



The Influence of Geometric Characteristics on The Performance of Steel Shear Wall

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ABSTRACT

The aim of this study is to investigate the mutual effect of geometrical properties of steel shear walls on their performance. This study was numerically performed using ABAQUS finite element software for simulation. In this study the effect of the diameter of the openings to the steel shear wall height ratio and the hardeners angles have been studied nonlinearly. The results show that as a result of the opening of the sheet, the shear resistance decreases proportionally to the decrease in its cross-sectional plane, but on the other hand, it increases the steel plate shear wall ductility and the 8% diameter is the largest diameter of opening which has a good effect on shear wall performance and the presence of reinforcing elements such as hardener increases the hardness of the steel shear wall and in this case it shows that using cross hardeners has the most effect in absorbing the energy of steel shear wall.

Keywords:

SPSW, Energy Absorption, Non-linear analysis, Opening and stiffener.



1. Introduction

In recent years, the use of the steel plate shear walls (SPSW) system has been the focus of attention of scholars in different countries as a load-resisting system, including our country, which is located in a high-risk seismic zone. This system is made of hardened or thin steel sheet without hardener, which is surrounded by a steel frame, with each plate inserted into and attached to the steel frame. This type of deployment resembles a steel shear wall to a cantilever beam in which the columns and sheet are as flange and web plates, and the beams are as the vertical hardeners. This type of wall is a relatively new system that was the focus of attention in the 1970s for its many advantages. These advantages include high ductility, high energy absorption, high hardness and resistance, and stable hysteretic behavior, as well as being economical and easy to implement. Takahashi et al (Takahashi et al, 1973) [1] performed the first major research program on the behavior of steel shear panels in 1973. They conducted a number of experiments by quasi-static cyclic loading on one- and two-story reinforced and unreinforced steel shear panels. The idea of using a special opening in the wall goes back to Omori and Muth (Omori and Muth, 1966, 1968) [2-3]. They suggested the use of notch in concrete shear walls in order to improve the seismic behavior of reinforced concrete shear walls. Hitaka and Matsui (Hitaka and Matsui, 2003) [4] studied the function of notch in steel shear walls. They tested 42 steel sheet walls, samples with 1/3 scale under cyclic and monotonic lateral loading. All specimens behaved in a ductile manner. In a 1992 study, the effect of a central opening with deferent diameters on the cyclic behavior of steel shear panels was investigated. It has been suggested that the stiffness and toughness of panels with openings can be conservatively estimated by applying a linear decrease coefficient to the hardness and strength of the panels without openings (Robert TM and Sabouri Ghomi, 1992) [5]. Also Nateghi F, Alavi (Nateghi F and Alavi, 2010) [8] has shown that the diagonal stiffeners increase the shear resistance on steel shear walls with diagonal stiffeners increase and improve the cyclic behavior of the thin steel plate shear walls. Accordingly, it is assumed that the combination of the special openings with the diagonal hardener may behave effectively. Therefore, this study focuses on the reinforcement of shear strength and hardness of the panels having openings and even the improvement of the nonlinear behavior of the steel walls with openings by diagonal hardening method. This paper presents the results of an in vitro and numerical research on three single-story steel plate wall samples with a scale of 1.2. Hosseinzadeh and Tehranizadeh (Hosseinzadeh and Tehranizadeh, 2012) [6] have studied the behavior of thin steel shear walls with large rectangular openings, which is used as a door or window in conventional buildings, numerically using the finite element method. The results indicate that the location, geometry, and type of door or window of openings alone do not affect the behavior of reinforced open systems. In addition, with the opening of and the reinforcing elements around it, it increases the strength and stiffness of the system, while its ductility decreases. The results also showed that the role of the reinforcement elements in increasing the frame resistance can be quite significant.

