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Seismic behavior of two exterior beam–column connections made of normal-strength concrete developed for precast construction

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ABSTRACT

The lack of in-depth understanding of the seismic behavior and ductility of precast concrete structures makes it difficult to reach to ductility demand which could be exhibited during an earthquake. The limitations are mainly related to the beam-to-column connections as the main load transfer paths. Two distinct exterior beam–column connections made of normal-strength concrete are investigated experimentally. Both dry and wet type installment techniques are used in *the industrial type joints* while *the residential type joints* are wet connections. The specimens are subjected cyclic displacement reversals in order to obtain information on strength, stiffness and ductility characteristics of the connection details. The preliminary design of the joints has been updated during the tests based on the damages observed, thus a set of improved specimens have also been built and tested, and a relatively better performance is obtained expectedly. The *industrial* and *residential* types of connections showed stable load–displacement cycles with high energy dissipation up to structural drift of 2%, though a significant level of pinching and deterioration of the critical section have occurred at around 3% drift level. The tested specimens have been numerically modeled to calibrate the analytical tools, and a satisfactory approximation has been obtained between experimental and numerical results.

1. Introduction

One of the major challenges in the design of precast structures in earthquake prone areas is the proper design of the connections, primarily beam-to-column ones. Various types of beam-to-column connections such as monolithic, emulative, bolted, and dry pinned are being used in the practice. Details of different types of connections, in terms of design and behavior, are discussed extensively by Park [1] and fib Bulletin 43 [2].

Bhatt and Kirk [3] and Seckin and Fu [4] developed some welded connections for use in precast concrete structures. Although the behavior of the connections is acceptable, the details require welding of the beam and column reinforcement, which may cause some problems on site. French et al. [5,6] tested various types of beam–column connections; some of them developed plastic hinges outside the connection region. It was revealed that the threaded reinforcing bar connections with tapered, threaded splices proved to be the most favorable solution in terms of performance, fabrication, and economy. Ersoy and Tankut [7] tested precast concrete beams with dry joints under reversed cyclic loading. The original beam consisted of two steel plates one at top, the other at the bottom, welded to the anchored steel plates in the column bracket and the beam. The design was later revised by adding side plates. The strength, stiffness and energy dissipation of the member with side plates are comparable to those of monolithic member. However, application of such a detail on site is quite difficult and requires a careful quality control mechanism. Priestley and Tao [8] proposed the use of lateral load resisting systems built incorporating unbonded prestressing for use in earthquake prone areas. Nakaki et al. [9] proposed a precast concrete ductile frame that takes advantage of the inherent discrete nature of precast concrete by providing ductile links in the connections. These ductile connectors which are also eliminating the need for corbels contain a rod that yields at a well-defined strength, effectively limiting the load that can be transferred to less ductile components of the frame. PRESSS project [10,11] is the most notable effort on the experimental investigation of the earthquake response of precast structures. Ductile connections for precast concrete frame system, ductile connections for precast concrete panel systems, precast frames with unbounded tendons, high performance fiber-reinforced-concrete energy absorbing joints for precast

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Notation

ϕ	diameter	K	effectiveness factor of the confinement
ε_c	confined concrete strain	M	monotonic
C	Cyclic	R-	improved specimen
f_c	compressive strength of unconfined concrete	RT	residential type
f_{cc}	compressive strength of confined concrete	S_L	geometric scale factor
IT	industrial type		

concrete frames are among the main topics studied. Korkmaz and Tankut [12] tested six beam-to-beam connection subassemblies under reversed cyclic loading. The behavior of the precast members was compared with that of the monolithic specimen. In order to improve the seismic performance of the connection, several recommendations for future research and practices are also given in the context of the paper. Ertas et al. [13] tested four types of ductile moment-resisting precast concrete frame connections and one monolithic concrete connection. The modified bolted connection showed the best performance in terms of strength, ductility, and energy dissipation in addition to ease and speed of construction. Three of the specimens could sustain up to 3.5% story drift. Kaya and Arslan [14] tested post-tensioned precast beam-to-column connections at different stress levels, and performed a series of analytical works by using ANSYS software. The results obtained from the analytical works are compared with the test results.

