PAPER • OPEN ACCESS

Experimental study of precast concrete beam-to-column connection under sustained loading

To cite this article: V A Noorhidana 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **669** 012034

IOP Conf. Series: Materials Science and Engineering **669** (2019) 012034 doi:10.1088/1757-899X/669/1/012034

Experimental study of precast concrete beam-to-column connection under sustained loading

V A Noorhidana [1]

[1] Civil Engineering Department, Universitas Lampung, Jl. Sumantri Brojonegoro No.1 Gedong Meneng, Bandar Lampung, Indonesia, 35145

vera.agustriana@eng.unila.ac.id

Abstract. The long-term behaviour of an exterior precast concrete beam-column (PCBC) connection has been investigated in this study. The connection consists of a precast U-beam, precast column with corbel, and interlocking bars to connect the precast column and precast beam. The specimen was tested under sustained loading for 120days. The crack propagation, the development of strain and the deflection of the beam was observed throughout the test. The results show that the PCBC connection behaved in similar manner to correctly designed conventional reinforced concrete members under long-term loading. Flexural cracks occurred within the plastic hinge region of the beam. No cracks occurred in the joint core and column. The long-term behaviour of the PCBC connection was influenced by shrinkage and creep. The significant increase of deflection occurred in the first 15 days of testing, which is 37% of the total long-term deflection. The experimental long-term deflection has bigger value than the theoretical deflection evaluated using ACI 318-08.

1. Introduction

Precast concrete systems are a popular system in the recent years. These systems have some advantages in terms of quality, cost and time in comparison with the conventional system [1]. In addition, precast concrete systems satisfy the green construction rules, which have been developing to face the global warming issues.

Technical problems, such as the ease of implementation of the joints and the behavior of the connection are still a concern in precast systems. These problems could increase the construction time and costs. Because of that the design of the connection between precast elements are important. The complicated connection with high degree of precision should be avoided.

Many types of connections, in terms of beam to column connections in moment resisting frames, have been developed such as bolted, welded, cast-in-place (CIP) connection. Bolted connection could be the east method to install the precast elements on site, but require a high degree of precision in placing the steel plates or profiles. Welded connections need skilled labours in order to guarantee the quality of welding connection. Cast-in-place (CIP) connections are more monolithic connections and recommended for seismic resistant buildings. Unfortunately, this connection takes longer to construct due to the concrete has to gain its strength [2, 3].

