J. Civil Eng. Mater.App. 2019 (June); 3(2): 79-89

Journal of Civil Engineering and Materials Application

Journal home page: http://jcema.com

Received: 02 March 2019 •Accepted: 21 May 2019

Research

doi: 10.22034/JCEMA.2019.92089

Effect of Opening Location in the Wall with Corrugated Steel Plate Using the Pushover Analysis

Fatemeh Sadat Asadi[1], Arash Mohammadi Farsani[2]*

Department of civil engineering, Shahre kord Branch, Islamic Azad University, Shahre kord, Iran.

*Correspondence should be addressed to Arash Mohammadi Farsani, Department of civil engineering, Shahre kord Branch, Islamic Azad University, Shahre kord, Iran. ; Tel: +989132855421 ;Fax: +9888944857; Email: amohammadi@cv.iut.ac.ir

ABSTRACT

Steel shear walls are far cleaner and are considered more rapid replacements for the concrete shear walls in terms of execution and more reliable in terms of strength and behavior. Also, the system takes advantage of all good characteristics of concentrically braced frames (CBF) like V and X-shaped bracings, etc. and also those of eccentrically braced frames (EBF). They are also efficient in terms of execution and good behavior and in many cases, act better. In this research, the effect of opening location in the corrugated plate is investigated using the pushover analysis. For the analysis and investigation of the model, use has been made of ABAQUS software and the two available methods for analysis and design of steel shear walls are incorporated. The obtained results showed that the opening in the corrugated steel shear wall causes reduced safety and lateral resistance of the wall, so that where the openings are located at the corners, the effect of reduction is more severe. On this basis, the minimum reduction in stiffness and strength of the steel shear wall with opening is where it is located at the middle of the wall and the worst case is where the opening is located at the corners and close to the columns.

Keywords: opening, corrugated plate, stiffness, strength, pushover analysis

1. INTRODUCTION

Steel shear walls have been under the focus of attention during the past three decades to resist against the earthquake and wind lateral loads, especially in high rising buildings. This new phenomenon has been widely spread all over the world and is implemented in construction of new buildings and retrofitting the existing buildings especially in the earthquake-prone countries like the USA and Japan. The first serious work for investigating the strength of shear panels after buckling of their web was done by Wagner in 1931 [1]. After performing experiments on the thin shear panels made of aluminum, he presented the theory of diagonal tension field. After him, many researchers studied and examined the diagonal tension field of girder plates [2-5] and gradually, the stiffness of flanges was also taken into account with considering the experimental results in the calculation of their ultimate strength. The use of steel shear walls with thin plates was first introduced in 1980's at Alberta University in Canada by Kulak et al. based on the studies performed on the girder plates [6]. They focused their investigations and also their theoretic and experimental studies merely on the steel shear walls with thin plates. While performing tests for calculation of their ultimate capacity, they replaced the thin plate of webs with a series of diagonal tensile bars. To prevent the buckling of steel plate, especially in the elastic state, one could use the stiffeners [7 & 8]. The stiffeners may be used on one or both sides of the steel plate [9]. In the studies performed on the steel shear panels with different plate thicknesses and different dimensions of stiffeners at different distances from each other, it is concluded that the panels with stiffeners at both sides exhibit a better performance with respect to those with stiffeners at one side [10]. Steel shear walls are simple for execution and lack any special complexity [11]. Therefore, engineers, technicians and technical workers with the available knowledge and without need for any new skill, could execute them. The accuracy of the work is similar to that of the common steel structures and in case of careful execution could provide higher safety factor with respect to other system types. Regarding the simplicity of this system and possibility of its manufacturing at the factory and its installation at the site, the execution speed is high and the costs are greatly decreased. Steel shear walls are far cleaner and are considered more rapid replacements for the concrete shear walls in terms of execution and more reliable in terms of strength and behavior [12]. Also the mentioned system takes advantage of all good characteristics of the concentrically braced frames (CBF) like v and x-shaped etc. bracings and also, the eccentrically braced frames (EBF), in terms of efficiency and good behavior in execution and at many instances outperform other systems [13]. The system is stiffer than the stiffest x-shaped bracing systems and considering the possibility of creating opening at any part of it, has the efficiency of all other bracing systems. Also the system behavior in the plastic region and the amount of energy absorption is better than other bracing systems [14]. In the system of steel shear walls, due to the extended use of materials and connections, the stress distribution is much better than other resistant systems against lateral loads like frames with various types of bracings, where the materials are categorized and connections are concentrated and the system behavior is more appropriate especially in the plastic region [15]. In the steel shear wall, using the thin steel plates, one could take advantage of the post-buckling phenomenon like the girder plates without any disturbance in the stability [16]. Various experiments show that the hysteresis loops of the mentioned walls under the cyclic loads with thin plates or reinforced with plates, are fully stable and energy absorption is high in them. The experience obtained from the recent earthquakes exhibits the significant shear stiffness of the steel shear walls [17-20]. Therefore, application of this system for strong lateral loads and displacement control due to them is very useful. Now, regarding the performed studies, in the present study the effect of opening location in the wall with corrugated plate using the pushover analysis was investigated.

2. MATERIALS AND METHODS

2.1. ANALYSIS AND DESIGN METHOD

Up to day two major methods of analysis and design have been introduced for the steel shear walls. The first method was introduced in 1980's by Kulak et al. Based on the studies and experiments conducted at Alberta University in Canada [6]. In this method, as shown in Figure 1, the steel plate is replaced by a number of diagonal tensile bars and then the system is analyzed and designed. The application of this method which is also cited in the national building code of Canada [21], is now limited to the steel shear walls with thin plates and is not intended for the shear walls with thick plates or reinforced steel shear walls. Furthermore, there is no analysis and design method introduced for the steel shear walls with openings. In the above method, as the steel plate is replaced by a number of bars, thus the frame and plate are simultaneously analyzed as a virtual system. In this system the designer has not a physical understanding of the system behavior, especially the interaction between the frame and steel plate.

