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CYCLIC BEHAVIOUR OF PRECAST BEAM TO COLUMN CONNECTIONS WITH JOINT IN BEAM REGION

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Abstract

The present study investigates the behavior of dry joint connection between beam elements of precast concrete under reverse cyclic loading. A one-third scale model was adopted for the reference monolithic and precast specimens. The reverse cyclic loading was applied as displacement-controlled lateral loading at the end of the beam. The column was hinged at the bottom and laterally restrained at the top. The precast beam to beam connections were made using stud nuts. In the first stud nut connection (SD1), the stud nut was connected at a distance of 350 mm at top and 250 mm at bottom from the column face. In the second stud nut connection (SD2), the stud nut was connected at a distance of 250 mm at top and 150 mm at bottom from the column face. The test results of the precast specimens have been compared with that of the reference monolithic connection (ML). Various parameters like ultimate load carrying capacity, load-displacement hysteretic behavior, crack pattern, energy dissipation and ductility were observed for the precast specimens and compared with the monolithic specimens. Out of the two precast connections, stud nut connection (SD2) performed better. The precast connections in general showed comparable behavior in terms of ductility. But the monolithic specimen was found to perform better when compared to the precast specimens in terms of strength and energy dissipation.

Keywords: precast concrete; beam to beam connection; stud nut; reverse cyclic loading

1. Introduction

Precast concrete construction has been getting popular and being widely applied in construction sector today. The rapid growth of the building industry together with increasing demand for quality buildings necessitates the construction industry to continuously seek for improvement, leading to industrialization in this industry. Structural systems based on precast concrete elements have been shown to be safe, durable, reliable and cost-effective. However, their full implementation in seismic design has been limited due to scarce design guidelines compared to reinforced concrete systems [1]. Precast concrete buildings performed poorly in past earthquakes like 1988 Spitak, Armenia earthquake 1994 Northridge earthquake and 1995 Kobe earthquake due to poor connections between the structural components. The reasons for the poor performance was due to lack of adequate seismic design considerations like ductility [2], lack of proper diaphragm connection [3] and insufficient connection detailing [4]. Past earthquakes indicate that the poor performance of the connections between the precast elements was the primary reason for the widespread damage. Hence more research is required in understanding the behaviour of connections under cyclic loading.

2. Literature Survey

Munaf et al. [5] investigated the properties and behaviour of dry joint connection between beam elements of precast concrete. Six specimens of which two were normal beams and four beams were of precast concrete. The precast concrete beam was of two types, one type of beam was with a rectangular section (type-I) and another type was beam with an I-section (type-II). The specimen was tested as simply supported beam for monotonic and cyclic loading with two point load for models of pure bending condition. The test parameters observed were the comparison of behaviour of normal beam and two types of precast concrete element like strength, rigidity, ductility, strength and rigidity degradation, and energy dissipation. Ultimate load capacities of beam type-I and type-II have loading capacity more than normal beam up to ductility 4 in the first cycle. The rigidity of degradation of type-I and type-II were 88.85% and 89.45% respectively whereas that of the normal beam was 82.16%. The precast beam type-I and type-II showed cumulative energy dissipation up to ductility 4, greater than the normal beam.

Korkmaz et al. [6] investigated the seismic behaviour of a precast connection detail to develop a moment resisting precast concrete beam-to-beam connection. Six beam–beam connection subassemblies were tested under reversed cyclic loading simulating severe earthquake action. The first specimen was a monolithic specimen used as a reference specimen and tested to define the reference behaviour. The second specimen was a precast specimen, which was detailed by a company specializing in precast concrete production. The remaining specimens were modified according to the results of the formerly tested specimens. All of the specimens were identical in dimensions. All test specimens were 1⁄2.5 scaled models of the improved connection details used in the highly critical earthquake zones. The original connection detail of precast member was not suitable for seismic use. Significant improvements were achieved by introducing the modifications in the original detailing of precast member. Connecting the top steel via welding solved the problem of anchorage, and the modified detail performed quite satisfactorily not only in the case where reasonable beam reinforcement had been used but also in the case of more heavily reinforced beams where the connection was subjected to higher shear forces and bending moments.

