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Seismic experimental study on a precast concrete beam-column connection with grout sleeves

Qiushi Yan [a,*], Tianyi Chen [a], Zhiyong Xie [b]

[a] Key Laboratory of Urban Security and Disaster Engineering, Ministry of Education, Beijing University of Technology, Beijing 100124, China
[b] State Grid Zhangzhou Electric Power Supply Company, Zhangzhou 363000, China

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ABSTRACT

The seismic behavior of the beam-column connections in concrete frame is studied in this paper, including five precast specimens and one cast-in-place specimen. For the precast specimens, the column, joint and part of the beam away from the joint are prefabricated, while the part of beam close to the joint is cast-in-place. The rebar is connected by grout sleeve. The specimens were tested under low-reversed cyclic loading, and were evaluated in terms of failure mode, skeleton curves, stiffness, energy dissipation, and drift capacity. Differences in seismic performance between these specimens were also revealed. From the test results, the seismic performance of the precast connection is similar to that of the cast-in-place connection. However, the distribution of cracks, the strain of reinforcements and the deformation of joint are different. The strength ratio between column and beam is an important factor on the failure mode of the precast connections. For precast connection, the seismic behavior of the plastic hinge as well as the core region of the joint are clearly affected by the grout sleeve, the cast-in-place region and the rebar hole. Also in the core region of the joint, slippage of longitudinal rebar is observed.

1. Introduction

Precast concrete (PC for short) is defined as any concrete product that is made in a factory and is ready for final installation on leaving. The range of products is vast, from small bricks and roof tiles to thousand tonne caissons produced in temporary waterside plants [1]. Compared with conventional concrete structure construction, precast concrete structure construction saves time, reduces labor cost and energy consumption, and makes cost and quality control easier.

Precast concrete frame structure has been widely used in various countries and regions in the world, and consequently the corresponding building codes and standards have been developed. The American Concrete Institute (ACI) and the American Society of Civil Engineers (ASCE) jointly formulated the “Guide to Emulating Cast-in-Place Detailing for Seismic Design of Precast Concrete Structures (ACI 550.1R-09)” [2], in which detailed provisions are made for the design of precast concrete structures. New Zealand is one of the countries in which precast concrete structure developed early, and its “Guidelines for the Use of standard Structural Precast Concrete in Buildings” [3] introduced three types of precast concrete frame connection, namely the Precast Beam Units between Columns, Precast Beam Units through Columns, and Precast T or Cruciform Shaped Units. In Japan, research on precast concrete structure has been carried out for several decades and “JASS 10” [4] is the general outline for precast concrete structure design. In addition, many Japanese construction companies are experienced in precast concrete construction and these companies have also developed their own technology and guidelines for precast concrete structure design and construction. Precast concrete structure constructions are applied in Hong Kong, which is generally limited to non-structural components. The “Code of Practice for Precast Concrete Construction 2016” [5] formulated by the Hong Kong Buildings Department stipulates specific requirements for different connections.

The biggest challenge precast concrete frame structure faces at the present is the lack of structural integrity, which is a common problem for precast concrete structures. Ensuring the effective and integral connection between precast structural members is the key to address this problem. For precast concrete frame structure, the beams and columns are usually precast, and they are assembled together at the beam-column joint (namely the core region of the joint). The integrity of beam-column connection is the most important aspect in frame structure, as such the concept of ‘strong connection, weak member’ is applied in the structural design for earthquake resistance. To sum up, it is crucial to ensure

* Corresponding author at: Pingleyuan 100, Beijing University of Technology, Beijing 100124, China.
E-mail address: yqs2011@bjut.edu.cn (Q. Yan).

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that the structural performance of the connection is equal or better than that of the precast member when the precast concrete frame structure are assembled on the construction site.

The seismic capacity of joint has significant impact on the dynamic response of frame. The joint transfers load between column and beam. The Chinese building code "Code for seismic design of buildings" [6] states that "The deformation capacity of the frame structure is closely related to the failure mechanism. Research shows that if beam yields first, the whole frame has a better capacity of redistribution of internal force and energy dissipation, as well as higher ultimate story drift and better seismic performance.' As such, the ideal failure mode is that plastic hinge first forms in beams which are followed by a ductile failure, while columns remain intact. This is the design principle of "strong column, weak beam and Strong connection, weak member". Apart from the wide accepted principle "Strong column, weak beam" in structural design, the principle "Strong connection, weak member" is also an important understanding especially in engineering practice in China. That is also why this paper focuses on joint and plastic hinge formed in beams. Different with the cast-in-place connection, precast connection has several assembly interfaces which have complex effects on the connection performances. The existing design codes for cast-in-place concrete structures are not applicable. However, the existing design codes for precast concrete structures do not cover various possible connection types in practices, which is different from the codes of America and New Zealand [2,3]. The investigation of the precast concrete connection in this study could be used to further improve related design codes.

