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Editorial

Welcome from the Editor

The Editorial welcomes all readers to this second issue of Malaysian Construction Research Journal (MCRJ). Special thanks to all contributing authors for their technical papers. The Editorial would also like to express their acknowledgement to all reviewers for their invaluable comment and suggestion. This issue highlights seven titles which focus on topics related to Industrialised Building Systems (IBS).

In this issue, ***Hamid et. al.*** highlights the current state of IBS in Malaysia and its related R&D initiatives. The study addresses the current scenario of IBS adoption and identified the difficulties in its implementation. The authors also stress the important role of R&D and proposed the strategic approach to be taken on board by Construction Research Institute of Malaysia (CREAM).

Mahmood and Arizu discuss on the development of a standardised partial strength connection tables of extended end-plate connections for trapezoidal web profiled (TWP) steel sections. These tables will assist designers and improve the design of semi-continuous construction of multi-storey braced steel frames. Laboratory tests were carried out to validate the results and presented them in the standardised tables.

Ahmad Baharuddin et. al. writes on the comparative study of monolithic and precast concrete beam-to-column connection. The response of the connection subjected to incremental loading was studied. Specimens of monolithic and precast concrete beam-to-column were tested to evaluate the ultimate loading capacity, moment rotation characteristic as well as their crack response.

Mahyuddin evaluates the structural performance of ferrocement sandwich panel used in Industrialised Building Systems. Experimental investigation was carried out to assess the load-deflection characteristics, crack resistance and moment curvature of ferrocement elements that were exposed to air and salt water environment.

In his second paper, ***Mahyuddin*** reports on the permeability of polymer-modified cement system for structural applications. The durability enhancement of the cement system is achieved by reducing the permeability of the material through polymer modification. He had also investigated and reported the intrinsic properties, mechanical properties and the durability performance of the polymer-modified cement system.

Doh et. al. discusses the findings of their research works on the use of oil palm shell as structural topping for semi-precast concrete slab. Their works focus on the strength characteristic and flexural behaviour of concrete slab and to check its compliance to the requirement specified by the Code of Practice.

Finally, ***Mohd Al Amin et. al.*** investigates the response of ceramic foam core sandwich composite under flexural loading. Their study focuses on the determination of a range of sandwich properties which include shear modulus and bending stiffness through conducting a series of bending tests. They concluded that the ceramic foam core sandwich composite were comparable to those of polymeric foams core materials and has a high potential to be used as core material for sandwich structure construction.

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new approach to be taken on board. As highlighted in the Construction Industry Master Plan 2003-2010 (CIMP) the role and functionality of R&D in Strategic Thrust 5: Innovate through R&D to adopt new construction method, it is pertinent to R&D to path (or lead) the way of promoting better adoption of IBS in Malaysia. The establishment of Construction Research Institute of Malaysia (CREAM) initiated by Construction Industry Development Board (CIDB) Malaysia should be seen as very significant development in the structure of R&D, which was previously at very formative stages rather organisationally ad-hoc and often confusing. CREAM can be assigned a task of managing the IBS research (CIDB, 2007a).

The R&D themes and topics for IBS identified through series of workshops organised by CREAM are aligned to the requirement of IBS Roadmap 2003-2010 (CIDB, 2003a). The initiatives in IBS though lead by CIDB, participative from contractors, consultants, universities, companies and research institutes are critical. The obligation to implement IBS serves concurrent both to improve performance and quality in construction, also to minimise the dependency of unskilled foreign labours flooding the construction market. It is a daunting task as 2010 is just around the corner. The process and mechanism to achieve the target depend on the integration and acceptance of the players towards IBS. Three years ahead will be a challenging one. A strategic approach will be the way forward. As the R&D arm for CIDB, CREAM’s R&D output will geared towards industry’s application and requirements.

CREAM shall take the following actions as a pre requisite to expedite the success of the roadmap implementation with respect to R&D in IBS (Hamid *et. al.*, 2007):

- A long term and strategic approach of conducting research on IBS shall be established.

- Involvement of universities, companies, organisations and research institutes right from the onset of any IBS R&D projects.

- Participation and inclusion of IBS in JKR building design, i.e. JKR IBS Design must be incorporated in its *Rekabentuk Bangunan Piawai* for government quarters, schools and government administrative offices. (CREAM will discuss this matter further with JKR on any issues related to R&D).

- Malaysian standard joints for IBS (wet or dry) must be designed and made available for use by the industry.

- CREAM initiatives to lead Centre of Research Excellence (CORE) on IBS and act as One Stop Centre for R&D are critical as this moves will consolidate the effort to centralise and able to identify issues and problems first hand from the industry.

- The formation of R&D laboratory and acts as CORE for IBS is urgent and CREAM should initiate and take the lead.

COMPARATIVE STUDY OF MONOLITHIC AND PRECAST CONCRETE BEAM-TO-COLUMN CONNECTIONS

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Abstract:

The performance of a precast concrete structure have greatly influenced by the response and characteristics of beam-to-column connections. The information on connection characteristics such as moment-rotation is very important for the analysis and design. Without proper understanding of the connection response and characteristics, it is difficult to design a safe structural system of the global precast frame. This paper discusses the connection response when subjected to incremental gravity loadings. Two specimens comprising one monolithic (CF-RC) and one precast concrete beam-to-column (CF-PC) connections were considered. The concrete strength for all specimens including the wet connection was 30 N/mm^2. All the two specimens were tested to failure under incremental point loads that produced hogging moments to the connections. The response of the connections was studied through the ultimate loading capacity, moment-rotation characteristic, and crack response. The results of moment-rotation characteristics of the precast connection show similar response to the monolithic connection. It was observed that the ultimate moment resistance of the precast connection was higher by about 11% as compared to the monolithic. For these reasons, the CF-PC precast connection can be categorised as a moment resisting connection under the action of gravity loads. Hence, engineers can consider similar precast connection details to obtain moment resisting connections, provided hogging moments due gravity loads are more dominant than sagging moments due to lateral loads.

Keywords : Beam-to-column connections, precast concrete frame, rigid connection.

