InSights

new trends, new techniques and current industry issues

Advances in Steel Plate Shear Walls

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Steel plate shear wall (SPSW) technology is advancing, making more wide-spread implementation of seismic force resisting systems possible. These stiff and ductile systems have had years of research that has demonstrated their excellent seismic performance, explored various details and configurations, and resulted in the design provisions in ANSI/AISC 341-10, where they are denoted special plate shear walls. The key principal for design is that yielding is expected in the web plates, at the beams ends and at the column bases.

SPSW ductility is superior to braced frame and even moment frame systems. *Figure 1* shows the base shear versus story drift behavior for a well-detailed SPSW (Li et al. 2014) and a concentrically braced frame detailed to provide better ductility than a modern special concentrically braced frame (Roeder et al. 2011). Both are results from two-story, nearly full-scale tests with somewhat different base shear capacities. Admittedly, the SPSW strength would have to be increased to make a direct comparison; however, it is clear that the SPSW has superior ductility, retaining a larger percentage of its peak strength to significantly larger drifts. The maximum drift of nearly 5% for the SPSW is more than could be expected for many moment frame systems as well.

Recent Advances in SPSWs

Recently, important advances in SPSW design and behavior have been made and are described below. Note that many other considerations for design, including the use of reduced beam section beam-to-column connections, perforated web plates, and horizontal struts for tall first stories, were described along with general SPSW deign methods in AISC *Design Guide 20* (Sabelli and Bruneau 2006).

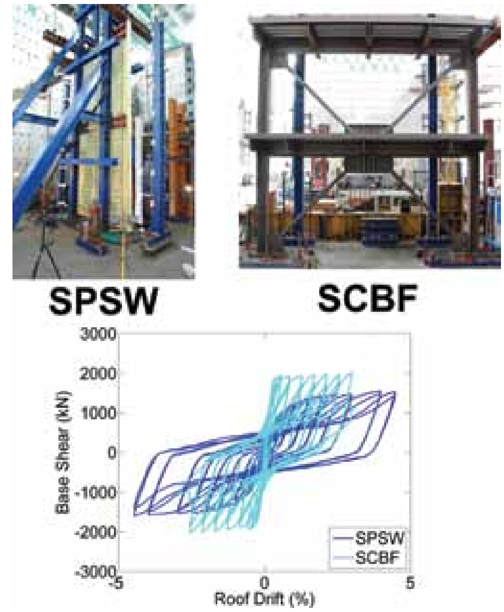

Figure 1. Large-scale SPSW and SCBF test specimens and hysteretic behavior. Courtesy of K.C. Tsai and NEESHub.

Tension Field Action & Web Plate Modeling

Experimental and computational studies on inelastic tension field action have recently demonstrated that the angle of inclination of the web plate tension field changes as the web plate undergoes plastic strain. Web plate yielding and significant plastic strain is expected in design level earthquake events when maximum demands will be imposed on the surrounding beams and columns. Therefore, it makes sense that numerical models used for design of SPSWs should use the angle of inclination after yielding. Equation F5-4 in ANSI/AISC 341-10 was derived using elastic strain energy and is a good approximation of the inclination angle after web plate elastic buckling but prior to yielding. *Figure 2* shows the migration of the inclination angle with increasing story drift from experiments and numerical simulation where the angle approaches 45°. This result has been supported by other tests and analyses (Webster et al., 2014) and a 45° angle is proposed for seismic design.

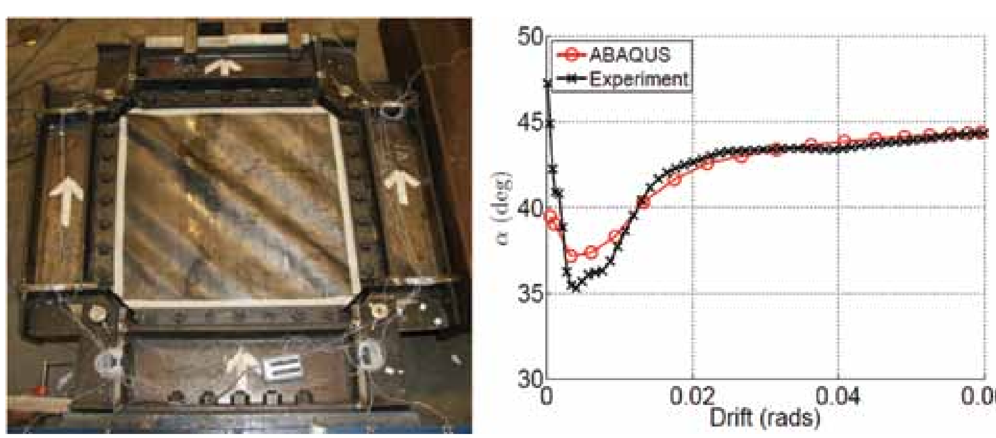

Figure 2. Web plate inelastic tension field action test setup and angle of inclination migration with increasing drift.

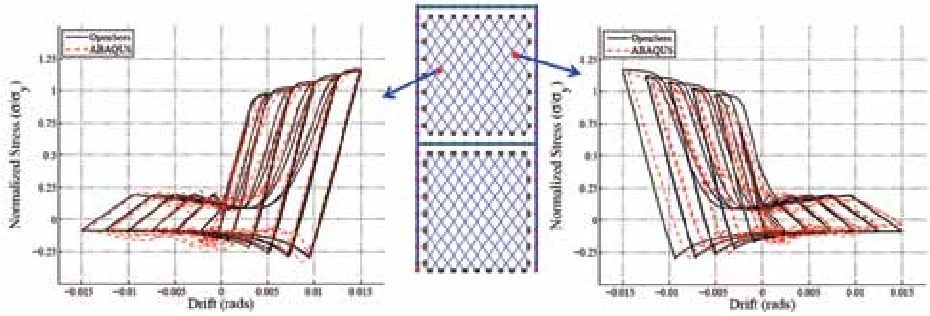

Figure 3. New web plate material models for truss elements in strip modeling of SPSW.

