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Post-Tensioned Building Analysis and Design – A Case Study

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Abstract: In this fast-paced and competitive world, building sector is at the apex of the growth of any country. High-rise buildings are admired by every human being. Traditionally the construction of a building is done by RCC but in present world, construction of high rise buildings is done by Post-Tensioning. In RCC, the economic expenditure is very high in commercial and institutional buildings because of more material required in construction and hence, Post Tensioned building proves to be more economic and durable. Post-Tensioned building saves quantity of steel and concrete as compared to RCC and increases clear span in rooms. Through this paper, the emphasis is to design a post-tensioned building using ETABS and SAFE. ETABS stand for Extended Three-Dimensional Analysis of a building systems. The main purpose of this software is to design multi-storeyed building in a systematic process which will be in accordance with Indian Standard design codes.

Keywords: Post Tensioning, Multi-storeyed, SAFE, ETABS.

A. INTRODUCTION

The history of post-tensioning concrete stretches back to the 1930's, where a Frenchman named Eugene Freyssinet, realized that placing concrete under compression greatly increases its strength. It includes laying sheathed cables and pouring concrete around them and allowing it to set up, then stretching the cables and locking them into place.

Post World War II, post-tensioned concrete became a popular building method as there was a shortage of steel and there was a need to replace damaged and war-torn bridges. The design and use of this method diminished until the mid-1960, when much of its utilization was in the area of ground-supported slabs for warehouse, apartment, and residential floors.

In 1976, PTI (Post Tensioning Institute), which realised the future potential of PT, was formed.

A concrete when being placed under compression is known as Pre-stressed concrete. This is done before the application of supporting any loads beyond its dead weight. This compression which is produced by the tensioning of high-strength "tendons" is located within or adjacent to the concrete volume, and this in turn improves the performance of the concrete in service. The tendons which are used in post-tensioning consists of single, multi-wire strands or threaded bars which are made from tensile steels, carbon and aramid fiber. The quintessence of prestressed concrete is that once the initial compression has been applied, the resulting material has the characteristics of high-strength concrete when subjected to subsequent compression forces and high-strength steel when subject to tension forces. Increased structural capacity and/or serviceability compared to conventionally reinforced concrete is noticed in many situations.

Prestressed concrete is used in a wide range of building and civil structures where its improved performance can allow longer spans, reduced structural thicknesses, and material savings compared to simple reinforced concrete. Typical applications include high-rise buildings, residential slabs, foundation systems, bridge and dam structures, silos and tanks, industrial pavements and nuclear containment structures.

First used in the late-nineteenth century, prestressed concrete has developed beyond pre-tensioning to include post-tensioning, which occurs after the concrete is cast. Tensioning systems may be classed as either monostrand, where each tendon's strand or wire is stressed individually, or multi-strand, where all strands or wires in a tendon are stressed simultaneously. Tendons may be located either within the concrete volume (internal prestressing), or wholly outside of it (external prestressing). Whereas pre-tensioned concrete uses tendons directly bonded to the concrete, post-tensioned concrete can use either bonded or unbonded tendons.

To meet the architecturally challenging applications of this modern world, while still providing a durable concrete structure, designers specify cast-in-place construction. Cast-in-place construction allows the engineer the flexibility to meet any geometric floor plan and to use varying section dimensions. This results in the most economical solution for the concrete application. Using post-tensioned reinforcement in cast-in-place construction helps the engineer in even more improved economical solution by reducing the depth of the structural elements. Reduction in depth optimizes the quantity of concrete required and can reduce the overall weight of a structure which saves foundation costs and can reduce the overall height of a building saving in exterior cladding costs. A post-tensioned cast-in-place concrete solution for a slab-on-ground application or a high-rise building floor system affords the owner, architect, and engineer the most cost-effective solution to meet today's challenging construction environment. The model work is carried out to analyse and design of hospital building.

Both these methods are used specifically in the construction of bridges and storage tanks for many decades due to its decisive technical and economic advantages. The focus of this paper is on applications of post-tensioning in building sector.

The most important advantages offered by post-tensioning briefly are:

❖ There is a considerable percentage saving in concrete and steel, due to the participation of the entire concrete cross-section, more slender designs are possible.
❖ Smaller deflections compared to structural members with steel and reinforced concrete.
❖ Good crack behaviour and therefore better protection of the steel against corrosion.
❖ There is constant serviceability even under considerable overload, since temporary cracks close again after the removal of overload.
❖ High fatigue strength, since the amplitude of the stress changes in the prestressing steel under alternating loads are quite small.

