J. Basic. Appl. Sci. Res., 2(9)8687-8697, 2012
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ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Nonlinear Behavior of Stiffened Steel Plate Shear Walls

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ABSTRACT

Steel plate shear walls were raised and studied for considering lateral forces of earthquake and wind in buildings especially long buildings .Behavior of this system resembles a steel plate girder used in a vertical cantilever application. The columns fulfill the function of the flanges of the vertical girder, while the horizontal floor beams act as web stiffeners. Before acceptance of the idea to utilizing post-buckling strength of infill steel plate, stiffened walls with heavy stiffeners were used to prevent infill steel plate buckling but after acceptance of this idea, un-stiffened walls replaced stiffened walls. However in seismic rehabilitation of existing buildings and retrofitting the structures which are more considered recently or where wall has an opening, it is important to use stiffeners. . In this research, influence of X, K, V, inverse V and V-H shaped stiffeners on steel plate shear walls was studied. . Results show that X shape stiffener has more desirable effect on increase of yield load , ultimate load and capacity to absorb panel energy in comparison to other diagonal stiffeners including K, inverse V and V shape especially V-H shape stiffener which is used commonly. Unlike plate girders in which stiffener are used for economizing design, it is better to use unstiffened panel instead of stiffened panel in steel plate shear walls.

KEYWORD: Load-lateral displacement diagram, stiffener, yield load, ultimate load, performance surface

1- INTRODUCTION

Application of steel plate shear wall (SPW) attracted more attention as a system resistant to lateral load in the buildings 10 years ago. Steel plate shear wall is like a steel plate girder which is placed vertically and continues in total height of the building. Although it seems that theory of plate girder is suitable for design of SPW structure, there is main difference relating to high bending strength and hardness of girders and columns which compose border elements of the wall. It seems that those elements have important effect on general behavior of the building. Of characteristics of this system are high elastic hardness, high ductility, and stable hysteresis behavior. Steel plate shear wall is able to absorb and waste high energy so that we can apply it in high seismicity areas. Large scale tests on SPW in British Columbia University, Alberta University and California University show exceptional performance of these systems under rapid Reciprocating loading. In the past, steel plate shear walls were designed in such a manner that the pate is not allowed to buckle. The above idea was very conservative while it has very high post-buckling capacity. Most of the common design methods for post-buckling strength are based on Wagner studies. In 1973, Takahashi et al performed a series of laboratory and finite element studies on SPW with stiffened thin plate with quasi-static reciprocating tests of 12 samples with 1and 2 stories. All samples had vertical o0r vertical and horizontal stiffeners in one or two sides of steel plate except for the first sample. Border elements joints are considered articular. Results showed that samples are able to tolerate large transformations and show very stable and ductile behavior. In 1991, Sabouri-ghomi and Roberts did quasi-static reciprocating tests on 16 unstiffened thin panels in small scale for study of load –displacement specifications. Frame joints were articular and plate was connected to other elements with use of screw. Some panels had opener. Reciprocating loading was applied across diameter for creating pure cut. All panels showed sufficient ductility. Researchers also concluded that strengths and hardness linearly decrease with increase of (1-D/d) where D is diameter of opener and d is height of panel. In 1997, Driver et al performed reciprocating tests on a sample with four stories without stiffener and presented an analytical model in which steel plate was modeled with shell element and nonlinear geometrical and material behavior was considered. Researchers concluded that steel plate shear wall has high ductility. Behbahanifard did a large scale tests on a sample with three stories with SPW under quasi-static reciprocating loading in laboratory section in presence of weight loads. The sample showed high primary hardness, capacity to absorb energy and excellent ductility and stable hysteresis loops. Then Behbahanifard created a finite element model on the basis of dynamical express relation with use of ABAQUS software. Validity of the above model was mentioned by comparing uniform and reciprocating behavior with results of tests. At the end, he defined a set of 10 dimensionless parameters which show behavior of a panel under shear and weight loading. It was concluded that column ductility parameter has important effect on behavior of panel. Kharrazi et al suggested a theoretical model which was called modified plate – frame interaction (M-PFI) for shear and bending analysis of ductile steel plate walls. This model divided behavior of steel shear walls into three parts: elastic buckling, post buckling and yield. Firstly, shear analysis of plate and frame behavior was done and then relations of shear force against panel displacement which is obtained with sum of shear

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behavior. Then buckling analysis was done by assuming that plate and frame act singly. Interaction between shear behavior and buckling behavior elaborated behavior of SPW system. The above model had good compatibility with different laboratory results.