Also Alavi and Nateghi (Alavi and Nateghi, 2013) [9] conducted an experimental study on diagonal stiffened steel shear walls with central holes in 2013 and the seismic behavior of the system significantly improved. The test results show that the ductility of the perforated sample is about 14% higher than the specimens with hardener. There is good agreement between the experimental and numerical outputs. And in another study, Bhowmick et al (Bhowmick et al, 2014)[10] in 2014 investigated the behavior of steel plate shear walls with circular holes in the



filling plate, in their research they developed a shear force model based on the string model where all strings are removed with a hole and the comparison between the nonlinear Push – Over analysis and the proposed equation show good agreement. In the same year, Egorova et al (Egorova et al, 2014) [11] conducted a study titled: the empirical study of circular-shaped steel plate shear and suggested that a new type of steel plate shear wall is developed which is resistant against out of plane buckling and has a good hysteretic response. Farzampour et al (Farzampour et al, 2015)[12] studied a research titled as predicting the behavior through corrugated steel sheet with opening was which the method of this study was finite element. This analysis investigates the steel shear walls with openings in simple and corrugated steel shear walls. And also in the same year Saeed Sabouri - Ghomi (Saeed Sabouri – Ghomi, 2015) in 2015, examined the shear wall of stainless steel sheets with two rectangular openings empirically.

In this study, they investigated the performance of a steel shear wall with hardener with two openings and its method was in vitro and the analysis is obtained from cyclic load and hysteresis diagrams. And in another paper, Abadi and Zandi (Abadi and Zandi, 2016) [13] in a study “evaluating the effect of shape, size, and distance of POPs on the nonlinear behavior of steel shear walls” state that the shape and location of shear wall holes affect tensile and non-adhesive transitions as well as the ductility, flexural strength, and absorptive energy capacity of the earthquake. Analyzes were conducted by abacus finite element software. The final load and displacement load curves obtained by numerical analysis are in good agreement with the results of related experiments. In recent research into the 2018 J.Kiani1, K.D. Tsavdaridis (J.Kiani1, K.D. Tsavdaridis, 2018) [15] studied the convergence and impact of mesh size (networking) on the response of the steel shear wall with the circular opening and investigated the influence of the number of meshing on the hysteretic response in the Abacus software. And finally Khaloo et al (Khaloo et al, 2019) [16] reported that past several experimental studies have reported SPSW fractures due to crack propagation during the experiment, but experimental studies have not investigated the crack effect. Regarding the thickness of the steel sheet and the crack rigidity, crack propagation in SPSW with hardeners cannot be ignored. In this paper, the behavior of SPSW with diagonal hardeners is enhanced and has been studied using finite element considering the crack propagation. Numerical results showed that the solid walls behave better than SPSW in both elastic and non-elastic regions. It is also concluded that thicker hardeners enhance the SPSW seismic parameters (hardness, energy absorption and capacity). The crack effect is also presented as mathematical equations for estimating the displacement load curve. The equations presented are in agreement with the results of numerical studies of the element. The steel plate shear walls have shown favorable performance in past experiments and earthquakes. The benefits of SPSW and its good performance against side loads encourage designers to use these systems in their projects. Some important aspects of SPSW remain unknown despite valuable empirical and numerical studies. One of the unknown properties is the influence of the relation of number and diameter of the openings with the height of the steel shear wall on the SPSW behavior. Numerous empirical and numerical studies have investigated openings with hardeners, but the impact of the hardener angle and the relation of openings on the SPSW height are not investigated in experimental studies. For this purpose, 8 SPSW samples were simulated that lead to increased energy absorption by varying the diameter of the openings relative to the height and angle of the hardeners in different models.



2. Simulation Assumptions and Verification

In this numerical study, the effect of openings and hardeners on SPSWs has been investigated, and since it has always been one of the benchmarks of the research, it has been compared to similar research studies. Hence simulation of non-hardener steel shear wall without openings (Alavi and nateghi, 2013) is studied to ensure the accuracy of the obtained results. This sample was performed one-story with scale of 1/8 under push loading according to the paper. It was simulated on a scale of 1/2 with 2 m wide and 1.5 m high in ABAQUS [17] software. The width / height ratio of the samples was 1.33 to represent the average dimensions of the shear wall in the building. This apparent ratio was assumed to be the actual size of the wall at 4 m wide and 3 m high. The border elements were made of standard HEB160 profile and thickness of the inner plate was 1. The boundary elements were designed to meet the basic requirements of steel shear wall and AISC 341-05 [18] regulations. The beam connections to the bending column are assumed.

