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BEHAVIOUR OF THE PRECAST PORTAL FRAMES UNDER LATERAL LOADING

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ABSTRACT

Nowadays, there is an increasing trend towards construction of buildings using precast concrete. In precast concrete construction, all the components of structures are produced in controlled environment and they are being transported to the site. At site, such individual components are connected appropriately. In precast construction, ductility is essential for providing protection against the effects of unexpectedly large lateral forces. Dry connections in a precast structure usually introduce discontinuities in strength and stiffness which is expected to attract deformations and damage under lateral load during an earthquake. Therefore, it is important to study the behaviour of precast connection under lateral loading, since slender structures are mostly sensitive to lateral forces. In this paper, experimental study of behaviour of precast portal frame with different connection detailing under lateral load is reported. Experiments are conducted on three test specimens including one monolithic portal frame and two portal frames having precast connections with cleat angle and with reinforced concrete (RC) corbel, that are subjected to lateral load. Performance of test specimens are evaluated in terms of load carrying capacity, deflection profile of columns and measurement of strain at critical locations on concrete surface as well as steel reinforcement bars and failure pattern. From the results, it is observed that behaviour of precast portal frame having beam column connection with cleat angle is almost similar as that of monolithic portal frame.

Keywords: Precast portal frame; lateral load; RC corbel; cleat angle; dry connection.

1. INTRODUCTION

The concept of precast construction includes buildings, where the majority of structural components are produced in plants under controlled environment and then transported to the site for assembly. The precast elements are connected either by mechanical means or by embedding reinforcements in preformed ducts which are subsequently filled by grouting.

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Accordingly, the precast connections are known as dry or wet connections [1]. This leads to faster construction, reduced formwork and scaffolding, less requirement of skilled labours, massive production with reduced amount of construction waste, better quality and better surface finishing as compared to typical reinforced concrete construction. Because of such advantages, the precast concrete construction is considered as sustainable construction technology being adopted world-wide. In precast concrete construction, connections are the critical elements of the structure, because in past, major collapse of precast buildings took place because of connection failure [2-4]. The connections between precast elements affect the load distribution, strength, stability and constructability of the global structure. Therefore, it is very important to evaluate the performance of precast connections through experimental study. The poor behaviour of precast concrete building structures during earthquakes are due to the improper design and detailing of element, inadequate diaphragm action, poor joint and connection details, inadequate separation of non-structural elements and inadequate separation between structures.

Vidjeapriya and Jaya [5] compared the performance of precast beam column connection with that of monolithic connection under reverse cyclic loading. For experimental investigations, one monolithic and one precast test specimen of 1/3rd scale model was considered, which was extracted from exterior beam column joint of a three storey reinforced concrete building. In precast specimen, the beam was connected to the column using tie rod and supported on concrete corbel. The precast beam was then connected to the precast column by welding the two steel plates. The steel plate in the column was welded to a dowel bar which was embedded in the column and the steel plate in the beam was welded to the bottom reinforcement of the beam. Parameters such as ultimate load and moment carrying capacity, cracking pattern and failure mode, load-displacement hysteretic behaviour, energy dissipation capacity, flexural over strength factor and displacement ductility was considered to assess performance of test specimens. The results showed inferior performance of precast specimen as compared to monolithic specimen.

Baharuddin et al. [6] discussed the behaviour of a proposed precast concrete beam to column connection using steel plate. Author has compared three precast concrete beam to column connections developed using steel plates with different parameters of corbel length with monolithic connection. The behaviour of the connection was investigated through the moment-rotation responses of connection. The results showed that the length of corbel influences the strength and ductility of connection and longer corbel showed higher strength of connection.

Gopinathan and Subramanian [7] studied the performance and efficiency of precast connections in members of six storey precast frame having three bays. Behaviour of precast frame with different connection detailing under reverse cyclic loading was compared with that of monolithic frame. Response of test specimens was measured in terms of load deflection relationship as well as the failure modes of frame. The results showed better performance of precast frames as compared to conventional frames.

Shariatmadar and Beydokhti [8] reported experimental results of three precast and one monolithic connection in moment resisting concrete frame subjected to constant axial compression and lateral reversed cyclic loads. Three different connection detailings i.e. straight spliced, U-shaped spliced in column, and hybrid U-shaped splice with steel plate within connection region were considered for the study and performance was compared with monolithic specimen. Seismic behaviour of test specimens were assessed with respect to dynamic parameters such as stiffness degradation, energy dissipation, damping ratios and ductility factors. The results showed that behaviour of monolithic specimen was satisfactory in terms of strength and ductility as compared to precast specimens.

Nimse et al. [9-10] investigated performance of different reduced scale precast beam column connections under progressive collapse scenario. Authors have studied behaviour of dry and wet precast connections provided at beam column junction by adopting different connection detailing and observed that precast connections having adequate connection detailing performs similar to that of monolithic connection. Joshi and Patel [11] reported performance of different dry precast connections provided at beam column junction under column removal scenario and its comparison with monolithic connection. From the study, author have observed that performance of precast dry connections was inferior as compared to monolithic connection under column removal scenario, which can be enhanced through adequate connection detailing between precast elements.

Magliulo et al. [12] reported seismic vulnerability of precast concrete structures during two past earthquakes occurred in the Emilia region of northern Italy. Typical connections between precast elements like roof to beam connection, beam to column connection, column to foundation connection etc. were discussed. Based on the study, author has observed that damage to precast concrete structures was mainly attributed to connection failure.

In this paper, behaviour of precast portal frames with different types of connections detailing at beam column junction under lateral loading are presented. For comparison of behaviour of precast and monolithic portal frame, parameters such as load-deflection, load-strain and failure pattern of specimen are considered.

