PERFORMANCE OF EXTERIOR PRECAST BEAM-COLUMN DOWEL CONNECTIONS UNDER CYCLIC LOADING

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LISBOA 2012

SUMMARY:
The present study focuses on the performance of precast beam-column dowel connections subjected to cyclic loading. In this study, one-third scale model of two types of precast and a monolithic beam-column connection were cast and tested under reverse cyclic loading. The monolithic specimen was used as a reference specimen and tested to define the reference behavior.The precast connections considered here is a beam-column connection where beam is connected to column with corbel using (i) dowel bar and (ii) dowel bar with cleat angle. The experimental results of the precast specimens have been compared with that of the reference monolithic connection. The sub-assemblage specimens have been subjected to cyclic displacement-controlled lateral loading applied at the end of the beam. The performance of the precast connections in terms of the load-displacement hysteresis behaviour, ultimate load carrying capacity, energy dissipation and ductility factor were compared with that of the monolithic beam-column connection. The monolithic specimen was found to perform better when compared to the precast specimens in terms of strength and energy dissipation. In terms of ductility, the precast specimen using dowel bar and cleat angle showed better behaviour when compared to the reference monolithic specimen.

*Keywords**:** precast concrete, beam-column connection, cyclic loading, dowel bar, cleat angle*

1. INTRODUCTION

In the recent years, there is enormous infrastructural growth in India. The rapid infrastructural growth together with increasing demand for quality buildings necessitate the construction industry to continuously seek for improvement. This will lead to industrialization in the building industry, which can be achieved in the form of precast concrete construction. In the International arena precast concrete sector has experienced reasonable growth in the recent years. This is because precast concrete provides high-quality structural elements, construction efficiency, and savings in time and overall cost of investment. Though it has many advantages over the cast-in-situ concrete construction, still there is hesitancy in extensively constructing precast concrete structures in highly seismic areas. It can be observed that many precast concrete structures have failed in the past earthquakes. Failure of the structures in these earthquakes was mainly due to the poor connections between the precast elements themselves and between the precast elements and lateral load-resisting system. Hence, there is a necessity to carry out more research in this area. For the past four decades though a lot of research has been carried out on the behavior in precast structures, a complete understanding of the behaviour of precast beam-column connections to dynamic loading has not been completely understood. In India, most of the construction utilises cast-in-situ technique. Precast concrete construction is still in its early stage. Generally, precast concrete construction is more preferred for construction of flyovers. As India is a fast developing country, there is a large scope for improvement in the construction sector, especially towards development and utilization of factory made quality controlled precast units that provides for faster construction leading to economy. For the present study precast concrete with dry mechanical connections were considered. The behavior of two types of precast beam-column dowel connections and a reference monolithic connection were investigated.

2. LITERATURE SURVEY

Several Studies were conducted to evaluate the performance of precast beam-column moment resisting frames under cyclic loading. Chun et al (2007) assessed the effectiveness of headed bars terminating in exterior beam-column joints under reversed cyclic loading. The primary test parameters were the anchorage type, size and arrangement of the beam bars and the heads and the detailing provided for roof joints. The test results indicated that hysteretic behaviour of exterior joints constructed with headed bars was similar or superior to joints constructed and tested with hooked bars. It was also concluded that in addition to providing vertical U-bars at roof joints, heads on column bars should extend beyond the beam top bars to provide improved behavior. Li et al (2009) conducted experimental and analytical investigations of hybrid-steel concrete connections under cyclic load reversals. The precast specimen's performance was good at exhibiting adequate ductile behavior under seismic loading and it also agreed well with cast-in-place specimen. Embedment of the steel sections in the joint greatly enhanced the strength of the joint core with the specimens carrying storey shears up to a ductility factor of 3.5. Xue and Yang (2010) studied the behavior of precast concrete connections in a moment resisting frame under cyclic loading. The connections studied were exterior connection, interior connection, T connection and knee connection. It was observed that Knee connections were less effective when compared to other connections. All the connections exhibited strong column - weak beam failure mechanism. It was concluded that all the connections performed satisfactorily in seismic conditions with respect to strength, ductility and energy dissipation capacity. From the literature, it is observed that the precast connections can be detailed as strong as that of the monolithic connections. It can be widely observed in the literature that a lot of research on precast structures emulating the behaviour of reinforced concrete cast-in-situ seismic resistant frames had been carried out. However limited research work has been carried out on jointed systems for use in seismic regions. Hence, the present study aims at developing dry connections using dowel bars and cleat angle.

