CIVIL & ENVIRONMENTAL ENGINEERING
UNIVERSITY of WASHINGTON

NEESR-SG: Smart and Resilient Steel Plate Shear Walls for Reducing Earthquake Impacts

CMMI: 0830294 George E. Brown Network for Earthquake Engineering Simulation Research

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Abstract:

This poster provides an overview of the NEES Small Group Research supported by NSF grant CMMI: 0830294, which seeks to develop a resilient steel shear wall system while also filling critical knowledge gaps regarding steel plate shear wall behavior that are currently impeding widespread implementation of these robust and ductile systems. The project utilizes NEES equipment sites at the University at Buffalo and University of Minnesota as well as experimental facilities at the National Center for Earthquake Engineering Research in Taiwan and at the University of Washington. The resilient steel plate shear wall system (R-SPSW) will leverage the advantages inherent in steel plate shear walls (SPSWs) and self-centering technologies to achieve seismic performance objectives including post-event functionality and easy post-event repair. To break down barriers to more widespread SPSW implementation, the project will investigate the vertical distribution of yielding in the systems under dynamic ground shaking and the performance of coupled SPSWs and will develop new analytical models that are capable of capturing nonlinear web plate response.

The current progress of the project includes the development of models that represent the behavior of the self-centering beam-to-column connections that will be utilized in the resilient steel plate shear wall system, the execution of a parametric study that quantifies column demands in steel plate shear walls under dynamic ground motion, the development of a database of archived steel plate shear wall test data and preliminary identification of steel plate shear wall damage states and fragility curves for developing performance based design recommendations. Additionally, undergraduate students from Seattle University have worked all year on developing SPSW designs that will be the basis for test specimens and three high-school students from Seattle-MESA have been selected for internships in the Structural Engineering Laboratory at UW.

Project Overview:

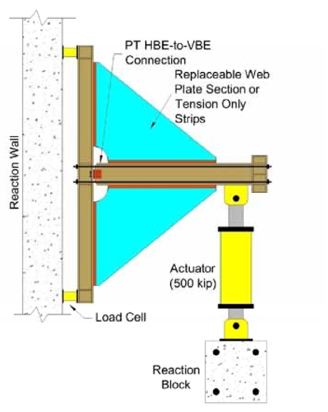
The project focuses on two major issues: (i) developing the resilient steel plate shear wall system and (ii) breaking down barriers to steel plate shear wall implementation. Three primary experimental tasks will be used to develop the resilient wall along with supporting analysis. Post-tensioned beam-to-column connections will be tested at UW with appropriate boundary conditions to capture the impact of web plate tension field yielding on the connection behavior. Then selected connections will be used in three-story shake table testing at UB-NEES where the dynamic self-centering capability of the system will be explored. The same frame will be used in quasi-static testing at UB-NEES to further investigate system response. Then a full-scale pseudo-dynamic experiment on a multi-story resilient wall will be carried out at NCREE to verify system performance. Students from Seattle University, a primarily undergraduate institution, have been working to design steel plate shear walls from which experimental specimens will be derived.

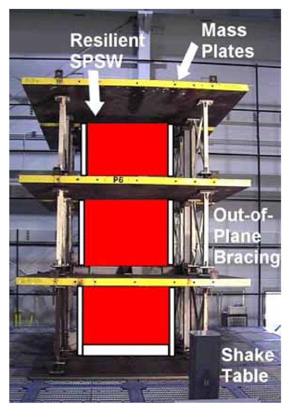
Developing the Resilient Steel Plate Shear Wall System

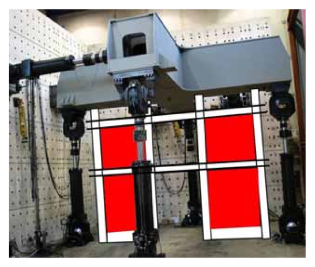
- UW: Connection Testing with System Effects
- UB: Shake Table Testing
- NCREE: Full-Scale Multi-Story Testing

