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Providing an economical and practical jointing method

Precast Concrete Beam-To-Column Connection Using Interlocking Bars, An Alternative

A new connection between a precast concrete U-beam and a precast concrete column which incorporates interlocking bars and cast-in-place concrete has been studied. The main aim is to provide an economical and practical jointing method. In order to understand the structural behaviour of the connection, several full-scale joint arrangements were investigated in the laboratory. The test results showed that the beam-column specimens behaved structurally very well and met the acceptance criteria stated in ACI 374.1-05. This paper introduces a potentially new beam-to-column connection for use in precast concrete moment resisting frames. The connection is still under development in the laboratory, however, progress has been made in understanding its behaviour particularly in terms of strength, stiffness and mode of failure under different types of loadings.

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Precast concrete systems are believed to be an efficient solution to many problems/requirements found in the construction industry. These systems offers advantages in terms of time, quality, cost and sustainability, all of which are very important factors within the industry. Precast systems have become more popular and have been used on infrastructure projects including housing, multi-storey buildings, roads, bridges, etc. However, research on these systems is still ongoing as there is still potential to improve them.

The structural behaviour of a precast concrete structure is dictated by the method and efficiency of the connection between the precast elements (Choi, et al, 2013). Many types of connection have been developed, i.e. bolted/welded/pre-stressed/cast-in-place (CIP) connection or a combination of two or more of these. Each type of connection has its own advantages and disadvantages in terms of strength, structural stiffness and ease of implementation.

Even though precast concrete systems have many advantages in comparison with conventional systems, precast systems still face several technical problems, particularly in terms of connecting the precast units on site. A connection system which has a high degree of precision; such as a complex connection with steel box or pipe and involving bolting or welding, should be avoided. Such systems could causes difficulties in implementation, which can extend the construction time and increase the construction cost. Therefore, innovation and development, particularly in the area of the beam-to-column connection, is still required.

The new precast concrete beam-to-column connection

The connection developed and discussed here in this study was designed as a ductile connection. Figure 1 presents a description of the system. Figure 2 and 3 present details of an exterior and interior connection which could be found in a moment resisting frame.

The precast concrete moment resisting frame suggested here consists of multi-storey (potentially 3 storeys) precast columns connected to horizontal elements (precast beams) using interlocking bars and cast-in-place concrete. The detail of the system is explained below:

a) Columns

It is expected that the precast columns will typically be a length equivalent to 3 storeys; the intention here is to accelerate the erection work for precast concrete system. The column is designed to have corbels that can support the precast beams during the installation process and hence minimize the use of scaffolding during the construction process. There will be a gap (see Figure 4) in the concrete of the column at each intended floor level (the column steel will be continuous through this gap); the corbel will be located at the bottom of the gap – see Figure 2. The column will be braced across the gap to maintain its stiffness; the height of the gap is equal to the beam depth.

In order to avoid any difficulties that may be present when casting corbels on three or four faces, it is likely that corbels will be cast monolithically only on two opposite sides of the column. If further corbels are required these will be in the form of steel corbels, bolted to the side of the column (see Figure 3).

