Prestressed Concrete Structures

UNIT - I

Introduction :

Q) What is meant by Prestressed Concrete. (2m)

Q) What is the basic principle of Prestressed concrete (2m).

Prestressed Concrete :

Prestressed concrete is basically a concrete in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting from external loads are counteracted to a desired degree. In RCC members, the prestress is commonly introduced by tensioning of the steel reinforcement (or) tendons.

Q) Write a short notes on Historical development of Prestressed Concrete (5m).

Historical Development of Prestressed Concrete :

→ The earliest examples of wooden barrel construction by force fitting of metal bands and shrink fitting of metal tyres (or) rings on wooden wheels indicate that the art of prestressing has been practised from ancient times

→ In 1886, Jackson of San Francisco applied prestress to concrete pavements by tensioning the reinforcing rods set in sleeves.

→ In 1888, Dohring of Germany manufactured slabs and small beams using embedded tensioned wires in concrete to avoid cracks.

→ In 1896, Mandl, an Austrian Engineer put forward the idea of prestressing to counteract the stresses due to loads

→ In 1907, M. Koenen, of Germany further developed the subject by reporting on losses of prestress due to elastic shortening of concrete.

→ In 1908, Steiner of USA, explained the importance of losses in prestressing due to shrinkage of concrete.

→ In 1928, the use of unbonded tendons was first demonstrated by Dischinger, in the construction of girder type bridge.

→ In 1928, Freyssinet demonstrated the advantages of using high strength steel and concrete to account for various losses of prestress.

→ The development of vibration techniques for the production of high strength concrete and the invention of the double-acting jack for stressing high tensile steel wires are the most significant contributions by Freyssinet between 1928 and 1933.

→ The use of prestressed concrete spread rapidly from 1935 onwards. Many long span bridges were constructed in USA and Europe. During the last 60 yrs, PSC has been widely used for construction of long span bridges, industrial shell roofs, marine structures, nuclear pressure vessels, water-retaining structures, transmission poles, railway sleepers and other structures.

In the words of Guyon: "There is probably no structural problem to which prestress cannot provide a solution and often a revolutionary one. Prestress is more than a technique; it is a general principle".

Q) What is the need for the development of PSC. (3m)

Need for the development of PSC:

→ The tensile strength of plain concrete is only a fraction of it's compressive strength.

→ The problem of concrete, being deficient in tensile strength is the driving force for the development of "Reinforced Concrete".

→ The development of early cracks in Reinforced concrete due to incompatibility in the strains of steel and concrete was the main behind the development of Prestressed Concrete.

Q) What are the general principles of PSC. (3m)

General Principles of PSC:

→ The application of permanent compressive stress to a material like concrete, which is strong in compression but weak in tension, increases the apparent tensile strength of that material

→ The subsequent application of tensile stress must first nullify the compressive prestress.

→ The internal stresses of a suitable magnitude are introduced based on the resulting stresses (to be counteracted) from the external loads

→ The prestress is commonly introduced by tensioning the high tensile steel tendons through the concrete.

→ The transfer of prestress from steel to the concrete takes place due to friction (or) and contraction.

Q) What are the advantages of Prestressed Concrete. (5m)

Advantages of Prestressed Concrete:

→ Prestressed concrete offers great technical advantages in comparision with other forms of construction, such as RCC and Steel.

→ In case of fully prestressed members, which are free from tensile stresses under working loads, the cross section can be effectively used than RCC. (i.e, no cracks under loads).

→ Permanent dead loads can be counteracted by increasing the eccentricity of the prestressing force, thus effecting savings in use of materials.

→ PSC members possess improved resistance to shearing force, due to compressive prestress.

→ A prestressed concrete flexular member is stiffer under working loads, than a reinforced concrete member of same depth.

→ The use of high-strength concrete and steel in PSC members results in lighter and slender members than RCC.

→ High strength concrete and freedom from cracks makes PSC members more durable than RCC members under adverse environmental conditions

→ PSC improves the ability of members to absorb energy under impact loads

→ Long span members are possible due to increased strength.

→ Factory made precast members are possible, which will have better quality control.

→ Precast PSC members also reduces time of construction.

→ Suitable for mass production of precast (PSC) members.

→ Fatigue strength of PSC is comparatively better than that of other materials, due to small stress variations in prestressing steel.

Q) What are the limitations of Prestressed Concrete. (3m)

(or)

What are the Disadvantages of Prestressed Concrete. (3m)

Limitations of Prestressed Concrete:

1) The availability of skilled labour is scanty.
2) The availability of experienced builders & engineering in PSC members is scanty.
3) Initial equipment cost is very high.
4) The unit cost of high strength material will be high.
5) Uneconomical for short spans and lighter working loads.

Materials for Prestressed Concrete:

Q) What is the need for High-Strength steel and Concrete in making prestressed concrete member, explain briefly. (5m)

Need for High-Strength steel and Concrete:

The significant observations which resulted from the pioneering research on prestressed concrete were:

1) Necessity of using high-strength steel and concrete.
2) Recognition of losses of prestress due to various causes.

→ The early attempts to use mild steel in prestressed concrete were not successful, as working tensile stress of 120 N/mm² in mild steel is more (or) less completely lost due to elastic deformation, creep & shrinkage of concrete

→ The normal loss of prestress in steel is generally about 100 to 240 N/mm².

In order to have sufficient prestress after losses, the intial stress in steel must be very high, about 1200 to 2000 N/mm².

→ These high stress ranges are possible only with the use of high strength steel.

→ High strength concrete is necessary in prestressed concrete, as the material offer high resistance in tension, shear, bond and bearing.

