The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Special precast beam-column connection using pure dry cast method

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ABSTRACT

In high seismic zones, the lateral ductility of a precast concrete beam-column frame system is one of the most critical design aspects. Without mechanisms to ensure adequate ductility or lateral drift capacity, precast systems are not applicable in the regions of high seismicity. An emulated connection is often inefficient and not economical. Also, it is desirable not to have any steel or concrete horizontal elements protruding from a column to maximize the constructability of precast concrete systems. A superior solution is to use embedded rods (with a headed plate at one end and a nut at the other) and pretension bolts that connect between the column and the beam. This paper presents a full-scale experimental study of such non-emulative precast concrete beam-column connections that incorporate the pretension bolts. A total of 5 exterior beam-column connections (including 2 reinforced concrete connections) were tested under deformation reversals for assessing their seismic performance. The primary variables were the dimension of the connection, the diameter of the embedded nut, and the presence of post-tensioning tendons.

1. INTRODUCTION

There are several types of structures, which are widely used over the globe, including reinforced concrete structures, steel structures, and steel-concrete composite structures (Englekirk, 2003; Kang et al., 2009; Probst et al., 2011; Piyawat et al., 2011). Reinforced concrete construction belongs to a wet construction method, and all works are accomplished at the construction site. However, it has a shortcoming in that its construction cost is constantly increasing due to such costs of labor, formwork, etc., as well as its difficulty in carrying out all-weather, year-round construction. Although steel frame construction is a dry construction, its cost is also very high and requires additional works of preparing bolt connection, welding, etc. at the construction site.

For these reasons, the need for precast concrete construction is increasing. Precast concrete construction is a dry construction method and is advantageous in that members of good quality can be mass-produced in a factory. The work at the construction site involves assembly work only and thus is minimized. Furthermore, the construction cost is reduced due to shorter construction period. However, precast concrete construction has been used only in limited capacity due to the difficulty in

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connecting the members, inadequate construction technology, and uncertainty of the performance.

Although the wet construction method is being used to apply concrete to connect the precast concrete beam and column, this emulating method does not fully take advantage of the dry construction method of the precast concrete. Moreover, its constructability is inferior to reinforced concrete, and its seismic performance is disadvantageous if the connection part is not properly integrated. It is current situation that there is a need for the research and development of the pure dry connection method and secures the safety and constructability of connecting the members, for the precast concrete to be used more widely in various construction sites.

2. RESEARCH PURPOSE

This study aims to experimentally evaluate a method of connecting precast beam-column moment with bolts. The tested exterior beam-column moment connection maintains the advantage of a dry construction method of precast concrete, and it can be assembled at the construction site with bolts only so that the constructability can be improved as well as reduced construction period. Additionally, an embedded nut with anchor is used to promote ductility in the seismic region.

3. CONNECTION CONCEPT AND DESIGN

Fig. 1 shows the pre-tension bolting connection. The connected joint was developed with the purposes of maintaining the advantage of precast concrete dry engineering method, improvement of constructability of connecting the members, and the securing of ductility of the precast concrete structure in severe seismic regions.

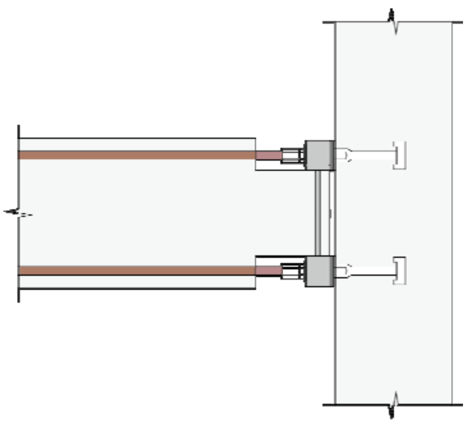

Fig. 1 Pre-tension bolting connection concept

The concrete failure due to concentrated stress can be minimized with the greater bearing force owing to the axial load to the column once the plastic hinge takes place in the joint connection, and the increase in the transverse confining force can also be expected from the transverse reinforcing steel of the column. The deformation at the end of the beam can be controlled. Shear force can be transferred by using the friction between the steel plate and column. Likewise, an embedded nut with anchor, which can induce ductility upon its own yield, was inserted inside the column to have plastic hinge take place in the column. The beam and column are connected through steel block (Fig. 2). It is designed so that the joint can be easily assembled at the construction site with bolts.