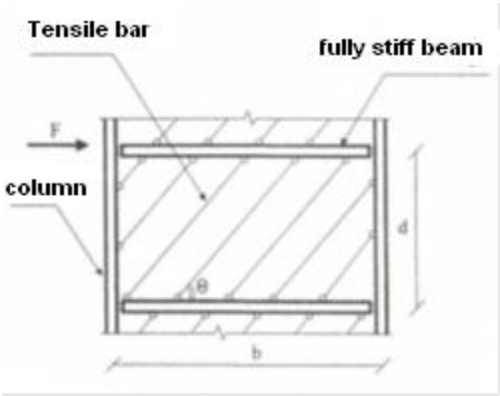

Figure 1. Steel shear wall, where the web plate is replaced by the tensile bars

In the second method which has been presented by Saeed Saboori et al. in the late 1980s and was later developed, the attempt is made that the method could respond for all states of the system including the steel shear walls reinforced with thin to thick plates and with the opening. Furthermore, in this method the behavior and performance of frame with steel plate is considered separately and their interaction, which is of great importance in terms of understanding the system behavior in the design process, In this method, both the analysis and design of the steel shear walls are simply done manually. In this section, we deal with this method of analysis and design. Having known the amount of acting lateral load on the steel shear wall, as shown in Figure 2, one could obtain the shear are explained in the physical terms. Thus using this method, having both the behavior and performance of the frame and steel plate, separately and also their interaction, the designer would be able to apply his/her engineering judgment with full knowledge in the design process. In order to use the method for design of structures, it is essential to incorporate some modifying factors to account for practical conditions with respect to the theoretical and ideal ones.

force diagram of the stories and thus the load of each shear panel is calculated. Also knowing the amount of shear force acting on each story panel and assuming a safety factor of 1.7, the ultimate shear load of the intended frame is calculated.

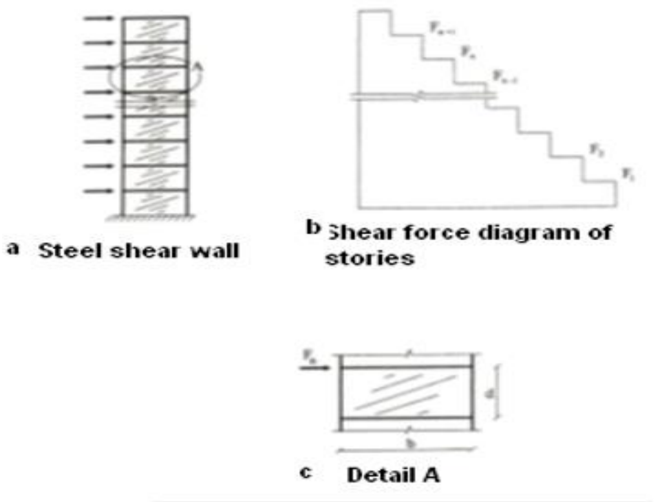

Figure 2 . Steel shear wall under lateral load

2.2. DESIGN OF INVESTIGATED MODEL

Here, attempt is made using the principles of steel structures and all that is contained in the valid codes, concerning the design of steel shear walls, the model be designed and other essential analyses be performed on it. In general, a section of the steel structures design code together with seismic provisions in AISC, wherein the steel shear wall system has been formally recognized [22], are incorporated for design of the model.

2.3. PROVISIONS OFAIS CCODE

Corresponding to the design of different components of a special steel shear wall system

In AISC-10 code, the behavior factor of the special steel shear walls (R) for the simple building frame system is equal to 7, and for the dual systems is equal to 8. Also the corresponding overstrength factor (Ω_o) for them is 2 and 2.5, respectively. The abovementioned parameters of seismic design were previously recommended by NEHRP (23) and then by AISC2005 (seismic provisions).

2.4. STEEL PLATE

2.4.1. Shear strength

Based on the seismic regulations of AISC, the panel design shear strength ϕv_n (LRFD) and the allowable shear strength $\frac{v_n}{\Omega}$ (ASD), should be determined according to the limit state of shear yielding as follows:

$$V_n = 0.42 F_y t_w L_{cf} \sin 2\alpha \quad (1)$$

Where

Vn, is the nominal shear strength in N

ϕ , is the shear strength factor which is equal to 0.9 (LRFD)

Ω , is the shear safety factor equal to 1.67 (ASD)

Fy, is the characteristic yielding stress in MPa

tw, is the thickness of steel plate in mm

Lcf, is the clear distance between the flanges of vertical boundary elements in mm

α , is the web yielding angle with respect to the vertical axis in radians which is calculated by the following equation:

$$\tan^4\alpha = \frac{1+\frac{t_w L}{2A_c}}{1+t_w h\left(\frac{1}{A_b}+\frac{h^3}{360 I_c L}\right)} \quad (2)$$

Where:

h, is the distance between the center of horizontal boundary elements lines (beams) in mm

Ab, is the cross-sectional area of a horizontal boundary element in mm^2

Ac, is the cross-sectional area of a boundary element in mm^2

Ic, is the moment of inertia of a vertical boundary element around the vertical axis perpendicular to the plate plane in mm^2

L, is the distance between the center of vertical boundary elements lines in mm

The Ratio of width to height of panel

The ratio of width to height of the panel, L/h, should be limited to:

$$0.8 < L/h \leq 2.5 \qquad (3)$$

2.5. STEEL PLATE CONNECTION TO THE BOUNDARY ELEMENT

The required strength for the web connection to the vertical and horizontal boundary elements should be equal to the yielding strength expected for the steel plate under tension at angle α. The angle α is calculated by equation (4). Where the strip model is used for analysis of the special steel shear wall, the expected tensile strength of strips is obtained from RyFyAs. Where:

Ry, is the ratio of expected yielding stress to the characteristic yielding stress

As, is the cross-sectional area of a single strip which is calculated by the following equation:

$$\left(\frac{L\cos\alpha + H\sin\alpha}{n}\right) t_w \qquad (4)$$

Where:

L is the panel width, H is the panel height, tw is the thickness of steel plate and n is the number of strips in each panel which should be at least equal or greater than 10.

