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EXPERIMENTAL STUDY OF PRECAST BEAM-COLUMN HIDDEN CORBEL CONNECTION UNDER CYCLIC LOADING

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Abstract

The aim of this study is to investigate the behavior of hidden corbel precast beam to column connection due to cyclic loading by conducting laboratory test. Two types of connections were selected namely monolithic connection and hidden corbel connection. Both of the connections were having the same size of 100 mm × 100 mm × 1200 mm (Base × Width × Height) for column and 100 mm × 100 mm × 550 mm for beam. The monolithic connection acted as a control model with rigid type of connection while hidden corbel was a semi-rigid connection. Both models were subjected to a vertical cyclic loading until 40mm displacement using 500 kN actuator. Hysteresis load versus displacement graphs were generated and the connection behavior for both models were studied in terms of strength, ductility, stiffness and crack patterns. Based on the results, ductility of hidden corbel was equal to 3, which were higher than the monolithic. The hidden corbel connection was also experienced less degradation of stiffness and cyclic strength. This can be proved by less visible crack pattern that occurred at the connection. With that regard, hidden corbel connection model is more suitable to be used for cyclic loading and at the area prone to seismic loading.

Keywords: Crack pattern, Cyclic loading, Ductility, Hidden corbel connection, Stiffness.

1. Introduction

Construction Industry Development Board (CIDB) has been actively promoting the use of Industrialized Building System (IBS) in the local construction industry since 1998. One of the reasons IBS continues to be the choice in the field of construction is that it gives good quality and durability of the system of the building. Precast concrete has many advantages such as reliability, durability, faster in construction, higher quality and can be built in all kinds of weather conditions However, the quality of the IBS depends on its connections. Connections in precast concrete construction, particularly of primary members, form a critical part of the load carrying and transfer mechanism [1].

Several studies were conducted to evaluate the performance of precast beam-column moment resisting frames under cyclic loading. Loo and Yao [2] conducted experimental investigations on eighteen half-scale interior connection models to evaluate their strength and ductility properties under static and repeated loading. It was concluded that under both static and repeated loading, the precast connections attained a higher flexural strength and larger energy absorbing capacities than monolithic connections. Khaloo and Parastesh [3] carried out an experimental study to investigate a simple moment-resisting precast concrete beam-column connection under cyclic inelastic loading. The variables examined were the connection length of reinforcements and presence of transverse bars at mid height of connection. It was concluded that the reduction in connection length reduced strength, ductility and energy absorption. The presence of transverse bars in the connection length enhanced the seismic behavior of the precast connection system.

Chun et al. [4] 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. [5] 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 [6] 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 the other connections. It was concluded that all connections performed satisfactorily in seismic conditions with respect to strength, ductility and energy dissipation capacity. Vidjeapriya and Jaya [7] have tested two mechanical precast beam-column connection under reversed cyclic loading. The first beam was connected to the column with corbel using a cleat angle with a single stiffener, and for the second sample of precast connection, cleat angle with two stiffeners was used. From the experimental test, it was found that the ultimate load carrying capacity of monolithic specimen was comparable to that of both precast samples. Meanwhile, the energy dissipation and ductility gave satisfactory behaviour as compared to monolithic specimen.

Based on past studies showed that the precast connections can be proved as strong as that of the monolithic connections. It can also be widely observed in the literature that a lot of research on precast structures emulating the behavior 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 proposing beam-column connections using dowel and steel box act as hidden corbel inside it. The main focus of the work is to develop this novel idea for dry connection in the moment resisting frames. The behavior of precast beam-column with corbel connections and a reference monolithic connection were investigated and tested.

2. Specimen Preparation and Test Set-Up

Laboratory study was conducted on one-third scaled specimens of monolithic beam-column connection and hidden corbel connection. For the present study, an exterior beam-column joint of a three-story reinforced concrete building was considered. Two test specimens on one third-scale model were cast and tested under reverse cyclic loading. The 28th day average compressive strength of the concrete, fcu was 41 MPa. The cylinder compressive strength has been evaluated based on the relationship, $fc' = 0.8\, fcu$ and was observed as 33 MPa by testing three cylinders of 150 mm diameter and 300 mm height.