2. DESIGN AND DETAILING OF PRECAST PORTAL FRAME

The workshop building having 9 meter span of beam and column height of 4.5 meter is considered for the study. It has 5 bays in longitudinal direction and 1 bay in transverse direction with 4 meter c/c spacing in longitudinal direction. Overall plan dimensions of the workshop building is 20 m × 9 m, as shown in Fig. 1.

Dimensional analysis has been carried out to establish sizes of test specimens [13]. Each test specimen contains two columns with one connecting beam. Modelling and analysis of building is carried out using ETABS software [14]. Precast building considered for the study is assumed to be located in seismic zone-III (having moderate seismic intensities) with importance factor 1 (residential building) and soil type II (medium soil conditions), according to seismic provisions of IS: 1893 [15]. Self-weight of structural components is considered as dead load in addition to floor finish of 2.25 kN/m^2, Live load of 0.75 kN/m^2 is considered on roof. The resultant internal forces like axial force, shear force, bending moment at beam-column junction due to various load combinations are calculated. Workshop building is analysed by considering different load combinations as suggested by relevant Indian standards [16-17] such as 1.5DL, 1.5DL + 1.5LL, 1.5DL ± 1.5EQ, 1.2DL + 1.2LL ± 1.2EQ, and 0.9DL ± 1.5EQ, where, DL = Dead Load, LL = Live Load and EQ =

Earthquake Load. Out of all considered load combinations, connections are designed for forces developed due to governing load case 1.5DL + 1.5EQ. Connections for precast elements are designed based on forces obtained considering monolithic joint [18-19]. Design and detailing of test specimens having monolithic and precast connections are carried out by following the design provisions of relevant Indian Standards [20].

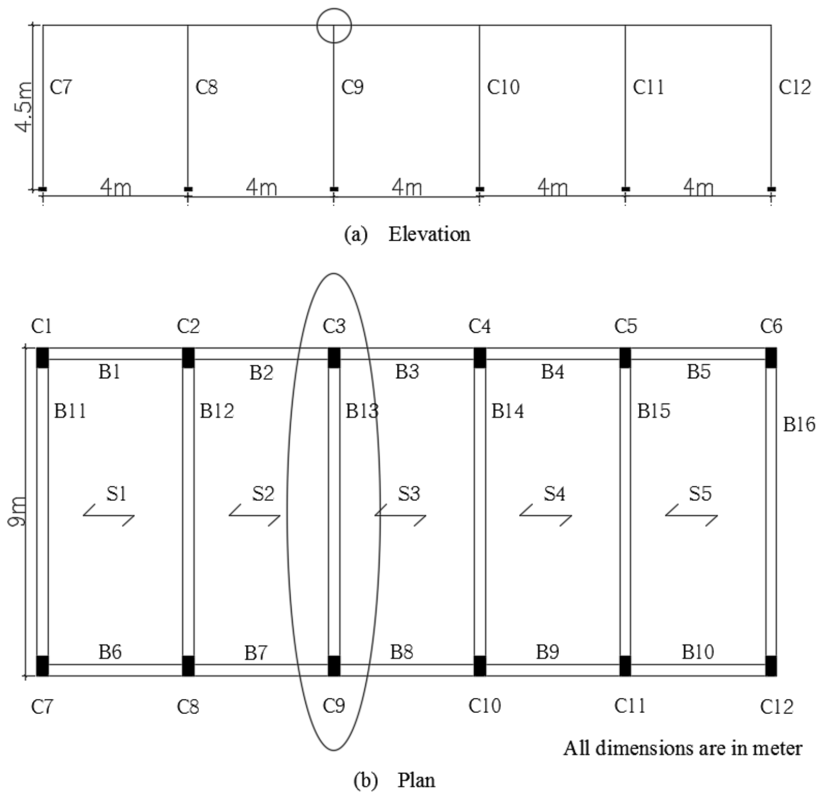


Figure 1. Plan and elevation of the workshop building (structural layout)

One-third scaled models are prepared for monolithic and precast test specimens. The dimensions of the beam are 150 mm depth and 100 mm width. The column are of size 150 mm depth and 100 mm width. Height of the column is 1500 mm. Span of beam is 3000 mm. Closely spaced stirrups are provided at the beam ends near the junction. To avoid the crushing of concrete, closely spaced stirrups are also provided near the ends of column.

In Monolithic portal frame (ML), the longitudinal reinforcement of the beam consisted of two 12 mm diameter bars at bottom of the beam and two 8 mm diameter bars at top of the beam. The shear reinforcement consisted of 8 mm diameter two legged stirrups spaced at 90 mm c/c with spacing of stirrups reduced to 50 mm c/c near the junctions. The column reinforcement arrangement consisted of four 10 mm diameter longitudinal bars and 8 mm diameter lateral ties provided at spacing of 90 mm c/c. At beam column junction and at column ends spacing of stirrups reduced to 50 mm c/c to avoid concrete crushing at top and bottom of column. Typical reinforcement detailing of monolithic portal frame is shown in Fig. 2.

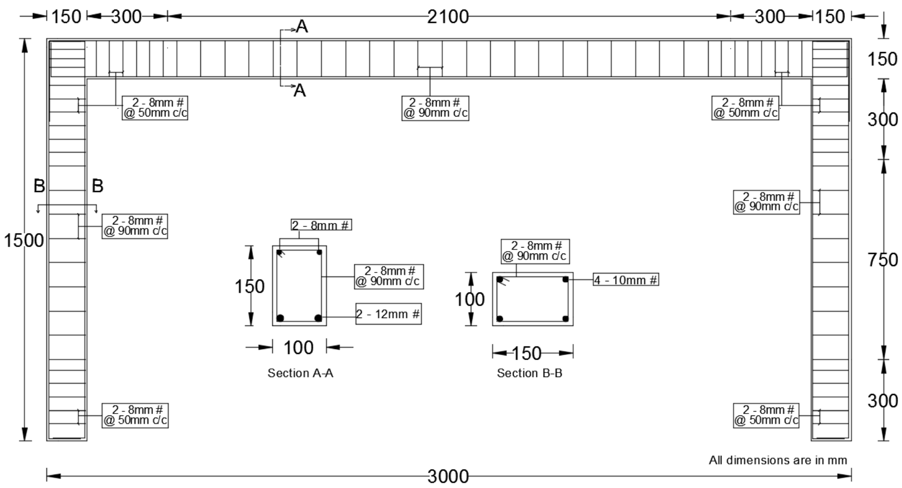


Figure 2. Reinforcement detailing of monolithic portal frame (ML)

