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Behavior of two new moment resisting precast beam to column connections subjected to lateral loading

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ABSTRACT

In this study, two new moment resisting connections of beams to precast concrete columns under lateral load were analyzed via application of nonlinear finite element analysis software ABAQUS 6.10. The precast connections considered were the beam-column connections in which precast beams is connected to continuous precast column with corbel using (i) inverted E (bolted connection) and (ii) box section (welded connection). Connection responses associated with lateral resistance, lateral stiffness, ductility, and energy dissipation were compared to a reference monolithic connection. Achieved lateral resistance, lateral stiffness and ductility of the proposed connections was approximately 98%, 80% and 80% of the equivalent monolithic connection, respectively. The effect of axial load on column and compressive strength of concrete on behavior of the connections were studied. The analytical results show that the performance of two proposed precast connections were close to the performance of corresponding monolithic connection.

1. Introduction

Advantages of precast concretes have increased worldwide usage of precast concrete structures. Beam to column connections in frame systems affect significantly the constructability, stability, strength and flexibility of structure. Furthermore, connections play an important role in the dissipation of energy and redistribution of loads as the structure is loaded. Also, the creation of totally rigid connections of beams to columns in precast structures is very difficult and time-consuming, there by negating advantages gained using precast features Studies have shown that if a semi rigid connection stiffness is more than 80% of an equivalent monolithic connection stiffness, seismic behavior of the system will not significant change [1]. Therefore, properly designed connections could develop expected mechanical features and demonstrate a low-cost fast-construction system for multi-storey buildings.

In 1987, the research and development department of the Precast Concrete Institution (PCI) conducted a laboratory investigation of 16 samples of precast connections (eight simple and eight moment resisting connections). The aim of the project was to obtain connections behavior such as resistance, ductility, energy dissipation, sustainability and economical performance [2]. In 1989, Dolan and Pessiki created laboratory models with scales of one-half and conducted an analytical study of connection in order to demonstrate that a computer model can be an appropriate and acceptable method for analysis of precast concrete connection behavior [3]. Bull and Park created laboratory specimens in order to evaluate seismic behavior of one type precast moment resisting beam to column connection in New Zealand [4]. This connection was made by placing a U-shaped precast concrete beam at the joint, and the connection was completed using in situ concrete and slabs. The connection has been used to make frame structures with small height. They adopted formulations for connection design also. French et al. had looked into the issue of moving the connections away from the column face [5]. In their research, the connections were relocated to the beam span at a distance away from the column faces. The models comprised a precast reinforced concrete column and a precast partially prestressed beam. With such a frame configuration, the beam-column joint core, in which the reinforcement details are complicated, can be prefabricated precisely under factory conditions. The reinforcement continuity will further enhance the integrity of the joint and prevent premature failure. Most importantly, the coinciding condition between the inherent plastic hinge locations and the connection regions can be avoided. Also researchers such as Restrepo et al. and Khoo et al. proposed beam to beam connections [6,7]. The primary variable in the tests was the connection detail