2- Research goal :

In the past two decades, steel plate shear walls were applied in some buildings in Japan and North America as a part of system of strength against lateral loads. Steel plates of these walls had vertical –horizontal stiffeners. After accepting idea of using post-buckling strength of the plate, unstiffened steel plate shear walls replaced stiffened walls. However, the available building and reinforcement of the structures were considered in recent years in seismic rehabilitation or where wall has opener, it is very important to use stiffener. For example, the building of which lateral strength system includes X, V, inverse V or K shaped bracings and this structure needs strength of its lateral system against earthquake forces will be turned into stiffened SPW by adding plate in the related panel of the structure lateral strength system or vice versa, the structure of which lateral strength system is steel or concrete plate shear wall can e stiffened by adding X, V, K or V-H shaped stiffeners. Stiffeners are used in the above systems only in vertical –horizontal form and other forms have not been analytically and experimentally studied. Only tests on steel plate shear walls stiffened with V-H shaped stiffeners were performed by Takahashi et al. in this research, effect of X ، K، V and V-H shaped stiffeners was studied on steel plate shear walls. Behavior of the related models was predicted on the basis of Pushover nonlinear static analysis including nonlinear geometrical analysis and behavior of material was predicted on the basis of code laws FEMA356 and with use of nonlinear express dynamic relations in ABAQUS software. Code acceptance terms were used to control performance surface of the related models and compare it with the results obtained from finite element analysis. Use of stiffeners was studied from two points of view: stiffening web plates and comparing increase of yield and ultimate load and capacity to absorb energy of walls with use of different forms of stiffeners. Another attitude includes decreasing consumption of steel and economizing the project. ASD-AISC code terms have been applied regarding stiffeners in plate girders for selection of stiffeners in the related models so that local buckling doesn't occur in them and plate doesn't displace in stiffener contact place. It seems that diagonal stiffeners (X, K and V shaped) has more desirable effect on increase of yield load , ultimate load and capacity to absorb panel energy in comparison to other diagonal stiffeners including K, inverse V and V shape especially V-H shape stiffener which is used commonly and x shape type is the most proper of other diagonal stiffeners.

3- Specifications of samples:

1-story and 1-opening sample was selected for modeling and analysis (SPW sample). Control of the related sample sections specifications with use of M-PFI method showed that steel plate is under yield load before buckling or formation of plastic joint in column. Dimensions and specifications of the sample were selected similarly to the third story of three-story building with steel plate shear wall designed on the basis of Canada code (NBCC 2005). The samples were stiffened with X، V-H ،K and V shape stiffeners on both sides. In all samples, area and inertia moment of stiffeners were selected so that buckling doesn't occur in them before yielding and general buckling of plate is prevented and is limited to lower part of panels. On the other hand, the related stiff stiffeners were selected. With regard to similar behavior of steel plate shear walls to plates girders, AISC-ASD terms relating to stiffened plates girders were applied for stiffeners. According to AISC terms, the following relations should hold true to prevent local buckling and the minimum necessary inertia moment:

$$I_s \geq (h/50)^4 \tag{1}$$

Where w is width and t is thickness of stiffener, f_y is stiffener steel yield stress.

$$w/t \leq 797/\sqrt{f_y} \tag{2}$$

Where h is height of plate girder.

Table 1 shows geometrical specifications of panels and sample stiffeners of SPW. In the above table, width and height of panels are based on distances between the centers and girder around panels. In that table, weight of stiffeners in models 4,6,8,10 and 12 was equivalent to increase of plate thickness to 1.5 mm and in models 5,7,9,11 and 13 was equivalent to increase of plate thickness to 2 mm. weight of the steel consumed for different stiffeners is equal in stiffened panels for each case. For example, weight of the steel used for stiffeners is equal in models 4, 6,8,10 and 12. For more study on effect of diametric stiffeners in the sample, more stiffeners were embedded. Weight of these stiffeners was equivalent to increase of plate thickness to 2.5, 3 and 5.5 mm (models 14 to 16) and the related specifications are shown in table 2. Table 3 shows specification of girder and column sections of the sample.

4- Selection of element :

A suitable design of steel plate shear wall is the design in which the plate wastes more energy in comparison to frame. In order to use the plate suitably, it is necessary to yield the plate before creating buckling or yield in the frame and border members are able to tolerate against stresses resulting from diametrical stress field in the plate.

Table 1: geometrical specifications of SPW sample –all dimensions in mm

Model number	Type of panel	Dimensions of panel		Thickness of steel plate	Stiffeners section surface	
		Width	Height			
1	Un-stiffened	4000	3500	1.5	-	
2		4000	3500	3	-	
3		4000	3500	3.5	-	
4	With x shaped stiffener	4000	3500	1.5	3588.9	
5		4000	3500	1.5	4785.1	
6	With V-H shaped stiffener	4000	3500	1.5	V	H
					675.2	4160.1
7		4000	3500	1.5	675.2	5741.4
					V	H
8	With K shaped stiffener	4000	3500	1.5	4354.5	
9		4000	3500	1.5	5806	
10	With V shaped stiffener	4000	3500	1.5	4750.5	
11		4000	3500	1.5	6224	
12	With inverse V shaped stiffener	4000		1.5	4750.5	
13		4000	3500	1.5	6224	

Table 2- specifications of x-shaped stiffeners for stiffening samples –all dimensions in mm

Sample	Model No.	Thickness of steel plate	Stiffeners section surface
SPW	14	1.5	5981.4
	15	1.5	7177.7
	16	1.5	13159.2

Table 3- specifications of border elements of SPW sample

Sample	Girder section		Column section
	Base girder	Ultimate girder	
W14×82	W14×68	W14×74	W14×82

The above cases were controlled with use of equations in M-PFI method for all models. Although border elements can be modeled with BEAM element, in case local buckling occurs in them, this will not be considered in analysis. Terms elaborated in M-PFI method cause girders and columns to be strongly selected but plate , border elements and stiffeners were modeled for predicting behavior of models in all models with S4R shell element which is four-node and two-curve element reduced through integration with regard to connection of stiffeners to flanges of girder and column and local buckling. Any node of the above element has 6 degrees of freedom i.e. 3 degrees of transfer and 3 degrees of rotation.

