High Performance and Efficiency of Joints in Precast Members

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***Abstract*— The use of precast element enables the possibility of developing and simplifying the construction and facilitates the introduction of new technological methods. The usage of precast concrete began about 70 years ago. Till now the technology has maintained its status in the construction industry as "The Least Understood form of Construction". The advantages of the pre-cast construction are not explored by most part of the world especially by the developing countries. In the competition between precast and monolithic structures, prefabrication gains an ever increasing prominence because it is accompanied by the improvement of quality, while the requirement in materials, working time and cost shows a decreased tendency. This paper presents the results of a two dimensional 3-bay G+5 storeyed prefabricated frame subjected to lateral loading. The joints in beam column junction and joints in beam to beam connection were strengthened by specially designed steel bolts and L-angles by welding and bolting. The frame was subjected to lateral cyclic load until failure. The results are compared with ANSYS model. The efficiency and performance of beam-column joints and beam-beam joints were studied and the behaviour of prefabricated frame is compared with monolithic frame.**

Key words- Precast Concrete- GFRP Fibers-High Strength Concrete-Beam-Column Joints.

I. INTRODUCTION

Prefabrication is an advanced and up to date method of reinforced concrete construction. In the comparison between precast and monolithic structures, prefabrication gains an ever increasing prominence, because it is accompanied by the improvement of quality, while the requirement in materials, working time and cost show a decreased tendency. The cost of monolithic reinforced concrete structures is distributed into three nearly equal parts: cost of concreting, of reinforcement, shuttering and scaffolding. For halls of great height the cost of shuttering might even reach 60 percent of the total cost. Therefore solution should be sought to diminish the considerable costs of the form work, due to chiefly to the great consumption of shuttering. The prefabrication of reinforced concrete structure is a solution appropriate for the mentioned purpose. In order to assess and evaluate the earlier work done on precast concrete frames and to identify the effective load resisting structure, a detailing review of literature has been undertaken.

Reference [1] studied the seismic response of precast concrete frames with hybrid connections. The enhanced and versatile model was developed to represent the inelastic behaviour of hybrid precast connection region. Reference [2] studied Simulated Seismic loading of a two-story precast reinforced concrete building. In that behaviour of precast building subjected to seismic loading. The performance of a precast concrete beam-to-beam connection subject to reversed cyclic loading was studied by [3]. The test results of four types of ductile, moment-resisting precast concrete frame connections and one monolithic concrete connection, all designed for use in high seismic zones was presented by [4]. The performance of the precast concrete connections subject to displacement control reversed cyclic loading is compared with that of the monolithic connection.Reference [5] evaluated about Seismic assessment of existing precast industrial buildings using static and dynamic nonlinear analyses. The presented research study shows that existing industrial precast buildings can be affected by severe damages under medium seismic intensity seismic forces because of beam–column connection failure The advantages and construction methods in precast concrete construction, precast concrete technology in high rise and long span construction was briefly analysed by [6]. Reference [7] carried out a nonlinear finite element (FE) analysis of ductile concrete connections.

This research paper focuses on the study of performance and efficiency of connections in members of a 3-bay G+5 storeyed precast frame with various connections subjected to lateral cyclic loading and to compare the results with that of a control frame.

II. MATERIALS USED

The details of materials used in this research work are as given below.

A. Materials used

The materials used are Ordinary Portland Cement of 53grade conforming IS-12269, and the properties of fine aggregate and coarse aggregate are given in Tables I and Table II. The aggregates used were maximum of 12.5mm and confirming to BIS 383-1970. Potable water is used for casting of concrete and Fe415 grade steel is adopted.

TABLE I
Properties of fine aggregate

Properties	Test Results
Fineness Modulus	2.2
Specific Gravity	2.7
Zone	III

TABLE III
Properties of coarse aggregate

Properties	Test Results
Specific Gravity	2.72
Water Absorption	0.15%

B. Mix Proportion

Two types of concrete mixes M20 and M60 were adopted. The properties adopted are as follows in weight basis.

For M20 Grade of concrete design based on IS 10262 - 2009

Cement:		FA	:	CA	:	W/C
1	:	1.48	:	3.33	:	0.5

For M60 Grade of concrete design based on ACI code

Cement:		FA	:	CA	:	W/C
1	:	1.36	:	2.2	:	0.28

III. EXPERIMENTAL INVESTIGATION

A. Methodology

In this precast frame model various types of joints were designed and the following two types of joints were studied experimentally.

1. Joints in beam column junction
2. Joints in beam to beam connection

In above mentioned, the connection is strengthened by the help of Steel bolts and L- Angles by welding and bolting. Then both are bonded to the reinforced concrete beam using welding and bolting, such that the steel materials tied with all around the beam as well as beam column joint. The two different types of models were cast and tested by applying lateral cyclic load. The load deflection behaviour as well as the modes of failure was studied. The results are compared with the model cast by monolithic construction.