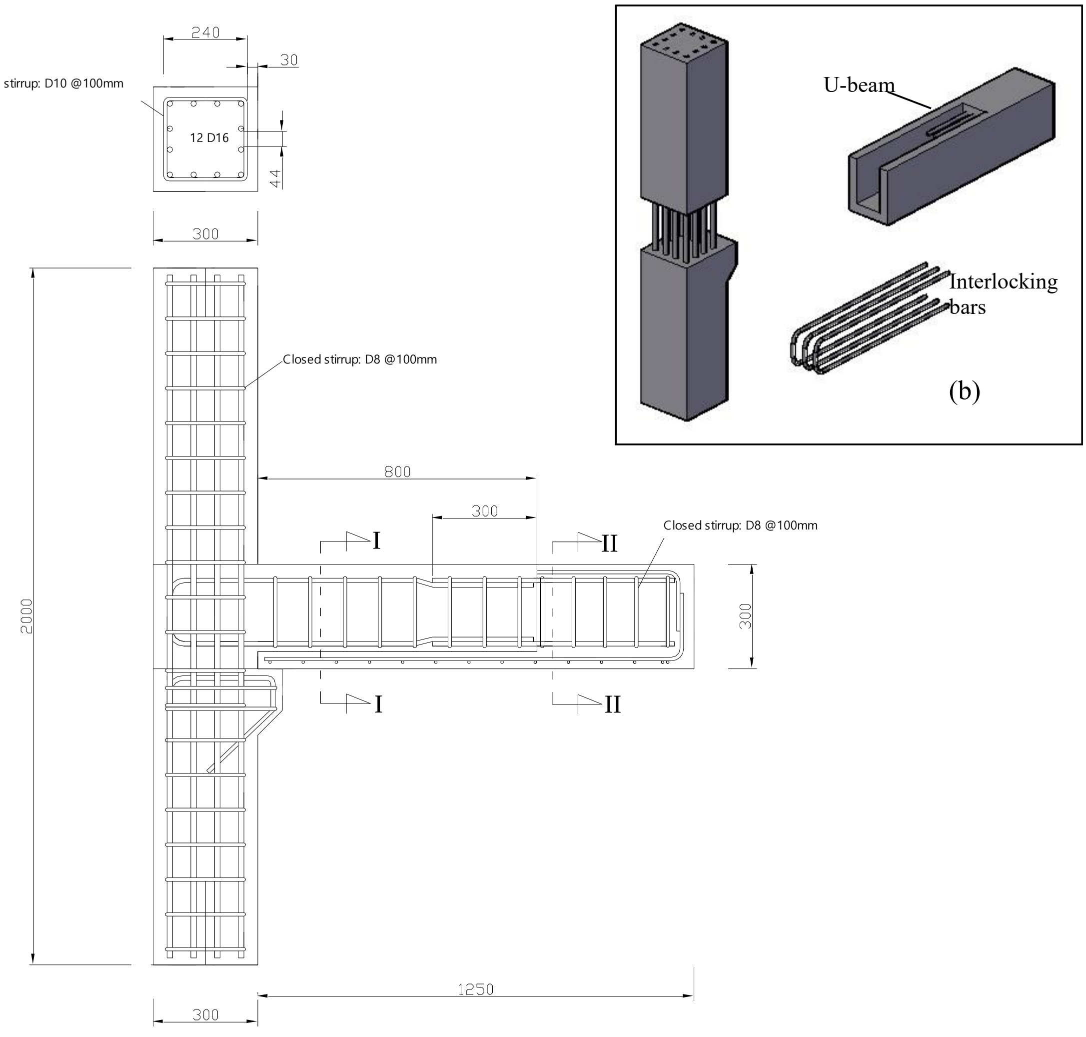
A new precast concrete beam-column (PCBC) connection has been developed as presented in Noorhidana & Forth [4]. This joint connection consists of a precast beam with corbel and a precast column which are connected using interlocking bars and cast-in-place concrete.

PCBC connection behavior under static loading has been investigated and presented by Noorhidana & Forth [5]. The results showed that the specimen exhibited a flexural failure mode and behaved monolithically until failure. To understand the behavior of PCBC connection under other loading types, this paper will present the experimental investigation of the connection under sustained loading which represents the service load working on the structure. The result will be compared with those of the connection under short-time loading (static loading).

2. Experimental program

2.1. Test specimen

The beam-column specimen of this investigation consisted of one precast concrete beam and one precast concrete column joined using a cast-in-place (CIP) concrete, and represented an exterior beam-column joint of a moment resisting frame. The length of the column and the beam were determined based on the location of the contra-flexure points determined via a software analysis of a representative planar frame. Figure 1 and 2 show the reinforcement details of the PCBC specimens, while Figure 1(b) presents the precast concrete beam-column specimen as an isometric.



(a)

Figure 1. Reinforcement detail of PCBC specimen (a), Isometrics of precast concrete beam-column connections (b)