In precast portal frame with seated angle (PC-1), four numbers of 8.8 grade high strength friction grip bolts of diameter 16 mm are kept inside the column in which two bolts are vertical and two bolts are horizontal as shown in Fig. 3. While casting of specimen, straight portion of bolts are protruding outside of formwork. The beam is then inserted on to the bolts which are vertical and seated angle is also attached at beam column junction. Non-shrink grout (CEBEX-100) is used to fill the gap between the bolt and the hole in the beam.

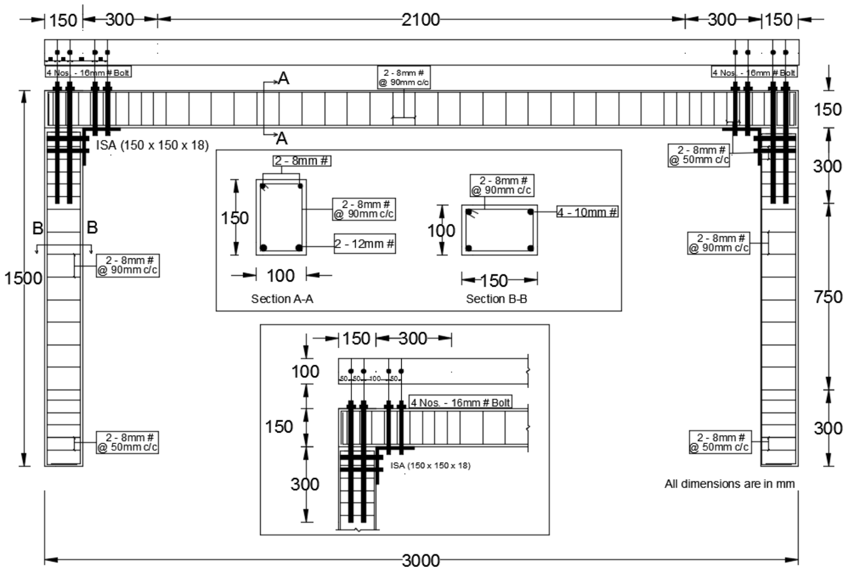


Figure 3. Reinforcement detailing of precast portal frame with seated angle (PC-1)

In precast portal frame with reinforced concrete corbel (PC-2), three numbers of 8.8 grade high strength friction grip bolts of diameter 16 mm are kept inside the column as well as in the corbel and cast by keeping its straight portion protruding outside as shown in Fig.

4. The beam is inserted on to the bolt and then nuts are tightened. Non-shrink grout (CEBEX-100) is used to fill the gap between the bolt and the hole in the beam.

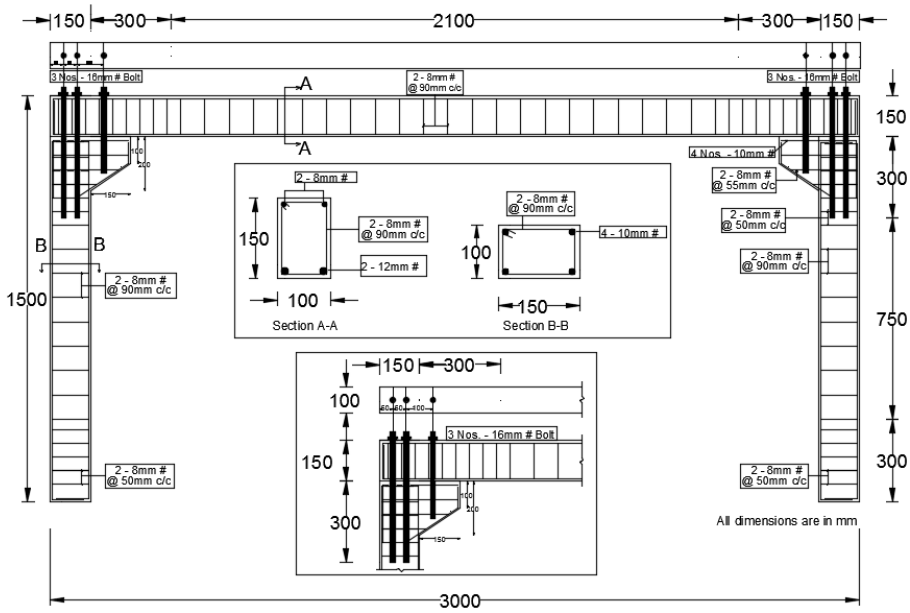


Figure 4. Reinforcement detailing of precast portal frame with corbel (PC-2)

3. CASTING OF TEST SPECIMENS

M25 grade of concrete with characteristic compressive strength of cube as 25 N/mm^2 and Fe500 grade of steel with 0.2% proof stress 500 N/mm^2 are used for casting of all the specimens. Because of reduced scale and small cross section, aggregate of size 10 mm are used. Sand of Zone II and OPC 53 grade cement is used. Specific gravity of coarse aggregates (10mm) and fine aggregate used for casting are 2.81 & 2.55 respectively. Mix design of concrete is carried out according to IS: 10262 [21]. Concrete mix proportion of various ingredients used for casting of test specimens is shown in Table 1. Total 5 batches of concrete mix are produced for casting during experimental program. From each batch, three cubes of 150 mm × 150 mm × 150 mm are prepared to measure the compressive strength of concrete. Strength of concrete is confirmed by cubes which are tested after 28 days of curing period. Average compressive strength of 32.8 MPa is achieved. Wooden formwork is used for casting of monolithic as well as precast test specimens.