b) Beams

The precast beams (see Figure 4) are U-shaped at both ends (this is part of

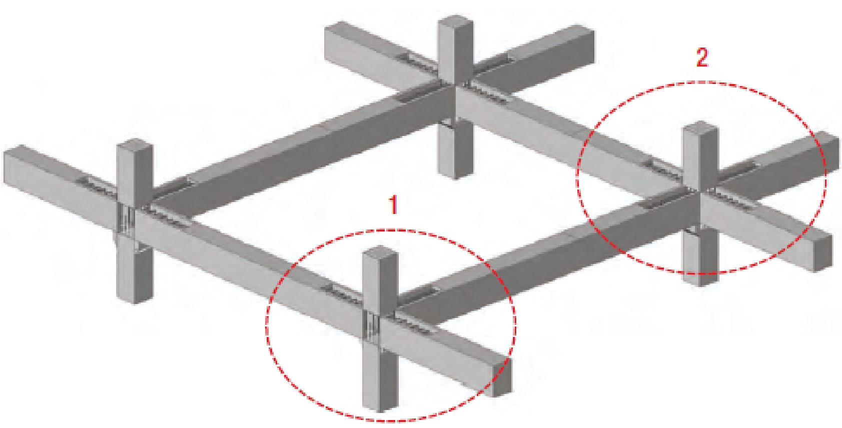

Fig. 1: Description of system concept

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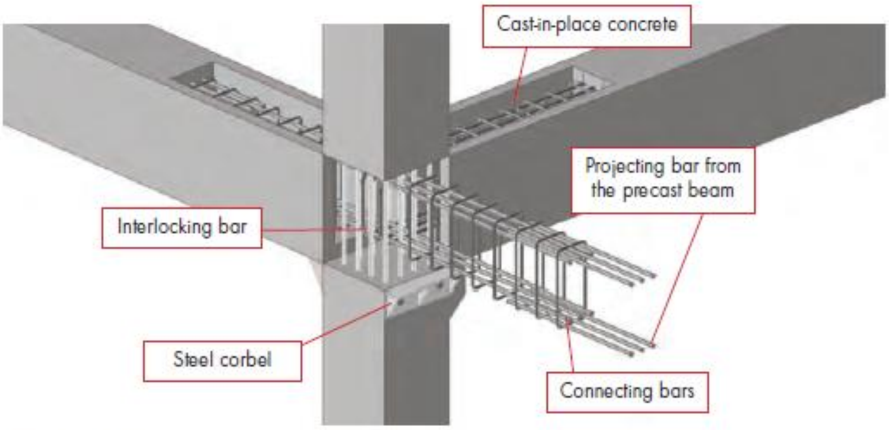

Fig. 2: Detail 1 (exterior beam-column joint)

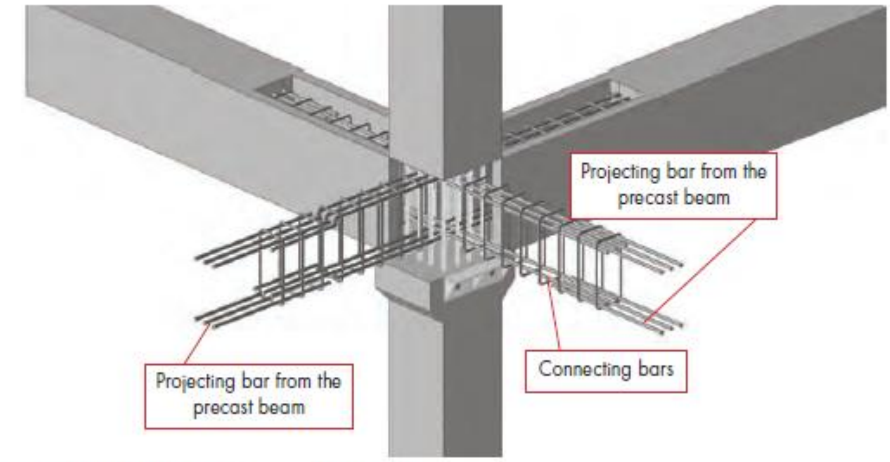

Fig. 3: Detail 2 (interior beam-column joint)

the connection) and solid in between. The U-shaped part of the beam acts as permanent formwork and is not connected directly to the column. The connection between the column and the beam is made using interlocking bars which are located in the U-section and extend into the gap in the column and cast in situ concrete (see c. below).

c) Interlocking Bars and Cast-in-Place (CIP) Concrete

For an exterior joint, interlocking bars are used as longitudinal reinforcement, which connect the precast beam and the column/joint core (see Figure 2). The function of these bars is to withstand the sagging and hogging moments. These bars are also designed to ensure the continuity of the top and bottom reinforcement of the precast concrete beam into the joint core. (Normally, the discontinuities of the bottom reinforcement of the beam in many current systems causes a lower moment capacity of the beam (Li, et al, 2003)).

For beams spanning orthogonally to the one mentioned in the previous paragraph, to avoid any clash of reinforcement bars in the joint core, the connecting bars will pass through the column joint at the lower level, as can be seen in Figure 3.

The connection region (the joint core and beam core) are then filled CIP concrete.

The new connection offers several advantages; this connection will negate the need for high precision engineering, hence increasing practicality; reduce the use of formwork due to the use of a precast partial U-beam (acting as permanent formwork); and lower the volume of cast-in-place concrete. The use of corbels, which support the precast beam, will minimize the need for scaffoldings. This new connection also avoids the use of welding, bolts and prestressing, which therefore leads to a reduced need for skilled labour and a reduction in the construction time. Overall, this new connection can be expected to offer a more economical and practical solution (Noorhidana & Forth, 2016).

Laboratory Test Result

At the time of drafting this technical note, two tests had been performed on the connection (a T-joint) in the laboratory. The specimen represents an exterior beam-to-column connection of a two-dimensional moment resisting frame. The beam-column connection was designed using the strong column-weak beam principle to ensure that the plastic hinge occurred in the beam, which is important, particularly for a seismic resistant structure.

