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Experimental seismic study on shear walls with fully-connected and beam-only-connected web plates

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ABSTRACT

Typically, in conventional steel plate shear walls (SPSWs), web plates are connected to both beams and columns; however, steel shear walls connected to beams only (SSW-BOs) with the idea of reducing surrounding columns demands and alleviating web plate damage was proposed since the mid-2000s. This paper presents an experimental investigation on seismic behavior of steel plate shear walls comprising SPSWs and SSW-BOs. Cyclic loading tests were performed on four 1:6 scaled one-story specimens with two plate thickness and two different web plate boundary conditions. The observed predominant failure modes include i: plate tearing at the corners, ii: slippage along connection zone of web plates, and iii: plate-to-frame connection bearing. Using frame connection for plates increases the energy dissipation, shear strength and elastic stiffness by up to 150%, 200% and 110% on average, respectively compared to those of beams-only connected walls. Experimental results indicate that the SSW-BO systems reached a ductility ratio of 7.3 on average, almost 1.5 times the value for SPSWs. It is demonstrated further that with an increase in the slenderness ratio (height to thickness), the strength, stiffness and energy absorbed by the SPSW and SSW-BO systems show a decreasing trend being less stiff for SSW-BO panels.

1. Introduction

Steel plate shear walls (SPSWs) have been in use as the primary lateral load-resisting system of buildings in high seismic areas for a long time [1,2]. These systems have specific advantages in terms of ductility, stiffness and shear strength that merit their consideration for use as a load bearing system in different structures whole over the world [3,4]. In a conventional SPSW (Fig. 1(a)), the web plates connected to the surrounding beams and columns, buckle in shear at low lateral loads and develop a diagonal tension field that induces sever stresses on the surrounding frame members, as shown in Fig. 1(b). In addition, using of web plates with minimum available thickness larger than required for resisting specified lateral loads may also result in excessive design forces to the horizontal and vertical boundary elements (HBEs and VBEs), thus increasing their size. As a result, there exists an obstacle concerning VBEs high demand that may impede further widespread acceptance of this system. To prevent plastic hinges in the columns and thus to prevent collapse of the structure, strong columns with large sections must be used [6].

Attempts at mitigating column demands were recently addressed by the use of (i) light-gauge, cold-formed steel plates [7], (ii) low-yield steel [8,9], (iii) coupling beams to alleviate overturning forces [2,10], (iv) perforations layout covering the entire web plate in a specified regular pattern [11] and (v) web plates connected to the beams only [12,13].

The presumed benefits of alleviating column demands gained from the use of beam-only-connected web plates must be weighed against possible drawbacks associated with their reduced shear strength and mitigated energy absorption compared with fully-connected web plates. The web plates are not connected to frame columns, large stresses due to tension field, developing plastic hinges in the columns are avoided (Fig. 2).

Limited performed experimental studies on SSW-BO illustrated that these systems have considerable shear strength and can be used to separate the shear walls from the main columns and therefore, reduce the dimension of columns [14,15]. It was recognized that the frame has the capability of developing a tension field in the wall plate, so that the wall plate yields before the frame [14].

A comparative experimental study was conducted in this research to investigate the structural performance of SPSW and SSW-BO systems. Four wall specimen configurations were tested under cyclic loading and the results are presented as follows.

2. Analytical shear load-displacement of SPSW and SSW-BO

Considering the web plate of width L, height H and thickness t, the nominal lateral strength of a SPSW, V_{nf}, using the kinematic method of