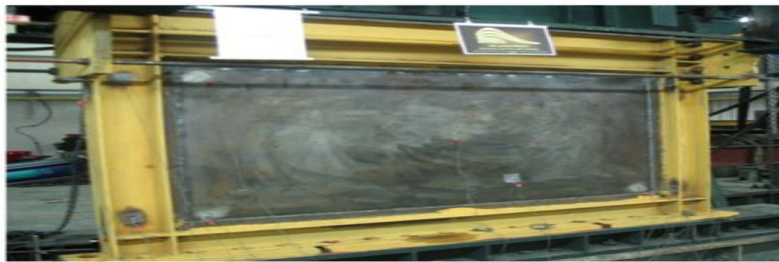


Figure 1. Sample used in the paper (Alavi and nateghi, 2013).

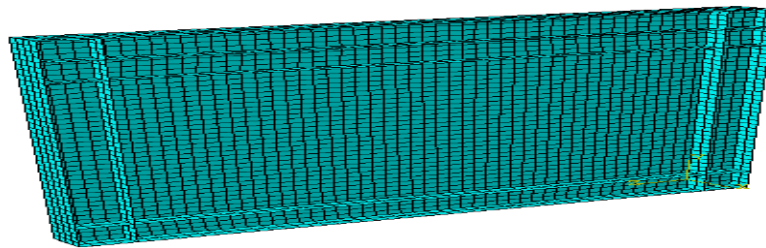


Figure 2. Simulation sample for verification.

The multilinear kinematic hardening model for soft steels was assumed based on the experimental data of the Coupon test (Alavi and nateghi, 2013). Unsteady analysis of large displacements was performed to combine nonlinear buckling and post-buckling effects on outputs. And to alleviate the convergence problem, J.Kiani1, K.D. Tsavdaridis (2018) paper is used to mesh and model the shear wall. The sample without hardener and opening was used as reference in the article. Structural steel was selected as steel materials. Mechanical properties of steel material are shown in Table 1.



Table 1. Specifications of used materials.

steel material	Elastic modulus (mpa)	Static yield (mpa)	Static ultimate (mpa)	Yield strain %	Hardening strain %	Ultimate strain %	Rupture strain %
HEB160	207000	400	450	0.19	2.7	13.2	15.1
Plate (THK.= 5 mm)	205000	3	470	0.17	3.06	20.5	22.3
Plate (THK.= 4 mm)	205000	460	550	0.22	2.67	19.1	20.8
Plate(THK.= 0.8 & 1 mm)	204000	280	500	0.14	0.3	21.6	27

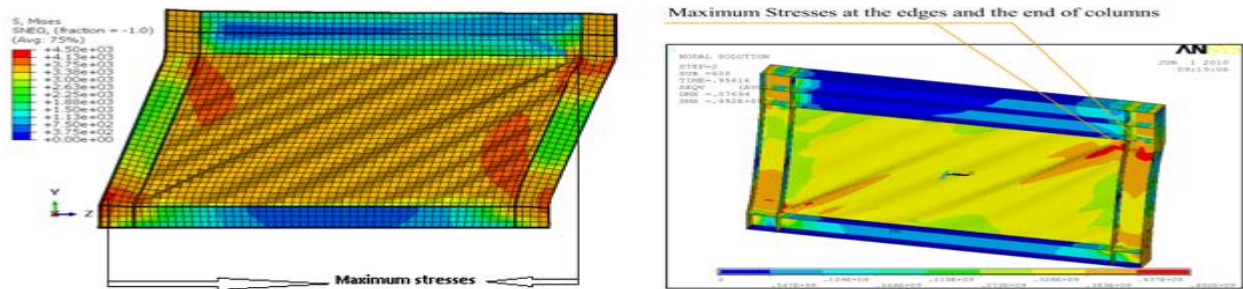


Figure 3. Comparison of stress color contour with von Mises criteria (Alavi and Nateghi, 2013) and simulated sample.

