

Seismic Performance Evaluation of Steel Shear Wall by Equivalent Truss Approach Modeling

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ABSTRACT

Steel plate shear wall is one of the efficient and economical lateral resistance systems which has been implemented in various structures, located in highly seismic prone. Infill steel panel is surrounded by beams and columns as boundary elements, to provide sufficient lateral stiffness of structure. This study presents verification between prior studies and computer modeling of various structures equipped by steel shear walls based on equivalent truss element method. Furthermore the efficiency of aforementioned system is compared with special brace frame in terms of maximum displacement, base shear, axial force, rotation of critical columns and material usage by aid of time history analysis. The results shows that existence of shear wall as lateral resistance system decrease maximum displacement, base shear, axial force, torsion of critical columns about 25 %, 60%, 50% and 80% respectively, compared with structure equipped by special steel concentrically braced frame. Both systems passed the code requirements for maximum displacement, but application of steel plate shear wall reduced total weight of structural steel elements around 21%. Furthermore results reveal that equivalent truss element is reliable method for modeling shear wall element in computer modeling since results are verified by previous studies as well.

INTRODUCTION

Nowadays application of effective resistance system for structures subjected to lateral force such as earthquake and tsunami incredible increased (Hejazi 2009 2013). Steel plate shear wall (SPSW) systems have been used as lateral resistance component in recent years in a few structures around the world. SPSW system consists of vertical steel plate infill which is connected to the adjoining beams and columns and installed in one or more bays along the full height of the structure to form a cantilever wall. General types of steel shear walls are introduced as unstiffened and stiffened wall with or without openings (Astaneh-Asl 2001). As

determined by several experimental and analytical investigations SPSWs subjected to cyclic inelastic deformations exhibit high initial stiffness, behave in a very ductile manner, and dissipate significant amounts of energy. These characteristics make them suitable to satisfactorily resist and dissipate seismic loading (Thorburn et al., 1983; Timler and Kulak 1983; Driver et al., 1997). Behaviour of unstiffened thin steel plate shear wall with various thicknesses under seismic and wind loads was evaluated by aid of experimental study as well as finite element analysis. The results reveal that the thickness of SPSW plays an important roles in lateral resisting performance (Caccese et al., 1993; Berman and Bruneau 2005). Besides, Post buckling behaviour of SPSW was investigated through numerical modelling and finite element analysis by considering both material and geometry nonlinearities. Results from numerical study were verified with experimental test as well. Thin plates where sufficiently supported along their edges had a post buckling strength several times more than their elastic buckling strength (Elgaaly et al., 1993). Cyclic test on full-scale 4-Story structures equipped by unstiffened shear wall were assessed and results proved that, SPSW initially was very stiff, but subsequently demonstrated excellent energy dissipation and ductility characteristics and stable behaviour at very large deformations after many cycles of loading (Driver et al., 1998). Rezai (1999) conducted a study on seismic behaviour of unstiffened steel shear wall through numerical and experimental shaking table test. Efficiency of SPSW application as lateral resistance system in structures was confirmed throughout the results. Plastic analysis and new design approach of SPSW were proposed by Berman and Bruneau (2003). In addition, finite element model and simplified method of SPSW which used in commercial software was established by Driver et al.(1998). Strip model is one of the alternative for simplified and modelled the thin shear wall which is originally introduced by Thorburn et al.(1983). Strip model analyses were illustrated good agreement results by experimental and finite element modelling.

This study focuses on seismic performance of building structure equipped by SPSW. Therefore at first stage, to prove reliability of software, verification between results from software analysis with prior researches is indispensable. Subsequently 18-story buildings are modelled with Special Steel Concentrically Braced (SSCB) Frame and SPSW systems. Then, the results in terms of structural response as well as economic aspects are compared.

DESCRIPTION OF MODELS AND METHOD

Present research is aimed to evaluate the behaviour of SPSW by aid of structural analysis program package. Verification with previous researches is essential to ascertain the efficiency of software. Therefore SPSW models which were investigated by Lopez-Garcia and Bruneau (2006) are considered as benchmark. 4-story building are modelled and assumed that a total of 4 SPSWs provide lateral resistance system where situated at the central bay of the 3-bay frames. Seismic loads were calculated for structure which is located in Northridge, California. The natural period of model was estimated by: 0.38 sec with total height of 51 ft. Assuming, Occupancy Factor $I = 1.5$ (hospitals belong to Seismic Group III), Soil Type D and $R = 7$ (AISC 2005). So seismic response coefficient is equal to $C_s = 0.25$.

