Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/03/jls.htm
2015 Vol. 5 (S3), pp. 1958-1969/Azimi et al.
Research Article

STUDY OF EFFECTS OF STEEL PLATE THICKNESS ON NONLINEAR BEHAVIOR OF SHEAR WALLS

Sadegh Azimi, Mazaher Rozbahani*, Mehdi Alirezaee
Department of Civil, Malayer Branch, Islamic Azad University, Malayer, Iran
**Author for Correspondence*

ABSTRACT
Steel shear wall is a system resistant against lateral loads which has shown a proper behavior in laboratory and during the past earthquakes. According to some properties of this system such as hardness, resistance and high ductility, any researcher around the world have tried to study this system in order to improve its seismic behavior; of course such studies now are developing. However, in order to execute the projects it is necessary to use the plates thicker than the designed ones. Here the effects of using thicker steel plates on the seismic behavior of the system such as hardness, resistant and energy absorption could be studied. To study the effect of plate thickness on the steel shear wall behavior, both normal and semi-preserved steel shear walls have been evaluated. According to the required nonlinear analysis, ANSYS Software has been used in this study. In regards to the results it could be noted that increased thickness is always not to ensure, and it enhances the resistance to a certain level but then decreases resistance in the final minute.

***Keywords**: Steel Shear Wall, Analysis of Finite Elements, Nonlinear Analysis, Semi-preserved Wall at the Edge*

INTRODUCTION
The researchers have studied several systems to bear the lateral loads; each of these systems has advantages and disadvantages. Meanwhile the parameters such as hardness, resistant, ductility and economically are the most important ones that providing them is a system at the same time is not easily possible.
Steel shear wall system that is resistant to lateral loads and has shown a proper behavior during the last earthquakes and also in the laboratories. Due to the hardness, resistant and high ductility of the system, researchers around the world have developed many studies on the seismic behavior of the system to improve it; also these studies now are being done. Steel shear wall includes some steel plates surrounded by beams and columns as shown by Fig.1. This wall is similar to the steel cantilever beam that its plates, columns and beams are similar to wings and hardener, however, in the face of such difference that hardness and resistance of beams and columns have a significant effect on the system's behavior as compared with the hardener and wings plate beams. It should be noted that the behavior of steel shear wall is differ from plate beam; reference (Astaneh-Asl, 2000) shows a perfect description of this issue.

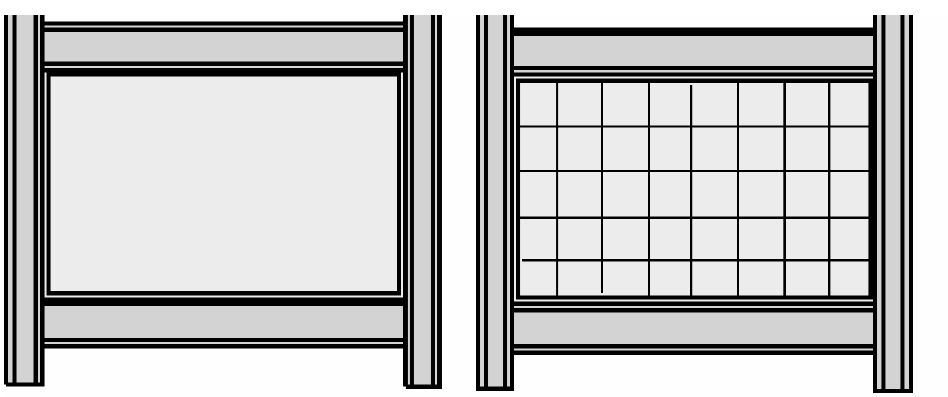


Figure 1: Steel Shear Wall (Driver, 1998)

The Course of Studies

Perhaps the most important studies about the steel shear walls have been conducted in Canada that was the source of further researches by the researchers. Researchers at the University of Alberta, including Tymlr and Koulak (1987), Koulak (1991) and Driver (1996) have done some cyclic and monotonic tests on the steel shear walls without use of hardener (Hatami and Ghamari, 2010).

In 1992 in England, researchers such as Qumi, Saburi and Roberts have done some tests on 16 samples of steel shear walls with diagonal loading with ups-downs modes in the laboratory (Hatami and Ghamari, 2011). The sample consisted of steel plates, which were in a frame with articulated joints. Experiments showed that all panels possessing sufficient ductility (Hatami and Ghamari, 2011).

In 1998, *Driver et.al* from the University of Alberta, Canada, have tested a four -storey steel shear walls which as a special bending frame system and steel plate was welded to the frame in the environment; they have tested it under a cyclic loading (Hatami and Rahai, 2008).

During 2001 to 2012, Iranian researchers at Amirkabir University of Technology have investigated and tested the behavior of steel shear walls and composite steel shear walls as numerically and experimentally.

In these researches, a new system of composite shear walls was studied as in composition of carbon polymer fiber in the laboratory and also under numerical calculations. Thus, more than 224 numerical models, shear wall behavior in composition of a layer of reinforced concrete wall and polymer fibers were studied.

In addition, a new system of steel shear wall with double plates was investigated and introduced (Hatami and Ghamari, 2011; Hatami and Ali, 2014; Hatami and Ghamari, 2010; Hatami and Ghamari, 2009; Moharrami *et al.*, 2006; Sabouri-Ghomi and Roberts, 1992).