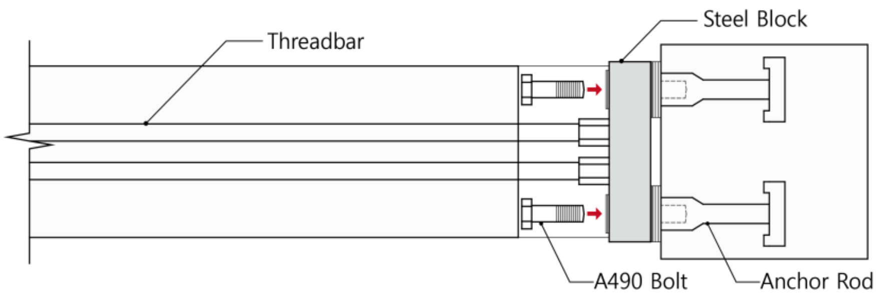

Fig. 2 Pure dry cast method; Beam-to-column connection using pre-tension bolts

Fig. 3 Embedded nut with anchor rod

Since the embedded rod with rod is the only yielding part among the materials of the developed connection, it is closely related to the behavior of the structure after yielding. The nut with anchor rod is embedded into the column and yields due to the stress of the beam end transferred through the steel block. The beam is directly bolted to the column of the precast concrete column. Fig. 3 shows a notch of anchor head to increase the contact area with the concrete, preventing the rotation of the head during locking with the bolt.

3. EXPERIMENTAL PROGRAM

This study carried out an experiment to investigate the structural and seismic performance of precast concrete beam-column moment connections. A test specimen of cast-in-place concrete beam-column moment connection having the same moment strength as the precast concrete (PC) specimen was prepared to compare and analyze its seismic performance with typical reinforced concrete (RC) connection.

3.2 Test specimen

The test specimens were fabricated in two sizes of column 500 x 500 mm plus beam 400 x 650 mm and column 700 x 700 mm plus beam 500 x 700 mm according to the moment strength of the beam-column connection. The number of embedded nuts with anchor was varied for the connection, and test specimens (PC-T) with post-tensioning (PT) steel tendons added to the precast concrete connection were prepared to improve the moment strength and seismic performance of the beam-column connection. Table 1 summarizes the nomenclature of each test specimen and the variables.

Table 1 Test specimens

	Column		Beam		Connection
Specimen	Dimension (mm)	Longitudinal Steel (mm)	Dimension (mm)	Longitudinal Steel (mm)	Embedded Nut with Anchor
RC1	500×500	12-D25	400×650	10-D29	-
PC1	500×500	12-D25	400×650	Ø40 threaded bars	2-Ø45 (300 mm long)
PC1-T	500×500	12-D25	400×650	Ø40 threaded bars & 3-Ø12.7 PT tendons	2-Ø45 (300 mm long)
RC2	700×700	12-D29	500×700	16-D29	-
PC2-T	700×700	12-D29	500×700	Ø40 threaded bars & 3-Ø12.7 PT tendons	3-Ø45 (400 mm long)

The test specimen was designed in accordance with ACI 318-11 Codes for special moment frames. The transverse reinforcement of the column used D13 and D16 rebars depending on the column size, and the moment strength varied with the number of anchor rods. The tendon was post-tensioned up to 85% of the tensile strength (f_{pu}) after the curing of the concrete. However, the experiment was held two months after post-tensioning, and the tension force was lost substantially due to the elastic shortening and creep after the tension was applied. Finally, when the tension force reached about 42% of f_{pu}, the experiment was carried out.