Breaking Down Barriers to Steel Plates Shear Wall Implementation

- UW: Next-Generation Web Plate Model
- UM: Coupled Wall Testing
- UW: SPSW Analysis to Improve Design







To advance the state-of-practice regarding steel plate shear wall design and promote the use of this robust and ductile system, new analytical model for representing web plate tension field yielding is being developed that will be able to be efficiently meshed and capable of representing nonlinear web plate behavior, greatly reducing model building time and improving model quality. A major portion of the project is dedicated to studying the design and behavior of coupled steel plate shear walls, which will culminate in a series of coupled wall tests at the MAST facility. Finally, extensive analytical work already underway will further the understanding of the seismic behavior of steel plate shear walls. This work will result in design recommendations that will make the system more practical, including reducing the overly conservative column design requirements. Further, data from steel plate shear wall tests from around the world is being collected and damage states and associated fragility curves are being developed to promote performance based design of this ductile steel system.

Database of SPSW Tests and PBEE Tools:

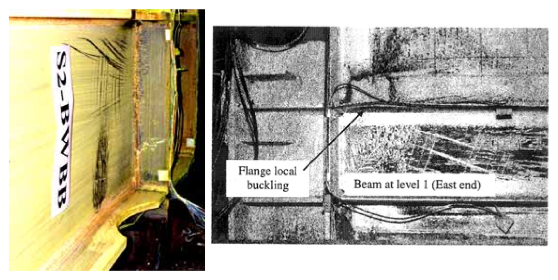
Under the project objective of breaking down barriers to SPSW implementation, a database of previous SPSW tests has been assembled. From the data, preliminary damage states, generally associated with repair costs, have bee developed and fragility curves have been constructed. Additional test data is being collected and the curves will be continue to be updated throughout the project.

SPSW Damage States

1. Elastic Panel Buckling
2. Panel Yielding
3. Residual Panel Buckling
4. Boundary Element Yielding
5. HBE and VBE Local Buckling
6. Panel Tearing
7. Connection and Boundary Element Fracture

DS 3: Residual Web Plate Buckling

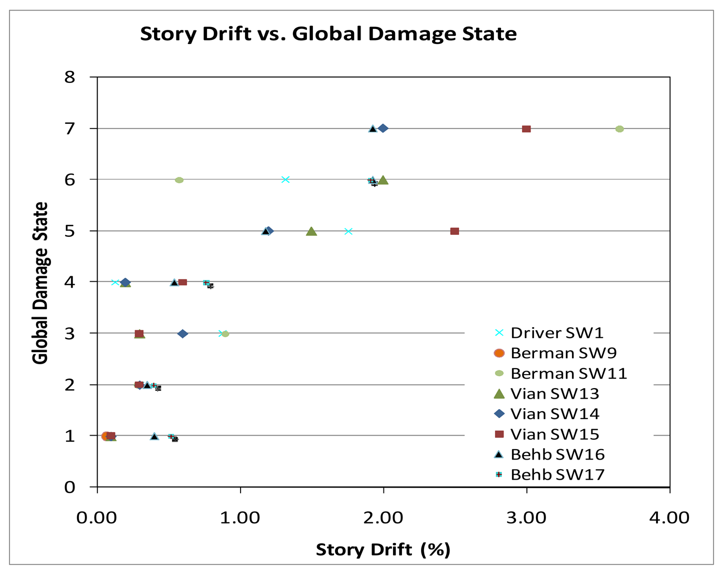
DS 4: Boundary Element Yielding (VBE)