Table 1: Concrete mix proportion

Grade of Concrete	Water	Cement	Fine Aggregate	Coarse Aggregate	Plasticisers (Gleniymsky)
	(kg/m^3)				
M25	178.88	357.76	985.28	895.37	2.28
Proportion	0.5	1	2.75	2.5	

4. TEST SETUP AND INSTRUMENTATION

In this experimental work with lateral loading, fixity of the column is the most important factor during testing. For the fixity of the column, Steel plate is attached at the bottom of column by passing column reinforcement through the plate and welded at bottom. This steel plate is attached with the base assembly by bolting. This base assembly is attached with rigid concrete pedestal by dowel bars which have 25 mm diameter, 500 mm embedded length in concrete, 100 mm length outside to connect the base assembly. Centre to centre spacing between dowel bars is 500 mm. Schematic diagram of test setup is shown in Fig. 5. Actual test setup during experiment is shown in Fig. 6.

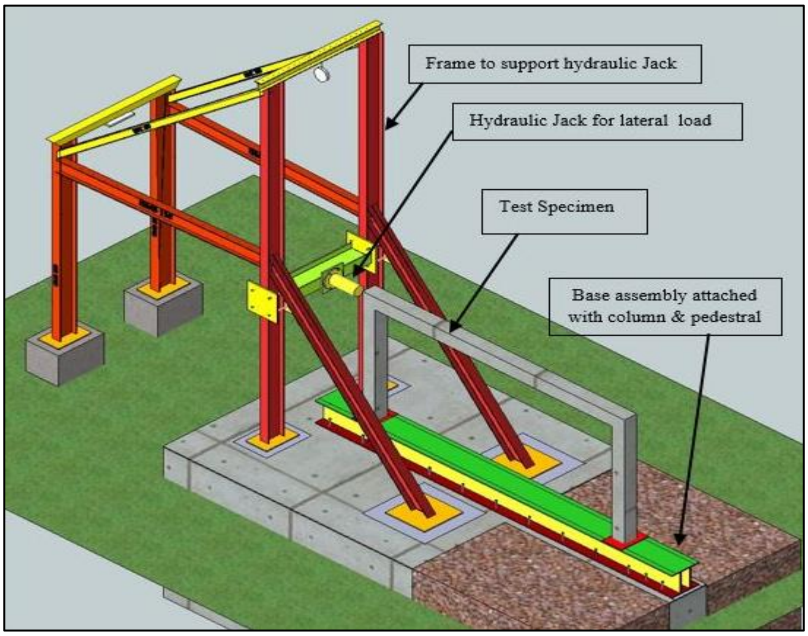


Figure 5. Lateral load test setup

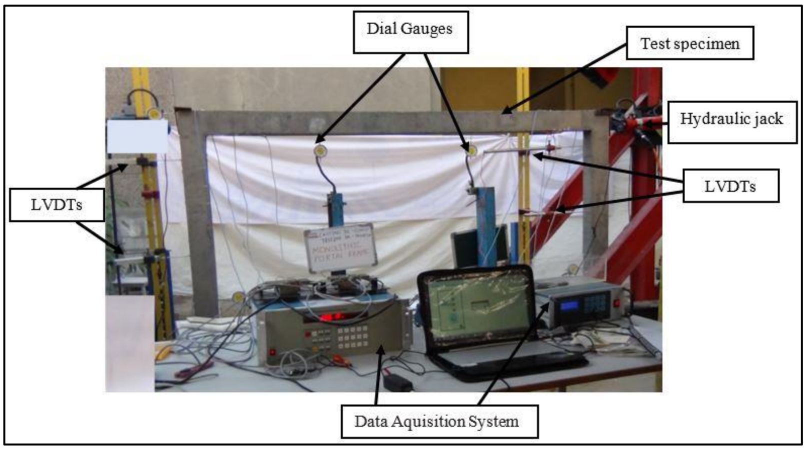


Figure 6. Actual test setup

For application of lateral load an assembly is fabricated to transfer the reaction force of the jack to the foundation. Hydraulic jack of 250 kN capacity is attached to the plate which is welded with the ISMB 250 which in turn attached with ISMB 200 column of frame structure by using plate and bolted connection. The portal frame specimens are tested on above shown test setup of loading frame. The load is applied through hydraulic jack of capacity 250 kN at the top of portal frame at beam column junction. Response of portal frames under lateral loading are measured in terms of horizontal displacement of portal frame at different height of column and also vertical displacement at different location of beam by using LVDTs and dial gauges. Measurement of strain at critical locations on concrete surface as well as on steel reinforcement bars are also carried out. Behaviour of specimen is measured in terms of load - displacement relationship, strain and failure pattern. A schematic layout of instrumentation for measurement of displacement is shown in Fig. 7. For measurement of strain, electrical strain gauge of 5 mm gauge length are attached on steel surface and 90 mm gauge length strain gauges are applied on concrete surface. A schematic layout of instrumentation for measurement of strain is shown in Fig. 8. Data acquisition system is used for measurement of lateral deflection and strains.