The RC specimens were fabricated cast-in-place with the beam and column connected in the same way as typical cast-in-place RC concrete. Five D29 bars were placed in the top and bottom of the beam and the RC1 specimen was designed to have the same moment strength as that of PC1 with two embedded rods of Ø45. The transverse reinforcement of the column was designed in compliance with the ACI 318 Building Codes for special moment-resisting frames. The ratio of joint shear strength to demand was designed to be close to 1 in order to investigate the seismic behavior of the joint. When the main rebar of the beam reaches the yielding state, the shear force which is applied to the beam-column joint is computed, and the shear strength of the beam-column joint is computed pursuant to the Section 21.7.4.1 of ACI 318-11.

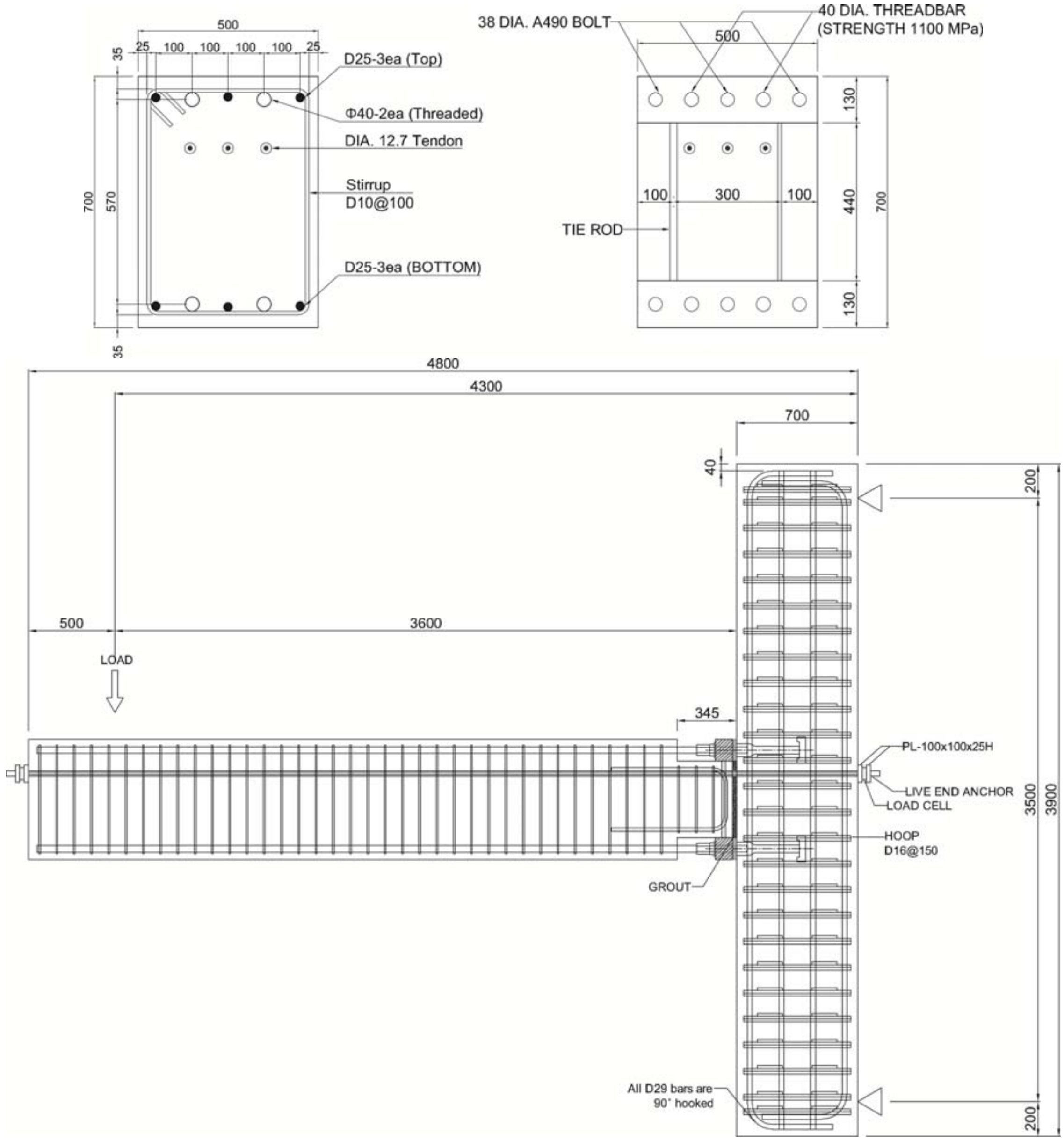

Fig. 4 Specimen drawing (PC2-T)