By comparing the amount of stress color contour formed on the SPSW and the maximum von Mises stress that occurred at the same locations and considering the push-over curve analysis, the resulting load-displacement is shown in Fig. 4. The highest shear strength of the reference model in (Alavi and Nateghi, 2013) is obtained by finite element analysis which is about 700 KN. This value is in good agreement with the model simulated in this study. And as for the cyclic loading, the results are consistent.

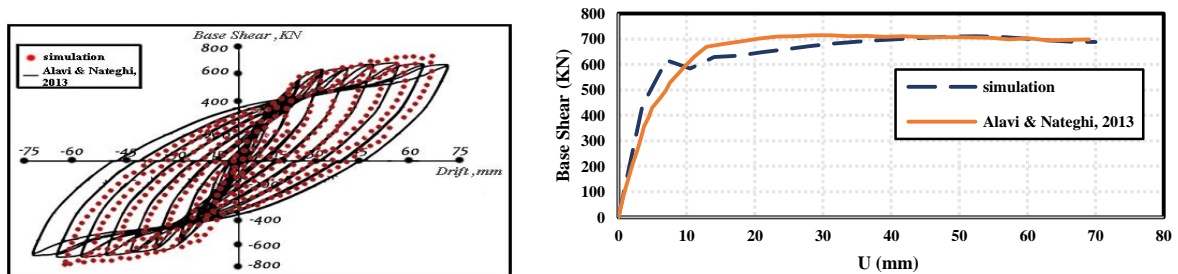


Figure 4. Comparison of the force-displacement push-over graph and hysteresis of the reference model (Alavi and Nateghi, 2013) and the simulated model



3. Optimal SPSW Design and Numerical Results

Numerical studies have been conducted on one-story single-span frame samples with cross, vertical and horizontal hardeners and 5%, 8% and 10% wall height hardeners which were performed numerically in Abacus finite element software. Each test was performed under quasi-static complete loading according to the ATC-24 test protocol. Horizontal loads were applied on samples with a capacity of 1000 kN. Considering the size of the building and depending on the dimensions of the samples, the gravity loads were considered to be 160 kN. The sample is 80 KN for each beam, and the boundary and loading conditions of the samples are quite similar to the conditions mentioned in (Alavi and nateghi, 2013).

Table 2. Specifications of simulated samples.

	Model specifications	Hole diameter	Number of holes	Kind of STIFFNER	Number of STIFFNER
S1	spsw with an opening of d=5% of height	6	40	-	-
S2	spsw with an opening of d=8% of height	9.6	40	-	-
S3	spsw with an opening of d=10% of height	12	40	-	-
S4	spsw with vertical stiffener	-	-	vertical	8
S5	spsw with horizontal stiffener	-	-	horizontal	5
S6	spsw with x-type stiffener	-	-	x-type	10
S7	spsw with x-type stiffener and 8% opening of height	9.6	40	x-type	10

Table 2 shows the dimensions of the studied samples in this paper and focuses on the relationship between the diameter and the height of the shear wall. It also studies the effect of the shape of hardeners and eventually we tried to study the simultaneous performance of 8% diameter opening and cross hardener.

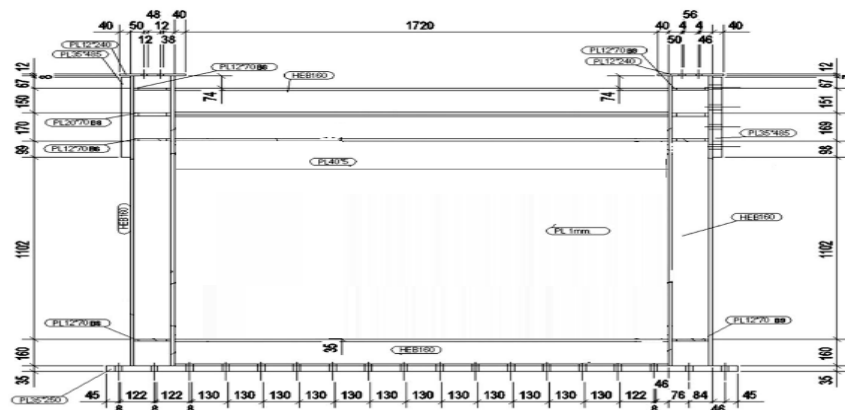


Figure 5. Schematic form of SPSW in which an example of hardeners is specified.