For the above listed reasons, post-tensioned construction has also come to be used in many situations in buildings. The following advantages of post-tensioned slabs over reinforced concrete slabs may be listed:

➢ 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. The condition of greater slenderness 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.
➢ Under permanent load, very good behaviour in respect of deflections and cracking.
➢ Higher punching shear strength is achieved by appropriate layout of tendons
➢ There is considerable reduction in construction time because of earlier striking of slab formwork.

The real development took place in the USA and Australia. The First post-tensioned slabs was constructed of higher strength steel, better attachment hardware, better construction techniques, and simplified design methods, the use of P-T to reinforce structures became more popular. In the next decade numerous post-tensioned slabs were designed and constructed in connection with the lift slab method. Post-tensioning enabled the lifting weight to be reduced and the deflection and cracking performance to be improved. Attempts were made to gain in depth knowledge by theoretical studies and experiments on posttensioned plates. By the early 1990s the mystery of P-T subsided with further refinements to the tensioning process, the development of more corrosion resistant anchorages, and the widespread dissemination of design software.

Due to these factors, P-T has become a preferred method for reinforcing concrete today even in building sector [1].

B. LITERATURE REVIEW

1. Dr Manmohan R Kalgal explained through his paper the need for post-tensioning in our
Building sector. The major advantages of post-tensioning is that it is economic, considerable saving of concrete and steel can be achieved. The Post-tensioned slabs result in larger spans and greater slenderness. There is reduction in construction time as a result of earlier striking of formwork. Dr Kalgal also explained us bonded and unbonded tendons. Advantages and disadvantages of both tendons are explained. An effort is made through this paper that will help post-tensoning to be familiar among more and more people.
2. V.G.Kiran Kumar et al. (2014) explained through their paper the use of ETABS for a High Rise Building. Load calculation, wind load calculation, seismic load calculation and the design of a post-tensioned slab can be studied. With the use of post-tensioning method, thickness of the slab is reduced. If thickness of slab is reduced, this creates a chain reaction i.e number of columns and beams is reducing which leads to the structure being more economic and eco-friendly.
3. B.Anjaneyulu et al. (2016) explained the importance of flat slab in India as this construction is a developing technology. It has many advantages over conventional slabs and can be used this modern world where every building needs to have a high degree of structural stability and it should have an eye-catching look to it. Flat slab can be built by both conventional reinforced concrete as well as post-tensioning. However, for span up to 10 metres conventional concrete design is used in India.

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4. Jnanesh Reddy et al. (2017) gave us a comparison between post tensioned and RCC Flat Slab in a multi-storey post tensioned building. The need of concrete in a RCC Flat Slab is comparatively more than a PT slab. Cost of steel required is also more than the combined price of steel and tendons in PT slab construction. Stiffness and strength of the structure will also be more than that of the RCC Flat Slab. As thickness is reduced in PT slab aesthetic look can be increased and also the structure is lighter as the dead load gets reduced.

5. Sreenivasa Prasad Joshi explained the qualitative and quantitative analysis of a Post Tensioned Slab through manual calculations. The primary advantages of Post-Tensioned Floors is longer spans, overall economic structural cost, reduced floor to floor height, waterproof and deflection free slab, early formwork stripping and material handling. The comparison result of RCC and PT Slab shows us that there is 67% saving of concrete in PT, also the comparison between RCC and PT Beam shows us that there is 79% saving of concrete in PT. The rate analysis between the two shows us that there is 48% saving of cost in PT. However post-tensioning is rejected in buildings due to lack of knowledge and flexibility.

C. DESCRIPTION OF STUDY MODEL

A. Project Details

1. Purpose of building: Institutional
2. Shape of building: Regular (rectangular)
3. No of stories: (G+18)
4. Type of wall: Masonry
5. Height of stories: 4.8m (similar)

B. General conditions of area of construction

1. Area: Mumbai
2. Zone: III
3. Soil Type: Moderate
4. Zone factor:0.16
5. Response Reduction Factor, R=5.0
6. A eighteen floor institutional building of asymmetrical plan.

C. Material Properties

To carry out the work in ETABS software, the properties of the material such as concrete and steel should be defined, similarly the loads should be defined such as live load, dead load, seismic load, wind load.

