Science Arena Publications
Specialty Journal of Architecture and Construction
ISSN: 2412-740X
Available online at www.sciarena.com
2019, Vol, 5 (2): 1-8

Investigating the Effect of Openings in Steel Plate Shear Walls Reinforced Based on Method V

Saeid Jafarpour[1]*, Nader Abdoli[2]

[1] Master of Science in Civil Engineering - Earthquak
[2] Faculty Member, Islamic Azad University, Taft Branch, Iran.

***Corresponding Author**

Abstract: *Background and Objective: steel shear walls are used as an effective lateral load-bearing and cost-effective resistant system in newly built high-rise buildings for counteracting the forces resulting from wind and earthquake in regions prone to frequent earthquakes. These walls are also utilized for reinforcing the existing buildings for increasing the resistance and hardness. The main duty of the steel plate shear wall is providing resistance against horizontal shear of the floor and overturning moment resulting from the lateral loads. Study Method: the present study seminally analyses the effect of openings in steel plate shear walls reinforced based on method V following which the openings' edges are strengthened and analyzed. To perform modeling, Abacus software was used. Moreover, the single-floor model proposed by Dr. Sabouri Ghomi (2008) was employed. Findings: to model the laboratory specimen in Abacus software in 3D, deformable shell-extrusion elements were utilized. According to the obtained results, creation of opening degrades the performance of the steel plate shear wall. The openings' edges in the steel plate shear walls have been reinforced in the present study using the method proposed in [V] to make up for the performance degradation. Conclusion: according to the results, reinforcement work based on the method proposed in [V] played a good role in retrieving the opening-induced performance diminishment of the steel plate shear walls.*

Keywords: *Steel Plate Shear Wall, Openings' Effect, Openings' Edge Reinforcement, Method [V]-Based Reinforcement*

INTRODUCTION

The steel plate shear wall is like a steel cantilever plate beam in which the columns are the plate beam's wings, the floors' beams are the stiffeners and the steel plates constitute the body. In this system, the connection between the beams and columns can be simple or rigid and, unlike the plate beams in which the wings do not play a considerable role in depreciating the shear forces for their being weak, the columns can play a good deal of role in load-bearing in steel plate shear walls for the fact that these members are strong enough (Hosseini, 2014).

During the recent years, steel plate shear walls have been used as systems capable of resisting the lateral loads in a number of buildings mostly built in Japan and Northern America. Steel plate shear walls feature a great many of advantages as compared to the other building systems in terms of cost, implementation and ease of design. In comparison to the concrete shear walls, thickness reduction (hence plan substructure's surface area enlargement) is deemed as an essential benefit.

Mass reduction can also be very important in designing of the foundation with its most important merit being that the steel plate shear walls can be installed at a time a lot shorter than the concrete shear walls. The steel plate shear walls can be considered as an option for braced frames. They can supply equivalent hardness and resistance and need similar or smaller plan area. The speed of shear wall construction, as well, is comparable to that of the braced frames. While there is a need for a large amount of welding in the workshop, most of the workshop welding of the web stiffener can be done in the form of a fillet weld pass so the installation operation is usually carried out in a faster pace (Hosseini, 2014).

The essence of the steel plate shear walls lies in the enjoyment of a diagonal tension field that comes about following the buckling of the steel plates therein. It has been made clear since long ago that buckling in the plates does not equal their load-bearing capacity and that a considerable post-buckling resistance is created in the unreinforced shear panels with the formation of the diagonal tension field. In the elastic buckling limit point, load bearing mechanism shifts from intraplate shear towards diagonal tension field and a notable amount of energy is absorbed in the periodic loads till the steel plates' yield (Khatami & Ghomri, 2014).

Shear wall's supportive columns are one of the important parameters in the performance of thin steel plate shear walls that have been less frequently investigated despite their key role's importance in the designing of the steel plate shear walls. In line with this, studies have been conducted by Thorburn et al, Aliniya and Dastfan and Khaki and Esfandiyari (Bahrami, 2011).