Shariatmadar and Asgari [7] tested six beam-to-beam connection subassemblies under reversed cyclic loading simulating severe earthquake action. The first tested specimen was a monolithic specimen and used as a reference specimen to define cast-in-place connection. The first precast specimen was the original specimen designed and detailed by the company in cooperation. Others had some modification to improve the response behaviour. In this research, the modified specimen and the original specimen are compared with reference monolithic specimen. The nonlinear push-over analysis are performed for a three stories-two bays frame designed using each mentioned connections. The original connection details were not suitable for high seismic zone and it was not recommended to be used instead of cast in place connection. Significant improvements were achieved by introducing the modifications proposed as given for modified connection. All response curves show that after occurrence of a new moment hinge in the beams the structural ductility increases, whereas, the total strength decreases. The structure with precast connections had a weaker behaviour than the structure with modified precast connections in total strengths, but had a better ductility and energy dissipation.

3. Details of Test Specimens

3.1 Material Properties

Ordinary Portland Cement (OPC) 53 grade was used for the precast and monolithic specimens. M30 grade concrete with the water-cement ratio of 0.44 has been used. The fineness moduli of the fine aggregate and coarse aggregate used in the design mix were 2.9 and 6.1, respectively. The deformed bars designated as Fe415 were used as longitudinal reinforcement. For transverse reinforcement plain mild steel bars (Fe250) were used. The concrete mix was designed according IS:10262 [8]. The mix proportion of 1:1.94:2.91 by weight of cement, fine aggregate and coarse aggregates respectively was used. The 28th day average cube compressive strength (f_{cu}) was 40.8 MPa.

3.2 Analysis of the structure

An exterior beam to beam connection of five storey reinforced concrete building was considered. Seismic analysis had been performed using equivalent lateral force method recommended by IS:1893 [9]. The design and detailing of beam, column and exterior joint had been done based on the guidelines given in IS:456 [10] and IS:13920 [11] respectively. The column was designed for an axial load of 1098 kN and maximum moment of 143 kNm. The beam was designed for shear force of 154 kN and maximum moment of 140 kNm.

3.3 Geometry and reinforcement detailing

Two types of precast beam to beam specimen and a reference monolithic specimen were cast and tested under reverse cyclic loading. One-third scale models had been developed for monolithic and precast specimens with cross-sectional dimensions 100 mm × 140 mm for both the beam and column. The clear span of the beam was 600mm. The height of the column was 1250 mm. The cover thickness of monolithic and the two precast beam and column specimens were 10 mm. The dimensions and reinforcement details of the test units are shown in Fig.1.

4. Types of precast connection used

4.1 Precast connection using stud nut 1 (SD1)

This is a dry connection. In this type of connection, beam to beam elements are connected by using stud nut. It is connected at distance of 350 mm at top and 250 mm at bottom from the column face. These dimensions have been chosen to ensure that the beam-to-beam connection is located at a distance between the effective depth and twice the effective depth from the face of the column.

4.2 Precast connection using stud nut 2 (SD2)

This is also a dry connection. In this type of connection, beam to beam elements are connected by using stud nut. It is connected at distance of 250 mm at top and 150 mm at bottom from the column face. Here the dimensions have been chosen to ensure that the connection is located at a distance greater than the effective depth from the face of the column. Fig 2 shows the precast beam-to-beam connections SD1 and SD2.