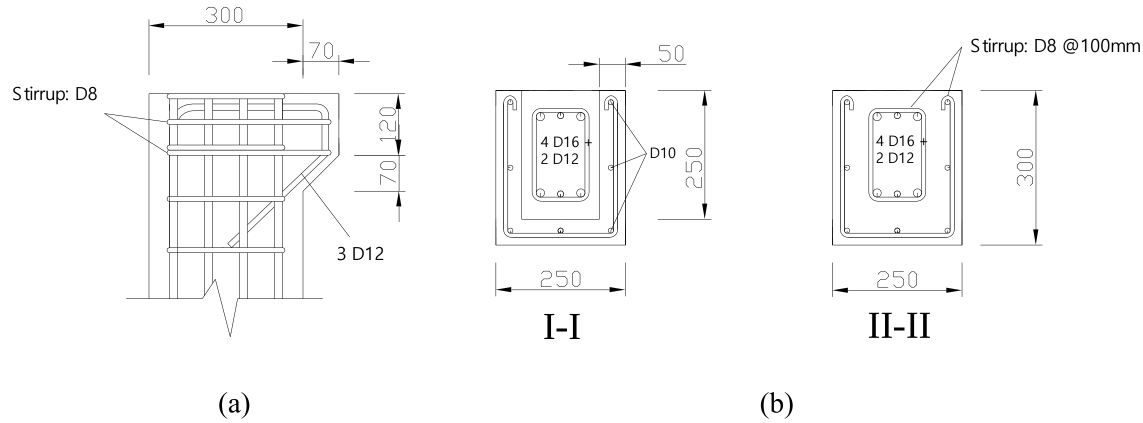


Figure 2. Reinforcement detail of PCBC specimen, (a) Corbel reinforcement, (b) Beam cross sections.

Two precast concrete beam-column (PCBC) specimens were fabricated in this study, namely P1 and P5. P1 was loaded until failure. The testing was done in less than 1 hour (short-time loading). The maximum load of P1 then was used to determine the load level which was sustained for P5 testing. P5 was tested under long-tem loading. The specimen was loaded until 20kN (which is within a serviceability limit state), then that load was sustained until 120 days. The deflection of the beam tip and the crack was observed during testing.

2.2. Materials

There were 2 concrete mixes, i.e., one for the precast concrete beam and column (a design compressive strength of 30MPa) and one for the cast-in-place (CIP) connection (a design compressive strength of 45MPa). Table 1 shows the compressive strength of concrete; standard deviations were between 1.87MPa and 2.71MPa. The compressive strength was obtained from 100 mm x 100mm cubes, where the concrete cylinder strength fc' was taken as 80% of the cube strength fcu [6].

Four different diameters of steel bar were used for the PCBC specimens, i.e. 8 mm, 10 mm, 12 mm, and 16 mm. The yield strength of the steel reinforcing bars was 500MPa.

Table 1. Compressive strength of concrete

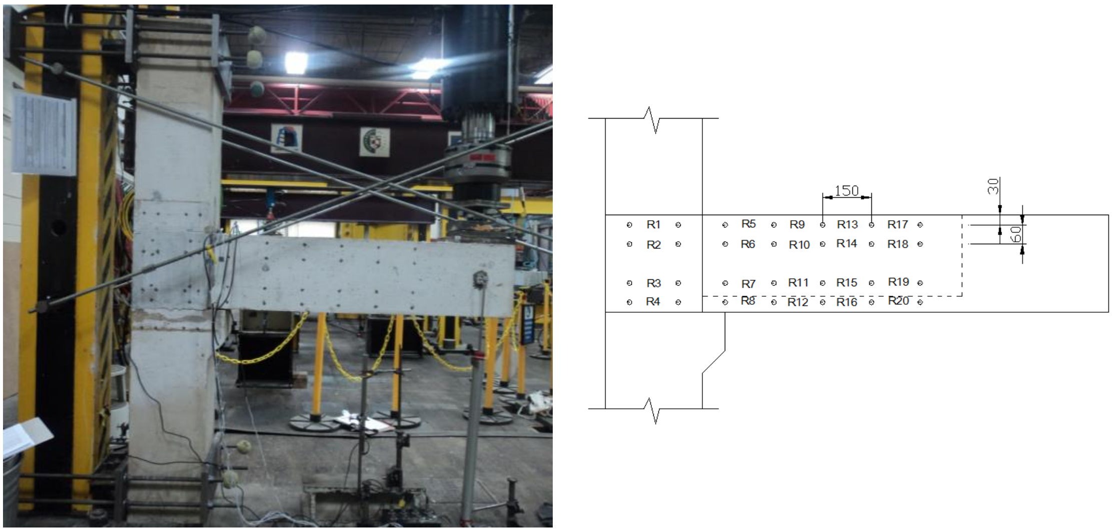
Specimens	Average cube strength f_{cu} (f_c')* (N/mm^2)	
	Precast concrete	CIP concrete
P1	38.07 (30.46)	59.12 (47.30)
P5	44.58 (35.66)	55.02 (44.02)

* Concrete cylinder strength was taken as 80% of the cube strength [6].