5- Specifications of material :

All materials used in models were modeled in isotropic manner with bilinear stiffening non-elastic behavior. Their behavior was accepted in stress and pressure equally and Von Mises yield surface was accepted as yield term. Yield stress of steel plate and border elements are 250 Mpa and 350 Mpa and their ultimate strain is 0.00625 and 0.00875. Elasticity module is 200 Gpa, tangent module is 2 Gpa and Poisson coefficient is 0.3.

6- ANALYSIS METHOD

Numerical model of all samples was analyzed with use of nonlinear finite element plan ABAQUS. This software is able to solve engineering problems with high nonlinear degrees. Sudden transformation out of steel plate causes convergence problems in SPW systems analysis due to development of stress field. With regard to weak performance of implicit FE method, dynamic explicit method was selected for analysis of SPW. Behavior of the related models was predicted on the basis of pushover static analysis including nonlinear geometrical and materials models. Criterion for testing quasi-static analysis is controlled by studying kinetic energy of system which should be negligible during analysis. In contrary to implicit methods in ABAQUS/Standard which is necessary for obtaining acceptable answers, it is necessary to have suitable meshing. Mesh size in explicit method can be considered large. Mesh size of 25 cm is predicted for un-stiffened panels and panels with V-H shaped stiffener of models behavior. However, diagonal stiffeners cause not to have suitable panel meshing. For this reason, panels with diagonal stiffeners were divided into smaller parts for acceptable meshing and mesh size of 25 cm predicted behavior of models with precision. Figure 1 shows SPW sample modeling in ABAQUS software.

7- Loading and border conditions:

All models were loaded by applying lateral load in girder joints nodes to the column on the basis of FEMA356 code. With regard to the fact that target displacement calculated on the basis of code terms didn't describe perfect behavior of the samples and by reliance on paragraph 3-3-7-5 of the code, lateral loads were applied beyond target displacement in order to do pushover analysis of steel plate shear wall and obtain load – displacement diagram up to failure so that they caused plastic joint or buckling in column. In order to model connection of column to floor of column, displacement of the lower nodes of both columns was bounded in all directions. In order to model displacement out of the plate bounded by roof slab in the buildings, displacement out of girder web plate was prevented in samples.

8- Terms of acceptance and determination of performance surface of steel plate shear walls on the basis of FEMA356 code terms :

Terms of acceptance and determination of performance surface of the wall are determined on the basis of table 4. θ_y is obtained by dividing Δ_y by panel height .for example, structure will be included in performance surface of LS when target displacement (rotation) is lower than permissible plastic rotation which equals to $10\theta_y$ or when target displacement (rotation) is higher than $13\theta_y$ value (performance surface of CP) and performance of structure is disordered. As mentioned above, loading of the samples was applied until displacement beyond target displacement on the basis of FEMA356 terms causing plastic joint or buckling in columns. In order to control performance surfaces of the related panels, target displacement was considered up to 0.02 of panel height according to FEMA450 terms.

Table 4: terms of acceptance and performance surface of steel plate shear walls in nonlinear processes

	Acceptance Criteria		
	Plastic Rotation Angle , Radians		
	Immediate Occupancy	Primary	
		Life Safety	Collapse Prevention
Steel Plate Shear Wall	$0.5\theta_y$	$10\theta_y$	$13\theta_y$

9- Validation of modeling and analyses of this research :

In order to validate the results obtained in this research, results of one sample modeling and comparison with the obtained results are shown.

Comparison with reference No. 13: ("Unstiffened Steel Plate Shear Wall Performance under Cyclic Loading"): In this article, reciprocating behavior of two samples with one story (SPSW1 and SPSW2) and a sample with 4 stories (SPSW4) were tested. For comparison, SPSW2 sample was tested, modeled and analyzed in ABAQUS software according to the specifications. Figures 2 and 3 show SPSW2 tested in laboratory and modeled by software respectively. Load-lateral displacement resulting from pushover analysis in ABAQUS and reciprocating behavior obtained in laboratory from SPSW2 sample was shown in figure 4. As you see, numerical analysis performed by the software, pushover predicted hysteresis behavior very well.