3. EXPERIMENTAL PROGRAMME

3.1 Material Testing

The 28th day average cube compressive strength of the concrete (f_{cu}) was 41.6 MPa. The cylinder compressive strength has been evaluated based on the relationship, $f_c' = 0.8\, f_{cu}$ and was observed as 33.28 MPa. The tensile strength of the concrete has been observed as 3.06 N/mm^2 by testing three cylinders of 150mm diameter and 300mm height. Three beams of 100mmx100mmx500mm were cast and tested for the flexural strength. The flexural strength of the concrete was 5.95 N/mm^2.

3.2 Design and Detailing of Specimens

The exterior beam column joint of a three storey reinforced concrete building was considered for this study. Six test specimens of 1/3 rd scale model were cast and tested under reverse cyclic loading. The shear forces, bending moments and axial forces in the exterior beam-column joint in the first floor had been calculated for the various load combinations including earthquake loading. Figure 3.1 shows the plan and elevation of the building showing the exterior beam-column joint considered (joint A). Seismic analysis had been performed using equivalent lateral force method recommended by IS:1893-2002. The design and detailing of beam, column and exterior joint had done based on the guidelines given in IS:456-2000 and IS:13920-1993 respectively. One-third scaled models had been developed for monolithic and precast specimens with cross-sectional dimensions 100 mm x 100 mm for both the beam and column. The clear span of the beam was 550mm. The height of the column was 1200 mm. The cover thickness of monolithic and the two precast beam and column specimens were 10 mm. Figure 3.2 shows the cross section and reinforcement configurations for monolithic and the precast specimens.

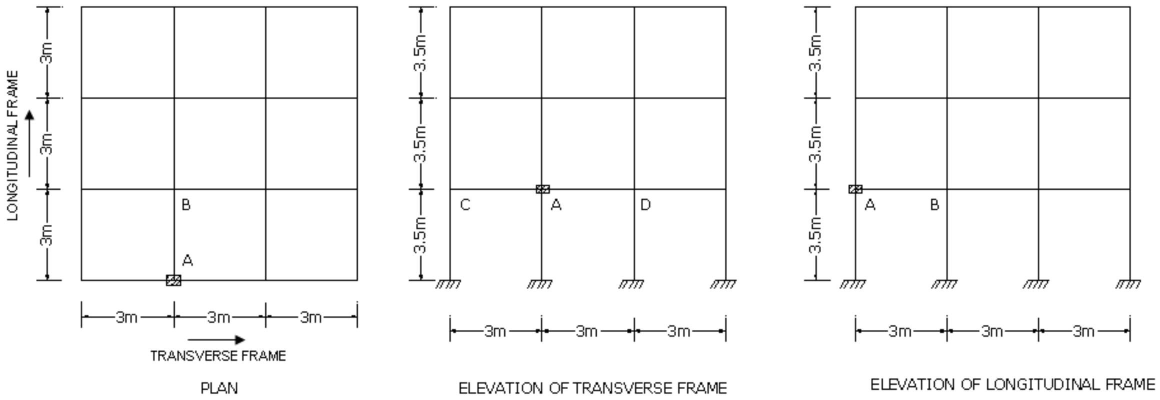
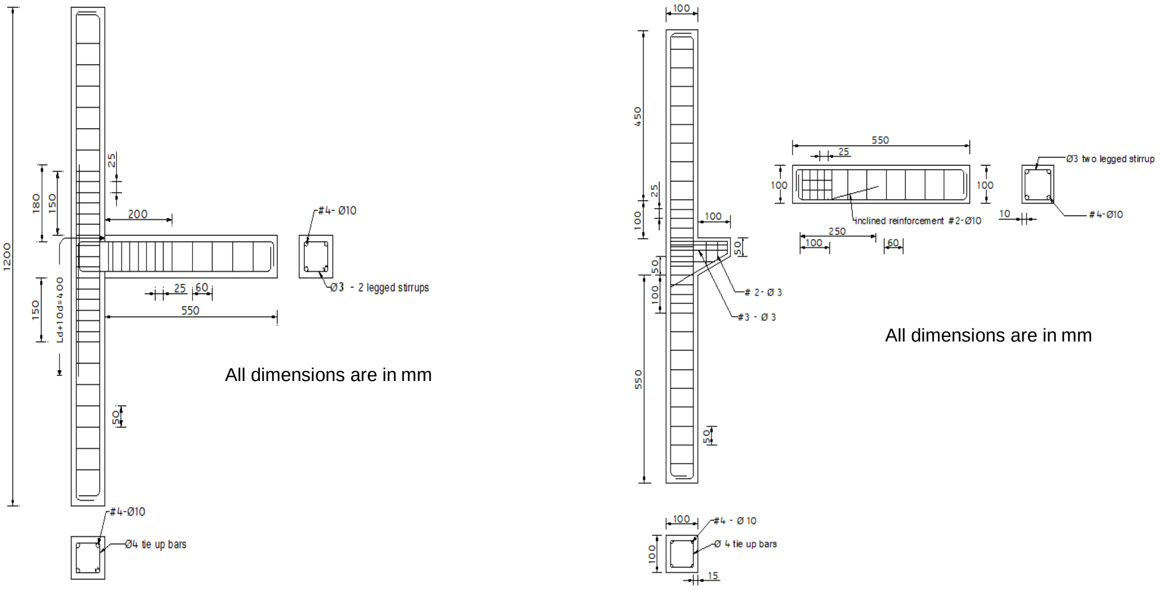


