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Seismic performance assessment of blind bolted steel-concrete composite joints based on pseudo-dynamic testing

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ABSTRACT

This paper aims to investigate seismic behavior and dynamic responses of semi-rigid composite joints composed of steel-concrete composite beams and concrete-filled thin-walled steel tubular (CFTST) columns. A range of pseudo-dynamic tests (PDTs) was performed on two full-scale blind bolted end-plate joint specimens, including one flush and one extended end-plate typed joint. The input ground motion adopted for the PDTs was Ispara seismic acceleration record and scaled to represent various seismic hazard levels. Using Ispara earthquake record with different peak ground accelerations (PGAs), a lot of useful data about hysteresis behavior, stiffness degradation and energy dissipation capacity was obtained. The data was also estimated in detail to characterize the seismic performance of this kind of composite joints. Dynamic responses of beam-to-column joint including displacement and acceleration responses, and dynamic magnification factor were discussed. The experimental results indicated that the structural responses of the test joints under seismic actions coincided with the desired performances analyzed for varying damage levels. The study affirms that the blind bolted end-plate composite joints to CFTST columns possess good energy dissipation seismic performance, so they can provide sufficient ductility and adequate strength to satisfy the seismic design requirement.

1. Introduction

Concrete-filled steel tubular (CFST) structures have been extensively applied in modern buildings owing to their fine structural performance as high strength, appropriate stiffness and ductility, improved fire resistance and large energy dissipation capacity. Furthermore, the application of CFST columns can save construction time by avoiding tying steel reinforcement cages and eliminating complicated formwork. In the entire CFST columns family, CFTST column is a typical member, which consists of thin-walled steel tubes and concrete. The column makes use of not merely the excellent behavior of thin-walled steel structures, but also the favorable compressive capacity of concrete structures [1–4]. The thin-walled steel tube offers lateral confinement for improving the stiffness and strength of the concrete; meanwhile, the concrete greatly decreases the possibility of local buckling of the thin-walled tube. Once the local buckling is successfully avoided in a column design, thin-walled tubes will become extremely attractive to utilize with the development of high-strength steel [5]. Consequently, aforementioned advantages would result in CFTST columns becoming a cost-effective selection in low- and multi-story building.

In these composite framed building structures, there are many kinds of connection alternatives to CFST columns, including internal and external diaphragm plates, additional fittings, or passing the beam continuously through the column [6–9]. Many researchers have paid attention to investigating the connection details between CFST column and steel beam, and exploring their monotonic or cyclic behavior. Nonetheless, the main issue is that the existing construction methods of connections have not always been possible since site welding is hard to guarantee quality. In order to leave out these complex technical processes, the blind bolted end-plate connections have been favorably employed to connect steel or composite beams to a CFST column. Due to the fast and easy installation as well as sufficient strength, favorable stiffness and ductility, blind bolted end-plate joints have a broad developing prospect in structural connections to CFST columns.

In recent years, considerable effort has been directed towards to investigating the blind bolted joints. A series of research programs have been carried out to analyze the monotonic or cyclic behavior of semi-rigid connections to HSS or CFST columns, such as Elghazouli et al. [10], Lee et al. [11,12], Tizani et al. [13] and Wang et al. [14]. In particular, an innovative blind bolted joint to CFTST

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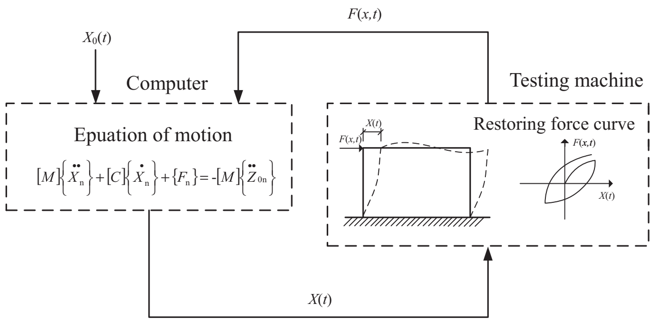

Fig. 1. Architecture of PDT.

column has been firstly proposed by Wang et al. [15,16], so as to provide an alternative approach instead of welded connections. The experimental outcomes [16] confirmed that the steel beam with end-plate tied to the thin-walled steel tube by blind bolts with extensions into the concrete core was a feasible and effective method to enhance the strength and stiffness of the joint.