→ In the zone of anchorages, the bearing stresses are higher, therefore high strength concrete is necessary.

→ High strength concrete is less liable to shrinkage cracks, has higher modulus of elasticity and smaller creep strain, resulting in a smaller loss of prestress.

→ High strength concrete also reduces cross-sectional dimensions of members. With a reduced dead weight of material, longer spans becomes possible techincally and economically.

Q) What are the different forms of Prestressing steel used in prestressed concrete members, discuss briefly.

Forms of Prestressing Steel:

→ High strength steel is used for making prestressing the concrete member. It is an alloy of iron, carbon, manganese and optional materials

→ In addition to prestressing steel, conventional non prestressed steel i.e, reinforcement is used for flexure capacity, shear capacity, temperature and strinkage requirements.

Various forms of prestressing steel are as follows:

1) Wires:

A prestressing wire is a single unit made of steel. The nominal diameters of the wires are 2.5, 3, 4, 5, 7 and 8 mm.

There are two types of wires.

1) Plain wire : No indentations (marks) on the surface.

2) Indented wire : There are circular (or) elliptical indentations on the surface.

2) 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 other wires.

3) Tendons :

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

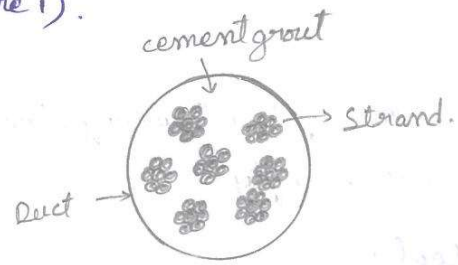


Figure 1 : Cross Section of Typical Tendon

4) Cables :

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

5) Bars :

A tendon can be made up of steel bars. 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.

Q) Discuss briefly about different types of Prestressing steel and treatment ~~their~~ processes (10 m)

(see page 7, for alternate answer)

Types of Prestressing Steel :

The steel is treated to achieve the desired properties. The ~~following are the~~ types of prestressing steel are based on treatment processes, which are.

1) Cold Working (or) 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.

2) Stress relieving :

The stress relieving is done by heating the strand to about 350°c and cooling slowly. This reduces the plastic deformation of the steel after the onset of yielding and increases the yield tensile strength.

3) Strain Tempering for low relaxation :

This process is done by heating the strand to about 350°c while it is under tension. This also reduces the plastic deformation after the onset of yielding. In addition, the relaxation of stress is reduced.

IS : 1343 - 1980 the material properties of steel in Section 4.5.

The following are the types of steel allowed for prestressing.

(1) Plain ~~and~~ cold drawn stress relieved wire conforming to IS : 1785, Part 1, "Specification for Plain Hard Drawn Steel Wire for Prestressed Concrete, Part 1 : Cold Drawn Stress Relieved Wire".

(2) Plain as-drawn wire confirming 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 confirming to IS : 6003, "Specification for Indented Wire for Prestressed Concrete.

(4) High Tensile steel bar confirming to IS : 2090, "Specification for High Tensile Steel Bars used in Prestressed Concrete".

(5) Uncoated stress relieved strand confirming to IS : 6006, "Specification for Uncoated Stress Relieved Strand for Prestressed Concrete".

Characteristics of High Strength Concrete

Q) Discuss briefly about the a) High-Strength Concrete Mixes (10 m)
b) Strength requirements of High Strength Concrete

a) **High Strength Concrete Mixes:**

→ Prestressed concrete requires concrete which has high compressive strength at early ages, with comparatively higher tensile strength than ordinary concrete

→ Low shrinkage, Minimum Creep, High Value of Young's modulus, durability, impermeability and abrasion resistance are generally the desired characteristics for prestressed members, which are highly influenced by strength of concrete.

→ With the development of vibration techniques, it became possible to produce, high strength concretes having cube compressive strength in the range of 30 - 70 mm^2 at 28 days.

→ Recent developments in the field of concrete mix design have indicated that it is now possible to produce even Ultra high strength concrete with 28 days cube compressive strength ranging from 70 - 100 N/mm^2.

→ High-strength concrete mixes can be designed by using any of the following established methods:

1) Erntroy and Shacklock's empirical method.
2) American Concrete Institute's mix design procedure for no slump concrete.
3) British D.O.E method
4) Indian Standard code method. (IS : 10262)

→ The Indian standard code IS:1343 stipulates that only controlled concrete should be used for prestressed concrete construction.

→ IS:1343 specifies that not more than 5 % of the test results should fall below the 28 days characteristic compressive strength.

b) Strength requirements of High Strength Concrete :

→ The minimum 28-day cube compressive strength prescribed in the Indian Standard code IS : 1343 is as follows

* 30 N/mm² for Post-tensioned members
* 40 N/mm² for Pre-tensioned members.

→ The ratio of standard cylinder strength to cube strength may be assumed as 0.8 in the absence of any relevent test data.

→ A minimum cement content of 300 to 360 kg/m³ is prescribed mainly to cater durability requirements.

→ For high strength, the water content should be as low as possible with due regard to adequate workability and ease of compaction.

→ It is general practice to adopt vibration to achieve thorough compaction of prestressed concrete.

→ To avoid excessive shrinkage, the code prescribes that the cement content should preferably not exceed 530 kg/m³.

Q) Write a short notes on Permissible Stresses in Concrete used for Prestressed members. (3m)

Permissible Stresses in Concrete :

→ The permissible compressive and tensile stress in concrete at the stage of transfer and service loads are defined in terms of the corresponding compressive strength of concrete at each stage.