Figure 3.1. Plan and elevation of the building



a) Specimen ML b) Specimen PC-DW and PC-DWCL

Figure 3.2. Reinforcement detailing for specimen ML, PC-DW and PC-DWCL

3.3 Specimen Details

3.3.1 Monolithic specimen (ML)

The monolithic reinforced concrete test specimen (ML) was designed according to IS:456-2000 and detailed according to IS:13920-1993. The Flexural reinforcement for the beam consisted of four bars with one bar at each corner of the transverse reinforcement. Two numbers of 10 mm diameter bars were provided as tension reinforcement and two numbers of 10 mm diameter bars were provided as compression reinforcement. The shear reinforcement consisted of 3 mm diameter two legged stirrups spaced at 60 mm. For a distance of 100 mm from the column face the spacing of the lateral ties were decreased to 25 mm. The column reinforcement arrangement also consisted of four 10 mm diameter bars. Along the column height excluding the joint region, the lateral ties were spaced at 50 mm. At the joint region the spacing of the lateral ties were reduced to 25 mm.

3.3.2 Precast concrete connections

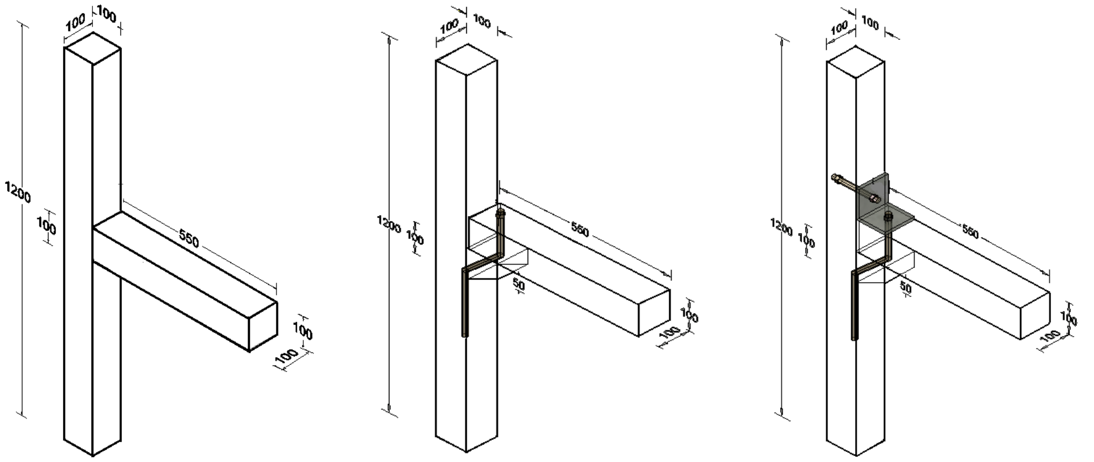
The precast concrete elements were designed according to IS: 456-2000 and detailed according to IS: 13920-1993. The design of cleat angle and bolts which are the connecting elements in the precast concrete connections were designed according to IS: 800-2007. Additional horizontal stirrups were provided for a distance 100mm to cater for the confinement of concrete at region of the bolt hole in the beam. For the precast beam-column connection, two mechanical connections were considered for this study as detailed as follows