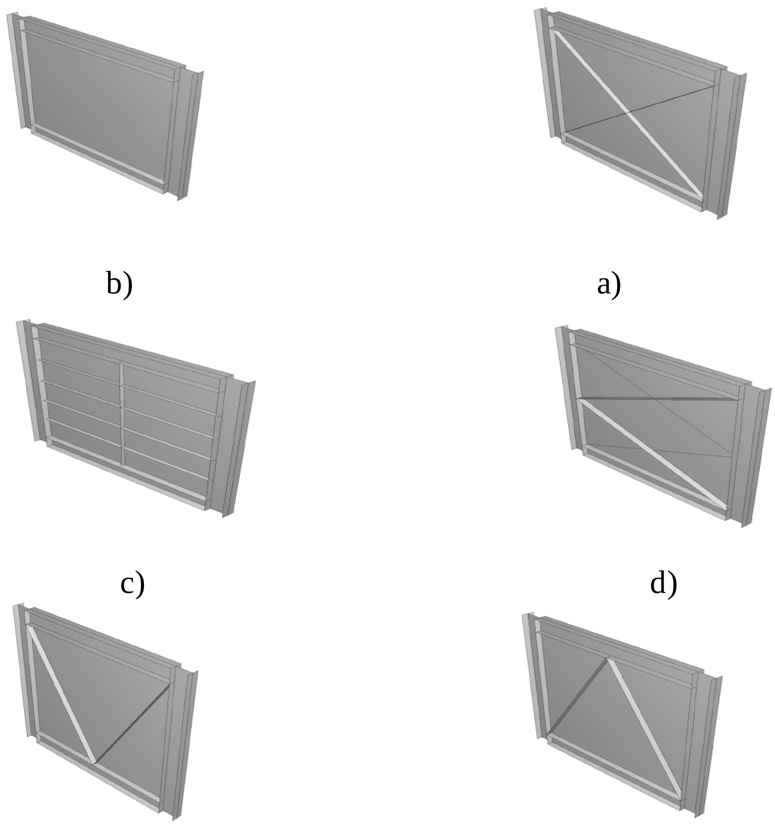

Figure 1: SPW sample modeling in ABAQUS:

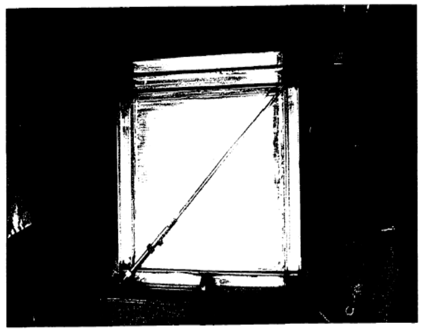

Figure 2: SPSW2 sample tested by Lubell in Laboratory

a- unstiffened panel, b-panel with x shaped stiffener, c- panel with V-H shaped stiffener, d-panel with K shaped stiffener, e-panel with V shaped stiffener, f- panel with inverse V stiffener, g-panel with inverse v stiffener

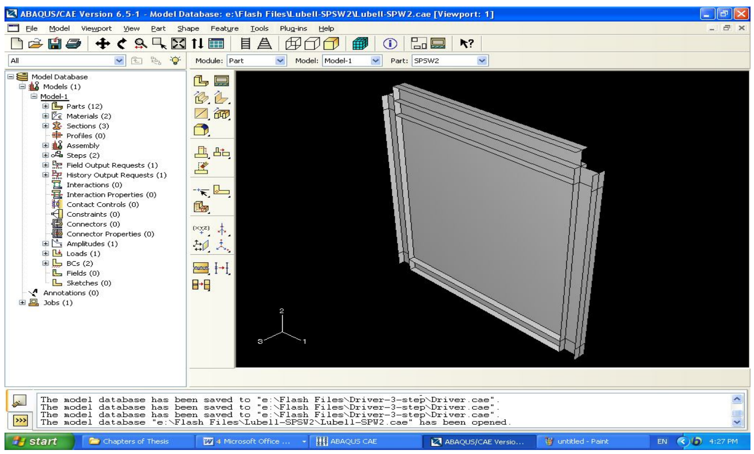

Figure 3: SPSW2 sample modeled in ABAQUS

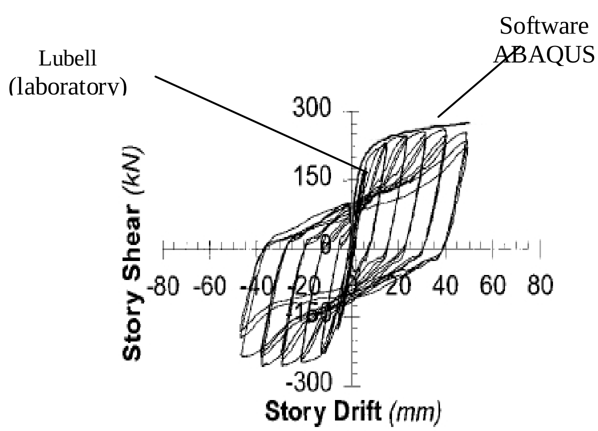

Figure 4: comparison of load –lateral displacement diagram obtained from ABAQUS software and reciprocating behavior obtained from test by Lubell

10- ANALYSIS RESULTS OF SAMPLES FINITE ELEMENT:

10-1- study on effect of stiffener on panel stiffening:

In figure 5, load-lateral displacement diagram of models 1,4,6,8,10 and 12 is shown. Weight of the stiffener was considered equivalent to increase of plate thickness to 1.5 mm. table 5 shows percentage of yield and ultimate load increase of the stiffened panels in comparison to the unstiffened case. Figure 6 shows load- lateral displacement diagram of models 2,5,7,9,11 and 13. Wight of the stiffeners was considered equivalent to increase of plate thickness to 2 mm. Table 6 shows percentage of yield and ultimate load increase of the stiffened panels in comparison to the unstiffened case. As observed, x shaped stiffener increased capacity of unstiffened panel loading capacity in comparison to other stiffeners in both cases. Increasing percentage of yield load, ultimate load and panel energy absorption capacity with x shaped stiffener in comparison to other stiffeners. This problem can be considered in reinforcement of structures. Plate stiffening causes to suspend plate from buckling stage to post buckling stage. The above expression holds true for all applied stiffeners. On the other hand, different forms of stiffeners used for stiffening plate causes to increase panel buckling load but because t/b ratio of the plate (t, thickness of plate and b , panel width)is very small in SPW systems , buckling load of these systems will be very low and most of panel capacity relates to post buckling stage. Therefore, an effective stiffener causes to increase panel post buckling capacity. V shaped and inverse v stiffener panel has equal behavior with regard to similar formation condition. K shaped stiffener was effective on panel stiffening differently from v shaped stiffeners. V-H shaped stiffener had little effect on unstiffened panel. In fact, effect of V-H shaped panel in post buckling area was higher than that of other stiffeners especially X shaped panels. Finite element analysis results showed that stress rates in V-H shaped stiffeners are very low before perfect yield of plate and has no considerable effect on loading indicating weak efficiency of such stiffeners in comparison to other stiffeners but another lateral strength system is added to panel like diametrical bracing in addition to the plate which resists against lateral loads and this stiffening form causes to increase capacity of the structure in the post buckling stage.

In figure 7, load –lateral displacement diagram of panel with V-H shaped stiffener is shown with regard to weight of stiffeners equivalent to increase of thickness to 1.5 and 2 mm. it is observed that stiffening of panel with V-H shaped stiffener has no effect on the sample pushover curve capacity while energy absorption capacity of X shaped stiffener increases by stiffening panel in X shaped stiffener. This is shown in figure 8. On the basis of figure 8, yield and ultimate load increase diagram with X shaped stiffener is drawn in figure 9 against increase of total section of the stiffeners. As specified, yield and ultimate loads of the panel increase linearly with increase of its stiffening. Main difference of X shaped stiffeners effect on stiffening of structures in comparison to V-H shaped stiffeners which are used commonly is evident from figures 5,6,7,8 and tables 5 and 6.

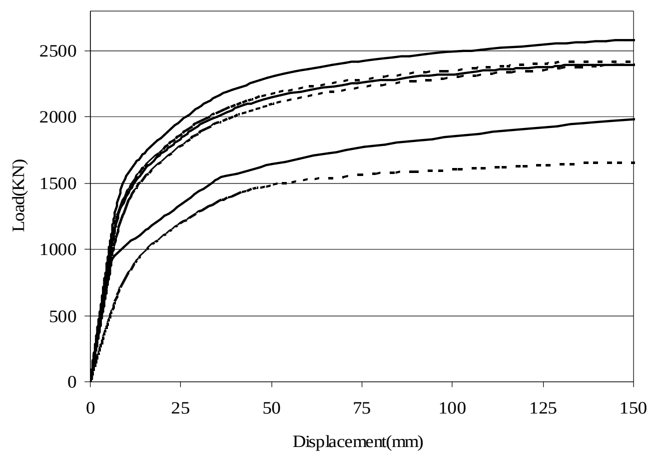

Figure 5: load –lateral displacement diagram of models 1, 4, 6,8,10 and 12

Table 5-increasign percentage of yield and ultimate load of panel n comparison to unstiffened case on the basis of figure 5

Type of panel	Yield load	Ultimate load	Increasing percentage of yield load of panel in comparison to unstiffened case	Increasing percentage of ultimate load of panel in comparison to unstiffened case
With X shaped stiffener	1501.51	2590.62	97.43	55.91
With inverse V stiffener	1273.44	2420.60	67.44	45.68
With V-shaped stiffener	1273.44	2396.64	67.44	44.24
With K-shaped stiffener	1203.14	2398.73	58.20	44.36
With V-H shaped stiffeners	903.68	1987.59	18.82	19.62
Without stiffener	760.53	1661.58	-	-

10-2- control of acceptance terms and performance surface of stiffened panels with use of code FEMA 356 terms:

Table 7 and 8 show performance surfaces of stiffened panels on the basis of figure 5 and 6. Yield period is obtained from division of yield displacement by height of the story according to FEMA 356 code terms. As observed from tables, target rotation of all stiffened panels other than panel with V-H shaped stiffener is higher than permissible rotation of IO performance surface but it is lower than permissible rotation of LS and CP. Target rotation of panel with V-H shaped stiffener is higher than permissible rotations of performance surfaces IO and LS but lower than performance surface Target rotation doesn't exceed permissible rotation of CP performance surface in any stiffened panels. With regard to the shown tables, we can conclude suitable and flexible performance of all stiffened panels. Although panel with K shaped stiffener increased yield load of unstiffened panel in comparison to panels with V shaped stiffeners, it has better performance surface. We can observe in the above tables that distance between target rotation and permissible rotation of LS performance surface in panel with X shaped stiffener is larger which indicates effective X shaped stiffeners on stiffening of panel in comparison to other stiffeners as we concluded from finite element analyses.

