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Design of Pre-Stressed Concrete T-Beams

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Abstract: ***The concept of pre-stressed concrete appeared in the year 1888. In this present engineering technology Durable and sustainable bridges play an important role for the socio-economic development of the nation. Owners and designers have long recognized the low initial cost, low maintenance needs and long life expectancy of pre-stressed concrete bridges. This is reflected in the increasing market share of pre-stressed concrete, which has grown from zero in 1950 to more than 55 percent today. This growth continues very rapidly, not only for bridges in the short span range, but also for long spans in excess of length which, here therefore, has been nearly the exclusive domain of structural steel. Many bridge designers are surprised to learn that precast, pre-stressed concrete bridges are usually lower in first cost than all other types of bridges coupled with savings in maintenance, precast bridges offer maximum economy. The precast pre-stressed bridge system offered two principal advantages: it is economical and it provides minimum downtime for construction. Pre-stressing is the application of an initial load on the structure so as to enable the structure to counteract the stresses arising during its service period. In this present project I am going to know the behavior of pre-stressed concrete beam, how they stressed, percentage of elongation, pressure applied to make beam stressed. This thesis completely going to do in a practical approach that on a major bridge having 299 mts span, 36 no's of PSC Beams & 8 no's of RCC Beams. My attempt is on PSC Beams, where the Beam post tensioning values, rate of elongation & behavior can be defined after stressing. The main code that I follow in this course is IS: 1343 – 2012. The title is Code of Practice for Pre-stressed Concrete. It is published by the Bureau of Indian Standards. Remembering that am expected to know IS: 456 - 2000 which is the Code of Practice for Structural Concrete. Some of the provisions of IS: 456 are also applicable for Pre-stressed Concrete.***

Keywords: PSC T-Beam, IRC: 1343-2012, IRC: 5-1998, IRC: 6-2000, IRC: 18-2000, IRC: 21-2000, IS: 6006-1980.

1. Introduction

Bridge is life line of road network, both in urban and rural areas. With rapid technology growth the conventional bridge has been replaced by innovative cost effective structural system. One of these solutions present a structural PSC system that is T-Beam. PSC T-beam, have gained wide acceptance in freeway and bridge systems due to their structural efficiency, better stability, serviceability, economy of construction and pleasing aesthetics. PSC beam design is more complicated as structure is more complex as well as needed sophisticated from work. In the place of PSC T-beam if we talk about RCC T- beam geometry is simple and does not have sophisticated in construction. Bridge design is an important as well as complex approach of structural engineer. As in case of bridge design, span length and live load are always important factor. These factors affect the conceptualization stage of design. The effect of live load for various span are varied. In shorter spans track load govern whereas on larger span wheel load govern. Selection of structural system for span is always a scope for research. Structure systems adopted are influence by factor like economy and complexity in construction. The 24 m span as selected for this study, these two factor are important aspects. In 24 m span, codal provision allows as to choose a structural system i.e. PSC T- beam. This study investigates the structural systems for span 24 m and detail design has been carried out with IRC loadings and IS code books. The choice of economical and constructible structural system is depending on the result.

2. Basic Concepts of Pre-Stressing

Pre-stressed concrete is basically 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 reinforced concrete members, the pre-stress is commonly introduced by tensioning the steel reinforcement. The earliest examples of wooden barrel construction by force-fitting of metal bands and metal tyres on wooden wheels indicate that the art of pre-stressing has been practiced from ancient times. The tensile strength of plain concrete is only a fraction of its compressive strength and the problem of it being deficient in tensile strength appears to have been the diving factor in the development of the composite material known as "reinforced concrete". The development of early cracks in reinforced concrete due to incompatibility in the strains of steel and concrete was perhaps the starting point in the development of a new material like "pre-stressed concrete". 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, because the subsequent application of tensile stress must first nullify the compressive pre-stress. In 1904 Freyssinet1 attempted to introduce permanently acting forces in concrete to exist the elastic forces developed under loads and this idea was later developed under the name of "pre-stressing".