2.1. Specimen details

The detailing of ML specimen is shown in Fig. 1. 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 shear reinforcement 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 was reduced to 25 mm. The cantilever part of the column, steel frame is inserted as in Fig. 2.

2.2. Testing setup and loading sequence

Testing set up for the specimens is shown as in Fig. 3. The end of column for both of ML and hidden corbel precast specimen were supported using fixed support, which the top column was restrained into the column holder 1600-psi hydraulic jack while the bottom was restrained into the column shoe which was fastened to the strong reaction floor. A 500 kN capacity actuator with a displacement range of 50 mm was used to apply the reverse cyclic loading. The cyclic loading was applied as displacement controlled at the free end of the beam. LVDT were placed below the beam to measure the vertical displacement of the beam. The cyclic loading history consists of displacement cycles as shown in Fig. 4.

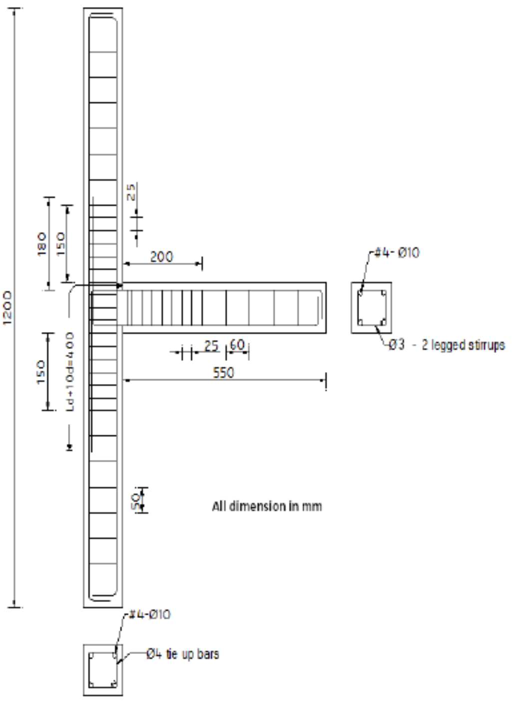

Fig. 1. Details of monolithic.

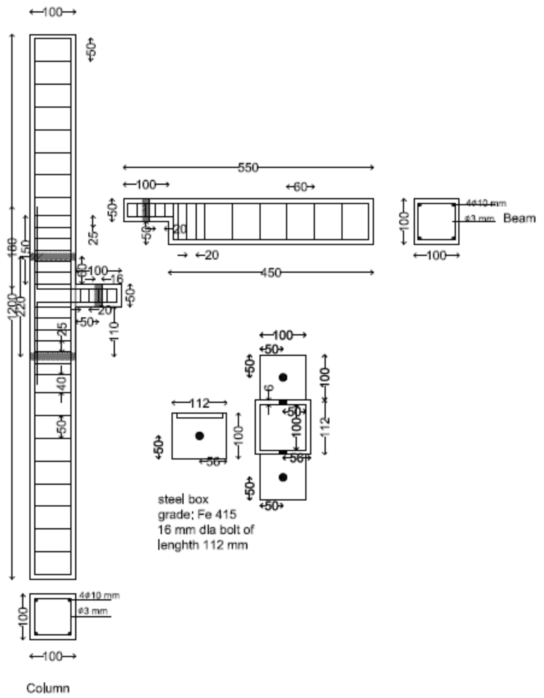

Fig. 2. Details of hidden corbel.

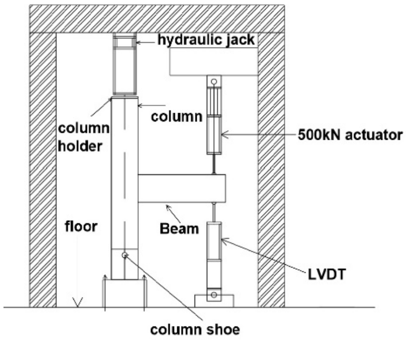

Fig. 3. Test setup.

