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Experimental study of earthquake-resilient PBCSC with double flange cover plates

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ABSTRACT

Prefabricated steel structure systems have become new trends in the development of steel structures. Meanwhile, earthquake-resilient steel structures have also become a hot issue in structural seismic performance research. Based on the idea of damage control, this study proposes a new type of earthquake-resilient prefabricated beam-column steel connection (PBCSC), which is formed by a circular tube steel column with a cantilever beam, an independent beam segment, and a connection component. The thickness of the flange cover plates, distance between bolts, and some other parameters could be adjusted suitably to obtain a proper connection stiffness so that sliding of the bolts and plastic deformation of the flange cover plates could dissipate energy and prevent the beam and column from plastic collapse. Quasi-static tests, tests of repaired connections, and fatigue tests were performed on six specimens. The influences of several factors, such as thickness of the cantilever beam flange, weakened form of the flange cover plate, retrofit by adding brass friction plates, and repair after earthquake, were investigated to assess the seismic behaviour of the connection. The experimental results showed that the new type of PBCSC could dissipate energy through the plastic deformation and slip friction of the flange cover plate. The plastic damage of the PBCSC was mainly concentrated in the replaceable plates, which was beneficial to the earthquake resilience of the connection. The bearing capacity and the energy dissipation capacity of the connections remained stable after repair. The stable performance of the connection under low-cycle fatigue load showed that it could be used as a displacement-control damper.

1. Introduction

Prefabricated steel structures have a green life cycle and possess the following advantages: standardized design, factory production, assembly construction, integrated decoration, and easy information management. A lot of progress has been made in related fields [1–6], but on-site welding is still unavoidable. This may affect the efficiency of construction and reduce the connection quality by uncertainties in the on-site operation. Moreover, bearing capacity and earthquake resistance are mainly considered in current structural designs. The seismic energy is mostly dissipated by the deformation of the entire panel zone, which may cause unrecoverable plastic deformation in beams and columns and increase the difficulty of repairing earthquake-damaged structures. Therefore, it is necessary to develop a new type of prefabricated steel structure system that improves the construction quality by reducing on-site welding. In addition, the plastic deformation caused by the energy dissipation can be concentrated on the replaceable members by proper design to protect the beams and columns, so that earthquake resilience can be realized by replacing the energy dissipation members with those that are assembled by bolts. Thus, the earthquake resistance and earthquake resilience of the structure can be significantly improved.

A lot of research has been undertaken in the field of steel beam-column connection. Zhang et al. [7] designed three types of Z-type cantilever beam splices of a column-tree connection and proposed a simplified computation formula and seismic design requirements for beam splices based on tests and finite element analysis. Astaneh-Asl [8] proposed that high-strength bolted splice connections should be designed as semi-rigid connections so that energy dissipation could be concentrated on the slip between the friction surfaces and the compression between bolt shanks and holes. Chen et al. [9, 10] studied the cyclic behaviour of beam-column connections with a widened flange of the stub beam used in steel frames by analytical and experimental methods. Zhang et al. [11] presented a finite element analysis of a type of beam-column connection with both strengthening and weakening parts. Oh et al. [12] proposed that using reduced and tapered beam sections in beam-column joints connecting in weak axis with H-shaped beams could develop ductile behaviour without brittle fracture until 5% storey drift ratio. Chang et al. [13] performed a non-linear analysis of equal-strength and weak-strength beam-column connections with cantilever

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beams by finite element method. Zhou et al. [14] suggested that the bearing capacity of beam-column connections should be reduced properly to prevent the connections from brittle fracture at the welds. Liu et al. [15] proposed a type of all-bolted connection and established a mechanical model and simplified calculation method of the connection. Wilkinson et al. [16] proposed a connection, which was capable of plastic rotations greater than 0.05 rad without any significant loss of energy dissipation capability, by setting a wedge beam to locate the plastic hinge away from the column to dissipate the energy. Plumier [17] proposed the idea of setting a dog-bone to prevent the connection from brittle failure. Popov et al. [18] provided explanations on failure modes of welded beam-column connections before and after the Northridge earthquake and suggested two design methods using a dog-bone and reinforcing plates. Chen et al. [19] presented a method of setting a dog-bone to enhance the ductility of beam-column connections and proposed a shaking table test of a steel frame designed by the method. Yu et al. [20] conducted an analysis of five connections with reduced beam sections and one ordinary connection under a cyclic loading by analytical and experimental methods, suggesting that the connections with reduced beam section have better ability of energy dissipation than ordinary connections. Chen et al. [21] also investigated the performance of dog-bone connections under a cyclic loading.