a)Precast connection using dowel bar (PC-DW)

In this connection the beam was supported on concrete corbel using dowel bar. The dowel bar of 16mm diameter was embedded in the column to a length equal to the development length and cast with the bar projecting from the corbel. The precast beam with 21 mm diameter sleeve hole which was cast inside the beam was inserted into the projecting dowel bar. The gap between the dowel bar and the hole was filled iso-resin grouts.

b)Precast connection using dowel bar and cleat angle (PC-DWCL)

In this connection the beam was supported on concrete corbel using dowel bar and cleat angle. The dowel bar of 16mm diameter was embedded in the column to a length equal to the development length. The cleat angle used for the connection was ISA 100x100x10. A sleeve of 21 mm diameter was cast inside the column and beam to facilitate the connectivity between precast elements. A part of the dowel was projecting outside the corbel for connection with the beam using cleat angle and nuts. A bolt of 16 mm diameter of grade 4.6 was used to connect the cleat angle and the column. The gap between the dowel bar and the hole was filled isoresin grouts. Figure 3.3 shows the schematic representation of the isometric view of specimens ML, PC-DW and PC-DWCL.



a)Specimen ML b)Specimen PC-DW c)Specimen PC-DWCL

Figure 3.3. Isometric view of the three specimens

3.4 Testing Setup And Loading Sequence

The sub-assemblages were tested within a loading frame as shown schematically in Figure 3.4. One end of column for both the monolithic and precast specimen were supported using an external hinge support, which was fastened to the strong reaction floor and the other end of the column was free to move and rotate by a roller support. The experiments were carried out on a loading frame of capacity 2000kN. A 400kN capacity hydraulic jack was fixed to the loading frame for the application of the axial load along the axis of the column to simulate the gravity load on the column. Two hydraulic jacks of capacity 100kN and 200kN with a displacement range of 100mm were used to apply the reverse cyclic loading. The cyclic load was applied as displacement controlled at the free end of the beam. Dial gauges were placed at three locations to measure the vertical displacement of the beam. The three dial gauges were placed at 100mm, 200mm and 425mm from the face of the column. In order to account for the dead load transferred from upper floors, an axial load of equal to $0.1f_c' A_g$ was applied to the column at the beginning of the test and maintained throughout the test using hydraulic jack of capacity 400kN (Cheok and Lew 1993). The loading history consists of displacement cycles as shown in Figure 3.5. The drift has been calculated as the ratio of beam displacement to the length of the beam measured from the joint to the position of dial gauge.