2.3. Test setup and instrumentation/loading procedure

The test set-up of the precast concrete beam-column (PCBC) Specimen P5 is explained as follows: as mentioned above, both precast column ends were restrained by steel plates which were bolted to the test rig, while the beam end was free. The vertical load was applied on the beam end in the negative direction (downward), which represented the gravity load. While, there was no axial load applied the precast column since this tends to enhance the joint shear strength; hence, this is a worst loading case scenario. The test-set up is presented in Figure 3.

One LVDT was located under the beam end to measure the deflection of the beam. Several DEMEC points were mounted on the surface of the beam of the specimen in order to measure the strain of the concrete surface. There are 5 positions horizontally. Each position consisted of 4 levels. The top and bottom levels were placed at the level of the longitudinal bars of the beam. The measurement of the strains was taken manually using a digital DEMEC strain gauge at specific days in order to evaluate the curvature development during the testing. The deflection of the beam tip and the crack was observed during testing.



(a) (b)

Figure 3. (a) Test set-up of the PCBC connection, (b) Demec points' position

3. Results and discussion

3.1. Load-deflection curves

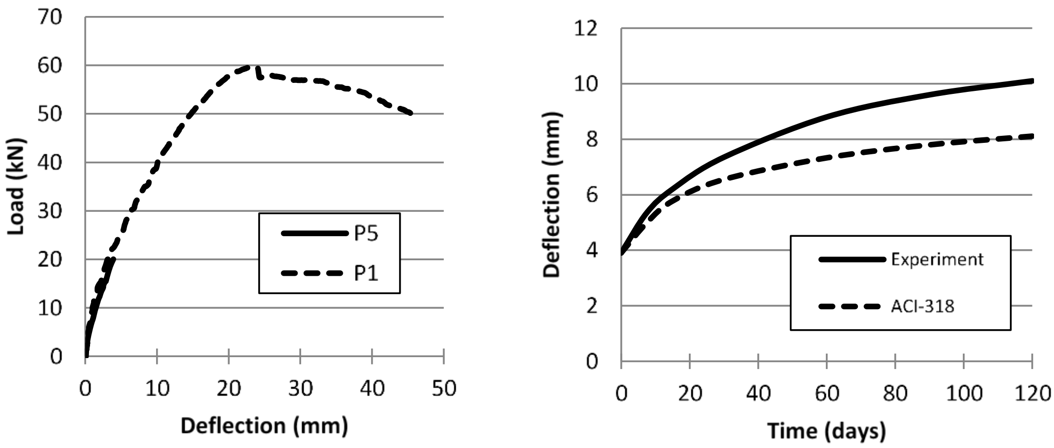
Specimen P1 was loaded under static loading until failure. The load-deflection relationship is presented in Figure 4(a). The maximum load was 59.80kN at the deflection of 23.5mm. After reaching the maximum load, the curve decreased and the specimen failed at a load of 50kN and the deflection of 46.5mm.

Specimen P5 was loaded by static loading until 20kN (about 30% of the maximum load of SpecimenP1), the load-deflection relationship is presented in Figure 3 (a). The graph shows that P5 curve is coincident with P1 curve. Then, the load of 20kN was sustained for 120 days. The deflection development was observed within this period.

Figure 4(b) presents the development of deflection of Specimen P5 under sustained loading of 20kN for 120 days. The deflection increased as the time increased. This is because of shrinkage, creep and other factors, such as loading configuration, the steel reinforcement, and the environment (i.e. temperature and humidity) during 120days of testing. The deflection at 0 day was 3.9mm. The deflection increased to 10.1mm after 120 day. So, the total long-term deflection was 6.2mm.

