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Experimental and analytical investigation of semi-rigid CFST frames with external SCWPs

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ABSTRACT

An experimental and numerical research on the seismic performance of semi-rigid concrete-filled steel tubular (CFST) frames with external sandwich composite wall panels (SCWPs) was reported. Four specimens of semi-rigid CFST frames with external SCWPs and one specimen of pure semi-rigid CFST frame subjected to low-cyclic loading were conducted. Failure modes, horizontal load versus displacement relation curves were analyzed. The test specimens exhibited good hysteretic behavior, energy dissipation and ductility. Finite element (FE) analysis modeling was developed and the results obtained from the FE model matched well with the experimental results. Extensive parametric studies have been carried out to investigate the effect of steel strength, column slenderness ratio and steel wire diameter of wall, etc. on the strength and stiffness of the typed composite frames. The opening ratio and location of the SCWPs were also discussed. The experimental study and numerical analysis will provide the scientific basis for design theory and application of the SCWPs in fabricated steel structure building.

1. Introduction

Widespread and unanticipated brittle fractures occurred in welded steel beam-column connections in the 1994 Northridge and the 1995 Kobe earthquakes. To avoid extensive welding and the required high tolerance, the static and seismic behavior of blind bolted joints to CFST columns has been studied by experiments and FE analysis, such as Mirza and Uy [1], Lee et al. [2], Wang et al. [3–6], Ataei et al. [7], and Wang et al. [8]. However, little studies focused on the semi-rigid concrete-filled steel tubular (CFST) frames with external sandwich composite wall panels (SCWPs).

The development and construction of lightweight pre-fabricated sandwich panels in building construction are a growing trend in China due to its high strength, reduced weight, good thermal insulation, money-saving and better fire resistance, etc. The SCWPs studied in this paper consisted of two outside layers separated by an insulation layer. The outside layers were constructed of precast concrete and the core layer was polystyrene foam. Diagonal steel wire with alternating direction was welded to steel wire mesh which embedded into each concrete layer to form space truss connectors. The SCWPs could be prefabricated in factory and assembled in spot and speed construction schedule up to maximum extent. However, previous earthquake damage surveys indicated that the wall destruction and collapse caused large casualties and property losses and scare studies have been done to investigate failure mechanism of composite frame with SCWPs. Thus, the cooperative work and failure modes of semi-rigid CFST frames with external SCWPs under the earthquake action are a research topic with a high priority.

Up to now, a great deal of study on the seismic behavior and interaction between the panels or blocks and H-shaped steel frame have been conducted. Flanagan et al. [9] tested nine steel frames with hollow clay tile under in-plane loading; the experimental results showed that all infills failed by corner crushing. Markulak [10] reported the hysteretic behavior of steel frames infilled with three different masonry infill types: perforated clay blocks, lightweight AAC blocks and newly proposed combination of these materials. Tasnimi et al. [11] conducted six brick-infilled steel frames with openings. Moghaddam [12] carried out eleven experimental tests on masonry and concrete infilled steel frames. Fang et al. [13] completed a shaking table test of a full-scale steel frame with ALC external panels. Tong et al. [14] and Sun et al. [15] investigated seismic behavior of the semi-rigid steel frame with RC infill walls. Matteis and Landolfo [16] investigated the behavior of sandwich panels inserted into a pin-jointed frame systems. Hou et al. [17] described a cyclic loading test results of H-shaped steel frames with sandwich composite panels.

Apart from experimental research, many accurate theoretical models and FE analysis on the behavior of steel frames with various infill walls have been proposed. Saneinejad and Hobbs [18] proposed a method to predict the strength and stiffness of concrete or masonry infilled steel frames. Dawe et al. [19] set up a series of complex

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calculation model for steel frames with masonry infilling walls. Doudoumis [20] simulated single-bay, single-story infilled frames through a precise FE micromodel to investigate the elastic behavior of infilled frames. Moghaddam [12] proposed an approximate method based on FE analysis to evaluate cracking strength and shear resistance of steel frames with masonry or concrete infills. Chen and Liu [21] developed a FE model to study the effect of opening size and opening location on the seismic behavior of masonry infilled steel frames. Matteis [22] reported a profitable methodology to predict seismic response of lightweight sandwich shear walls infilled pin-jointed steel frames and accounted for the contributing effect to the structural behavior by using ABAQUS.

These above-mentioned experimental studies and numerical analysis mainly focused on the behavior of rigid, semi-rigid or hinged H-shaped steel frame with infilled various type of masonry, brick, RC walls and ALC panels, etc. In addition, few scholars studied the complicated interaction of composite structure with ALC walls. Wang et al. [23] investigated the rigid circular CFST frames with ALC panels under in-plane cyclically increasing lateral loads by five specimens, the failure modes, hysteretic curves, energy dissipation and ductility were analyzed. However, little literature on the experiment and numerical analysis of semi-rigid CFST frames with SCWPs has been reported.

This paper is to investigate the seismic performance of semi-rigid CFST frames with external SCWPs. Four specimens of semi-rigid CFST frames with external SCWPs and one specimen of pure semi-rigid CFST frame were tested under cyclic loading. Moreover, the FE program ABAQUS was applied in the analysis. Comparisons between the FE analytical results and the experimental results indicated that the FE model could well predict the horizontal load versus corresponding displacement relations of the semi-rigid CFST frames with SCWPs. In addition, twelve parameters were also completed to investigate the effect of variation of parameters on the structure performance, such as steel strength, column slenderness ratio, steel wire diameter on walls and column axial load level. The opening ratio and location of the SCWPs were also discussed.