2.6. VERICAL AND HORIZONTAL BOUNDARY ELEMENTS

2.6.1. Required strength

In addition to the requirements of the seismic provisions in AISC, the needed strength of the vertical boundary elements should be calculated based on the corresponding forces of expected yielding strength of the steel plate in tension at angleα, or should be determined by the loading combinations specified in the building codes. It should be noted that for dual systems, the provisions corresponding to the ratio of beam to column moments, the AISC seismic regulations should be met for all the crossings of the vertical and horizontal boundary elements. According to this section, the following relation should be established:

$$\frac{\sum M^*_{pc}}{\sum M^*_{pb}} \succ 1 \qquad (5)$$

Where:

$\sum M^*_{pc}$, is the sum of columns moments at the top and bottom of the connection which is equal to:

$$\sum Z_c \left(F_y - P_{uc}/A_g\right)$$

$\sum M^*_{pb}$ is the sum of beams moments at the beam to column connection which is equal to

$$\sum\left(1/1R_yF_yZ_b + M_{uv}\right)$$

Zc, is the plastic section modulus of column

Puc, is the required compressive strength of column, based on the LRFD loading combinations

Ag, is the gross cross-section of column

Zb, is the plastic section modulus of beam

Muv, is the additional moment due to shear amplification from the location of the plastic hinge to the column centerline based on the LRFD loading combinations.

2.7. WIDTH TO THIKNESS LIMITATION

The vertical and horizontal boundary elements should meet the requirements of section 8-2 of AISC seismic provisions. According to this section, the vertical and horizontal boundary elements should meet the following compactness conditions:

$$\frac{b}{t_f} \leq 0.3\sqrt{\frac{E}{F_y}} \qquad (6)$$

$$\frac{h}{t_{wc}} \leq 3/14\sqrt{\frac{E}{F_y}}\left(1 - 1/54C_\alpha\right) \qquad (7)$$

$$\frac{h}{t_{wc}} \leq \left\{1/12\sqrt{\frac{E}{F_y}}\left(\frac{2}{33} - C_\alpha\right) \geq 1/49\sqrt{\frac{E}{F_y}}\right\} \qquad (8)$$

In the above relations:

b is half of the column flange width, tf is the column flange thickness, C_α is the ratio of required strength to the existing strength $\frac{P_u}{\emptyset_b P_y}$, h is the height of column web, twc is the column web thickness, Py is the axial yielding strength and $\emptyset_b$ is the flexural strength factor equal to 0.90.

2.8. STIFFNESS OF VERTICAL BOUNDARY ELEMENTS

The moment of inertia of a vertical boundary element around the vertical axis perpendicular to the web plane, Lw should not be less than $\frac{0/00307\, t_w h^4}{L}$. Where, L and h have been defined previously and tw is the steel plate thickness.

2.9. DESIGN OF THE ONE STORY STEEAL SHEAR WALL

The structure includes a one-story two dimensional frame with the combined system of steel moment resisting frame and steel shear wall, having a single span of 4m length. The height of story is 3m. All the seismic provisions of Iranian standard No. 2800 are met in its seismic design. For calculation of the story mass, use has been made of the deal load plus 20% of live load. In design of the frame, the soil type of the site is taken as Type II, in an area with very high relative seismic hazard and residential use. Table 1, shows the characteristics of the gravity loads.

Table 1. Gravity loads characteristics

Roof load	Dead load (daN/m2)	Live load (daN/m2)	Snow load (daN/m2)
	650	150	120

Gravity loads acting on the frame per unit length are equal to:

Distributed dead load on the roof beam:

$q_D = 6000 \times 2 + 2000 = 14000\ N/m$

Distributed live load on the roof beam:

$q_L = 1500 \times 2 = 3000\ N/m$

B- Calculation of the lateral load due to the earthquake by the equivalent static analysis method:

$V = CW = \frac{ABI}{W} W$

S=1.5

A=0.35

I=1

R=7

T0=0.1

TS=0.5

$T = 0.05H^{\frac{3}{4}} = 0.05(3)^{\frac{3}{4}} = 0.113\ S$

$T_0 \prec T \prec T \quad \rightarrow \quad B = S + 1 = 1.5 + 1 = 2.5$

$T = 0.113 * 1.25 = 0.141$

$C = \frac{0.35 \times 2.5 \times 1}{7} = 0.125$

modelling software like SAP2000 and ETABS have not the capability of directly design the steel shear walls, the design process of this system and determining the wall plate thickness is done manually by writing down the code relationships in Excel. Also in the studied model the rule of 25 and 50% of seismic base shear is satisfied. Table 2 shows the results of the one story model design.