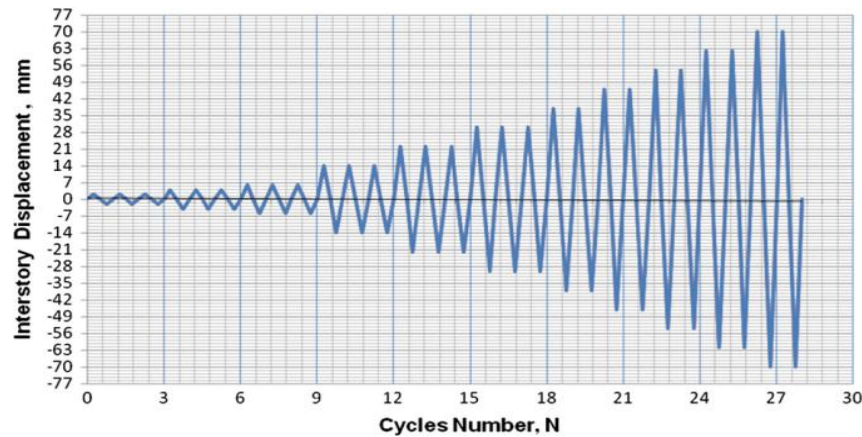


Figure 6. Cyclic load based on (Alavi and Nateghi, 2013) retrieved from ATC-24 Regulations.

Displacement history (loading protocol) is retrieved from TC-24 for the examination of these samples. This history corresponds to Figure 6 in the different cycles. It should be noted that the ATC-24 is a guideline that specifies the testing protocols used to determine the seismic performance of structures and non-structural components. The characteristics and geometrical model of the structure studied are illustrated in Figure 5.

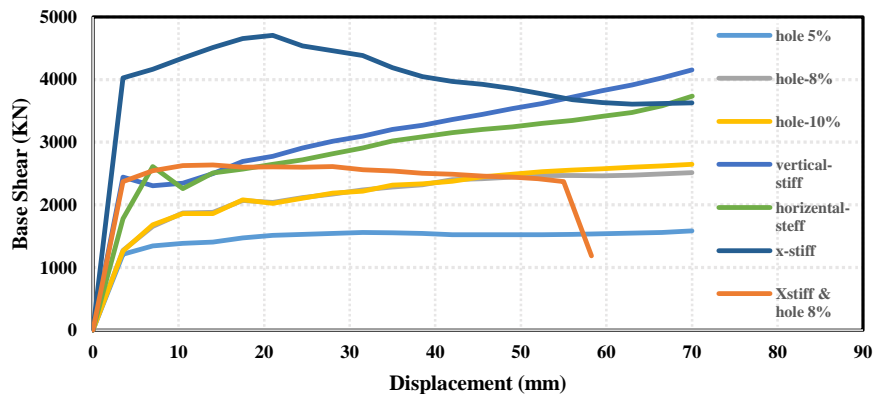


Figure 7. Push-over diagram of finite element analysis of samples.

As mentioned before, one of the objectives of numerical analysis of samples is to estimate the yield load and displacement of the samples. This data is required to create a loading program in accordance with the ATC-24 loading protocol. According to this loading protocol, the timeline includes step-by-step increase of periodic deformation, and the number of these cycles is recommended to apply at each loading step. Therefore, in the elastic area, the initial slope of the two displacements was 1.3 and 2.3 times the estimated yield displacement, and three cycles were determined for each loading step. Given this, 6 cycles were defined to be performed prior to the sample yield point. And three cycles were selected in the yield displacement. After the yield point and for the next three loading stages, the number of cycles remained at 3. Then for the subsequent loading stages until the final state, the number of cycles was reduced to 2 at each loading step. Figure 7 shows the load-displacement push-over curve analysis for all the studied samples. The



shear strength of the models differs from the finite element analysis method. And all the samples support up to 70 mm displacement but as it can be seen S7 is not able to endure high shear strength and cannot withstand 70 mm displacement and thus S7 is excluded from cyclic analysis of samples.