At Berkeley University (1998-2000), two independent researches were conducted by *Astane Asl and Zhao*. One of researches is about the composite shear wall and the other one reviews the steel shear wall (2000-2001).

Samples were made for the steel shear wall in three storeys and with 1/3 scale. The sample contains ductile behavior and was satisfactory. Up to 6% drift samples are elastic. In this level of drift, the yielding lines will be appeared; up to 2.2% yielded the compressive-diagonal wall as buckling and formation of a tension field; thus in the column it is like as a local buckling. The sample could bear up to 79 cycles and it was entered to the inelastic area after bearing of 39 cycles.

In this level of drift the upper beam drift was broken on the level of the column and shear resistance of sample was decreased to 60 % of capacity.

Like as sample 1, the sample 2 showed a ductile behavior and the sample was placed in an elastic state to 0.7 %. In levels of drift, the yielding lines were appeared on the steel plate. In the next cycles the diagonal yielding lines were clearly visible (Driver *et al.,* 1998).

Introducing of Semi-Preserved Steel Shear Wall at the Edges

In 2011, the results of researches about a new type of steel shear wall named as “semi-preserved steel shear walls at the edges” were published (Timler and Kulak, 1983) was based on laboratory studies by Dr. Moharram.

By this new shear wall, the steel plate can’t cover the entire surface of the main elements of building, but it can be built separately and by borderline elements (Figure 2). The system also benefits due to built-up steel shear walls because of ups-facilitates in the line of demarcation of the main columns of the building, the architectural considerations to be met significantly.

According to designing of lateral columns of panel separate from the main columns; it is prevented to become large the main sections of structure. Also any damage to the boundary element is much less than the other members of the structure.

Because of bearing the lateral load by the separate shear wall, the forces of lateral load can be exerted to the structure foundation within the boundary of panel, thus the structure foundation shall be designed normally.

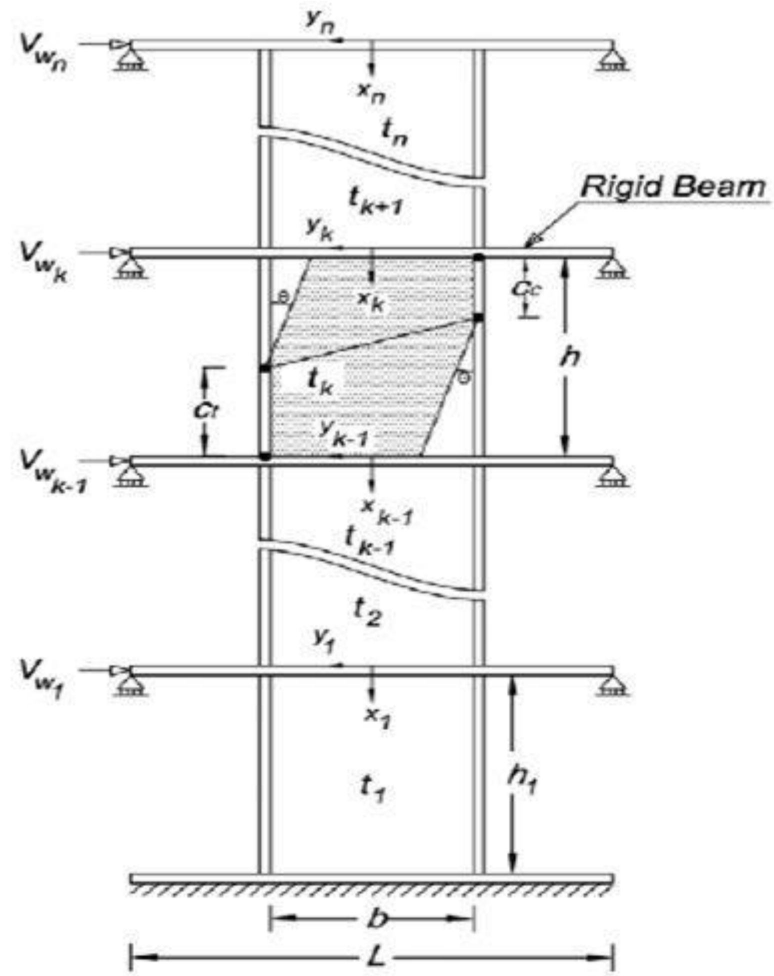


Figure 2: Semi-preserved wall at the edges

MATERIALS AND METHODS

An increaser nonlinear static analysis has been used in this study. Increaser nonlinear static analysis is a simple, effective and approved technique in order to predict the seismic response before any dynamic analysis. The increaser nonlinear static analysis can determine the sequences of yielding of members, potential ductility capacity and capability of the lateral resistance. Here the structure should be non-linear analyzed under a lateral load distribution as a cumulative, incremental or increaser structure.

The increaser nonlinear static analysis can be done by controlling the shift of displacement or controlling of force. In case of analysis through the control of force, the structure is located under lateral load distribution and shift of incremental places could be calculated. In case of controlling the displacements, the structure is placed under the profile of incremental displacements and then the forces which required making these displacements should be calculated. To apply the method of control of displacement, it is necessary to determine the maximum rate of lateral displacements and then gradually should be applied to the structure increasingly.

At the same time, nonlinear and geometrical effects of materials have been considered in numerical analysis.

Designed models have been loaded laterally up to 2.5% drift.

