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Analysis and Design of Pre-Tensioning and Post Tensioning Thesis Synopsis

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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 Ordinary Portland cement conforming to IS269 Portland slag cement conforming to IS455. But the slag content should not be more than 50%. Rapid hardening Portland cements conforming to IS8041. 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/m3 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/mm2 to 400 N/mm2. 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/mm2.

History and development of prestress of PSC:

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.

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

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.

That tension in spoke will nullify the applied compression.

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.

Forms of Prestressing Steel:

Wires:Prestressing wire is a single unit made of steel.

Strands: Two, three or seven wires are wound to form a prestressing strand.

Tendon: A group of strands or wires are wound to form a prestressing tendon.

Cable: A group of tendons form a prestressing cable.

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.

Nature of Concrete-Steel Interface

Bonded tendon:

When there is adequate bond between the prestressing tendon and concrete, it is called a bonded tendon. Pre-tensioned and grouted post-tensioned tendons are bonded tendons.

Unbonded tendon:

When there is no bond between the prestressing tendon and concrete, it is called unbonded tendon. When grout is not applied after post-tensioning, the tendon is an unbonded tendon.

Stages of Loading

The analysis of prestressed members can be different for the different stages of loading. The stages of loading are as follows.

1) Initial: It can be subdivided into two stages.

a) During tensioning of steel.

b) At transfer of prestress to concrete.

2) Intermediate: This includes the loads during transportation of the prestressed members.

3) Final: It can be subdivided into two stages.

a) At service, during operation.

b) At ultimate, during extreme events.

Advantages of Prestressing

The prestressing of concrete has several advantages as compared to traditional reinforced concrete (RC) without prestressing. A fully prestressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete.

The following text broadly mentions the advantages of a prestressed concrete member with an equivalent RC member. For each effect, the benefits are listed.

1) Section remains uncracked under service loads

Reduction of steel corrosion

- Increase in durability.

Full section is utilised

- Higher moment of inertia (higher stiffness)
- Less deformations (improved serviceability).

Increase in shear capacity.

Suitable for use in pressure vessels, liquid retaining structures.

Improved performance (resilience) under dynamic and fatigue loading.

2) **High span-to-depth ratios**

Larger spans possible with prestressing (bridges, buildings with large column-free spaces) Typical values of span-to-depth ratios in slabs are given below.

Non-prestressed slab	28:1
Prestressed slab	45:1

- For the same span, less depth compared to RC member.
- Reduction in self weight
- More aesthetic appeal due to slender sections
- More economical sections.

3) Suitable for precast construction

The advantages of precast construction are as follows.

- Rapid construction
- Better quality control
- Reduced maintenance
- Suitable for repetitive construction
- Multiple use of formwork

⇒ Reduction of formwork

• Availability of standard shapes.

4) The cross-section is utilized more efficiently in pre-stressed concrete as compared to reinforced concrete.

5) Pre stressed concrete allows for a longer span.

6) Pre-stressed concrete members offer more resistance against shear force.

7) Considering same depth of concrete member, a pre stressed concrete member is stiffer than the reinforced concrete member under working loads.

8) The use of higher strength concrete and high strength steel results in smaller cross-section.

Limitations of Prestressing:

Although prestressing has advantages, some aspects need to be carefully addressed.

- Prestressing needs skilled technology. Hence, it is not as common as reinforced concrete.
- The use of high strength materials is costly.
- There is additional cost in auxiliary equipments.
- There is need for quality control and inspection.
- Prestressed concrete sections are less fire resistant.

Types of Prestressing

Prestressing of concrete can be classified in several ways. The following classifications are discussed.

Source of prestressing force

This classification is based on the method by which the prestressing force is generated. There are four sources of prestressing force: Mechanical, hydraulic, electrical and chemical.

External or internal prestressing

This classification is based on the location of the prestressing tendon with respect to the concrete section.

Pre-tensioning or post-tensioning

This is the most important classification and is based on the sequence of casting the concrete and applying tension to the tendons.

Linear or circular prestressing

This classification is based on the shape of the member prestressed.