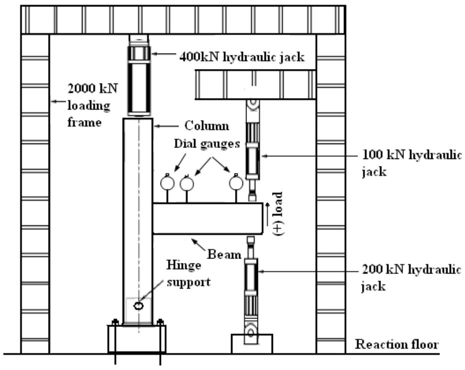


Figure 3.4. Schematic experimental test setup

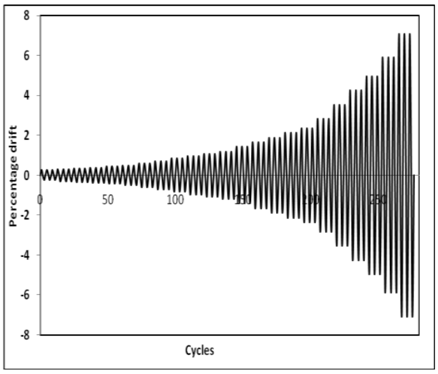


Figure 3.5. Cyclic loading history

4. TEST RESULTS AND DISCUSSION

4.1 Cracking Pattern And Failure Mode

Consistent with a strong column weak beam system, in all the precast specimens the column damage was minor. During the load cycles, a predetermined crack opening or closing type of response was observed in the connection region. This was because the precast concrete connections had predetermined crack locations at the beam column interface because of imposed cold joints. Figure 4.1(a), 4.1(b) and 4.1(c) gives the failure mode photos of specimen ML, PC-DW and PC-DWCL respectively. The pattern of cracking and the modes of failure of all the specimens are observed. For the monolithic specimen, ML, the first flexural crack occurred on the beam at the column face at 2mm displacement cycle and propagated at ±2.5mm, ±3mm displacement cycle. Flexural crack occurred at 2.5mm displacement cycle on the beam away from the beam-column junction. Also flexural cracks occurred in the beam away from the beam-column junction at ±3mm, ±4mm, 6mm (6.58kN), 7mm, -8mm (10.19kN),-10mm (10.66kN) displacement cycle. Shear cracks first occurred at the beam-column junction at 7 mm (9.92kN) displacement cycle and cracks further propagated at 12mm (10.61kN), 15mm (10.94kN), 18mm (10.95kN), ± 21mm, and 25mm (11.29kN) displacement cycles.

a)Specimen ML b)Specimen PC-DW c)Specimen PC-DWCL

Figure 4.1. Crack pattern for specimen ML, PC-DW and PC-DWCL

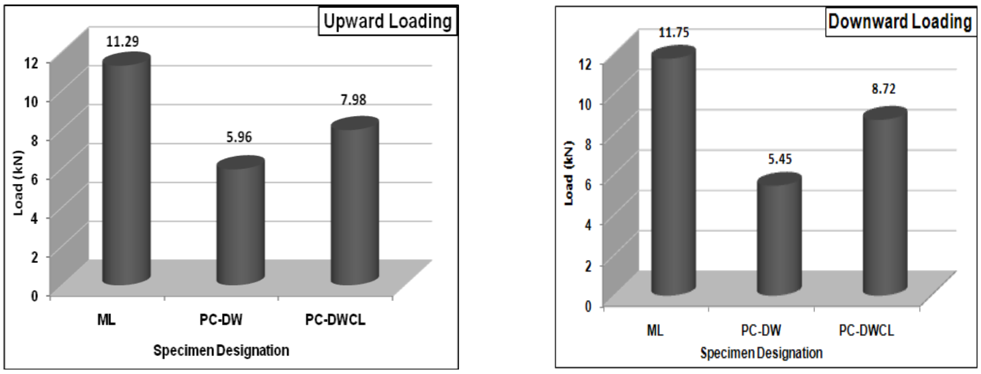
In the case of precast specimen with dowel PC-DW, the first flexural crack occurred in the beam region at -3.5mm (2.7kN) displacement cycle at a distance of 12cm from the face of the column. Also flexural cracks occurred in the beam at 5mm (4.33kN) displacement cycle and propagated at 7mm (4.87kN) displacement level. This crack further propagated in shear mode to the top towards the dowel at -15mm (8.71kN) displacement cycle. On the rear face, cracks started in flexural mode from the bottom of the beam at 7mm (4.87kN) displacement cycle and started propagating in the shear mode towards the dowel. Cracks first occurred in the corbel at the top at -4mm (2.93kN) displacement cycle and cracks started at the bottom at 15mm (5.69kN) displacement cycle at the rear side. Similarly cracks occurred on the front face, at 9mm (4.87kN) displacement cycle and propagated in shear mode at -10mm (7.78kN) displacement cycle. For precast specimen with dowel and cleat angle PC-DWCL, the first flexural crack occurred at beam bottom at 1.6mm (4.87kN) displacement cycle and further propagated at 2mm (5.96kN) and 2.5mm (5.96kN) displacement cycles in the flexural mode. At the beam bottom, shear cracks developed at 2.5mm and propagated at 3mm (5.96kN) displacement cycle. At the top of the beam flexural cracks occurred at -3.5 mm (4.93kN)displacement cycle. Cracks started in the corbel at -4mm (5.05kN) and propagated at -6mm (6.88kN) displacement cycle in shear mode.

