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Bearing capacity of embedded channel-shaped steel connections at precast concrete beam end

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ABSTRACT

Embedded channel-shaped steel (ECS) connection at precast concrete beam-end proposed in this paper is a kind of novel connection. To study the performance of ECS connection, experiments on 12 specimens were carried out. The embedded length of the ECS, the stirrup spacing, the cavity in the mid-span of the beam and the eccentricity of the ECS were taken into account. Two kinds of failure modes were observed: lever-out of ECS and crushing of the beam-end concrete. The experimental results indicate the following: (1) as the length of ECS increases, the bearing capacity of the ECS connection increases; (2) the stirrup densification could significantly improve the bearing and deformation capacity; (3) the mid-span cavity of the beam has limited influence on the bearing and deformation capacity of the connection; (4) the eccentricity of ECS could slightly reduce the bearing capacity owing to the additional torsion. Subsequently, finite element (FE) models were developed using ABAQUS and validated by the test results. The FE simulations show good agreement with the test results. Based on the verified FE models, a parametric study was conducted, considering different ECS properties including embedded length, section and eccentricity, various stirrup spacing at the beam-end, concrete grade and the distance between cavity and ECS. Finally, to prevent the lever-out of ECS, the optimum design of the ECS connection was proposed according to previous discussion.

1. Introduction

Compared with traditional structure, prefabricated structures have many advantages such as green environmental protection, higher construction efficiency, lower construction cost, industrialized production, and well-guaranteed construction quality [1–6]. In view of this, prefabricated structures has been promoted vigorously to replace cast-in-site structures in China in recent years and has attracted more attention [7–10]. However, as for prefabricated concrete structures, the mechanical property of the beam-column connections has strong influence on the lateral stability and seismic performance. On the whole, the typical beam-column connection of prefabricated concrete structures mainly includes bracket connection and cast-in-site connection [11–14], as shown in Fig. 1. Generally, the bracket connection is excellent in the high bearing capacity, but inefficient in the architectural space. In contrast, cast-in-site connection can maintain the integrity of structures, but it has some drawbacks, including more wet constructions, longer construction period and reinforcement congestion in connection regions.

To overcome the above shortages, numerous researchers have made transformations and innovations on conventional beam-column connections of prefabricated structures. H Wang et al. [15] proposed a novel prestressed precast beam-column joint. For this joint, the beam ends adjacent to the column are reinforced by steel jacket to prevent concrete spalling. Steel strands and mild steel bars are used to provide the joint with self-centering capacity and energy dissipation capacity, respectively. Huang Y et al. [16] experimentally and numerically investigated the behavior of an innovative prefabricated beam-column joint. In this approach, a composite steel truss and concrete beam is adopted and connected to prefabricated high-strength composite columns. And the lattice girders are introduced to restore the continuity of the beams and improve the seismic behavior of the joints. Morgen and Kurama [17–19] improved the unbonded post-tensioned precast concrete beam-column joints by placing a supplemental friction dampers at the traditional joints. The reformed joints can substantially provide energy dissipation for structures. Meanwhile, the structures can also possess favorable self-centering capacity. Some novel beam-column connections created to improve the ductility of building structures are also available. Nakaki et al. [20] proposed a new-style beam-column connection by introducing ductile connectors. Connector itself can

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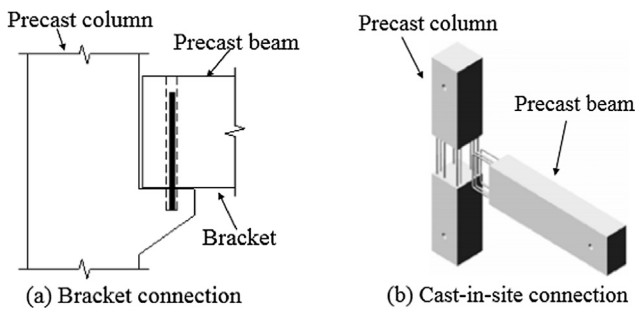

Fig. 1. Typical beam-column connections.

utilize outstanding ductile performance and energy dissipation to enhance seismic resistance of the whole structure. The ductile connection allows considerable displacement, without reducing structural integrity. Tong L et al. [21] introduced cast steel connectors as replaceable energy-dissipating components in beam-column joints. And the research indicated that joints with cast steel connectors were shown to have good energy dissipation capacity with stable and plump hysteretic curves. Li X et al. [22] created a new type of high-ductility joints for precast reinforced concrete (RC) frame, in which the high-ductility rods embedded in joint core. Based on the results of their study, the rods were yielded at first while the beams and the columns kept elastic. It greatly improved the load-bearing capacity and ductility relative to monolithic joints. In addition, a new ductile moment-resisting beam-column connection was developed by Hossein Parastesh et al. [23]. In the proposed system, prefabricated concrete columns are cast continuously to connect beam elements. Four diagonal bars are used in beam-column joint core to provide adequate strength and stability of the joints. Experimental study on the new connection specimens subjected to cyclic loading indicated that the proposed connection showed considerably higher ductility and satisfactory energy dissipation capacity, compared with the similar monolithic specimens. Moreover, in the study of Saeed Bahrami et al. [24], the performance of two new precast beam-column connections under lateral load are analyzed using nonlinear FE model. The analytical results explained that the performance of these two precast connections was close to the corresponding monolithic connections. In addition, Guan D et al. [25] experimentally investigated the hysteretic behavior, strength, deformability, stiffness, and energy dissipation of the new full-scale beam-column connections. It was showed that the new connections presented superior flexural strength and enhanced ductility.