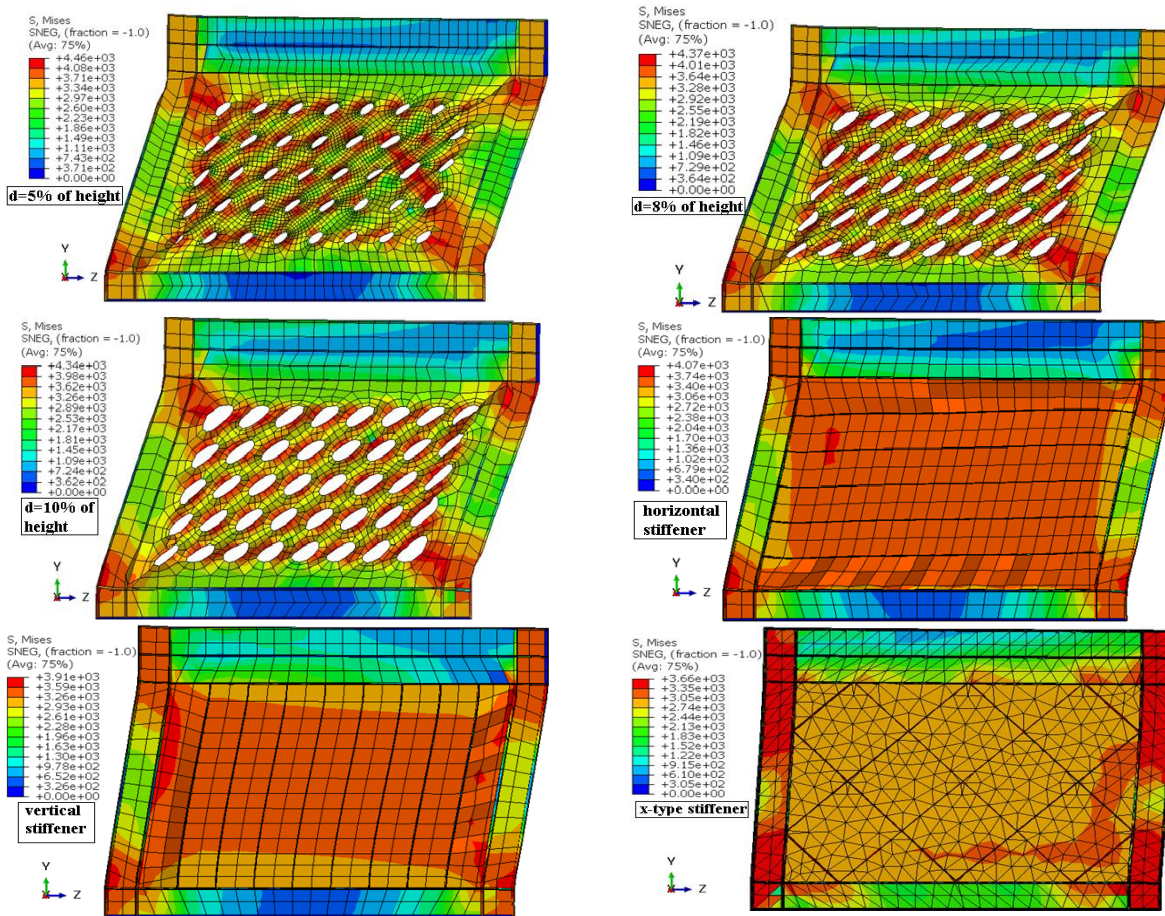


Figure 8. color stress contours with Von Mises criterion on SPSWs.