In structural perspectives, it becomes sometimes necessary to create openings in the steel plate shear walls. The designer's need for thinner plates in the designing of the steel plate shear wall and/or use of steel plates with low yield strength that might not be available and existent in the market can be amongst the effective structural cases in the creation of the openings (Bahrami, 2011).

Study Background

In a study, the experimental results of four laboratory models constructed in 2004 in building and housing research center were utilized for the investigation of the effect of columns' stiffness on the various behavioral aspects of these walls, including the formation of tension field, deformability, stiffness, strength and energy absorption so that the ground can be set for the improvement and development of the design relations of this element of the shear wall via more exact and more practical examination of the stiffness of the supportive columns. The specimens were built in ½ dimensions and they only differed in terms of their columns (Moharrami & Habibnejad, 2009).

As for the effects of openings on the behavior of the steel plate shear walls, several studies have been conducted by several researchers. Roberts and Sabouri Ghomi (2013) performed studies on specimens without stiffeners and with circular openings in wall plate center. They suggested a reduction factor equal to $1-\frac{D}{d}$ for estimating the strength and hardness of the panels with openings wherein D denotes the diameter of the opening and d is the panel height. Then, Sabouri Ghomi replaced the modified coefficient $1-\frac{A}{A0}$ for the previous in a later research wherein A0 is the plate's area and A is the openings area (Roberts & Sabouri-Ghomi, 1992).

Furthermore, Vian and Broneu (2004) designed three samples of steel plate shear walls with low yield strength in Buffalo University's earthquake research center and examined it subject to cyclic loading in Taiwan University. In Iran, Sabouri Ghomi and Gholhaki continued these laboratory studies and conducted a research on steel plate shear walls with circular openings and stiffener.

In an investigation of the effect of slenderness on the behavior of the steel plate shear walls with openings, studies were also carried out in Tabriz Industrial University and it was found out that the increase in slenderness ratio causes reduction in the walls' stiffness and strength. In addition, the increase in slenderness ratio was found decreasing the wall's strength and hardness as a result of the openings created there. The increase in the slenderness ratio brings about an increase in the deformability and such a trend of increase in the wall's deformability is gradually reduced with the increase in slenderness ratio (Bahrami, 2011).

The medium-rise and high-rise buildings with repetitive plans and continuous structural cores are especially appropriate for steel plate shear walls (Hosseini, 2014).

Xu and Loo (1994) conducted an analytical research on a twelve-storey three-span structure with fixed beam to column connections and the medium span filled with steel plate. The study was concentrated on the effect of beam to column and plate connections. The result was that the type of the beam to column connection in the infilled frame's span does not exert an important effect on the force-displacement behavior of the system and the plate to column connection has a relatively low increasing effect on the system's final capacity (Hosseini, 2014; Moharrami & Habibnejad, 2009).

Wegener (1931) showed that a diagonal tension field is formed following the buckling of a thin aluminum sheet that had been peripherally fixed with a hard frame. He developed the net tension field theory and considered the diagonal tension field forming in a thin sheet restrained by hard border members as the main mechanism of shear strength.

Takahashi et al (1973) who believed in extensive research on the panel behavior of the steel plate shear wall figured out that the behavior of the stiffened shear walls subject to cyclic loads is better than unstiffened ones (Hosseini, 2014; Moharrami & Habibnejad, 2009). In the present study, a single storey model was constructed in Abacus and the models were analyzed and investigated subsequently via being embedded with stiffeners and openers in various forms in the steel plate shear walls reinforced based on method [V] in various spots. Next, the hysteresis diagrams of each of the models were extracted and compared.

Study Method

The study models were designed and analyzed in Abacus that is one of the strong computer-based engineering software packages for performing analysis based on finite element method (FEM) (Souragi & Hadidi, 2011). In validation stage, a single storey model designed by Dr. Sabouri Ghomi (2008) was utilized (Sabouri, 2011). The general model used in this study, is a single storey model wherein the steel plate shear wall has been built without opening and reinforcement. The specimen features one third scale and its height and width respectively are 1250mm and 1590mm. the beam's cross-section is 140×290mm in dimension and it has been modeled in 3D form with shell-extrusion-deformable features. The wing and body of the column were 20mm and 15mm in thickness, respectively. In addition, the plate was 960×1410mm in dimension. In laboratory specimen, the steel shear wall is 2mm in thickness. In constructing the laboratory specimen, the plate, angular iron and stiffeners are seminally connected and the beam and column are installed around them. The heat usually produced during welding causes angular iron's warping by the plate for which reason 60×60×60 angular iron has been used so that it can sufficiently resist warping (Sabouri Ghomi & Sajjadi, 2013).