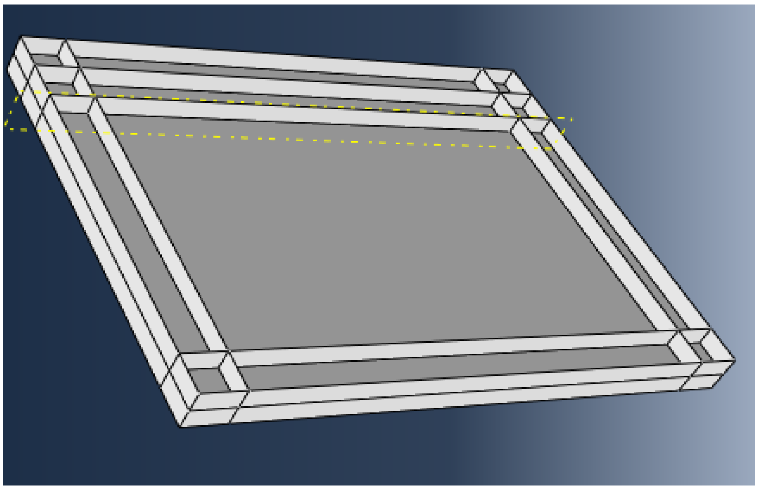

Figure 3. Studied steel shear wall model

Table 2. Dimensions of different sections in the one story model

Story	Beam section	Columns section	Thickness of the steel plate (mm)
1	IPE200	IPB180	5

For validating the software, a one-story frame with a single span having a steel shear wall of 1102mm height and 1720mm width, which has been experimentally studied in 2013 by Nateghi and Elahi, is selected. This is modeled in ABAQUS software using the pushover analysis method. The results indicated the good accuracy of ABAQUS software in comparison with the experimental model. The following table shows the characteristics of experimental model:

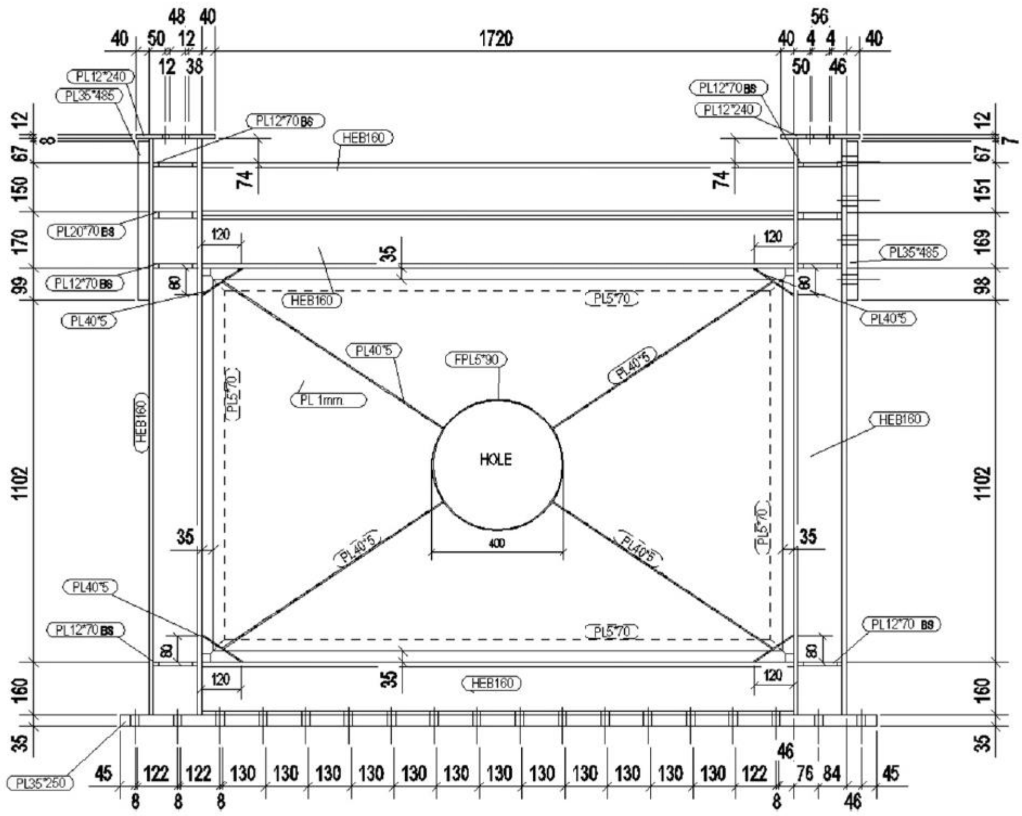

Figure 4. A view of the 2D frame in the laboratory

Table 3. Properties of the sections and materials in the experimental model

Yielding strength of steel (kg/cm2)	Ultimate strength of steel (kg/cm2)	Columns sections	Beams sections	Thickness of steel plate (mm)
3400	4500	HEB160	HEB160	1

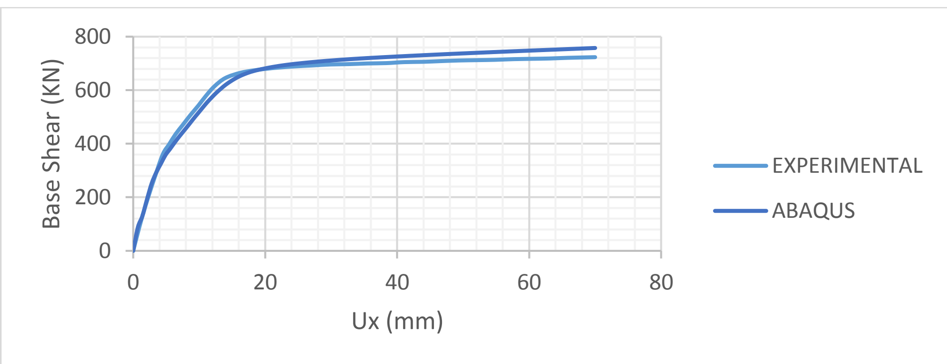

Figure 5. Comparison between the pushover curves obtained in the laboratory and ABAQUS software

2.10. DEFINITION AND DESIGNATION OF NONLINEAR BEHAVIOROF STEEL MAERIAL

As in the nonlinear analyses the structure enters the plastic region, therefore, it is essential to define the nonlinear behavior of material in the plastic region. To introduce the nonlinear behavior of the steel, use has been of the bilinear model and kinematic strain hardening. Table 4, shows the properties of used steel in the modeling.