Full, limited or partial prestressing

Based on the amount of prestressing force, three types of prestressing are defined.

Uniaxial, biaxial or multi-axial prestressing

As the names suggest, the classification is based on the directions of prestressing a member.

Source of Prestressing Force:

Hydraulic Prestressing

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This is the simplest type of prestressing, producing large prestressing forces. The hydraulic jack used for the tensioning of tendons, comprises of calibrated pressure gauges which directly indicate the magnitude of force developed during the tensioning.

Mechanical Prestressing

In this type of prestressing, the devices includes weights with or without lever transmission, geared transmission in conjunction with pulley blocks, screw jacks with or without gear drives and wire-winding machines. This type of prestressing is adopted for mass scale production.

Electrical Prestressing

In this type of prestressing, the steel wires are electrically heated and anchored before placing concrete in the moulds. This type of prestressing is also known as thermo-electric prestressing.

External or Internal Prestressing:

External Prestressing:

When the prestressing is achieved by elements located outside the concrete, it is called external prestressing. The tendons can lie outside the member (for example in I-girders or walls) or inside the hollow space of a box girder. This technique is adopted in bridges and strengthening of buildings. In the following figure, the box girder of a bridge is prestressed with tendons that lie outside the concrete.

Internal Prestressing:

When the prestressing is achieved by elements located inside the concrete member (commonly, by embedded tendons), it is called internal prestressing. Most of the applications of prestressing are internal prestressing. In the following figure, concrete will be cast around the ducts for placing the tendons.

Pre-tensioning or Post-tensioning:

Pre-tensioning:

Pre-tensioning is accomplished by stressing wires or strands, called tendons, to predetermined amount by stretching them between two anchorages prior to placing concrete as shown in fig.1. the concrete is then placed and tendons become bounded to concrete throughout their length. After concrete has hardened, the tendons are released by cutting them at the anchorages. The tendons tend to regain their original length by shortening and in this process transfer through bond a compressive stress to the concrete. The tendons are usually stressed by the use of hydraulic jacks. The stress in tendons is maintained during the placing and curing of concrete by anchoring the ends of the tendons to abutments that may be as much as 200m apart. The abutments and other formwork used in this procedure are called prestressing bench or bed.

Post-tensioning:

The tension is applied to the tendons (located in a duct) after hardening of the concrete. The pre-compression is transmitted from steel to concrete by the anchorage device (at the end blocks).

The alternative to pre-tensioning is post-tensioning. In a post-tensioned beam, the tendons are stressed and each end is anchored to the concrete section after the concrete has been cast and has attained sufficient strength to safely withstand the prestressing force as shown in fig.2. in post-tensioning method, tendons are coated with grease or a bituminous material to prevent them from becoming bonded to concrete. Another method used in preventing the tendons from bonding to the concrete during placing and curing of concrete is to encase the tendon in a flexible metal hose before placing it in the forms. The metal hose is referred to as sheath or duct and remains in the structure.

Analysis of Prestress Member:

Basic assumption:

1) Concrete is a homogenous material.
2) Within the range of working stress, both concrete & steel behave elastically, notwithstanding the small amount of creep, which occurs in both the materials under the sustained loading.
3) A plane section before bending is assumed to remain plane even after bending, which implies a linear strain distribution across the depth of the member.

Analysis of prestress member:

The stress due to prestressing alone are generally combined stresses due to the action of direct load bending from an eccentrically applied load. The following notations and sign conventions are used for the analysis of prestress members.