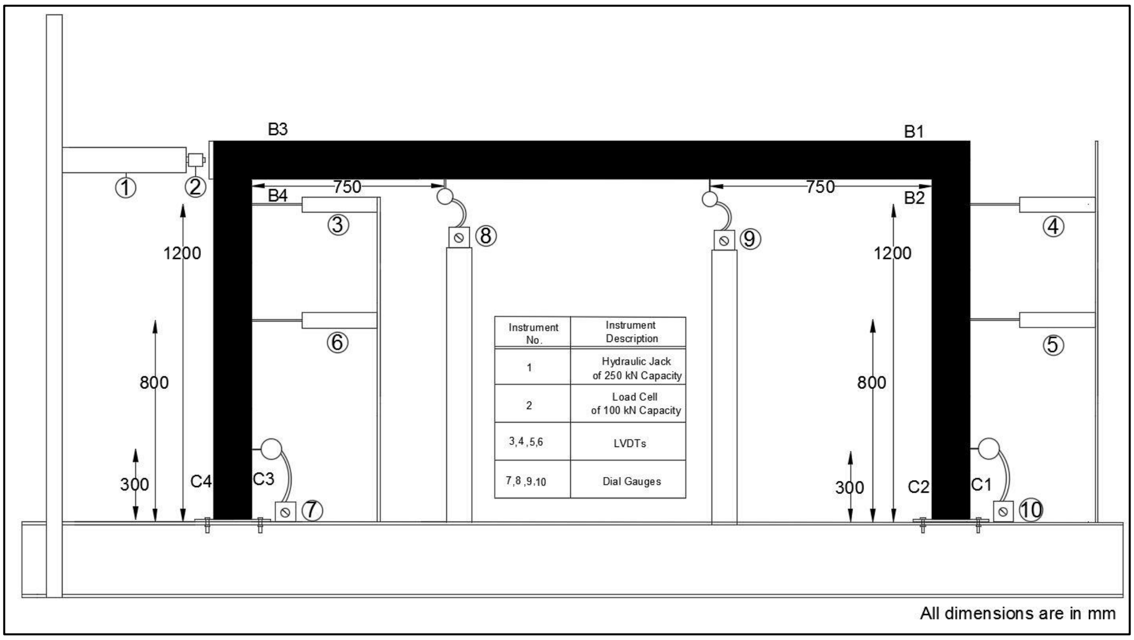


Figure 7. Instrumentation for measurement of displacement

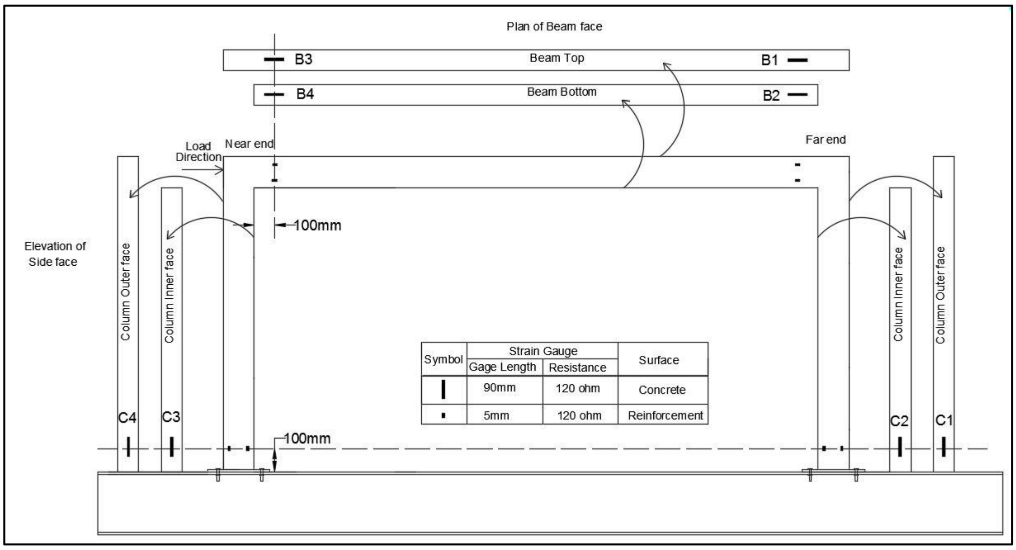


Figure 8. Instrumentation for measurement of strain

5. RESULTS AND DISCUSSION

Behaviour of monolithic as well as precast portal frame is observed at monotonically increasing lateral loading. Lateral deflection of portal frame under lateral loading is obtained at near end where load is applied as well as at far end i.e. opposite loaded junction. As there is no much variation in lateral displacement at near end and far end, so average lateral displacement are plotted. Further to understand behaviour of column under lateral loading, lateral displacement at lower, middle and upper end of column are measured. Load v/s average lateral displacement of monolithic portal frame and precast portal frames with seated angle and RC corbel is shown in Fig. 9 to Fig. 11.

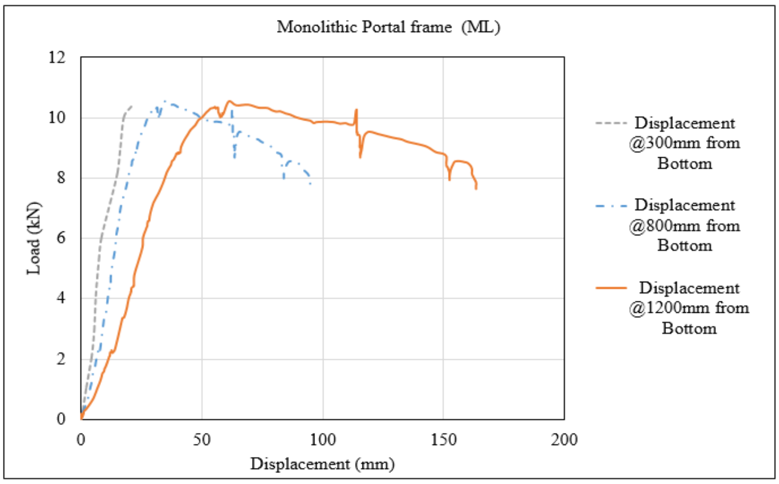


Figure 9. Load v/s average displacement curve for monolithic specimen (ML)

