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Investigation of Viscous Damper Effect on the Behavior of Thin Steel Plate Shear Walls

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ABSTRACT: Steel plate shear wall systems have attracted researchers' attention as lateral force-resisting systems, owing to their high stiffness, capacity, considerable ductility, and energy dissipation. On the other hand, retrofitting and repairing these systems is uneconomical for low and medium seismic levels. Therefore, to limit damage, a new steel plate shear wall system equipped with viscous dampers has been proposed as a system capable of resisting lateral loads. In this paper, the behavior and performance of a composite thin steel plate shear wall system with viscous dampers is investigated numerically using OpenSees software. Structures are analyzed and designed in two cases: one with steel plate shear walls alone and one with steel plate shear walls coupled with viscous dampers. Their seismic performance and collapse assessment are studied. Furthermore, the interaction between the steel shear wall and the viscous damper is examined. Results show that with the increasing number of stories and the dominance of flexural mode over the structure, the interfering deformations of the wall and damper produce interaction between the steel plate shear wall and the viscous damper bracing frame. Collapse assessment results demonstrate that utilizing viscous dampers along with the steel plate shear wall system in 8, 16, and 24-story structures leads to the significant increase in collapse margin ratio by 100%, 92%, and 66% respectively. It also reduces annual collapse probability by 75%, 79% and 58% respectively, which indicates the influence of the viscous damper and underscores the importance of using this component.

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1- Introduction

Steel plate shear walls (SPSWs) have emerged as efficient lateral load-resisting systems due to their high initial stiffness, strength, and energy absorption capacity [1]. However, repairing damaged SPSWs is typically not cost-effective for low-to-moderate seismic hazard levels [2]. To address this issue, it has been proposed to combine SPSWs and supplemental damping devices to enhance seismic resilience over a range of hazard levels. Viscous fluid dampers can provide beneficial supplemental damping and dissipate significant energy through fluid flow [3,4]. This study focuses on the use of viscous dampers coupled with SPSWs for improved seismic performance (Figure 1). This paper numerically analyzes the behavior and collapse capacity of SPSWs with and without viscous dampers. Incremental dynamic analysis is utilized to develop collapse fragility curves across building heights. Furthermore, the interaction between the SPSW and damper brace frame is examined through nonlinear time history analysis.

2- Verification of the numerical Model with Experimental Results

A single-story steel shear wall specimen named DS-SPW was experimentally tested by Sabouri and Sajjadi (Figure 2) [5]. The numerical model of this specimen was created in

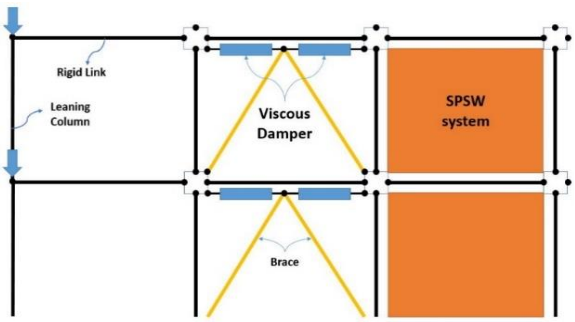

Fig. 1. Structure with steel shear wall and viscous damper systems

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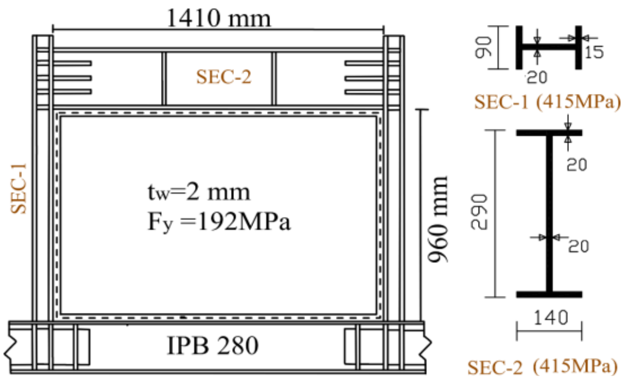

Fig. 2. Details of Tested Sample [5]

Table 1. Results of incremental dynamic analysis of models

	model	$[S_a]_{collapse}$	Sa [2/50]	$\lambda_{collapse}$ [$\times 10^{-4}$]	S_{MT}	CMR
8 story	SPSW	1.75	0.155	0.943	0.7	2.50
	SPSW-VD	2.25	0.81	0.235	0.45	5.00
16 story	SPSW	0.96	0.37	2.14	0.45	1.85
	SPSW-VD	1.05	0.15	0.42	0.22	4.47
24 story	SPSW	1.80	0.3	2.26	1.05	1.71
	SPSW-VD	2.21	0.4	0.95	0.8	2.76