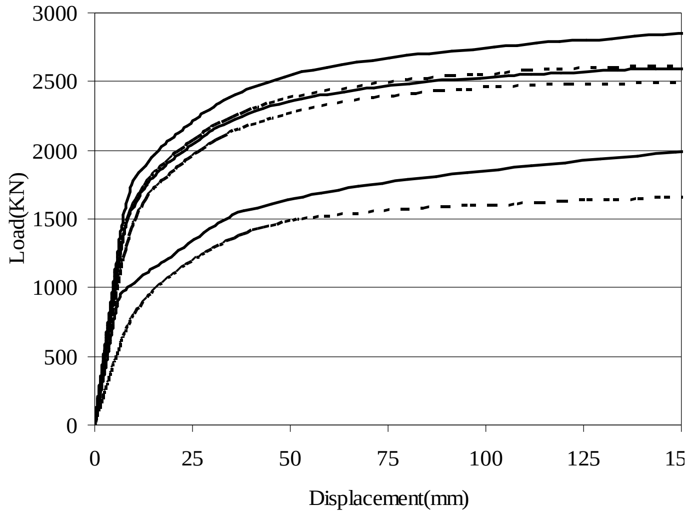

Figure 6: load –lateral displacement diagram of models 2,5,7,9,11 and 13

Table 6: -increasing percentage of yield and ultimate load of panel in comparison to unstiffened case on the basis of figure 6

Type of panel	Yield load (KN)	Ultimate load (KN)	Increasing percentage of yield load of panel in comparison to unstiffened case	Increasing percentage of ultimate load of panel in comparison to unstiffened case
With X shaped stiffener	1751.76	2858.86	130.33	72.06
With inverse V stiffener	1478.70	2626.87	94.43	58.10
With V-shaped stiffener	1478.70	2626.87	94.43	58.10
With K-shaped stiffener	1372.75	2495.19	80.63	50.17
With V-H shaped stiffeners	912.12	2029.42	20.06	22.11
Without stiffener	760.53	1661.58	-	-

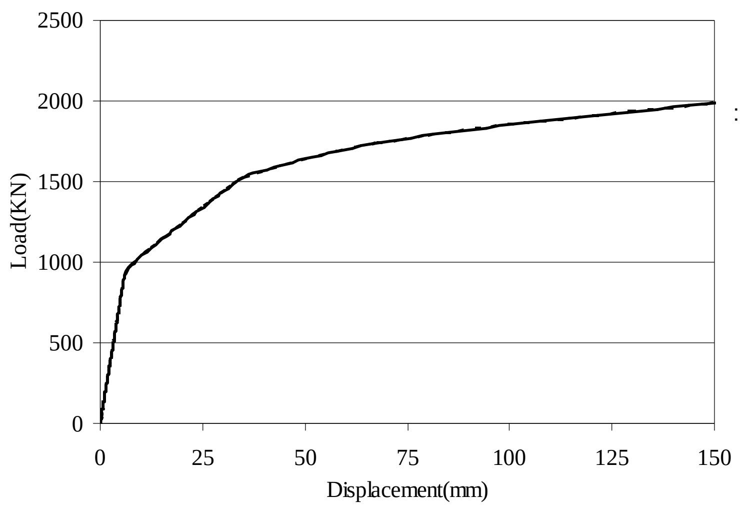

Figure 7: in effectiveness of increased weight of V-H shaped stiffeners on stiffening of panel (models 6 and 7)

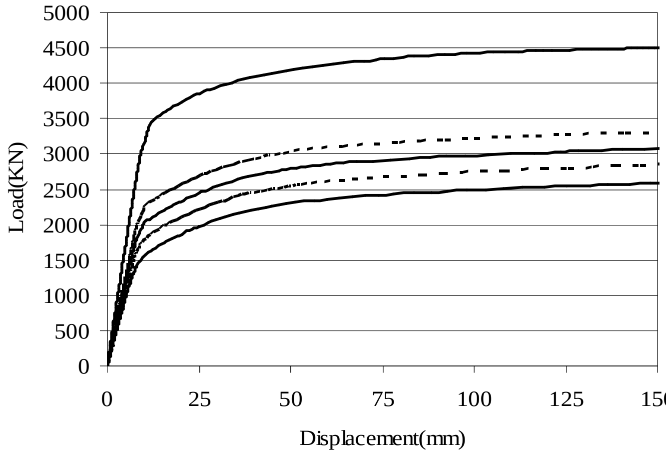

Figure 8: increase of pushover capacity of the panel with X shaped stiffener with increase of stiffeners weight (models 4,5,14,15 and 16)