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between the beam and beam. For frames adopting mid-span beam-to-beam connections, Park noted that the precast components of this system can be very heavy and difficult to transport due to their relatively large dimensions. This transportation difficulty would then hinder the choice of precasting the cruciform members for frames with long beams. Parastesh and Khaloo conducted experiments on one type precast concrete connections with a scale of 0.4 under different bar ratio and stirrup distances in the beam. The primary objective of their research was to develop moment resistant connection of precast beam to precast column for zones with high seismicity. In these experiments, cruciform specimens were made of continuous columns and beams that were separated. A gap was created in the columns to provide enough bearing area for sitting the beams and transferring the construction loads before in-situ concrete becomes structural. The cross-section of the beams was U-shaped at near connection, while the rest of cross-section was rectangular. Forces resulting from flexure occurred due to overlapping of protruding bars from columns and beams buried with in situ concrete [8,9]. The test results showed that the connection can be successfully designed and constructed to emulate cast-in-place construction. But, on site, the placement of the beams on column need for using formwork and temporary vertical supports for the beams. Shariatmadar and Zamani studied three interior precast concrete connections and one monolithic reference connection (MO). In two proposed precast connections (PC1, PC2), column was discontinuous at connections. After placing the beams at the axe of the column gap and entering the add-bars in beam and column free gap, 100 mm top of precast beams, and free spaces of column and beam were filled simultaneously with cast-in-place concrete. In the third connection (PC3), the column was continuous and the seated of the beam was created by welding available pending plates in the beams and column [10]. Fabrication of PC3 specimen was easier from the other precast connection. Discontinuity of columns at each story level slow down construction time of buildings of systems PC1 and PC2. Elliott et al. tested four semi rigid connections. Supports for beams are provided by means of steel corbel or solid section on each side of the columns which also transferred shear forces. The top bars passed from the columns and provided connection continuity. This can lead to a low-cost fast-construction system for multi-storey buildings, where multiple stories can be constructed at once. [11,12]. Connections were made using proprietary pinned jointed billet, cleat and welded plate connectors, to form cruciform assemblages subjected to sway and gravity load. They were not purposefully intended as moment resisting frame. In some cases 200 mm deep slab and high tensile reinforcement completed the connections. They reported moment resistance and flexural stiffness gained from each of the connections. Also equations were presented to calculate effective length factor for column in semi rigid sway frame and percentage of rigidity of connections. The Elliot et al. connections achieved 10–48%, and 8–40% of strength and stiffness of the corresponding monolithic connection, respectively. SAFECAST project, with the aim of validating multi-story precast concrete experimental models, performed 3 pseudo dynamic seismic tests on full scale three story structural models. Hollow core section beams connected to column capitals serving as beams provided equivalent mechanical properties to that of T or I shape, offering economic advantage by increasing floor area. Connections are embedded inside the structural elements using steel connectors and bolts. Finally, any remaining gaps are filled with grout to finalize the process of forming the connection. Emulative beam to column joints were reported to be satisfactory in terms of stiffness and inter-story drift; yet, the structural responses differ from a equivalent rigid joint and the connection behavior is categorized as semi-rigid [13,14]. Choi et al. performed experimental test on 4 precast beam to column assemblies and a monolithic assembly, in order to achieve structural continuity, high shear deformation demand, strength, stiffness and drift requirements along with introducing ease of erection and reliability [15]. Connections were simply formed by connecting steel elements, embedded inside the structural members that connect the beam and column using bolts; and finally, fiber reinforced concrete in the joints slightly increase the tensile strength and shear toughness. Assemblies are laterally loaded with reversing load pattern increasing the drift up to 5%. In terms of strength, connection were able to maintain over 75% of the strength at 3.5%. In connections where the plastic hinge was designed to be away from the beam-column interface (Outside type), higher stiffness reduction was observed, while the connections in which the plastic hinge location was near the column face (inside type) resembled more with the monolithic counterpart. The outside type, compared to other specimen, dissipated more energy and responded more ductile.

The presented manuscript provides the preliminary numerical study for proposing two new beam-to-column connections in precast structures. The results of the presented study have been used to construct 0.6-scale experimental specimens that are explained in detail in Refs. [23] and [24]. As discussed in Ref. [24], the experimental results are in a good agreement with numerical results presented here. The proposed connections are designed not only to satisfy the required mechanical properties, but also minimize construction time and labor work by providing simple construction methods. During the construction period, semi precast beams were placed on corbels, partly embedded inside the continuous columns. This will remove the need for shoring and temporary bracing to hold he precast unit in place and during the erection of the precast components. Furthermore, the hidden corbel addresses the architectural drawback of ordinary concrete corbels. These goals were also among the objectives of SAFECAST project. The proposed connections in this study shows better performance in comparison to Elliot connections, while not scarifying the ease of construction.

2. Proposed two precast connections and reference monolithic connection

Design and performance of completely rigid connections in precast concrete structures is difficult and time-consuming. For some connections, the need for framing or large volumes of in-situ concrete undermines the inherent beneficial features of prefabrications. Therefore, the industry of precast concrete structures seeks connections with easy quick installation that provide required mechanical features.

Two moment-resisting precast connections are proposed and their performance is assessed in the presented study. The monolithic reference specimen (MC) was designed for comparison the behavior of cast-in-place connection with precast connections.

Fig. 1 illustrates details of the interior moment-resisting connections for precast concrete frames before cast-in-place concreting. In both proposed connection systems, the prefabricated concrete columns are cast continuously in elevation with steel corbel embedded in the connection core to connect beam elements. Four vertical bars are welded to the corbel in the connection zone of the precast columns to provide adequate shear strength and stability during the installation and prevent the slip of corbel during lateral loading. The steel corbel provide enough bearing area for sitting the precast concrete beams and transferring the construction loads before in-situ concrete becomes structural. Consequently, in the proposed systems, there is no need for using formwork and temporary vertical supports for beam and slab elements. This can lead to a low-cost fast-construction system for multi-storey buildings, where multiple stories can be constructed at once.

In both connections, the precast beam is placed on the steel corbel, and steel bars below the beam were connected to the steel