Complete joint penetration groove welding has been used for connecting the beam wings to the column wing and fillet welding using E7018 electrodes was performed for connecting the beam body to the column wing. The specimen was subjected to periodic load as advised in ATC-24 Standard. The load was imposed by two hydraulic jacks on both sides of the specimen and the load and displacement were recorded. The specimen displacement is measured using four displacement sensors installed at the side of the jacks.

Table 1: mechanical properties of the laboratory specimen's members (Sabouri Ghomi & Sajjadi, 2013)

Members	Flow stress (N/mm^2)	Final stress (N/mm^2)
Plate	192.4	288.7
Beam and column	414.8	551.7

The highest bearable load of the specimen was 789.6kN in 39-mm displacement. The maximum ratio of the specimen's lateral displacement to height is 5.34%. The number of the periodical loading was 32 cycles. The experiments performed on the steel plate shear walls indicated that the specimens' failures occurred in the form of plate tearing and zipping of the plate edge. The tearing began from the plate corner and rapidly expanded to the plate edge with the tiny increase in load. To prevent zipping in this specimen, small stiffeners were installed on the four corners of the plate. The specifications of the main model, named (S-1), have been summarized in the table below:

Table 2: specifications of S-1model

Model	Column dimension (mm)	Beam dimension (mm)	Plate dimension (mm)	Opening dimension (mm)	Opening position	Opening type
S-1	90×140	290×140	1410×960	0	-	-

The following table gives the specifications and names of the models.

Table 3: specifications of all the models

Model name	Reinforcement method	Opening type	Opening position	Opening edge reinforcement	Opening dimension (mm)
S-1	Not applicable	Not applicable	Not applicable	Not applicable	0
S-15	**V**	Not applicable	Not applicable	Not applicable	0
S-16	**V**	Window	Middle	Not applicable	400×400
S-17	**V**	Window	Middle	Applicable	400×400
S-18	**V**	Fixtures	Top-middle	Not applicable	150×150
S-19	**V**	Fixtures	Top-middle	Applicable	150×150
S-20	**V**	Fixtures	Side-middle	Not applicable	150×150
S-21	**V**	Fixtures	Side-middle	Applicable	150×150

Study Results

Models Reinforced Using Method [V]:

In this model, four stiffeners, 60mm in dimension and 4mm in thickness, were installed on both sides of the wall as explained in [**V**].

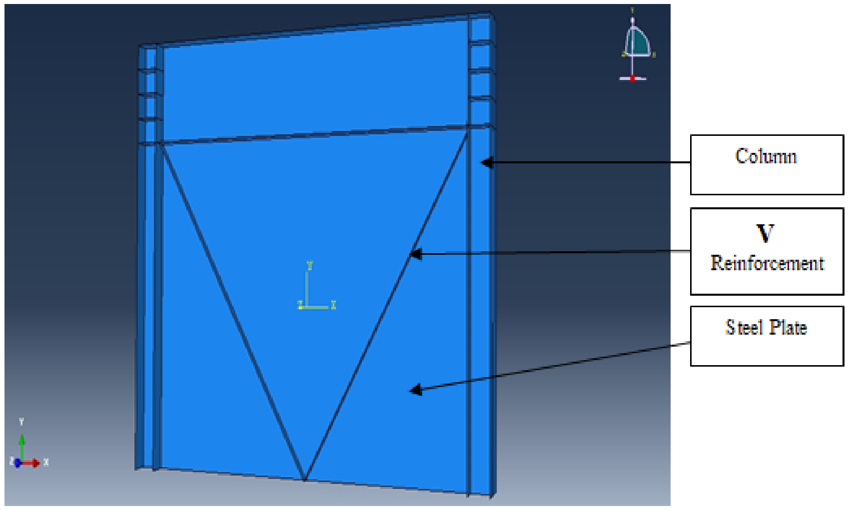

Figure 1: Model S-15

The steel plate shear wall reinforced based on method [V], with its connections and loads, is compared with the simple S-1 steel plate shear wall model. The following diagram compares the hysteretic curves of S-15 and S-1 models.