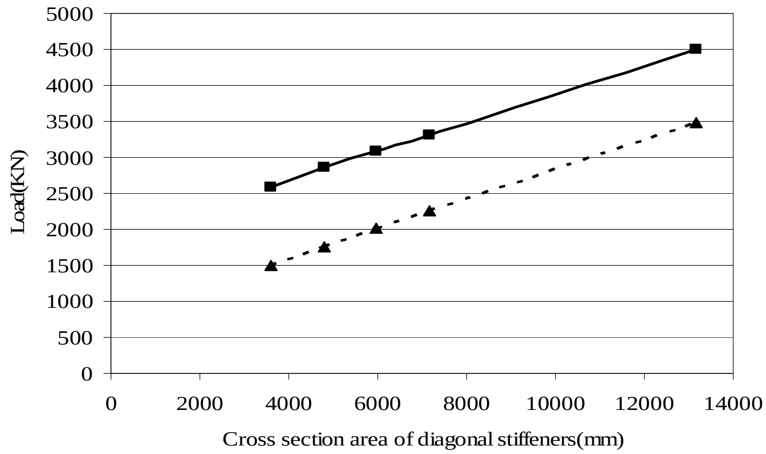

Figure 9: increase of yield and ultimate load of panel with X-shaped stiffener against increase of section surface of all stiffeners

Table 7: control of acceptance terms and performance surfaces of stiffened panels on the basis of figure 5

Type of panel	Target rotation	Yield rotation (radian)	Permissible rotation in IO performance surface	Permissible rotation in LS performance surface	Permissible rotation in CP performance surface
With X shaped stiffener	0.02	0.002575	0.001289	0.025770	0.033501
With inverse V stiffener	0.02	0.002178	0.001089	0.021780	0.028314
With V-shaped stiffener	0.02	0.002178	0.001089	0.021780	0.028314
With K-shaped stiffener	0.02	0.002350	0.001175	0.023500	0.030550
With V-H shaped stiffeners	0.02	0.001685	0.000843	0.016850	0.021905

Table 8: control of acceptance terms and performance surfaces of stiffened panels on the basis of figure 6

Type of panel	Target rotation	Yield rotation (radian)	Permissible rotation in IO performance surface	Permissible rotation in LS performance surface	Permissible rotation in CP performance surface
With X shaped stiffener	0.02	0.002705	0.001353	0.02705	0.035165
With inverse V stiffener	0.02	0.002287	0.001144	0.022870	0.029731
With V-shaped stiffener	0.02	0.002287	0.001144	0.022870	0.029731
With K-shaped stiffener	0.02	0.002504	0.001252	0.025040	0.032552
With V-H shaped stiffeners	0.02	0.001711	0.000856	0.017110	0.022243

10-3- study on effect of stiffeners in the stiffened panel and comparison with unstiffened panel with equivalent consumable steel:

Figures 10 and 11 show load –lateral displacement diagram models 2,4,6,8,12 and 10 and models 3,5,7,9,11 and 13 respectively. In both cases, consumed steel of the panels with stiffener and panel without stiffener is equal. Tables 9 and 10 show increase of yield and ultimate load of panels with stiffener in comparison to panel without stiffener. Yield load of panel can be selected as criterion for design of SPW system. With regard to tables 9 and 10 with equal consumed steel, yield load with X shaped stiffener increased to 15.55 and 16.59% in comparison to panel without stiffener. However, there is no considerable difference between pushover diagrams and stiffness of panel with X-shaped stiffener and panel without stiffener on the basis of figures 10 and 11 and in case we want to use panel with x shaped stiffener instead of unstiffened panel by decreasing consumption of steel, it will not be cost effective. V and K shaped stiffeners not only didn't increase panel yield load, but also, their ultimate load was reduced in comparison to the unstiffened panel. Panel with V-H shaped stiffener decreased yield and ultimate load in comparison to panel without stiffener. This is because V-H shaped stiffeners have little effect on loading before yield of the plate. As result, there will be thinner plate than unstiffened panel plate in post buckling stage for creating diametrical tensile field and strength against lateral forces with the equivalent consumable steel. In design of plates girders, use of stiffener causes to decrease with of steel but buckling load of the system is very low in steel plate shear wall systems with regard to very low ratio of plate t/b and most of the panel capacity relates to post buckling capacity and as figures 10 and 11 show, post buckling capacity of panel with x shaped stiffener is not so different from unstiffened panel. Therefore, it is more cost effective to use unstiffened panel instead of stiffened panel.