→ The provisions made in the Indian standard code (IS : 1343) regarding the maximum allowable stresses are as shown below.

At Transfer of Pre stress ; Permissible values of.

→ Compressive stress varies from $\boxed{0.54 f_{ci}}$ to $\boxed{0.37 f_{ci}}$ for post tensioned & from $\boxed{0.51 f_{ci}}$ to $\boxed{0.44 f_{ci}}$ for pretensioned work based on strength of concrete

→ No permissible values given for Tensile stress.

At Service Load : Permissible values of

→ Compressive stress varies from $\boxed{0.41 f_{ck}}$ to $\boxed{0.35 f_{ck}}$ depending upon the strength of concrete

(2) → Tensile stress permissible are as follows.

Type 1 members : None

Type 2 members : Tensile stress not to exceed 3 N/mm².

Type 3 members : Hypothetical tensile stresses vary from 3.2 N/mm² for M-30 to a maximum of 7.3 N/mm² for M-50 grade concrete depending upon the limiting crack width.

Q) Discuss briefly about Shrinkage of Concrete in prestressed members. (5M)

Shrinkage of Concrete in prestressed members :

→ The shrinkage of concrete in prestressed members is due to the gradual loss of moisture which results in change in volume of cement gel.

→ The drying shrinkage depends on the aggregate type & quantity, relative humidity, water/cement ratio and the time of exposure.

→ The rate and amount of shrinkage of the structural members under ambient conditions will depend very much upon the ratio of surface area to volume of member, since loss of moisture occurs from surface.

→ Aggregates of rock types having high modulous of elasticity and low strains are more effective in restraining the contraction of the cement paste.

→ The commonly used aggregates in increasing order of effectiveness in restraining shrinkage are Sandstone, Basalt, Gravel, Granite, Quartz and Limestone.

→ As the phenomenon of shrinkage is time-dependent, only the total residual shrinkage strain is considered in computing loss of prestress.

→ The values of total residual shrinkage strain recommended in the IS code for the purpose of design are.

$$\varepsilon_{sh} = \boxed{3.0 \times 10^{-4}} \text{ for pretensioned members}$$

$$= \boxed{\frac{2.0 \times 10^{-4}}{\log(t+2)}} \text{ for post tensioned members}$$

where t = age of concrete in days at the time of transfer of prestress

→ A higher value of shrinkage is recommended in case of pretensioned members than posttensioned members since in pretensioned members total shrinkage from casting is to be considered, while in post-tensioned members only shrinkage after transfer of prestress is considered to calculate loss of prestress

→ Where light weight aggregates are used, the values of shrinkage should be increased by 50%.

Q) Discuss briefly about the creep of concrete in prestressed members.

Creep of Concrete:

→ The progressive inelastic strains due to creep in concrete member are likely to occur under the smallest sustained loads under room temperatures

→ Shrinkage and creep of concrete are basically of same origin, mostly due to migration of water in the capillaries of the cement paste.

→ Creep occurs due to externally applied stresses, whereas shrinkage occurs without externally applied stresses.

→ As the increase in strain under sustained stress is several times larger than the strain on loading, considerable importance is given for creep in prestressed concrete members.

→ The various factors influencing creep of concrete are relative humidity stress level, strength of concrete, age of concrete at loading, duration of stress, water/cement ratio and the type of cement and aggregate in concrete.

→ For stresses upto half of the crushing strength of concrete, the creep is directly proportional to the stress, but above this value it increases rapidly

→ Creep of concrete continues for a very long time, tending towards a limiting value after an infinite time under load.

→ The rate of creep decreases with time.

→ In a 20 yrs creep, 55 % occurs within first 3 months, while 76 % occurs in 1 yr.

→ The loss of prestress due to creep of concrete can be estimated if the magnitude of ultimate creep strain (or) creep coefficient are known

→ As recommended by IS: 1343, the values of creep coefficient are as follows

Time (Age of concrete)	Creep Coefficient (ϕ)
7 days	2.2
28 days	1.6
1 year	1.1

$$\text{Creep Coefficient } (\phi) = \frac{\text{Ultimate Creep Strain}}{\text{Elastic strain}}$$

Q) Discuss briefly about the Deformation Characteristics of Concrete. (5M)

Deformation Characteristics of Concrete:

→ The stress strain characteristics of concrete in compression is not linear, but for loads not exceeding 30 % of the crushing strength, the load-deformation behaviour may be assumed as linear.

→ The deformation characteristics of concrete are necessary for determining flexural strength and modulus of elasticity of concrete, which are required in computing deflections of prestressed members.

→ The short term modulus of elasticity, which is specified in most of the codes is secant modulus determined by experimental stress-strain curve of standard specimens under loads.

→ The modulus of elasticity of concrete increases with the increase of average compressive strength, but at a decreasing rate.

→ Several emperical formulae have been given by codes to compute secant modulus of elasticity (E_c), based on compressive strength of concrete.

→ According to the Indian Standard Code, IS: 1343, $\boxed{E_c = 5000\sqrt{f_{ck}}}$ N/mm²

→ Experimental investigations have indicated that, the present Indian Standard code provisions generally overestimate modulus of elasticity of High strength concretes. A simple relation of type $E_c = 750\, f_{cu}$ is suggested for secant modulus of elasticity of high strength concretes in the range of 40 to 45 N/mm².

Q) Write a short notes on Lightweight Aggregate in Prestressed Concrete. (5m)

Lightweight Aggregate Prestressed Concrete :

→ The use of light weight aggregate concrete for Prestressed concrete construction is well established since 1955.