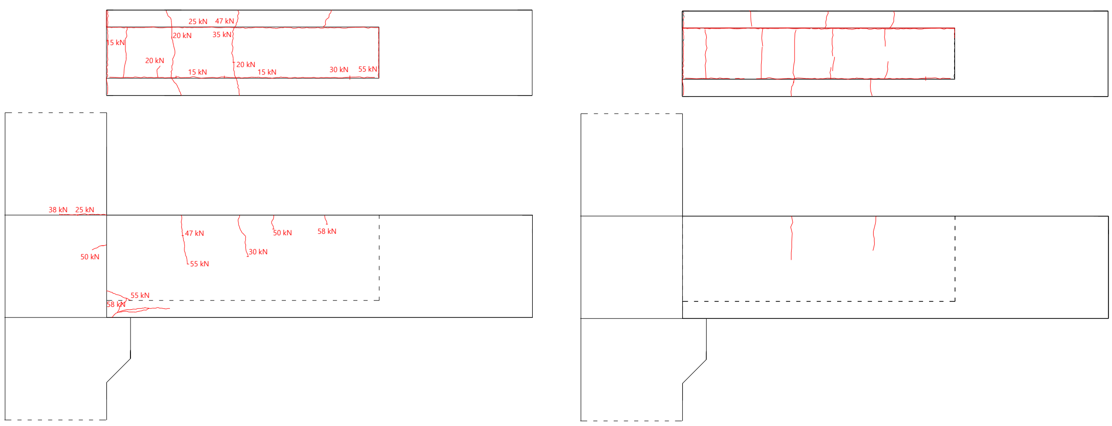
The significant increase occurred in the first 15 days of sustained loading, which was about 37.% of the total long-term deflection. The deflection increase became smaller with time which was showed by the curve become flat.

The experimental of long-term deflection obtained from Specimen P5 test was evaluated using ACI 318-08 [7]. The theoretical long-term deflection is presented in Figure 4(b) indicated by dash-line. As seen in the figure, the theoretical methods under-predict the experimental behaviour. As the theoretical deflections are based on a cantilever which is assumed to have full restraint at its support it is not surprising that these models under-predict the long-term experimental deflection.



(a) (b)

Figure 4. (a) Load-deflection relationship, (b) Deflection-time relationship



(a) (b)

Figure 5. Crack-pattern of (a) Specimen P1, (b) Specimen P5.

3.2. Cracks Observation

The crack propagation of the PCBC connection under static loading until failure (Specimen P1) is presented in Figure 5(a). The first crack appeared on top side of the beam core, on the beam adjacent to the column, in line with the tip of the corbel. The cracks occurred both in the beam core and the wall of the precast U-beam. In general, all cracks were categorized as typical flexural cracks which were distributed along the cast-in-place (connection) region. Due to a high load level (about 55kN), the longitudinal bars of the U-beam started to slip which was indicated by a horizontal crack in the bottom of the U-beam which extended from the support until 200mm from the corbel. There was no significant cracks occurred in the joint core.

Under sustained loading at service limit state, the cracks pattern of PCBC connection (P5) was similar with those of P1, as can be seen Figure 5(b). The cracks occurred both in the beam core and the wall of the U-beam. The extension of cracks and new cracks throughout the sustained loading period were due to the effect of shrinkage and creep. No cracks occurred in the joint core because the applied load is relatively low.

3.3. Curvature developments of the U-beam

Figure 6 shows that the curvatures at Positions II-VI (of the U-beam) increased with time. The curvatures at III and V are bigger than those at II and IV (both at the beginning and during the long-term test), owing to the fact that vertical cracks occurred in regions III and V when the immediate load of 20kN applied. The cracks then lengthened during the sustained load applied. The curvatures at II and IV appear to be similar, with a dramatic increase at the age of 30 days; at this stage the cracks occurred on the top surface of the beam core.

The curvature at Position I (the joint core), as presented in Figure 6, decreased as the loading time increased. This behaviour is similar with the beam-column joint Specimen P1 under static loading, i.e. the joint experienced a compression strut mechanism.