INTRODUCTION

In precast construction, connections are use to assemble beams and columns to make a complete multi-storey framed building. The beam-to-column connections form the important structural component of a precast concrete structure. To satisfy the structural requirements of the overall frame, each connection must have the ability to transfer shear forces and bending moments from one precast component to another, safely.

The transfer of forces between beams and columns, and its effect to the performance of global frame, is governed by the characteristics of the connections. However, in practice, the characteristics and the response of precast connections is not well established and not fully understood to fulfil the requirements needed in design and construction. Realising the significant contributions of connections in precast concrete structures, many research works were carried out around the world.

In the United States of America, the most well known research was the PRESS projects carried out by researchers at University of Washington and University of California at San Diego; sponsored by National Science Foundation and Precast Concrete Institute. One of the successful findings was the ductile connectors developed by Englekirk (1999). The developed beam-to-column connection can be used to construct a moment resisting frame of pre-cast concrete components that could outperform comparable cast-in-place and structural steel systems (see Figure 1). This ductile connector contains a rod that yields at a well-defined strength, effectively limiting the load that can be transferred to less ductile components on the frame.

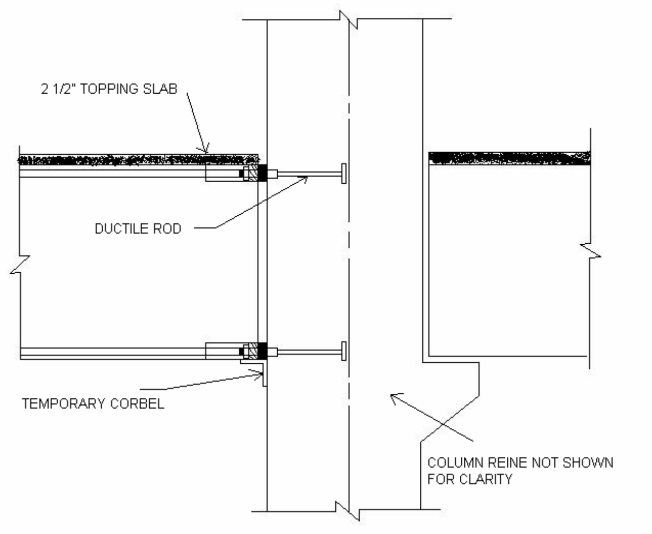


Figure 1. Ductile Connectors

In New Zealand, Restrepo *et. al.,* 1995 developed several moment resisting connections to be used with precast buildings. The trend is that the increased use of precast concrete structures has encouraged the researchers to consider innovative connections for their precast concrete structural systems because of the country's location in an active seismic zone.

In the United Kingdom, Elliot *et. al., 2003* has conducted numerous research works on precast concrete beam-to-column connections. Knowing that most of precast connections behave semi-rigidly, he proposes that the global precast frame can be designed semi-continuously, to take advantage of the semi-rigid characteristics. This may results in more economical design, as compared to a precast structure designed with pinned connections.

In Turkey, Ertas *et. al.* investigated the performance of ductile connections, to be employed in precast concrete moment resisting frames. Several connections comprising cast-in-place, composite and bolted connections were tested and compared with the monolithic connection. The performance of each connection evaluated based on the properties of stiffness, strength, ductility and energy dissipation.

In Malaysia, research on beam-to-column connections was carried out at the Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), with the financial support provided by Construction Industry Development Board (CIDB). Several existing and new connections were tested. The main objective of this research was to investigate the response and performance of precast concrete beam-to-column connections as part of structural components in a precast framed building. The response and the characteristics of the beam-to-column connections, as part of the cruciform subframe, was evaluated based on the ultimate loading capacity, load-deflection, moment-rotation characteristic and cracking pattern.

Moment connections are widely used in most of precast concrete buildings constructed in Malaysia (Ahmad Baharuddin Abd Rahman and Wahid Omar, 2007). The most common moment resisting precast connection is a wet connection shown in Figure 2. This connection is obtained by extending the reinforcement bars from the beam through the column and followed by casting the beam-to-column junction with wet cast-in-place concrete. This connection is normally used when a moment resisting frame is needed. However, there is no evidence to prove that this connection can provide the required moment resistance. As a result, there are different opinions among engineers regarding the performance of the precast frame when this wet connection is used. For this reason, a comparative study based on experimental results between the precast connection and monolithic was carried out.

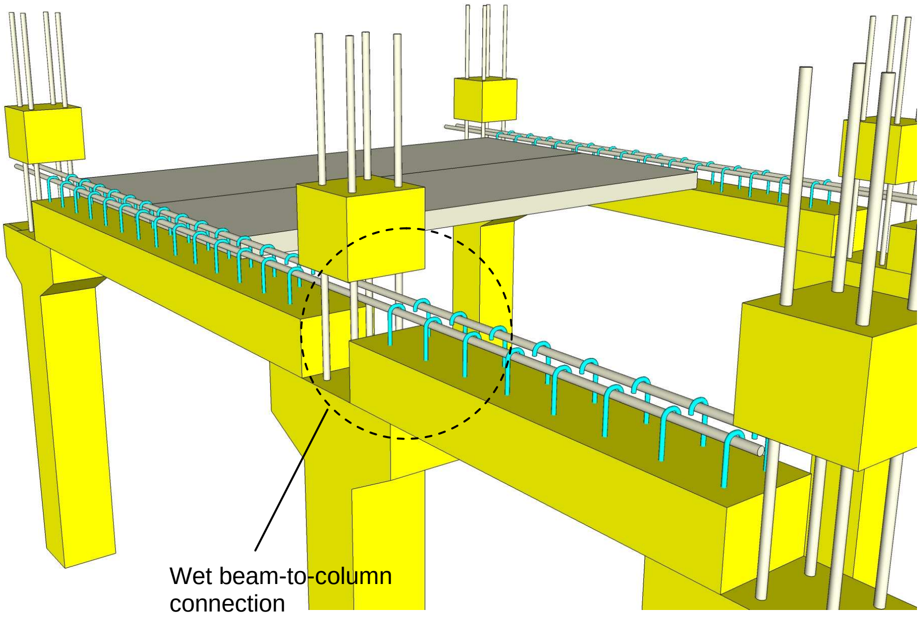


Figure 2. Beam-to-column connection using cast-in-place infill in precast concrete construction

DESCRIPTION OF MONOLITHIC AND PRECAST CONCRETE BEAM-TO-COLUMN CONNECTIONS

To model an internal connection in a multi-storey frame building, a cruciform subframe was considered (see Figure 3). In the test program, one cruciform conventional reinforced concrete denoted as CF-RC to act as the control specimen and one cruciform precast beam-to-column connection denoted as CF-PC specimen were conducted. Each cruciform subframe consisted of one column and two continuous beams.

