International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 18
December 2016

Analysis of Post-tensioned Flat Slabs Considering Seismic Effect

[1]G. BHAVYA BHARATHI, [2] Dr. B. RAMESH BABU, [3] S. NIRAMALA

[1] M.Tech Dept of CIVIL Engineering, ALITS College, Affiliated to JNTUA, AP, India.
[2]Principal , ALITS College, Affiliated to JNTUA, AP, India
[3] Associate Professor Dept of CIVIL Engineering , ALITS College, Affiliated to JNTUA, AP, India

Abstract: The post-tensioning method is now a day's increasing widely, due to its application. By using post-tensioning method one can design the most economic and the safe design. While using this method more precautions has to be made for shear and deflection criteria for the slabs. The design of post-tensioned flat slab can be done by using load balancing and equivalent frame method. For the application of design procedure an office building is considered as a case study. The plan of the office building (G+4) is considered. This building is designed by considering four cases with different floor systems. The quantities of reinforcing steel, prestressing steel, concrete required for the slab, beam and column is calculated for the same and are presented in tabular form. Along with this total cost of the building per square meter is found and comparison of all the four cases with respect to cost is done.

I. INTRODUCTION

As the floor system plays an important role in the overall cost of a building, a post-tensioned floor system is invented which reduces the time for the construction and finally the cost of the structure. In some countries, including the U.S., Australia, South Africa, Thailand and India, a great number of large buildings have been successfully constructed using post-tensioned floors. The reason for this lies in its decisive technical and economical advantages. According to Park. E. H. Kim *et al* [1] and Y. H. Luo, A. Durrani [2] the most important advantages offered by post-tensioning systems are as follows -

By comparison with reinforced concrete, a considerable saving in concrete and steel since, due to the working of the entire concrete cross-section more slender designs are possible. Smaller deflections compared to with steel and reinforced concrete structures. Good crack behavior and therefore permanent protection of the steel against corrosion. Almost unchanged serviceability even after considerable overload, since temporary cracks close again after the overload has disappeared.

High fatigue strength, since the amplitude of the stress changes in the prestressing steel under alternating loads are quite small.

If a significant part of the load is resisted by post-tensioning the non-prestressed reinforcement can be simplified and standardized to a large degree. Furthermore, material handling is reduced since the total tonnage of steel (non-prestressed + prestressed) and concrete is less than for a Reinforced Concrete floor.

Assembling of precast elements by post-tensioning avoids complicated reinforcing bar connections with insitu closure pours, or welded steel connectors, and thus can significantly reduce erection time.

Usually the permanent floor load is largely balanced by draped post-tensioning tendons so that only the weight of the wet concrete of the floor above induces flexural stresses. These are often of the same order as the design live load stresses. Post-tensioning usually balances most of the permanent loads thus significantly reducing deflections and tensile stresses. The P/A stress provided by post-tensioning may prevent tensile stresses causing the floor to crack.

For the above reasons post-tensioned construction has also come to be used in many situations in buildings. In addition to the above mentioned general features of post-tensioned construction systems, the following advantages of post-tensioned slabs over reinforced concrete slabs are listed as follows: More economical structures resulting from the use of prestressing steels with a very high tensile strength instead of normal reinforcing steels.

Larger spans and greater slenderness, which results in reduced dead load, which also has a beneficial effect upon the columns and foundations and reduces the overall height of buildings or enables additional floors to be incorporated in buildings of a given height

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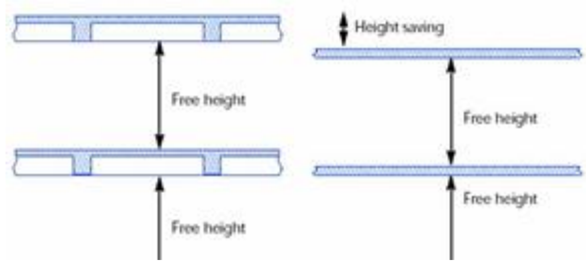


Traditional R.C.C. design PT slab design
Fig. 1. Height comparison of R.C.C. & PT slab design

II. RELATED WORK

The post-tensioning method is now a day's increasing widely, due to its application. By using the post-tensioning method one can design the most economic and the safe design. But while using this method more precautions has to be made for the shear and the deflection criteria for the slabs. The design of the post-tension flat slab can be done by using load balancing and equivalent frame method. Among of both the equivalent frame method is widely used. In the load balancing method the 65 to 80% of the dead load is carried by the tendon itself. So that there is an upward deflection due to tendon profile resulting the reduction in overall deflection. In the present study the design of the post-tensioned flat slab is done by using both methods, load balancing method and equivalent frame method. As the shear and deflection check is the most important for the post-tensioned slabs the detail design for the shear and deflections (short term deflection and long term deflections due to creep and shrinkage) is carried out. The parametric study of the post-tensioned flat slab by varying the span by 0.5m interval is done and results of the different parameters such as thickness of slab, grade of concrete, loss due to stress, normal reinforcement, reinforcement for the shear, number of tendons, stressing force per tendon and deflection etc. are presented in the graphical form. Continuing to this a design of post-tensioned beam is also done. For the study of post-tensioned slab and beams a case study of a multistory office building (G+4) is taken and it is designed by four cases, the post-tensioned flat slab, post-tensioned beams and the R.C.C. slab, only R.C.C. flat slab and the R.C.C. slab and beams. After the design of these four cases the comparative study with respect to the economy is carried out.