4.2 Strength

Comparison of yield and ultimate loads for all the specimens is given in Table 4.1. The specimen with dowel bar and cleat PC-DWCL performed better than specimen with dowel bar PC-DW. The specimen PC-DWCL exhibited 25.31% and 37.54% greater load carrying capacity than the specimen PC-DW in the positive and negative direction respectively. The load carrying capacity of specimen PC-DW was 47.19% and 53.68% lesser than the monolithic specimen ML in the positive and negative direction respectively, whereas, specimen PC-DWCL was 29.32% and 25.79% lesser than the monolithic specimen in the positive and negative direction respectively. The ultimate load carrying capacity for specimen PC-DWCL in the positive direction is greater when compared to PC-DW because more resistance is offered by the cleat angle. The ultimate load carrying capacity of the monolithic specimen was found to be 11.29 kN and 11.75 kN in the positive and negative directions respectively. Figure 4.2(a) and 4.2(b) compares the measured strength of the three specimens in the positive and negative direction respectively.

Table 4.1. Comparison Of Experimental Yield And Ultimate Loads For All The Specimens

S.No	Specimen	Experimental Yield Load(kN)		Experimental Ultimate Load(kN)	
		Upward direction	Downward direction	Upward direction	Downward direction
1	ML	8.80	9.40	11.29	11.75
2	PC-DW	4.90	4.18	5.96	5.45
3	PC-DWCL	6.17	7.20	7.98	8.72



a) Positive direction b) Negative direction

Figure 4.2. Comparison of measured strength for all the specimens in the positive and negative direction

4.3 Hysteretic Behaviour

The hysteretic behavior of the joint with respect to load – displacement has been discussed in this section. The load - displacement relations for the monolithic (ML) and two precast specimens (PC-DW, PC-DWCL) are shown in Figure 4.3. The lateral load at the beam tip and the displacement at 425mm away from the joint (the position of the farthest dial guage) have been plotted in the load displacement hysteretic curve.

At the early stage of loading, the three connections exhibited a stable load versus displacement hysteretic response and then pinching could be observed in the hysteresis loops of all the three connections. Figure 4.3(a) shows the load- displacement response of the monolithic specimen (ML). This figure exhibited fat hysteresis loops with very less pinching, due to good bonding between reinforcement and joint concrete. The slight pinching was due to diagonal cracking in the joint region and flexural cracking in the beam. The areas of the hysteresis loops gradually became larger as the displacement cycle increased, which indicates good energy dissipating capacity. Figure 4.3(b) and 4.3(c); show the load- displacement hysteretic response of the precast specimens PC-DW and PC-DWCL respectively. For specimens PC-DW and PC-DWCL, the load-displacement hysteretic curves exhibited greater pinching. This is because of predefined gap opening at the connections, which indicates minimal energy dissipation. For specimen PC-DW and PC-DWCL, cracks were observed around the recess provided for the accommodation of the dowel bar in the beam and corbel region, whereas no cracks were observed in the column. The load displacement envelope is shown in Figure 4.4.