PPrestressing force (Positive when compressive)

E - Eccentricity of prestressing force

M = Pe

A - Cross-sectional area of the concrete member

I - Second moment of area of the section about its centroid

Zt, Zb, - Section modulus of the top & bottom fibre respectively

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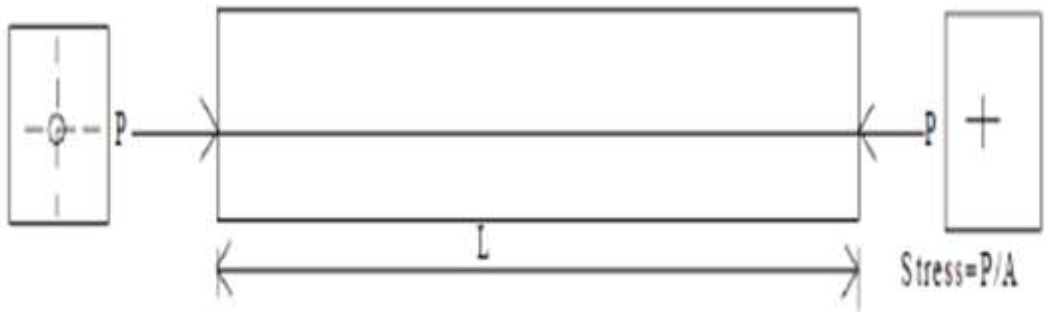
ftop, f bot=Prestress in concrete developed at the top & bottom fibres
yb yt, - Distance of the top & bottom fibre from the centroid of the section
r -Radius of gyration

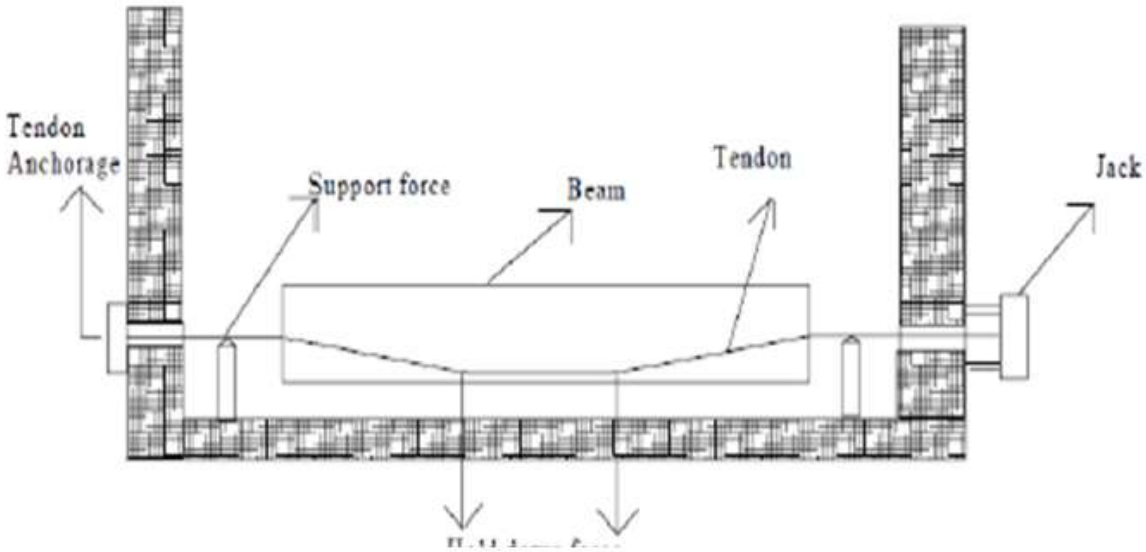
(i) Concentric tendon

In this case, the load is applied concentrically and a compressive stress of magnitude (P/A) will act throughout the section. Thus the stress will generate in the section as shown in the figure below.

