Comparative Study between Precast and Cast In-Situ Structure Under Combination of Dynamic Loads and Connections between Precast Elements

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Abstract— Precast building system offers a wide range of benefits and advantages to the designer to meet all the client`s requirements. The rapid growth in usage of precast systems demands the improvement of its structural behavior when it is subjected to dynamic loads. This Project deals with the analysis and design of Precast Substation building with Crane (5tons capacity) subjected to Dynamic loads due to Earthquake. In order to justify its structural behavior, the cast in-situ structure is also analyzed and compared with precast structure. Hence in this project, the substation building of 78m (length) x 22m (breadth) x 9.6m (height) is designed by considering various loads such as Dead load, Live load, Soil load, Wind load, Seismic load and Crane load as per IS 875: 1987 (Part – I, II, III & V), IS 1893: 2002, IS 456: 2000 and the other guidelines for the crane loads. Seismic loads are calculated using seismic coefficient method and base shear values were obtained. Further the substation building is modeled and analyzed using STAAD.ProV8i software. Both Static and Dynamic analysis (Response Spectrum Analysis) is performed in it. Then from the obtained STAAD.ProV8i results, the various structural elements were designed and quantity estimated. Finally, by using above results, the behavior and quantity comparison between precast and cast in-situ structures were done and conclusion is given.

Key words: Precast structures, substation building with crane loads, seismic resistant structure, dynamic analysis in STAAD.Pro V8i, comparative study between precast and cast insitu structures, connection for precast

I. INTRODUCTION

Precast concrete structures offer a wide range of benefits and advantages to the designer to meet all of the client`s requirements. Its most dramatic benefit will be speed with which it can be designed, cast, delivered and erected. This can ensure that projects stay on schedule and meet tight deadlines. Precast concrete components can be erected shortly after foundations are ready and can be installed quickly, often cutting weeks or months from the schedule.

Seismic resistant design for substation building should provide a level of safety for the workers in and around the substation in the event of Earthquake. The fatalities and serious injuries by collapse of substation building onto the persons are not only due to earthquake but also in addition to the dynamic loads from crane that operates during such seismic conditions. This leads to our objective to reduce the probability that, the building itself becomes a hazard in an earthquake. It is more relevant for Substation buildings with cranes which need to be under operation without a break and cranes handling materials of weight five tons or more.

The function of the crane girders is to support the rails on which the traveling cranes move. It is a component which acts as laterally unsupported beam. An Electronic Overhead Travelling crane which is normally called as EOT Cranes are mainly used for material movements in substation buildings. Their design features vary widely according to their major operational specifications such as type of motion of the crane structure, weight and type of the load, location of the crane, geometric features, operating regimes and environmental conditions.

II. OBJECTIVE

The main objective of this project is design of Precast Substation building with crane that is subjected to earthquake loads which must resist dynamic loads due to earthquake without complete failure or collapse of the building or crane or both, which may interrupt power supply and comparative study of designed precast structure with conventional cast in-situ structures in terms of functionality and structural behavior during earthquake. Finally, connections needed for precast elements were discussed.

III. GEOMETRY AND NATURE OF THE SUBSTATION BUILDING

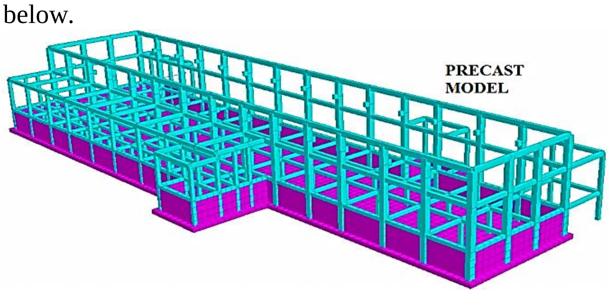
Location of the substation	=	Chennai
Structure details	=	One Storey with basement floor
Length of the building	=	77.818m
Width of the building	=	21.48m
Height of the building	=	+9.6m from G.L
Bottom of the Raft	=	- 3.4m from G.L
Basement floor level	=	- 2.9m from G.L
Seismic Zone	=	Zone – III
Wind Zone	=	Zone – V
Crane capacity	=	5 tons
Soil conditions,		
Bearing Capacity	=	200kN/m2
Density of Soil	=	18kN/m3
Angle of Friction	=	30˚

Nature of Structural Elements,

In Precast structure, every member at the Superstructure was precast members (Beams, Columns, Roof slab) and it is connected to the cast in-situ substructure by providing proper and suitable connections among various joints of the precast elements.