In Figure 8 it is evident that in models with openings, there is a greater stress on the wall plate, but it is also more ductile and has greater displacement, but in models that use hardening, Fig. 8 shows that there is less force in the shear wall and the displacement is less. In other words, when the hardeners are used, the performance and behavior of the SPSWs shows more hardness. This hardness was more in cross mode but when opening was used, the samples were more displaceable or more ductile, but it can be said that when the opening was used like the paper of Alavi and Nateghi, 2013 the maximum stress occurred in the boundary elements of the column, but the maximum stress has occurred on the shear wall sheet when using Etifner, but it can be said more precisely by changing the hardener shape (cross hardener) the maximum stress is formed on the columns.

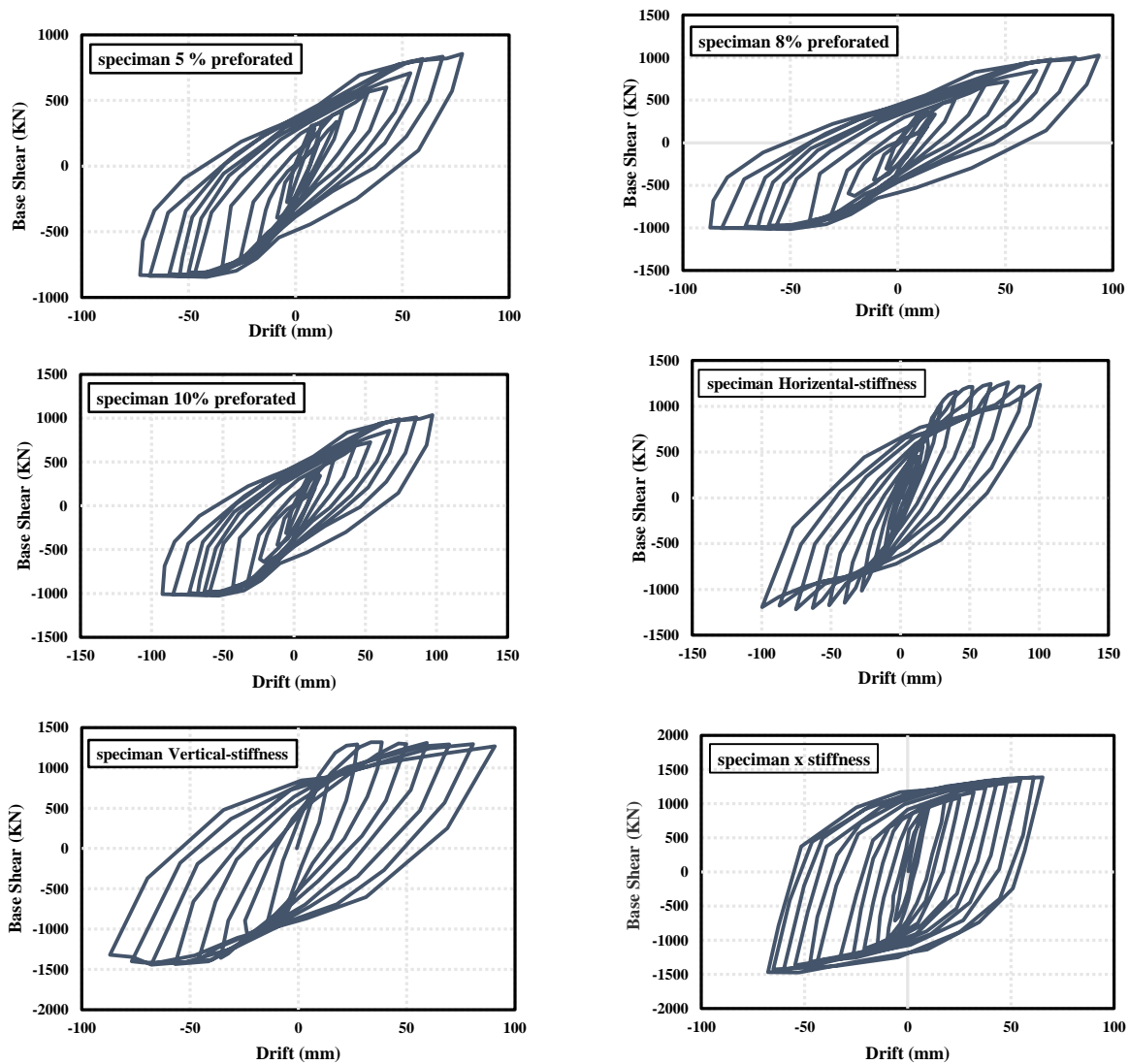


Figure 9. SPSW hysteresis diagrams.