→ The main advantage of lightweight concrete is reduction of self weight, thus minimizing the amount of concrete & steel.

→ The lightweight concrete becomes important in case of long span structures where dead load is the major part of design loads and also in the case of prestressed precast construction where heavy members are to be transported and erected.

→ At present light weight aggregate concretes of high strengths with 28 day cube compressive strengths of 30-50 N/mm² are being made.

→ The modulus of elasticity of light weight concrete is 50-55% of the modulus of elasticity of normal concrete and hence loss of prestress & elastic deformation is higher for lightweight prestressed concrete.

→ The unit weight of light weight concrete varies considerably between 1450 and 1750 kg/m³.

→ The creep and shrinkage of lightweight concrete is same as sand and gravel concrete with little variations

→ An excellent survey of the effective utilisation of light weight concrete in prestressed concrete structures is reported by Gerwick.

High Tensile Steel

Q.) Discuss briefly about High Tensile Steel types used in Prestressed Concrete. (10 m)

Types of High Tensile Steel :

→ For prestressed concrete members, the high tensile steel used generally consists of wires, bars (or) strands.

→ The higher tensile strength is generally achieved by marginally increasing the carbon content in steel in comparision with mild steel.

→ High Tensile steel usually contains 0.6 to 0.85 % carbon, 0.7 to 1 % manganese, 0.05 % of sulphur and phosphorous, traces of silicon.

Types of High Tensile Steel used in Prestressed Concrete :

1) Plain Cold drawn stress relieved wires :

→ The high Carbon steel ignot are hot rolled into rods and cold drawn through a series of dies to reduce the diameter and increase the tensile strength to form wires.

→ These should confirm to IS : 1785, Part 1, "Specification for Plain Hard (Cold) drawn Steel wire for Prestressed Concrete, Part 1 : Cold drawn Stress Relieved Wire".

→ The process of cold drawing through dies decreases the durability of the wires. So, the cold drawn wires are subsequently tempered to improve their properties.

→ Stress relieving (or) Tempering (or) Agening is done by heating the wires at 150 - 420°c and cooling slowly. This reduces plastic deformation and increases the yield tensile strength.

→ The Cold drawn stress relieved wires are generally available in nominal sizes of 2.5, 3, 4, 5, 7 and 8 mm diameter.

2) Plain As-Drawn Wires :

→ These are also cold hard drawn wires similar to Plain Cold drawn wires but not stress relieved.

→ These should confirm to IS : 1785, Part II, "Specification for Plain Hard Drawn steel Wire for Prestressed concrete, Part II, As: Drawn Wire.

3) Indented Cold Drawn Wire :

→ The hard-drawn steel wires which are indented are preferred for Pretensioned members because of their superior characteristics.

→ The specifications for indented wires are covered in IS : 6003, "Specification for Indented Wire for Prestressed Concrete."

→ The small diameter wires of 2 to 5 mm are mostly used to form strands comprising two, three (or) seven wires.

→ The helical form of twisted wires in the strand subsequently improves bond strength.

4) High Tensile Steel Bar :

→ The high tensile steel bars commonly employed in prestressing are manufactured in nominal sizes of 10, 12, 16, 20, 22, 25, 28 and 32 mm diameter.

→ These should confirm to IS : 2090, "Specification for High Tensile steel Bars used in Prestressed Concrete."

→ The ultimate tensile strength of bars does not depend on diameter much, since the high strength of the bars is due to alloying of materials.

5) Uncoated stress relieved strand :

→ Two and Three Ply strands are made up of 2 mm and 3 mm diameter individual wires, while 7-ply strands are twisted using wires of 2 to 5 mm diameter.

→ The nominal diameter of 7-ply strands vary from 6.3 mm to 15.2 mm

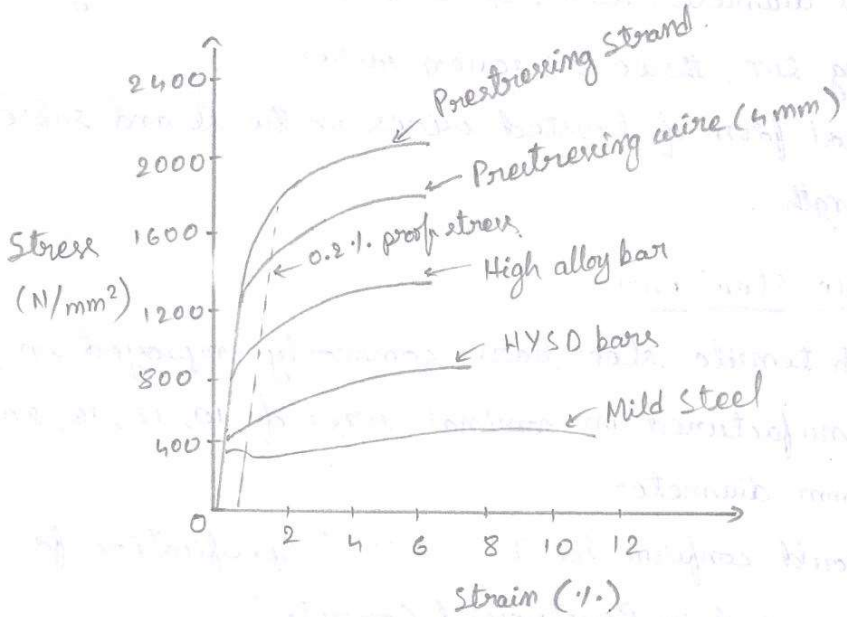
→ These should confirm to IS : 6006, "Specification for Uncoated Stress Relieved Strand for Prestressed concrete."

