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Experimental and analytical research on the hysteretic behavior of steel plate deep beams infill steel frame

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ABSTRACT

The aim of this paper is to experimentally and analytically evaluate the hysteretic behavior of steel plate deep beams infill steel frame. Three reduced-scale specimens subjected to cyclic loading have been tested and their responses measured and analyzed. The test results showed the good behavior of the steel plate deep beams infill steel frame, mainly improving the strength, stiffness, ductility and energy dissipation capacity of the steel frame. Then parametric studies, using a finite-element analysis program, were carried out to investigate the structural behavior with variations in: forms of stiffeners, height-width ratio α, height-thickness ratio β, and the size of the column and beam. The numerical results indicate that the parameters of full stiffeners, including cruciform and bilateral stiffeners, $\alpha = 0.75$, $\beta = 150$ are reasonable for use in steel plate deep beams infill steel frame.

1. Introduction

Controlling the lateral displacement under horizontal load is a central issue in high-rise building and in earthquake prone regions. For the sake of controlling the large lateral displacement, extensive experimental and analytical studies have been conducted on internal filling element in the steel frame, especially the shear wall infill steel frame [1–3]. However, the steel frame and the shear wall infill steel frame reflect two endpoint values of the structural stiffness and the change is abrupt, so it is not easy to achieve the controlling of the structural stiffness. In order to make up for the above deficiencies, the resistance system of deep beams infill steel frame was proposed, in which the lateral force resisting member-deep beams was separated from the frame column. However, relatively little testing has been carried out on the deep beams infill steel frame.

Kahn and Hanson [4] proposed the concept of deep beams infill frame structure for the first time and investigated the seismic behavior of reinforced concrete deep beam infill reinforced concrete frame. Then Kabele and Horri [5–6] further studied the seismic performance of fiber concrete deep beam infill reinforced concrete frame experimentally and theoretically for structural repair and retrofit. At the same period, Kanda [7] proposed the bolted connection to connect the precast fiber concrete deep beam and reinforced concrete frame beams. Afterwards, Kesner [8] applied the fiber concrete deep beam to the steel frame for seismic strengthening, and the parameters of single fiber concrete deep beam were studied through test methods. More recently, Giuseppe [9] evaluated the influence of circular openings in reinforced concrete deep beams with low shear span-to-depth ratio experimentally and analytically. Jiang [10] introduced a composite deep beam and applied it to the steel frame. When it comes to steel plate infill steel frame, little research has been conducted, but a significant amount of research has been performed on the steel plate shear walls [11–13]. And in recent years, in order to improve the ductility and energy dissipation capacity of the structure and adjust the stiffness and strength, research has been flourishing on the steel plate shear walls with perforations or slits [14–21]. However, opening or slitting would be complicated for fabrication and lead to extra cost.

Based on the concept of deep beams and steel plate shear walls with slits, this paper proposed steel plate deep beams infill steel frame (SDBF). In this system, the upper and lower ends of the steel plate deep beam (SDB) are connected to steel frame beams by high strength bolts through two-sided angles, and the right and left ends do not contact with steel frame columns, as shown in Fig. 1(a, b and c). Stiffeners bolted to the steel plate mainly aim to prevent the lateral buckling of SDB through reducing its slenderness, but also increase the strength and stiffness of the SDB. This developed infill steel frame can be constructed by the following procedure:

(1) Design the section of steel column and beam according to the requirements of projects, and then decide the size of SDB based on the common design philosophy that the yielding of energy dissipation devices has to occur earlier than the main structural components to trigger the energy dissipation mechanism and thus protect the main structural members [22].