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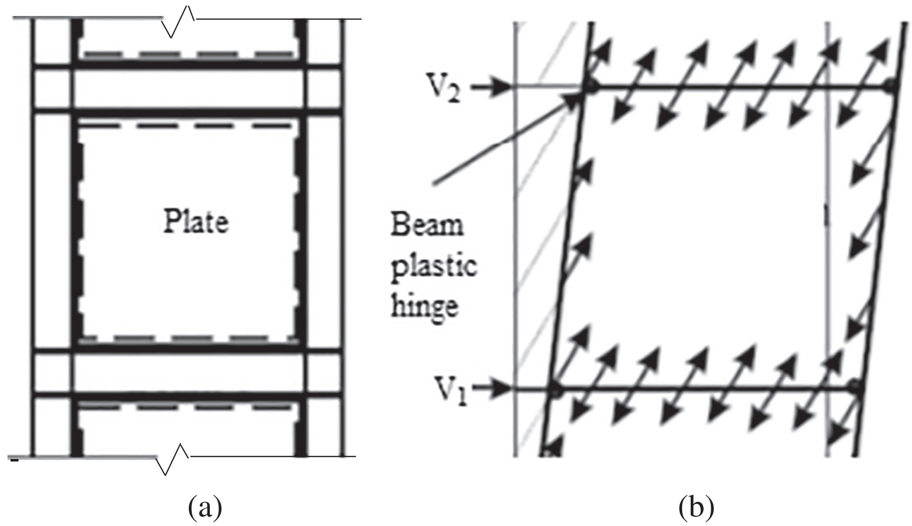

Fig. 1. Conventional SPSW: (a) fully-connected web plate; (b) stresses on boundary elements [5].

plastic analysis is obtained as presented in the AISC Seismic Provisions [16]:

$$V_{nf} = 0.42 F_y t L \sin 2\alpha \quad (1)$$

where F_y and α are yield strength and angle of inclination of tension field from the vertical.

The elastic shear displacement, U_e, neglecting buckling shear strength is obtained as [16]:

$$U_e = \frac{2F_y H}{E \sin 2\alpha} \quad (2)$$

where, E is modulus of elasticity.

Using Eqs. (1) and (2), the elastic stiffness of SPSW is calculated as follows:

$$K_f = \frac{0.21LtE}{H} \quad (3)$$

The nominal lateral strength for SSW-BO, V_{nb}, can be assessed as [17]:

$$V_{nb} = 0.42 F_y t L_{PTF} \sin 2\theta \quad (4)$$

where the inclination angle, α, was replaced with that of a SSW-BO partial tension field, θ, and the total fully-connected web plate length, L, with the partial tension field length, L_{PTF}. The rest of the web plate outside of the partial tension field does not contribute to the plate's lateral force resistance.

In Eq. (4), the partial tension field length along the beams, and partial tension field inclination are given as [17]:

$$L_{PTF} = L - H \tan(\theta) \quad (5)$$

$$\theta = 0.5 \tan^{-1}(L/H) \quad (6)$$

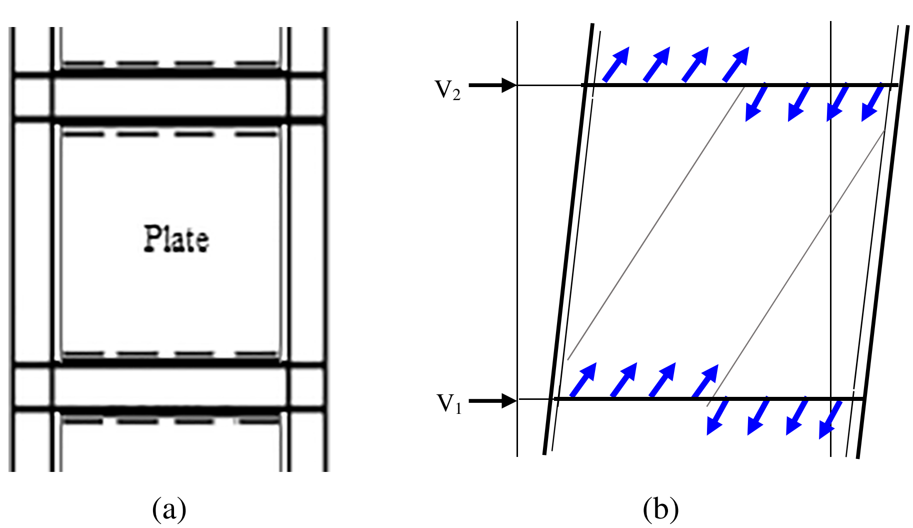

Fig. 2. SSW-BO: (a) beam-only connected web plate; (b) stresses on boundary elements.