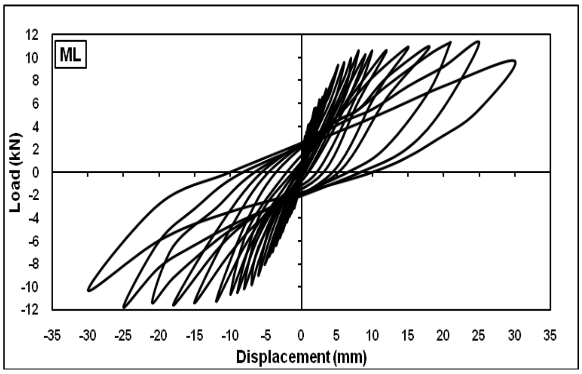


Figure 4.3. a) Load-Displacement hystersis of specimen ML

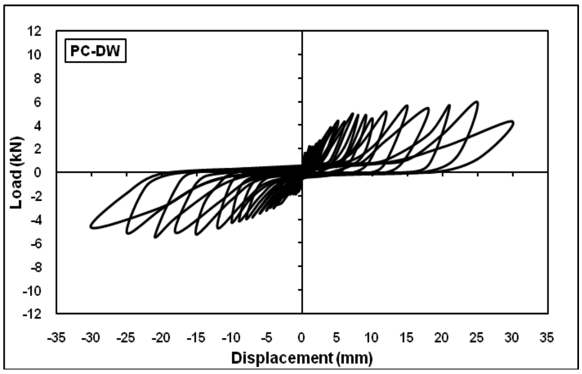


Figure 4.3. b) Load-Displacement hystersis of specimen PC-DW

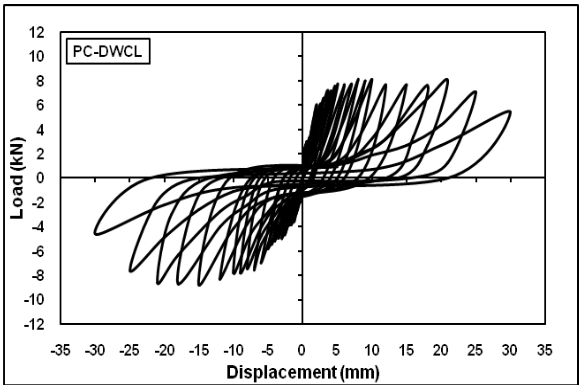


Figure 4.3. c) Load-Displacement hystersis of specimen PC-DWCL

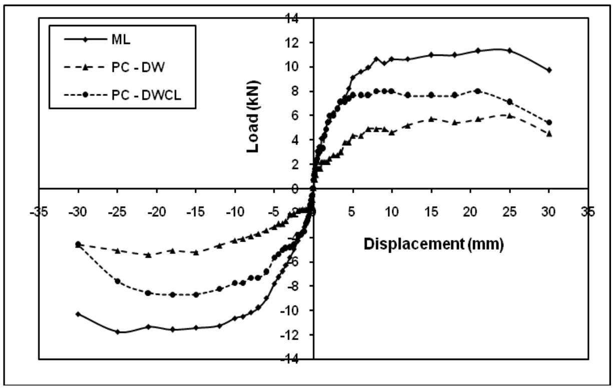


Figure 4.4. Load-Displacement envelopes of all specimens

4.4 Energy Dissipation Characteristics

For the structure to perform satisfactorily in the inelastic range, it should exhibit good energy absorption capacity. A beam column connection subjected to cyclic loading is considered to be ductile if sufficient amount of energy is dissipated without a substantial loss of strength and stiffness. The area enclosed by the hysteretic loop in a given cycle represents the energy dissipated by that specimen during that cycle. Figure 4.5 provides a comparison of the cumulative energy versus displacement levels of all the specimens. The cumulative energy dissipated was computed by summing up the energy dissipated in the consecutive cycles throughout the test. The specimen ML and PC-DWCL exhibits similar patterns of energy dissipation. It is observed that the monolithic specimen ML dissipated greater energy of 857.05 kNmm when compared with the precast specimens. At the drift ratio of 7.1% the precast connection with dowel PC-DW shows 24.56 % reduction in the cumulative energy dissipation when compared to monolithic specimen ML whereas precast connection with dowel and cleat PC-DWCL has exhibited very good energy dissipation capacity almost in comparison with the monolithic specimen ML.

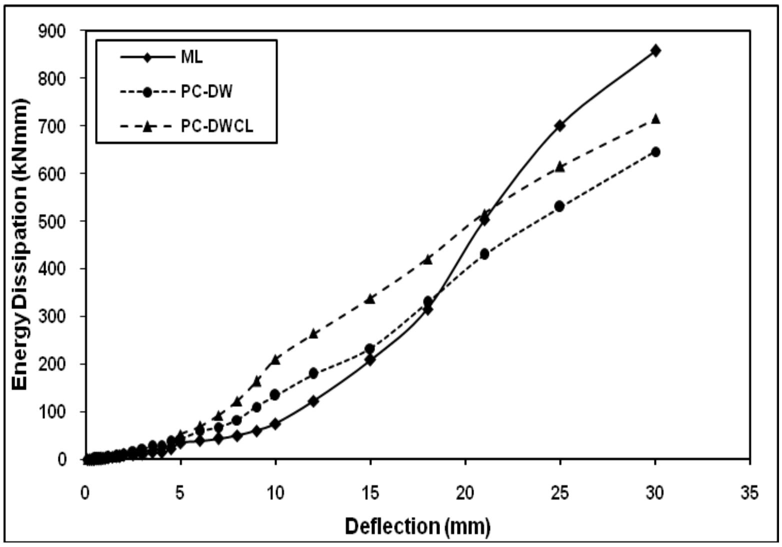


Figure 4.5. Cumulative energy dissipation versus displacement curves of the three specimens