This paper presents a study of the seismic behavior of a new precast concrete beam-column connection by applying low-reversed cyclic loading, and analyses its seismic performance in terms of strength and axial compression ratio. According to the failure mode, displacement vs. load relationship, strength and stiffness of the specimens with different parameters, critical factors which affect performance of the specimens are revealed. The investigation results of the column to beam strength ratio and column axial compression ratio can be used as reference in design for related engineering practices. For the possible practice implication for industry, the investigation in this study presented an innovative types of precast concrete beam to column connection. It provides more choices of precast connection and can improve the development of the industry practices.

2. Literature review

In term of construction method, precast concrete connection can be divided into two types, the dry connection and the wet connection. For dry connection, joining members are embedded with steel plates or other components and are welded or bolted together. For wet connection, joining members are put together by grouting or cast-in-place concrete. Only the wet connection is chosen for the experimental investigation in this study.

Many wet concrete connections exist in related researches and practices, such as cast-in-place beam-column joint core, precast beam-column joint core and precast prestressed joint. When adopting the cast-in-place beam-column joint core, the straight beams and columns are precasted with regular shape, small in size and easy to transport and assemble. However, the cast-in-place beam-column joint core leads to construction of the joint area complicated with reinforcement tying and concrete pouring, which hard to ensure the construction quality. When adopting the precast beam-column joint core, precast members are various such as cross type, T type and straight type [2,3], which leads to relatively not easy to transport. However, compared with the use of cast-in-place beam-column joint core, small error tolerance for precast beam-column joint core would ensure construction quality of the connection core. The precast prestressed joint can rationally improve the distribution of joint internal force but the type of joint has complex construction procedure. In this study, the cast-in-place beam-column joint core is chosen and fabricated for research.

A large number of studies of the precast concrete frame connection were conducted in different countries. PRESSS (Precast Seismic Structural System Research Program) [7] is a large scale precast concrete structure seismic research program chaired by American and Japanese scientists. The objective of the PRESSS program is to develop design guidelines for precast concrete structures in regions of high and moderate seismicity, which can be incorporated into the existing building codes. Daisuke [8] did a test to compare three types of precast concrete beam-column connections with a cast-in-place connection. All three types of precast connections are wet connections and the main difference between them is the horizontal bar connection in the joint (bending lap of lower bar, sleeve splice of lower bar and sleeve splice of both upper and lower bar). It was reported that the precast connections had lower initial stiffness and lower shear strength of core zone. Uramoto [9] found that the longer the horizontal projection of horizontal bar connection in the joint, the better the seismic performance. Both Daisuke and Uramoto's research was part of the PRESSS program. In order to investigate different precast connections, Onur Ertas [10] did an experiment on five types of concrete frame connection, including one cast-in-place connection, two precast wet connections (one at end of beam and the other at end of column) and two precast dry connections (welded and bolted with bracket). The experiment results indicate that bolted connection delivers the best performance in terms of strength, ductility and energy dissipation. For the two precast wet connections, the one with wet connection casted at the end of beam has larger plastic hinge and better energy dissipation than the one with that casted at the end of column. Jose et al. [11] conducted research on the two types of precast connections included in the New Zealand standards, namely the 'Precast Beam Units between Column' and 'Precast Beam Units through Columns' in "Guidelines for the Use of standard Structural Precast Concrete in Buildings" [3]. The study shows that both precast connections has good seismic capacity, but the former one is weak at the junction of cast-in-place and precast components. In contrast, the joint of the latter one is precast, which avoids the complicated in situ construction procedure, and consequently the quality of the structure can be guaranteed. Vidjeapriya et al. [12] compared cast-in-place connection with precast connection with stiffeners. He found that ultimate load-carrying capacity of the cast-in-place specimen was higher than that of both the precast specimens, but the precast specimen sex hibited decent behavior in terms of energy dissipation and ductility compared with the cast-in-place specimen. A new ductile moment-resisting beam-column connection tested by Parastesh et al. [13] provided adequate flexural strength, strength degradation and drift capacity, the connection also exhibited considerably higher ductility and energy dissipation compared to similar cast-in-place specimens. Yuksel et al. [14] reported the results of their experimental investigations on the industrial and residential types of connections. It was revealed that both connections had 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. Wu et al. [15] conducted an experiment to compare the precast concrete connection with the cast-in-place connection. The hysteretic character is tics of the two connections are similar, but the degradation velocity of bearing capacity of the precast connection is higher than that of cast-in-place connection. Also the cumulative damage of the precast connection is more significant after yielding. Amadio et al.