For the PC and PC-T specimens, a dry construction method of assembling the beam and column after fabrication of them was used. The representative drawing of PC2-T is provided in Fig. 4. Two or three anchor rods of Ø45 were embedded in the joint at the top or bottom level of the beam. Before the concrete was placed, a tube that passes through the beam and the column was inserted to use a post-tensioning method for the PC-T specimens. Grouting was carried out at the interface between the beam and column to effectively transfer the compression caused by the steel wire, and the post-tensioning of the steel wire was conducted after a week of curing. The transverse reinforcement of the joint was designed pursuant to the ACI 318 Codes of special moment-resisting frame. The ratio of joint shear strength of the beam-column joint to the shear force being applied to the joint was designed to be close to 1 for PC1 and PC2-T (or 1.2 for PC1-T) in order to investigate the structural behavior of the joint.

3.3 Test plan

The test was carried out under deflection control to load the beam in positive and negative directions with 3 cycles at each drift ratio. The drift was increased in 0.25% increment at the early stage of loading. The increment increased to 0.5% and 1%, and the loading stopped at the maximum drift of 5% or when the test specimens fails with the decrease in lateral load capacity of 20% or greater from the peak.

4. TEST RESULTS

The following Figs. 5 to 7 show the selected load-displacement hysteresis curves, which were measured during the seismic experiment of the test specimens.