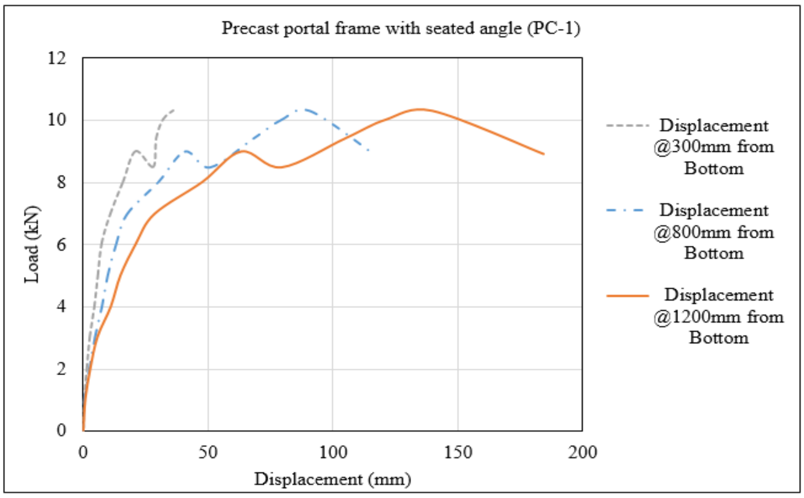


Figure 10. Load v/s average displacement curve for specimen PC-1

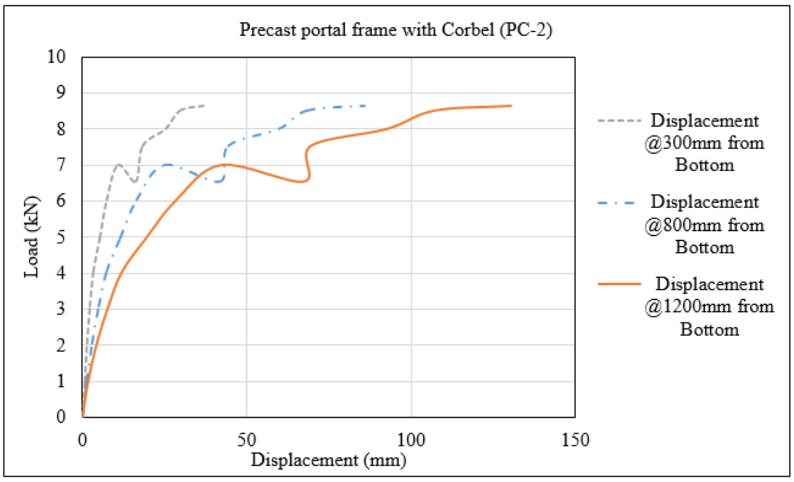


Figure 11. Load v/s average displacement curve for specimen PC-2

Further to understand deflection pattern of column at different loading, average lateral deflection of column along the height is observed. Average lateral deflection of column at various load at 300 mm, 800 mm and 1200 mm above base are plotted in Fig. 12, Fig. 13 and Fig. 14, respectively, for monolithic portal frame, precast portal frame with seated angle and precast frame with RC corbel.

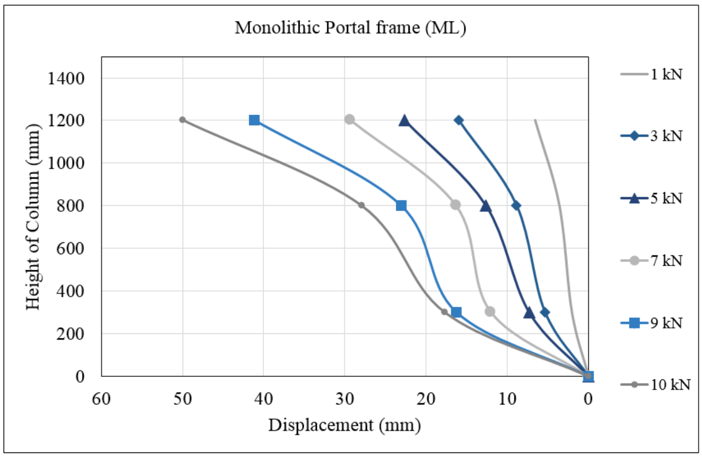


Figure 12. Deflection profile of column of monolithic portal frame (ML)

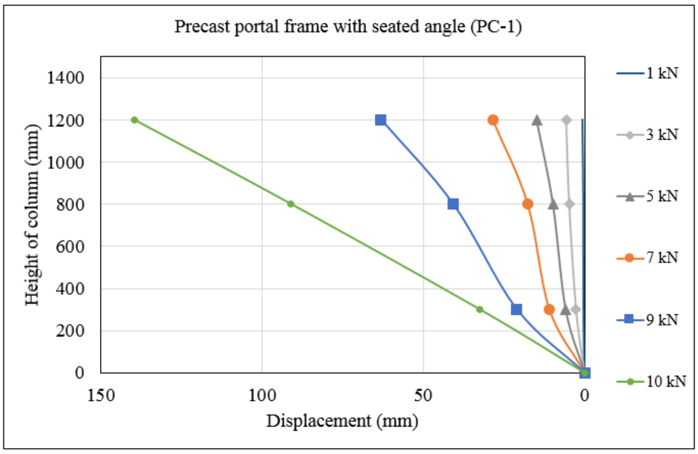


Figure 13. Deflection profile of column of precast specimen with seated angle (PC-1)