3. Advantages of Pre-Stressed Concrete

Pre-stressed concrete offers great technical advantages in comparison with other forms of construction, such as reinforced concrete and steel. In the case of fully pre-stressed members, which are free from tensile stresses under working loads, the cross-section is more efficiently utilized when compared with a reinforced concrete section which is cracked under working loads. Within certain limits, a permanent dead-load may be counteracted by increasing the eccentricity of the pre-stressing force in a pre-stressed structural element, thus effecting savings in the use of materials. Pre-stressed concrete members possess improved resistance to shearing forces, due to the effect of compressive pre-stress. This reduces the principal tensile stress. The use of curved cables, particularly in long-span members, helps to reduce the shear forces developed at the support sections. A pre-stressed concrete flexural member is stiffer under working loads than a reinforced concrete member of the same depth. However, after the onset of cracking, the flexural behavior of a pre-stressed member is similar to mat of a reinforced concrete member. The use of high-strength concrete and steel in pre-stressed members results in lighter and slender members than is possible with reinforced concrete. The two structural features of pre-stressed concrete, namely high-strength concrete and freedom from cracks, contribute to the improved durability of the structure under aggressive environmental conditions. Pre-stressing of concrete improves the ability of the material for energy absorption under impact loads. The ability to resist repeated working loads has been proved to be as good in pre-stressed as in reinforced concrete.

The economy of pre-stressed concrete is well established for long-span structures. According to Dean6, standardized precast bridge beams between 10 and 30 m long and precast pre-stressed piles have proved to be more economical than steel and reinforced concrete in the United States. According to Abeles7, precast pre-stressed concrete is economical for floors, roofs, and bridges of spans up to 30 m. and for cast in situ work, up to 100 m. In the long-span range, pre-stressed concrete is generally more economical than reinforced concrete and steel.

4. Applications of Pre-Stressed Concrete

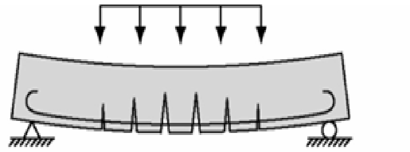
Notable examples of pre-stressed concrete structures in India include,

a) The Lubha bidge24, the nation's longest single-span 172mlongpre-stressedconcretebox-girder-typecontinuous Bridge built across a 30 m deep gorge of the Lubha river in Assam.
b) Gomti aqueduct, which is the longest and the biggest aqueduct in India comprising 9.9 m deep pre-stressed concrete girders each weighing as much as 5500 kN over a span of 31.8 m, located in Uttar Pradesh.
c) Ball tank, Tom bay, Maharashtra, consisting of a pre-stressed concrete, tank of 4 million liter capacity for the department of atomic energy.
d) The Boeing hanger at Santa Cruz airport with a hoof consisting of barrel shells supported on pre-stressed concrete edge beams spanning over 45.73 m.

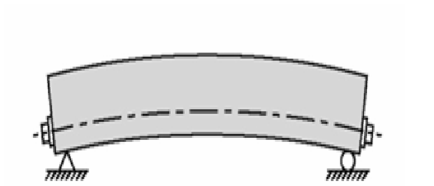
5. Principle of Pre-Stressing

The function of pre-stressing is to place the concrete structure under compression in those regions where load causes tensile stress. Tension caused by applied loads will first have to cancel the compression induced by the pre-stressing before it can crack the concrete. Figure shows a plainly reinforced concrete simple span beam and fixed cantilever beam cracked under applied load. Figure shows the same unloaded beams with pre-stressing forces applied by stressing post-tensioning tendons. By placing the pre-stressing low in the simple-span beam and high in the cantilever beam, compression is induced in the tension zones; creating upward camber.

