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Seismic behavior of novel partially connected buckling-restrained steel plate shear walls

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ABSTRACT

A partially connected buckling-restrained steel plate shear wall (SPSW) consisting of an internal steel plate connected to two external reinforced concrete cover plates by bolts, is proposed. Only the four corners of the inner steel plate are connected to the boundary frame elements so that the steel plate can develop tension field action and to reduce potential damage to the surrounding frame elements under cyclic lateral loads. Two one-third scaled specimens were tested to quasi-static cyclic loading to investigate the hysteretic behavior of the proposed new lateral load resisting system. The test results show that the proposed partially connected buckling-restrained SPSW exhibits high initial stiffness, adequate ductility, good energy adsorption capacity, and stable hysteresis loop. Based on the observed failure modes and test results, a theoretical model in which the high-order shear buckling modes of the inner steel plate is developed to predict the shear resistance of the inner panel. The experimental results are compared with the predicted results in order to establish its accuracy in predicting the response behavior of the partially connected buckling-restrained SPSW under lateral loads.

1. Introduction

In the past several decades, experimental and numerical investigations on steel plate shear wall (SPSW) have been conducted [1–7]. Their research demonstrated that the SPSW is an effective and economical lateral load resisting system against both wind and earthquake forces. However, shear buckling of the thin plate was observed at early load stage by Wagner [8]. In order to effectively prevent early buckling of inner steel plate, Astaneh-Asl [9] proposed an innovation composite SPSW where the pre-cast reinforced concrete (RC) cover panel was not engaged with the surrounding boundary elements and was not participating in resisting the horizontal and vertical loads from the main frame. The RC cover plates only provide an out-of-plane constraint to prevent the inner panel from buckling. Moreover, due to practical imperfections such as lack of fit and initial gap between the RC cover panels and the inner steel plate, the high-order buckling modes was observed for the inner steel plate [10,11]. After buckling, the tension field action develops and provides further shear resistance. In order for the tension field to fully develop, the boundary elements to which the shear panel is connected should have sufficient bending stiffness. ANSI/AISC 341-10 [12] recommends that the vertical boundary elements (VBEs) shall have a moment of inertia about an axis taken perpendicular to the plane of 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, large member size would be required for the VBEs to satisfy the minimum stiffness requirement. Against this background, many types of SPSWs with various structural configurations have been proposed to reduce the stiffness requirement of VBEs, such as perforated steel plate shear panels [13]; light-gauge steel plate shear walls [14]; low yield point steel shear walls [15]; steel plate shear wall with slits [16]; steel plate shear walls with opening or partially connected inner plate [17]; bound-columns with buckling-restrained steel plate shear wall [18]; buckling-restrained steel plate shear walls with inclined-slots [19] and so on. The corresponding schematic diagrams are given in Fig. 1.

Recently, a novel partially connected buckling-restrained SPSW is proposed by the authors [20–22], as shown in Fig. 2. The concept is to create a system that is strong enough to resist lateral forces with less stiffness requirement for VBEs. The proposed shear wall system generally consists of horizontal boundary elements (HBEs), vertical boundary elements (VBEs), inner steel plate, pre-cast RC cover panels, equal angle plates, gusset plates, and bolts. It is worth noting that only quarter of height/width of inner plate at four corners are bolted to the

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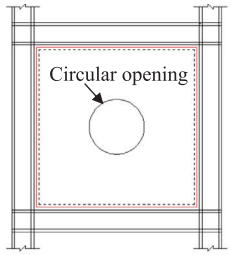
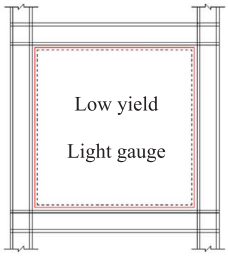
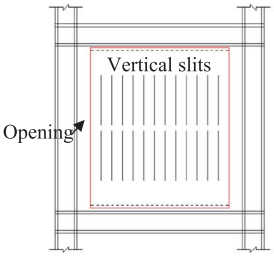