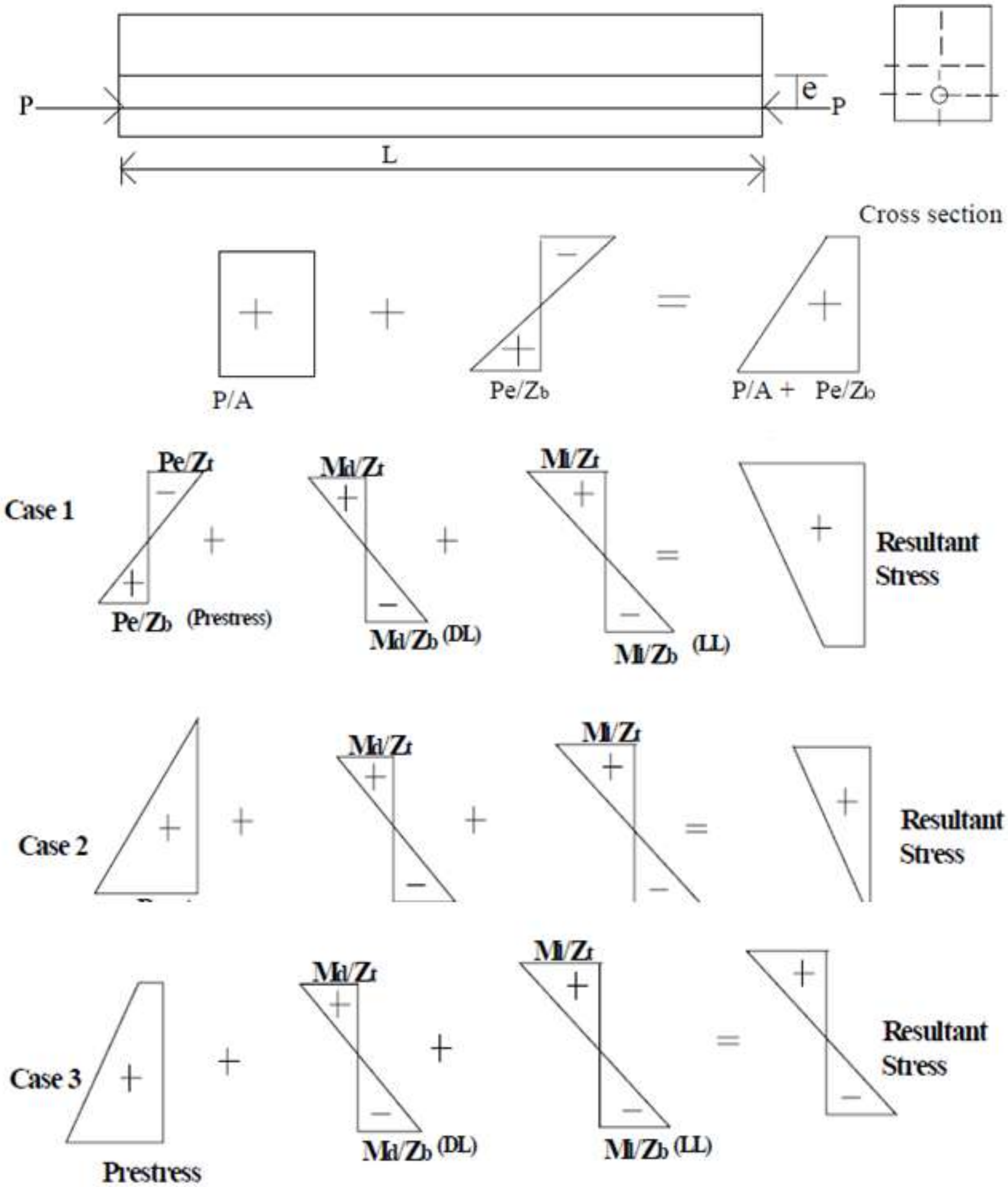


Concentric prestressing

(ii) **Eccentric tendon**



Thus the stresses developed at the top & bottom fibres of the beam can be written as:



LOSSESOFPRE-STRESS

Losses in Prestress

The initial prestressing concrete undergoes a gradual reduction with time from the stages of transfer due to various causes. The force which is used to stretch the wire to the required length must be available all the time as prestressing force if the steel is to be prevented from contracting. Contraction of steel wire occurs due to several causes, effecting reduction in the prestress. This reduction in the prestressing force is called loss in prestress. In a prestressed concrete beam, the loss is due to the following:

Types of losses in prestress

Pretensioning

During the process of anchoring, the stressed tendon tends to slip before the full grip is established, thus losing some of its imposed strain or in other words, induced stress. This is known as loss due to anchorage draw-in From the time the tendons are anchored until transfer of prestressing force to the concrete, the tendons are held between the two abutments at a constant length. The stretched tendons during this time interval will lose some of its induced stress due to the phenomenon known as relaxation of steel. As soon as the tendons are cut, the stretched tendons tend to go back to their original state, but are prevented from doing so by the interfacial bond developed between the concrete and the tendons.