Figure 1 illustrates the summary of loads which are implemented in modelling. Dead load for all level are considered as 0.8 Kip/ft and live load for all story and roof are calculated 0.25 and 0.13 respectively. Furthermore equivalent seismic lateral forces are calculated too.

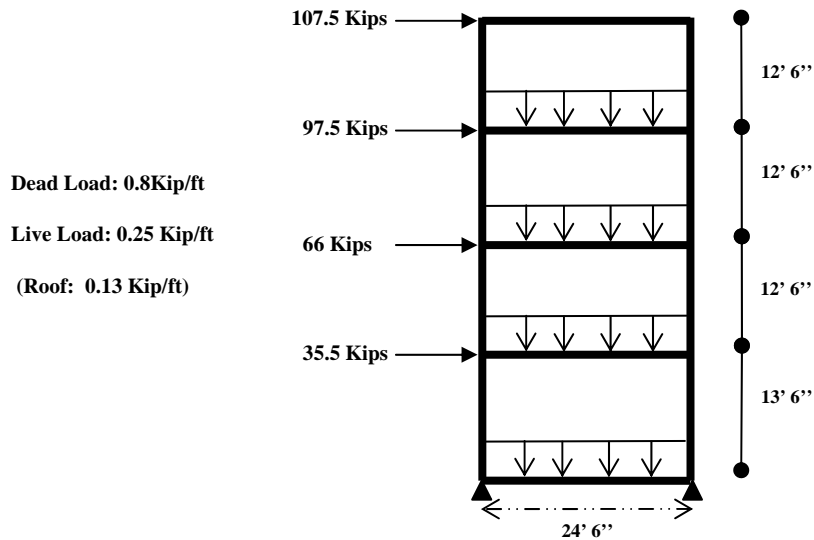


Figure 1. Loads and geometry description of the SPSW models.

The SPSWs were modelled and analyzed by aid of commercial computer program. Each web was modelled by a set of 10 both ends pinned strips which are uniformly spaced, parallel and acted as tension elements. Meanwhile all beams and columns were modelled by normal frame elements. Young modulus of strip is assumed as equal to normal steel. Modelling approach of SPSW is known as the strip model. The accuracy has verified throughout comparisons with previous numerical and experimental results (Driver et al., 1998; Lopez-Garcia and Bruneau 2006). Forces applied by the ASCE 7 load combinations provision and were prognosticated via FEMA 450's Equivalent Lateral Force (ELF linear static analysis) process. All the intermediate beams are considered with same size. For SPSW, A36 steel was assumed ($f_{yp} = 36$ ksi) and A992 steel was considered for Vertical Boundary Element (VBEs) and Horizontal Boundary Element HBEs ($f_{ym} = 50$ ksi). Drift of models were checked to satisfy story drift's limitation based on FEMA 450 limitations ($\leq 1.50\%$). Models are designed based on FEMA/AISC regulations and CAN/CSA S16-01 regulations. Two models are analyzed with constant and variable thickness size of SPSW. Geometry description for both models can be found in Tables 1 and 2. Moreover the schematic view of two models are shown in Figure 2.

Equivalent Truss Member Area

$$A = \frac{\frac{Wl}{2} \sin 2\alpha}{\sin \phi \sin 2\phi}$$

A = Area of Equivalent Truss Member , W Thickness of infill panel, $\tan \phi = \frac{L}{h}$

$$\tan^4 \alpha = \frac{1 + \frac{Lw}{2A_c}}{1 + \frac{hw}{A_b}}$$

Where, h= Height of Panel, L = Length of Panel, A_c= Cross Sectional of Column, and A_b= Cross Sectional of Beam

Table 1. Geometry Description of First Model with Variable Thickness of SPSW.