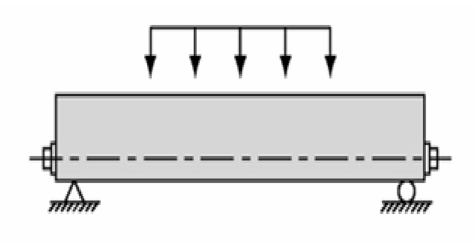
Figure shows the two pre-stressed beams under the action of post-tensioning and applied loads. The loads cause both the simple-span beam and cantilever beam to deflect down, creating tensile stresses in the bottom of the simple-span beam and top of the cantilever beam.



a. Reinforced concrete cracked under load



b. Post-tensioned concrete before loading



c. Post-tensioned concrete after loading

6. Materials for Pre-Stressed Concrete

5.1 High-Strength Concrete Mixes

Pre-stressed concrete requires concrete which has a high compressive strength at a reasonably early age, with comparatively higher tensile strength than ordinary concrete. Low shrinkage, minimum creep characteristics and a high value of Young's modulus age generally deemed necessary for concrete used for possessed members. Many desirable properties, such as durability, impermeability and abrasion resistance, age highly influenced by the strength of concrete.

With the development of vibration techniques in 1930, it became possible to produce, without much difficulty, high-strength concrete having 28-day cube compressive strength in the range of 30-70 Nmm2. The minimum 28-day cube compressive strength prescribed in the Indian standard code IS: 1343-1980 is 40 N/mm2 for pre-tensioned members and 30 N/mm2 for post tensioned members. The ratio of standard cylinder to cube strength may be assumed to be 0.8 in the absence of any elegant test data. A minimum cement content of 300 to 360 kg/m3 is prescribed mainly to cater to the durability equipments. In high-strength concrete mixes, the water content should be as low as possible with due egad to adequate workability, and the concrete should be suitable for compaction by the means available at the site. It is a general practice to adopt vibration to achieve thorough compaction of concrete used for possessed members.

To safeguard against excessive shrinkage, the code prescribes that the cement content in the mix should preferably not exceed 530 kg/m3. The specified works cube strength of 40 N/mm2 equated for possessed members can easily be achieved even at the age of seven days using rapid hardening Portland cement.

Table 1: Maximum Permissible Stresses in Concrete (N/mm2)

1	2	IS: 1343-1980
At Transferce	compressive stress	Varies linearly from 0.54 to 0.37 fck for post-tensioned work and from 0.51 to 0.44 fck for pre-tensioned work depending on the strength of concrete.
At Transferce	Tensile stress	–
At Service load	compressive stress	Varies linearly from 0.41 to 0.35 fck depending on the strength of concrete.
At Service load	Tensile stress	Type 1 members : none Type 2 members : Tensile stress not to exceed 3 N/mm2 . Type 3 members : Hypothetical tensile stress vary from 3.2N/mm2 for M-30 to a maximum of 7.3 N/mm2 for M-50 Grade of concrete depending upon the limiting crack- width.

5.2 Shrinkage of Concrete

The shrinkage of concrete in pre-stressed members is due to the gradual loss of moisture which exults in changes in volume. The drying shrinkage depends on the agree¬ gate type and quantity, relative humidity, water/cement ratio in the mix, and the time

5.3 Creep of Concrete

The progressive inelastic strains due to creep in a concrete member are likely to occur under the smallest sustained stresses at ambient temperatures. Shrinkage and creep of concrete are basically similar in origin, being largely the result of the migration of water in the capillaries of the cement paste. The loss of pre-stress due to creep of concrete can be estimated by the creep coefficient method, as recommended in the Indian Standard Code IS: 1343-80.

5.4 Deformation Characteristic of Concrete

The complete stress-strain characteristic of concrete in compression is not linear, but for loads not exceeding 30 per cent of the crushing strength, the load deformation behavior may be assumed to be linear. The deformation characteristics of concrete under short-term and sustained loads is necessary for determining the flexural strength of beams and for evaluating the modulus of elasticity of concrete, which is required for the computation of deflections of pre-stressed members. The short-term modulus of elasticity, which is specified in most of the codes, corresponds to the secant modulus determined from an experimental stress-strain relation exhibited by standard specimens under loads of one third of the cube compressive strength of concrete. The modulus of elasticity of concrete increases with the average compressive strength of concrete, but at a deceasing rate. Several empirical formulae have been recommended in various national codes for the computation of secant modulus of elasticity of concrete, which is invariably expressed as a function of the compressive strength of concrete.