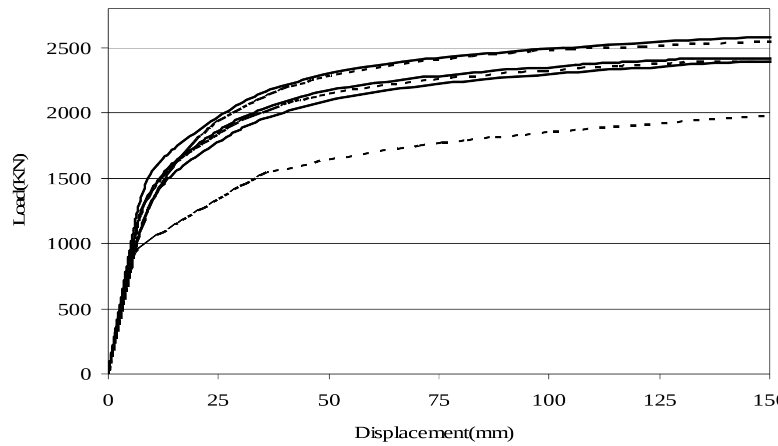

Figure 10-load-lateral displacement diagram of models 2,4,6,8,10,12

Table 9: -increasing percentage of yield and ultimate load of panel in comparison to unstiffened case on the basis of figure 10(equivalent steel)

Type of panel	Yield load (KN)	Ultimate load (KN)	Increasing percentage of yield load of panel in comparison to unstiffened case	Increasing percentage of ultimate load of panel in comparison to unstiffened case
With X shaped stiffener	1501.51	2590.62	15.55	1.44
With inverse V stiffener	1299.39	2225.76	0	-12.84
With V-shaped stiffener	1299.39	2203.72	0	-13.70
With K-shaped stiffener	1299.39	2398.73	0	-6.07
With V-H shaped stiffeners	903.68	1987.59	-35.45	-22.17
With X shaped stiffener	1299.39	2553.79	-	-

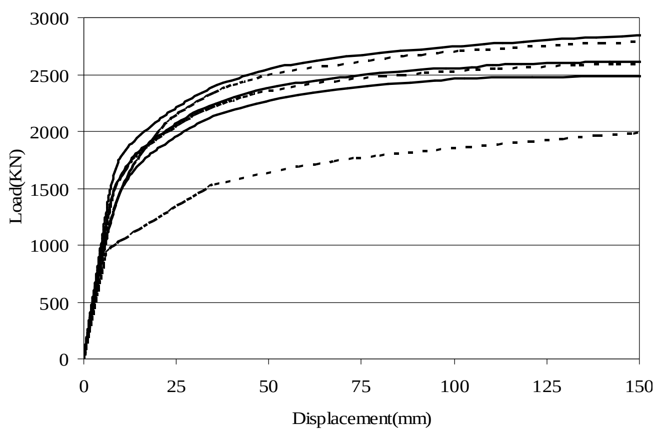

Figure 11-load-lateral displacement diagram of models 3,5,7,9,11 and 13

Table 10: -increasing percentage of yield and ultimate load of panel in comparison to unstiffened case on the basis of figure 11(equivalent steel)

Type of panel	Yield load (KN)	Ultimate load (KN)	Increasing percentage of yield load of panel in comparison to unstiffened case	Increasing percentage of ultimate load of panel in comparison to unstiffened case
With X shaped stiffener	1724.04	2858.86	16.59	2.02
With inverse V stiffener	1478.70	2412.37	0	-13.92
With V-shaped stiffener	1478.70	2412.37	0	-13.92
With K-shaped stiffener	1478.70	2495.19	0	-10.96
With V-H shaped stiffeners	913.12	2029.42	-35.5	-27.58
With X shaped stiffener	1478.70	2802.34	-	-

11- conclusions

Results obtained from this study are given as follows. It is worth noting that field of these results is limited to the states considered for analytical samples in this research but it is expected that these results have more comprehensive application.

1- In general case, stiffening the plate causes to increase its capacity. Such capacity increased can include buckling and post buckling capacity. It is worth noting that such capacity increase depends on solidity of the stiffeners.

2- X shaped stiffener is more effective in stiffening the steel plate shear walls than V, Inverse V and V-H shaped stiffeners .

3- X shaped stiffeners have equal effect in stiffening of panel due to similar geometrical status.

4- . V-H shaped stiffener has no considerable effect on stiffening of pane. Although V-H shaped stiffener causes suspension of the plate from buckling stage to post buckling stage, its efficiency decreases in post buckling stage.

5- Although it was shown that yield capacity of the panel with X shaped stiffener may be higher than that of unstiffened panel with the equivalent consumed steel with regard to effect of X shaped stiffener in comparison to other stiffeners, pushover capacity of two panels is not so different. In spite of similar behavior of steel plate shear walls to plate's girders with stiffeners for lower steel consumption, it is better to use unstiffened panel in steel plate shear walls.

6- Due to effectiveness of X shaped stiffener in comparison to V, Inverse V , K, V-H shaped stiffeners, it was shown that there is linear relationship between increased yield and ultimate capacity of X shaped stiffener and increased weight of the stiffeners .

7- Control of acceptance terms and performance surface of the analytical models with use of FEMA356 code terms showed that all stiffened panels show suitable and flexible performance. We concluded effectiveness of X shaped stiffener compared to other stiffeners as well as weaker performance of V-H shaped stiffener with use of code terms as finite element analyses show.

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