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

Post-tensioning

The tendons are located inside ducts, and the hydraulic jacks held directly against the member. During stressing operation, the tendons tend to get straightened and slide against the duct, thus resulting in the development of a frictional resistance. As a result, the stress in the tendon at a distance away from the jacking end will be smaller than that indicated by the pressure gauge mounted on the jack. This is known as loss due to friction.

With regard to elastic shortening, there will be no loss of prestress if all the tendons are stressed simultaneously because the prestress gauge records the applied stress after the shortening has taken place.

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.

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

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

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

Therefore, Loss of stress in steel = $\alpha_e f_c$

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:

1. 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. Consequently, the total residual shrinkage strain will be larger in pretensioned members after transfer of prestress in comparison with post-tensioned members, where a portion of shrinkage will have already taken place by the time of transfer of stress. 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:

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$\varepsilon_{cs} \rightarrow$ 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,

$t \rightarrow$ Age of concrete at transfer in days.

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

Here, $E_s \rightarrow$ Modulus of elasticity of steel

Loss due to creep of concrete

The sustained prestress in the concrete of a prestress member results in creep of concrete which is effectively reduces the stress in high tensile steel.

The loss of stress in steel due to creep of concrete can be estimated if the magnitude of ultimate creep strain or creep-coefficient is known.

1. Ultimate Creep strain method

The loss of stress in steel due to creep of concrete = $\varepsilon_{cc} f_c E_s$

Where, $\varepsilon_{cc} \rightarrow$ Ultimate creep strain for a sustained unit stress.

[illegible]l of steel

2. Creep Coefficient Method

$$\text{Creep coefficient} = \frac{\text{Creep strain}}{\text{Elastic strain}} = \frac{\varepsilon_c}{\varepsilon_e}$$

Where, $\phi \rightarrow$ Creep Coefficient

$\varepsilon_c \rightarrow$ Creep strain

$\varepsilon_e \rightarrow$ Elastic strain

$\alpha_e \rightarrow$ Modular ratio

$f_c \rightarrow$ Stress in concrete

$E_c \rightarrow$ Modulus of elasticity of concrete

$E_s \rightarrow$ Modulus of elasticity of steel

$$\left. \frac{f_c}{E_c} \right) E_s = \phi f_c \alpha_e$$

The magnitude of creep coefficient varies depending upon the humidity, concrete quality, duration of applied loading and the age of concrete when loaded. The general value recommended varies from 1.5 for watery situation to 4.0 for dry conditions with a relative humidity of 35%.

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/mm2 for stress in wires varying from

Where, $f_{pu} \rightarrow$ Characteristic strength of pre-stressing tendon.

$0.5 f_{pu}$ to $0.8 f_{pu}$

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.

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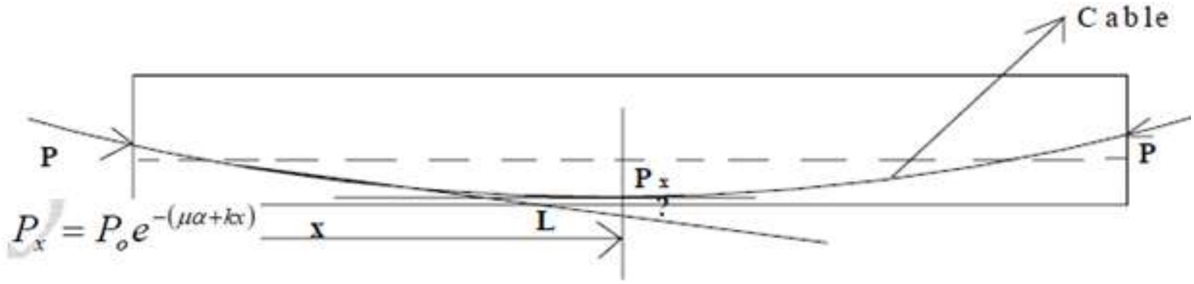

