Journal of Constructional Steel Research 151 (2018) 122–131

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental study on bolted CFST-column joints with different configurations in accommodating column-loss

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ARTICLE INFO

Article history:
Received 8 July 2018
Received in revised form 9 September 2018
Accepted 21 September 2018
Available online xxxx

Keywords:
CFST
Progressive collapse
Catenary action
Long bolts
Beam-column joints

ABSTRACT

Three different types of joints with long bolts were designed and tested in the scenario of column loss. The performance of different joints including flush endplate, extended endplate and stiffened angle under column removal was studied in detail. The investigation was focused on failure modes, formation and developing of catenary action and deformation capacity. The equivalent dynamic response of different joints would also be assessed. The results show that the match of plate thickness and bolt diameter plays an important role in the performance of joint. Relatively thinner plate would help the formation of catenary action. The configuration of flush endplate is more beneficial for the formation of catenary action than extended endplate. By using different connection configuration, the performance of flexural action in joint would affect the contribution of catenary action. The acceptance criteria in DoD and GSA are suitable to assess the rotation related to the first load drop of joints whilst those in FEMA350 is suitable for assess the rotation related to maximum load which represents the anti-collapse behavior of joint. The dynamic amplification coefficient (DAC) suggested by DoD is appropriate if the joint carry vertical load mainly by flexural action. With the influence of catenary action, the DAC would be larger than the values suggested by DoD.

1. Introduction

In the design of resisting progressive collapse, beam-column joint plays a critical role in load-redistribution after structural column loss [1,2]. With a reliable horizontal boundary condition, the load-carrying mechanism of the joint above the damaged column would transfer from flexural action to catenary action, as shown in Fig. 1. The tensional load triggered by catenary action would affect the behavior of the joint, especially in the transition of load-carrying mechanism [3]. In normal design of joint, only moment and shear force are taken into account. Eurocode 3 suggests that the axial force in joint should not exceed 5% of the design resistance of beam cross-section [4–7]. Moreover, the rotation capacity of the joints should be fulfilled to mobilize catenary action [1,2]. These demands are rarely met in normal design of joint, but crucial in the design of resisting progressive collapse.

In order to improve the rotation performance of concrete filled steel tubular (CFST)-column joints and simplify the construction procedure, the configuration of bolted connections with endplate or angles is adopted in the structures with CFST-columns. In practice, blind bolts are usually used to connection beam to CFST-column as shwon in Fig. 2 (a)which could mitigate the inconvenince of placing bolts into the closed section column. Some studies have been conducted on the behavior of the joints with blind bolts [8,9].

However, by using blind bolts, steel beam would be connected to the column wall directly. When the bolts under tension, the connected wall of column would be under bending as shwon in Fig. 2(b)whilst the contribution of core concrete in tubular column is very limited. In that case, the resistance and stiffness of the joint are supposed to be relatively low. On contrary, if long bolts are adopted as shwon in Fig. 3, tensional force in bolts would not only be carried by the connected wall of column directly, but also core concrete [10].

Many researches have been conducted on the performance of CFST-column joints under monotonic loads and hysteretic loads. Li and Han [11] conducted a numerical parametric analysis to reveal the failure modes of CFST column joints with concrete slab. A formula to calculate the rotation stiffness of RHS-column connection was proposed by Park and Wang [12]. A bending test of CFST-column joints with extended endplate and blind bolts was carried out by Wang and Chen [13]. The test results indicated that the rotation capacity of the designed joints met the requirements of aseismic design. Thai and Uy [14] developed an analytical model to determine the flexural capacity of CFST-column joints with endplates. Based on component method suggested by Eurocode 3, a calculation process for the load capacity of CFST-column joints was proposed by Huang et al. [15].

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https://doi.org/10.1016/j.jcsr.2018.09.021
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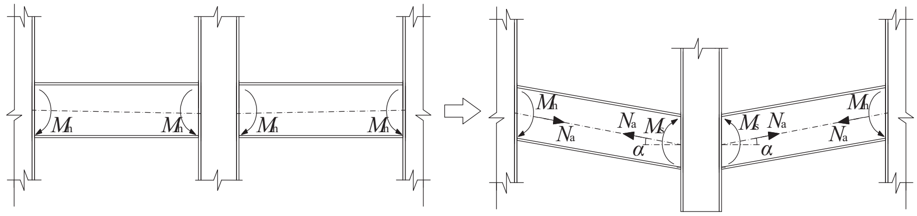


Fig. 1. Load-carrying action transition.

