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Experimental and numerical investigation of novel partially connected steel plate shear walls

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ABSTRACT

A steel plate shear wall system, consisting of a thin steel plate connected to the boundary frame members, is proposed as lateral load resisting system for use in the multi-storey building. To reduce the potential damage on the boundary elements caused by the tension field action in the steel plate after buckling, the steel plate is partially connected at the corner edges to the boundary frame members by bolts. Two scaled specimens were tested under cyclic loads to investigate the hysteretic behaviour of the partially connected steel plate shear wall (SPSW). Test results showed that the proposed SPSW exhibited good structural performance in terms of initial stiffness, shear resistance, ductility and energy absorption capability. An analytical method was developed to predict the shear resistance of the partially connected SPSW. The shear resistances obtained from the tests were compared with those predicted by the analytical method and a reasonable agreement was observed. In addition, a nonlinear finite element (FE) model was proposed to analyze the behaviour of the partially connected SPSW system. The accuracy of the FE models was verified by comparing the computed results with the cyclic load test results. Parametric analyses were then carried out to study the effects of plate slenderness ratio, plate aspect ratio (width/height), stiffness of the boundary frame members and initial plate imperfection on the lateral load resisting behaviour of the proposed steel plate shear wall system.

1. Introduction

Steel plate shear wall (SPSW) has been proposed as a robust and efficient lateral load resisting system in high seismic countries such as North America and Japan [1]. In the past years, experimental and numerical investigations have been widely performed on the SPSW systems [2–8]. It has been demonstrated that the SPSW has better performance on ductility, initial stiffness, shear resistance and energy absorption than the conventional reinforced concrete shear wall. Thorburn et al. [4] reported that the more rigid were the vertical boundary elements (VBEs), the more efficient was the tension field of steel plate in resisting the lateral force. Based on force equilibrium, the tension field developed in the steel plate will be resisted by the boundary frame elements which consist of horizontal boundary elements (HBEs) and vertical boundary element (VBEs). A full tension field action can only be formed if it can be anchored by the rigid boundary elements. ANSI/AISC 341-10 [9] recommends that the VBEs shall have a moment of inertia about the axis perpendicular to the plane of its web not less than $0.00307th^4/L$, where t, h, and L are the thickness, height, and width of the steel plate, respectively. This is to allow for a full-yield zone to be developed in the tension region of the steel plate. As a result of this, large member size is generally required for the VBEs to satisfy the stiffness requirement and this implies more cost for the SPSW system. Set against this background, many types of SPSWs with various structural configurations have been proposed to reduce the stiffness requirement on the VBEs [10–15].

In this paper, a novel partially connected SPSW system is proposed, as shown in Fig. 1, with an aim to reduce the tension force acting on the boundary elements. The partially connected SPSW system comprises of a thin steel plate which is bolted connected at the four-corner edges to the horizontal boundary elements (HBEs) and the vertical boundary elements (VBEs) using equal angle sections and gusset plates. The main novelty of this system is that only the quarter height and width of the steel plate at the four corners are bolted to the boundary elements (HBEs and VEBs) by the gusset plates and equal angle plates, whereas the corresponding mid portions of the plate are not connected to the boundary elements. The advantages of using the proposed partially connected SPSW to resist lateral loads are:

(1) Smaller tension field action shall be developed in the steel plate and less force will be acting on the VBEs after the steel plate buckled. The partially connected SPSWs have lower stiffness demands for the VBEs [16].