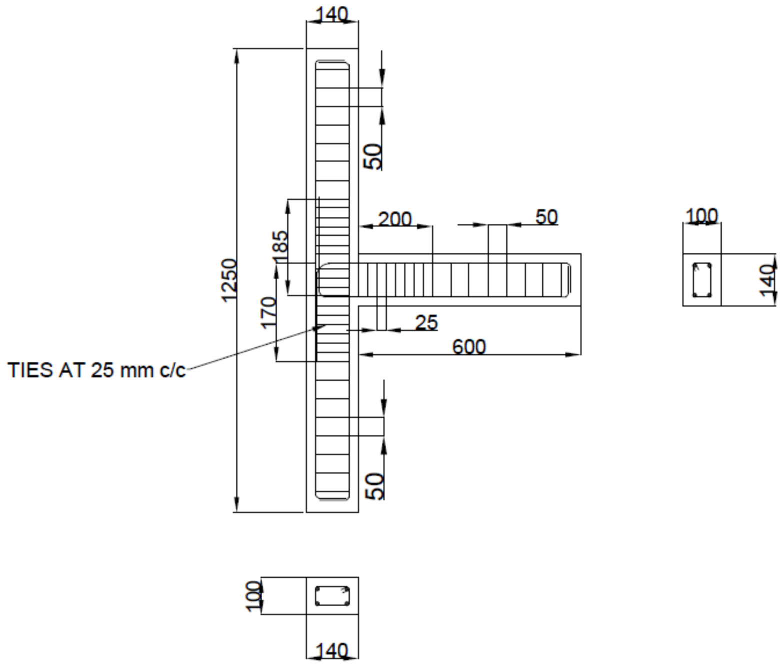
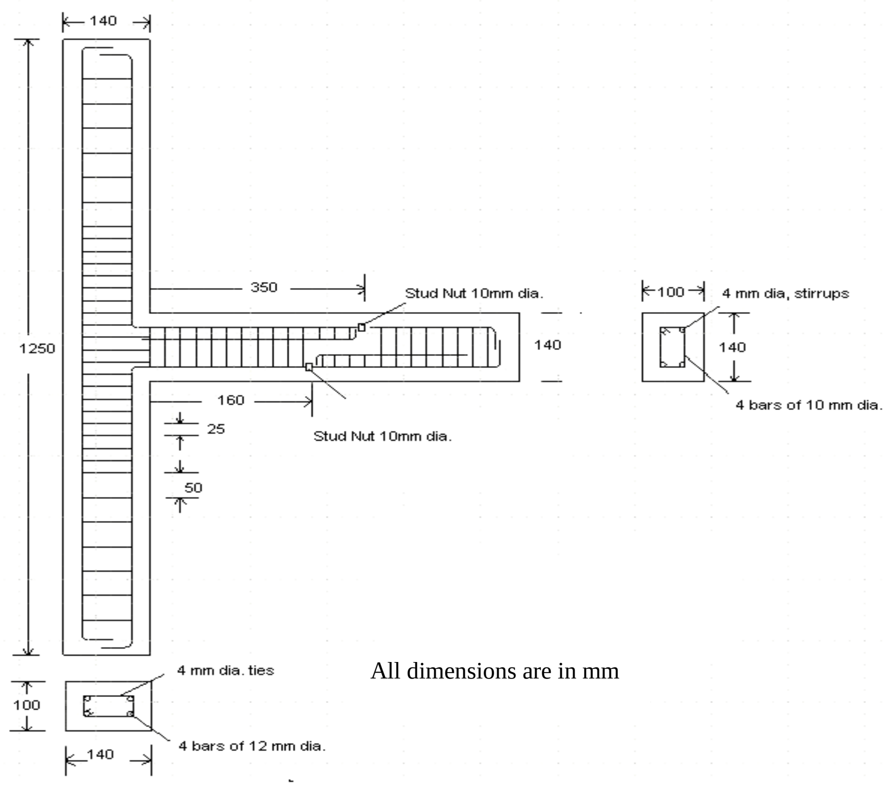
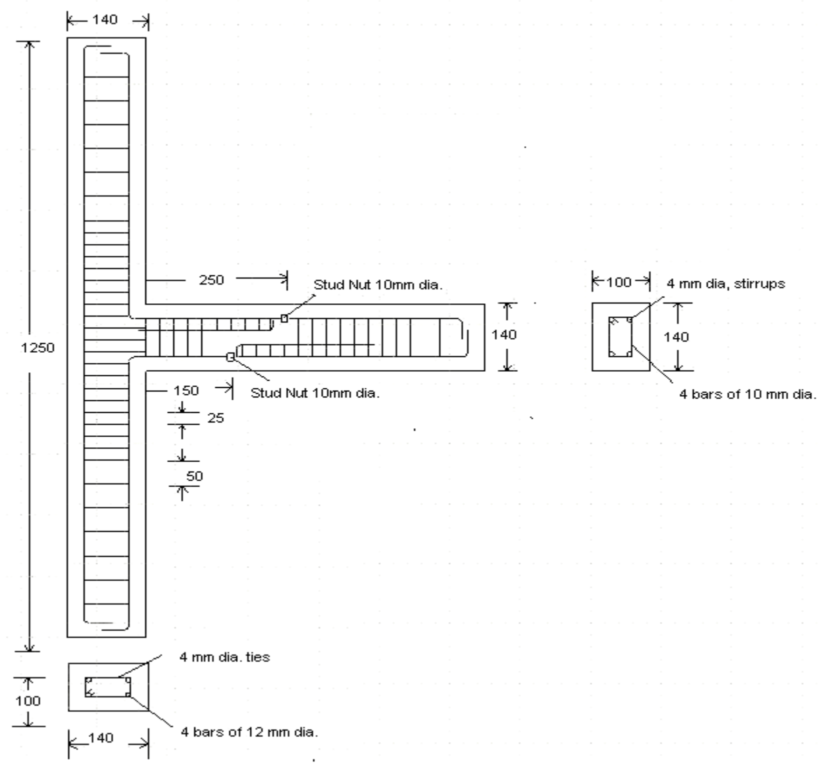