Table 4. Properties of the used steel in modelling

Specific weight, w	$7800\ {}^{kg}/_{m^3}$
Elastic modulus, Es	$2.1 \times 10^6\ {}^{kg}/_{cm^2}$
Poisson ratio, v	0.30
Fy Yielding strength,	$2400\ {}^{kg}/_{cm^2}$
Ultimate strength, Fu	$4000\ {}^{kg}/_{cm^2}$

3. RESULTS AND DISCUSSION

3.1. PERFORMANCEING PUSHOVER ANALYSISAND EXTRACTING THE RESULTS

In order to investigate the behavior of steel shear wall with corrugated plate, the studied one- story, single-span model is analyzed in the software using the pushover analysis. The diagram of structure capacity is derived once for the case of using simple plate and once for using corrugated one. Figure 6 shows the induced stresses in the plates and Figure 7 compares the diagrams obtained from pushover analysis.

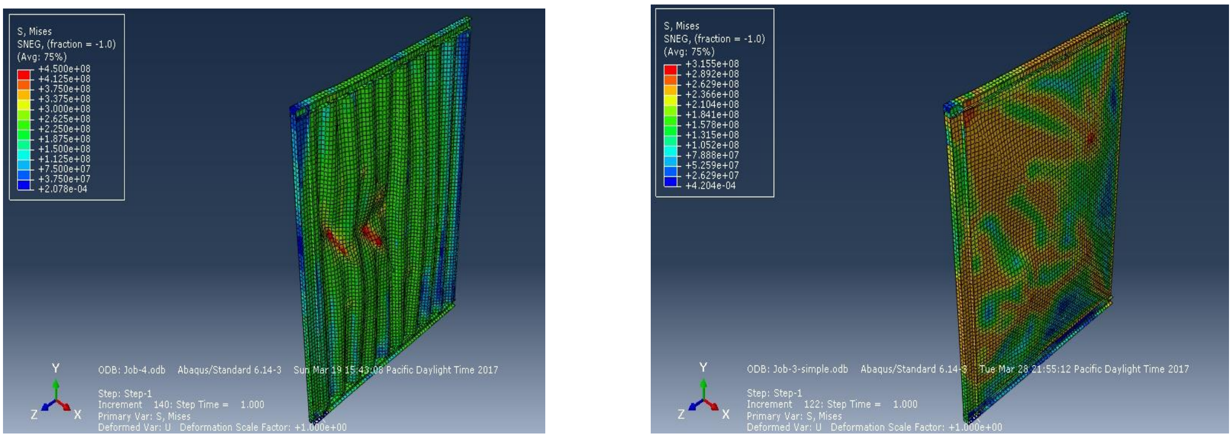

Figure 6. Stresses generated in the simple and corrugated plates under pushover analysis

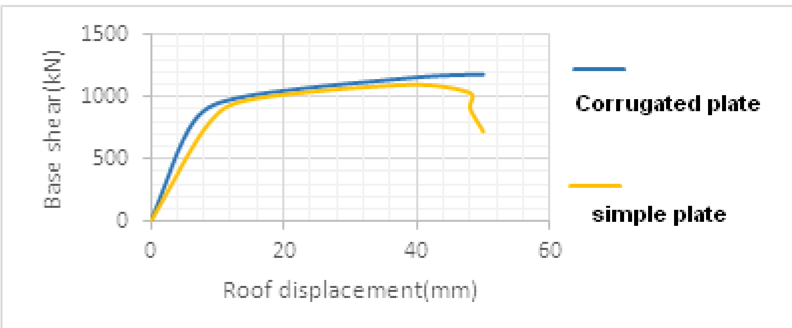

Figure 7. Comparison between the capacities of studied model for cases of simple and corrugated plates

As is seen, according to the analyzed model in Figure 7, both plates have undergone stresses in some areas. It is observed that the corrugated plate, due to existing waves in it and better distribution of load, has exhibited better behavior. On the other hand, comparing the capacity diagrams of simple and corrugated models it is found that up to 1000KN loading both exhibit a relatively similar behavior. When loading exceeds 1000 KN, the simple plate yields and losses its strength, but the corrugated plate, due to the existing wave and proper stress distribution, exhibits a higher strength and capacity.

For investigation of opening location effect in the steel shear wall with corrugated plate, 5 different states of opening in the corrugated shear wall are considered. Also the opening dimensions are assumed constant in all the models and equal to 800cm x 80cm. After providing openings in the wall and building the models, the model has been analyzed per each state using the pushover analysis method. The capacity diagram of each state is shown in the following figures:

State 1: Opening at the left corner and bottom of wall
State 2: Opening at the left corner and top of wall
State 3: Opening at the center of wall
State 4: Opening at the right corner and bottom of wall
State 5: Opening at the right corner and top of wall