Where,
Po -The Prestressing force at the jacking end.
M - Coefficient of friction between cable and duct
A - The cumulative angle in radians through the tangent to the cable profile has turned between any two points under consideration.
k- Friction coefficient for wave effect.
The IS code recommends 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 mm2
Es - Modulus of elasticity of steel in N/mm2
P -Prestressing force in the cable, in N
Δ = PL /A Es
Hence, Loss of stress due to anchorage slip=

$$\frac{P}{A} = \frac{E_s \Delta}{L};$$

Pressure line or thrust line :
In prestress, the combined effect of prestressing force & external load can be resolved into a single force. The locus of the points of application of this force in any structure is termed as the pressure line or thrust line. The load here is such that stress at top fiber of support & bottom fiber of the central span is zero.
Let us consider a beam which is prestressed by a force P at a constant eccentricity e. The magnitude of load & eccentricity is such that the stress at the bottom fiber at the mid span is zero. It is possible if the eccentricity is e = d/6 it can be seen from the resultant stress distribution at the support due to a prestressing force P at an eccentricity e = d/6 & bending moment zero is equivalent to a force P applied at an eccentricity e = d/6. At quarter span the resultant stress distribution due force P applied at an eccentricity e = d/12. Similarly, at mid span the resultant stress distribution due to a force P at an eccentricity e = d/6 & BM due to uniformly distributed load is equivalent to a force P applied at an eccentricity e = -d/6.

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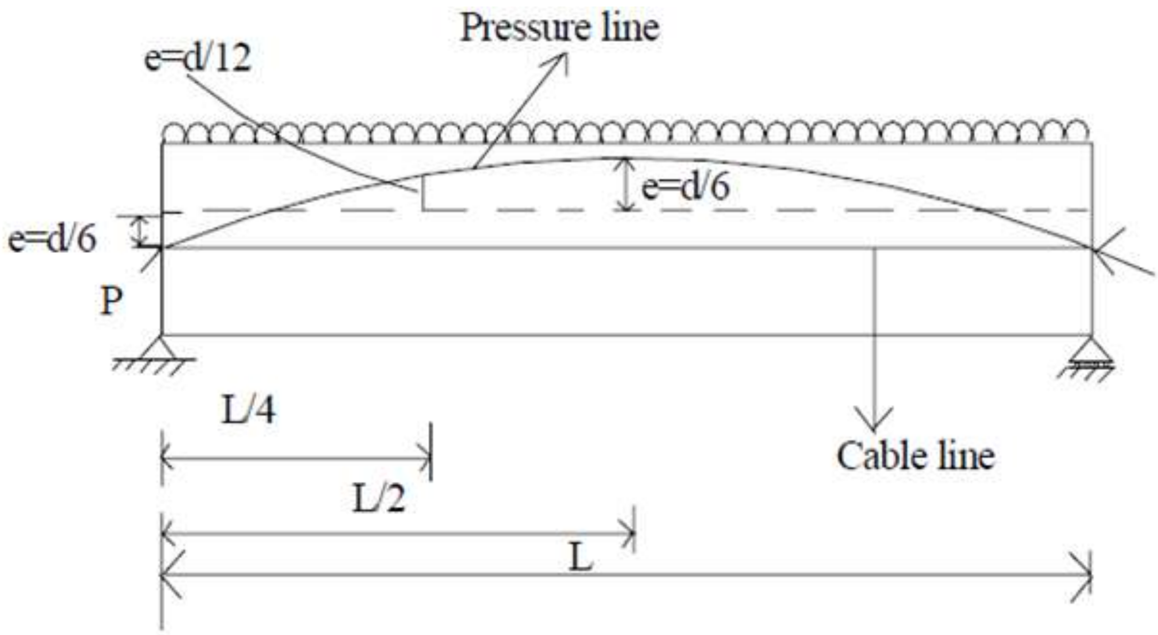

Deflection
Introduction

- The effect of deflection in a structure varies according to the use of the structure.
- Excessive deflections may lead to sagging floors, to roof that do not drain properly, to damage partitions and finishes, to the creation of pools of water on road surface of bridges, and to other associated troubles

The total deflection is a resultant of the upward deflection due to prestressing force and deflection due to prestressing prestressing force and downward deflection due to the gravity loads.