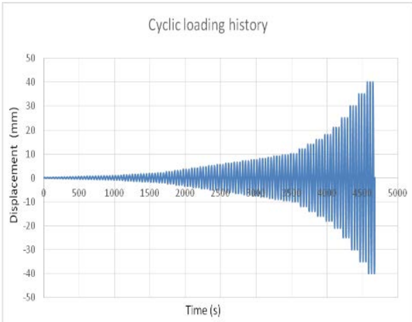

Fig. 4. Cyclic loading history.

3. Test Results and Discussion

The test results here consist of analyses and discussion on load vs displacement, ductility, stiffness and crack pastern observed during testing of the samples.

3.1. Load vs. displacement

The load hysteresis curve of ML specimen shown in Fig. 5 gave higher loads of 9 kN at constant displacement of 31 mm as compared to hidden corbel specimen shown in Fig. 6, which gave lower loads of 3.18 kN at the same displacement. The same behavior also recorded at negative displacement. This indicates that ML connection can support more loads compared to hidden corbel at certain displacement.

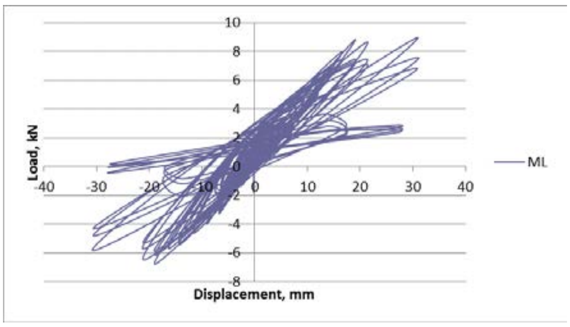

Fig. 5. Monolithic (ML) hysteresis curve.

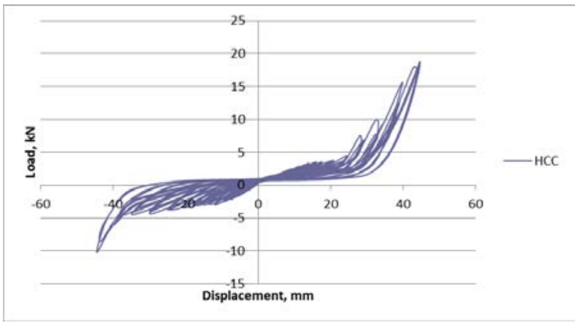

Fig. 6. Hidden corbel hysteresis curve.

The precast specimens exhibited lesser deterioration than monolithic specimen ML. This behaviour was due to the good confinement of the joint core by steel box provided as part of joint system. These figures 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 indicated good energy dissipating capacity. Figures 5 and 6 show the load-displacement hysteretic response of the monolithic specimen and HCC specimen respectively. Greater pinching was observed for the HCC because of predefined gap opening at the connections, which indicated minimal energy dissipation. For specimen HCC, cracks were observed around the recess provided for the accommodation of the dowel in the beam region and corbel, whereas no cracks were observed in the column. The load-displacement envelopes of the specimens ML and HCC is shown in Fig. 7.

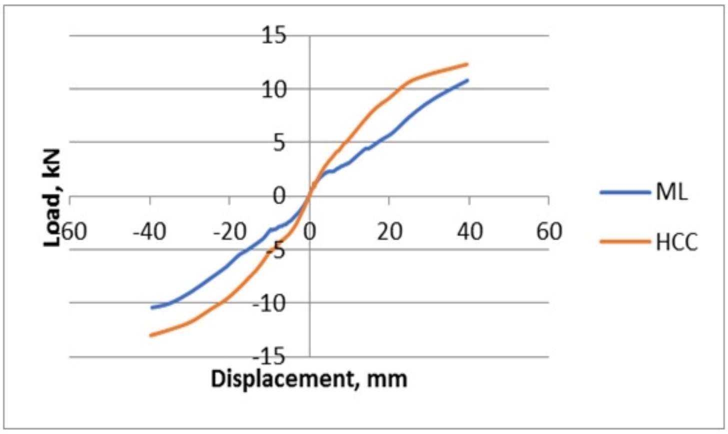

Fig. 7. Load-displacement envelopes of specimens ML and HCC.