1. Grade of concrete and steel: M40 and Fe500
2. LL=4kN/m^2
3. FF= 1.5kN/m^2
4. Beam size = 300*500 mm^2
5. Column size = 500*500 mm^2

D. Properties of Tendon used in designing

a. Type of tendon- Cold drawn steel.
b. Modulus of elasticity- 210000 N/mm^2.
c. Diameter of one wire in a strand- 2.5mm.
d. No. of wire in one strand-7
e. Yield stress of tendon-1865 N/mm^2.
f. Tendon jacking stress- 1488 N/mm^2.

D. METHODOLOGY

All the process which was carried out while designing the structure is represented in form of flowchart given below:

- **ARCHITECTURAL PLAN**

1. A plan was selected and proposed.
2. Plan was of G+18 floors of hospital building.
3. Built-up area of one slab was 47300 ft^2.
4. Plan consists of different levels having non-typical type.

- **MODELLING IN ETABS**

1. Centre line plan was prepared in autocad to simplify the work in etabs.
2. Grids was laid in ETABS.

3. Structure was modelled according to the plan selected in ETABS.
4. Modelling of structural members is given below .

• **ASSIGNING OF VARIOUS LOADS**
1. Reinforcing bars of desirable diameter was allowed.
2. Loads of various types was defined along with mass source for seismic loaing.
3. Loads like live load, seismic load, wind load was assigned to structure according to IS 875 and IS 1893.

• **ANALYSIS OF STRUCTURE**
1. Model was locked in ETABS.
2. Model was checked before analysis for the errors in modelling.
3. Errors was rectified.
4. Analysis of structure was carried out with the help of software.

• **DESIGN OF STRUCTURE**
1. Design of different members was carried out with the help of software.
2. Detailing preferances was selected.
3. Rebar selection rules was applied.
4. Detailing was also done by same software.
5. Report generation was also done in software.

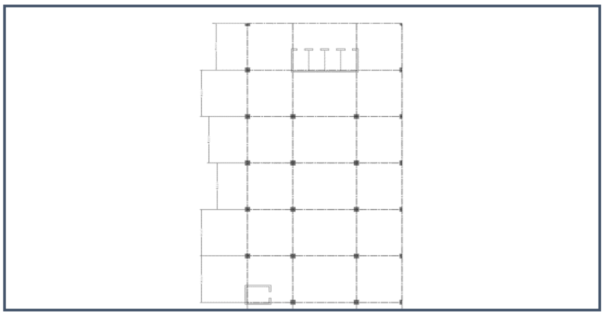

Fig.1. Autocad center line plan

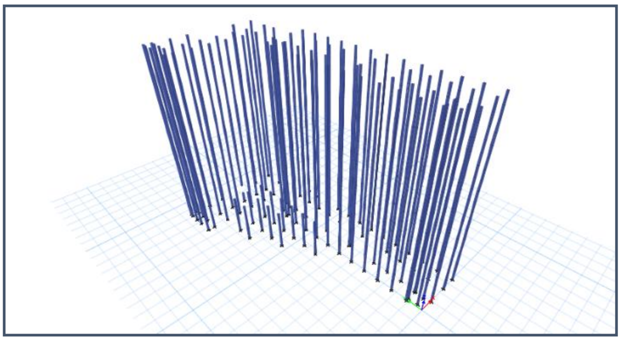

Fig.2. Columns placed

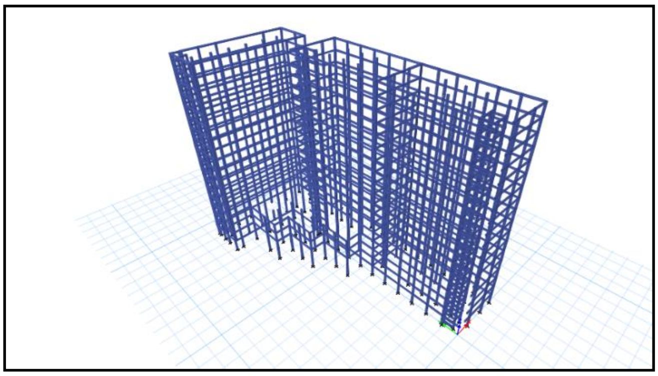

Fig.3. Beams placed

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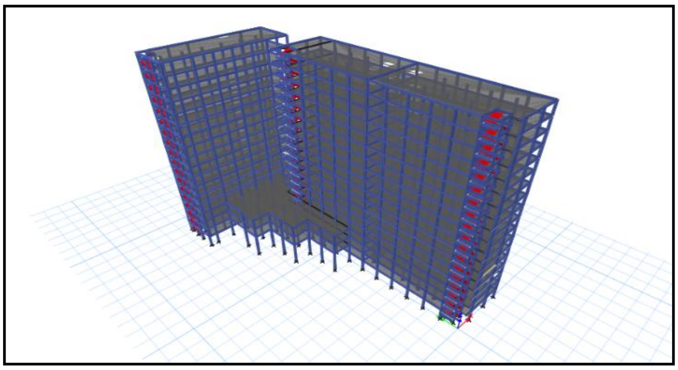

