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Hysteresis model of a novel partially connected buckling-restrained steel plate shear wall

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ABSTRACT

An equivalent brace model is developed to evaluate the nonlinear behavior of a novel partially connected buckling-restrained steel plate shear wall (BRSPSW) subjected to seismic loading. The high-order buckling modes of the equivalent brace under compression are taken into account meanwhile a hysteresis model is proposed to describe the stress–strain relationship of the equivalent brace. A nonlinear finite element (FE) method is employed to establish the validity of the partially connected BRSPSWs with the equivalent braces under monotonic, cyclic and seismic loads. A comparison with the FE results shows that the equivalent brace model with the proposed hysteresis properties can reasonably predict the shear resistance, hysteretic and seismic behaviors of the novel partially connected BRSPSWs. The effect of initial imperfection on the buckling responses of the restrained steel plate is also investigated. Nonlinear push-over analyses show that the increase of the initial imperfection essentially triggers the buckling mode of the restrained steel plate from high order to low order.

1. Introduction

The buckling-restrained steel plate shear wall (BRSPSW) was originally proposed by Astaneh-Asl et al. as a novel lateral load resisting system [1]. Until now, many types of BRSPSW with various structural configurations have been proposed to reduce the stiffness demand of the vertical boundary elements (VBEs) and they actually showed high performance on ductility, initial stiffness, shear resistance and energy absorption [2–6]. In terms of structural design for the VBEs, the American code ANSI/AISC 341-05 [7] requires the VBEs to have a moment of inertia about an axis normal 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 across the entire steel plate. To satisfy the said stiffness requirement, a large member size would be needed for the VBEs. However, functional requirements from the architect would not allow the oversized VBEs. Set against this background, a novel partially connected BRSPSW as shown in Fig. 1 is proposed to reduce the stiffness demand and then the member size of the VBEs. The proposed BRSPSW comprises of horizontal boundary elements (HBEs), vertical boundary elements (VBEs), restrained steel plate, pre-cast reinforced concrete (RC) panels, equal angle plates, gusset plates and bolts. A quarter of the height/width of the restrained steel plate is bolted to the surrounding boundary elements (HBEs and VBEs) by the gusset and equal angle plates whereas the mid-height/width is not connected to the boundary elements. The restrained steel plate is sandwiched between bilateral pre-cast RC panels by bolts. The RC panels aim to restrain the lateral low-order buckling modes of the steel plate so that the steel plate will only buckle in high-order modes. The occurrence of the high-order buckling modes is owing to the existence of initial bow imperfections of the steel plate and construction errors. This will be further elaborated hereinafter. The RC panels do not participate in resisting horizontal and vertical loads from the HBEs and VBEs. It is worth noting that the bolt holes on the steel plate are generally oversized for the purpose of precise installation. Hence the lateral buckling of the steel plate would not be prevented by the bolts. In other words, the bolts are not considered as lateral restraints in the high-order buckling modes of the steel plate.

Nonlinear behavior of the proposed partially connected BRSPSWs could be evaluated by using an advanced finite element (FE) method. However the FE modeling and analysis are complicated and basically involve high computational configuration and time consumption. To make the FE analysis more effective, a simplified model has been developed where the restrained steel plate and the RC panels are converted into the equivalent brace members, as shown in Fig. 2.

The "equivalent brace model" or "equivalent truss model" was originally proposed by Thorburn et al. [8] to predict the nonlinear behavior