The beams and columns for both monolithic and precast specimens were manufactured using concrete of grade 30 N/mm^2. The ready mixed concrete was produced using maximum coarse aggregate size of 20 mm with 60-180 mm concrete slump.

Figure 4 shows the cross-sectional details of all beams, columns and corbels for the cruciform specimens. Each beam specimen comprised 2Y16 in Grade 460 for its top (tension) and bottom (compression) steel bars respectively, and R8 mild steel bar in Grade 250 N/mm^2 at 125 mm spacing for the stirrups. Each column specimen comprised 4Y16 in Grade 460 for the main longitudinal bars and R8 in Grade 250 at 125 mm spacing for the stirrups. In addition, more information on the making of the monolithic and precast subframes is illustrated in Figures 5 and 6 respectively.

With reference to Figure 6(b), half-depth precast beams were installed on both sides of corbels, followed by the installation of 2Y16 top reinforcement bars, while 2Y16 of the bottom reinforcement bars were already cast in the half beam. To complete the connection between precast beam and precast column, see Figure 6(c), a second stage of concreting using wet cast in-place concrete was carried out, with the use of simple side formwork along the beam. Due to the procedures of installation, the top steel bars continue to the adjacent beam but the bottom steel bars terminated at beam end resulting in discontinuity. This steel bar discontinuity might affect the moment resistance of the connection. Therefore, it was the objective of this paper to asses the moment resistance of the connection based on experimental tests.

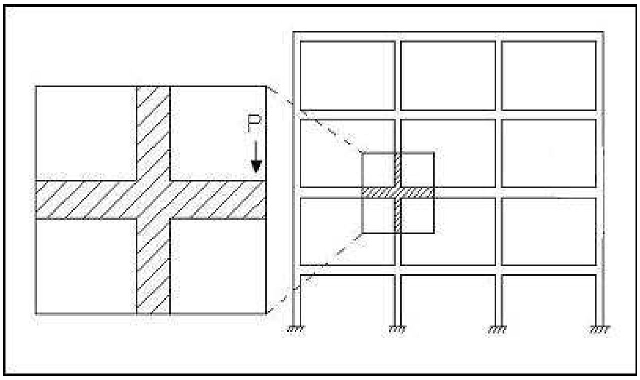
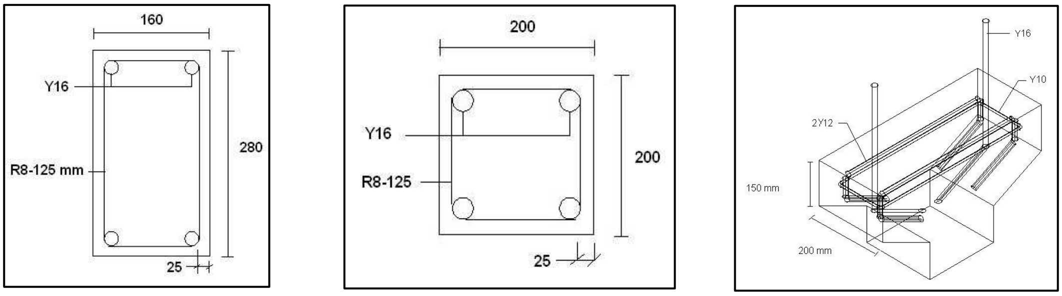