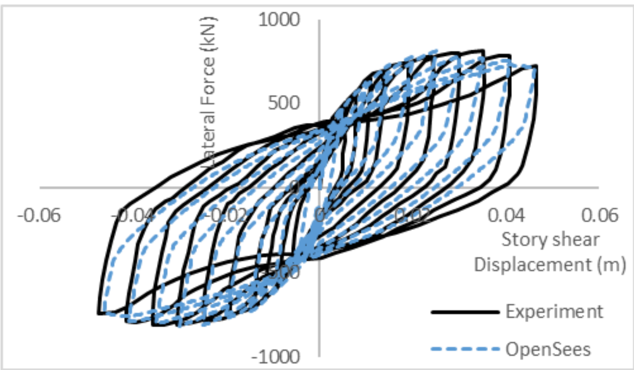

Fig. 3. Experimental and Numerical hysteresis loops

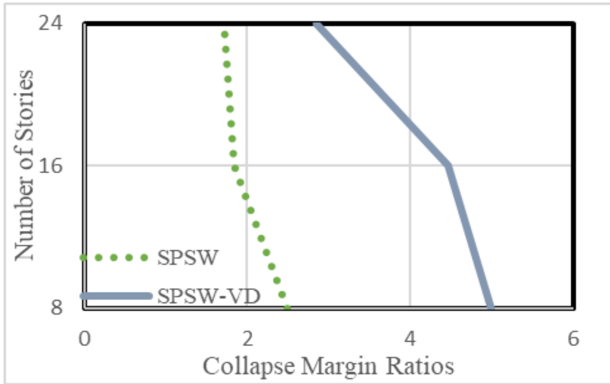

Fig. 4. Collapse Margin Ratio (CMR)

OpenSees and verified by comparing results. The test setup consisted of attaching the specimen to a rigid floor via a bottom beam. Lateral shear forces were applied to the top beam using two hydraulic jacks per ATC-24 [6]. The steel plate yielded at 7.1 mm drift in the sixth cycle. Maximum load and drift reached 6,789 kN and 34.5%, respectively. The hysteresis loops of the experimental and numerical (OpenSees) models were compared (Figure 3). The analytical model reasonably captured the lateral forces, story drifts, and stiffness compared to the test specimen. In summary, the verification study showed good agreement between the OpenSees model results and experimental data, validating the numerical modeling approach used.

3- Results and Discussion

Steel shear wall systems in 8-, 16-, and 24-story buildings were analyzed with and without viscous dampers under earthquake ground motions. The results of the incremental dynamic analysis of the models are presented in Table 1. Using dampers with steel shear walls substantially increased collapse margin ratios by 100%, 92%, and 66% for 8-, 16-, and 24-story buildings, respectively, highlighting the effectiveness of dampers (Figure 4).

Viscous dampers considerably reduced annual collapse probabilities by 75%, 79%, and 58% for 8-, 16-, and 24-story buildings, respectively, demonstrating the importance of dampers. Collapse risk increased with building height (Figure 5).

In the 8-story building, the steel shear wall exhibited larger drifts throughout compared to the damper bracing frame, deforming in a shear mode. The bracing frame restrained the wall drifts, especially at the base, deforming in flexure below and shear above mid-height. In 16- and 24-story buildings, the damper frame limited the wall drifts at the top and base, transitioning from flexure to shear between mid-height and top. The wall is deformed predominantly in shear below and flexure above mid-height. In taller buildings, steel shear wall drifts increased above mid-height, while the damper frame restrained the wall. Interaction forces between the wall and frame were significant at upper stories. At mid-height, interaction depended on relative stiffness and deformation modes.

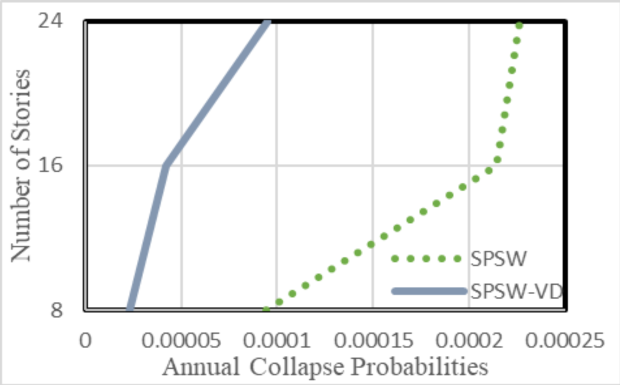

Fig. 5. Annual Collapse Probability (λCollapse)

4- Conclusions

Overall, the results demonstrated that the dual system of steel plate shear walls and viscous dampers enhances the seismic performance and collapse resistance of steel structures over a wide range of heights.

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