Fig.1 – Reinforcement detailing of the monolithic specimen.



(a) Connection by Stud nut (SD1)



(b) Connection by Stud nut (SD2)

Fig.2 – Connection detailing of precast specimens

5. Experimental Program and Loading Sequence

A loading frame of 2000 kN capacity frame was used for testing the monolithic and precast specimens. The test specimens were loaded by a hydraulic jack on the top of the column to simulate the gravity load. The capacity of the hydraulic jack was 1000 kN. Two hydraulic jacks with load cell are fixed to the loading frame for application of the reverse cyclic loading. One hydraulic jack is mounted on the top face of the beam end and another one is mounted on bottom face of the beam end. The capacities of the hydraulic jacks are 100 kN and 200 kN, respectively. Fig 3 shows the schematic diagram of the experimental setup of the test specimen. The downward direction is positive direction of loading. Table 1 shows the loading sequence for the testing program. Fig 4 shows the photograph of test setup.

Table 1 Loading Sequence

S.No	**Displacement**		**Increment**
	Start(mm)	**End(mm)**	**(mm)**
1	1	6	1
2	6	20	2
3	20	40	4

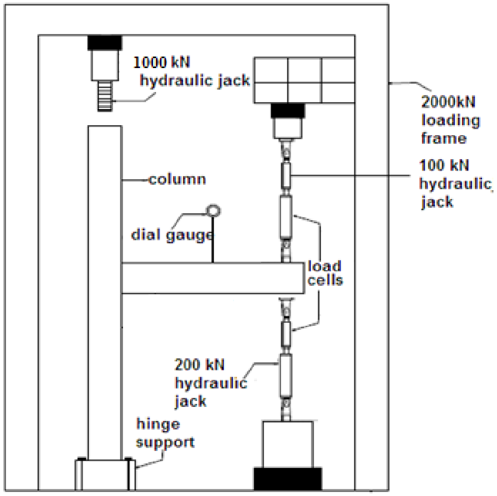


Fig.3 – Schematic diagram of Test setup

Fig.4 – Photograph of Test setup

6. Test Results

6.1 Ultimate Load Carrying Capacity

The ultimate load carrying capacity of the monolithic specimen was found to be 13.3 kN and 13.47 kN in positive and negative directions respectively, whereas for precast specimen SD1 the ultimate load carrying capacity was found to be 8.4 kN and 5.9 kN in positive and negative directions. The load carrying capacity of precast specimen SD2 was found to be 10 kN and 12.05 kN in positive and negative directions. From the results, it is observed that the ultimate load carrying capacity of specimen SD2 was 25% and 11% lesser than the monolithic specimen in the positive and negative direction respectively. Out of the two precast specimens, SD2 performed better than specimen SD1. The monolithic specimen (ML) performed better in resisting the load when compared to the precast specimens. Table 2 shows the ultimate load carrying capacity of all the specimens. Fig 5 and 6 shows the Ultimate Load of all the specimens in the positive and negative directions, respectively.