Figure 3. Cruciform subframe, CF

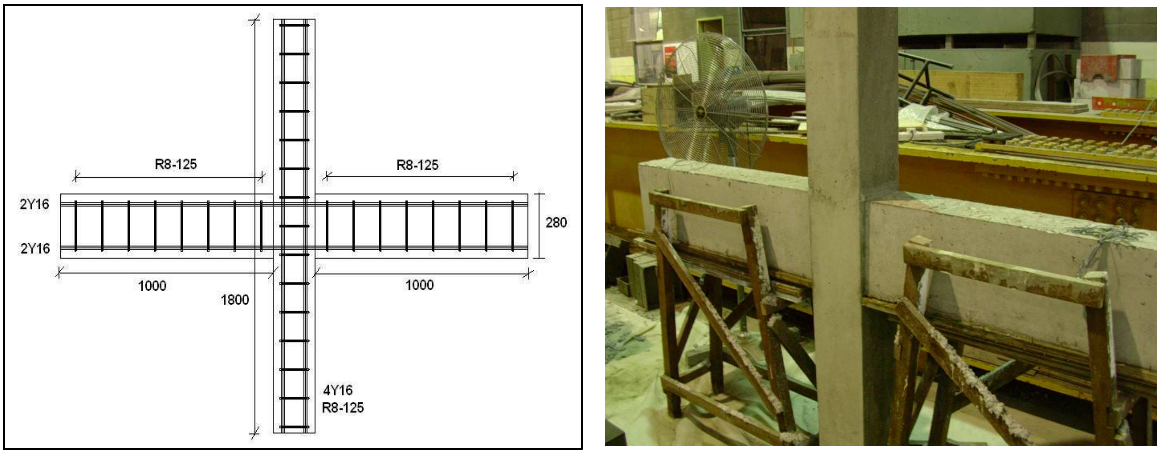


(a) Beam

(b) Column

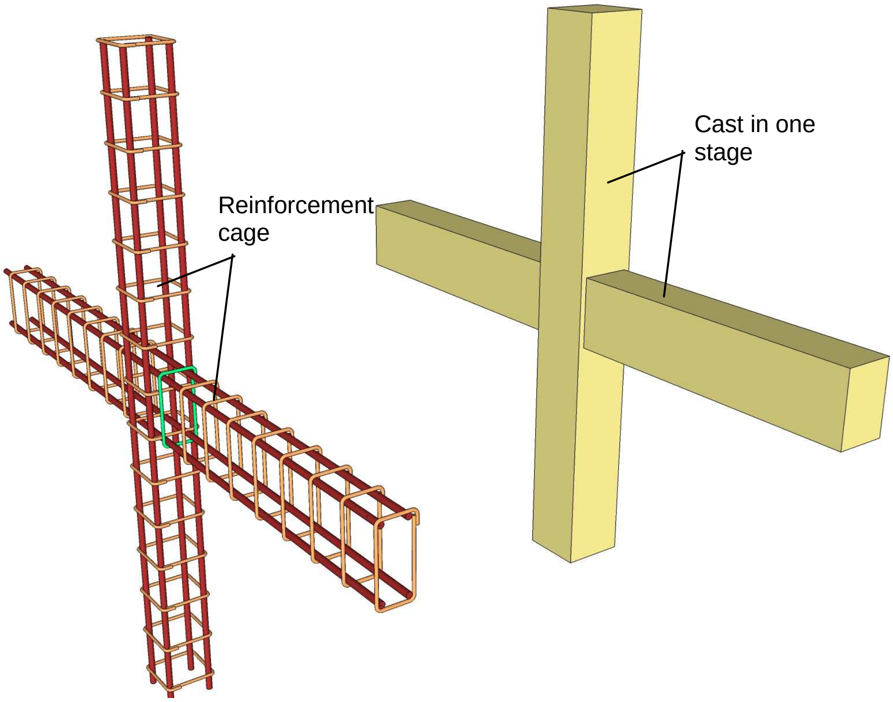
(c) Corbel for precast specimen

Figure 4. Details of beam and column for both monolithic and precast specimens, and corbel for precast specimen



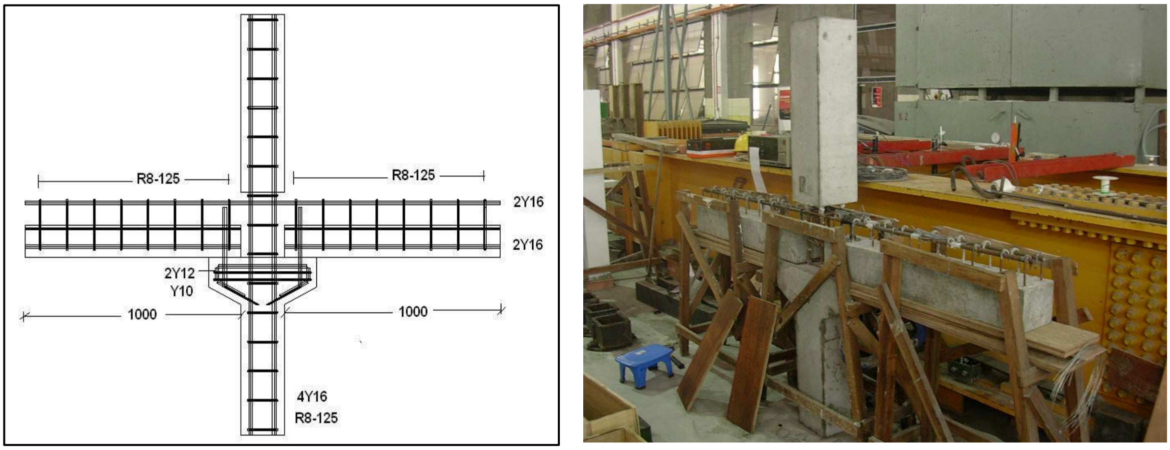
(a) Reinforcement details

(b) Monolithic specimen



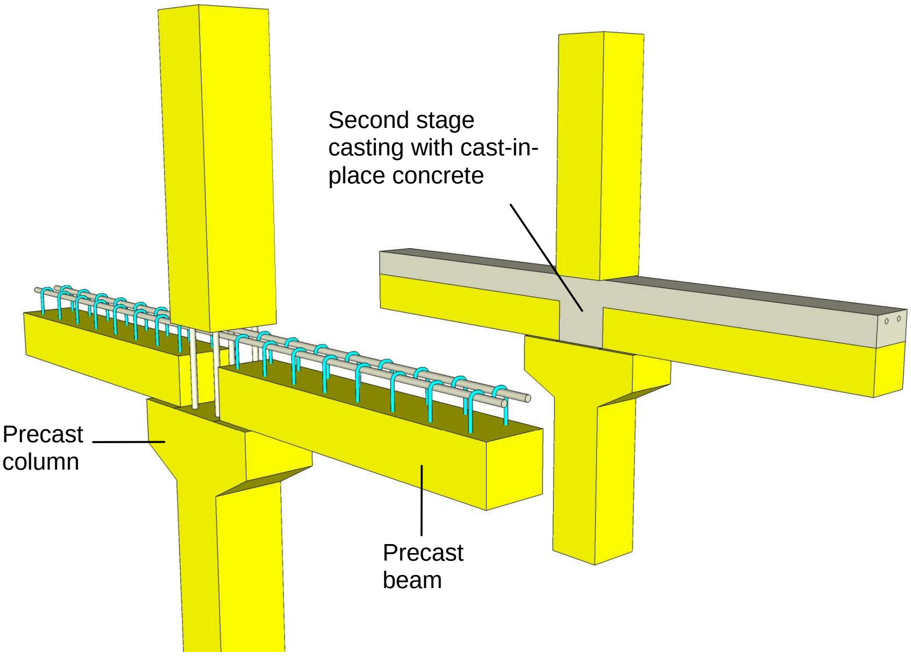
(c) Before and after concreting of monolithic connection

Figure 5. Monolithic specimen, CF-RC



(a) Reinforcement details

(b) Precast specimens ready for wet connection



(c) Before and after concreting of wet connection

Figure 6. Precast specimen, CF-PC

EXPERIMENTAL SETUP AND PROCEDURES

Test specimens were restrained at both top and bottom ends of the column as shown in Figure 7. All the beam-to-column specimens were extensively instrumented to record their response under incremental loads. Strain gauges were installed at midspan of internal steel bars of the beam and at the extreme compression face of the concrete. Six linear variable displacement transducers (LVDT), T1 to T6, were used in the test whereby four of them were located under the beam and another two at the column.