Q) Discuss briefly about the strength requirements of High Tensile Steel for prestressed concrete. (5m)

Strength Requirements:

→ The ultimate tensile strength of a plain hard drawn steel wire varies with it diameter. The tensile strength decreases with increase in the diameter of the wires.

→ The typical stress-strain characteristics of high tensile steel strands & wire are shown in figure below, in comparision with other steels.



→ Unlike ordinary mild steel, high tensile wires have no well defined yield point and it is necessary to refer to the proof stresses

→ The 0.2% proof stress for high tensile steel wires and bars should not be less than 85 and 80% respectively, of the minimum specified tensile strength.

→ Minimum plasticity is required be failure to have sufficient warning. The IS code specifies minimum percentage elongation varying from 2.5% for wires to 10% for bars. For strands it should not be less than 3.5% on a gauge length of not less than 600 mm.

→ IS: 1343 specifies the values of modulus of elasticity of high tensile wires, bars and strands as 210, 200 and 195 KN/mm^2 respectively.

Q) Write a short notes on a) Permissible Stresses b) Relaxation of stress, in prestressing steel. (5m)

a) Permissible Stresses in prestressing steel :

→ Tensile stresses in steel at the time of tensioning and after all possible losses are generally expressed as a fraction of the ultimate tensile strength (or) Proof stress

→ The specifications regarding allowable stresses in prestressed members at different stages, vary marginally based on various international codes.

→ As per IS : 1343, At the time of initial tensioning, prestress should not exceed 80 % of the characteristic tensile strength of tendons.

→ Final stress after allowing for all losses of prestress, should not be less than 45 % of the characteristic tensile strength of tendons.

b) Relaxation of stress in Steel :

→ When a high tensile steel wire is stretched and maintained at a constant strain, the initial force in the wire does not remain constant but decreases with time.

→ The decrease of stress in steel at a constant strain is termed as Relaxation.

→ In high tensile strength steels at stresses > 0.01 % proof stress, the relaxation of stress increases with increase of initial prestress

→ It has been observed that, in a 1000 hr. test, the loss of prestress due to relaxation from an initial stress of 70 % of the tensile strength is about the same as that over a period of 4 yrs from an initial stress of 60 % of the tensile strength.

→ The Indian standard codes for wires and bars prescribe the 1000 hr relaxation test with no relaxation exceeding 5 % of initial stress

→ The actual loss of stress due to relaxation of steel will be less than what we get in tests as there will be shortening of member due to other causes like creep, shrinkage, elasticity etc. Experiments shown that a preliminary over-stress of 5 - 10 % for 2 to 3 min. will reduce loss due to relaxation of stress.

Q) Discuss briefly about a) Stress Corrosion b) Hydrogen Embrittlement c) Durability, Fire resistance and Cover requirements for PSC members d) Protection of Prestressing Steel, Sheathing and Anchorages.

a) Stress Corrosion:

→ Stress corrosion results from the combined action of corrosion and static tensile stress in prestressed steel.

→ Stress corrosion results in sudden brittle fractures.

→ This type of attack is due to internal metallurgical structure, which is influed by composition, heat treatment and mechanical processing.

→ The heat treated wires are more prone to stress corrosion than cold drawn wires.

→ Other common types of corrosion in PSC are pitting corrosion & chloride corrosion.

→ Some of the important measures to protect steel from stress corrosion include protection from chemical contamination, protective coatings for steel and grouting of ducts immediately after post tensioning operations.

b) Hydrogen Embrittlement:

→ Atomic hydrogen is liberated as a result of the action of acids on high tensile steels. This penetrates into the steel surface, making it brittle and fracture prone under tension. This is called Hydrogen Embrittlement.

→ Use of high alumina cement and blast furnace slag cement which are rich in sulphides causes hydrogen embrittlement.

→ Minute traces of sulphur, which come in contact with steel wires in the presence of moisture, can drastically reduce their strength.

→ In order to prevent this, steel should be properly protected from acids. Protective coverings reduces the changes of contamination during transport

→ The wires should be protected from rain water and excessive humidity by storing them in dry conditions.

c) Durability, Fire Resistance and Cover Requirements for PSC members:

→ The alkaline environment of Portland cement generally protects steel from corrosion. However, the carbonation of hydrated cement gradually takes place from surface to the interior of concrete, thus reducing protection against corrosion. (i.e, Durability).

→ For this purpose, IS: 1343 provides a minimum clear cover of 20 mm for protected pre-tensioned members, while it is 30 mm or the size of cable (which ever is bigger) for post tensioned members.

→ If PSC members are exposed to an aggressive environment, these cover requirements are increased by 10 mm.

→ IS: 1343 also prescribes minimum cement content and maximum w/c ratio in concrete to ensure durability under specified conditions of exposure.

Exposure	Min. Cement Content Kg/m³	Maximum W/C ratio
Mild	300	0.65
Moderate	300	0.55
Severe	360	0.45.

→ Fire resistance is a measure of the ability of the structural member to withstand the effect of fire without reaching any limit states.

→ It is expressed in terms of time for failure in standard tests.

→ Indian standards provides for minimum cover to steel against fire along with various international codes.

d) Protection of Prestressing Steel, Sheathing and Anchorages:

→ To prevent deterioration, the unbonded tendons should be coated with non reactive materials like epoxy (or) Zinc (or) Zinc aluminium.

→ Non corrosive sheathing material like high density polyethylene is used.

→ The space b/n sheathing & duct can be filled with corrosion resisting materials like grease, wax (or) petroleum jelly.