The similarity of the curvatures in all zones (except Position I-joint core) suggests that beyond the initial cracking during loading and due to shrinkage restraint, the system appears to be quite homogeneous.

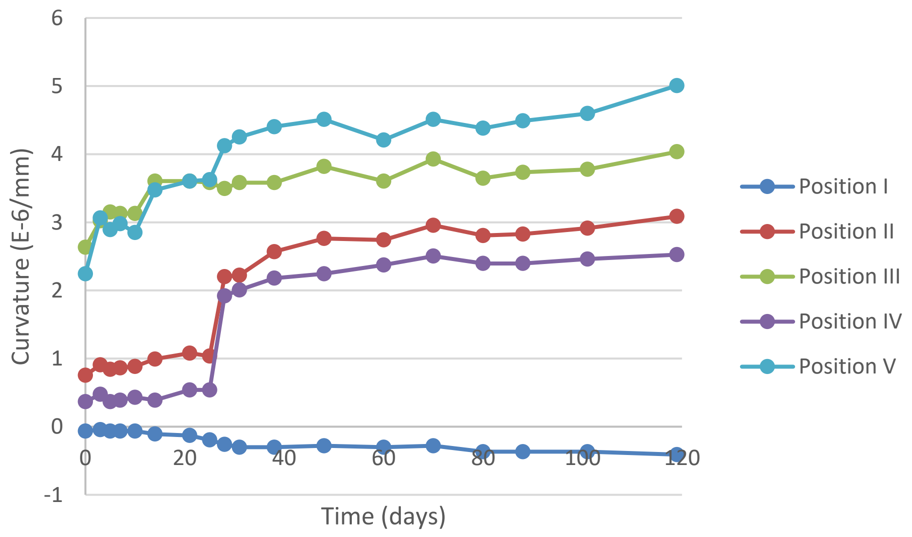


Figure 6. Curvature development with time of the U-beam of Specimen P5

4. Conclusion

- Specimen P1 (PCBC connection under short/static loading) performed good structural behaviour with flexural failure mode and behaved monolithically until failure.
- Specimen P5 (PCBC connection under sustained loading for 120 days) have similar behaviour with Specimen P1 in terms of load-deflection curves and crack pattern.
- The deflection and curvatures of the beam increased with time due to creep and shrinkage. The significant increase of deflection occurred in the first 15 days of testing, which is 37% of the total long-term deflection.
- The cracks are typical flexural cracks which were distributed along the cast-in-place (connection) region which is the plastic hinge region of the beam. No cracks occurred in the joint core and column.
- The experimental long-term deflection has bigger value than the theoretical deflection evaluated using ACI 318-08.

References

[1] Nurjaman H N, et al 2011 Sistem pracetak beton sebagai sistem konstruksi hijau: studi kasus perbandingan energi konstruksi dan dampak lingkungan di pembangunan rumah susun di

Batam. in *Seminar HAKI*. 2011. Jakarta, Indonesia.
[2] Bhatt P and D W Kirk 1985 Test on an improved beam column connection for precast concrete *ACI Journal*, p. 834-843.
[3] Ertas O S, et al 2006 Ductile connections in precast concrete moment resisting frames *PCI Journal*, p. 2-12.
[4] Noorhidana V A and Forth J P 2016 *Precast concrete beam-to-column connection using interlocking bars* An alternative in Concrete Plant International (CPI).
[5] Noorhidana V A and Forth J P 2016 An experimental study on precast concrete beam-to-column connection using interlocking bars. in *The 2nd International Conference on Concrete Sustainability* (Madrid, Spain).
[6] Kaung J S and H F Wong 2011 Effectiveness of Horizontal Stirrups in Joint Core for Exterior Beam-Column Joints with Nonseismic Design. Procedia Engineering 14: p. 3301-3307.
[7] ACI 318-08 2008 *Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary* American Concrete Institute.

Acknowledgments
This research was sponsored by the Ministry of Research Technology and Higher Education, Republic of Indonesia, and the School of Civil Engineering, University of Leeds.