According to the Indian standard code IS: 1343 (Under revision)

Fc = 5000 N/mm2

5.5 High-Tensile Steel

For pre-stressed 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 comparison with mild steel. High-tensile steel usually contains 0.6 to 0.85 per cent carbon, 0.7 to 1 per cent manganese, 0.05 per cent of sulphur and phosphorus with traces of silicon. The high-carbon steel ingots are hot-rolled into rods and cold-drawn through a series of dies to reduce the diameter and increase the tensile strength.

The specifications of hard-drawn steel wire for pre-stressed concrete (as drawn wire) are covered in the Indian standard code IS: 1785 (part II)-198324.

The process of cold-drawing through dies decreases the durability of the wires. The cold-drawn wires are subsequently tempered to improve their properties. Tempering or ageing or stress relieving by heat treatment of the wires at 150-420°C enhances the 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 and they should conform to the Indian standard code IS: 1785(part D-1983).

The hard-drawn steel wires which are indented or crimped are preferred for pre-tensioned elements because of their superior bond characteristics. The specification for indented wires are covered in IS: 6003-198326. The small diameter wires of 2 to 5 mm are mostly used in the form of strands comprising two, thee or seven wires. The helical form of twisted wires in the strand substantially improves the bond strength. Two- and 3-ply strands are made up of 2 mm and 3 mm diameter individual wires, while the 7-ply strands are twisted using wires of 2 to 5 mm diameter. The nominal diameter of 7-ply strands varies from 6.3 mm to 15.2 mm. The properties of strands are covered in IS: 6006-1983.

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Table 2: Mechanical properties of uncoated stress –Relieved Strand (IS: 6006-1983)

class	Designation	Nominal diameter of strand (mm)	Tolerances on the nominal diameter of strand	Nominal cross sectional area of strand(mm2)	Breaking load minimum(N)	0.2 percent proof load minimum(N)
–	2–ply 2mm	–	–	6.28	12,750	10.84
	2–ply 3mm	–	–	14.14	25,500	21,670
	3–ply 3mm	–	–	21.21	38,250	32,460
	7.9 mm 7-ply	7.9	+/– 0.4	37.4	64,500	547000
	9.5 mm 7-ply	9.5	+/– 0.4	51.6	89,000	75600
	11.1mm 7-ply	11.1	+/– 0.4	69.7	1,20,100	102300
	12.7 mm 7-ply	12.7	+/– 0.4	92.9	1,60,100	136200
	15.2 mm 7-ply	15.2	+/– 0.4	139.4	2,40,200	204200
2	9.5 mm 7-ply	9.5	+ 0.66	54.8	1,02,300	87000
			– 0.15			
	11.1 mm 7-ply	11.1	+ 0.66	74.2	1,37,900	170200
			– 0.15			
	12.7 mm 7-ply	12.7	+ 0.66	98.7	1,83,700	156100
			– 0.15			
	15.2 mm 7-ply	15.2	+ 0.66	140	260700	221500
			– 0.15			

7. Bridge Loading Standards

6.1 Evolution of Bridge Loading Standards

The first loading standard (IRC: 6) in India was published by the Indian Roads Congress in 1958 and subsequently reprinted in 1962 and 1963. The Section-II of the code dealing with loads and stresses was revised in the second revision published in 1964. The metric version was introduced in the third revision of 1966. The IRC: 6 Code has been revised to include the combination of loads, forces and permissible stresses in the Fourth revision published in 2000s.