Parastesh et al. [15] proposed a joint type in which prefabricated concrete columns are cast continuously in the elevation with a free space in the connection zone to connect beam elements. Four diagonal bars are used in the empty zone of the precast columns to provide adequate strength and stability during the installation process. Flexural strength, ductility, strength degradation and energy dissipation capacity of the precast and monolithic connections are compared. While the precast connections provided adequate flexural strength, strength degradation and drift capacity, they exhibited considerably higher ductility and energy dissipation compared to similar monolithic specimens. Negro et al. [16] and Bournas et al. [17] presented the full-scale test results of three-storey precast building studied in the framework of the SAFECAST project. Dry mechanical connections were adopted to realize the several joints. The effect of two types of beam–column connections on the seismic behavior was evaluated. They were the pinned beam–column joints and a new connection system with dry connections. It was concluded that the new beam-to-column connection system is a viable solution toward enhancing the response of precast RC frames subjected to seismic loads, in particular when the system is applied to all joints and quality measures are enforced in the execution of the joints.

The beam–column connections shown in Fig. 1 have been started to be used in Turkey for low-rise *industrial* and *residential* buildings. In spite of this fact, there is no experimental evidence for validation of the effectiveness of these connections under seismic actions. In order to have better insights to the matter, an experimental campaign has been initiated as part of the SAFECAST, a European Commission FP7 funded research project focused on improving the seismic behavior of precast structures.

The tested sub-assemblages represent the exterior beam–column connections of inner axes of the precast buildings.

2. Description of specimens

Two different types of beam–column connections have been tested at Structural and Earthquake Engineering Laboratory of Istanbul Technical University (ITU) as a partner of the SAFECAST. The connections are categorized as *industrial type* and *residential type* depending on the existence of corbels on the lower column, Fig. 2.

Dimensions of the *industrial type* connection are reduced in geometric scale of $S_L = 1/2$ to fit the existing testing set-up. The similitude law are utilized in the determination of some parameters. The scale factors are (i) (S_L) for length and displacement, (ii) $(S_L)^2$ for area and forces, (iii) $(S_L)^3$ for bending moment, (iv) (1.0) for stress and strain, Noor and Boswell [18]. And yet the *residential type* connections are produced in full scale.

Five specimens are constructed for each type of connections. Symmetrical behavior is not expected in two opposite directions. Two of the specimens from each group are tested under monotonic loading, while others are tested under reversed cyclic loading. The specimens marked with "R-" indicates the *improved specimens* for which some features are modified and/or enhanced depending on the results of the preliminary tests. Tags of the specimens, some descriptions about the loading type and the governing internal forces are presented in Table 1.

In the *industrial type* connection, columns are continuous having a small gap at the level of slab. The beams to be installed in longitudinal and transverse directions are welded to the steel plates placed on top of the corbels and supplementary reinforcements, which will be active for negative moment, are inserted into the joint. The gap in the column, void portion of the beam and topping are filled by normal-strength concrete in the construction site, see Fig. 2a, Karadogan et al. [19].

In the *residential type* connection, a cylindrical pipe and four large diameter bars extending out from the lower column are inserted into the holes formed in the bottom part of the upper column. After installation, these holes are grouted. The semi-cast beams with upper and lower longitudinal reinforcements are positioned in the connection. The connection, void portion of the beam and topping are filled by normal-strength concrete in the construction site, see Fig. 2b. In point of fact two columns and one beam are connected each other in the construction site.

Three different types of reinforcements are used during production of the specimens. The first is the regular rebars used for flexural and shear reinforcement. According to the tensile tests performed prior to the experiments, yield strength of the regular rebars is 419 MPa for the *industrial type* connections, and varies between 489 and 538 MPa for the *residential type connections*. Wire mesh is used as the slab flexural reinforcement with yield strength of 587 MPa. The pre-stressing tendons, which are used in beam of the *industrial type* connections have 4.5 mm diameter and 1400 MPa yield strength.

Concrete compressive strength determined from the compression tests of 150×300 mm cylinders at 28 days are 30 and 32 MPa for the *industrial* and *residential type* connections, respectively. The obtained compressive strengths are assessed as normal-strength. Hence, this research explains the behavior of joints made of normal-strength concrete.