2. Experimental program

2.1. Test specimens

In order to explore the effect of the wall concrete type, the wall connection type, the brace setting and the wall setting on the seismic behavior and failure modes of the typed composite structure, four specimens of semi-rigid CFST frames with external SCWPs and one specimen of semi-rigid CFST frame were tested and analyzed in this paper. Details of the specimen are illustrated in Fig. 1. The columns for all specimens are concrete-filled square steel tubes with a cross section of 150 × 150 × 6 mm and its length is 1785 mm. The self-compacting concrete was filled in the square steel columns. The beams were designed as hot-rolled H-shaped steel section with a cross-section of 150 × 75 × 5 × 7 mm and the length of the beams is 1350 mm. The steel beams and columns were fabricated through extended end plate connections with blind bolts which were two rows of M16 Grade 10.9 high strength bolts. The ratio of the yielding strength to the ultimate strength of the bolt is 0.9. All bolts for the beam-to-column connections were finally tightened to a torque of 228 Nm according to specification GB50017 [24].

The extended end plate was fastened to square steel tubes by blind bolts with hooked extensions into the concrete core for the purpose of reducing the deformations of the tube wall and the end plate, as seen in Fig. 2. The hook-typed extension to the bolt is high strength reinforcing rebar with 16 mm in diameter, 70 mm in horizontal length and 35 mm in hooked length and the yield strength of the extensions is of grade 335 N/mm^2. The high strength bolt welded with a hooked reinforcing rebar to form a complete unit. Gardner and Goldsworthy [25, 26] concluded that the hooked anchorage welded to the blind bolts

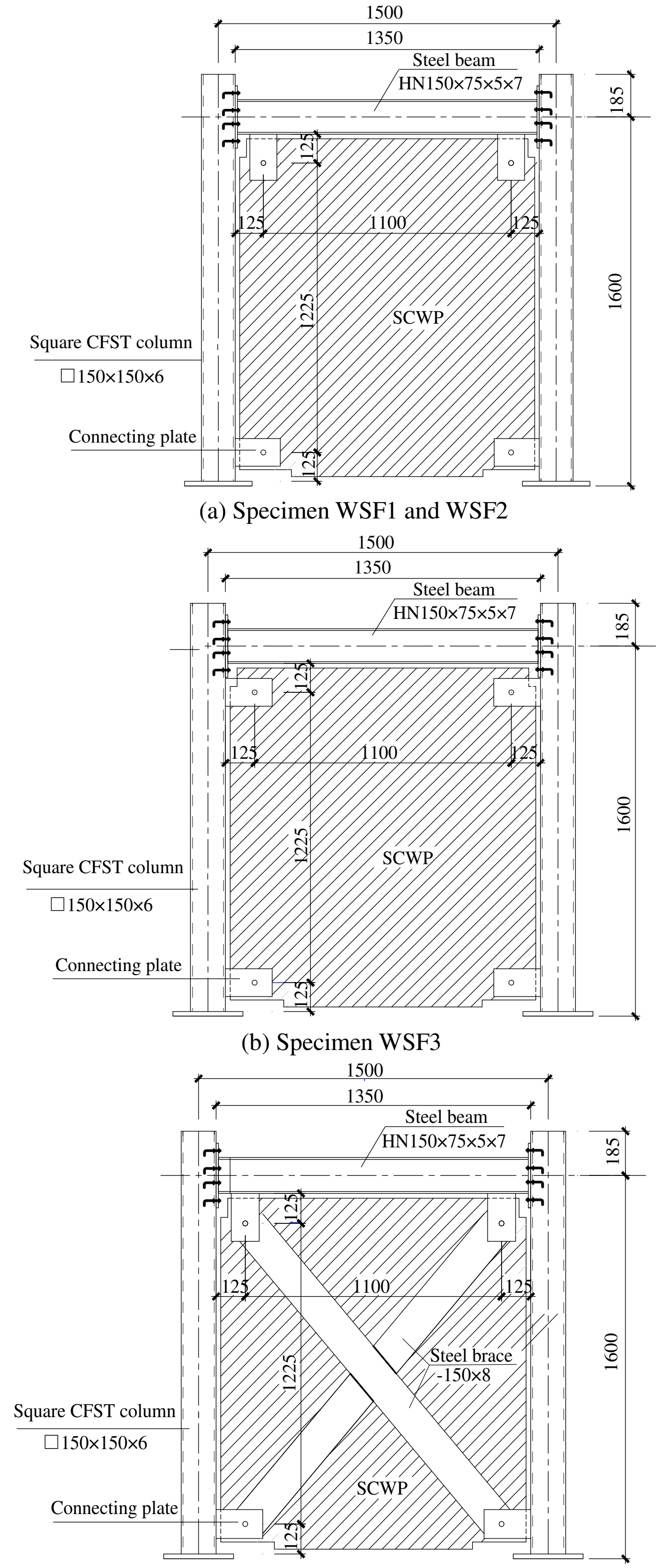

Fig. 1. Dimension of specimens (unit: mm).

into CFST column could obviously improve the strength and the initial stiffness of the joints.

The sandwich composite wall panel is a three-layer element comprising of two outside layers and one core insulation layer. The outside layers were constructed of precast concrete and the core layer was