Table 2 Ultimate load carrying capacity of all the Specimens

Specimen	Ultimate load (kN)	
	Positive load	Negative load
ML	13.3	13.47
SD1	8.4	5.9
SD2	10	12.05

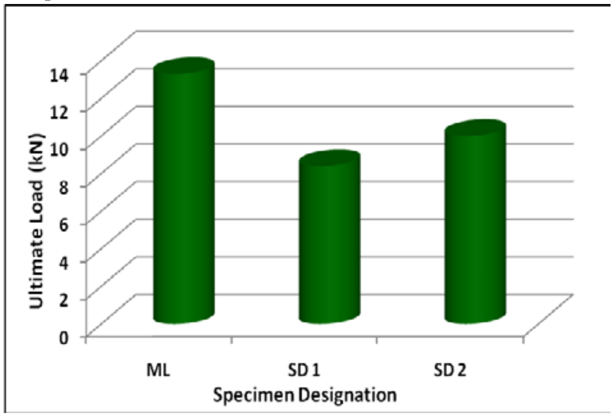


Fig 5 –Ultimate Load in positive direction

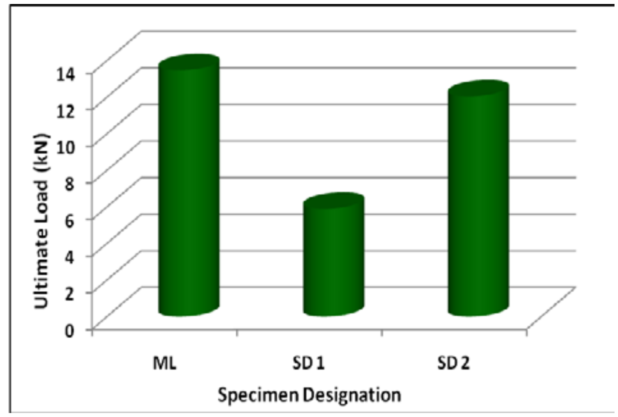


Fig 6 –Ultimate Load in the negative direction

6.2 Yield load

Table 3 shows the yield load of all the specimens. Fig 7 and 8 shows the Yield Load of all the specimens in the positive and negative directions, respectively.

Table 3 Yield load of all the Specimens

Specimen	Yield load (kN)	
	Positive load	Negative load
ML	9.31	9.42
SD1	5.88	4.13
SD2	7	8.44