→ External parts of anchorages and protecting cables should be covered by suitable casing.

→ The prestressing steel stored at site should also be protected by proper packaging films to gaurd against corrosion.

Objective type Questions :

1) The grade of concrete for prestressed members should be in the range of M-30 to M-60

2) High strength mixes should have w/c ratio in the range of 0.3 to 0.4

3) Creep of concrete in a structural member is due to Elasto-Plastic strain

4) Shrinkage of concrete is due to loss of moisture and drying of concrete.

5) Modulus of elasticity of concrete is expressed in terms of compressive strength

6) Target mean strength of concrete depends upon. characteristic strength of concrete

7) Workability of concrete is influenced significantly by Water/cement ratio

8) High tensile steel is basically high carbon steel.

9) In prestressed concrete members, the steel is under tension.

10) In axially prestressed members, concrete is under compression

11) Prestressing is possible by using high tensile steel.

12) Prestressing steel has an ultimate tensile strength nearly thrice that of mild steel reinforcements.

13) Prestressing is economical for members of long span.

14) Linear prestressing is adopted in beams.

15) Circular prestressing is advantageous in pipes and tanks

16) Prestressing wires in electric poles are concentric

Methods and Systems of Prestressing.

Q) What are the various methods of prestressing the concrete. (5m)

Methods of prestressing the concrete:

The various methods by which precompression is imparted to concrete are as follows.

1) Generation of compressive forces between the structural element and abutments using flat jacks. (for arches and pavements)
2) Development of hoop's compression in cylindrically shaped structures by circumferential wire winding. (for tanks and pipes)
3) Use of longitudinally tensioned steel embedded in concrete (pre tensioning) or housed in ducts (post tensioning), for beams and girders.
4) Use of the principle of distortion of a statically indeterminate structure either by displacement (or) by rotation of one part relative to the other.
5) Use of deflected structural steel sections embedded in concrete until the hardening of concrete.
6) Development of limited tension in steel and compression in concrete by using expanding cements (chemical prestressing)
7) Development of prestress by using heated tendons (Thermo Electric Prestressing)

Q) List various types of tensioning devices used in PSC (2m)

Q) Discuss briefly about different types of Tensioning Devices (5m)

Types of Tensioning Devices:

1) Mechanical Devices:

→ The mechanical devices generally used include weights with or without lever transmission, geared transmission, screw jacks, and wire-winding machines.

→ These devices generally used for mass production in factories.

2) Hydraulic Jacks :

→ Hydraulic jacks are extensively used as tensioning devices, as they produce large prestressing forces.

→ Several commonly used jacks are Freyssinet, Magnel, Gifford Udall and Baur - Leonhardt for the range of 5 - 100 tonnes. Forces in the range of 200 - 600 tonnes can also be developed using Baur - Leonhardt.

→ In most of the jacks, calibrated pressure gauges gives the magnitude of force developing during tensioning of wires

3) Electrical Devices :

→ Electrical devices have been successfully used in USSR, for tensioning of steel wires and deformed bars.

→ The steel wires are electrically heated and anchored before placing concrete in the moulds. This method is ofted called as "Thermo-electric prestressing".

4) Chemical method :

→ In chemical method, expanding cements are used and the degree of expansion is controlled by varying the curing conditions.

→ Since the expansive action of cement while setting is restrained by circumferencial wires, it induces tensile forces in tendons and compressive forces in concrete.
(stresses)

Q) What is pre-tensioning system. (3m). What are the principles of pre tensioning (2m)

Q) Explain with sketches 'Hoyer's Long line system of pre tensioning.

Pretensioning System :

→ In the pretensioning system, the tendons are first tensioned between rigid anchor-blocks cast on the ground (or) in a column (or) unit-mould-type pretensioning bed, prior to the casting of concrete in moulds.

→ The tendons comprising of individual wires or strands are stretched with constant eccentricity as shown in fig (a) or with variable eccentricity as shown in fig. (b). The concrete is cast around the stressed tendon.

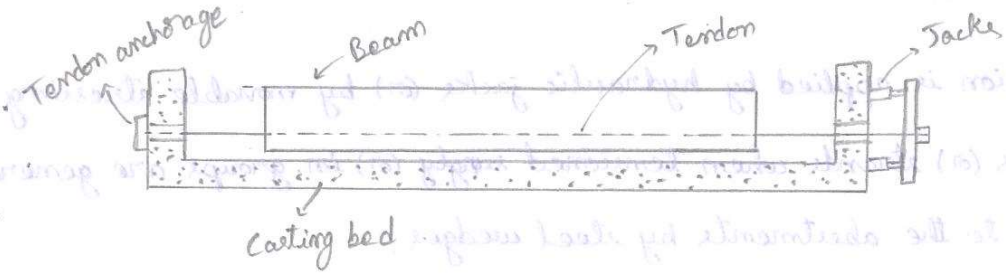


Fig. (a) Beam with straight tendon - Constant eccentricity

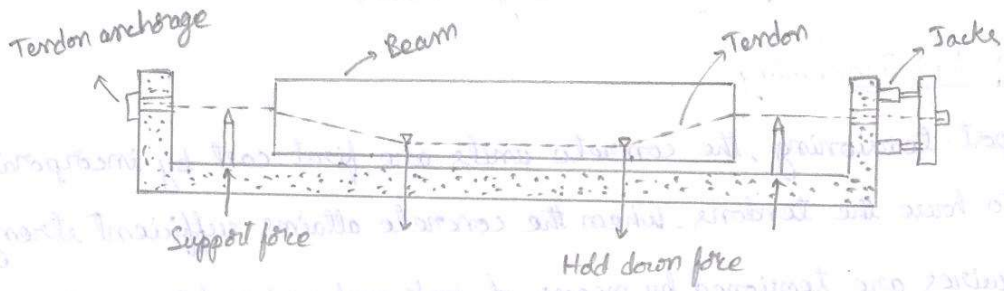


Fig. (b) Beam with variable tendon eccentricity

Principle of Pre-Tensioning:

When the concrete attains sufficient strength, the jacking pressure is released. The high tensile wires tend to shorten but are checked by the bond between concrete and steel. In this way prestress is transferred to the concrete by the bonding (mostly near the ends of the beam) and no special anchorages are required for pre-tensioned members.

