International Engineering Journal For Research & Development
Vol.4
ISSUE 4

E-ISSN NO:-2349-0721
Impact factor : 6.03

REVIEW PAPER ON ANALYSIS AND DESIGN OF DIFFERENT TYPES OF PRE-STRESSED CONCRETE SECTIONS

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Abstract:

Pre-stressed concrete is a method for overcoming concrete's natural weakness, i.e. tension. It can be used to produce beams, slabs, girders for heavy loading, longer span with effectively less depth and are light weight by providing the curved tendons and the pre-compression, a considerable part of the shear is also resisted.

Pre-stressed concrete sections are thinner and lighter than RCC sections, since high strength concrete and steel are used. Thinner sections in pre-stressed concrete results in less self weight and hence overall economy. Cracks do not occur under working loads in the pre-stressed concrete sections. Even if a minute crack occurs when overloaded, such crack gets closed when the overload is removed.

In this paper analysis and design of different types of prestressed concrete sections using pre-tensioning and post-tensioning methods is reviewed. Pre-stressing removes a number of design limitations that the conventional concrete faces. The deflections of the pre-stressed concrete sections are small as compared to the conventional concrete.

Keywords*: *Pre-stressed Concrete, High Strength Steel, Self weight, Economy, Deflection.

INTRODUCTION

In Pre-stressed concrete internal stresses of a suitable magnitude and distribution are deliberately introduced so that the stresses resulting from external loads are counteracted to a desired degree. The normal concrete undergoes compression on the top flange and tension at the bottom flange. In pre-stressing the tendons are stretched along the axis and then the cement is poured. When the tendons are released the compression takes place at the bottom which tries to counter balance the compression due to loading at the top part of the beam. The upward force along the length of the beam counteracts the service loads applied to the member.

Prestressed concrete structures are an attractive alternative for long span bridges and have been used worldwide since the 1950s. Savings in the materials and maintenance and life-cycle costs are additional advantages. The extensive application of prestressed concrete to buildings, military constructions and civil infrastructures has been increased by awareness with its principles, practice and further advances in its design and construction.

Pre-stressing removes a number of design limitations conventional concrete faces on span and load and also permits the building of roofs, floors, bridges and walls with longer unsupported spans. Due to pre-stressing it is easier to design and build lighter and shallower concrete structures without sacrificing strength. This helps in the construction of longer spans which reduces the intermediate pier construction and making bridge construction economical.

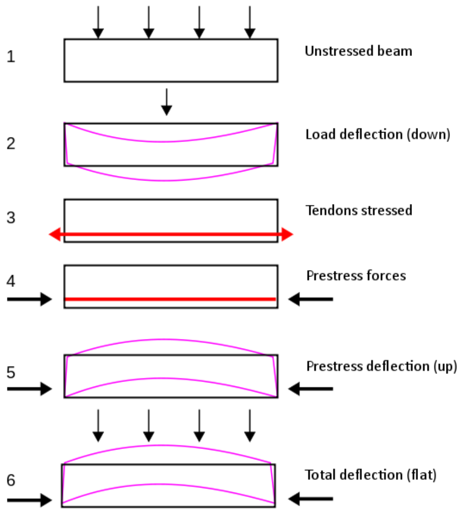

Fig. 1: Concept of Prestressing

In prestressed concrete cracking is prevented and prestressed concrete sections becomes more stiffer than the reinforced concrete sections. The downward deflection is eliminated due to the upward force which is imposed on the concrete in curved tendons. Prestressed concrete plays a vital role in the construction of liquid retaining structures and nuclear containment structures where absolutely no leakage is acceptable.

I. CLASSIFICATION OF PRESTRESSED CONCRETE STRUCTURES

Prestressing involves two different types of structures which are further classified by pre-tensioning and post-tensioning methods.

- Pre-tensioning method: In this method, prestressing is induced (the tendons are tensioned) before the concrete is placed. It is done in factories. In this method, the tendons are enclosed temporarily against some abutments and then they are pulled by using jack type devices. The concrete is placed while maintaining the tension. When concrete is hardened sufficiently, the tendons are released slowly or cut. This will transfer prestress from steel to concrete through bond. This type of prestressing method is commonly used for small sized members like beams, slabs, piles, sleepers and electric poles, etc. which can be casted easily in factories.

- Post-tensioning method: In this method, the prestress is induced or tendons are tensioned only after the concrete has hardened. In this system, the concreting is done first and a duct is formed in the member with tube or with a metal sheath. When concrete has sufficiently hardened then tendons or cable is transferred from the tendon to the member through anchorage wedges. The space between the tendon and the duct is filled with cement grout. Post tensioning method of prestressing is used for both precast and cast in situ construction. It is used for large span structures like bridges.