Properties of steels of beams and columns which form the wall materials are defined by the use of elastic-plastic model in which the hardness rate is decreased; thus hardness and stiffness are equal to the first yielding or 75% of the final lateral load; also to determine the plasticity, FONMISES is used.

Details of Modeling by the Use of Ansys Software

ANSYS Software was designed by the academic community. For the first time it was published by Us Company Swanson in 1971.

This software is capable of doing all types of static- (linear and nonlinear), and dynamic-, and thermal-analyses, buckling-analyses and etc. There are more than 200 types of elements in this software, each of them has certain properties which are classified in terms of the number of degrees of freedom in nodes, elastic or non-elastic analysis, two- or three-dimensional elements and different abilities include great changes, modeling of cracking, crushing, creeping and etc.

SHELL43 element has been used in this research that is a continuous element for modeling the nonlinear behavior of structures and thin or thick plates. It is a four-node element that each node has 6 degrees of freedom (displacement and rotation along and around all three axes).

This element has ability of shear displacement and for studied walls it has been used to model the steel beams and columns and steel plates.

Modeling Accuracy

To ensure the results of ANSYS, an experimental model has been selected and its results have been compared with the finite element model. The experimental model consisted of a plate with 2mm thickness, beam and column of IPE240, 2UNP60 respectively. The storeys height and bay width were 150cm and 120cm respectively. This model has been tested by Housing Research Center.

In comparison of the experimental model with both finite element models, by the use of modeling based on the experimental model and also by the use of simplified Canadian Regulation Model named as Truss-Method, the modeling process has been completed. Although based on Canadian Regulations as well as the results published by Dr. Moharrami, this method (due to low moment of inertia around the plate columns) is not suitable for modeling of semi-reserved shear walls, but modeling was done in order to complete the tests. The advantage of using Truss Method is its simplicity and less time to achieve results as compared with ANSYS modeling, but the results are not reliable. In Figure 3 we compared the results, it was concluded that the accuracy of ANSYS modeling is acceptable. In addition to load-displacement curve, ANSYS software shows the diagonal tension field formation truly that is obvious in Figure (4) and (5). But by Truss Modeling, the angle of diagonal tension field formation comes to 25.17 ° that shows a significant difference as compared with the experimental result which is equal to 38.65 °.

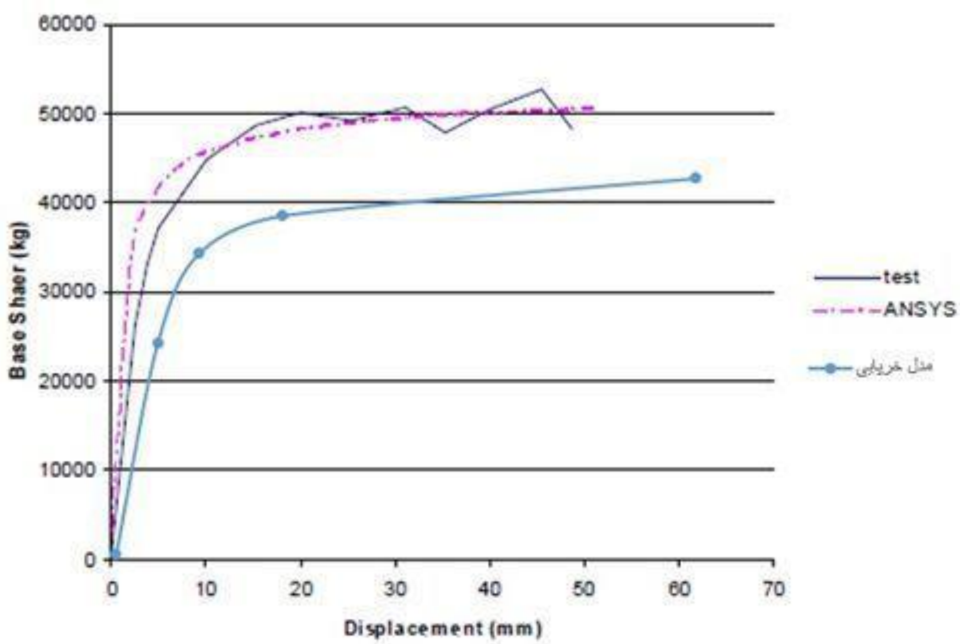


Figure 3: Comparison of results of experimental model and finite element

Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/03/jls.htm
2015 Vol. 5 (S3), pp. 1958-1969/Azimi et al.
Research Article