By examining the hysteresis diagrams of Fig. 9, it is found that almost all the samples hysteresis have good stability and there was no decrease in resistance. And considering the hysteretic behavior of samples with opening, it is evident that they had more ductile behavior and by focusing on the behaviors of samples with hardener, it is found that they behave harder, but the main aim of this study is to increase the energy absorption of the samples, which can be commented on by the energy of each sample, but what is clear is that there is increased resistance in hysteresis diagram of cross hardener sample and it also has acceptable ductility. Also it can be said that the behavior in hysteresis diagram of S2 and S3 is not changed significantly and neither hardness nor ductility is changed compared to S1.

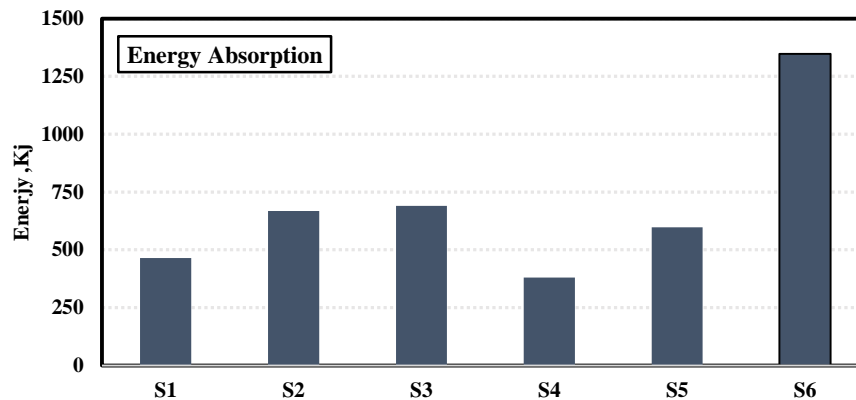


Figure 10. Energy absorption of specimen.

In the bar graph above, the area of the hysteresis diagram of each sample is calculated, as it can be seen that the area below the surface of the sample hysteresis diagram is equal to the amount of energy absorbed by each of the samples. Hence figure 10 shows the exact calculation of this area and considering this diagram it can be observed that in this paper, the area of hysteresis cycles of simulated samples has increased compared to previous researches, and the other reason for increasing the energy absorption is that the samples in this paper have withstood more hysteresis cycles, and did not have increased hardness or ductility. In general, the samples of this study can be divided into two groups: samples with opening having greater ductility and samples with hardener having more hardness, and it can also be said that openings with diameter of 8% of wall height can increase energy absorption and maintain a steady process, also the best way to use a hardener is a cross-type hardener that has higher energy absorption.

4. Conclusions

In this paper, the performance of steel shear walls is investigated using finite element method. According to studies and research, efforts have been made to increase the energy absorption by modifying the hardener shape and opening of these SPSW, so the following results are summarized in this paper:

- Cross hardeners appear to be an effective and capable modifier on shear panels.
- Cyclic simulation showed that almost all samples had stable hysteresis cycles and behaved as a suitable energy-consuming system.
- The panel opening diameter and panel height are proportional to the energy absorption ratio of the steel shear wall and the best ratio is 8%.
- Vertical and horizontal hardeners cause maximum stress in wall panels, while cross-hardeners cause maximum stress to be transferred to structural boundary elements.
- In the models of the vertical and horizontal hardeners, a slight decrease in resistance was observed in the hysteresis diagrams and this problem was solved in cross hardeners.
- If a combination of opening and hardener is needed, it is best to use circular hardeners around the circular openings to provide the required ductility.



- The results show that if the openings with diameter greater than 8% are used, the ductility will remain constant but this increase in diameter will cause a hard decrease in the steel shear wall, which regarding the constant ductility, this decrease in hardness can reduce the energy absorption of the steel shear wall.

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