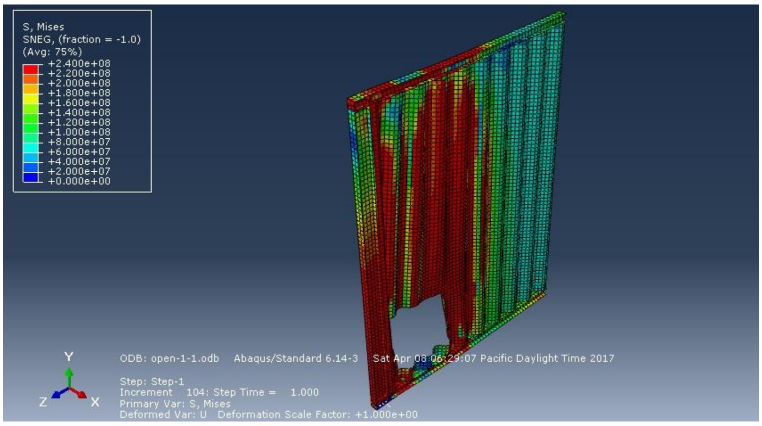

Figure 8. Stresses generated in the corrugated plate with opening in state 1 under pushover analysis

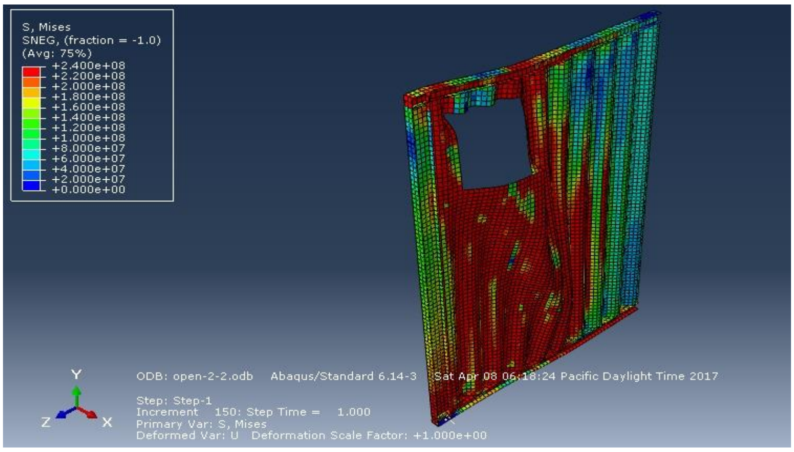

Figure 9. Stresses generated in the corrugated plate with opening in state 2 under pushover analysis

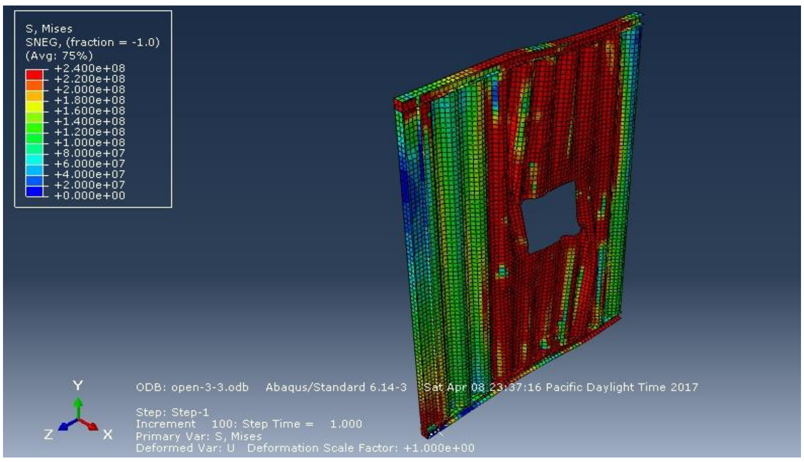

Figure 10. Stresses generated in the corrugated plate with opening in state 3 under pushover analysis

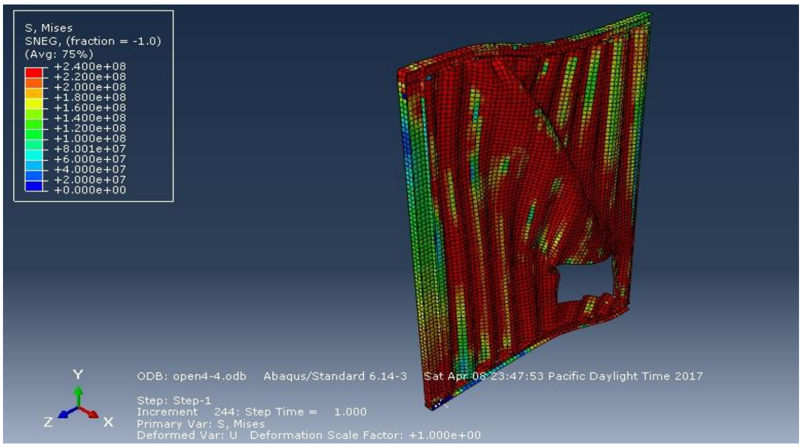

Figure 11. Stresses generated in the corrugated plate with opening in state 4 under pushover analysis

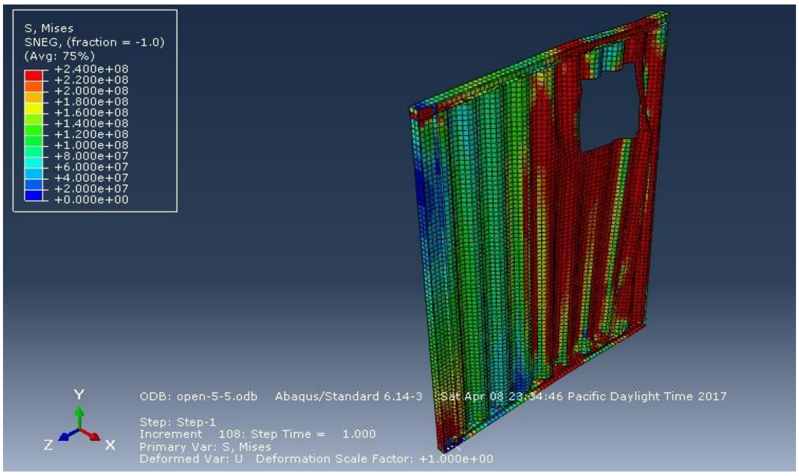

Figure 12. Stresses generated in the corrugated plate with opening in state 5 under pushover analysis