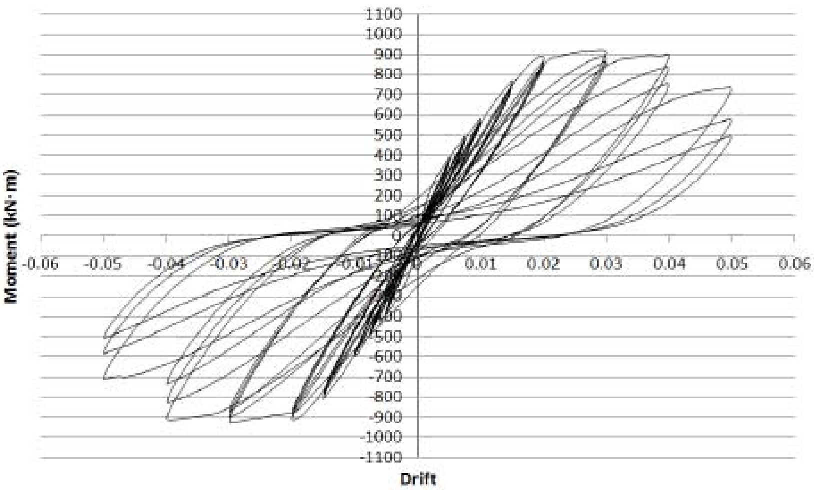

Fig. 5 Beam moment-story drift ratio relationship for RC1

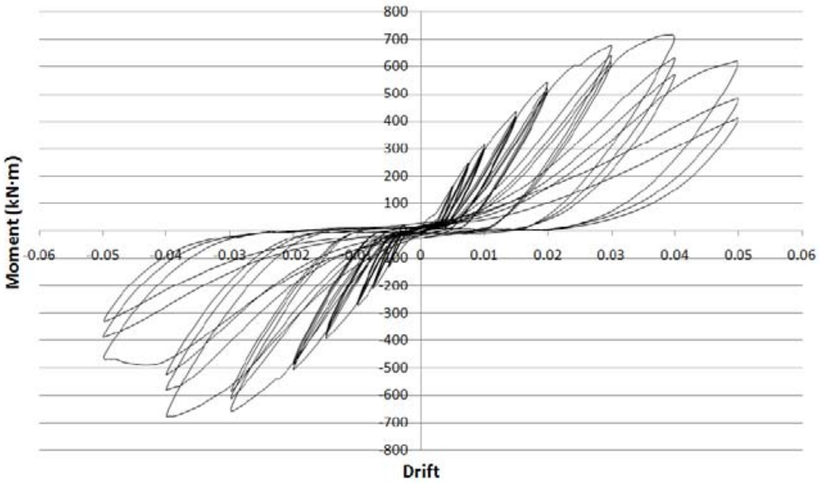

Fig. 6 Beam moment-story drift ratio relationship for PC1

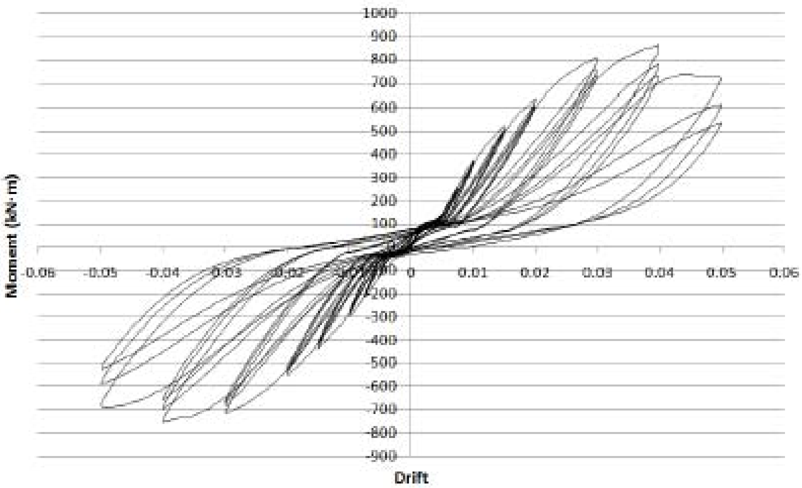

Fig. 7 Beam moment-story drift ratio relationship for PC1-T

The RC1 specimen exhibited maximum beam moment of 918.23 kN·m at story drift of 3%. The beam moment was larger than those of PC1 and PC1-T due to the large strain hardening of reinforcing bars. It appears to yield at the drift of about 1.5%, and the moment increased until the drift of 3%. Slip occurrence decreased, and the energy dispersion was excellent. However, the ductility decreased a bit in comparison to the joint of PC1 or PC1-T specimen. For PC1 and PC1-T, the maximum beam moments were 713.3 kN·m and 859.33 kN·m, respectively, at story drift of 4%. The embedded anchor rod appears to yield at the drift of about 2%, and the moment increased until the drift of 4%. In comparison to PC-1, PC1-T's maximum moment increased, exhibiting similar ductility and slowing down its decrease in the strength after reaching the maximum strength. Additionally, the pinching of the bolt due to the shift from tension to compression was reduced by post-tensioning. RC2 and PC2-T also performed quite well in terms of drift capacity. RC2 and PC2-T manifested maximum beam moment of 1526.76 kN·m at 3% drift and 1273.32 kN·m at 4% drift, respectively. For RC2, the moment strength decreased gradually after 3% drift, and crushing of the beam and buckling failure of the main compressive rebar took place at the loading of 5%. For PC2-T, the experiment was terminated due to the decrease in load capacity at the story drift of 5%, and this was caused by the bonding failure of the large-diameter high-strength threaded bar, which was used as the main reinforcement inside the beam. However, the joint and supplemental materials of the joint were not affected. It appears to have yielded at the drift of about 2%, and the moment increased until the drift of 4%.