Fig. 4. Slabs placed

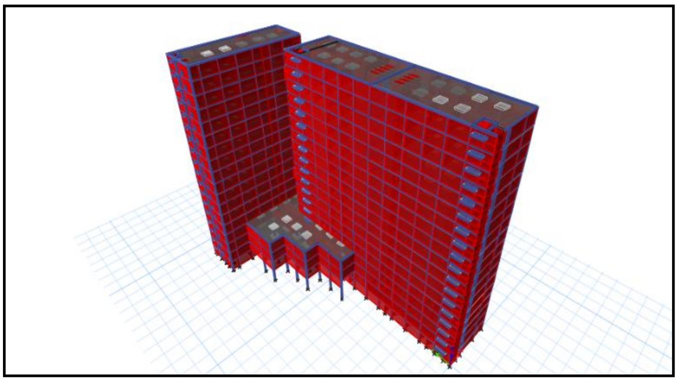

Fig. 5. Walls placed

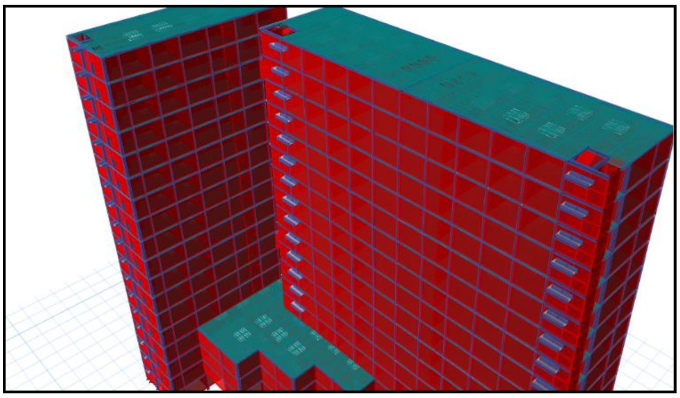

Fig. 6. Tendons placed

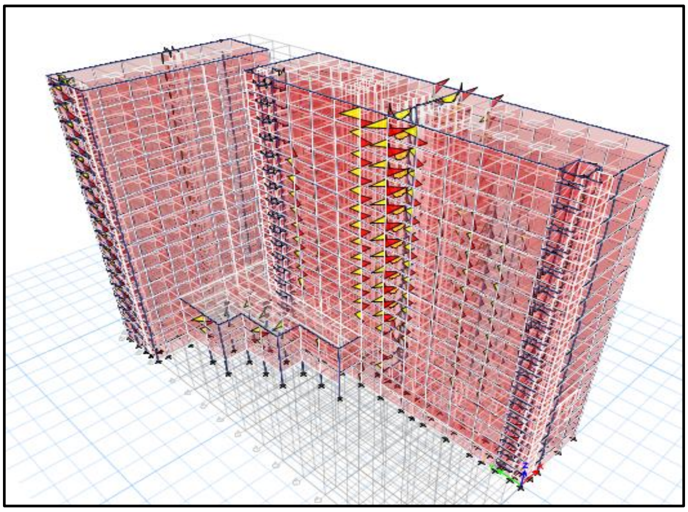

Fig. 7. Bending moment diagram

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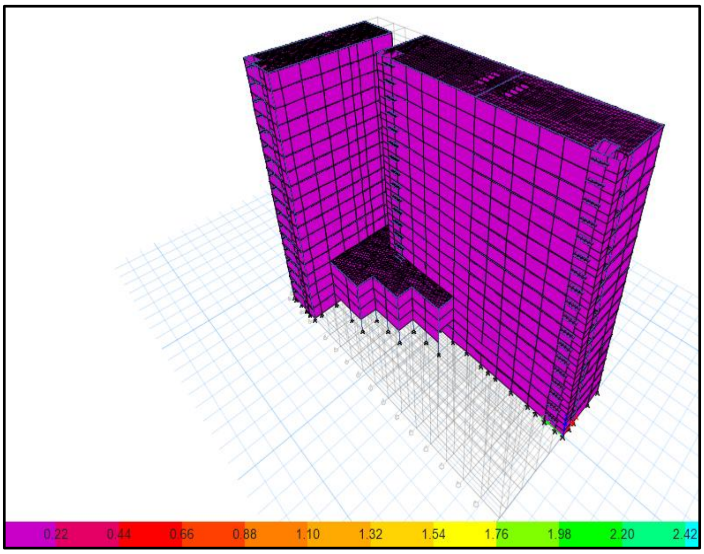