Figure 4: Sample of experimental model and modeling of finite element

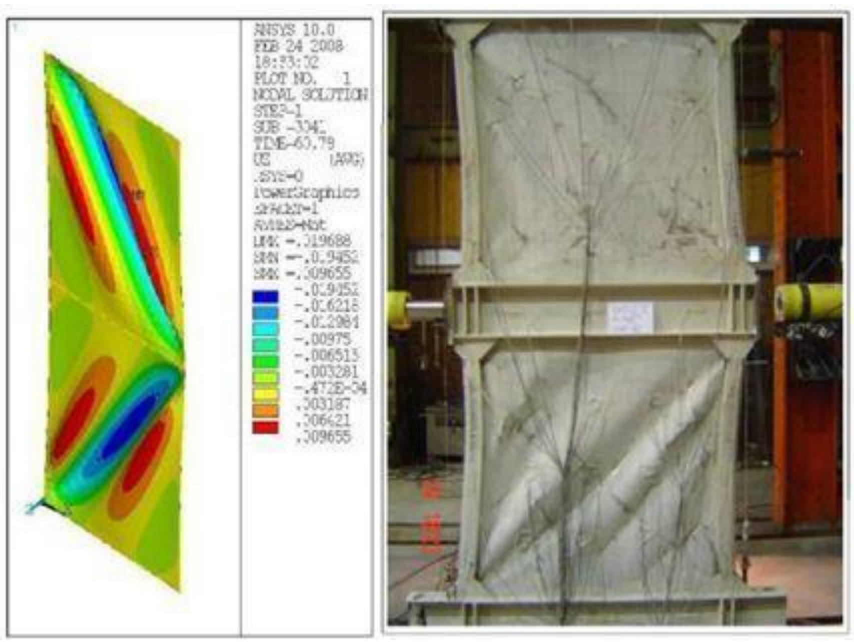


Figure 5: Comparison of results of experimental model and finite element

Numerical Models
In order to evaluate the effect of thickness on the steel shear wall behavior, both types of steel shear walls and semi-preserved steel shear walls at the edges were studied. In steel shear walls and semi-preserved walls, beam of IPB240 and column of IPB360 were used. In normal steel shear walls, thickness of plate was 4mm; and during the next cycles the other parameters were constant but the thickness was increased

and the analysis was repeated again. The width of 190 cm was maintained for semi-preserved shear wall panel but thickness was 6mm. In the next steps, the other parameters were kept constant, but thickness of plate was increased and the analysis was repeated again. PUSHOVER Analysis was used with ANSYS Software. Table (1) shows the properties of used sections.

Table 1: Properties of the used sections

Mode	Type of wall	Thickness of steel plate (mm)	Height of wall (mm)	width of bay (mm)	Column	Beam	Columns around the plate
SSW-4	Normal	4	3000	4000	IPB360	IPB220	----
SSW -6	Normal	6	3000	4000	IPB360	IPB220	----
SSW -8	Normal	8	3000	4000	IPB360	IPB220	-----
SSW -10	Normal	10	3000	4000	IPB360	IPB220	----
SSW -12	Normal	12	3000	4000	IPB360	IPB220	----
Semi-6	Semi-preserved	6	3000	5000	IPB360	IPB220	2UNP 100
Semi-9	Semi-preserved	9	3000	5000	IPB360	IPB220	2UNP 100
Semi-15	Semi-preserved	15	3000	5000	IPB360	IPB220	2UNP 100
Semi-22	Semi-preserved	22	3000	5000	IPB360	IPB220	2UNP 100

Table 2 summarizes the properties of the samples. Samples are labeled as: SSW is abbreviation of Steel Shear Wall and the second part represents the thickness of the steel plate. The semi- preserved walls at the edges so named as: "Semi" is abbreviation of Semi-steel Shear Wall and the second part represents the thickness of the steel plate. The maximum shift of steel shear walls was limited to the maximum permitted limit mentioned in 2800 Code.

Table 2: Properties of samples

Mode	Type of wall	Thickness of steel plate (mm)	Height of wall (mm)	Width of bay (mm)
SSW-4	Normal	4	3000	4000
SSW -6	Normal	6	3000	4000
SSW -8	Normal	8	3000	4000
SSW -10	Normal	10	3000	4000
SSW -12	Normal	12	3000	4000
Semi-6	Semi-preserved	6	3000	5000
Semi-9	Semi-preserved	9	3000	5000
Semi-15	Semi-preserved	15	3000	5000
Semi-22	Semi-preserved	22	3000	5000

RESULTS AND DISCUSSION

After analyzing the models, the results have been extracted. Both normal steel shear walls and semi-preserved walls at the edges will be discussed. It is noteworthy that because of significant importance of diagonal tension field of normal steel shear wall we would be benefited by the use of it; and in regards to the semi-preserved wall, beginning of yielding and distribution of yielding should be considered. So we show different reaction while comparing the results.

Normal Steel Shear Walls

Figure 6 shows the load-displacement of normal steel shear walls with different thickness. Valuable information can be extracted from load-displacement graph, and also the overall behavior of the system could be seen at first glance, but the exact behavior of the system should be compared with results; so the results should be gained and calculated through these results.

This graph shows that if the thickness is increased so the hardness and resistant of wall will be increased but at the end of loading, the graph becomes fall.