III. DESIGN METHODOLOGY

The design of post-tensioned slab is done by two methods, load balancing method and the equivalent frame method. The load balancing method introduced by T. Y. Lin is most suitable for the indeterminate structures rather than the determinate structures. In this method the 65 to 80% of dead load is balanced by the tendons so that the flexural member will not be subjected to bending stress under a given load conditions. On the other hand the equivalent frame method is widely use for the design of post-tensioned slabs. Here load balancing method and equivalent frame method are discussed in the following section.

A. Load-Balancing Method

The concept of load balancing is introduced for prestressed concrete structures, as per T.Y Lin *et al* [3] a third approach after the elastic stress and the ultimate strength method of design and analysis. It is first applied to simple beams and cantilevers and then to continuous beams and rigid frames. This load-balancing method represents the simplest approach to prestressed design and analysis, its advantage over the elastic stress and ultimate strength methods is not significant for statically determinate structures. When dealing with statically indeterminate systems including flat slabs and certain thin shells, load-balancing method offers tremendous advantage both in calculating and visualizing. According to load-balancing method, prestressing balances a certain portion of the gravity loads so that flexural members, such as slabs, beams, and girders, will not be subjected to bending stresses under a given load condition. Thus a structure carrying transverse loads is subjected only to axial stresses.

B. Equivalent Frame Method of Analysis

The equivalent frame method of analysis is known as the beam method. This method of analysis utilizes the conventional elastic analysis assumption and models the slab or slab and columns, as a beam or as a frame, respectively. This is the most widely used and applied method of analysis for the post-tensioned flat plates.

According to Y. H. Luo, A. Durrani et al [4] the effect of vertical of lateral services and design loading on post-tensioned flat plates, bonded or unbonded, may be analyzed as for rigid frames in accordance with the provisions of the code (IS, ACI etc.). When the columns are relatively slender or not rigidly connected to the slab, their stiffness may be neglected and continuous beam analysis applied. As per A.C. Scordelis, Lin, T.Y, and R Itaya et al [5] the moment induced by prestressing may also be determined by a similar analysis of a rigid frame or continuous beam, using equivalent load or load balancing concept. However it should be kept in mind that the distribution of moments due to loads may differ considerably from the distribution of moments due to prestressing. Service loads produce very pronounced moments peaks at columns, whereas the moment curve produced by post-tensioning has a more gentle undulating variation of the same form as the tendon profile.

According to A .Pan, and J. P. Moehle [6] the effects of reversed tendon curvature at supports are generally neglected in applying the load balancing method to design of flat plates since the reverse curvature has only a minor influence on the elastic moments (in the order of 5 to 10 percent), and does not affect the ultimate moment capacity. It is necessary to consider reverse tendon curvature tort adequately evaluate the shear carried by the tendons inside the critical section.

IV. PARAMETRIC STUDY

For the purpose of parametric study of post-tensioned slab the slabs with and without drop varying from 7m to 12m at an interval of 0.5m are considered.

Load considered- Dead load –self weight Live load – 2 KN/m2 Superimposed dead load - 1 KN/m2

Analysis and design is done by using following methods

Load balancing method

Equivalent frame method

For the application of design procedure a office building is consider as a case study. The plan of the office building (G+4) is considered. This building is designed by considering four cases with different floor systems. The different floor systems used for these four cases are as follows.

For the above four cases the quantities of reinforcing steel, prestressing steel, concrete required for the slab, beam and column is calculated and are presented in the tabular form. Along with this a total cost of the building per square meter is found and the comparison of all the four cases with respect to cost is given here

