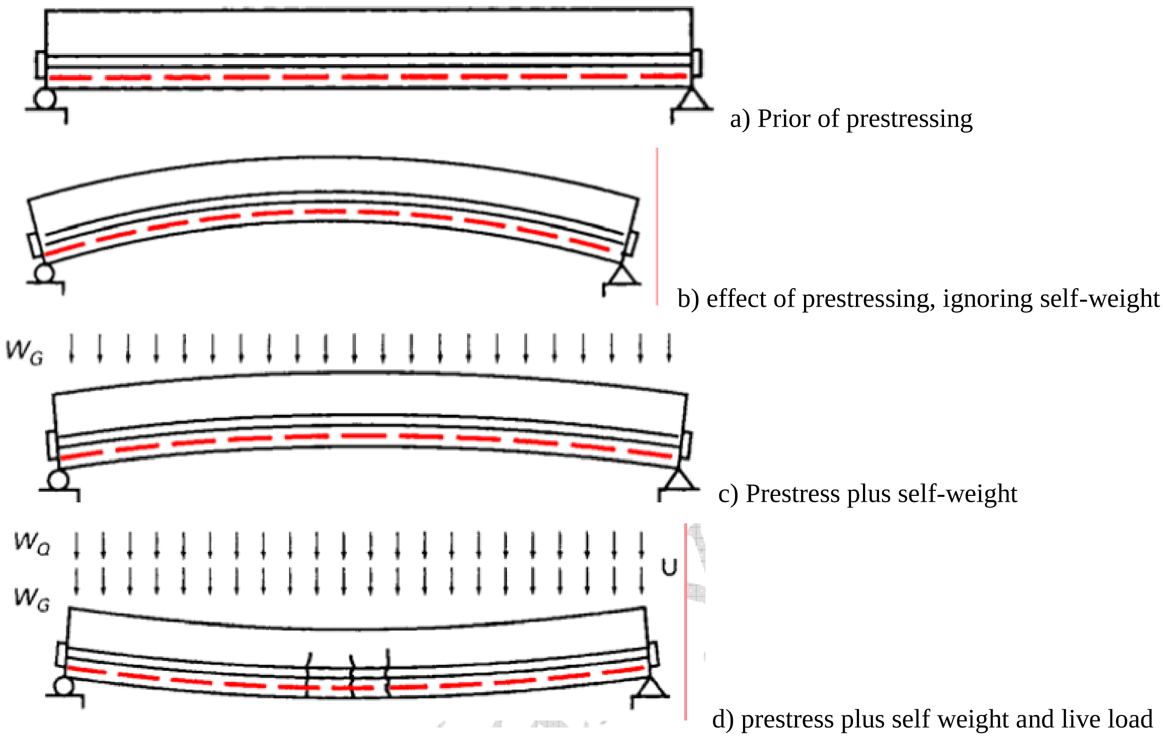


Fig. 2 Effect of load during Prestressing

2. Post-tensioned system:

In post-tensioning the concrete unit are first cast by incorporating ducts or grooves to house the tendons. When the concrete attains sufficient strength, the high-tensile wires are tensioned by means of jack bearing on the end of the face of the member and anchored by wedge or nuts. The forces are transmitted to the concrete by means of end anchorage and, when the cable is curved, through the radial pressure between the cable and the duct. The space between the tendons and the duct is generally grouted after the tensioning operation.

Most of the commercially patented prestressing systems are based on the following principle of anchoring the tendons:

1. Wedge action producing a frictional grip on the wire.
2. Direct bearing from the rivet or bolt heads formed at the end of the wire.
3. Looping the wire around the concrete.

Methods:

1. Freyssinet system
2. Gifford-Udall system
3. Magnel blaton system
4. Lee-McCall system

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 member 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 in variable with the lever arm.
3. Prestress concrete has more shear resistance, where as 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 are 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.

Comparative Study: Pretension Vs Post-tensioned Member

Pre-tension member	Post-tensioned member
1. In pretensioned prestress concrete, steel is tensioned prior to that of concrete. It is released once the concrete is placed and hardened. The stresses are transferred all along the wire by means of **bond.**	1. Concreting is done first then wires are tensioned and anchored at ends. The stress transfer is by **end bearing** not by bond.
2. Suitable for short span and precast products like sleepers, electric poles on mass production.	2. Suitable for long span bridges
3. In pretensioning the cables are basically straight and horizontal. Placing them in curved or inclined position is difficult. However the wire's can be kept with eccentrically. Since cables can not be aligned similar to B.M.D. structural advantages are less compare to that of post-tensioned.	3. The post tensioning cables can be aligned in any manner to suit the B.M.D due to external load system. Therefore it is more economical particularly for long span bridges. The curved or inclined cables can have vertical component at ends. These components will reduce the design shear force. Hence post-tensioned beams are superior to pretensioned beams both from flexural and shear resistances point.
4. Prestress losses are more compare to that of post-tensioned concrete.	4. Losses are less compare to pre-tensioned concrete

VII. LOSSES IN PRESTRESS

The initial prestressing concrete undergoes a gradual reduction with time from the stages of transfer due to various causes. This is generally defined as total "Loss of Prestress". The various losses are explained below:

Types of losses in prestress

Pretensioning

1. Elastic deformation of concrete
2. Relaxation of stress in steel
3. Shrinkage of concrete
4. Creep of concrete

Post-tensioning

1. No loss due to elastic deformation if all wires are simultaneously tensioned. If the wires are successively tensioned, there will be loss of prestress due to elastic deformation of concrete.
2. Relaxation of stress in steel
3. Shrinkage of concrete
4. Creep of concrete
5. Friction
6. Anchorage slip

Loss due to elastic deformation of the concrete

The loss of prestress due to deformation of concrete depends on the modular ratio &

the average stress in concrete at the level of steel.