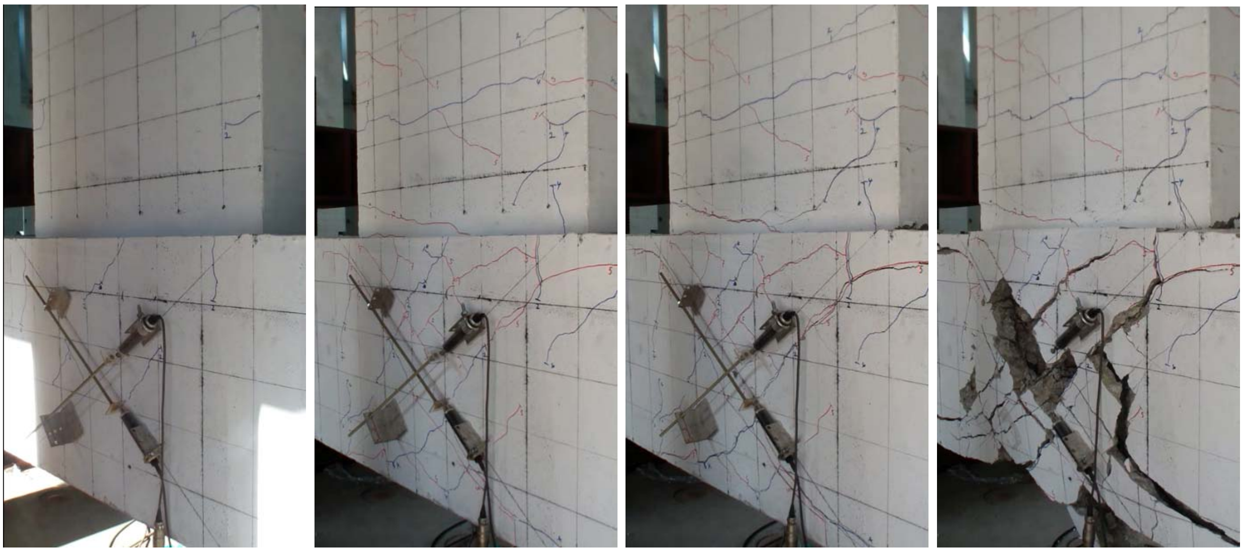

Fig. 8 Observations of RC1 at 0.75%, 2%, 3% and 5% drift ratios

Figs. 8 to 11 show the crack and failure patterns observed at increasing drift ratios for the selected specimens. Until 3% drift ratios, both the RC and PC specimens did not exhibit significant damage except a few joint shear cracks. In particular, PC2-T showed minimal damage in the panel zone, indicating that the embedded nut system performed effectively under very large deformation reversals. However, because of a very high-strength yield strength (1001 MPa) of the large-diameter (45 mm) threaded bar and its lack of development length along the beam (surprisingly), a bond failure occurred at 5% lateral drift when the hex nut was loosened. Note that the hex nut is not supposed to be tightened with a hydraulic torque wrench, unlike the pre-tension bolts used to connect the beam and column. This is not to deteriorate the precast beam’s integrity. If the bar length had been long enough, seismic performance would have been much better.

Fig. 9 Observations of PC1 at 0.5%, 2%, 3% and 5% drift ratios

Fig. 10 Observations of PC2-T at 4% drift ratio

4. CONCLUSION

While data reduction is still underway, the following preliminary conclusions can be made. The experimental results of this study indicated better seismic performance in terms of deformation capacity and ductility for the precast concrete beam-column joints in comparison to cast-in-place reinforced concrete beam-column joints. However, the RC specimens exhibited better performance in terms of energy dispersion or pinching resistance. These performance indicators are not intended to be achieved by the PC specimens, where pre-tension bolting was used for connection between the beam and column. The system of connecting members using all dry construction method with pre-tension A490 bolts allows for the detachment of the beam from the column when subjected to tension. The pinching phenomenon, which occurs upon re-connection of the beam and column during the shift from tension to compression, is an intended design concept and did not greatly affect the seismic performance. The energy dispersion capacity due to the yield of anchor rods was also excellent as a precast joint. The capacity to transfer the load from high-strength threaded bar to transfer steel block, from steel block to pre-tension bolt, from pre-tension bolt to anchor rod, and finally from anchor rod to concrete inside the joint was found to be very effective. Moreover, the precast concrete beam-column joint connection was also found to be very appropriate in exhibiting adequate seismic performance as part of the special moment frame in consideration of the concentrated yield mechanism in the anchor rod and the very large lateral drift capacity of the whole system.

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