External loads were applied by two hydraulic jacks denoted as jack 1 and jack 2 as shown in Figure 7. In addition, jack 3 was provided to act as a reaction support. In each test, an axial load, P2 was first applied at the top of the column, using jack 2. This load, which was equal to 80 percent of the design axial strength of the column, was kept constant throughout the test. Then, using jack 1, incremental vertical loads, P1 were applied to the beam end in stages to produce incremental hogging moments to the connections. The results were monitored by a high accuracy load cell with a load sensitivity of 0.1 kN. The incremental loadings, P1 were applied at 1 kN to 2 kN intervals up to the ultimate load of the beam-to-column connections.

Concrete and reinforcement strains, deflections and applied loads were recorded at every load increment using a data logger. In between load applications, visual inspection and manual marking of cracks and crack propagation were carried out. For each test, the loading was continued until failure occurred. Failure was indicated by a significant increase in beam deflection accompanied by a rapid decrease in the vertical load, P1.

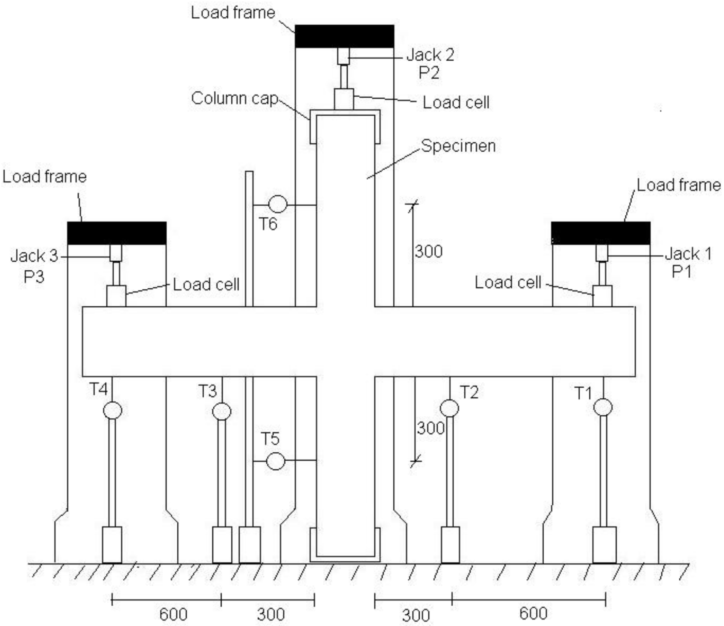


Figure 7. Schematic diagram for the setup of the beam-to-column specimens

RESULTS AND DISCUSSION

The response of beam-to-column connection, in particular the moment-rotation relationship, is very complex. Currently, there is no theoretical formulation available to predict the moment-rotation response of a reinforced or precast concrete connection. For this reason, in this paper, the moment-rotation response of each connection is compared against the theoretical moment resistance of the beam. This comparison is valid because a connection can be considered rigid if it is capable to transmit more than 90% of the beam moment resistance (Segui W. T., 2003). Also for this reason, the paper compared the response of the precast connection against the monolithic connection.

Response of Moment-Rotation

The response and characteristics of beam-to-column connections is best described by plotting the M-ϕ curves of the connections, describing the relationship between the applied moments and the corresponding connection rotations.

The M-ϕ curves of the monolithic and precast connections obtained from the tests are shown in Figure 8. The maximum moment resistance achieved by the monolithic connection, CF-RC was 52.84 kNm. While for the precast beam-to-column connection, CF-PC, the ultimate moment resistance was 59.5 kNm, about 11 % higher than the monolithic.

The ultimate moment resistance of the connections can also be compared with the design moment resistance of the beam. Taking the design strength of longitudinal steel bars equals 460N/mm^2, the design moment resistance of the beam is $M = 0.95fy.A_s.z = 35$ kNm. The results show that the ultimate moment resistance of CF-PC and CF-RC connections exceeded the design moment resistance of the beam by factors of 1.7 and 1.5 respectively. These results reflect that the strength of precast connection has outperformed the monolithic connection.

At the early stage of loadings, within the range of 0 to 5 milliradians of the connection rotation, it was seen that the characteristic of stiffness and strength of precast specimen CF-PC were close to the monolithic specimen, CF-RC. However, beyond 5 milliradians of connection rotation, the stiffness of monolithic specimen, CF-RC decreased significantly, as can be seen from the reduction of M-ϕ curve slope. Subsequently, the strength or moment resistance of the connection decreased accordingly. However, in the case of precast specimen, CF-PC, the stiffness continued to increase without any deterioration. It is believed, this response was due to the corbel that contributed to the increased stiffness of the precast beam-to-column connection and consequently delayed the yielding of the top steel bars. Finally, after further stages of loading, in particular at 58 kNm, the connection stiffness of CF-PC reduced drastically, and subsequently the connection rotations increased rapidly. This response occurred due to the yielding of the top steel reinforcement bars and cracking of concrete at the beam-to-column connection.