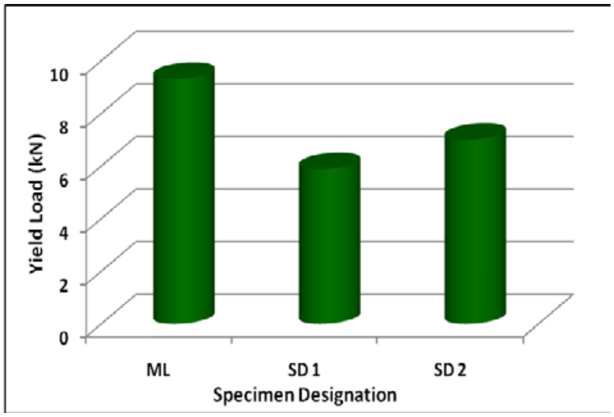


Fig 7 –Yield Load in positive direction

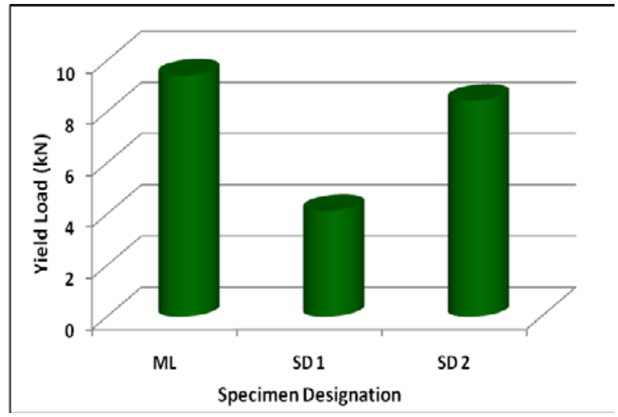


Fig 8 –Yield Load in the negative direction

6.3 Load displacement relationship

The Load-displacement relations for the precast specimens and the monolithic have been obtained from the test results. The load-displacement hysteresis loops for the cyclic loading at each displacement are obtained. Fig 9 shows the hysteresis loops for the monolithic specimen. Fig 10 and Fig 11 shows the hysteresis loops for the precast specimens SD1 and SD2, respectively. The monolithic specimen exhibited wide and stable hysteresis loop which is an indication of good energy dissipation. Out of the two precast specimens SD2 exhibited wider hysteresis loops than SD1 which is an indication of good energy dissipation.

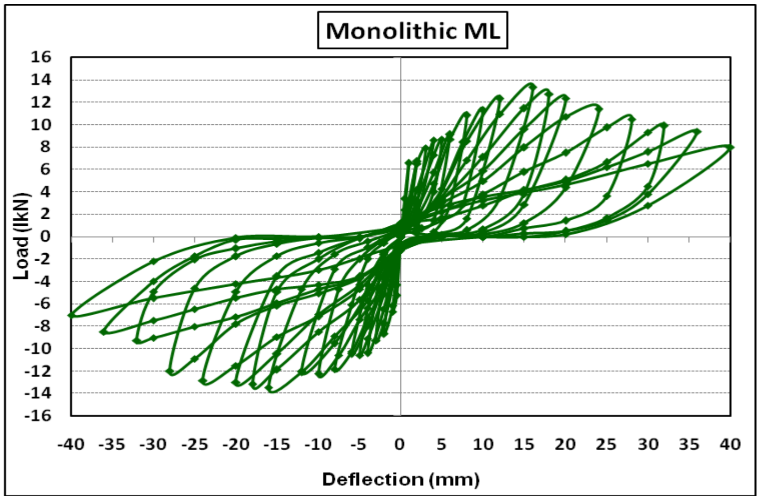
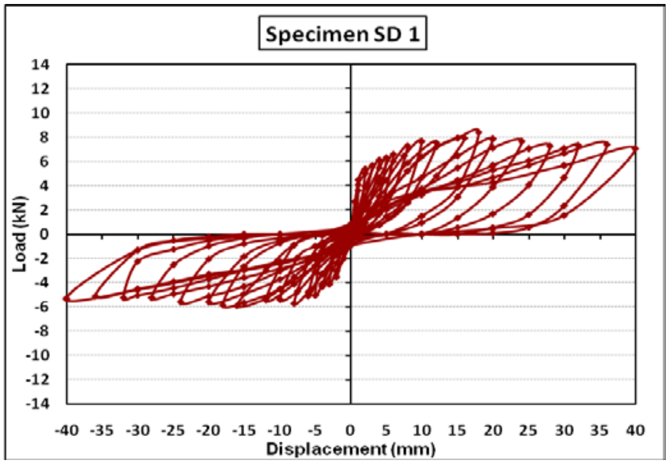