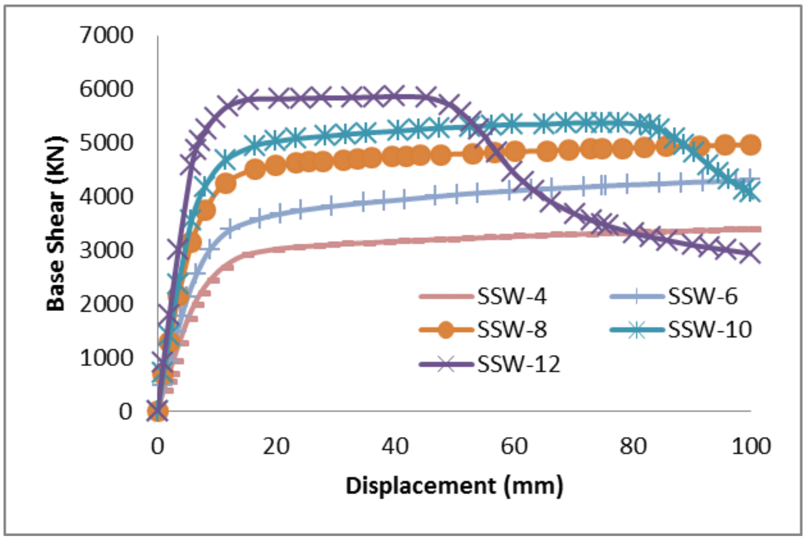


Figure 6: Load-displacement of normal walls

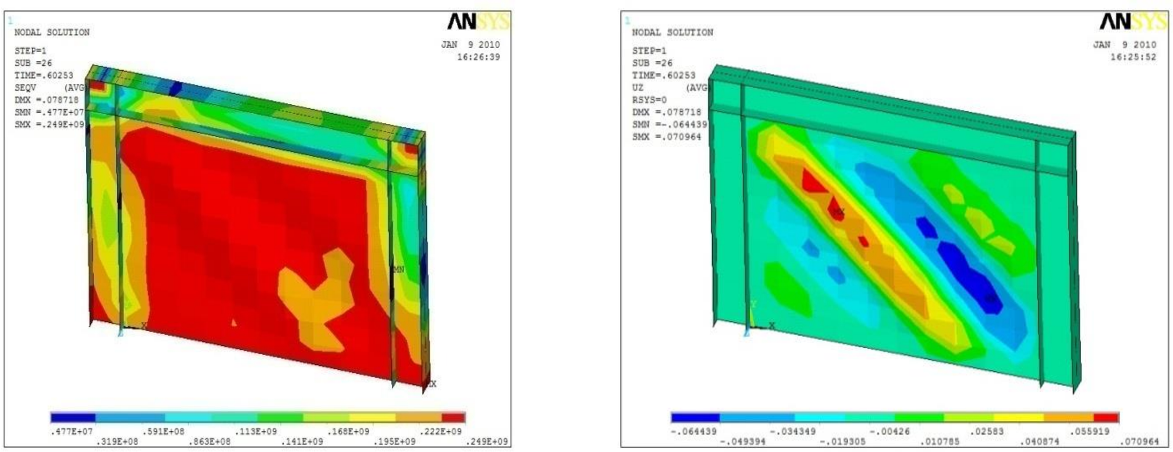
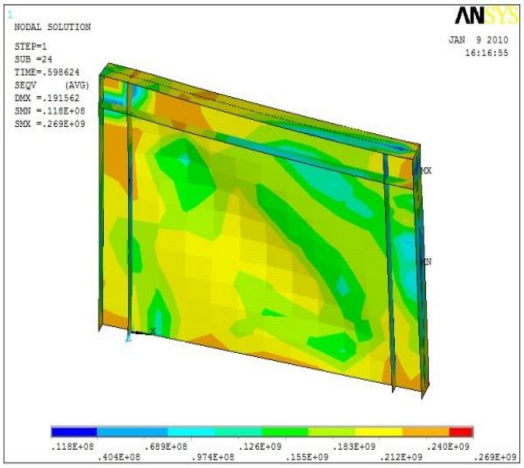


Figure A) VANMISZ Tension **Figure B) out-of-plate displacement**

Figure 7: Show of yielding and buckling out-of-plate of model SSW-4

Figure (6) shows the load-displacement curve of SSW-4 model shows that this model indicates elasto-plastic behavior of the system and also shows its proper behavior and without any resistance reduction. It is expected that at low loads, shear buckling or yielding occurred in steel plates and then the energy exerted to the structure could be damped. With regard to Figure (7), yielding has been distributed to the steel plate which shows the satisfactory behavior of the system. According to maximum drift levels in Regulation, environmental frame is located in elastic area; and it is expected that when an earthquake occurs, the energy arising from earthquake should be damped due to buckling and yielding of the steel plate.

Research Article



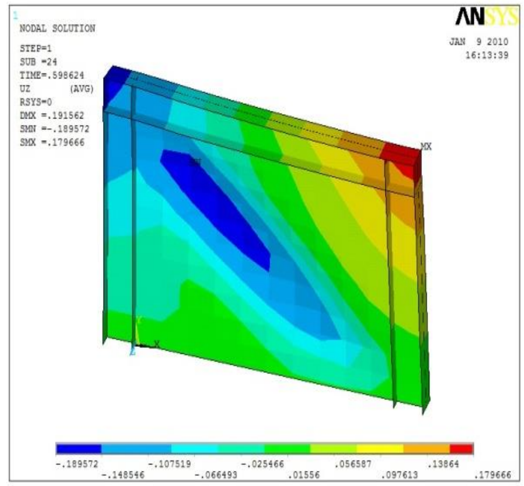


Figure A) VANMISZ Tension **Figure B) out-of-plate displacement**

Figure 8: Show of yielding and buckling of out-of-plate, model SSW-12

The thickness of 4, 6, 8, and 10 showed that if the thickness of steel plate is increased, the system's behavior gradually becomes worse. It is evident if thickness is 12mm. it means that we have maximum buckling of out-of-plate and maximum yielding in the environmental frame; even capacity structure curve will become fall according to Regulation limits.

Seismic Parameters

Figure (9) shows calculation of elastic hardness of samples that is drawn as a bar graph towards the thickness of steel plate. This graph demonstrated that if thickness of the steel plate is increased, its elastic hardness will be increased. So increase of thickness causes to increase the rate of hardness. Thus increase of thickness guarantees improvement of behavior in elastic areas.