B. Proportioning of Concrete

The details of the types of frames cast for testing are given in Table III.

TABLE IIIII
Types of frames cast for testing

Sl. No	Frame ID	Type of Specimen	Prefabricated Pattern
1	CF	Control frame 3bay x 5 storey	-
2	PS-I	Prefabricated frame 3bay x 5storey	Beam column joint connection

C. Dimensions of the model prefabricated frame

To study the behaviour of prefabricated frame under lateral loading, a series of two frames were cast. Out of two frames, one of the frames is control frame and the other one is prefabricated frame. The raft footing is of size 1600 mm x 800 mm having a thickness of 150 mm and with four numbers of columns. The size of the columns is 150 mm x 100 mm and that of beams is 100 mm x 100 mm.

D. Reinforcement details of control frame

The longitudinal reinforcement adopted for the columns and beams were HYSD bars of different sizes. For the first and second columns, six numbers of 10 mm dia bars were provided. The reinforcement was curtailed in the upper stores due to reduction in axial forces and bending moments. For the third, fourth and fifth storey columns, four numbers of 10mm dia bars were provided. For all the beams, four number of 8 mm dia bars were provided as the beams have same strength. The transverse reinforcement, in the form of closed rectangular two legged stirrups of 6 mm dia rods were provided at 30 mm c/c near the end of the beams, whereas in the middle portion of the beams the spacing was adopted as 60 mm c/c. similarly, for the columns, the spacing for lateral ties near the beam-column junction was 40 mm c/c and 80 mm for the remaining portion.

E. Types of joints adopted for the Prefabricated frame

For the prefabricated frame various types of Beam-column joints like L-joint, T-joint and Crossed – joint were adopted and the Figures 1(a), (b) and (c) shows the joints in the frames. The reinforcement for entire prefabricated frame is shown in Figure 2.

Fig. 1(a). L-Joint

Fig. 1(b).T-Joint

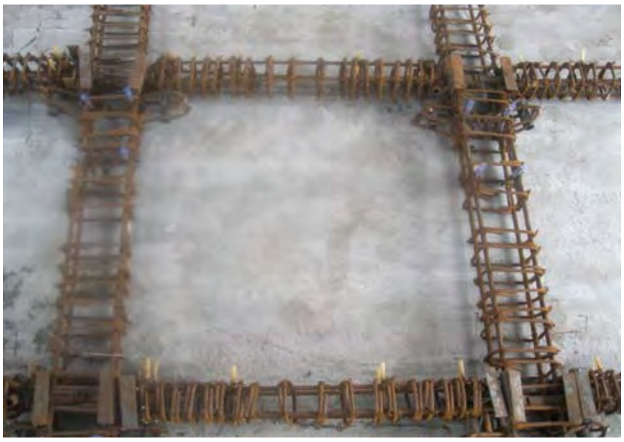

Fig. 1(c). Crossed Joint

Fig. 2. Reinforcement for Prefabricated frame

F. Casting of Precast multi-storey precast frame

A 1/4th scale three bay five storey precast reinforced concrete frame representing multistorey system is analysed and designed for gravity loads. The beam, column and the foundation block were cast separately and assembled together by means of connections made of steel flats, bolts and welds. The beams and columns of the precast model frame during casting is shown in Figure 3(a) to Figure 3(c). The frame during assembling is shown in figure 4.

Fig. 3(a). Mould and reinforcements for preparation of precast beam and column specimens

Fig. 3(b). Concreting of precast column and completed beam specimens

G. Assembling the test set up

The various connections were strengthened by the help of steel bolts and L-angles by welding and bolting. The column is bonded to the reinforced concrete beam by welding and bolting, such that the steel materials tied with all around the beam as well as beam column joint. The bolts and L-angles used for assembling the members of the precast frame are shown in Figure 4. The precast beams, with both side sleeves, column complete with corbel and beam to column connection with the help of L- angle and bolts is shown in Figure 5 and the assembling of members is shown in Figure 6.