Fig 9 –Hysteresis Curve of Monolithic Specimen



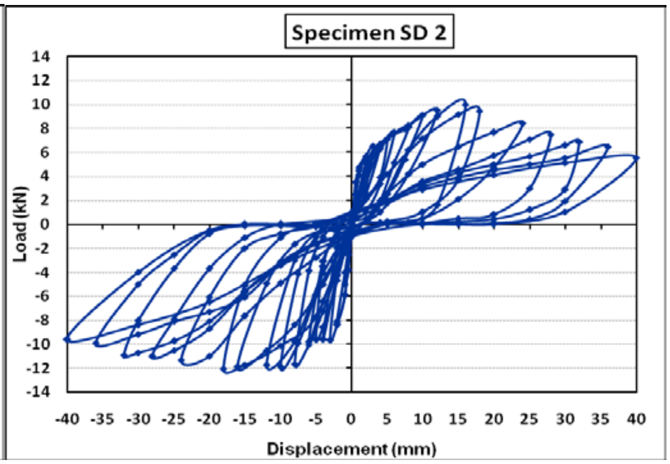
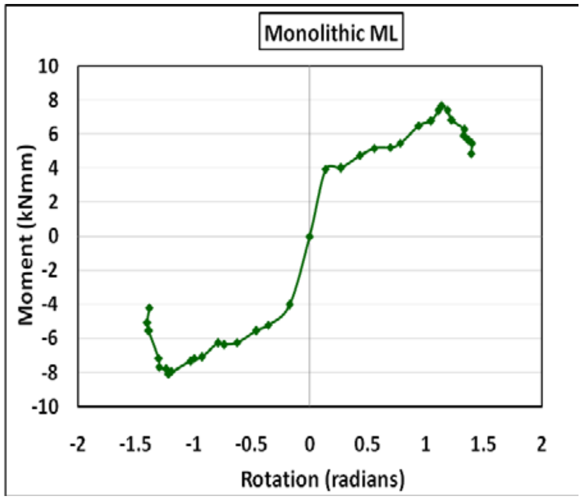


Fig 10 – Hysteresis Curve of SD1 Specimen

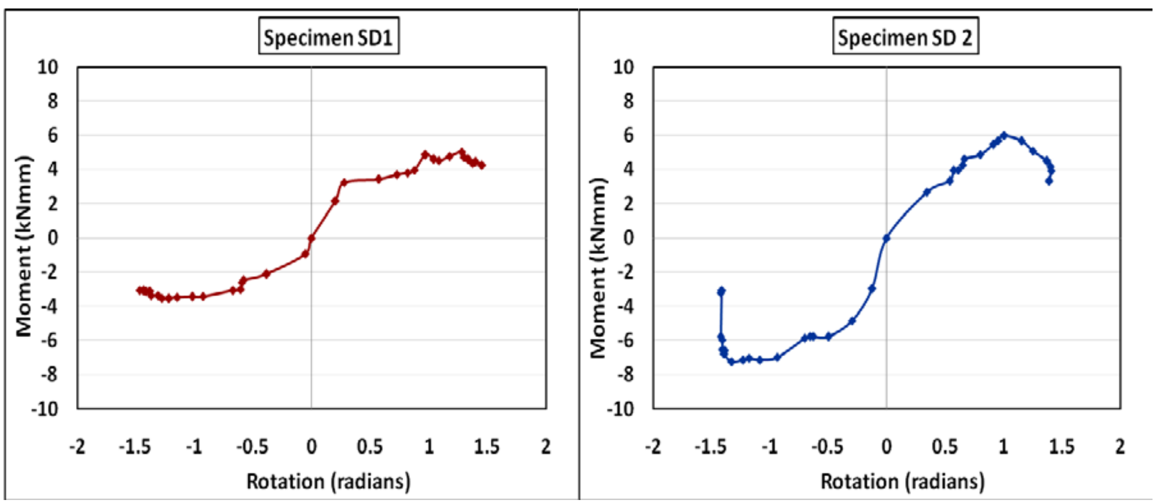
Fig 11 – Hysteresis Curve of SD 2 Specimen

6.4 Moment rotation curve

The flexural connection behaviour is represented by the moment rotation relationship, which relates the moment transmitted by the connection to the relative rotation of the connecting members. Fig 12 shows the Moment - rotation curve of all the specimens. Out of the three specimens, the monolithic specimen exhibited good moment rotation behaviour.