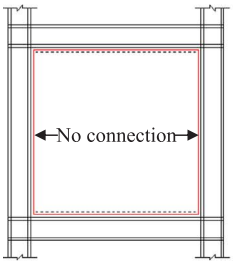
(a) Perforated steel plate shear panels (Robert et al. 1992)



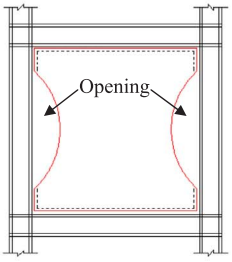
(b) Light-gauge steel plate shear walls (Berman et al. 2005); Low yield point steel shear walls (Chen et al. 2006)



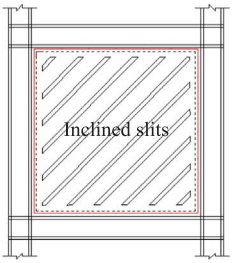
(c) Steel plate shear wall with slits (Hitaka et al. 2007)



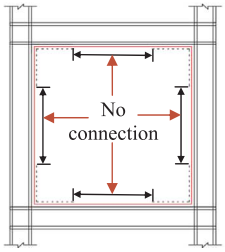
(d) Steel plate shear walls partially connected to the horizontal members (Choi et al. 2009)



(e) Bound-columns with buckling-restrained steel plate shear wall (Liu et al. 2014)



(f) Buckling-restrained steel plate shear walls with inclined-slots (Jin et al. 2016)



(g) Proposed partially connected buckling-restrained steel plate shear wall

Fig. 1. Many types of SPSW with various configurations.

surrounding boundary elements (HBEs and VBEs) by equal angle plates and gusset plates, whereas the mid-height/width are not connected the adjacent members. Meanwhile, the inner steel plate is sandwiched between two pre-cast RC cover panels by bolts. A moderate gap between the RC cover panels and main frame is left by design. Hence, in the proposed SPSW system, the RC cover panels are not connected to the boundary elements and are not participating in resisting horizontal and vertical loading from mainframe. The main role of the RC cover plates is to provide an out-of-plane constraint to prevent the inner steel plate from low-order buckling. The main advantages of using the novel partially connected bucking-restrained SPSW to resist lateral loading are:

(1) The proposed shear wall system has high initial stiffness, adequate ductility, excellent energy absorption capacity and stable hysteresis behavior whereas imposes less stiffness demand on the VBEs than the fully connected buckling-restrained SPSW.
(2) Since the yield stress of inner steel plate is designed to be lower than that of mainframe, the steel plate is allowed to develop yield zone across the entire diagonal area, whereas the main frame remains in elastic phase. Thus, the inner steel plate is considered as a “fuse” to prevent the main frame from the damage caused by wind or earthquake loads.
(3) The shear wall system can be constructed with field-bolted elements that significantly improve buildability and substantially reduce the cost of construction. Although the high-order buckling is generally developed in the inner panel and the crack commonly occurs in the RC cover panels after a severe earthquake, it would be much easier and faster to repair or replace the damaged members. As a result, the proposed shear wall works more efficiently than the traditional shear wall systems.
(4) In addition to the out-of-plane restraint to prevent the inner steel plate from buckling, the RC cover panels also provide sound and fire insulation to the steel plate.

In the present study, in order to investigate the hysteretic behavior of the partially connected buckling-restrained SPSW, two 1:3 scaled test specimens were fabricated and tested under quasi-static cyclic loading. The shear resistance, initial stiffness, ductility, energy dissipation capacity, and hysteretic behavior of test specimens are evaluated. Furthermore, a modified method is proposed to predict the initial stiffness, lateral deflection and shear resistance of the proposed SPSW system.

2. Experimental programs

The main objective of the tests is to investigate the response behavior of the partially connected buckling-restrained SPSW under the effect of quasi-static cyclic loading representing an idealized earthquake force. In addition, the effect of slenderness ratio of inner steel plate on the hysteretic behavior is also examined. Two single-bay, single-storey 1:3 scaled specimens were fabricated and tested under quasi-static cyclic loading in the structural engineering laboratory at the Nanjing Tech University.