Fig. 4. Steel bolts and L-angles used for connection of joints

Fig. 5. Connections of Beam-column joint using Steel bolts and L-angles

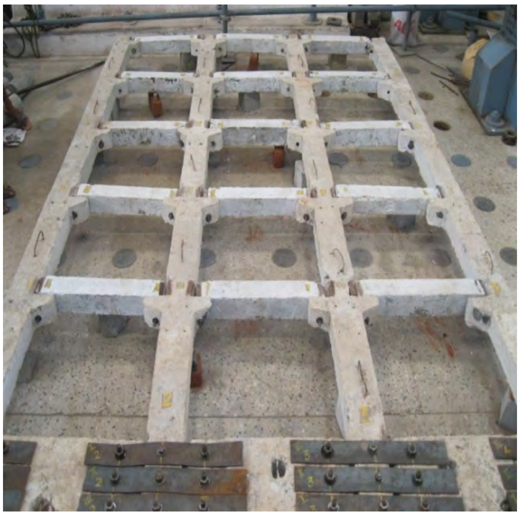

Fig.6. Assembling of Prefabricated model frame

H. Test set up

The model frames were tested as vertical cantilevers under a cyclic loading programme. The schematic diagram of test set-up is presented in Figure 7. The reaction frame, which is used for loading arrangements, is rigidly fixed to the test floor. A common console controlled all the jacks. Pressure gauges are used to measure the applied load. Lateral cyclic loading is applied at first and second storey levels in line with the beams using hydraulic jacks of capacity 500 kN. The lateral movement of the frames at the ultimate load stages is avoided by providing suitable guides using mild steel pipes. LVDT (Linear Variable Differential Transducer) of least count 0.01mm are used for measuring deflections at top and bottom storey levels as shown in Figure 7.

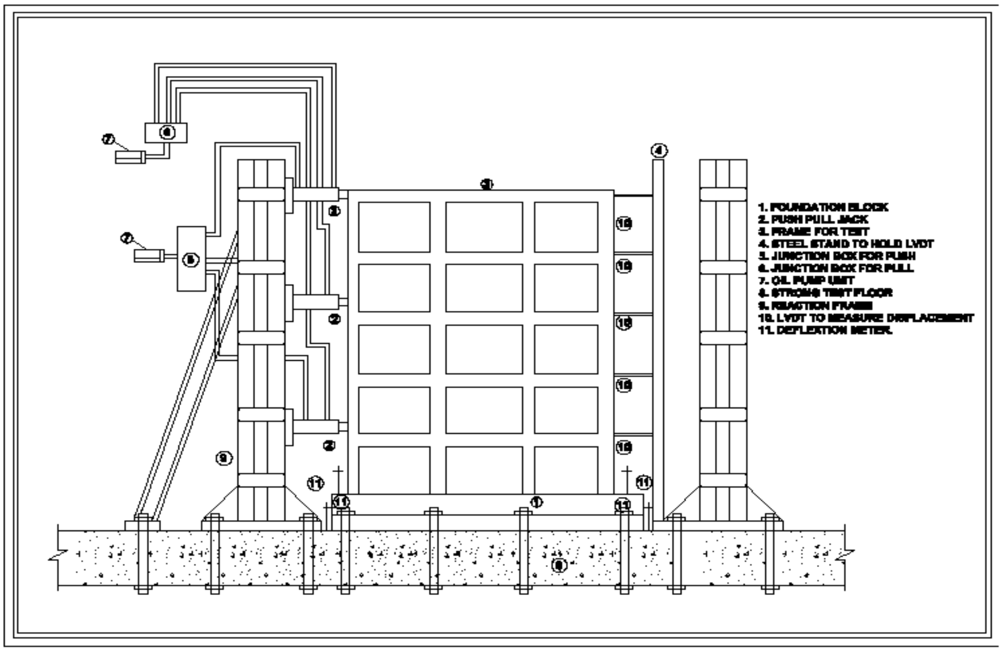

Fig. 7. Schematic diagram of test set up

An additional LVDT is placed at the top level of partial infill to identify the behaviour of column portion adjacent to the partial infill. The rigid body rotation of the frame with respect to foundation block is avoided by providing mild steel channels and horizontal rods on both edges of the specimen at the top of the foundation block. However the displacement due to rigid body rotation, if any, is measured by providing deflectometers on the sides of the footings. For measuring strain in steel, steel studs are welded to main reinforcement before casting the frame. DEMEC (Demountable Mechanical strain gauges) points are pasted for measuring strain in steel. For measuring surface strain on concrete and infill material, DEMEC points (pellets) were pasted to beam and columns faces of the RC frame and also on the surface of infill. Also DEMEC points are pasted on column-brick joints to measure the strain at the bond between column and the masonry.

IV. RESULTS AND DISCUSSION

A. *Initial cracking and ultimate load of frames*

The frames were subjected to lateral cyclic load and tested up to failure. Both the frames showed an increase in the initial cracking and ultimate load. The deflected precast frame is shown in Figure 8.

Fig. 8. Precast model frame after testing

Both the frames showed an increase in the initial cracking and ultimate load .The Table IV shows the details of initial crack load, ultimate load and ultimate deflection given below.