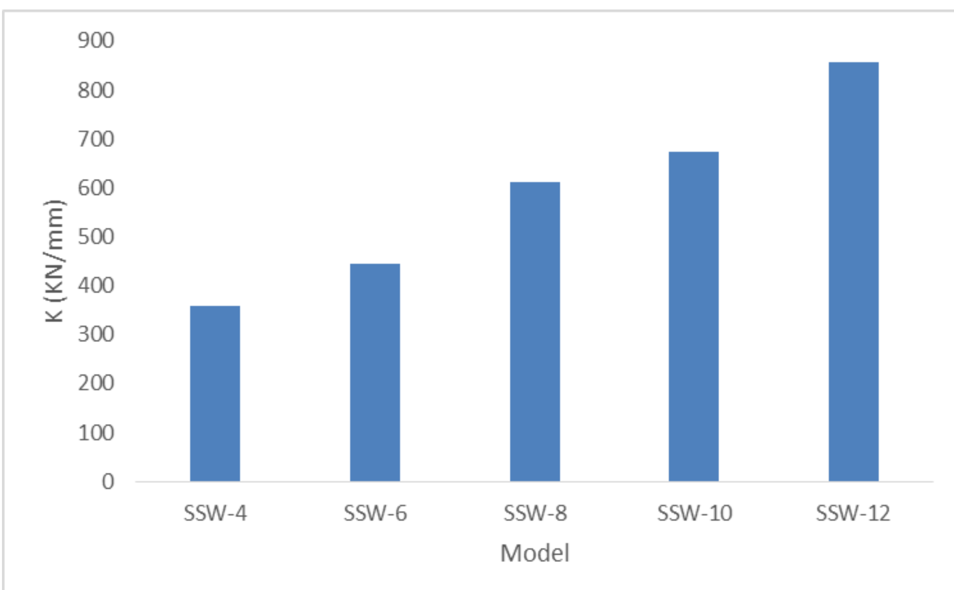


Figure 9: Bar-graph of hardness

Figure 10 shows the energy absorption as bar-graph. Energy absorption has been achieved by calculating the area under the load-displacement curve. Above graph shows that if thickness of steel plate is increased so energy absorption will be increased like as elastic hardness.

Figure 10: Bar-graph of Energy absorption

The most significant effect of load-displacement graphs was related to the loss of resistance. To examine this subject, the maximum resistance of the system and its value in the final moment has been listed by table (3). The table shows that increasing the thickness leads to decrease the resistance in the final moment. At a thickness of 12 mm its fall is 31% that is very significant.

Table 3: Final resistance of samples

	Fu (KN)	Fu-in final moment	Fu-frac/Fu
SSW-4	3395	3311	0.98
SSW-6	4308	4193.528	0.97
SSW-8	5966	4889.58	0.82
SSW-10	5372	4070.75	0.76
SSW-12	5875	3485.47	0.59

Effect of Thickness on Steel Sheet Walls and Semi-Preserved Walls

Figure (11) shows the load-displacement curve of semi-steel shear walls with thickness of plate. Comparison of them shows that increasing of thickness of shear panel causes to improve the behavior in elastic and inelastic area. Only a model with 22mm thickness shows falling at the end of loading which might be evaluated.

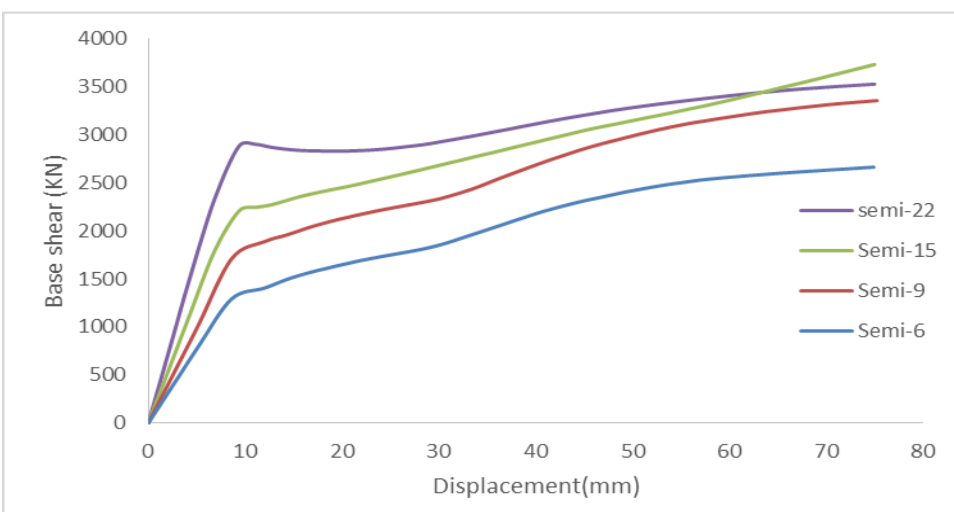


Figure 11: load-displacement graph

Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/03/jls.htm
2015 Vol. 5 (S3), pp. 1958-1969/Azimi et al.
Research Article

The forms of beginning of yielding and formation of plastic joints at the moment of the first yielding and plastic joints at the end of final deformation are shown as follow. All of these forms show that by increasing of thickness of plate, the place of yielding should be changed. It means that if thickness of plate is increased, the plastic joint should be formed both into the panel and frame, thus it causes to fall the final resistance of Semi-22 model.