6.2 Indian Roads Congress Bridge Loading Standards

Highway bridge decks have to be designed to withstand the live loads specified by the Indian Roads Congress. The different categories of loadings were first formulated in 1958 and they have not changed in the subsequent revisions of 1964, 1966 and 2000. The standard IRC loads specified in IRC: 6-2000 are grouped under four categories as detailed below:

6.3 IRC Class AA Loading

Two different types of vehicles are specified under this category grouped as tracked and wheeled vehicles. The IRC Class AA tracked vehicle (simulating an army tank) of 700 kN and a wheeled vehicle (heavy duty army truck) of 400 kN are shown in Fig. 2.1. All the bridges located on National Highways and State Highways have to be designed for this heavy loading. These loadings are also adopted for bridges located within certain specified municipal localities and along specified highways. Alternatively, another type of loading designated as Class 70 R is specified instead of Class A A loading.

6.4 IRC Class 70 R Loading

IRC 70 R loading consists of the following three types of vehicles.

a) Tracked vehicle of total load 700 kN with two tracks each weighing 350 kN.
b) Wheeled vehicle comprising 4 wheels, each with a load of 100 kN totaling 400 kN '
c) Wheeled vehicle with a train of vehicles on seven axles with a total load of 1000 kN

The tracked vehicle is somewhat similar to that of Class A A, except that the contact length of the track is 4.87 m, the nose to tail length of the vehicle is 7.92 m and the specified minimum spacing between successive vehicles is 30 m. The wheeled vehicle is 15.22 m long and has seven axles with the loads totaling to 1000 kN. The bogie axle type loading with 4 wheels totaling 400 kN is also specified. The details of IRC Class 70 R loading vehicles are shown in Fig. 2.2. The 700 kN tracked vehicle is common to both the classes, the only difference being the loaded length which is slightly more for the Class 70 R. Here second category is the wheeled type comprising 1000 kN train of vehicles on seven axles for the Class 70 R and a 400 kN bogie axle type vehicle for the Class AA.

The Class A loading is a 554 kN train of wheeled vehicles on eight axles. Impact is to be allowed for all the loadings as per the specified formulae which is different for steel and concrete bridges. The various categories of loads are to be separately considered and the worst effect has to be considered in design. Only one lane of Class 70 R or Class AA load is considered whereas both the lanes are assumed to be occupied by Class A loading if that gives the worst effect

6.5 IRC Class A Loading

IRC Class A type loading consists of a wheel load train comprising a truck with trailers of specified axle spacing and loads as shown in Fig. 2.3. The heavy duty truck with two trailers transmits loads from 8 axles varying from a minimum of 27 kN to a maximum of 114 kN. The Class A loading is a 554 kN train of wheeled vehicles on eight axles. Impact has to be allowed as per the formulae recommended in the IRC: 6-2000.

6.6 IRC Class B Loading

Class B type of loading is similar to Class A loading except that the axle loads are comparatively of lesser magnitude. The axle loads of Class B are a 332 kN train of wheeled vehicles on eight axles.

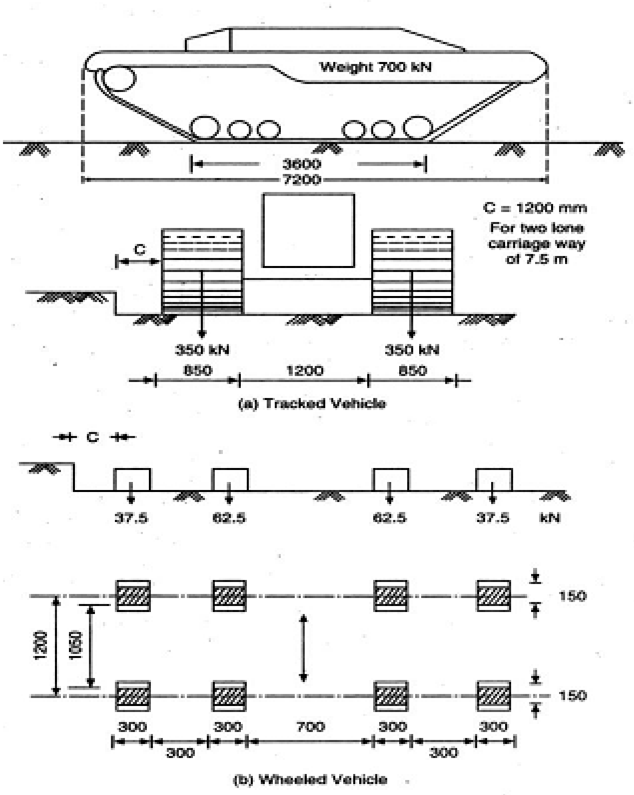

Figure 2.1: IRC Class AA Tracked and Wheeled Vehicles

8. Pre-Stressing Systems

The various methods by which pre-compressive is follows:

1. Generation of compressive force between the structural element and its abutments using flat jacks.
2. Development of hoop compression circumferential wire winding.
3. Use of longitudinally tensioned steel embedded in concrete or housed in ducts.
4. Use of the 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. The most widely used method for pre-stressing of structural concrete elements is longitudinal tensioning devices .Pre-stressing by the application of direct forces between abutments is generally used for arches and pavements while flat jacks are invariably used t structures, such as tanks and pipes, it is com in concrete by circular pre-stressing. With the development of expansive cements, pre-stress in concrete can be developed by chemical pre-stressing.

9. Tensioning Devices

The various types of devices used for tensioning steel ac grouped under four principal categories, namely:

1. Mechanical.
2. hydraulic,
3. Electrical (thermal), and
4. Chemical.

10. Pre-Stressed Concrete Bridges

Pre-stressed concrete is ideally suited for the construction of medium- and long-span bridges. Ever since the development of pre-stressed concrete by Freyssinet in the early 1930s, the material has found extensive application in the construction of long-span bridges, gradually emplacing steel which needs costly maintenance due to the inherent disadvantages of corrosion under aggressive atmospheric conditions.

Solid slabs are used for the span range of 10 to 20 m. while T-beam slab decks are suitable for spans in the range of 20 to 40 m. Single or multi cell box girders ac preferred for larger spoils of the order of 30 to 70 m. Pre-stressed concrete is ideally suited for long-span continuous bridges in which precast box girders of variable depth are used for spans exceeding 50 m. Pre-stressed concrete has been widely used throughout the world for simply-supported, continuous, balanced cantilever, suspension, hammer-head and bridle-chord type bridges in the span range of 20 to 500 m.

11. Codes & Standards

The design of various components of the structure, in general are based on provisions of IRC/IS Codes.

Wherever IRC code is silent, reference is made to other Indian/International codes and standards. The list of IRC Codes (latest revisions) given below will serve as a guide for the design of structures.

IRC: 5-1998 Standard Specifications and Code of Practice for Road Bridges, Section I – General Features of Design.
IRC: 6-2000 Standard Specifications and Code of Practice for Road Bridges, Section-II – Loads and Stresses.
IRC: 21-2000 Standard Specifications and Code of Practice for Road Bridges, Section-III – Cement Concrete.
IRC: 18-2000 Design Criteria for Pre-stressed Concrete Road Bridges (Post Tensioned Concrete) (Third Revision).
IRC: 22-1986 Standard Specifications and Code of Practice for Road Bridges, Section-VI –Composite Construction.
IS: 6006-1983 Indian Standard Specification For Uncoated Stress Relieved Strand For Pre-Stressed Concrete.

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12. Conclusions

The following conclusions are drawn upon:

1. Bending moments and Shear force for PSC T-beam girder are lesser than RCC T-beam Girder Bridge. Which allow designer to have lesser heavier section for PSC T-Beam Girder than RCC T-Girder for 24 m span.
2. Moment of resistance of steel for both has been evaluated and conclusions drawn that PSC T-Beam Girder has more capacity for 24 m and more than 24m of span.
3. Shear force resistance of PSC T-Beam Girder is more compared to RCC T- Girder for 24 m span.
4. As we go Total Super structure of a Bridge Project the Quantity of steel and the Cost of concrete for PSC T-Beam Girder is less than RCC T-Beam Girder as quantity required by T-beam Girder.
5. Deflection for PSC T-beam Girder is less than RCC T-Beam Girder Bridge.
6. Durability for PSC T-beam Girder is more than RCC T-Beam Girder Bridge.

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