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Panel action of novel partially connected buckling-restrained steel plate shear walls

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ABSTRACT

A novel partially connected buckling-restrained steel plate shear wall as a robust and effective lateral load-resisting system is proposed in this paper. The influence of the superposition of the tension field and the high-order buckling deformation of the inner steel plate which is called "panel action" on the behavior of the new system is investigated. A modified method considering the effect of the panel action is developed to determine the minimum stiffness requirements of the vertical boundary elements so that the tension field will fairly uniformly form in the diagonal area. In addition, the nonlinear finite element method is adopted to carry out the push-over analysis to evaluate the effect of the initial imperfection on the behavior of the proposed shear wall. Meanwhile, based on the FE models validated using the available test data, an extensive parametric study is also performed to examine the effect of a change in the second moment of area of VBEs on the behavior of the novel shear wall. Finally, the FE results are compared with that predicted by the proposed method and a reasonable agreement is generally achieved between them.

1. Introduction

In the past decades, the steel plate shear walls (SPSWs) have been experimentally and numerically demonstrated that it is a robust and effective lateral load-resisting system exhibiting high performance on the lateral stiffness, shear resistance, ductility, and energy dissipation capacity [1–9]. Wanger [10] was the first to present a theory called "pure diagonal tension" utilizing the post-buckling strength which develops in the thin webs subjected to a shearing force. Based on the theory, Thorburn et al. [4] further developed a model to represent analytically the resistance provided by the tension zone which was represented as a series of inclined truss members orientated at the same inclination as the diagonal tension stress. Later then, the model was experimentally validated by Kulak et al. [5,6]. It is therefore believed that the flexural stiffness limits of the boundary elements, and not the strength, will generally govern the design of a shear wall panel. The design concept is then adopted in Canadian design code S16-01 [11] and American design code ANSI/AISC 341-10 [12]. Moreover, in order to prevent the infill steel plate from buckling at an early stage of loading, Zhao and Astaneh-Asl [13] proposed an innovation composite SPSW where the pre-cast reinforced concrete (RC) cover panel was not engaged with the surrounding boundary elements and do not participate in resisting the horizontal and vertical loads from main frame. It only provides an out-of-plane constraint to prevent the infill panel from buckling. Nevertheless, as there generally are an initial gap between the RC cover panels and the inner steel plate mainly caused by the fabrication and construction error, the high-order buckling deformation visibly forms in the inner steel plate [14,15]. After buckling, the tension field action is the main mechanism for resisting the applied shear forces. Since the tension field forces generally exert additional reactions on the surrounding boundary elements bounding the inner steel plate, a uniform tension field will fully develop only if the boundary elements are sufficiently stiff. For this consideration, AISC 341-10 [12] recommends that the unstiffened SPSWs in terms of the vertical boundary elements (VBEs) shall have a moment of inertia about an axis taken perpendicular to the plane of the web not less than $0.00307th^4 / L$, where t, h, and L are the thickness, height, and width of the steel plate respectively. Thus, it generally requires a large size member to satisfy the flexural stiffness demand. To achieve the purpose of reducing the stiffness requirement for the VBEs, thereby cutting the construction cost for the oversized members, many types of SPSW with various configurations have been presented [16–23].

In the present study, a novel partially connected buckling-restrained SPSW is proposed which comprises of VBEs, horizontal boundary elements (HBEs), pre-cast RC cover plates, inner steel plate, equal steel plates, gusset plates, and bolts as shown in Fig. 1. Only quarter of height/width of the infill panel is attached to the surrounding boundary