SPSW	STORY	Length (inch)	Height (inch)	Panel Thickness (inch)	Aspect Ratio (L/H)	Equivalent Truss Area (inch ²)	Diameter of Truss (inch)
S1	1	295.2	163	0.1802	1.811043	18.52337	4.856478
S2	2	295.2	151.2	0.171	1.952381	18.95	4.9
S3	3	295.2	151.2	0.1245	1.952381	13.8	4.2
S4	4	295.2	151.2	0.0632	1.952381	7	2.98

Table 2. Geometry description of Second Model with Constant thickness of SPSW.

SPSW	STORY	Length (inch)	Height (inch)	Panel Thickness (inch)	Aspect Ratio (L/H)	Equivalent Truss Area (inch ²)	Diameter of Truss (inch)
S1	1	295.2	163	0.1875	1.811043	19.322	4.96
S2	2	295.2	151.2	0.1875	1.952381	24.28	5.56
S3	3	295.2	151.2	0.1875	1.952381	24.28	5.56
S4	4	295.2	151.2	0.1875	1.952381	24.28	5.56

After verification, two 18-story buildings are modelled with SPSW and Special Steel Concentrically Braced (SSCB) Frame systems, with same configuration of 3 x 5 bays. Panel thicknesses are selected as 1.5 and 4 mm along the structures height. Results from aforementioned models are compared in terms of structural response as well as structural material usages to assess economical perspectives. Moreover time history analysis is performed to evaluate structural response. El-Centro USA -1940 acceleration record is applied. Study outcomes are compared in terms of displacement, rotation at directions, base shear and critical axial forces at bottom columns. Figure 3 shows SWSP and SSCB models in software interface.

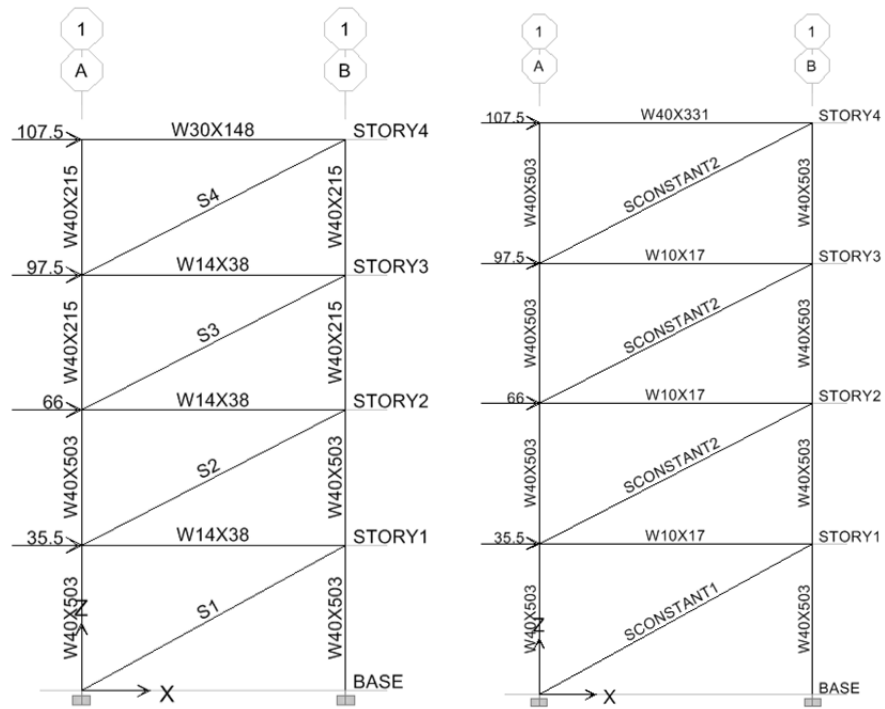
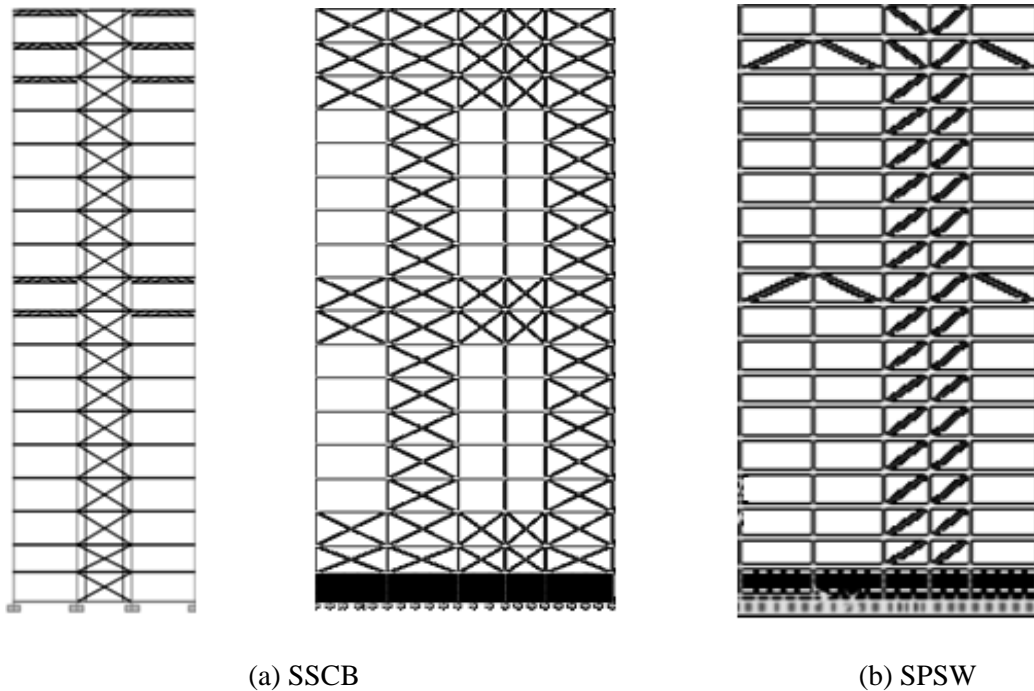