(a) monolithic specimen



(b) SD1 specimen (c) SD2 specimen

Fig 12 – Moment – rotation curve of the three specimens

6.5 Visual observation

The crack patterns due to the applied cyclic loading were observed. The cracks opened under tension and closed under compression. All the specimens were subjected to reverse cyclic loading. In the specimens, most of the damage was concentrated in the joint and in the beams. Consistent with a "strong column – weak beam" system, column damage was minor. Fig 13 shows the crack pattern for the monolithic and precast specimens SD1 and SD2.

(a) Monolithic specimen (b) SD1 Specimen (c) SD2 Specimen

Fig 13 – Hysteresis Curves of the three specimens

6.6 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 [12]. Table 4 shows that ductility factor of the three specimens. Both the precast specimens showed ductility behaviour comparable with that of the monolithic specimen.

Table 4 Ductility factor of the specimens

Specimen	**Yield displacement (∆y) (mm)**		**Ultimate displacement (∆u) (mm)**		**Displacement Ductility factor µ**		**Average displacement ductility factor**
	Positive	**Negative**	**Positive**	**Negative**	**Positive**	**Negative**	
ML	3.4	3.2	26.5	27.5	7.79	8.59	8.19
SD 1	3.8	4	31	32	8.16	8	8.08
SD 2	3.8	3.7	26	30	6.84	8.11	7.48

6.7 Energy dissipation

The area under the load–displacement curves is defined as the energy that is dissipated by joint. Table 5 shows the total energy dissipation of all specimens. Fig 14 shows the Comparison of Cumulative Energy Dissipation of all specimens. The precast specimen SD2 and monolithic specimen ML exhibited similar pattern of energy dissipation. The total energy dissipated by the monolithic specimen is 6.7% and 30 % greater than precast specimens SD2 and SD1. The precast specimens SD2 showed the better energy dissipation when compared to precast specimen SD1.

Table 5 Total Energy dissipation of all specimens

Specimens	Energy dissipation kNmm
ML	2134
SD1	1500
SD2	1991

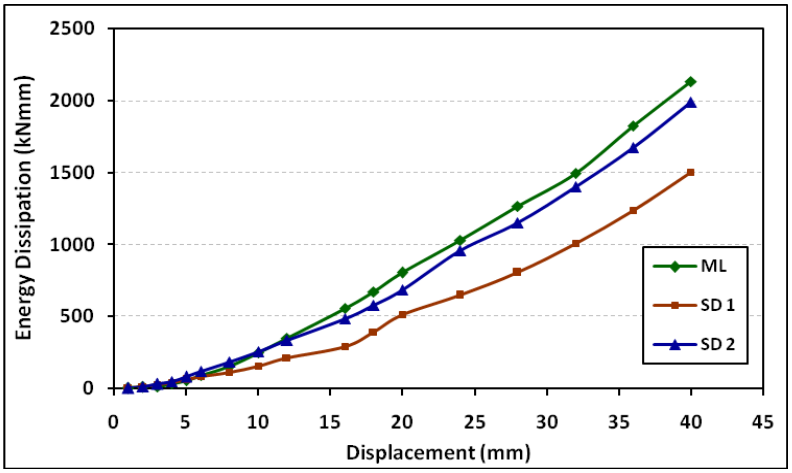


Fig 14 – Comparison of Cumulative Energy Dissipation of all Specimens

7. Conclusions

This experimental study was conducted to investigate the seismic performance of two types of precast beam to beam connection. In this study the load carrying capacity, energy dissipation and ductility factor were studied. Based on the observation during testing and data analysis, the following conclusions were developed.

- The visual observation and experimental results recorded showed that the monolithic connection develops more cracks when compared to the precast beam to beam connection.
- The load carrying capacity of precast specimen SD2 were 25% lesser than the monolithic specimen in the positive direction of loading and 11% less in the negative direction of loading
- The moment carrying capacity of precast specimen SD2 was 21% and 10% lesser than the monolithic specimen in the positive direction and negative direction respectively.
- Energy dissipation of the precast specimen SD2 was 6.7% less than the monolithic specimen.
- Out of the two precast specimens, SD2 shows good ductility and energy dissipation.
- Hence, the precast concrete beam to beam connection SD2 can be used in low seismic risk region.

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