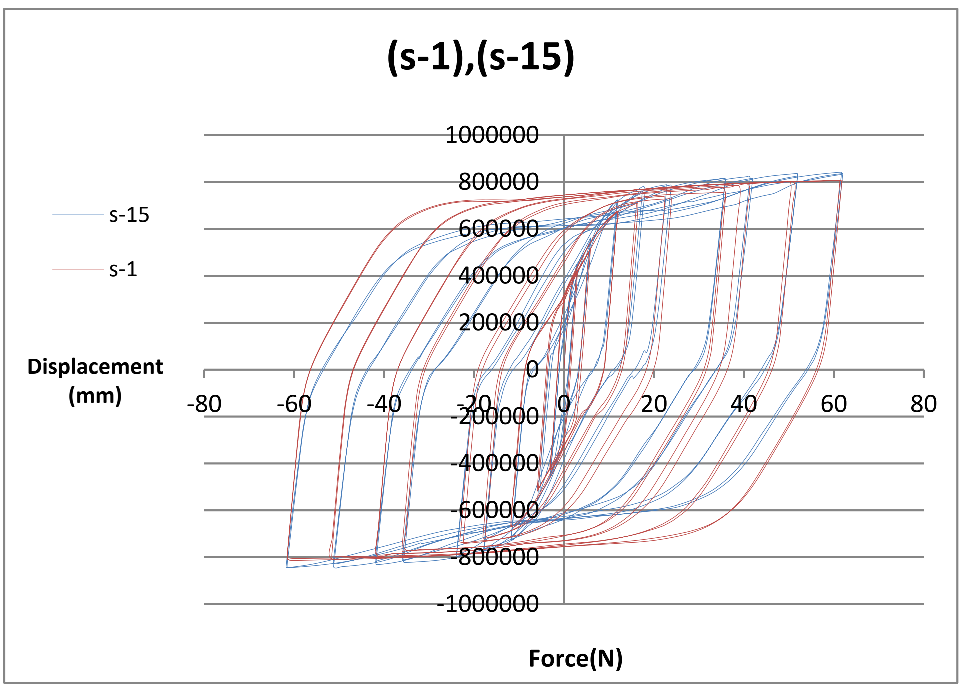

Figure 2: hysteresis diagram of S-15 and S-1 models' comparison

The following diagram compares the steel plate shear wall reinforced based on [V] with a window in the center of S-16 model and the steel plate shear wall reinforced based on [V] with an opening, window, in the middle and opening edges' reinforcement in model S-17.