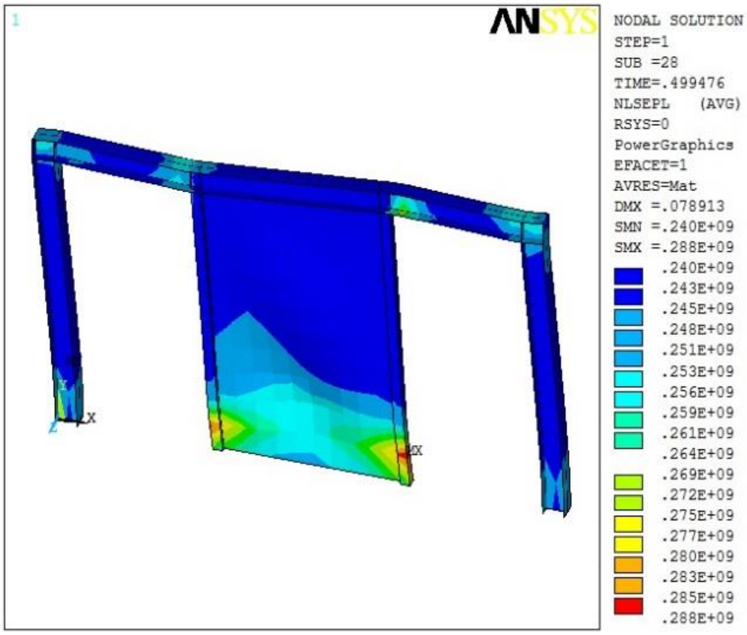


Figure 12: Place of plastic joints, semi-6 model

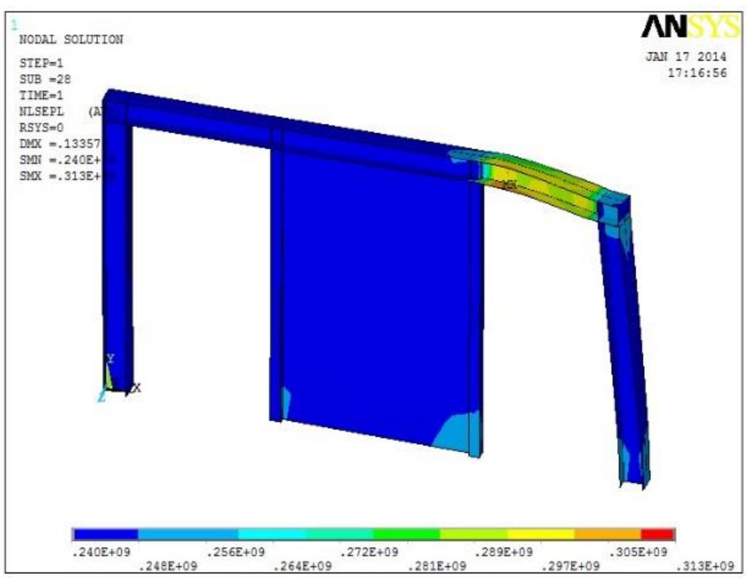


Figure 13: Place of plastic joints, semi-6 model

Figure (14) and (15) showed the bar-graph of hardness and final resistance of the system. Referring to these graphs, we find that increasing of thickness causes to increases hardness of the elastic area, but in regards to the final resistance, increase should be continued to a certain level and then resistance of the system will fall.