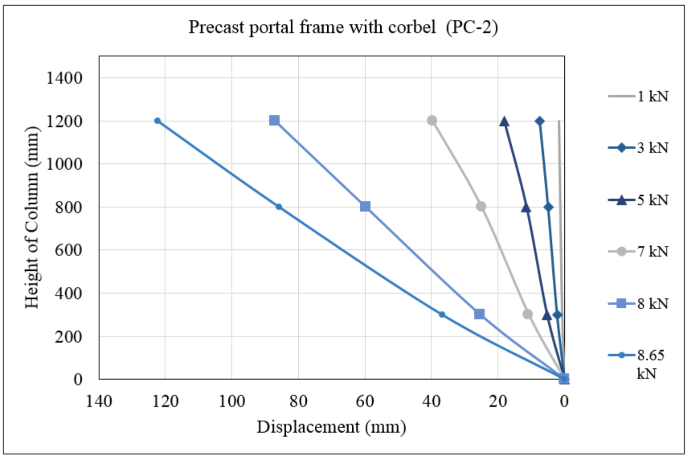


Figure 14. Deflection profile of column of precast specimen with corbel (PC-2)

For Monolithic specimen, minor horizontal crack at the bottom of beam-column junction is initiated at load of 4 kN. This horizontal cracks are developed on both the junctions and they are also widened with the increase in the load. At loading of 7 kN, inclined shear cracks are developed at both the beam column junction. After 10 kN load, some horizontal cracks are developed at the far end column at different heights. At 10.42 kN loading, rotation at base of the nearer column is observed. Failure pattern of monolithic specimen is shown in Fig. 15. The maximum load taken by the Monolithic specimen is 10.53 kN. Maximum lateral displacement of far end and nearer end is 150 mm and 176.3 mm respectively. After that only displacement of the whole frame is occurred with crushing of concrete at bottom of columns and beam-column junction.


(a) Nearer beam column junction


(b) Far end beam column junction


(c) Nearer column base


(d) Far end column base

Figure 15. Failure pattern of monolithic portal frame (ML)

For PC-1 specimen, first crack is initiated at the bottom of far end column at load of 6 kN. At 8 kN loading inclined crack in column is observed at nearer seated column junction. With increment in loading more inclined cracks are developed in column near junction. At loading of 8.5 kN, small rotation at base of far end column base is observed. At loading of

9.4 kN, crushing of concrete at nearer beam-column junction is observed. The maximum load taken by this PC-1 specimen is 10.31 kN. Maximum lateral displacement corresponding to maximum load of specimen is 151.90 mm. After maximum load carrying capacity, some shear cracks are developed in the beam at far end junction and rotation of base of column are observed. Failure pattern of this precast specimen is shown in Fig. 16.

(a) Nearer beam column junction (b) Far end beam column junction

(c) Nearer column base (d) Far end column base

Figure 16. Failure pattern of precast portal frame with seated angle (PC-1)

For PC-2 specimen, first crack at the bottom of far end column is initiated at load of 4.5 kN. At 5 kN loading crack is observed at nearer corbel column junction. At loading of 6 kN, inclined crack is observed in beam between two bolts of corbel and column. At loading of 7 kN, rotation of column base on one side and crushing of concrete on other side column is observed. Inclined cracks in far end corbel is also observed at 7 kN loading. Crack widening is occurred at bottom of nearer column after 7.5 kN load. At 8.5 kN loading, inclined shear cracks are observed at both the end of beam. Also in inclined cracks at junction of corbel and column is occurred at loading of 8.5 kN. At 8.67 kN loading, some sound of breakage of welding is heard at nearer column. Crushing of concrete at far end column base and at far end beam column junction is observed. The maximum load taken by this PC-2 specimen is 8.67 kN. Maximum lateral displacement corresponding maximum load of specimen is 133.80 mm. After maximum load carrying capacity, welding at base of frame at nearer column is failed and column is moved from its original location. Failure pattern of this precast specimen is shown in Fig. 17.

(a) Nearer beam column junction (b) Far end beam column junction

(c) Nearer column base (d) Far end column base

Figure 17. Failure pattern of precast portal frame with corbel (PC-2)

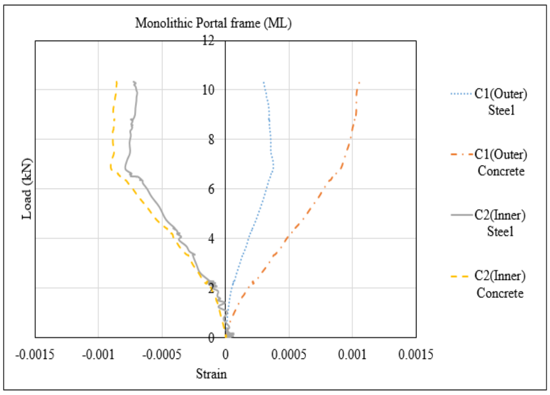
All the three specimens, after complete failure are shown in Fig. 18. Failure pattern of monolithic and precast specimen shows that the shear cracks occurred in monolithic and corbel connection. Rotation of the both the column after maximum load and crushing of concrete at compressive side of column is observed in all the specimen. Strain in steel and concrete are measured at different loading. As bottom of column is critical location under lateral loading, the strain results near the base of column is shown in Fig. 19 to Fig. 21 for monolithic specimen as well as precast specimens.