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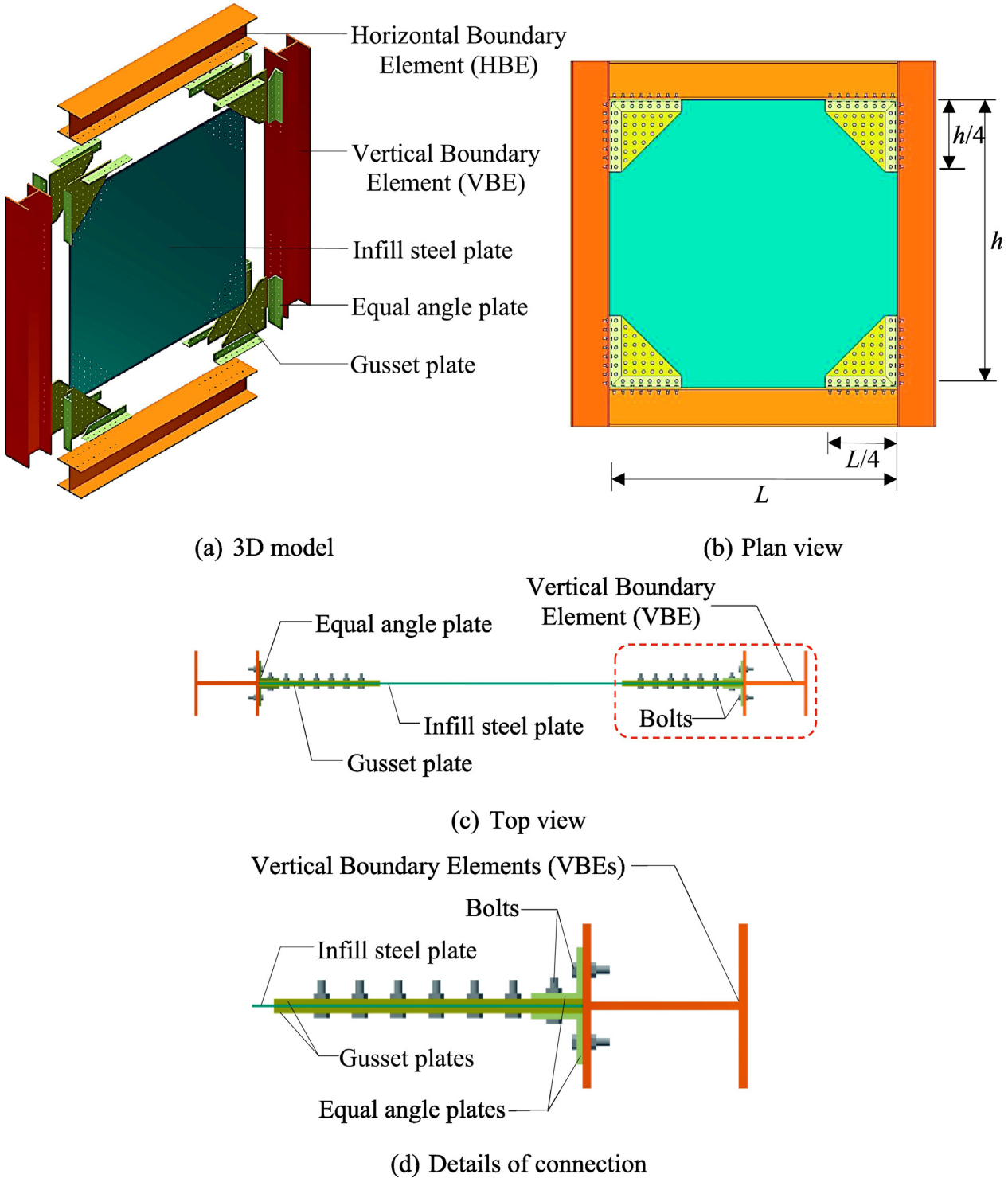

Fig. 1. Partially connected steel plate shear wall (SPSW).

(2) The tension field action in the steel plate would be directly transferred to the boundary elements via the beam-column joints as shown in Fig. 2. Thus, the proposed structural system greatly meets the requirement for seismic design for strong joint and weak member framing.

(3) The steel plate can be seen as a "fuse" in the system. The yield strength of the steel plate is designed to be lower than the frame members (HBEs and VBEs) so that the steel plate participates as an energy dissipation device due to the reversal loads, and thus preventing major damage in the structural framework.

(4) The steel plate is connected to the boundary elements by bolts. Hence, the assembled structural system is convenient to construct, transport and maintain with relatively lower cost than the traditional reinforced concrete shear wall system.

In this paper, two one-third scaled test specimens were prepared and tested under quasi-static cyclic loads to investigate their hysteretic behaviours. An analytical method was developed to predict the shear resistance of the partially connected SPSW. In addition, a nonlinear finite element (FE) model was developed to predict its lateral load