IV. MODELING OF THE STRUCTURE

The substation building for both precast and cast in-situ structure is modelled in STAAD.Pro V8i software for further analysis. The rendered view of the model is shown in Figure-1 below.



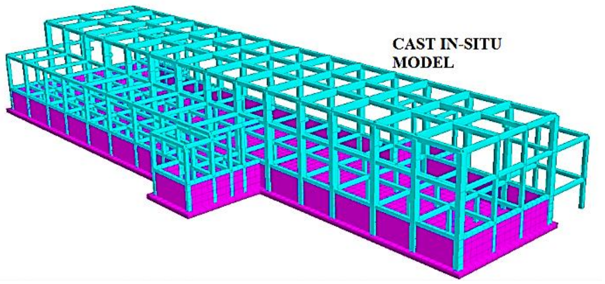


Fig. 1: Rendered view of Substation building

V. ANALYSIS OF THE STRUCTURE

For the better behaviour study, both the static and dynamic analysis is performed in STAAD.Pro.

For simple regular structures, analysis by equivalent linear static methods is often sufficient. This is permitted in most codes of practice for regular, low- to medium-rise buildings. In this analysis only the first mode in each direction is considered.

Linear dynamic analysis which is the Response Spectrum Analysis, measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of a structure. It gives the peak or steady-state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency.

VI. DESIGN OF THE STRUCTURAL ELEMENTS

Using the results from above mentioned analysis, the design of every structural elements at the superstructure of the substation building were done based on the IS limit state design codes and provisions. This design results were tabulated and estimated for amount of material (concrete and steel) quantity required for precast and cast in-situ structure. These results were discussed and compared below.

VII. COMPARATIVE STUDY BETWEEN PRECAST AND CAST IN-SITU STRUCTURE

A. *Structural Model Comparison:*

From the STAAD.Pro model (Rendered view) Figure-1, it is understood that the usage of Precast Double Tee slab at roof eliminates huge number of secondary beams at roof level for precast structure, thereby saving more material and cost of the project. In cast in-situ structure the secondary beams exists at roof level to transfer the load from cast insitu slab.

B. *Overall Weight Comparison:*

The below chart implies the overall self-weight comparison between precast and cast in-situ structure. (Including substructure weight). This weight is derived from STAAD.pro analysis results.

Thus this chart indicates that our single storey Precast structure having the self-weight of 6.7 % more when compared to cast in-situ structure.

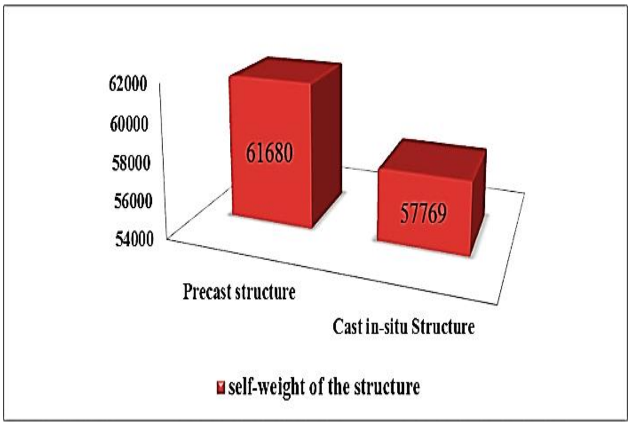


Fig. 2:

C. *Base Shear Comparison:*

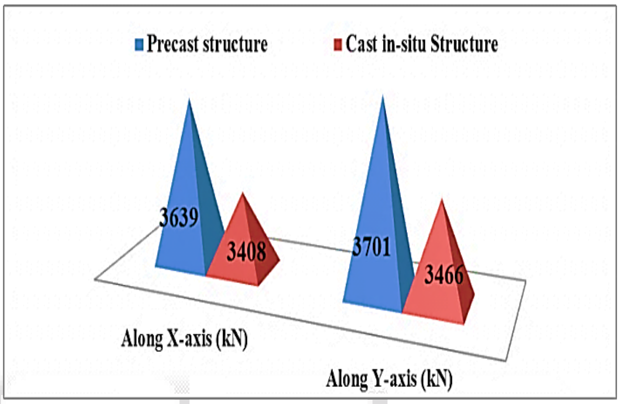


Fig. 3:

Precast structure base shear capacity is 7% more when compared to cast in-situ structure, so precast structure withstands more Base shear than Cast in-situ structure.