3.2. Energy dissipation capacity

When sufficient amount of energy is dissipated by the connection without any substantial loss of strength and stiffness under cyclic loading, the beam-column joint will behave in a ductile manner. Good energy dissipating capacity of a connection is an indication of the satisfactory performance of the connection in the inelastic stage. To determine the energy dissipated by the test specimen during each cycle, the area enclosed by the hysteretic loop in a given cycle is calculated. It is obvious that the larger the area occupied, the larger the dissipated energy and the larger the damping effect. The cumulative energy dissipated is computed by summing up the energy dissipated in the consecutive cycles throughout the test. Figure 8 provides a comparison of the cumulative energy of all the specimens. In comparison with the ML specimens, it is observed that the specimen HCC dissipated greater energy of 890 kNmm.

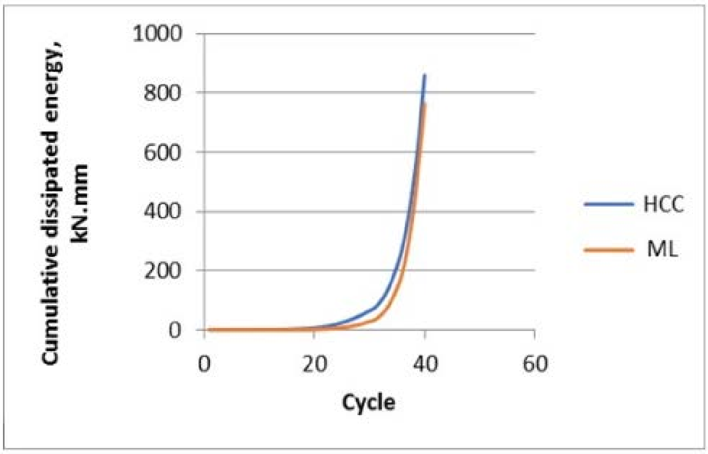

Fig. 8. Cumulative energy dissipation curves of the two specimens.

3.3. 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. From the laboratory test, the maximum and first fracture strain for ML and hidden corbel connection was recorded and calculated to determine its ductility. Based on the ductility equation given by Park and Paulay [8], the ductility value for monolithic and hidden corbel was 1.24 and 3 respectively. This indicates that the hidden corbel is more ductile (partial ductile ranging from 3-5) and capable to undergo elastic deformation that act alternately and repeatedly after the first melting phase [9].

3.4. Stiffness

The stiffness value of the connections was calculated based on tangent gradient of the load vs displacement graph as shown in Figs. 9 and 10. From the calculation, the stiffness of ML connection gave 0.35 kN/mm, which is higher than hidden corbel, which gave 0.21 kN/mm. This indicates that ML connection is a rigid connection which can resist deformation (produce small deflection) when load is applied. The higher the value of stiffness, the higher the value of the loads supported, the smaller the value of deflection.

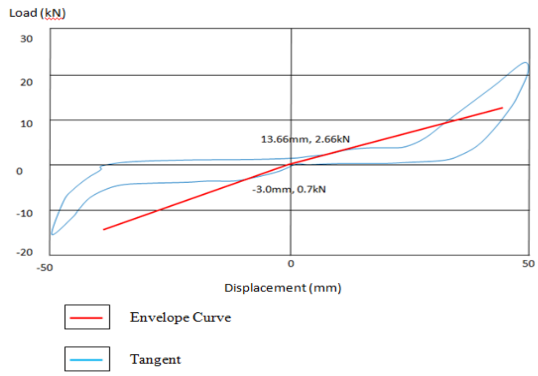

Fig. 9. Envelope curve for monolithic.