As regarding to the behavior of joints in steel structures in the scenario of column loss, both bare steel joints and CFST-column joints are studied. Khandelwal and EI-Taweil [16] identified some key factors that affected the formation and development of catenary action in steel frame structures. Based on the static response curve of joints or structures under column removal, a simplified evaluation process was developed by Izzuddin et al. [17] to assess the corresponding dynamic response. The influence of catenary action on the load capacity of endplate joint with slab was studied experimentally by Demonceau an Jaspart [18]. Sadek et al. [19] conducted a test to provide insight into the failure modes of steel joints under column removal. A series tests were conducted by Yang and Tan [20] to figure out the influence of connection configuration on anti-collapse performance of steel bolted joints. Li et al. [21] conducted a test on tubular column joints with outer-rings to reveal the failure modes of joints in the scenario of column removal. A calculation formula was developed by Stylianidis and Nethercot [22] to predict the performance of joints in progressive collapse analysis of structures. Six flush endplate steel joints with RC slab were tested by Gao et al. [23] to reveal the performance of the joints under bending moment and tensional force.

Up to date, most of studies focus on the performance of CFST-column joints with ring plates or blind bolts in the scenario of column loss, rather than with long bolts. In this paper, three different types of joints with long bolts are designed and tested in the scenario of column loss, including stiffened angle, flush endplate, and extended endplate. The aim of this study is to understand the behaviour and assess the performance of different joints under column removal, including failure modes, formation and developing of catenary action and deformation capacity. The equivalent dynamic response of different joints would also be assessed.

2. Experimental program

2.1. Design and fabrication of specimen

In order to emulate the scenario of single column removal, the joint directly above the removed column is extracted from the frame. The peripheral structural members of the joint are assumed as boundary conditions which are hinge supports, since the inflection point locating at the middle span of beams under vertical load after the middle column removal.

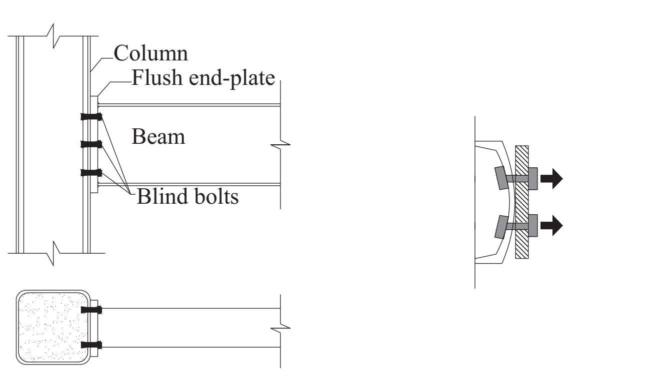
Three 2/3 scaled specimens were designed, including a flush endplate joint, an extended endplate joint and a new stiffened angle joint, as shown in Fig. 4 and Fig. 5. In specimen AJ with stiffened angle, the steel beam web was bolted with the fin plate welded on the column wall. High strength long bolts of Grade 10.9 M20 were used in three specimens. The profiles of steel tubular column and beam were 300 × 300 × 12 mm and 244 × 175 × 7 × 11 mm respectively (overall depth(d) × flange width(b_f) × web thickness(t_w) × flange thickness (t_f). The detailed dimensions of three specimens are listed in Table 1.

2.2. Material properties

The mechanical properties of steel used in the specimens are summarized in Table 2, where f_y, f_u, E_s stand for yield strength, tensile strength and Young's modulus of steel respectively. Standard concrete cubes and prisms for testing concrete strength and Young's modulus were casted in the same experimental condition with the specimens. The average compressive strength and Young's modulus of concrete were 40.6 MPa and 3.2×10^4 MPa respectively.

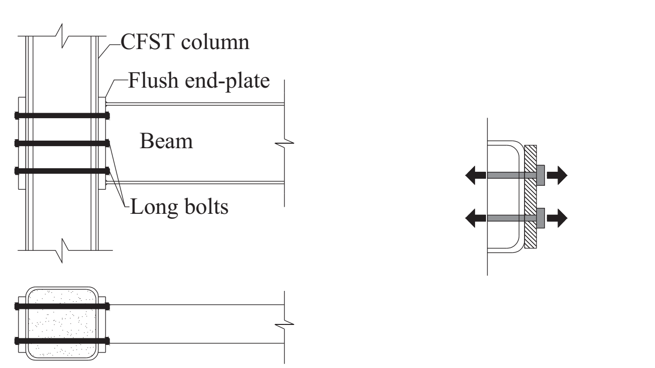
2.3. Experimental setup

Fig. 6 shows the experimental setup system. Reaction wall and reaction frame were employed to restrain the specimens horizontally in the tests. Pin connectors were used to connection specimen and the reaction devices. An extra out-plane restraint device was installed besides the column of the specimen to restrain the out-plane displacement and rotation of the specimens as shown in Fig. 6 (c). The axial force in beams was recorded by horizontal load sensors located inside the reaction frame. In order to accommodate the shear force on the pull-rods connection horizontal load sensors and reaction frame, a vertical sliding support was placed under the pin connector as shown in Fig. 6 (d). Vertical load was applied at the top of the column by a hydraulic actuator in



(a) Joint configuration (b) Deformation of column wall

Fig. 2. CFST column endplate joints with blind bolts.



(a) Joint configuration (b) Deformation of column wall

Fig. 3. CFST column endplate joints with long bolts.