The connection test consisted of a precast beam, a precast column, three interlocking bars and cast-in-place (CIP) concrete. Figures 4 and 5 illustrate the elements and dimensions of the beam-column specimen, respectively. The load was applied vertically to the beam tip. The first beam-column specimen (P1) was subjected to static-monotonic loading, whereas the second specimen (P2) was subjected to a quasi-static loading. The purpose of these tests was to understand the behaviour of the precast beam-to-column connection using interlocking bars, both under static and quasi-static (cyclic) loading.

The crack pattern and the load vs. deflection relationship of the beam-column specimens, which were subjected to static and quasi-static loadings, are presented in Figures 6 to 9. There is no significant crack in the column of the joint in Specimen P1 (under static loading), whereas Specimen P2 has 'X' cracks in the joint but was still deemed acceptable. Plastic hinges were formed in the beam of both specimens. Both specimens exhibited a flexural failure mode.

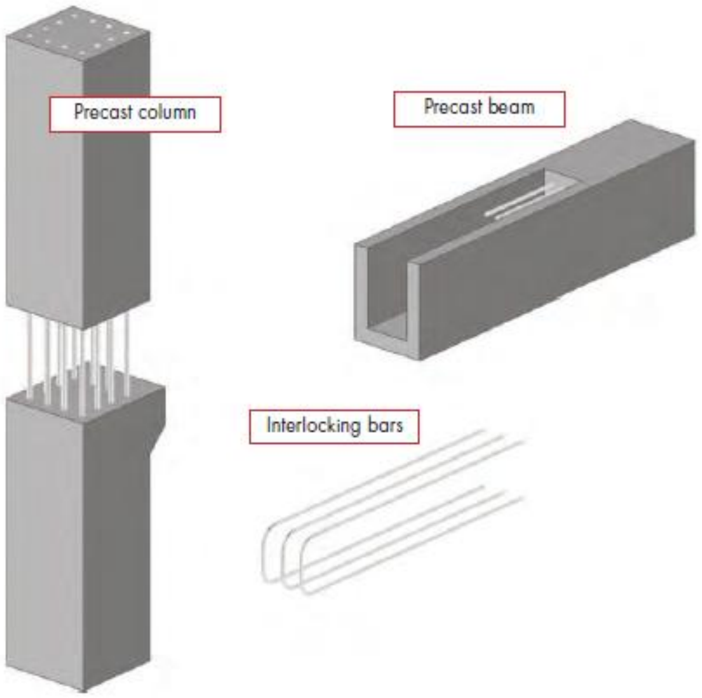

Fig. 4: Isometric of the beam-column specimen

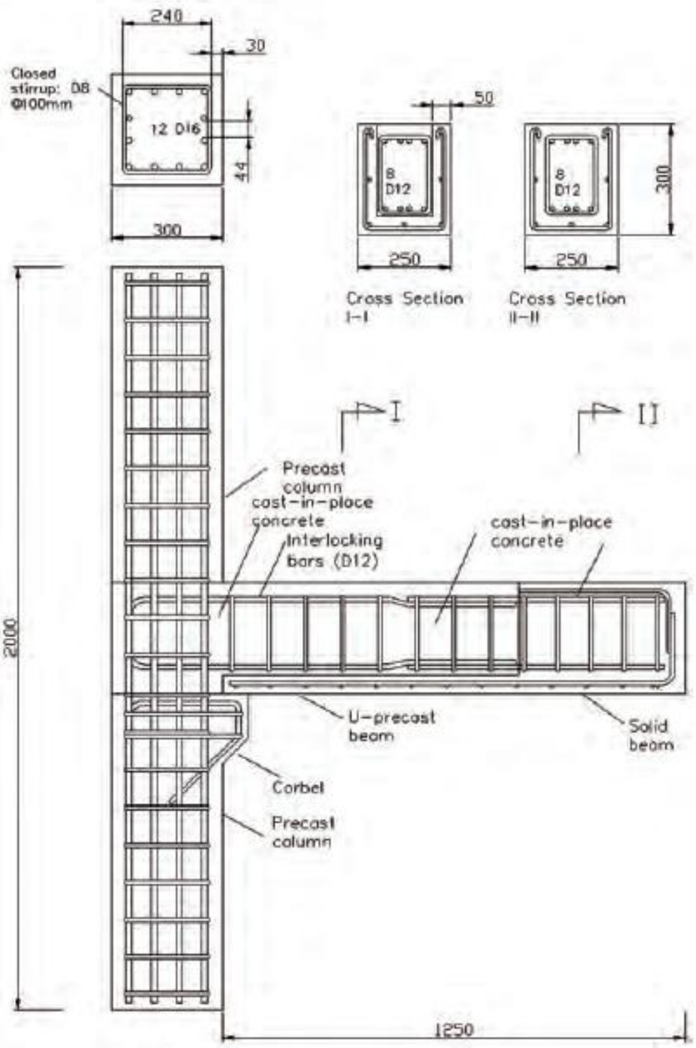