II. MATERIALS USED IN PRESTRESSED CONCRETE

- STEEL: In prestressed concrete loss of prestress (about 20 %) occurs due to many factors. If mild steel bars or HYSD bars are used then very little prestress will be left after the losses and will be of no use. Therefore, high tensile strength steel is used for prestressing. In addition to the high strength, the steel used in prestressing must have a higher ultimate elongation. Various forms of steel used for prestressing are as follows

  a) Tendons: Tendons are high strength tensile wires available in various diameters from 1.5 mm to 8 mm.
  b) Wires, Strands or Cables: A strand or cable is made of a bundle of wires spun together. The overall diameter of a cable or strand is from 7 to 17 mm. They are used for post-tensioning systems.
  c) Bars: High tensile steel bars of diameter 10 mm or more are also used in prestressing.

Fig. 2: Strands

Fig. 3: Cables

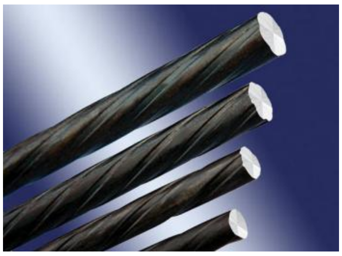

Fig. 4: Bars

- CONCRETE: Since high tensile steel is used in prestressed concrete, the concrete used should also be of good quality and high strength. Therefore, the code recommends a minimum mix of M 40 for pre-tensioned system and M 30 for post tensioned system. These mixes have high strength and a high value of modulus of elasticity of concrete which results in less deflection. The concrete used in prestressed concrete should be well compacted. High strength concrete is used in prestressed concrete for following reasons:

  a) Use of high strength concrete results in smaller sections.
  b) High strength concrete offers high resistance in tension, shear, bond and bearing.
  c) Less loss of prestress occurs with high strength concrete.

III. COMPARISION BETWEEN RCC AND PRESTRESSED CONCRETE

- In RCC beam the concrete in the compression side of the neutral side of the axis alone is effective. The concrete in the tension side of the neutral axis is ineffective. But in the prestressed concrete beam, the entire section is effective.
- Reinforced concrete beams are generally heavy. They always need shear reinforcements besides the longitudinal reinforcement for flexure. Prestressed concrete beams are lighter. By providing the curved tendons and the pre-compression, a considerable part of the shear is resisted.

- In reinforced concrete beams, high strength concrete is not needed. But in prestressed concrete beams, high strength concrete and high strength steel are necessary. High strength concrete is needed to resist high stresses at the anchorages. High strength steel is needed to transfer large prestressing force.
- Reinforced concrete beams being massive and heavy are more suitable in situations where the weight is more desired than strength. Prestressed concrete beams are very suitable for heavy loads and longer spans. They are slender and artistic treatments can be easily provided. Cracks do not occur under working loads. Even if a minute crack occurs when overloaded, such crack gets closed when the overload is removed. The deflections of the prestressed concrete beams are small.
- In reinforced concrete beams, there is no way testing the steel and the concrete. In prestressed concrete beams, testing of steel and concrete can be made while prestressing.

LITERATURE REVIEW

Ahmad Ali Khan and K.K. Pathak and N. Dindorkar (2010):

A new approach for analysis and design of pre-stressed concrete slabs was presented in this study. For finite element analysis of pre-stressed concrete slabs, tendons and concrete were modelled by 3 noded curved bar and 20 noded brick elements respectively. Using vector calculus formulae, the cable concrete interactions were precisely accounted. Further an efficient algorithm was proposed for cable layout design. Using the proposed techniques several prestressed concrete slabs were successfully analyzed and designed. Computational methods for analysis and design of prestressed concrete structures were discussed in this study. The cable segment in the finite element was modelled by three node bar elements, which was embedded in three-dimensional brick elements. The pre-stressing cables were modelled as B-spline curve whose ordinates were taken as design variables. Stress analysis was carried out using 3D finite element analysis. Using the proposed methodology, a two-way prestressed concrete slab had been successfully designed to satisfy several design criteria.

Adekunle Philips Adewuyi and Shodolapo Oluyemi Franklin (2011):

A general overview of the historical background, fundamental principles and previous applications of post compression techniques in the prestressed concrete structures were discussed in this study. In this analytical study of a simple beam, the prestressing forces in the post-tensioned tendons were found to be independent of the eccentricity ratio, but increase quadratically up to a prestressing ratio of 0.7 after which they became asymptotic as the post-compression force equals the post-tension force. On the other hand, the prestressing force ratio and the eccentricity ratio had direct effects on the eccentricities. There was reduction in the eccentricities as the post-compression force and eccentricity of post-compressed bar increased. This reduction was perfectly linear for the concentric post compression and quadratic or higher polynomial as the eccentricity of the post-compressed steel bars increased. This concept of the design was technically impracticable when the prestressing force ratio approached unity, because the eccentricities were approximate to zero when the axial forces were cancelled.