If

f_c → Prestress in concrete at the level of steel

E_s → Modulus of elasticity of steel

E_c → Modulus of elasticity of concrete

α_e → Modular ratio

Strain in concrete at the level of steel $= \frac{f_c}{E_c}$

Stress in steel corresponding to this strain $= \frac{f_c}{E_c} E_s$

Therefore, Loss of stress in steel = *eα cf*

If the initial stress in steel is known, the percentage loss of stress in steel due to elastic deformation of concrete can be computed.

Loss due to shrinkage of concrete

Factors affecting the shrinkage in concrete

1. The loss due to shrinkage of concrete results in shortening of tensioned wires & hence contributes to the loss of stress.
2. The shrinkage of concrete is influenced by the type of cement, aggregate & the method of curing used.
3. Use of high strength concrete with low water cement ratio results in reduction in shrinkage and consequent loss of prestress.
4. The primary cause of drying shrinkage is the progressive loss of water from concrete.
5. The rate of shrinkage is higher at the surface of the member.
6. The differential shrinkage between the interior surfaces of large member may result in strain gradients leading to surface cracking.

Hence, proper curing is essential to prevent cracks due to shrinkage in prestress members. In the case of pretensioned members, generally moist curing is restored in order to prevent shrinkage until the time of transfer. This aspect has been considered in the recommendation made by the code (IS:1343) for the loss of prestress due to shrinkage of concrete and is obtained below:

ε_{cs} → Total residual shrinkage strain= 300×10^{-6} for pre-tensioning and

$$= \left[\frac{200 \times 10^{-6}}{\log_{10}(t+2)}\right] \text{ for post-tensioning.}$$

Where,

t → Age of concrete at transfer in days.

Then, the loss of stress $= \varepsilon_{cs} E_s$

Here, E_s → Modulus of elasticity of steel

Loss due to relaxation of stress in steel

Most of the codes provide for the loss of stress due to relaxation of steel as a percentage of initial stress in steel.

The BIS recommends a value varying from 0 to 90 N/mm^2 for stress in wires varying from 0.5 *fpu* to 0.8 *fpu*

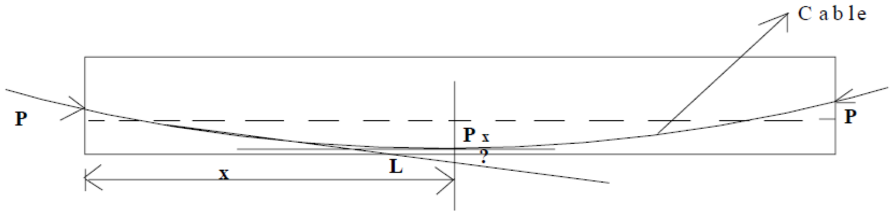
Where, *fpu* = Characteristic strength of pre-stressing tendon.

Loss of stress due to friction

The magnitude of loss of stress due to friction is of following types: -

a. Loss due to curvature effect, which depends upon the tendon form or alignment, which generally follows a curved profile along the length of the beam.

b. Loss of stress due to wobble effect, which depends upon the local deviations in the alignment of the cable. The wobble or wave effect is the result of accidental or unavoidable misalignment, since ducts or sheaths cannot be perfectly located to follow a predetermined profile throughout the length of beam.



$$P_x = P_o e^{-(\mu\alpha + kx)}$$

Where,

P_o → The Prestressing force at the jacking end.

μ →Coefficient of friction between cable and duct

α →The cumulative angle in radians through the tangent to the cable profile has turned between any two points under consideration.

, k→ Friction coefficient for wave effect.

The IS code recommends the following value for *k*

k = 0.15 per 100 m for normal condition

= 1.5 per 100 m for thin walled ducts where heavy vibration are encountered and in other adverse conditions.

Loss due to Anchorage slip

The magnitude of loss of stress due to the slip in anchorage is computed as follows: -

If

Δ = Slip of anchorage, in mm

L = Length of the cable, in mm

A = Cross-sectional area of the cable in mm^2

E_S = Modulus of elasticity of steel in N/mm^2

P = Prestressing force in cable in N

Then $\Delta = PL/AE_S$

Hence, Loss of stress due to anchorage slip = $\frac{P}{A} = \frac{E_s \Delta}{L}$

Total loses allowed for in a design

It is a normal practice in the design of prestressed concrete members to assume the total loss of stress as a percentage of the initial stress & provide for this in the design computation. However, typical values of the total losses of the stress that could be encountered under normal conditions of work are recommended as follows:

The typical values for losses are as follows:-

Types Of Loss	Percentage Loss of stress	
	Pre- Tensioning	Post- Tensioning
Elastic shortening & bending of concrete	4	1
Creep of concrete	6	5
Shrinkage of concrete	7	6
Creep in steel	8	8
TOTAL	25	20

In thses recommendation, it is assumed that temporary over stressing is done to reduce relaxation, and to compensate for friction and anchorage losses.

If

f_{pe} = Effective stress in tendons after loss

f_{pi} = Stress in tendon at transfer

η = Reduction factor for loss of prestress

Then,

$$\eta = \frac{f_{pe}}{f_{pi}}$$

η = 0.75 for pretensioned members

= 0.80 for post-tensioned member

VIII. CONCLUSION

Prestress concrete structure is different from a convensional reinforcement concrete structure due to the application of an initial load on the structure prior to its use.

The prestressing of a structure is not the only instance of prestressing. The concept of prestressing existed before the applications in concrete.

A fully pre-stressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete.

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