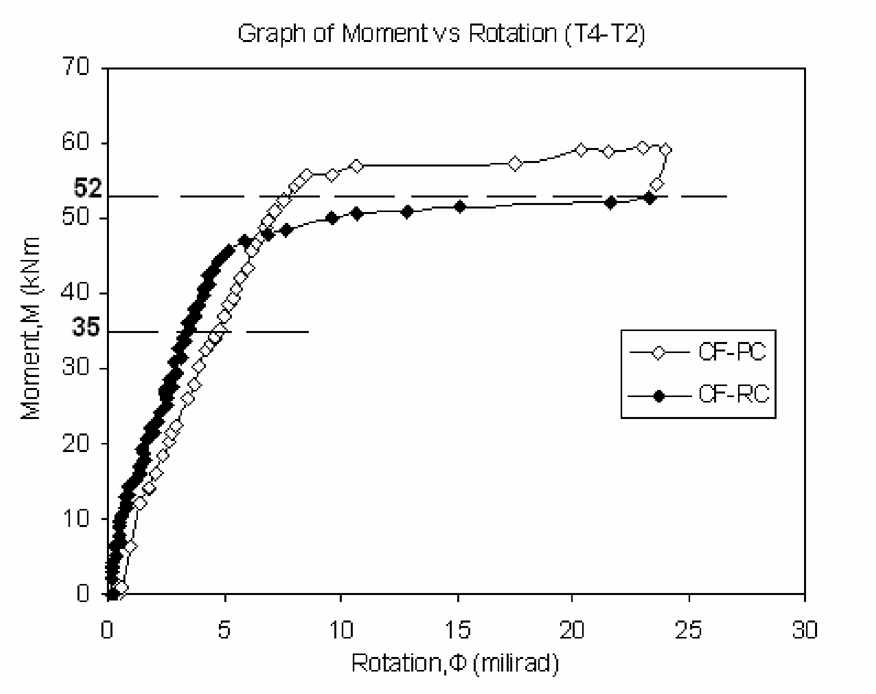


Figure 8. Moment – rotation curve

Response of Load-Deflection

The comparison of ultimate load and the corresponding deflection between monolithic and precast beam-to-column specimens is listed in Table 1. The results show that the ultimate load and the corresponding deflection of CF-RC were 57.9 kN and 42.63 mm respectively. In the case of CF-PC, the ultimate load and the corresponding deflection were 65.3 kN and 43.91 mm respectively. The results show that CF-PC outperformed CF-RC.

One of the parameters that influences beam stiffness is the fixity provided by the connections. Figure 9 shows the load-deflection behaviour of each beam with the slope of the curve representing the stiffness of the beam as influenced by the connection. It can be seen that the precast beam with cast-in-place connection, CF-PC performed satisfactorily and showed smaller deflection as compared to the monolithic beam, CF-RC. In the beginning of the test and within the range of 0 to 27 kN of the loading applied, the precast concrete specimen, CF-PC had the flexural stiffness that was similar to the monolithic specimen, CF-RC. As the incremental load reached 52 kN, the load-deflection slope of the precast specimen, CF-PC continued to increase, whereas, the load-deflection curve of the monolithic specimen, CF-RC decreased significantly to a second level of stiffness deterioration. At this load stage, the deterioration of the monolithic beam stiffness was contributed by the excessive strain of top internal steel bars, located at the middle of the connection (see Figure 10). However, the precast concrete specimen, CF-PC did not show any stiffness reduction as the monolithic specimen, CF-RC because the presence of corbel might delay the development of excessive strain in the top internal steel bars.

Table 1 Comparison of ultimate load and deflection between monolithic and precast specimens

Specimen	Ultimate Load (kN)	Deflection at Ultimate Load (mm)	Ultimate Load Difference (kN)	Percentage Difference (%)
CF-RC	57.9	42.63	-	-
CF-PC	65.3	43.91	7.4	11.3