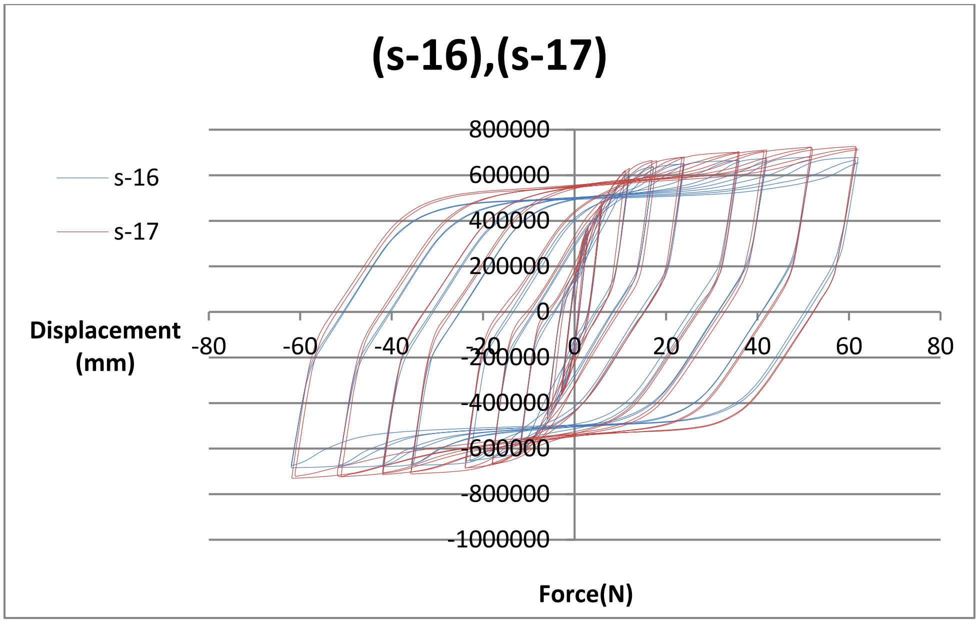

Figure 3: hysteresis diagram of S-16 and S-17 models' comparison

The following diagram compares the steel plate shear wall reinforced based on [V]with a fixture opening in the center and top of the plate in S-18 model and the steel plate shear wall reinforced based on [V] with an installation opening in the plate's center and top and plate edge reinforcement in S-19 model.

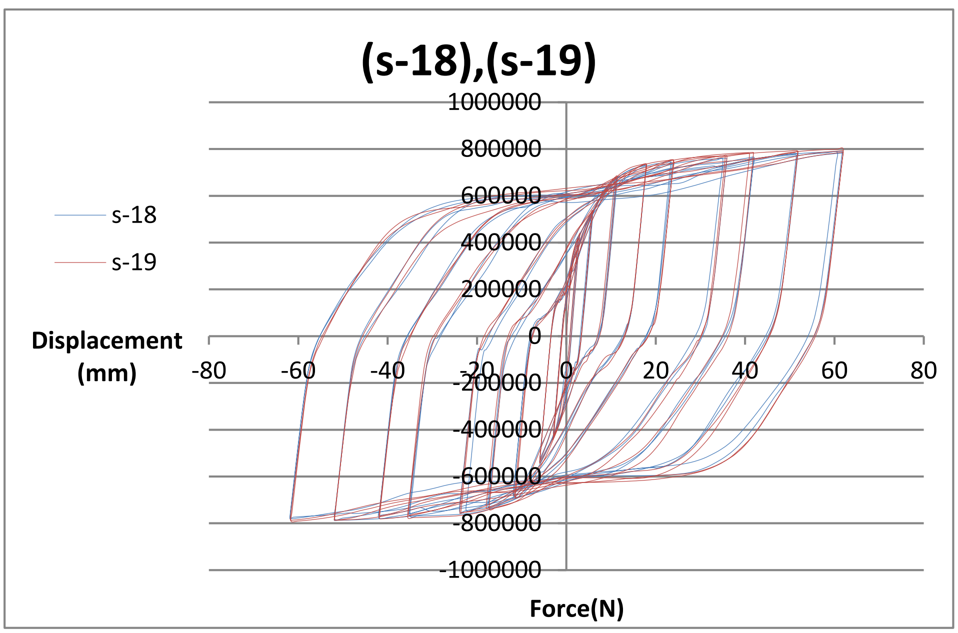

Figure 4: hysteresis diagram of S-18 and S-19 models' comparison

The steel plate shear wall reinforced based on [V] with an installation opening in the plate's side and middle in S-20 model and the steel plate shear wall reinforced based on [V] with an installation opening in the plate's center and middle and opening's edge reinforcement in model S-21 have been compared in the following diagram.