D. *Time Period and Frequency Comparison from Response Spectrum Analysis:*

After performing dynamic analysis in STAAD.Pro software for 90% mass participation of the structure, it gives the result for time period and frequency variation for different mode of applied load as shown in below table.

	TIME PERIOD	FREQUENCY
	Seconds	Hertz
PRECAST STRUCTURE	***49.89***	***52.31***
CAST-INSITU STRUCTURE	***36.85***	***50.54***

Table 1:

From the above table it can be concluded that, the Precast Structure takes more time period for its 90% mass participation, so it is More Efficient (withstands longer duration under seismic forces) when compared to cast in-situ Structure.

E. *Mode Shape Comparison:*

As per IS 1893:2002, the number of modes to be considered for analysis of the structure should be such that the total sum of modal masses of all modes is atleast 90% of the total seismic mass. Hence for our both precast structure (PCS) and cast in-situ structure (CIS), it takes around 500 modes to attain the 90% mass participation. This variation of mode for mass participation of both the structure at its x-direction is shown below.

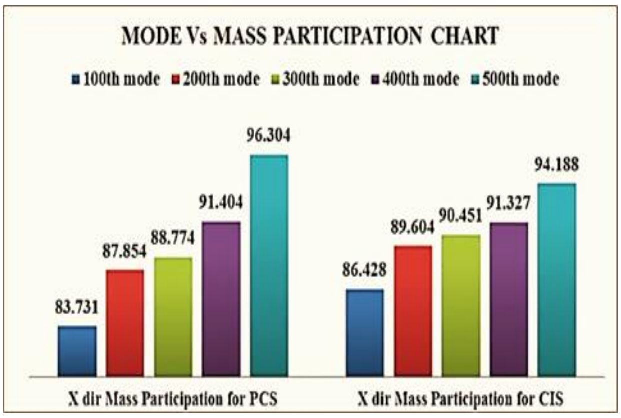


Fig. 4:

F. Structural Element Behaviour Comparison:

Precast beams were rigidly connected to the column corbel by bolting or welding and it acts individually as a single member. These precast beams behave like simply supported since it is discontinuous at their supports. Therefore there will be maximum bending moment at midspan and zero bending moment at the support as shown in fig below. The maximum tension reinforcement is required at the midspan bottom portion but at the supports the minimum reinforcement is enough.

At the cast in-situ structure beams run continuously thereby acting as a continuous beam. Hence there will be varying maximum bending moments both at midspan and the supports as shown in fig below. The tension reinforcement is required at both midspan as well as support.

G. Material Usage (Concrete & Steel) Comparison Based On Quantity Estimation From Design:

After performing analysis in STAAD.Pro, using those analysis results the design of structural elements were done for both precast and cast in-situ substation building as per IS codal provisions and few standard PCI structural elements data.

The design is done only for superstructure because, for both the cases the substructure is cast in-situ. From the design results, the quantity estimation is done and comparison is made between precast and cast in-situ structure. Those comparisons are discussed below.

– Quantity comparison for superstructure beams:

From the beam design results, the estimation of concrete and steel quantity required for superstructure beam is calculated. This comparison is done by estimating the quantity for all the beams that present at the superstructure as shown in the chart below.

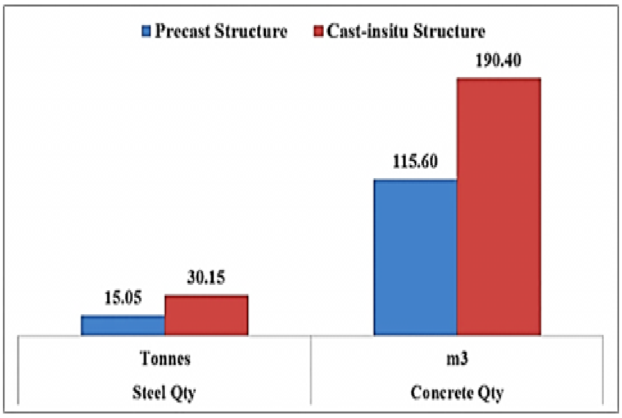


Fig. 5:

This chart concludes that the precast beams at superstructure of the substation building save around 50% of steel requirement and 40% of concrete requirement.

– Quantity comparison for superstructure columns:

The chart below shows the steel and concrete quantity comparison between precast column elements and cast in-situ columns at superstructure.