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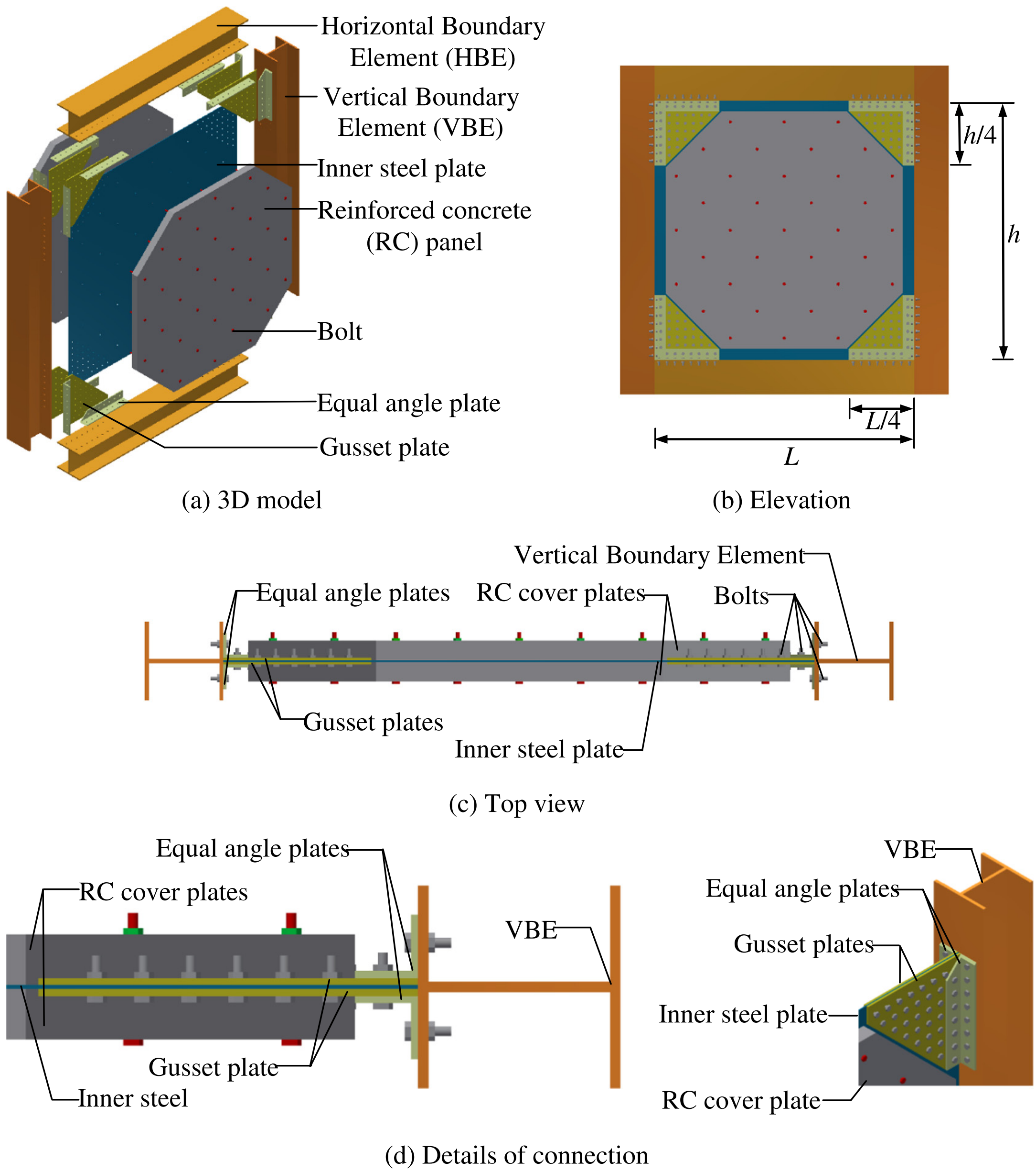

Fig. 1. Partially connected buckling-restrained steel plate shear wall.

elements by bolts at four corners whereas the corresponding middle portion is not connected to the adjacent members. Two pre-cast RC cover plates are employed to sandwich the inner panel by bolts. It is worth noting that the RC panels do not contact with the main frame as a moderate gap is left between them. In this case, the predominated contribution of the RC plates only is to provide out-of-plane constraint stiffness, thereby preventing the inner steel plate from low-order buckling deformation. The followings are some of the advantages using the proposed shear wall system to resist both wind and earthquake loads:

(1) The proposed shear wall system has high initial stiffness, adequate ductility, good energy absorption capacity and stable hysteresis behavior whereas requires less flexural stiffness for VBEs than the full connected SPSWs.
(2) Since the yield strength of inner steel plate is designed to be lower than that of main frame, the inner steel plate is allowed for full yielding zone across the entire diagonal area, whereas the main frame remains in elastic phase. Thus, the infill steel plate is considered as a "fuse" to prevent the main frame from a potential damage caused by wind or earthquake loads.
(3) The novel lateral load-resisting system can be constructed with field-bolted elements that significantly speed up the erection process and remarkably reduce the construction cost. Although the high-order buckling deformation generally develops in the inner panel and the RC cover panels slightly crack after severe earthquakes, it would be much easier and faster to repair or replace the damaged members. As a result, it is definitely deemed that the proposed shear wall works more efficiently than the traditional shear wall systems.
(4) In addition to the out-of-plane constraint to prevent the inner steel plate from buckling, the RC cover panels also provide sound and temperature insulation as well as fire proofing to the inner steel plate.

As the discussions above, it is noted that the buckling resistance of the diagonal compression zone strongly depends on the initial