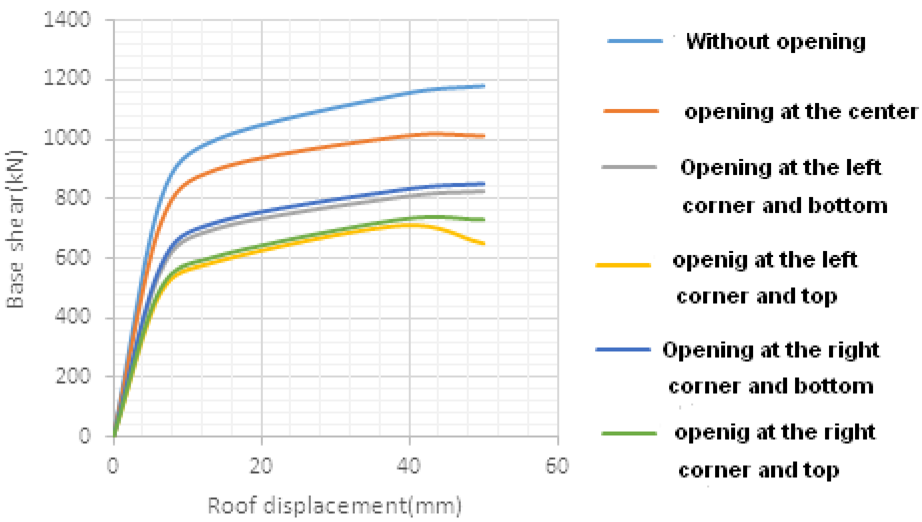

Figure 13. Comparison between the capacity diagrams obtained from the pushover analyses with different states

Regarding the previous studies [23&24], and observing the model behavior in Figures 6 and 7, it was found that the corrugated plate has higher strength and capacity with respect to the simple plate. So the corrugated plate was selected for the model. Considering the widespread use of corrugated plates in the industry with different forms of openings, as different models were built and analyzed based on the different openings as shown in Figures 8-12. As it was expected, the stress concentration was around the openings because force transmission does not take place in a proper way, and a critical state of stress concentration is seen around the openings. On the other hand, according to the pushover analysis in the diagram of Figure 13, the plate without opening has a higher capacity with respect to other plates, which is due to the inability of the plate with opening in force transmission. In continuation, it is seen that when the opening is located at the middle, the force transmission takes place better with respect to other states which is due to the symmetry (but not better than the state with no opening). In this state, the plate capacity is higher with respect to other states and exhibits better behavior. Furthermore, according to the capacity diagram, when the opening is located at the bottom of the plate, a higher capacity is seen with respect to the state in which the opening is at the top of the plate.

4. CONCLUSION

In this article the effect of opening location in the wall with corrugated plate was investigated using the pushover analysis. Finally, the following results were obtained:

1-Use of the corrugated (sinusoidal) plate instead of the flat (simple) plate causes increased lateral stiffness in the system in a way that in the one-story model with the flat plate in the elastic state, the lateral stiffness is equal to 101345 KN/m, whereas this value for the state of wall with corrugated plate is equal to 133333 KN/m. This shows that the use of corrugated plate in the one-story, single span model caused 33% increase in the lateral stiffness of the entire system.

2- Use of the corrugated (sinusoidal) plate instead of the flat (simple) plate causes increased lateral resistance in the system in a way that the ultimate resistance of the system in the state of using simple plate is equal to 1096 KN. But this value for the state of using corrugated plate is equal to 1200 KN which indicates that the use of corrugated plate in the one-story, single-span model caused 9.5% increase in the lateral stiffness of the entire system.

3-The reason for slight difference in the capacity diagrams in states that the openings are located at the corners, could be explained in this way that the investigated model is one story and type of analysis is pushover and in this type of analysis the load acts on the support of the top of structure. Therefore the worst state for application of pushover analysis is that the opening is located close to the acting load that is the left corner (in the analysis of model, the direction of lateral displacement is from left to right).

4-Investigating the obtained capacity diagrams for different locations of openings, it is observed that providing opening at the middle of shear wall, reduces the ultimate strength up to 17%. The reduction in strength for in state that the opening is located at the corners and bottom of the wall is 29%, and in the state that opening is located at the corners and top of wall is 37%.

5-Regarding the significant out-of-plane stiffness of the corrugated plate, this plate type has a far higher buckling strength with respect to the flat plate. So incorporating it, in addition to reducing the required plate thickness, could eliminate the need for stiffener.

FUNDING/SUPPORT

Not mentioned any Funding/Support by authors.

ACKNOWLEDGMENT

Not mentioned by authors.

AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

5. REFERENCES

[1] Wagner H. Flat sheet metal girders with very thin metal web. Part I: general theories and assumptions. United state: NACA Technical Memorandum. 1931 February 01. NACA-TM-604. [View at Google Scholar] ; [View at Publisher].

[2] Wu N. Friction and Impact Load Response of Ship Shafts under Microscope. Acta Microscopica. 2019 May 19;28 (3): 571-576. [View at Google Scholar] ; [View at Publisher].

[3] Nabian M, Nabian MA, Hashemi HN. Torsional Dynamics Response of Shafts with Longitudinal and Circumferential Cracks. engrXiv. 2018 March 3. 2018(1): 1-12. [View at Google Scholar] ; [View at Publisher].