TABLE IVV
Experimental Results of Control frames, Prefabricate frame-I, Prefabricate frame-II

Frame ID	Experimental Observations		Deflection at Ultimate Load (mm)
	Initial Crack Load (kN)	Ultimate Load (kN)	
CF	32.8	189.9	33
PS-I	76	210	43.2

B. *Load deflection behaviour of frames*

From the experimental results, Load vs Deflection graphs are plotted for all the frames. The load deflection curve plotted for deflection at various heights of the column like bottom, middle and top of the column. Load deflection curve for three frames are compared given below:

1. Load deflection curve for control frame
2. Load deflection curve for Prefabricated frame-I

C. *Load – Deflection Behaviour Based on Type of Connection*

The initial crack load, ultimate load and deflection at ultimate load observed for the control frame are 32.8 kN, 189.9 kN and 33 mm respectively. Whereas the initial crack load, ultimate load and deflection at ultimate load observed for the precast frame are 76 kN, 210 kN and 43.2 mm respectively. The graph indicating base shear and deflection at various positions of the precast frame is shown in the Figure 9. The Load – Cycle number graph for bare frame is shown in Figure 10.

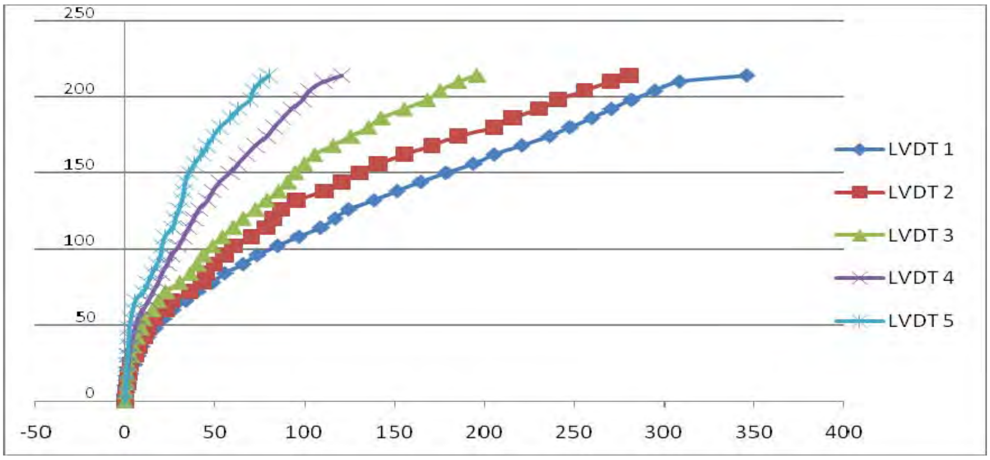

Fig. 9. Load deflection curve for control frame

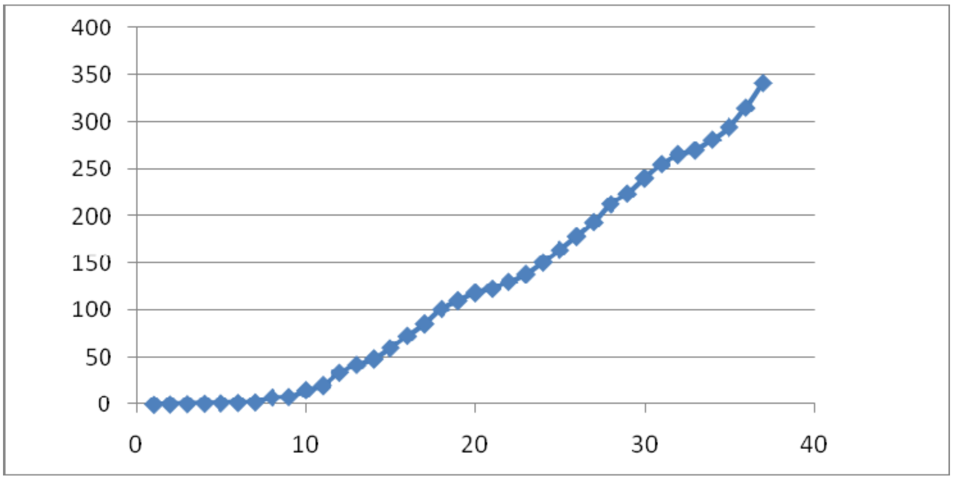

Fig. 10. Load deflection curve for Prefabricated model

V. CONCLUSION

The following conclusions were drawn for prefabricated frame specimen subjected to lateral cyclic loading based on experimental results.

- For the conventional frame, the ultimate base shear of 189.9 kN was reached in th 14^{th} load cycle whereas for the prefabricated frame specimen it was 210 kN in the 14^{th} cycle of loading.
- The storey deflection for the conventional frame, was 33 mm in the 16^{th} cycle of loading and that for the prefabricated frame specimen it was 43.2 mm in the 16^{th} cycle of loading.
- From the above results, it is concluded that among the two frames, PS-I nearly reaches the ultimate load of control frame, and the variation in deflection is also small. Hence, the prefabricated model performs somewhat efficiently compared to the conventional models.

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