Only the flexural deformation is considered and any shear deformation is neglected in the calculation of deflection.

Deflection of Prestressed concrete Beam:

1. Fully prestressed concrete members (class 1 and class 2) remain crack-free under service load
2. Can be assumed linearly elastic
3. Two types of deflection

– Short -term or instantaneous
– Long

4. Short-term deflection occurs immediately upon the application of a load (caused by elastic deformation of the concrete in response to loading)
5. The short term deflection at transfer is due to the initial prestressing force and self initial prestressing prestressing force and self-weight without weight without the effect of creep and shrinkage of concrete.
6. Long-term deflection takes into account the long-term shrinkage and creep movements (time-dependent)
7. The long term deflection under service loads is due to the effective prestressing force and the total gravity loads.
8. The deflection of a flexural member is calculated to satisfy a limit state of serviceability
9. Due to external loads
10. Due to prestressed force
11. Can use various methods to calculate deflections

Double Integration Method (McCauley)
Moment Area Method
Conjugate Beam Method
Principle of Virtual Load

Deflection due to Prestressing Force

- The prestressing force causes a deflection only if the CGS is eccentric to the CGC if the CGS is eccentric eccentric to the CGC.
- Deflection due to prestressing force is calculated by the load by the load-balancing method.

<u>Scope</u>

The subject of durability is extremely broad, and as a result a broad scope of research was developed for Project 0-1405. Based on the project proposal and an initial review of relevant literature

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Performed by West33, the project scope and necessary work plan were defined. The main components are

1) 1 Extensive Literature Review
2) Survey of Existing Bridge Substructures Inspection Reports (BRINSAP)
3) Long-Term Corrosion Tests with Large-Scale Post-Tensioned Beam and Column Elements
4) Investigation of Corrosion Protection (near joints) for Internal Prestressing Tendons in Precast Segmental Bridges
5) Development of Improved Grouts for Post-Tensioning
6) Development of recommendations and design guidelines for durable bonded post-tensioned bridges

Problems Encountered Around the World: The Ghent Workshop

In November 2001, engineers from many countries gathered at Ghent University, under the sponsorship of fib and IABSE, to discuss the "Durability of Post-Tensioning Tendons." The findings are containing in the fib-IABSE Technical Report, Bulletin 15.The problems reported from different countries lead to similar findings. Zivanovic et al.51 succinctly summarized the conference findings with respect to the inventory and condition of post-tensioning bridges as follows:

a) Design Defects:

• Lack of waterproofing;
• Lack of sealing behind tendon anchorages;
• Construction resulting in a large number of unprepared construction joints, which could give rise to cracking due to restrained shrinkage;
• Use of unprotected transverse tendons in grooves in the deck;
• Use of sheaths made from bitumen-coated Kraft paper wrapped around the tendons which made grouting impossible;
• Low ratio of rebar/total steel, as low as zero for longitudinal construction joints along the length of the deck between the beams and slabs;
• Large numbers of tendons per span in older structures with deck anchorages increasing the number of points of possible water ingress;
• Use between 1950 and 1970 of prestressing steel which was susceptible to stress corrosion which gave rise to the possibility of brittle fracture;
• Lack of provision for drainage
• Leaking expansion joints;
• Insufficient concrete cover over the reinforcement, resulting in corrosion of the reinforcement and spalling of the concrete giving easier access to the prestressing tendons for aggressive agents.

b) Construction defects

The main defects leading to corrosion are poor waterproofing, incomplete grouting of the prestressing ducts and poor sealing of end anchorages.