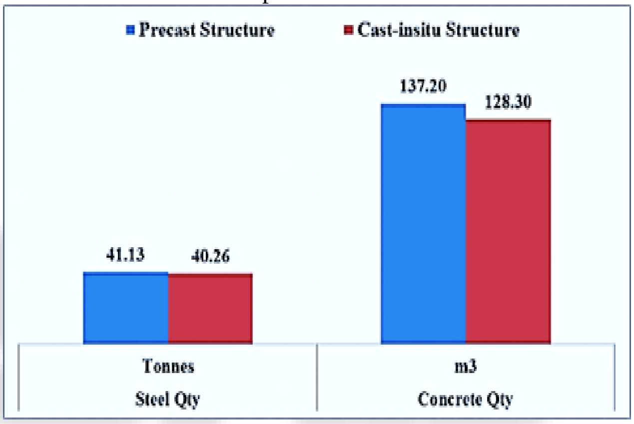


Fig. 6:

From the chart, we can say that the precast column elements requires around 3% more steel and 7% more concrete when compared to cast in-situ column.

Further from the above charts, it can also be witnessed that the quantity required for precast column elements is much greater than the precast beam elements. Whereas in cast in-situ structure this quantity difference is lesser than precast structure. So we could conclude that the precast structure follows the “STRONG COLUMN AND WEAK BEAM” approach well better than the conventional cast in-situ structure.

– Quantity comparison for roof slab elements:

The precast structure utilizes the Double Tee slab for roof, but the cast in-situ structure is laid with conventional roof system. The chart below shows the steel and concrete quantity requirement comparison between both the structures.

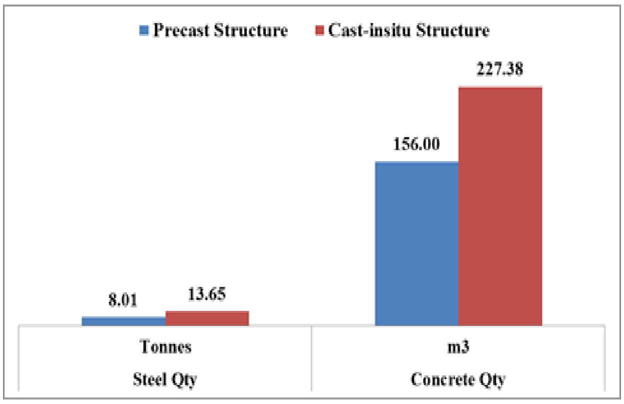


Fig. 7:

On comparing the quantity requirement for roof slab from the chart, Precast DT slab saves 42% of steel and 32% of concrete than cast in-situ slab. But for DT slab ½" Prestressing Strands were utilized, so it is little expensive for its usage.

VIII. CONNECTION FOR PRECAST STRUCTURE

A. Connection Between Precast Column And Cast In-Situ Column:

This connection is obtained through steel sockets inserted in the column base and bolted to the steel plate that is welded over the top of the in-situ column. The sockets are anchored to the column by means of bars welded to them and spliced to the current longitudinal reinforcement by lapping. Other transverse links can be welded to the sockets to avoid their lateral detaching. After bolting the gap is filled with Non-Shrink Grout.

At installation stage the column can be supported by lock-nuts screwed on the fasteners, by which its verticality can be adjusted and maintained without the need of provisional props. The installation is completed with the tightening of the upper nuts and the casting of the mortar embedding to fill the joint between the precast column base and the insitu column. This bed shall be sufficiently thin to avoid the buckling of the fasteners within the gap when subjected to strong compression otherwise a proper confining reinforcement shall be added. The typical detailing of column to column connection that is required for the substation building is shown below.

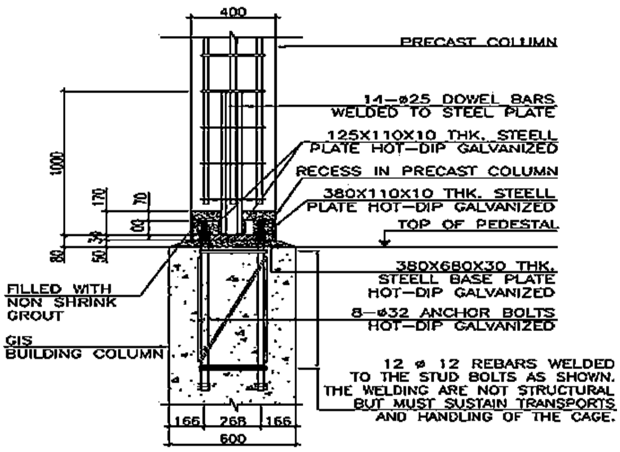


Fig. 8:

B. Connection Between Precast Beam And Precast Column:

There can be two cases for end connection of a beam to a supporting column. In case (a), dowel bar protrude from the top of the column corbel and enter into the sleeves inserted in the beam. The sleeves are filled with non-shrinkage mortar of adequate strength to ensure the bond anchorage of the dowels. The anchorage can also be ensured providing the dowels with a cap fixed at the top with a screwed nut. In any case the sleeve shall be filled in with mortar to avoid hammering under earthquake conditions. In case (b), the steel angle plates with studs were welded to the reinforcement of column elements before precasting. It is then lapped together with the connecting steel angle plates of beam element and field welded.