Figure 2. Schematic view of verification models.



(a) SSCB (b) SPSW
 Figure 3. Eighteen-story building with SSCB system and strip model of SPSW.

RESULTS AND DISCUSSION

Verification is performed based on prior studies in terms of displacements and base shear. The maximum differences between software values and experimental studies are just 3% and 8% for model with constant SPSW thickness and variable thickness respectively. Therefore reliability of software is verified.

Results from 18-story building's models shows that, maximum drift for both models are lower than the allowable drift limit which is stipulated in seismic code. Besides, maximum critical displacement at in SSCB model is around 24 mm, since this value is 18 mm for SPSW models. It means the application of SPSW as lateral resistance system, caused to decrease maximum displacement approximately 0.25%. Moreover both model satisfied the allowable displacement based on seismic code requirement. From economical aspects, the SPSW can be introduced as an alternative method due to reduction of structural material about 21% with same seismic performance level compared with SSCB system. Results from time history analysis also reveals maximum displacement of SSCB and SPSW system in structure are lower than allowable limit. Additionally maximum value of displacement at SPSW declines around 25% compared to SSCB.

Results from torsion time history shows that, the maximum torsion at critical columns in SPSW system is reduced dramatically around 80 % compared with SSCB model. Additionally, maximum axial force in bottom column at SPSW model is also declined roughly 50% compared to SSCB model. Also, value of base shear is diminished around 60% in SPSW models.

CONCLUSION

In this study an attempt has been made to evaluate to structural response of SPSW application in structures by aid of software modelling .at first step, the reliability of software is verified by former studies. Afterwards, the structural performance of SPSW is assessed via comparison by Special Steel Concentrically Braced (SSCB) system. Time history analysis is performed for both aforementioned models and results were obtained in terms of drift, displacement, maximum torsion, axial force in critical columns and base shear. Furthermore economical aspect is evaluated in terms of structural material usages in both models. Results discloses that, application of SPSW as lateral resistance components not only satisfied the limitation of seismic provision but also decrease maximum displacement, base shear, axial force, torsion of critical columns about 25 %,60%, 50% and 80% respectively, compared with structure equipped by Special Steel Concentrically Braced (SSCB). Moreover results from verification models, yields equivalent truss element is reliable method for modeling shear wall element in computer modeling since results are verified by previous studies as well.

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