(a) Monolithic portal frame

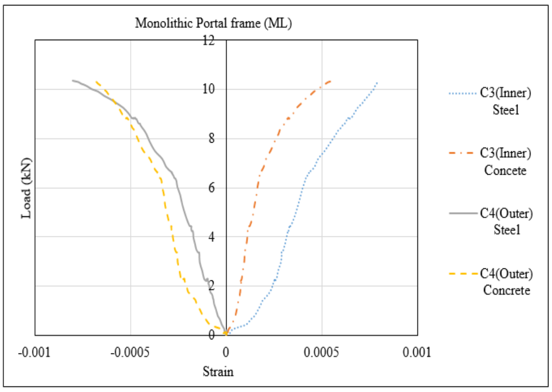
(b) Precast portal frame with seated angle

(c) Precast portal frame with corbel

Figure 18. Failed specimens with maximum lateral displacement

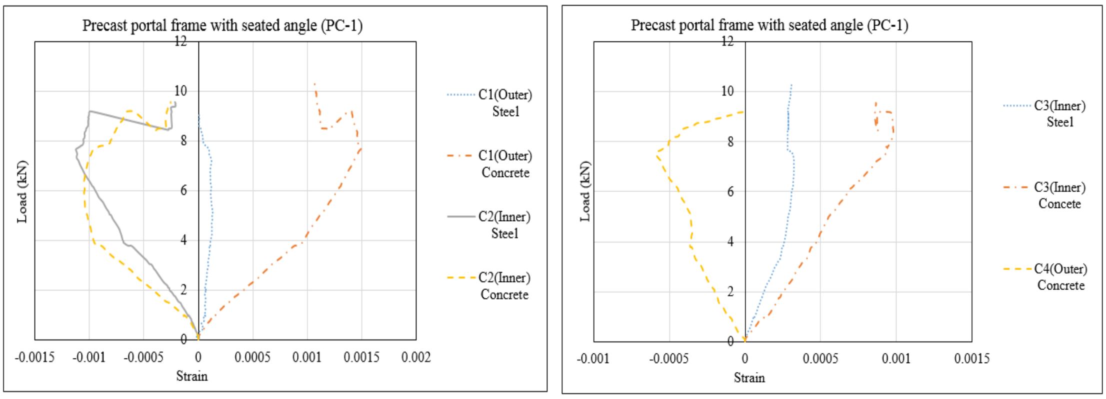


(a) Far end column



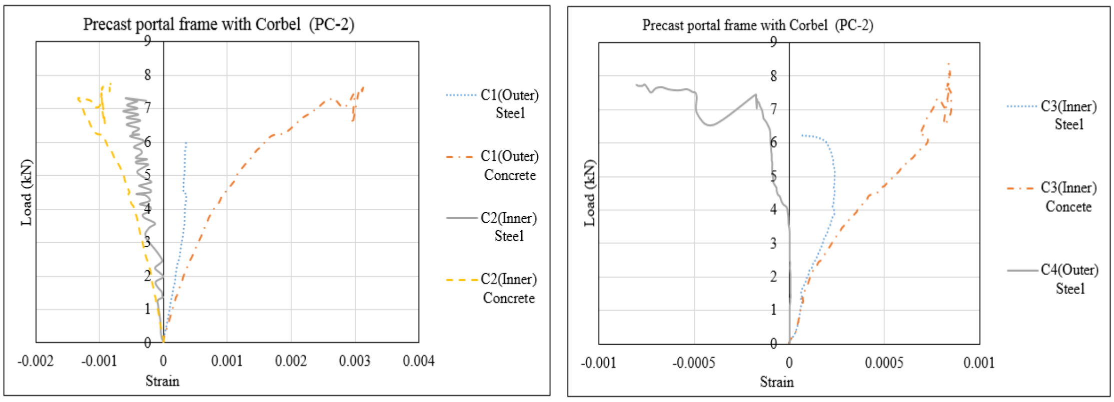
(b) Nearer column

Figure 19. Strain results for column of monolithic portal frame (ML)



(a) Far end column (b) Nearer column

Figure 20. Strain results for column of precast portal frame with seated angle (PC-1)



(a) Far end column (b) Nearer column

Figure 21. Strain results for column of precast portal frame with corbel (PC-2)

Experimental results shows that near the base of column the inner side of nearer column and outer side of far end column is in compression. It also shows that the outer side of nearer column and inner side of far end column is in tension. Strain is also measured in beam near the beam column junction. But as the beam has behaved as axially rigid member under lateral loading so that only strain results of column are presented here. Comparison of maximum value of load and displacement corresponding to maximum load value for all the specimens are presented in Table-2.

Table 2: Comparison of maximum load & displacement

Specimen	Maximum Load (kN)	% Difference in Load	Displacement corresponding Maximum load (mm)	% Difference in displacement corresponding Maximum load	Maximum Displacement (mm)	% Difference in Maximum Displacement
ML	10.53	-	64.50	-	150.60	-
PC-1	10.31	-2.09	151.90	135.50	189.20	25.63
PC-2	8.67	-17.66	133.80	107.44	172.90	14.81

From the comparison of experimental results, it is found that, precast portal frame with seated angle (PC-1) has 2.09% lesser lateral load carrying capacity and 25.63% higher displacement compared to monolithic specimen. The precast connection is intact throughout the experiment because the seated angle of higher capacity is used. Behaviour of connection is more ductile compared to monolithic. By avoiding the eccentricity in connection of holes and bolts at junction, this connection is behave as nearly monolithic specimen. Precast portal frame with corbel (PC-2) has 17.66% lesser lateral load carrying capacity and 14.81% higher displacement than monolithic specimen. After maximum load capacity its failure is brittle at junction and shear cracks in corbel is observed which can be avoided by providing shear reinforcement at beam column junction as well as in corbel.

6. CONCLUSIONS

Based on experimental study of portal frame with monolithic connection and precast connection with seated angle and corbel under lateral loading presented in this paper following concluding remarks can be drawn:

- Portal frame with seated connection between precast elements behave similar to monolithic portal frame. It shows singly less load carrying capacity but presents ductile behaviour under lateral loading.
- Portal frame with corbel connection between precast elements shows less lateral load carrying capacity but is capable of resisting lager deflection compared to monolithic frame.
- In order to improve behaviour of precast portal frame shear reinforcement in beam column junction as well as in corbel should be provided.
- In present study base plate is welded with column reinforcement at base to provide fixity to portal frame. It behaves properly up to maximum loads, but after that some rotation at base is observed. Some revised base connection can be thought of to provide fixity to portal frame even after reaching maximum loading.

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