Vishal U. Mishal and N. G. Gore and P. J. Salunke (2014):

In view of comparing the cost analysis and design of prestressed concrete girder a detailed literature survey was being carried out. Different methodologies adopted for analysis and design of prestressed concrete slabs and girders were discussed in this study. It was decided to use the software STAAD PRO for the analysis and design of slab and girders. The analysis results of a problem of “I-girder” using STAAD PRO software were compared with the corresponding analytical results for the validation purpose. It was observed that the results obtained by both the methods showed good agreement. By using this software a comparative study of analysis and design of prestressed concrete I-girder and reinforced concrete box girder was carried out. From the obtained results it was concluded that the pre-stressed concrete girder is costlier than the reinforced concrete girder.

A. Maazoun and J. Vantomme and S. Matthys (2017):

This study presented the experimental and numerical results of reinforced concrete hollow core (RCHC) and prestressed concrete hollow core (PCHC) slabs with a compression layer under blast loading. Numerical analysis showed a good agreement with the experimental results for the maximum deflection at the mid span of the slabs. The numerical model also gave a good prediction of the observed cracking. The effects of prestressing delayed the appearance and the growth of flexural cracks in the concrete and lead to a smaller deflection at the mid span of the prestressed concrete hollow core slab compared to reinforced concrete hollow core slab. The dynamic response of the prestressed concrete hollow core slab is stiffer than the reinforced concrete hollow core slab (reducing the maximum deflection and the oscillation period). The prestressing increased the flexural resistance capacity of the hollow core slabs. It was observed that proper analysis and design were necessary to determine the optimal prestressing levels to enhance the blast loading capacities of reinforced concrete slabs.

Shubham Landge and Umesh Bhagat and Ved Prakash (2018):

Discussed the analysis and design of longitudinal girder bridge using STAAD-PRO software. For the analysis of pre-stressed concrete I-girder bridge a 28 m length bridge was considered. By using precast pre-stressed concrete girder configuration over the ordinary deck slab configuration effective results were obtained. By using the precast prestressed concrete girder configuration most of the design parameters were within the permissible limits of serviceability, deflection and shear as compared to the ordinary deck slab configuration. To obtain even better working results the precast pre-stressed concrete girder configuration deck slab was subjected to post-tensioning. From the study it was observed that the ordinary configuration of deck slab creates long term maintenance and serviceability problems as it has a greater number of exposed components in the structure. This problem can be overcome by the use of precast pre-stressed concrete girder deck slab configuration.

ADVANTAGES OF PRESTRESSED CONCRETE

- Prestressed concrete sections are thinner and lighter than RCC sections, since high strength concrete and steel are used prestressed concrete.
- In prestressed concrete, whole concrete area is effective in resisting loads, unlike RCC where concrete below the neutral axis is neglected.
- Thinner sections in prestressed concrete results in less self weight and hence overall economy.
- Long span bridges and flyovers are made of prestressed concrete because of lesser self weight and thinner section. So, prestressed concrete is used for heavily loaded structures.
- Prestressed concrete members show less deflection.
- Since the concrete does not crack in prestressed concrete, rusting of steel is minimized.
- Prestressed concrete is used in the structures where tension develops or the structure is subjected to vibrations, impact and shock like girders, bridges, railway sleepers, electric poles, gravity dams, etc.
- Precast members like electric poles and railway sleepers are produced in factories using simple pre-stressing methods.

LIMITATIONS OF PRESTRESSED CONCRETE

- Prestressed concrete construction requires very good quality control and supervisions.
- Cost of materials used in prestressed is very high (high tensile steel is about three times costlier than mild steel).
- Prestressed concrete requires specialized tensioning equipment and devices which are very costly.
- Prestressed concrete sections are more brittle because of use of high-tension steel.

CONCLUSION

From the above study it is found that the pre-stressing in concrete structures is more effective than the reinforced concrete technology. Today pre-stressing is preferred for large structures like bridges and it is also adopted for all small concrete structural sections. Today it is the demand to replace reinforced concrete completely by the pre-stressed concrete, because reinforced concrete has large section with less strength as compare to pre-stressed concrete. In reinforced concrete system the section is first reinforced and then loaded after casting while in the pre-stressed concrete system the reinforcement which is called as "tendons" are stressed first and then casted and then the force is applied.

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