Fig. 8. Deflection in mm

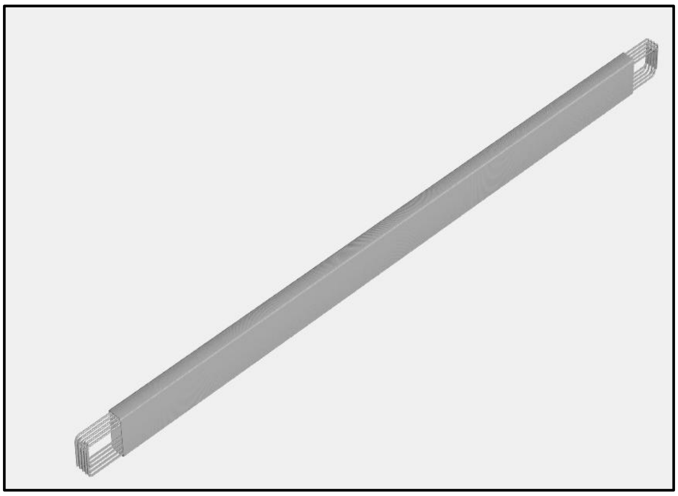

Fig. 9. Cage view of beam

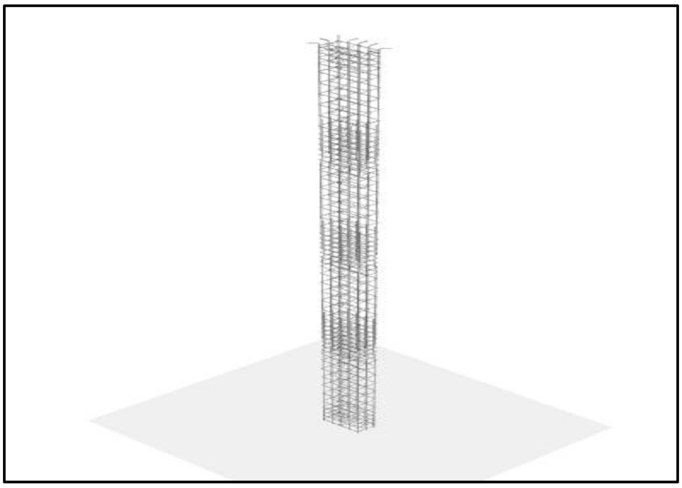

Fig. 10. Cage view of column

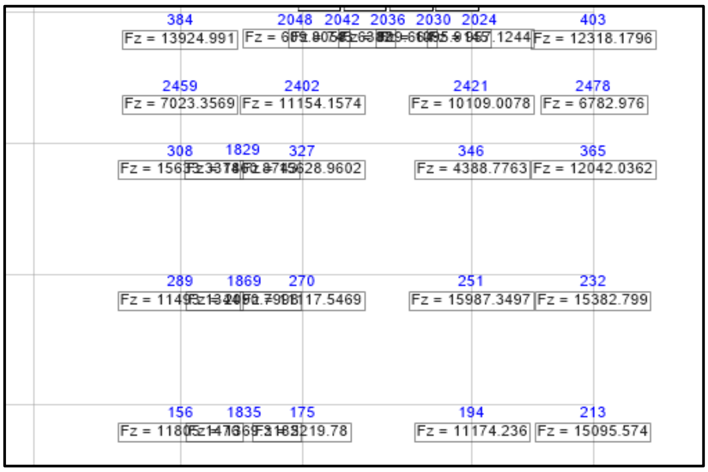

Fig. 11. Reactions on column in kN

E. CONCLUSION

I. Our project deals with provision of earthquake and wind resistance structure.
II. Minimum sizes of column and beam provided was C500*500 and B300*500.
III. Seismic analysis was done by using ETABS software.
IV. All the members were passed in design.
V. As building is post tensioned one, it proves to be economical.

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