Fig.5: Detail of the beam-column specimen

Fig. 6: Crack pattern of beam-column specimen subjected to static-monotonic loading (Specimen P1)

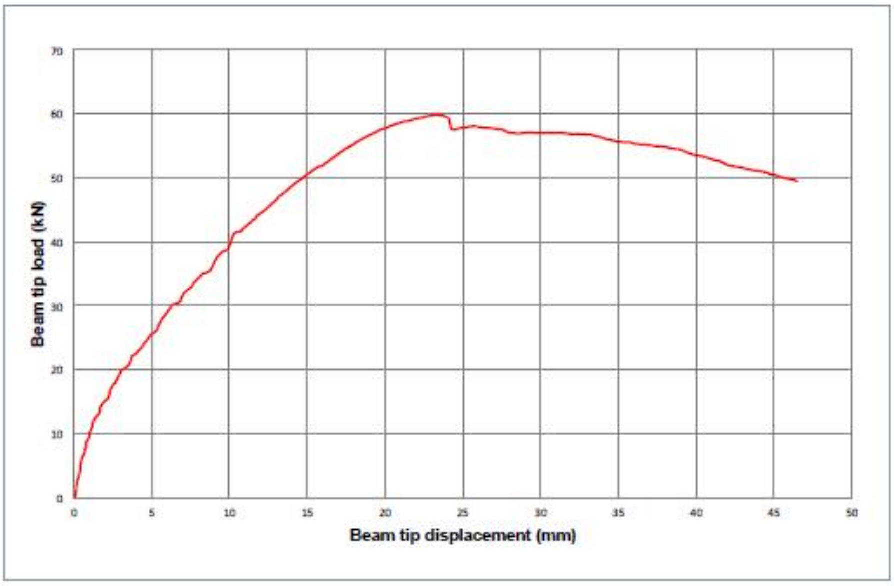

Fig. 7: The curve of load vs. deflection of the beam tip subjected to static-monotonic loading (Specimen P1)

The performance of the beam-column connection under cyclic loading has been evaluated using ACI 374.1-05 (Acceptance Criteria for Moment Frames Based on Structural Testing and Commentary); the results and evaluation are presented in Table 1. The evaluation of the connection showed that the strength degradation, relative energy dissipation ratio and the stiffness degradation met the ACI acceptance criteria.

Table 1: Comparison between test results of P2 and Acceptance Criteria ACI 374.1-05 (Noorhidana & Forth, 2016)

Items		Specimen P2	Acceptance Criteria*
P_{2nd}/P_{max}:	Negative loading	0.84	≥ 0.75
	Positive loading	0.89	
β		0.23785	≥ 0.125
$K_{0.035}/K$		0.2863	≥ 0.05
$K_{0.035}/K'$		0.167	≥ 0.05

*) ACI 374.1-05
β = relative energy dissipation ratio
K and K' = initial stiffness for positive and negative loading for first cycle.
$K_{0.035}$ = secant stiffness at drift ratio of 3.5%.