Steel-concrete composite beams have been applied widely in practice for the composite action between concrete slab and steel beam. Experimental results [17] have confirmed that the reinforced concrete (RC) slab can dramatically enhance both strength and stiffness of the joint, and also protect the steel beam from lateral torsion buckling. During the last few years, some research studies have been performed to gain a deeper understanding of composite joints [17–19]. On the one hand, the existing research was mainly concentrated on the behavior of welded or bolted composite joints; however, it appeared that limited investigators had focused on the blind bolted composite joints. Loh et al. [20] carried out five groups of tests on semi-rigid flush end-plate composite joints subjected to monotonic loading. Gracia et al. [21] tested several semi-rigid composite joints with extended end-plates subjected to monotonic and cyclic loading. Mirza and Uy [22] studied experimental and numerical analysis on the hysteretic behavior of semi-rigid composite joints with flush end-plates. Ataei et al. [23,24] carried out several static tests to characterize structural performance of flush end-plate beam-to-column composite joints.

On the other hand, little work has been conducted on composite joints subjected to PDTs [25–27]. The main benefit of PDTs compared to pseudo-static tests (PSTs) is to truly represent the whole process of structural responses under seismic action. The architecture of PDT is presented in Fig. 1. As a result, to characterize the seismic behavior of the semi-rigid composite joints, two full-scale blind bolted end-plate joints to CFTST columns are tested and discussed in this paper. The test composite joints are composed of composite steel-concrete beams and square CFTST columns. The steel beams with end-plates are connected to the CFTST columns by blind bolts, while the RC slabs are attached to steel beams using shear connectors. The tested joints were tested under pseudo-dynamic loading using different PGAs which were recorded during Ispara earthquake. Then seismic behavior and time-history responses were analyzed respectively based on the data provided from the tests.

2. Experimental program

2.1. Specimen description

To investigate seismic behavior of blind bolted end-plate composite joints to CFTST columns, a series of experiments were carried out, including PSTs and PDTs. The objective of the present paper is to introduce the behavior of specimens which were subjected to pseudo-dynamic loading. The general sketch of the test specimens is shown in Fig. 2. Fig. 3 and Table 1 provide the design details of test joint specimens which consist of steel-concrete composite beams and CFTST columns with the length to inflection point. The test flush end-plate composite joint and the test extended end-plate composite joint record as Specimen TFD2 and Specimen TED2 respectively. The CFTST columns, steel beams and RC slabs for both specimens were all the same, except for the various end-plate types adopted in each specimen (see Fig. 3a and b). Both flush and extend end-plates were 12 mm in thickness. Fig. 3c and d shows the detailed dimensions of the two typed end-plate respectively. The end-plate was welded to the beam end by fillet welds with the size of 8 mm. The thin-walled steel tubes of the CFTST columns (see Fig. 3e) were made of four thin steel sheets with nominal wall thickness 3.0 mm cold-formed into lipped angles (shown in Fig. 4) and then vertically seamed by a full penetration weld, forming a hollow square section of 200 × 200 mm. The rolled lips measured all 50 mm high and they actually played a role of longitudinal stiffeners for the CFTST column. Wang and Guo [15] conducted several static tests to explore the performance of blind bolted end-plate connections to CFTST columns. It was concluded that longitudinal stiffeners had a beneficial effect on the CFTST columns and filling thin-walled tubes with concrete could also restrict torsional buckling modes in this inner stiffened columns [5].

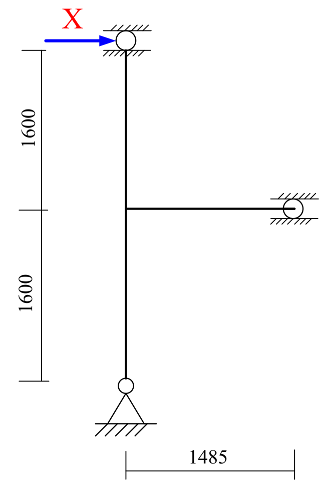

Fig. 2. General sketch of test specimens. Note: The aforementioned values respectively equal to the distances from the central point of the CFTST column to the central point of the corresponding pin.

The steel-concrete composite beam was made up of H-shaped steel beam with a cross section of HN300 × 150 × 6 × 10 mm and a cast-in-situ RC slab which had a width of 1200 mm and a thickness of 120 mm, as shown in Fig. 3f. A single row of round headed studs was welded to the upper flange of the steel beam to develop a full shear interaction. The number and layout of the studs were designed according to the full shear connection criteria recommended in GB50017 [28]. Every two shear studs with an interval distance of 40 mm were welded on the top flange of the steel beam, spacing at 200 mm. The distance of the first stud to the column face was 200 mm. The RC slab was reinforced with double layer reinforcement mats. A longitudinal reinforcement of 10 mm-diameter deformed bars was spaced at 120 mm in upper layer. Construction details of composite beam were presented in Fig. 3.

The flush or extended end-plate was fastened to the square hollow steel tube by blind bolts with extensions, as shown in Fig. 4. The extensions of the bolts were 20 mm in diameter and 50 mm