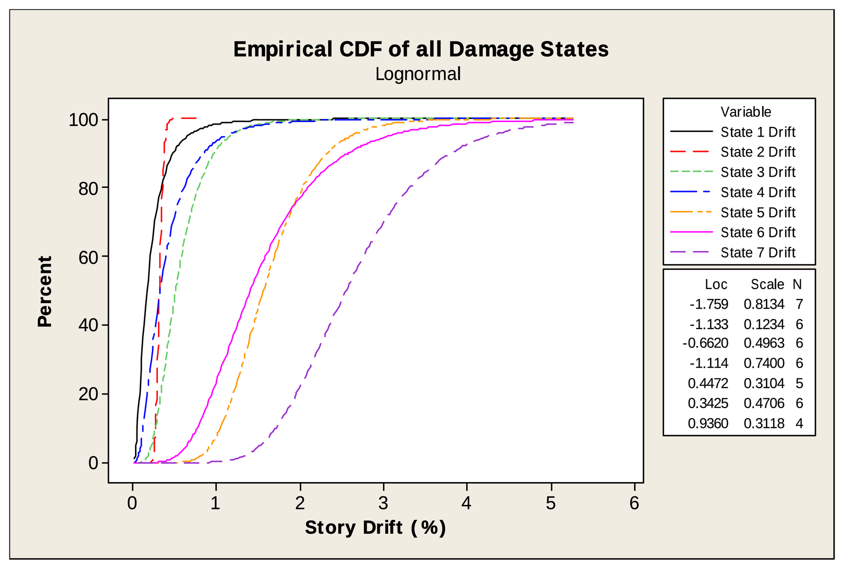


DS 5 Boundary Element Local Buckling

DS 6: Boundary Element Fracture

DS 7: Boundary Element Fracture



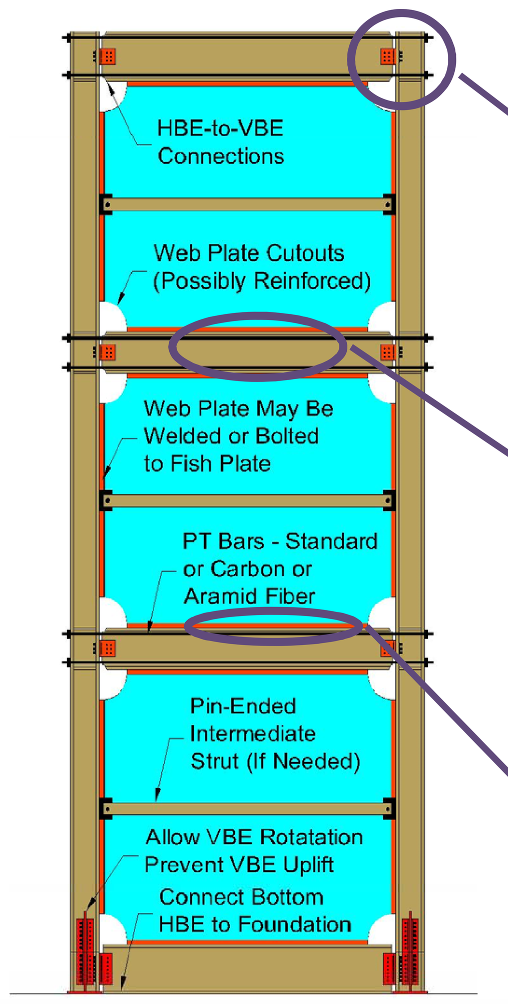


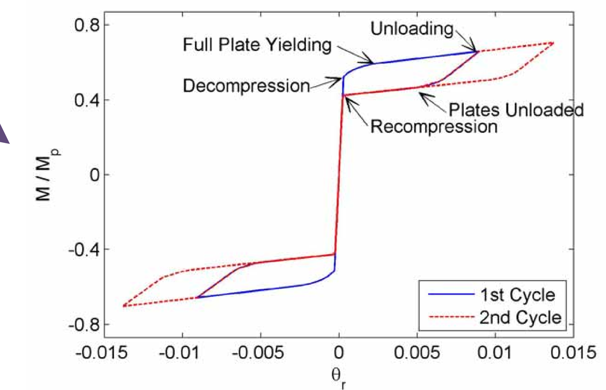
The Resilient Steel Plate Shear Wall:

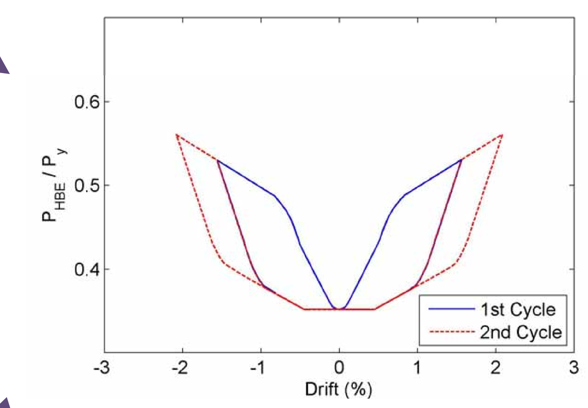
This research addresses challenges related to damage tolerant self-centering systems and SPSWs. Uniting these two systems leverages many of the benefits of each while reducing or eliminating many of the problems associated with each. The resilient SPSW (R-SPSW) system will be developed through the careful integration of component, substructure, and system level experiments with advanced computational modeling. The R-SPSW systems have the benefits of self-centering systems in that they enable post-event functionality and easy post-event repair; thereby reducing life-cycle costs in moderate and high seismic areas and enhancing the sustainability of the built environment. Sensing solutions will also be developed to determine the maximum web plate deformation, enabling identification of web plates in need of replacement following an event.

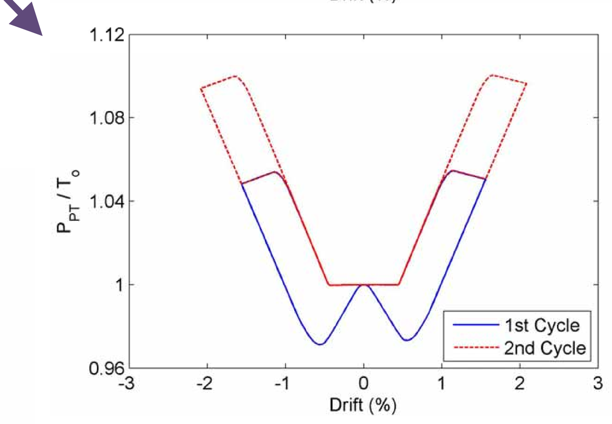
The R-SPSW system, shown schematically below, utilizes a thin steel web plate to provide lateral stiffness and strength and reconfigured PT beam-to-column connections (denoted PT HBE-to-VBE connections to be consistent with SPSW nomenclature). The primary purpose of the PT HBE-to-VBE connections is to re-center the frame following an event rather than provide lateral stiffness and strength. This enables the use of PT connections with low moment strengths, and thus enables designs where rocking occurs nearer to the beam web midpoint, reducing or eliminating the increase in the distance between column centerlines during rocking. Further, due to the hysteretic behavior of the web plate, which is similar to tension only bracing (but with yielding distributed over the entire bay width and occurring more gradually with increasing displacements), the required self-centering forces will be relatively low.

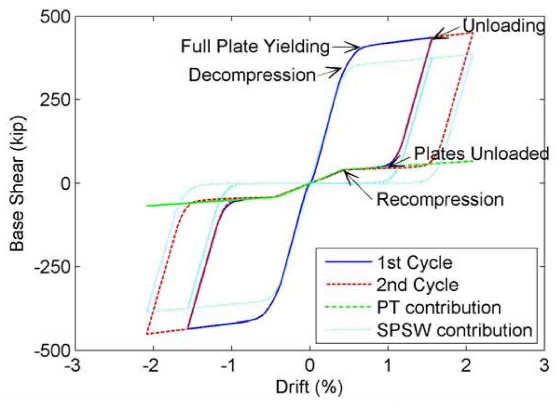
Sap2000 and OpenSees models have been developed to study the behavior of the system and develop design methods. The model is shown below along with the hysteretic behavior of each element. Currently nonlinear response history analyses are being performed for various designs and connection configurations to bound performance and investigate the requirements for re-centering. The models are also being used to develop test specimens for the UB testing.

