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# Behavior and mechanisms of steel plate shear walls with coupling

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ABSTRACT

The Steel Plate Shear Wall with Coupling (SPSW-WC) system consists of a pair of planar SPSWs linked together with coupling beams at the floor levels. The degree of coupling, which represents the level of interaction between the two piers, and the plastic strength for a SPSW-WC are important parameters in understanding behavior and developing designs for the system. This paper examines these two parameters using plastic analysis and numerical simulations of single story and multi-story SPSW-WC configurations. The focus is on desirable uniform-yielding mechanisms, but soft-story mechanisms are also briefly discussed, and analytical closed-form expressions are developed for ultimate strength and degree of coupling. Thirty-two SPSW-WC structures are designed with emphasis on varying the following parameters: height of the structure (number of stories), coupled length and coupling beam properties. These structures are studied with numerical models using monotonic nonlinear static analysis. Good agreement is observed between the numerical simulations and the analytical predictions for the ultimate strength and degree of coupling. The degree of coupling is shown to have a significant impact on structural weight, particularly for the taller structures studied, and the optimal degree of coupling to maximize material efficiency is found to be in the range of 0.4 to 0.6.



## 1. Introduction

The Steel Plate Shear Wall (SPSW) system is used in North America and Japan as a lateral force resisting system for high seismic regions. A SPSW consists of a steel frame with slender web plates connected to the surrounding beams and columns, referred to as Horizontal Boundary Elements (HBE) and Vertical Boundary Elements (VBE), respectively. Due to architectural requirements, the lateral force resisting system is typically placed around the perimeter of the building core. To accommodate openings in the core, it may be natural to place two SPSWs adjacently. Additionally, the American Institute of Steel Construction *Seismic Provisions* traditionally limited the panel length to height ratio to 2.5 [1], often encouraging the segmentation of a single bay into two adjacent SPSWs. Therefore, it is a logical extension of the SPSW system to link two planar SPSWs at the floor levels with Coupling Beams (CB) to form a Steel Plate Shear Wall with Coupling (SPSW-WC) as shown in Fig. 1.

In the United States, SPSW web plates are typically slender and unstiffened and the boundary elements are rigidly connected [1]. Thorburn et al. [2] first recognized the post-buckling strength of SPSW web plates. Similar to tension-field action in plate girders [3], a web plate buckles under shear force but provides significant post-buckling resistance by developing a diagonal tension field. However, unlike plate girders, the boundary elements are proportioned to anchor the diagonal tension field so that complete web plate tension yielding can develop. The angle of the tension field $\alpha$, measured from the vertical, was derived by Timler and Kulak [4] based on a least work formulation:

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

where $t$ is the web plate thickness, $h$ is the distance between HBE centerlines, $L$ is the distance between VBE centerlines, $A_b$ is the average cross-sectional area of the HBEs, $A_c$ is the average cross-sectional area of the VBEs, and $I_c$ is the average moment of inertia of the VBEs.

The strip model, a simplified analytical tool, was developed based on Eq. (1) to analyze the SPSW system [2,4]. The diagonal tension field is represented by tension-only truss elements inclined at an angle $\alpha$ with a cross-sectional area equal to the product of their tributary width and the web plate thickness as shown in Fig. 2. The strip model has been compared extensively with experimental data and has been demonstrate to accurately capture the global system behavior [4–6].

In a planar SPSW system the overturning moment due to lateral loads is resisted primarily through two mechanisms (Fig. 2): (1) the moment within the individual VBEs ($M_{VBE}$) and (2) the couple formed by the axial force in the VBEs induced by the web plates and HBEs ($M_{PIER}$). The SPSW-WC system introduces an additional mechanism

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