Although concrete has generally performed well in older structures, there may be areas where poor workmanship has given rise to honeycombing or shrinkage cracking. The most common location are the soffits of flanges where concreting has been made difficult by the congestion of ducts or where there has not been proper compaction, resulting in large areas where spalling may allow aggressive agents to penetrate.

During the workshop, Godart3 also mentioned that "…When …external tendons…are in a wet atmosphere, generally due to bad construction details (lack of ventilation, absence of waterproofing, non tight inspection access…), wire failures caused by corrosion occur and the durability of the tendons is lowered."

From Japan, Mutsuyoshi4 reported that internal post-tensioned concrete structures with cement grouting have been forbidden by the Japan Highway Public Corporation, because bad quality of grouting after construction has been found in many bridges. Now, almost all new prestressed concrete structures are being constructed using fully external tendons using transparent sheath with grouting.

FACTORS AFFECTING THE DURABILITY OF POST-TENSIONED CONCRETE STRUCTURES

Exposure Conditions

There are four general environments where concrete structure durability may be a concern: coastal exposure, freezing exposure, and aggressive soils. These exposures may occur singly or in combination.

Coastal Exposure

Coastal exposures are one of the most severe environments for concrete structures. This is particularly true for structural components located directly in the seawater, as in the case of bridge substructures. Seawater contains dissolved salts which affect the durability of concrete. The most prevalent salts in order of quantity are sodium, magnesium and potassium chlorides and magnesium, calcium and potassium sulfates. These salts provide sources of chlorides and sulfates which can lead to corrosion of reinforcement and sulfate attack on concrete. To a lesser extent, these salts also provide a source of alkalis which may lead to expansive alkali-aggregate reactions if reactive aggregates are present. There are four main exposure zones for a structure in a coastal exposure: atmospheric zone, splash zone, tidal zone and submerged zone.

Freezing Exposure

Environments where structures may be exposed to freezing temperatures may lead to freeze-thaw damage of concrete. A secondary effect is that the use of deicing chemicals in freezing exposures can exacerbate freeze thaw damage and may lead to corrosion of steel reinforcement if the deicing agents contain chlorides.

II. CONCLUSION & IMPLEMENTATION RECOMMENDATIONS

STUDIES

Grout studies generated the following findings for immediate implementation:

Post-Tensioned Tendons with Small Rises

For post-tensioned tendons with a rise less than 5 meters, the present TxDOT standard grout should be replaced by:

• 0.35 water-cement ratio, 30% cement weight replacement fly ash (class C), and 4 ml/kg Super plasticizer (similar and equal to Rheo build 1000)

This grout is recommended for situations requiring a high resistance to corrosion without extreme bleed conditions (vertical rise of less than 1 meter). This grout may also be appropriate for larger vertical rises
(1-5 m) but field testing should be performed on a case by case basis.

Post-Tensioned Tendons with Large Rises

For post-tensioned tendons with large rises (5-38 m), the present TxDOT standar grout should be replaced by:

• 0.33 water-cement ratio, 2% anti-bleed admixture (similar and equal to Sikament 300 SC)

This grout is recommended for situations requiring a high resistance to bleed (vertical rises up to 38 m) along with good corrosion protection. The maximum vertical rise recommended was based on results of the Gelman pressure test. The grout was not actually tested in a 38 m vertical rise.

DIRECTIONS FOR FUTURE RESEARCH

After the research results had been summarized, it is concluded that post-tensioning in concrete structures can provide enhanced durability, besides the well known structural and economical benefits. However, to ensure that the post-tensioning system is well protected against corrosion or deterioration, further research is needed in some specific areas. The authors recommend additional testing in the following fields:

- Use of encapsulated and electrically isolated systems
- Use of improved grouts for post-tensioning and better grouting procedures
- Use of post-tensioning duct couplers
- Development of better splice systems for galvanized ducts that might be used in non-aggressive environments.
- Use of impermeable surface membranes
- Development of better non-destructive methods for determining corrosion activity within post-tensioned concrete members.
- Use of improved concrete mix designs
- Use of improved strand or bar materials

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