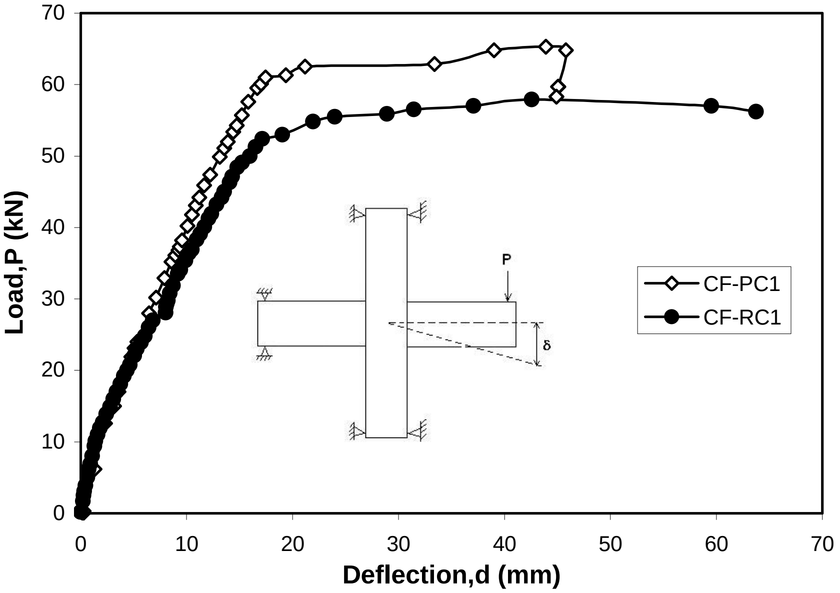


Figure 9. Load-deflection relationship

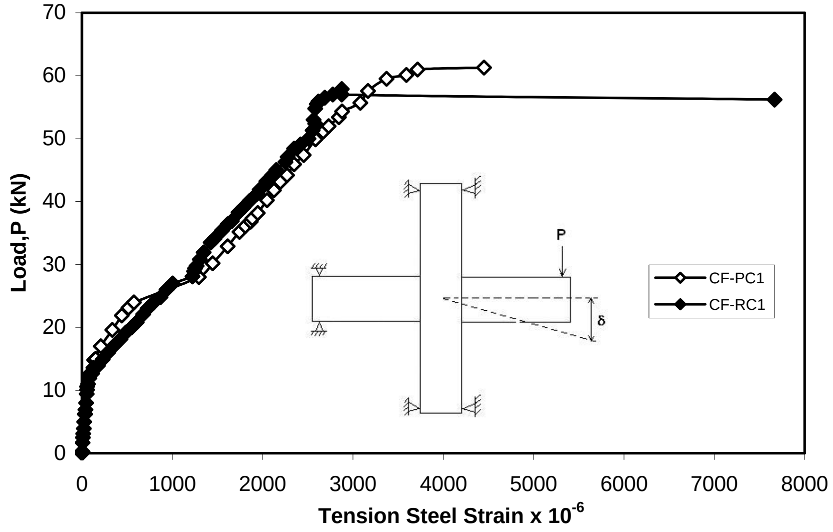


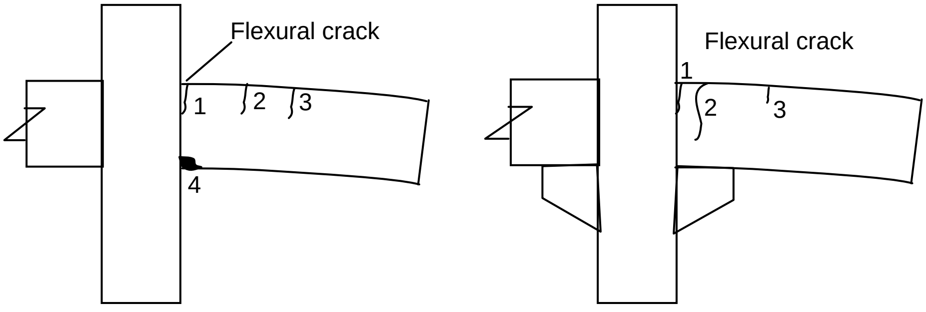
Figure 10. Load – strain at midspan of internal steel bar of the beam

Cracking Response

The illustrations of crack patterns between CF-RC and CF-PC are shown in Figure 11. The actual crack patterns of CF-RC and CF-PC at the ultimate loads are shown in Figure 12 and Figure 13 respectively.

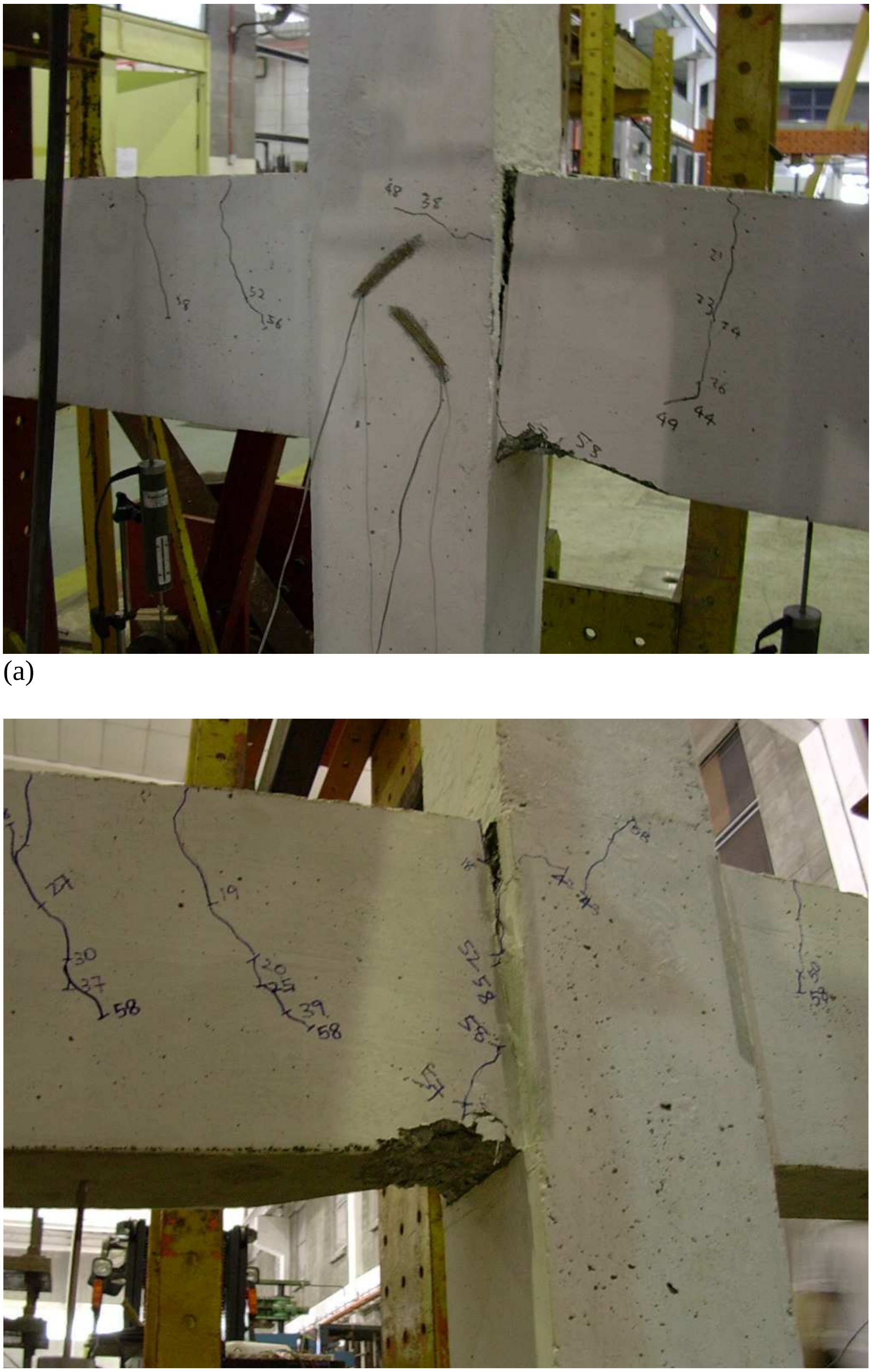
In the case of monolithic specimen CF-RC, see Figure 11(a), the first crack developed at point 1 within the tension zone of the beam, where hogging moments were maximum. As the hogging moment increased, crack at point 1 propagated further towards the neutral axis of the beam, followed by cracks at points 2 and 3. Based on Figure 12(b), it can be seen that the first concrete hair crack in the beam of CF-RC became visible at the beam-to-column interface, when the applied load was 16 kN. The load to cause this first hair crack to the connection was about 28% of the ultimate load. At load 52 kN (see Figure 12(b)), the crack at point 1 widened, resulting in the lost of connection stiffness, as the slope of the load-deflection curve of CF-RC decreased (see Figure 9). Subsequently, the connection rotation increased rapidly with the small increased in the applied loads. When the applied loads were close to the ultimate load, concrete at point 4 started to crush due to the high compression stresses produced by the applied loads.