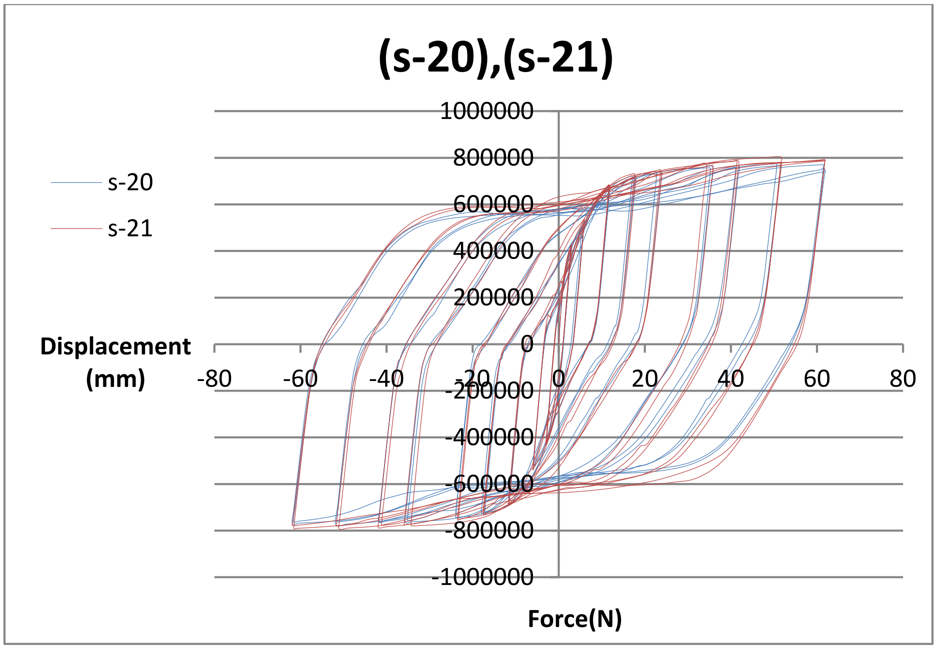

Figure 5: hysteresis diagram of S-20 and S-21 models' comparisons

Results

According to the results obtained from the models in Abacus software, it is clearly visible that the reinforcement of the steel plate shear wall based on the method proposed in [V] causes an increase in the load-bearing capacity. Moreover, comparison of the models' hysteresis diagrams resulted in the following findings:

1) In S-16 and S-17 models the specifications of which have been given in table (3), the load-bearing capacity was found being increased by 10.2% for the model the opening of which had been reinforced in its edges.
2) No significant change was evidenced in load-bearing capacity of S-18 and S-19 models that were found nearly matching one another in a comparison of their hysteresis diagrams and considering the position of their openings' placement.
3) In S-20 and S-21 models, the load-bearing capacity was found increased by 8.7% in the model the opening of which had been reinforced in its edges.
4) According to the results obtained from the software, it is well evident that the stiffeners in this method have caused topical buckling to occur seminally and this is well indicative of the good and proper behavior of the application of stiffeners as recommended in [V].
5) In the reinforced walls based on this method, the openings cause reduction in load-bearing capacity of the walls and this is pretty much dependent on the type and size of the openings. As it is clear in the diagrams, the window opening in this method makes wall's load-bearing capacity severely suffer. Furthermore, it is well clear that the larger the dimensions of the opener the lower the load-bearing capacity.
6) Because the construction of the buildings is architecturally constrained and these limitations, including the installation, window and/or door openings, cannot be avoided, the reinforcement of the opening's edge brings about an enhancement in load-bearing capacity of the walls and this is vividly observable in the models' hysteresis diagrams.

References

1. Bahrami, (2011), "steel plate shear walls", MA dissertation
2. Hosseini Lavasani, Sayyed Hussein, (2014), "principles and basics of designing steel plate shear walls", Adiban
3. Khatami, Farzad and Ghomri, Ali, (2014), "steel plate and combined shear walls", University Jihad Publication Center
4. Moharrami, Hamid and Habibnejad, Asghar, (2009), "thin steel plate shear walls with semi-stiffened edges", Building and Housing Research Center, issuance no.524-G
5. Roberts, T., M., and Sabouri-Ghomi, S., (1992), "hysteretic characteristics of unstiffened perforated steel plate shear panels", journal of thin-walled structures, pp.121-127
6. Sabouri Ghomi and As'ad Sajjadi, Ramin, (2013), "laboratory investigation of the behavior and energy absorption coefficients in deformable steel plate shear walls with and without stiffeners"
7. Sabouri Ghomi, (2001), "systems resisting lateral loads"
8. Souragi, Muhammad Hussein and Hadidi, Sa'eid, (2011), "launching and preparing applied Abacus guidelines", MA dissertation