Figure 4. Coupled SPSW test at the University of Illinois. Courtesy of Daniel Borello.

Similar tests and analyses on web plates within a pin-connected boundary frame have improved the understanding of the inelastic cyclic response of web plates. This understanding has led to the development of a phenomenological material model that can represent the complex web plate behavior as shown in *Figure 3* (Webster 2013). This material model can be used in simple strip models of SPSWs and will soon be available as a material option in OpenSEES. This advance provides an efficient way to model the nonlinear behavior of SPSWs.

Improved Efficiency in SPSW Column Design

One of the critical factors limiting the implementation of SPSWs is the large column sizes required to resist the combined axial and flexural demands from overturning, frame action and web plate forces. Recent research by Li et al. (2014a and 2014b) has developed recommendations for design that allow the formation of the column plastic hinges, not at the base as previously recommended, but at a height of ¼ to ⅓ of the story height above the base where the moment is typically maximum in the compression column. This reduces flexural demands significantly and does not impact performance of the system as long as the column does not form a plastic hinge at the top of the first story. In full-scale two-story tests, Li et al. (2014b) found that a 20% reduction in column weight could be achieved with no impact on performance.

Coupled SPSWs

Coupled SPSWs offer designers the flexibility to use SPSW systems in cores of taller buildings but there has been little guidance on design methods, steel coupling beam detailing, and general behavior until recently. Borello and Fahnestock (2013) describe design concepts for coupled SPSWs, recommend target values for the degree of coupling (ratio of the overturning moment resisted by the individual walls to the total overturning moment), demonstrate significant steel weight savings when two individual walls are coupled and show, through nonlinear analysis, that they have excellent seismic performance. Recently completed large-scale tests on two coupled steel plate shear wall systems as shown in *Figure 4* confirmed the numerical analysis results and validity of the design procedure (Borello 2014).

Self-Centering SPSWs

Minimizing residual drift and ensuring simple post-earthquake repair strategies is a current focus of much earthquake engineering research. In this context, recent research has implemented self-centering steel moment frame technology in steel plate shear walls. The system, illustrated in *Figure 5*, utilizes post-tensioned beam-to-column connections to provide recentering after earthquakes and web plate tension field action to provide stiffness and energy dissipation. Recent research on these systems has included the development of performance-based design recommendations (Clayton et al., 2012), large-scale subassemblage tests to explore design parameters (Clayton et al., 2013), shake table tests on systems with different connections to demonstrate system performance (Dowden and Bruneau, 2014), and two-story full-scale proof-of-concept tests as in *Figure 5* (Clayton et al., 2014).

Conclusions and Future Challenges

SPSWs remain an under-utilized lateral force resisting system despite their excellent seismic performance. Some of the recent advances described here are helping to solve this problem and also push the technology further. A better understanding of inelastic web plate behavior is making the system more efficient to design and analyze, alternative approaches for column design have resulted in reduced required sizes, advances in coupled steel plate shear wall design now provide a solution for building cores, and systems with self-centering provide a solution for applications where minimizing post-earthquake downtime is critical. Additional innovation is necessary from practicing engineers, fabricators and erectors to develop fabrication and construction techniques that help improve efficiency. Such advances would increase SPSW implementation which, considering its excellent performance, should be a priority for the industry.▪

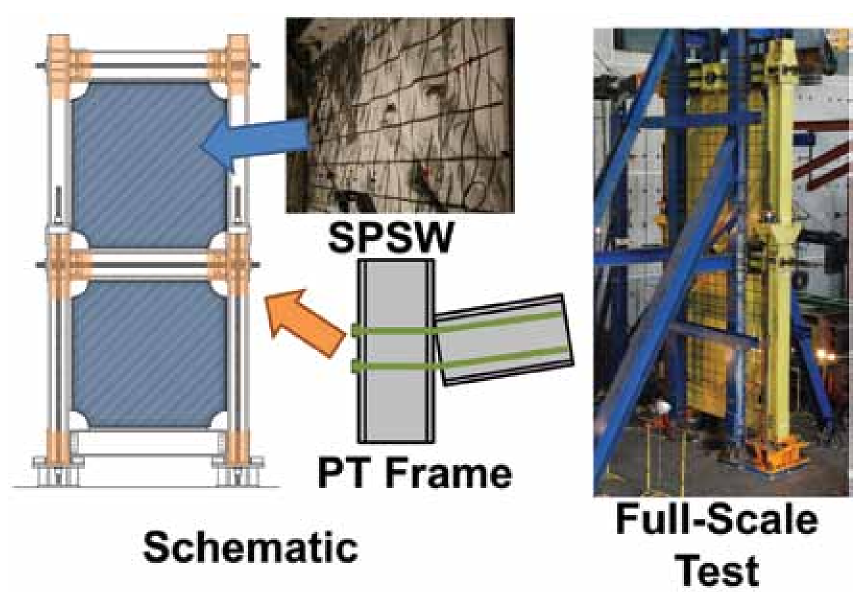

Figure 5. Self-centering SPSW schematic and full-scale test specimen.

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