[4] Shelton IV FE, Setser ME, Doll KR, Morgan JR, inventors; Ethicon LLC, assignee. Articulating surgical stapling instrument incorporating a two-piece E-beam firing mechanism. United States patent US 9,737,303. 2017 Aug 22. [View at Google Scholar] ; [View at Publisher].

[5] Shelton IV FE, Setser ME, Weisenburgh IW, inventors; Ethicon Endo Surgery Inc, assignee. Articulating surgical stapling instrument incorporating a two-piece e-beam firing mechanism. United States patent application US 13/029,272. 2011 Jun 23. [View at Google Scholar] ; [View at Publisher].

[6] Driver RG, Kulak GL, Kennedy DL, Elwi AE. Cyclic test of four-story steel plate shear wall. Journal of Structural Engineering. 1998 Feb 01;124(2):112-120. [View at Google Scholar] ; [View at Publisher].

[7] Dong L, King WP, Raleigh M, Wadley HN. A microfabrication approach for making metallic mechanical metamaterials. Materials & Design. 2018 Dec 15;160:147-168. [View at Google Scholar] ; [View at Publisher].

[8] Cao Q, Huang J. Experimental study and numerical simulation of corrugated steel plate shear walls subjected to cyclic loads. Thin-Walled Structures. 2018 Jun 1;127:306-317. [View at Google Scholar] ; [View at Publisher].

[9] Myers HC, inventor. Knotless adhesive impregnated sutures and method of use thereof. United States patent US 3,212,502. 1965 Oct 19. [View at Google Scholar] ; [View at Publisher].

[10] Roberts TM, Sabouri-Ghomi S. Hysteretic characteristics of unstiffened perforated steel plate shear panels. Thin-Walled Structures. 1992 Jan 1;14(2):139-151. [View at Google Scholar] ; [View at Publisher].

[11] Haji J, Kawasaki K, Ishizuka K, Yamada T, inventors; Nippon Steel, Sumitomo Metal Corp, assignee. Method of production of hot dip galvannealed steel sheet with excellent workability, powderability, and slidability. United States patent application US 10/023,931. 2018 Jul 17. [View at Google Scholar] ; [View at Publisher].

[12] Seo J, Varma AH, Sener K, Ayhan D. Steel-plate composite (SC) walls: In-plane shear behavior, database, and design. Journal of Constructional Steel Research. 2016 Mar 1;119:202-215. [View at Google Scholar] ; [View at Publisher].

[13] Shamim I, Rogers CA. Numerical evaluation: AISI S400 steel-sheathed CFS framed shear wall seismic design method. Thin-Walled Structures. 2015 Oct 1;95:48-59. [View at Google Scholar] ; [View at Publisher].

[14] Farzampour A, Laman JA, Mofid M. Behavior prediction of corrugated steel plate shear walls with openings. Journal of Constructional Steel Research. 2015 Nov 1;114:258-268. [View at Google Scholar] ; [View at Publisher].

[15] Premalatha DJ, Vengadeshwari RS, Abhijith B. Study On The Behaviour of Multistoreyed Steel Framed Building with Steel Plate Shear Walls Under Seismic Forces. International Journal of Civil Engineering and Technology. 2017;8(9): 361-370. [View at Google Scholar] ; [View at Publisher].

[16] Dou C, Pi YL, Gao W. Shear resistance and post-buckling behavior of corrugated panels in steel plate shear walls. Thin-Walled Structures. 2018 Oct 1;131:816-826. [View at Google Scholar] ; [View at Publisher].

[17] Fu MH, Xu OT, Hu LL, Yu TX. Nonlinear shear modulus of re-entrant hexagonal honeycombs under large deformation. International Journal of Solids and Structures. 2016 Feb 1;80:284-296. [View at Google Scholar] ; [View at Publisher].

[18] Chatté G, Comtet J, Niguès A, Bocquet L, Siria A, Ducouret G, Lequeux F, Lenoir N, Ovarlez G, Colin A. Shear thinning in non-Brownian suspensions. Soft matter. 2018;14(6):879-893. [View at Google Scholar] ; [View at Publisher].

[19] Ashrafi HR, Shahbazian K, Bidmeshki S, Yaghooti S, Beiranvand P. Compare the behavior factor of the ultimate resistance of moment frame, plain and perforated steel plate shear walls, and buckling restrained brace as yielding metal damper. Advances in Science and Technology Research Journal. 2016 March 29;10(29):1-12. [View at Google Scholar] ; [View at Publisher].

[20] Delnavaz A, Hamidnia M. Analytical investigation on shape configuration of CFRP strips on lateral loading capacity of strengthened RC shear wall. Structural Concrete. 2016 Dec 03;17(6):1059-1070. [View at Google Scholar] ; [View at Publisher].

[21] Fenton GA, Naghibi F, Dundas D, Bathurst RJ, Griffiths DV. Reliability-based geotechnical design in 2014 Canadian highway bridge design code. Canadian Geotechnical Journal. 2015 Jul 23;53(2):236-251. [View at Google Scholar] ; [View at Publisher].

[22] AISC (American Institute of Steel Construction). ANSI/AISC 341-16. Seismic provisions for structural steel buildings. Chicago: AISC; 2010. [View at Google Scholar] ; [View at Publisher].

[23] Council BS. FEMA302. NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Part1 Provisions. united state: Federal Emergency Management Agency; 1997. [View at Google Scholar] ; [View at Publisher].

[24] Zhang TL, Baumjohann W, Nakamura R, Balogh A, Glassmeier KH. A wavy twisted neutral sheet observed by Cluster. Geophysical research letters. 2002 Oct 01;29(19): 5-1-5-4. [View at Google Scholar] ; [View at Publisher].