However, in the precast specimen (CF-PC), see Figure 11(b), the first vertical hair crack developed at location 2, that is about 75mm from the column face, when the applied load was 24 kN. The load to cause this first hair crack was about 38% of the ultimate load. As the hogging moments increased, the vertical hair crack at point 2 propagated further into the neutral axis of the beam followed by flexural crack at points 1 and 3. At load 62 kN (see Figure 13(b)), the vertical crack at point 2 widened and caused the connection to lose its stiffness as can be seen from the reduced slope of the load deflection curve of CF-PC (see Figure 9). It was seen that the vertical crack at point 2 was the most severed as compared to the cracks at points 1 and 3.



(a) CF-RC (b) CF-PC

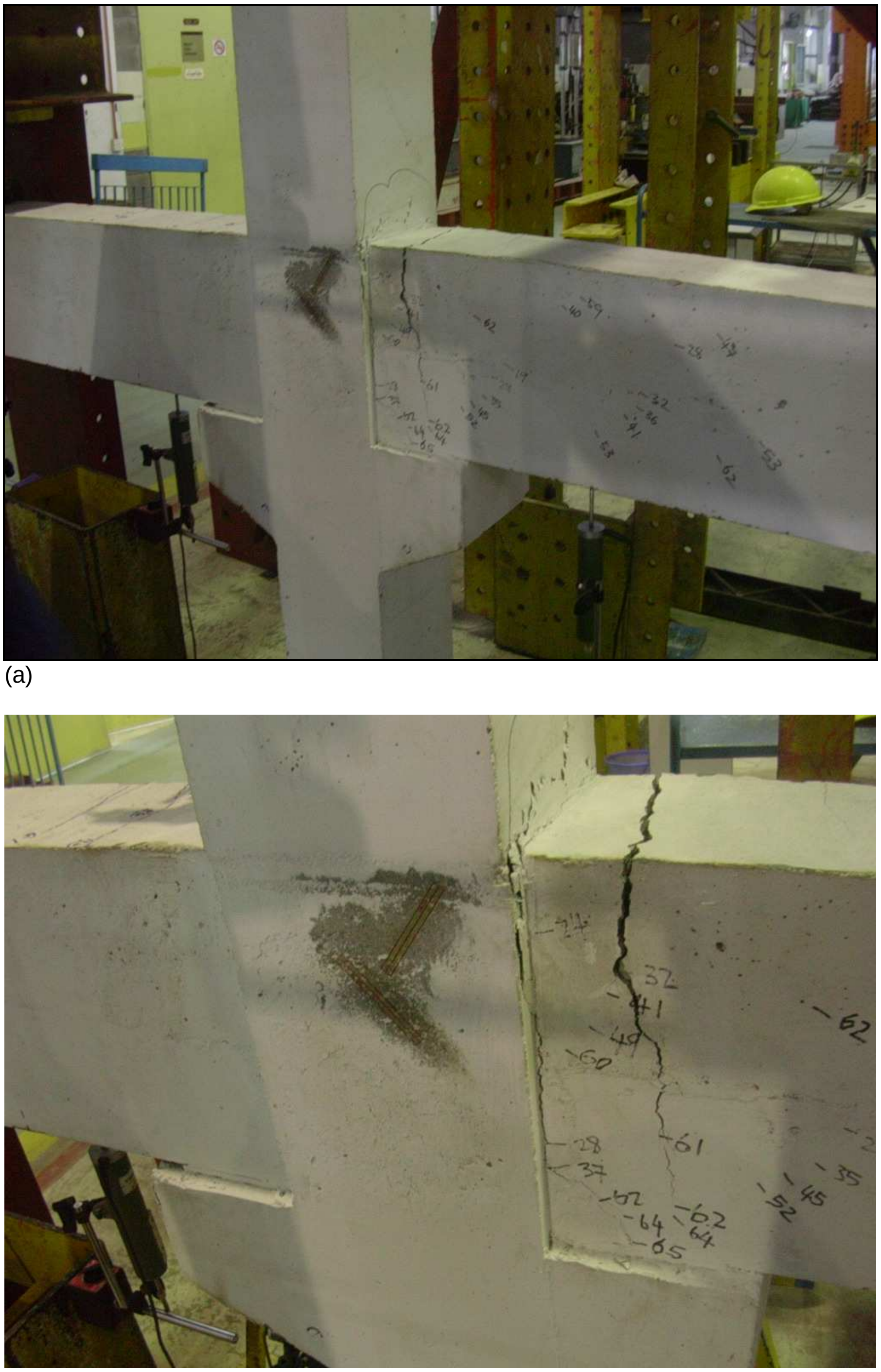
Figure 11. Comparison of crack development between CF-RC and CF-PC



(a)

(b)

Figure 12. Crack pattern of monolithic specimen CF-RC at ultimate load



(a)

(b)

Figure 13. Crack pattern of precast specimen CF-PC at ultimate load

CONCLUSION

This paper describes the testing and the response of interior beam-to-column connections under incremental hogging moments generated from incremental beam loads. Two subframes consisted of monolithic and precast beam-to-column connections were tested to failure.

Based on the limited tests carried out, the following conclusions are drawn:

1. The response of moment-rotation, M-ϕ of the precast connection is close to the monolithic connection in terms of stiffness and strength characteristics. This shows that the CF-PC precast connection can perform effectively, similar to the conventional CF-RC reinforced concrete connection.
2. The stiffness of CF-PC precast connection, as can be seen from the M-ϕ curve slope, is similar to the monolithic connection. This means the precast connection can provide degree of restraint to the precast beam similar to the monolithic connection.
3. The deflection of the precast beam is governed by the degree of fixity or stiffness provided by the CF-PC connection.
4. The ultimate moment resistance of the precast connection is larger than the monolithic. This may be due to the corbel that delays the yielding of top steel bars and hence maintains the precast connection stiffness at higher load levels and correspondingly the precast connection strength.
5. The CF-PC precast connection behaves as a moment resisting connection under the action of gravity loads only. Hence, engineers can consider similar precast connection details to obtain moment resisting connections, provided hogging moments due gravity loads are more dominant than sagging moments due to lateral loads.

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