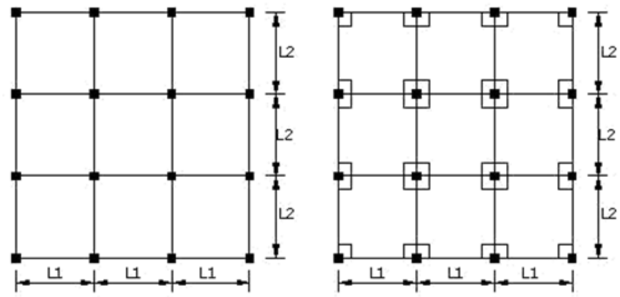


Fig. 2. Plan of slab with drop and without drop

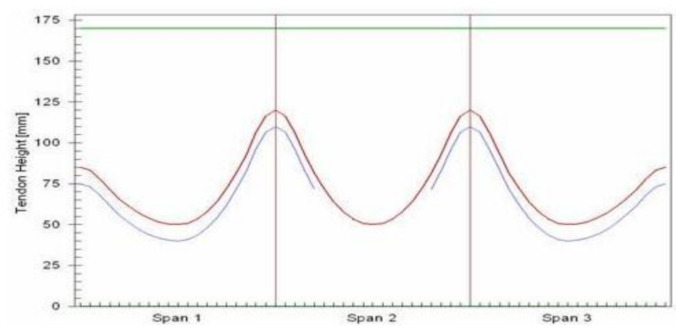


Fig. 3. Tendon profile for the slab without drop

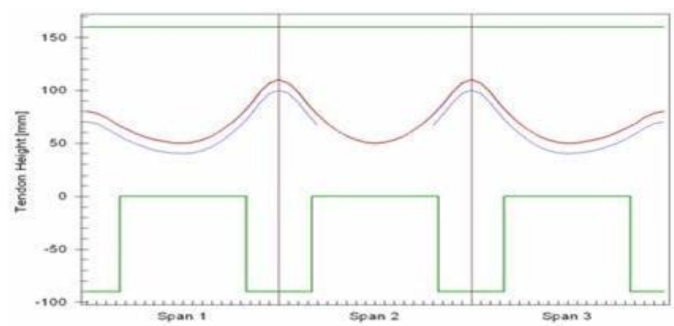
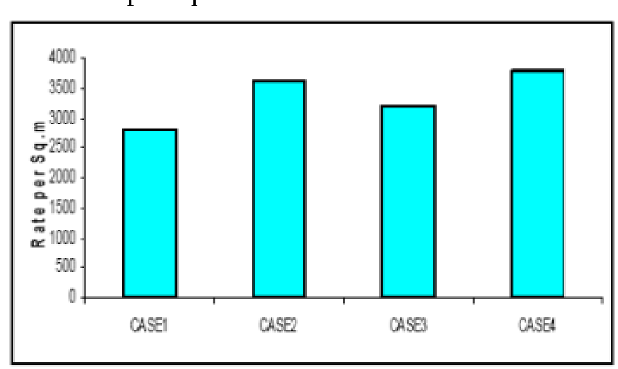


Fig. 3. Tendon profile for the slab with drop

VI. CONCLUSION

The analysis, design and the estimation of the office building for the four different floor systems is done and finally the rate per square meter for the construction of this building is found out. The fig .6 shows the variation of the rate per square meter for these four different cases



The design and the estimation of the office building for the four different floor systems is done and finally the rate per square meter for the construction of this building is found out. The Fig. 6 shows the variation of the rate per square meter for these four different cases. The observation made from the above work is as follows

1. From the economic point of view the post-tensioned flat slab is the most economical among all four floor systems and the reinforced concrete slab with reinforced concrete beam is the costlier one for this span.
2. If we consider the post-tensioned flat slab and reinforced concrete flat slab, the thickness of reinforced concrete flat slab is 12.5% greater and its cost is 27% greater than the post-tensioned flat slab.
3. From both post-tensioned floor system building the post-tensioned flat slab is more economical than the post-tensioned slab with reinforced concrete beams.
4. The quantity of prestressing steel is 4 Kg/m^2 for post-tensioned flat slab and 3.2 Kg/m^2 for post-tensioned slab with reinforced concrete beams i.e. the prestressing steel required for the post-tensioned flat slab is greater.
5. The reinforcing steel required for the post-tensioned flat slab and post- tensioned slab with reinforced concrete beam is 15 Kg/m^2 and 20.15 Kg/m^2 respectively.
6. The reinforcing steel is more in case of post-tensioned slab with reinforced concrete beams because the slab transfers the load on the beam and more loads is taken by the beams itself.
7. The reinforcing steel for the reinforced concrete flat slab is 41 Kg/m^2 while for the reinforced concrete slab and beam it is 40 Kg/m^2.
8. The floor to floor height available in case of post-tensioned flat and reinforced concrete flat slab is 2.65m while in case of post-tensioned slab with reinforced concrete beams and reinforced concrete slab and beams is 2.4m.
9. If we consider the period of construction for a floor it is less in case of post- tensioned flat slab than the other three cases as the post-tensioning allows the earlier removal of the formwork. In case of post-tensioned slab with reinforced concrete beams the formwork of slab can be removed earlier but the formwork for the reinforced concrete beams cannot be removed earlier.
10. While estimating the cost of the each building the labour charges are not considered, as the time period reduce the labour charges will reduce in case of post-tensioned flat slab.
11. The wall load is considered on all over the floor (KN/m^2) for the post-tensioned building While analysis. So there is flexibility to the user to construct a wall wherever required in case of post-tensioning.

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