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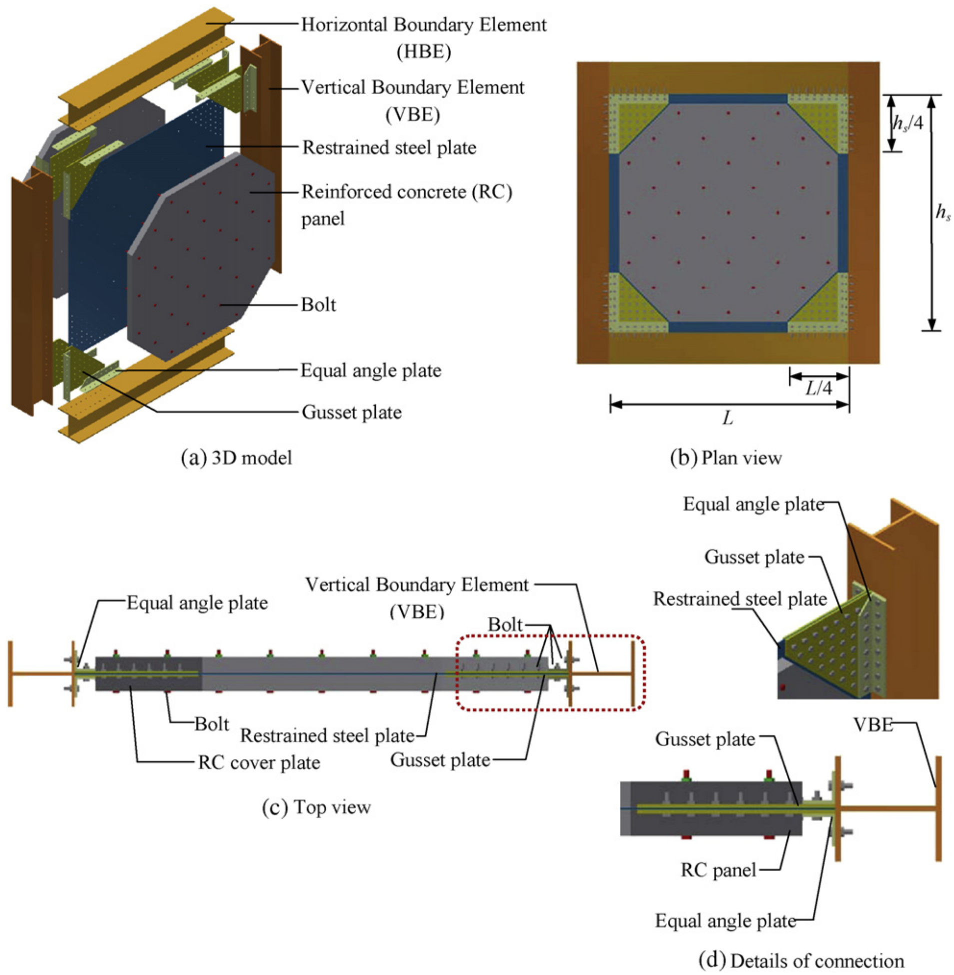

Fig. 1. Partially connected buckling-restrained steel plate shear wall.

of pure steel plate shear walls (SPSWs). The test results conducted by Timler and Kulak [9], Tromposch and Kulak [10], and Driver et al. [11] were compared with the predictions from the equivalent brace model, and they showed reasonable agreements. The equivalent brace model was proposed based on a strip model by using the "theory of diagonal tension" [12] where the compressive stresses in the orthogonal direction of the tension strip were not taken into account. The strip model was later adopted by Canadian design codes S16-01 [13] and ANSI/AISC 341-05 [7]. According to the strip model [9], the SPSW is represented by a series of inclined strips with pinned end, orienting at an angle of α expressed by

$$\alpha = \arctan\left(\frac{1+\frac{tL}{2A_c}}{1+th\left(\frac{1}{A_b}+\frac{h^3}{360I_cL}\right)}\right)^{\frac{1}{4}} \tag{1}$$

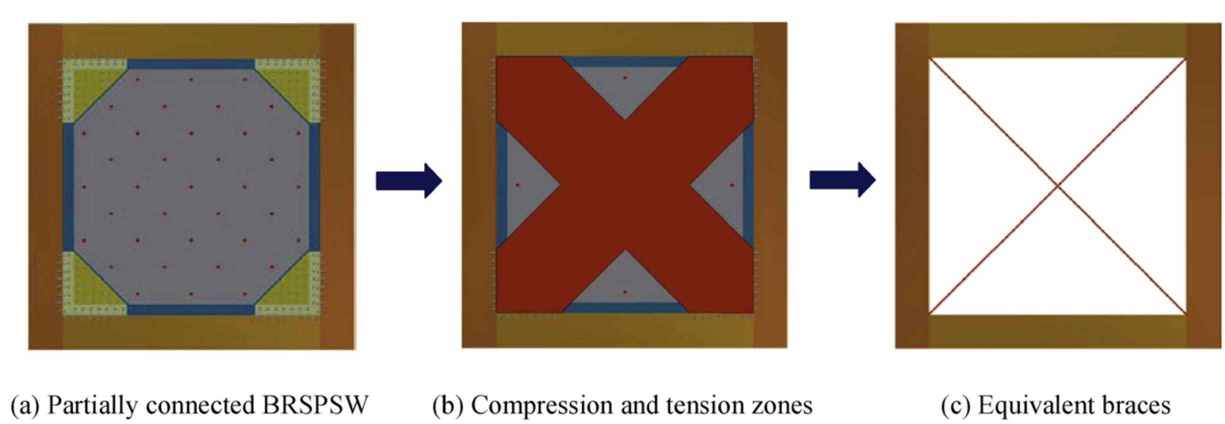

Fig. 2. Schematic diagram of an equivalent brace model.