4.5 Ductility

The displacement ductility is the ratio of the maximum displacement that a structure or element can undergo without significant loss of initial loading to the initial yielding deformation. The load versus displacement envelope was used to define the yield and ultimate displacement according to the criteria for reduced stiffness equivalent elasto-plastic yield (Park, 1988). The ultimate displacement corresponded to 85% of the peak load (Park and Paulay, 1975). The first yield displacement was found by extrapolating the measured stiffness at 75% of the theoretical flexural strength of the specimen up to the theoretical strength of the specimen (Park, 1989). The displacement ductility factor was calculated for monolithic and the two precast beam-column connections are shown in Table 4.2. The average displacement ductility factor of precast specimen PC-DWCL was slightly greater than the monolithic specimen ML. The average displacement ductility of the specimens indicated that all the three connections behaved in a ductile manner.

Table 4.2. Comparison Of Displacement Ductility Factor

Specimen	Yield displacement Δ_y, (mm)		Ultimate displacement Δ_u (mm)		Displacement Ductility factor(μ)		Average Displacement Ductility factor (μ)
	Positive	Negative	Positive	Negative	Positive	Negative	
ML	6.0	7.6	30	30	5	3.947	4.474
PC-DW	7	11	27.8	29.4	3.971	2.673	3.322
PC-DWCL	3.4	7.4	25.8	23.2	7.588	3.135	5.362

5. CONCLUSIONS

Experimental investigations were carried out on two types of simple mechanical concrete beam-column connections subjected to reverse cyclic loading. The results were then compared with the performance of a reference monolithic beam-column connection. The types of precast concrete connections considered for the present study are (i) Dowel Bar (PC-DW) and (ii) Dowel Bar with Cleat Angle (PC-DWCL). The parameters considered for the present study are load carrying capacity, energy dissipation and ductility. The summary of the observations are as follows

a) The load carrying capacity of the connection with dowel bar and cleat angle PC-DWCL exhibited 25.31% and 37.54% greater load carrying capacity than the specimen with dowel bar PC-DW in the positive and negative direction respectively. This is due to the additional stiffness developed due to the presence of cleat angle. Compared to the monolithic specimen ML, the specimen PC-DWCL exhibited lesser load carrying capacity. The variation is 29.32% and 25.79% in the positive and negative direction respectively.

b) The precast connection PC-DWCL exhibited wider hysteretic curves compared to specimen PC-DW. Both the specimens experienced pinching due to the predefined gap opening at the connections. The monolithic specimen ML showed comparatively better hysteretic behaviour because of the confinement in the joint core.

c) Considering the energy dissipation, the specimen PC-DWCL performed better than the specimen PC-DW and dissipated 10.71% higher energy than specimen PC-DW. The energy dissipation of specimen PC-DWCL is about 16.52% lesser than the monolithic specimen ML.

d) The specimen PC-DWCL has better ductility than that of specimen PC-DW and monolithic specimen ML. About 38.04% and 16.56% increase in ductility had been observed for PC-DWCL compared to specimen PC-DW and specimen ML respectively.

e) On comparison of both the precast specimens, specimen PC-DWCL performed much better than the specimen PC-DW. Also, it is observed that the precast specimen, PC-DWCL exhibited satisfactory behaviour in comparison with the monolithic specimen ML.

f) The proposed connection PC-DWCL is a simple dry connection that can be used for the construction of low rise moment resisting frames.

ACKNOWLEDGEMENT

This work is a part of the AICTE sponsored project on Seismic Behaviour of Precast Beam-Column Connections. The authors wish to acknowledge the funding agency for their support.

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