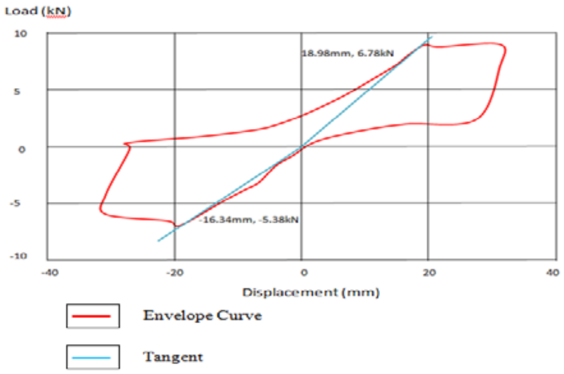

Fig. 10. Envelope curve for hidden corbel.

As the test specimens were subjected to reverse cyclic loading, it resulted in the accumulation of damage, which led to stiffness degradation. Stiffness degradation of the test specimens were determined based on the secant stiffness changes. The secant stiffness is peak-to-peak stiffness that is defined as the slope of the line that connects the peak positive and negative response during a load cycle. The variation of secant stiffness in each displacement cycle is calculated and is shown in Fig. 11.

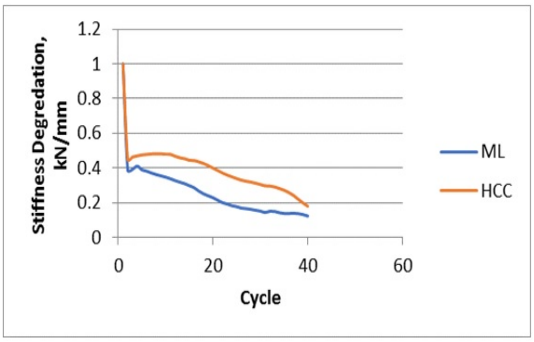

Fig. 11. Stiffness degradation of two specimens.

3.5. Crack pattern

For ML specimen, cracks were mostly concentrated at the connection. The first cracks occurred during 21 mm (8.68 kN) of displacement while the second crack occurred during 25 mm (2.4 kN) of displacement (Figs. 12 and 13). At the connection, concrete began to spall at 35mm of displacement and began to spread to the column at 40 mm of displacement. Moreover, shear cracks were also observed along the precast column.

Fig. 12. First crack of monolithic.

Fig. 13. Second crack of monolithic.

Whilst for hidden corbel, cracks are mostly concentrated at the beam. The first cracks occurred at the connection during 25 mm (2.6 kN) of displacement while the second crack occurred during 35 mm (9.38 kN) of displacement (Fig. 14). Concrete began to spall at 45 mm (18.64 kN) of displacement and crack began to spread along the beam at 50 mm (20.5 kN) of displacement that indicates the shear cracks as shown in Fig. 15. As observed, the cracks for hidden connection specimen are less than ML specimen especially at the connection region. This is due to its lower stiffness value, which allows the specimen to have more deformations. The hidden specimen also experienced less degradation of stiffness and cyclic strength that may lead to cracking and collapse of structures.

Fig. 14. First and second crack at hidden corbel connection.

Fig. 15. Spalling of concrete of the beam of hidden corbel.

4. Conclusions

New precast beam-column hidden corbel connection subjected to reverse cyclic loading was experimentally investigated. The results were compared with the performance of a reference monolithic beam-column connection. The type of precast beam-column connection considered for the present study was a hidden corbel with steel box type. The summary of the observations are as follows

- The load displacement envelope of HCC was higher than ML connection. This is due to the additional stiffness and strength developed in HCC by the presence of steel box.
- All the specimens were loaded up to 40 mm displacement cycle. There were no cracks developed in the column for the HCC specimen. Only minor cracks were developed in the corbel of the HCC specimen. The monolithic specimen developed cracks in the column region.
- Considering the energy dissipation, the specimen HCC performed better than the ML specimen and dissipated 13% higher energy than specimen ML.
- The precast specimen with dowel and steel box (HCC) showed better ductility than monolithic specimen ML. Specimen HCC showed about 18% increase in ductility when compared to specimen ML respectively.

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