Hoyer's long line system of pre-tensioning:

→ This method is generally used for mass production of pre-tensioned elements in a factory

→ In this method, tendons are stretched between two bulk heads several hundred metres apart so that a number of similar units may be cast along the same group of tensioned wires as shown in fig. 2.

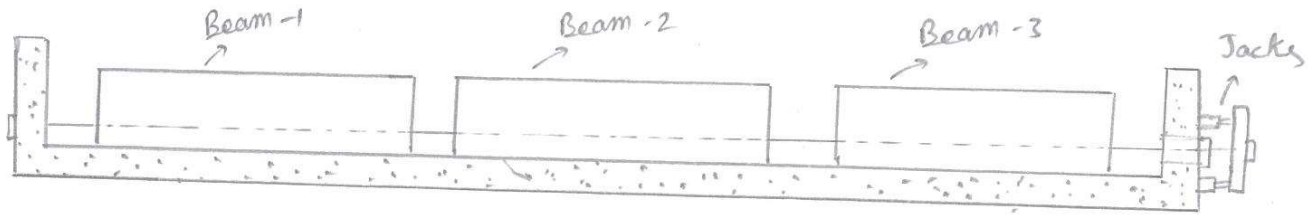


Fig. 2: Hoyer's long line system of pre-tensioning

→ The tension is applied by hydraulic jacks (or) by movable stressing machine. The wires (or) strands when tensioned singly (or) in groups are generally anchored to the abutments by steel wedges.

Q) What is the principles of Post-tensioning. (3 m)

Principle of Post Tensioning:

In post-tensioning, the concrete units 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 and anchored by wedges or nuts.

The forces are transmitted to the concrete by means of the end anchorages. When the cable is curved, the prestress is transmitted through the radial pressure. The space between the tendons and the duct is generally grouted after tensioning.

The following are the principles of anchoring post-tensioned tendons

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

Q) Discuss briefly about the following Post-tensioning anchorages

1) Freyssinet 2) Gifford Udall 3) Lee-McCall 4) Magnel-Blaton system (10 m)

1) Freyssinet System:

→ This system consists of a cylinder with a conical interior through which the high-tensile wires are passed and wedged by a conical plug with grooves to house the wires as shown in fig (3).

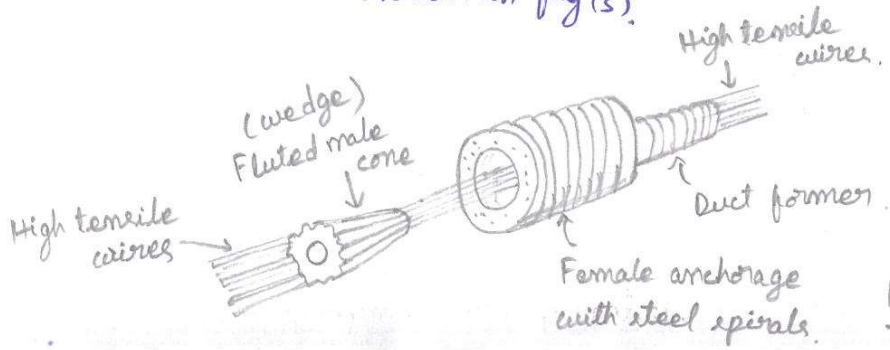


Fig (3) - Freyssinet anchorage

→ The main advantage of the Freyssinet system is that a large number of wires (or) strands can be simultaneously tensioned using the double acting hydraulic jack.

2) Gifford - Udall system:

→ This system consists of steel split-cone and cylindrical female cone anchorages to house the high tensile wires bearing against steel plates as shown in fig. 4.

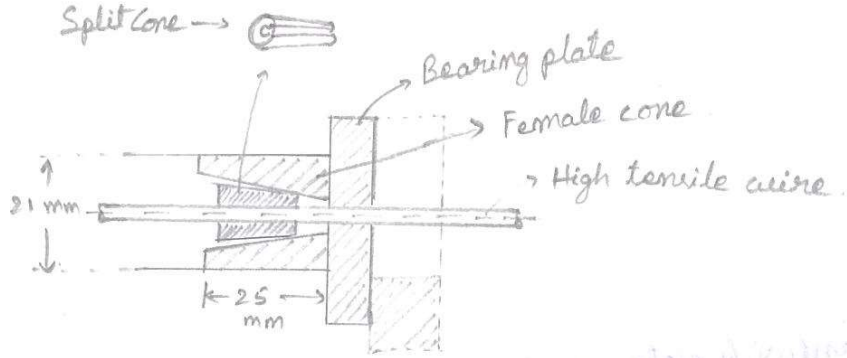


Fig. (4): Gifford Udall system

→ Each wire is tensioned separately and anchored by forcing a sleeve wedge into a cylindrical grip resting against a bearing plate.