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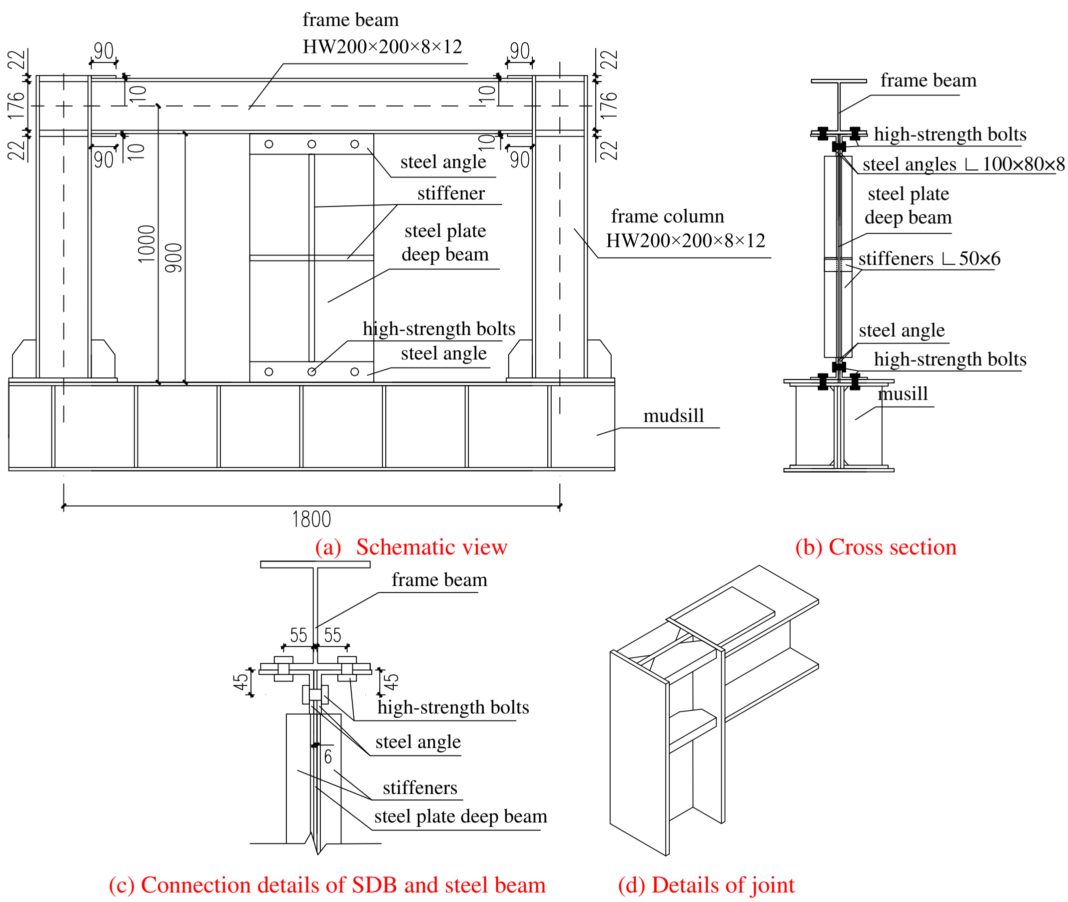

Fig. 1. Geometrical characteristics of steel plate deep beam infill steel frame.

(2) Reserve holes in the steel beam, SDB, steel angles and stiffeners.
(3) Connect the stiffeners and SDB through high strength bolts, which can be performed in the factory.
(4) After the construction of the steel frame on site, use high strength bolts to connect the SDB and steel beams through two-sided angles.

The advantages of SDBF system could be summarized as follows: 1) all components of SDB can be prefabricated in the factory, and it is easy to connect SDB with steel beams on-site, thus reducing the time, in turn reducing the construction costs; 2) the lateral resistance and stiffness can be freely adjusted by changing the width and the thickness of SDB, and the position of SDB also can be easily regulated, thus facilitating the arrangement of passage and window, which may be used to retrofit or strength existing structures; 3) the SDB can yield firstly under reversal lateral loads to dissipate energy to protect the main structural members against severe damage. It is expected that CDB can be used as the first defense line of earthquake-resistance, and then the steel frame act as the second.

This study aims to experimentally and analytically evaluate the hysteretic performance of SDBF, and this paper is organized as follows. This Section provides some background information of deep beams infill frame, and indicates the purpose and significance of this research. Then, Section 2 introduces the experimental program of test specimens, test setup, and test procedure. Test results, discussion and evaluation of test results are then reported in Section 3. Successively, nonlinear finite element analyses are presented in Section 4. Finally, conclusions and future developments are drawn in Section 5.

2. Experimental program

2.1. Test plan

In order to investigate the seismic performance of SDBF, three 1:3 scaled steel frames were designed and tested, as shown in Fig. 1, including one pure steel frame (PF), considered as a benchmark, and two SDBFs with different height-width ratio of SDB. The basic information of the three specimens is summarized in Table 1. The specimens were fabricated using standard rolled H-shaped steel in China, and were made with Grade Q235 with specified minimum yield strength of 235 MPa. All specimens had the same size and geometry, and each specimen consisted of two HW 200 × 200 × 8 × 12 columns (1100 mm height) and a HW 200 × 200 × 8 × 12 beam (1600 mm span). Beam-to-column connections of all specimens utilized complete joint penetration (CJP) groove welds and were strengthened by cover plates, which were widely used in China [23–25], as illustrated in Fig. 1(d). SDB and frame beams were connected by M20 Grade 8.8 high-strength bolts with nominal tensile strength of 800 MPa and yield ratio of 0.8, which were fully tightened

Table 1
Details of specimens.

Specimen	Steel beam	Steel column	Steel plate deep beams(width × thickness × height)
PF	HW200 × 200 × 8 × 12	HW200 × 200 × 8 × 12	–
SDBF-A	HW200 × 200 × 8 × 12	HW200 × 200 × 8 × 12	450 × 6 × 900
SDBF-B	HW200 × 200 × 8 × 12	HW200 × 200 × 8 × 12	1200 × 6 × 900