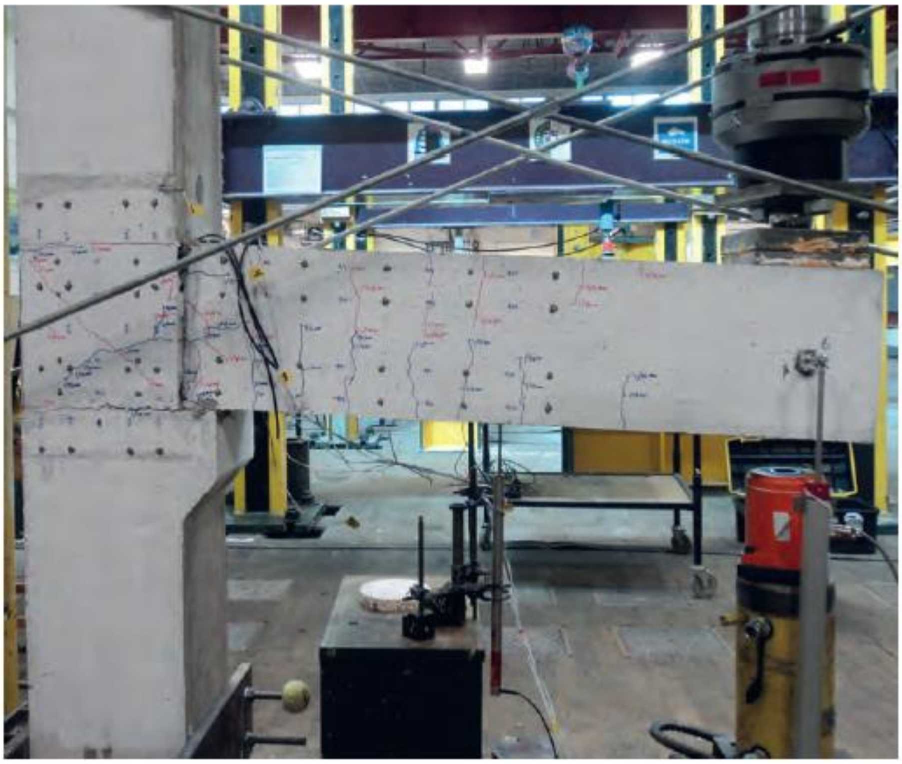

Fig. 8: Crack pattern of beam-column specimen subjected to quasi-static loading (Specimen P2)

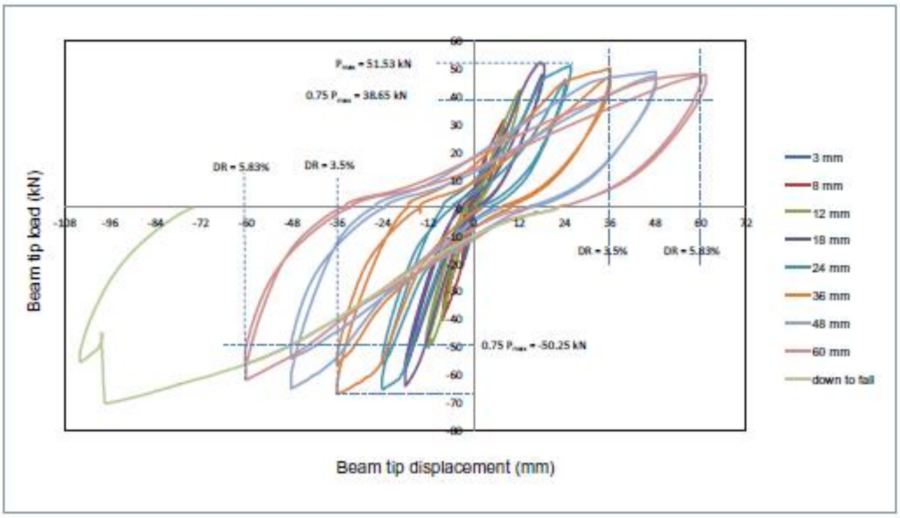

Fig. 9: The curves of load vs. deflection of the beam tip subjected to quasi-static loading (Specimen P2)

Summary

Based on the laboratory tests, the beam-column specimens performed well under both static-monotonic and quasi-static loading. The specimens failed in flexural and met the acceptance criteria in ACI 374.1-05.

The manufacturing of these precast elements (beam and column) appears to be economical and easy to construct. The shape and dimensions of the precast elements are simple and easy to transport; they also appear to have sufficient in-built tolerances to allow construction by unskilled staff. Therefore, this new connection can be expected to offer a better economical and practical method than those currently available.

Acknowledgment

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References

ACI 374.1-05 2005. Acceptance Criteria for Moment Frames Based on Structural Testing and Commentary (ACI 374.1–05). American Concrete Institute, Farmington Hills Michigan,, USA.

CHOI, H. K., CHOI, Y. C. & CHOI, C. S. 2013. Development and testing of precast concrete beam-to-column connections. Engineering Structures, 56, 1820-1835.

LI, B., YIP, W. K. & LEONG, C. L. Hybrid-steel concrete connections under reversed cyclic loadings. 2003 Pasific Conference on Earthquake Engineering, 2003.

NOORHIDANA, V.A. & FORTH, J.P. An experimental study on precast concrete beam-to-column connection using interlocking bars. Second International Conference on Concrete Sustainability, 2016.