→ The ducts are generally formed by metal sheaths cast into the concrete member.

3) Lee - McCall system:

→ In this system, the tendons comprising high tensile bars of diameter varying from 12 - 40 mm with threads near the ends are used.

→ After tensioning each bar is anchored by screwing a nut and washer tightly against the end plates as shown in fig. (5).

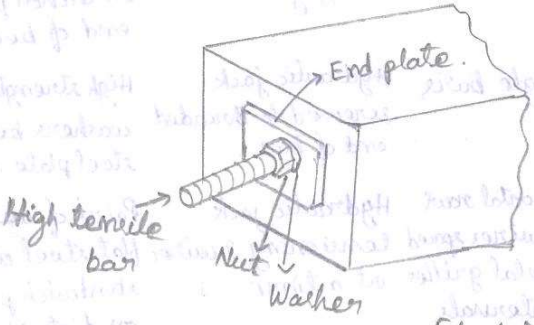
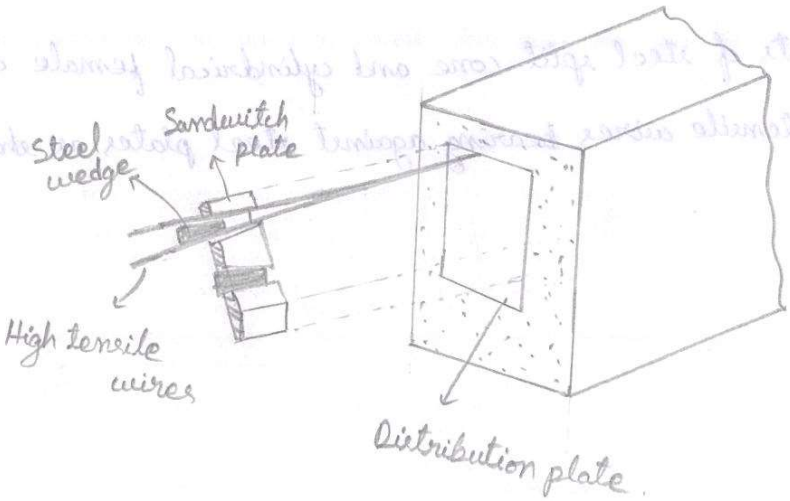


Fig. (5): Lee - Mc Call System

4) Magnel - Blaton System :

→ This system adopts metallic sandwich plates, flat wedges and a distribution plate for the anchoring the wires as shown in fig. (6).



→ Each sandwich plate can house up to four pairs of wires.

→ The distribution plate can be cast into the member at the desired location.

→ The no. of wires in the Magnel cable varies from 2 to 64.

Post Tensioning Systems

Post-tensioning system (country of origin)	Type of Tendon	Range of Force	Cable Duct	Arrangement of Tendons in Duct	Method of Tensioning	Type of Anchorage
Freyssinet (France)	Wires & Strands	Medium & Large	circular, formed by pneumatic tube (or) metal (or) plastic sheath	Annular, spaced by helical wire core.	Hydraulic jack, tensioning all wires at a time	Conical concrete wedge driven by jack into female core embedded at end of beam
Gifford Udall (Great Britain)	Wires	Small & Medium	circular, formed by pneumatic tube (or) steel rod.	Evenly spaced by perforated spacers.	Hydraulic jack tensioning wires singly.	Split conical wedge & bush to each wire, bearing on anchor plate cast into end of beam.
Lee-McCall (Great Britain)	Bars threaded at end.	Small, Medium, & Large	circular, formed by pneumatic tube (or) metal tube	single bars	Hydraulic jack screwed to threaded end of bar.	High strength nut and washers bearing on steel plate at end of beam
Magnel-Blaton (Belgium)	Wires	Small, Medium, & Large	Rectangular, formed by solid rubber core (or) metal sheath on cable.	Horizontal rows of 4 wires spaced by metal grilles at intervals	Hydraulic jack tensioning 2 wires at a time.	Pairs of wires held by flat steel wedges in sandwich plates, bearing on distribution plates

Q) What are the advantages and disadvantages of Pre-tensioning and Post-tensioning systems. (4 m)

→ Advantages of Pre-tensioning:

→ Pre tensioning is suitable for precast members produced in bulk.

→ In pretensioning large anchorage devices are not present.

Disadvantages of Pre-tensioning:

→ A prestressing bed is required for the pre-tensioning operation.

→ There is a waiting period in the prestressing bed, before concrete attains sufficient strength.

→ There should be good bond between concrete and steel over the transmission length.

→ Advantage of Post-tensioning:

→ Post tensioning is suitable for heavy cast-in-place members

→ The waiting period in the casting bed is less.

→ The transfer of pre-stress is independent of transmission length.

Disadvantages of Post-tensioning:

→ Anchorage devices are required.

→ Grouting equipment is required.

Objective Type Questions

1) In pre-tensioning system (c)

a) the member is cast first, followed by tensioning of high tensile wires

b) the member is prestressed by external anchors

c) the high tensile wires are tensioned before placing concrete in forms

2) Curved cables can be used in Post-tensioned member

3Q) In long line method of pretensioning (c)

a) Only one member can be cast

b) two members can be cast

c) Several members can be cast

4) In Post-tensioning system, the wires are tensioned against Hardened concrete

5) Freyssinet system is based on the principle of. Wedge action b/n steel & concrete

6) High tensile bars threaded at ends are used in Lee-McCall system.

7) Looping of high tensile tendons around the concrete is used in Baur-Leonhardt system

8) Tendon splices are required in Long span continuous members