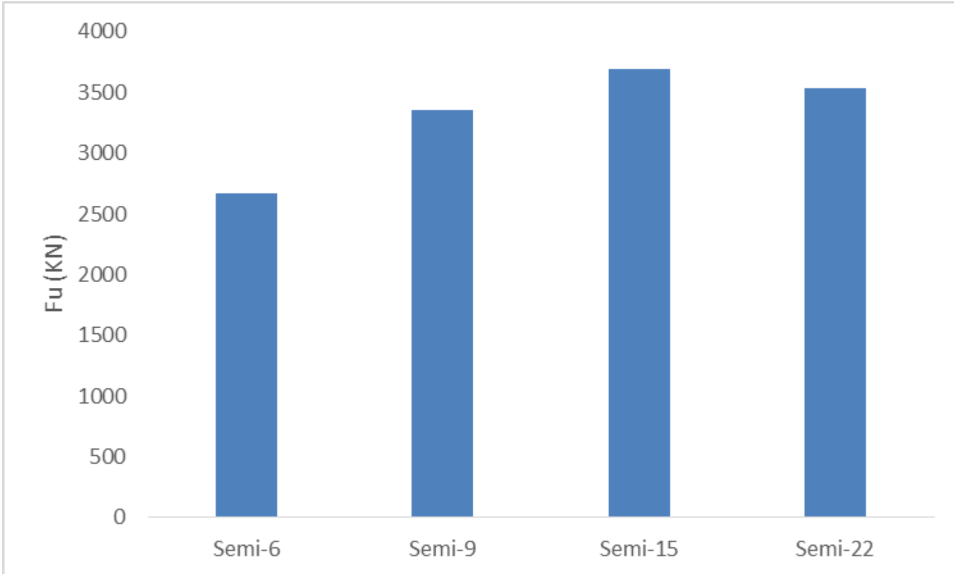


Figure 14: Bar-graph of resistance

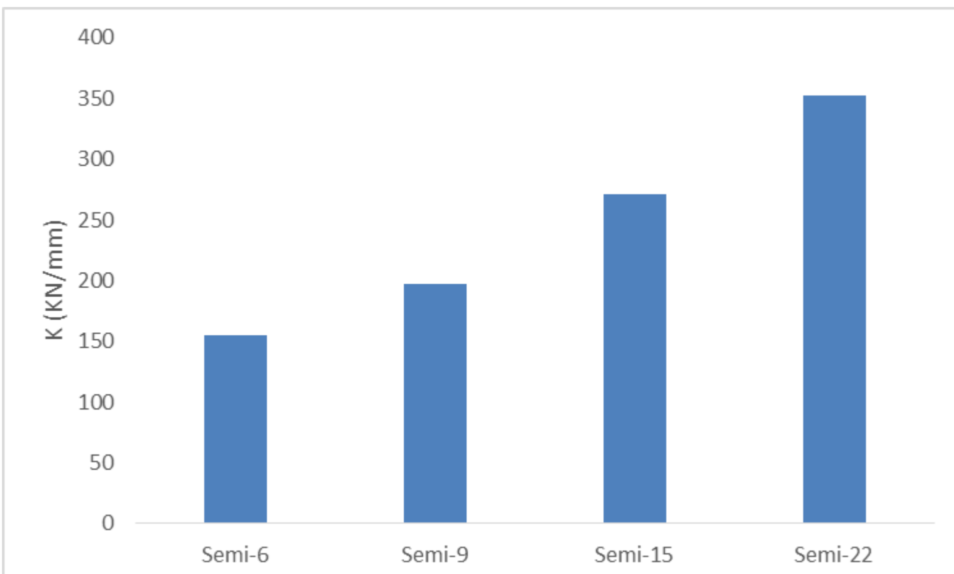


Figure 15: Bar-graph of hardness

Conclusion

In order to study the effect of the thickness on the steel shear wall behavior, both normal and semi-preserved steel shear walls at the edges were evaluated. Some models were evaluated by the use of ANSYS Software. The results are summarized as below.

- In the normal steel shear wall, if thickness increases, hardness and resistance of wall will increase, but at the end of loading, the graph shows fall.
- The load-displacement curve of SSW-4 model shows that this model demonstrates the elasto-plastic behavior of system. Also it shows that it has a proper behavior and has no resistance reduction.

If thickness of steel plate increases, the system behavior gradually will become worse. It is quite evident by 12mm thickness. The most out-of-plate buckling and the most yielding will occur in the environmental frame, even the structure capacity curve shall have resistance falling based on Regulations limits; value of this fall comes to 31% that is very significant and should be considered for designing of the system.

At semi-preserved steel shear wall, increasing of thickness of shear panel causes to improve the behavior in the elastic and non-elastic area. Only a model by 22mm thickness showed falling at the end of loading that is because of formation of a plastic joint in the frame.

REFERENCES

Astaneh-Asl A (2000). Seismic behavior and design of steel plate shear walls. Steel Tips Report. Structural Steel Educational Council, CA, July

Driver RG, Kulak GL, Kennedy DJL and Elwi AE (1998). Cyclic tests of four-story steel plate shear wall. *Journal of Structural Engineering (ASCE)* **124**(2) 112-120.

Farzad Hatami and Ali Ghamari (2009). Retrofit of Reinforced Concrete Frame by Steel Shear Walls. *Proceedings of the 1st International Conference on Concrete Technology, Tabriz, Iran, 6-7 November, Paper Code. No. CTO371.*

Farzad Hatami and Ali Ghamari (2010). Presenting Numerical Mathematical Formulas to Design Composite Steel Shear Walls. *8th International Conference Of Numerical Analysis And Applied Mathematics 2010 (Icnaam), Gease*.

Farzad Hatami and Ali Ghamari (2011). Investigating of Steel Shear Walls Reinforced with Carbon Fiber Polymer (CFRP). *Journal of Steel Research,* In press.

Hatami F and Ali AH (2014). *Steel and Composite Shear Wall Design*, first edition (Amirkabir University Press).

Hatami F and Ghamari A (2010). Strengthen of Steel Shear Walls by Carbon Fiber Polymer. *AES-ATEMA'2010 Fifth International Conference, Montreal& Quebec City, Canada: June 27 – July 03* 109 – 115.

Hatami F and Ghamari A (2011). A New Model of Steel Shear Wall by using Double Plates. *CSCE 2011 General Conference- Congrès générale 2011 de la SCGC, Ottawa, Ontario June 14-17, 2011 / 14 au 17 juin.*

Hatami F and Rahai A (2008). An investigation of frp composite steel shear walls (cssw) under cyclic loading on laboratory. *The 14th World Conference on Earthquake Engineering October 12-17, Beijing, China.*

Moharrami H, Habibnejad A, Mazrouei A and Alizadeh H (2006). Semi-supported thin steel shear walls. Research report no. 1–4679. The Building and Housing Research Centre.

Sabouri-Ghomi S and Roberts TM (1992). Nonlinear Dynamic Analysis of Steel Plate ShearWalls Including Shear and Bending Deformations. *Engineering Structures* **14**(5) 309-317.

Timler PA and Kulak GL (1983). Experimental Study of Plate Steel Shear Walls, Structural Report No. 114, University of Alberta, Canada.