The beam usually is placed over shims/pads to localise the load. If deformable rubber pads are used, due to their much lower stiffness all the loads applied after their bond anchorage will be conveyed into the steel dowels. And this will cause a local splitting damage of the concrete around the dowels. The use of rigid steel pads will prevent this effect. To avoid local splitting damage, rubber pads can be used with non-adherent dowels. So by considering this procedure the typical connection used for our structure is shown below.

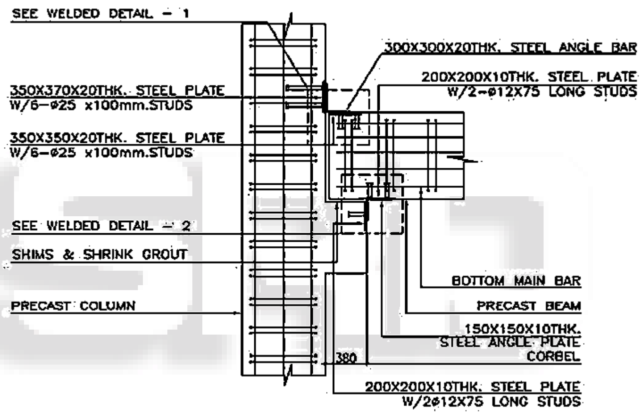


Fig. 9:

C. Connection Between Precast DT Slab and Precast Beam:

Connection between Double tee slab (DT slab) elements and supporting beam is done by providing proper links that protrude from the upper side of the beam, overlapped to those protruding from the precast Parapet wall element, which is further connected to slab through dowel bars and finally screed concreted.

Initially the beam and parapet wall elements were assembled and the dowels were connected to the corresponding sleeves, bolted and grouted to avoid further movement. Then the DT slab is placed over the beam on its ribs and its protruding dowel from the slab portion is tied to the parapet wall dowels. Finally, the screed of required thickness is laid over the DT slab and the joints between beam, parapet wall and slab to form a monolithic connection. The typical detailing of this DT slab and beam connection is shown below

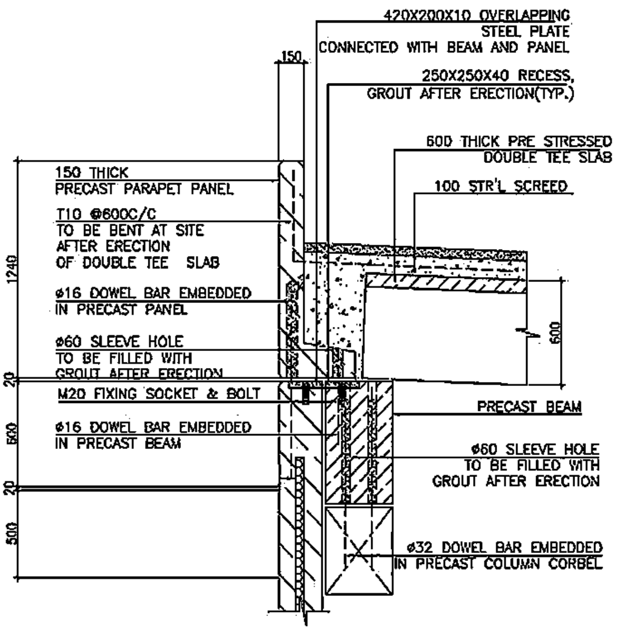


Fig. 10:

IX. CONCLUSION

The substation building with crane was considered to be held at a seismic zone and was analysed & designed for both the precast and cast in-situ structural systems. The overall comparative study between precast and cast in-situ structure specifies that the precast substation building shows superior behaviour than cast insitu building under seismic conditions and also on effective usage of materials over structural elements. Further it can be concluded that, by utilizing proper and better connections between precast elements it will an efficient building system under the combination of dynamic loads from earthquake and crane.

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