Li G put forward an original prefabricated energy dissipation structural system named hinge-connected steel frame with buckling restrained braces [26]. In this structural system (Fig. 2), precast RC beams and precast steel reinforced concrete (SRC) columns were hinged together for the convenience of installation. And the lateral stiffness of the structural system was supported by buckling-restrained brace or buckling-restrained steel plate shear wall. inspired by this, this article

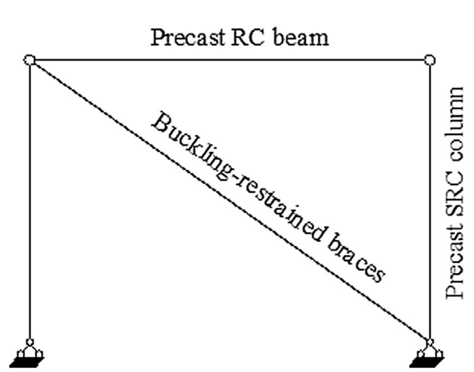

Fig. 2. Prefabricated energy dissipation structural system.

proposed the ECS connection at precast concrete beam end. Fig. 3 illustrates the details of the ECS connection of precast concrete beam. A specified length of channel-shaped steel is embedded at the end of precast RC beam. Similarly, a section of connected channel-shaped steel (CCS) is also welded on the precast SRC column. And the cross section of ECS and CCS is identical to each other. The ECS and the CCS are spliced with high-strength bolts on the construction spot. Considering the installation error, the slotted holes are arranged on the CCS. Accordingly, the proposed ECS connection can be assembled rapidly and handily, minimize site operation and eliminate the use of formworks. Moreover, it's easy to control construction quality of building structures adopted the ECS connections. Thus, this novel connection has a significant meaning to motivate the progress of building industrialization in China. As a result, this paper experimentally researched the bearing capacity of 12 ECS connection specimens subjected to unidirectional loading. Also, a parametric study was carried out based on the verified FE models to offer references for the subsequent design and application of this new connection.

2. Test program

2.1. Specimens

To investigate the bearing capacity of the new-type connection, a series of experiments were conducted on 12 ECS connection specimens. All precast RC beams had the same span of 1650 mm, the same cross-section of 250 mm × 350 mm (the width of the section was 250 mm and the height was 350 mm, respectively), and the same ECS extension length of 130 mm. All the specimens were fabricated with the same materials as below: each beam was casted with C30 concrete; the longitudinal reinforcement consisted of 3D18 bars (three bars with diameter of 18 mm) at the bottom and 2D18 bars at the top, adopting HRB400; the stirrup was HPB300 with a diameter of 8 mm. All precast concrete beams were designed in accordance with the guidelines of *Code for design of concrete structures* [27]. In addition, ECS of the beam and CCS of the column were connected together with three M24 high-strength bolts, whose grade was 10.9. The details and pictures of the specimens are shown in Fig. 4.

Four primary parameters were considered in the design of the specimen as follows:

(1) The embedded length of the ECS. In order to study the influence of the ECS embedded length on failure mode and bearing capacity, group A included three cases: 100 mm, 200 mm and 300 mm.
(2) The stirrup spacing. Compared with stirrup spacing of 100 mm in group A, group B considered denser stirrup spacing of 50 mm, in the range of 300 mm at the both beam-ends.
(3) The mid-span cavity of the beam. To reduce the self-weight of the beam, the beam with mid-span cavity was developed. The distance between cavity and ECS was designed as 200 mm in group C, as illustrated in Fig. 4.
(4) The eccentricity of the ECS. To consider the practical construction error, the ECS eccentricity of 20 mm was considered in group D, compared with no eccentricity of specimen in group A. As shown in Fig. 4, y0-y0 and y1-y1 are the neutral axes of the concrete beam and ECS, respectively. The eccentricity mentioned above is the distance between y0-y0 and y1-y1.

The detailed information of the specimens are tabulated in Table 1.

2.2. Materials

Mild steel Q235 was selected for the channel-shaped steel C25a/C25b, when HRB400 and HPB300 were chosen for longitudinal reinforcements and stirrups respectively. To obtain the mechanical properties, seven tensile specimens were tested according to the