Currently, more attention has been paid on damage control and post-earthquake resilience of structures. Farrokhi et al. [22] proposed a steel connection with drilled holes in the cover plates to alter the failure mechanism from weld fracture at the connection surface to plate yielding around the holes. Oh et al. [23] suggested that a metallic damper could be added at the bottom flange of a beam-column connection to attract energy dissipation and plastic deformation on the dampers and protect the beams and columns. Calado et al. [24] proposed a beam-column connection with a repairable fuse device, which was formed by a set of steel plates and bolts. The development of plasticity was concentrated on the device. They also presented two design models of the connection. Farsi et al. [25] investigated a replaceable steel coupling beam with end-plate connection and performed full-scale tests on two specimens. Lu et al. [26] proposed three types of fuse devices used on coupling beams that could dissipate seismic energy and investigated the seismic behaviour of these devices through cyclic loading tests. Ji et al. [27] proposed a type of replaceable steel coupling beam with a fuse device, in which the inelastic deformation and damage could be concentrated on the device and the fuse device could be replaced within the shortest time to recover the seismic damage on the specimen.

Based on the idea of damage control, a new type of earthquake-resilient prefabricated beam-column steel connection (PBCSC) with double flange cover plates was proposed. Six full-scale connections were experimented to obtain the results of cyclic loading tests and fatigue tests. The influences of brass friction plates, the thickness of the cantilever beam flange and the weakened form of the flange cover plate on the failure mode, the hysteretic behaviour, and the skeleton curve were investigated. The research results could help create a better understanding of the working mechanism, seismic behaviour, and earthquake resilience performance of this connection, which could lay the foundation for its design theory.

2. Structure of the connection

Fig. 1 shows that the PBCSC proposed in this study. It is mainly formed by a column segment, an independent beam segment, and a connection device. The column segment consists of a cantilever beam, annular stiffening plates, and circular tube steel column. All components are welded together in the factory. The independent beam segment is an H-shaped steel beam. The connection device consists of many flange cover plates and bolts, which can be assembled on site to join all parts together. A gap is set between the two beams to enhance the rotation

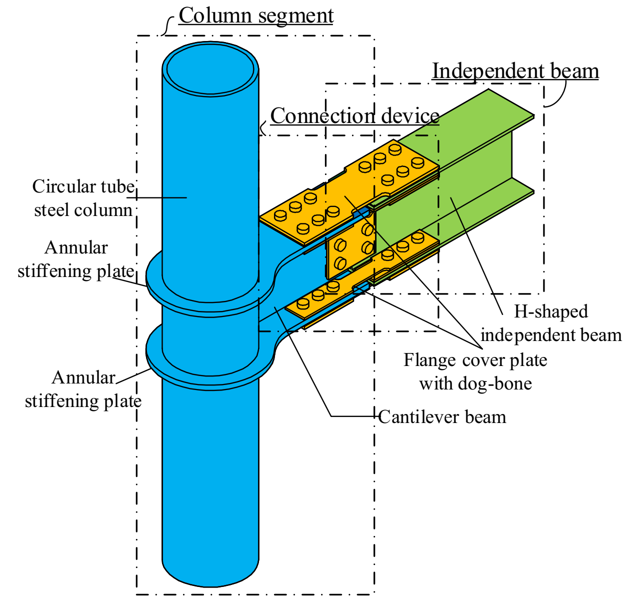

Fig. 1. Structure of the connection.

capacity of the connection, and avoid the contact of the two beams when the connection rotates.

By thickening the annular stiffening plates while weakening the connection device, the location of the plastic hinge can be transferred from the cantilever beam end to the flange cover plates. Energy dissipation can be achieved by slipping and plastic deformation of the flange cover plates and bolts. Significant plastic deformation will not occur in the beam and column segments, so that the bearing capacity and the seismic performance can be recovered by replacing the cover plates and bolts, satisfying the earthquake resilience requirements.

3. Test program

3.1. Design of specimens

In this study, six specimens of earthquake-resilient PBCSCs with double flange cover plates were tested. Q345B steel was used to manufacture the primary components such as beams and columns, while Q235B steel was used to manufacture the cover plates. The column of the specimen is a 299 × 16 mm steel pipe. The independent beam is a 300 × 200 × 6 × 12 mm H-shaped steel beam. In order to meet the requirement of earthquake resilience, the section of the cantilever beam was strengthened, and the cantilever beam is a 300 × 200 × 12 × 20 mm H-shaped steel beam. The length of the circle steel column is 3000 mm, the length of the cantilever beam is 500 mm, and the length of the middle beam is 1250 mm. In order to enhance the rotation capacity of the connection, the gap between the cantilever beam and the independent beam is set as 20 mm. The details of the specimens are shown in Fig. 2. Table 1 provides the characteristics of each specimen used in the tests. The influences of the cantilever beam flange thickness, weakened form of the flange cover plate, and brass friction plates as well as the performance of the repaired connection were investigated. The specimens were divided into three groups for different test purposes with the names of A, B, and C. In each group, the letter R means that the specimen is a repaired connection, which is formed by replacing the cover plates and bolts of the original specimen. The repaired specimens B-SJ2-R and B-SJ2-R30 in Group B had the same geometrical dimensions and material properties with specimen B-SJ2. Fatigue test was carried out on specimen B-SJ2-R30. Brass friction plates were installed between the cover plates and the beams of two specimens in Group C to investigate the influences. Specimen C-SJ3-R was the repaired