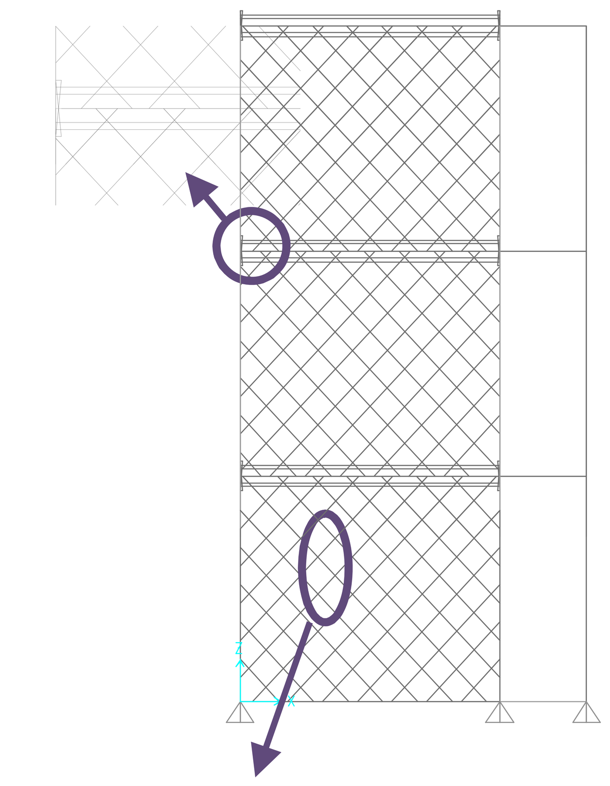


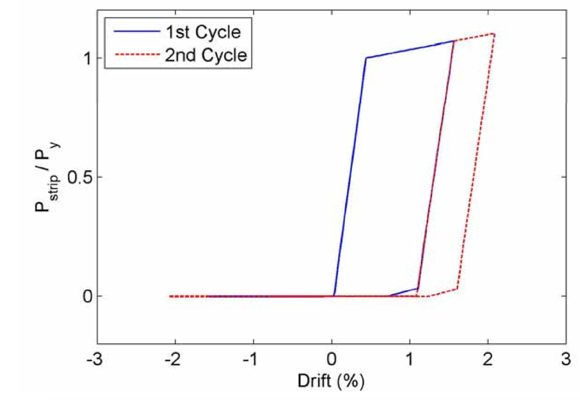


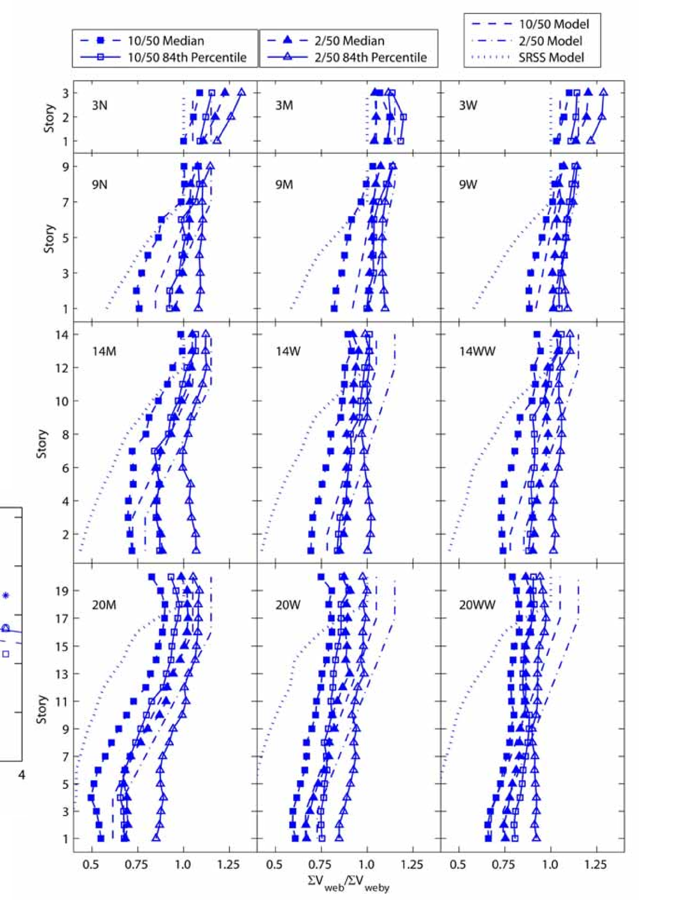






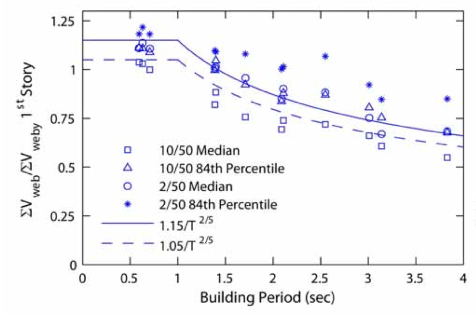






Column Axial Load Demands in SPSW:

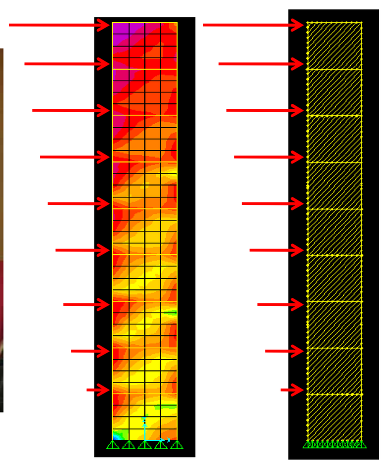
As part of the project focused on improving the understanding of SPSW behavior and developing more efficient designs, column axial load demands in multistory SPSWs have been studied via numerical analysis in OpenSees. This research utilizes nonlinear response history analysis using suites of ground motions and an array of steel plate shear wall designs to quantify expected VBE axial load demands. It is shown that demands resulting from capacity design are significantly larger than those from response history analysis for design level ground shaking for taller steel plate shear walls and are smaller for low-rise steel plate shear walls. The former is attributed to higher mode effects preventing simultaneous yielding of all web plates and the latter is due to strain hardening of web plates. A simple procedure for adjusting the VBE axial load demands found from capacity design to reflect the demands observed in design ground shaking is proposed. Drift demands were also evaluated and the deflection amplification factor is found to adequately approximate steel plate shear wall drifts in most cases.



Seattle U. Undergraduate Participation:

Undergraduate students from Seattle University have participated in the project in during Year 1. Four seniors have designed a set of SPSWs that will be used as the basis for analytical studies to improve the efficiency of SPSW design and compare performance with R-SPSW designs. The designs include three and nine story structures governed by wind loading, and three and nine story structures governed by seismic loading. After completing these designs, the students compared the demand forces and ease of implementation between the orthotropic plate modeling method and the strip modeling method among several other tasks. The students produced a comprehensive report of their results, design drawings, and presented their work at SU Projects Day and at the UW to graduate and undergraduate students. The students will continue to monitor the progress of the research remotely.

Glenn Strid (SU), PI Jeff Berman (UW), co-PI Laura Lowes (UW), Jeff Dragovich (SU Faculty), Sean Wegener (SU), James Grant (SU), and Jeri Shimazu (SU)



FINAL SECTION SIZES:

9 STORY WEST COAST DESIGN

FLOOR / SPSW	HBE	VBE	SPSW THICKNESS
ROOF (R)	W18 X 86	W14 X 370	NA
9	W18 X 86		0.0625"
8	W18 X 86		0.1046"
7	W18 X 97		0.1345"
SPLICE 2 (S2)	NA		NA
6	W18 X 86	W14 X 730	0.1875"
5	W18 X 119		0.1875"
4	W18 X 86		0.25"
SPLICE 1 (S1)	NA		NA
3	W18 X 86		0.25"
2	W18 X 143		0.25"
1	W14 X 74		0.3125"

NOTE:

SPSW MATERIAL: A36
W-SECTION MATERIAL: A992 GR. 50
TENSION FIELD ANGLE: 46° FROM HORIZ