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The effect of the perforated pattern on the energy absorption capacity of the steel plate shear wall

Hadi Darvishi[a,*]

[a]*Center of Excellence in Structures and Earthquake Engineering, Civil Engineering Department, Sharif University of Technology, P.O. Box 11155-9313, Azadi Ave., Tehran, Iran*

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Abstract

In addition to the conventional lateral load resistance system such as different brace system, using of another kind of system that called Steel Plate Shear Wall (SPSW) is extending. Most of the SPSW that used in the construction of the building structure are stiffened by other elements that perpendicular to the frame surface to prevent their buckling. Recent studies show that the performances of this kind of lateral load resistance systems will be improve if the infill plate buckled before the yielding of the surrounding frame. So using of too thick plate is developed that accrued some construction problem and decrease the economic advantage of them. Using of the perforated steel plate shear wall is an applied strategy to remove this problem and lead to the buckle of the infill plate. Using of the perforated steel plate incorporate some confusedness base on the lacking of the code. In this paper 21 number of perforated steel plate shear walls analyzed under cyclic loading by using of the ABAQUS. An appropriate perforated pattern is suggested by study on the hysteresis diagrams. The results show that using of bad pattern reduces the ability of energy absorption and suddenly remove the stability of the SPSW. Otherwise, using of the proper pattern improve the cyclic performance of the perforated steel plate shear wall camper to the other system.

Keywords: Shear wall, Perforated Infill Plates, Low yield steel, Cyclic load;

1. Introduction

Steel Plate Shear Wall (SPSW) is a panel that surrounded by tow beams and columns and a steel plate which is connected to these boundary elements. For construction, this system is too simple and does not have any special complexity; so engineers, technicians and workers can construct it with their knowledge and do not need any newer education. This system can be produced in the factory. So they can consider as a fast assembly, economic and prefabricated system. Steel plate shear walls have initial high stiffness and ductile behaviour under inelastic cyclic deformation; and dissipate the noticeable amount of energy [11, 12]; so they are one of the suitable lateral load resistance systems. Steel plate shear wall is not only used in the construction of new building; they can use for retrofitting of existing structure, too [9, 10, 15].

Finding a plate with actual design thickness is a problem of construction of unstiffened steel plate shear wall, because the plate thickness that calculated

* Corresponding author. Tel.: +989125733178; e-mail: h_darvishi65@yahoo.com

according to the design equations are too small, almost one mm. as the surrounding beams and columns are designed base on infill plate thickness, so using of thinner infill plate can change the dimension of these boundary element. Recently, for removing such a problem, using of the low yield steel [14, 16], cold rolled [9], light-gauge [9] and perforated steel plate [13, 16, 17, 18] and some other method are proposed to decrease the strength and the stiffness of the system. Some studies are conducted on reduced beam section (RBS) as a beam-column connection to reduce the demand of system [16, 17, 18].

In this paper, 21 perforated steel plat shear wall system are analysed under cyclic loading to propose a prorated pattern of perforated plate and study the effect of the perforate arrangement on the ability of the energy absorption.

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2. Method of study

In this paper, a single-story Steel Plate Shear Wall that proposed by Vian and Bruneau is used [18, 19]. As it shown in Fig. 1, the span lengths (L) and the high of the story (h) are equal to 4000 mm and 2000 mm, respectively, so the ratio of the L/h will be 2.0. W18X71 and W18X65 are used as a vertical and horizontal frame section, respectively. And a Low Yield Steel plate with 2.6 mm thickness is used as an infill plate. For ensuring of the beam inelastic behaviour, the RBS beam-column connection is used. By using of the RBS connection the strong-column/weak-beam criteria is satisfied. A solid panel model is shown schematically in Fig. 1.

21 different types of models with perforated infill plate are used. The diameter of all holes is equal to 150 mm. They are named base on the perforated pattern and their angles. The typical name of the models is Number#1-Number#2-(I, II, III) that the Number#1 indicate on the angle between the holes direction and the vertical axes; The Number#2 is referred to the number of the holes and (I, II, III) shows the especial pattern of the hole's location. (Fig. 2)

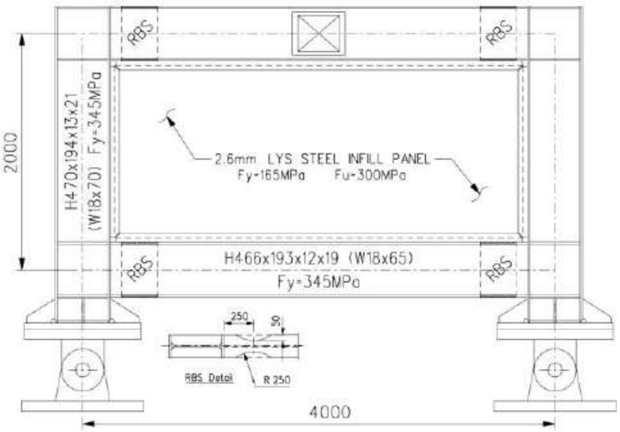
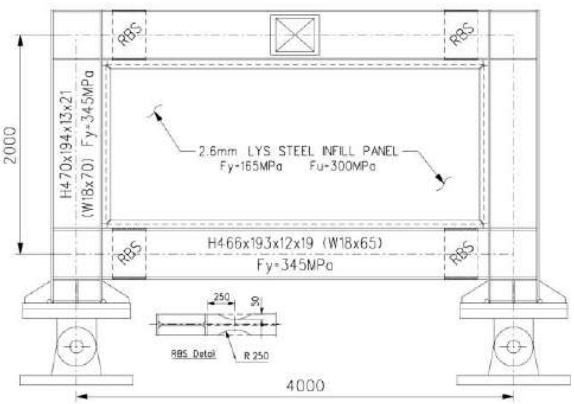


Fig. 1. Typical model dimension Vian, Bruneau et al. [19].



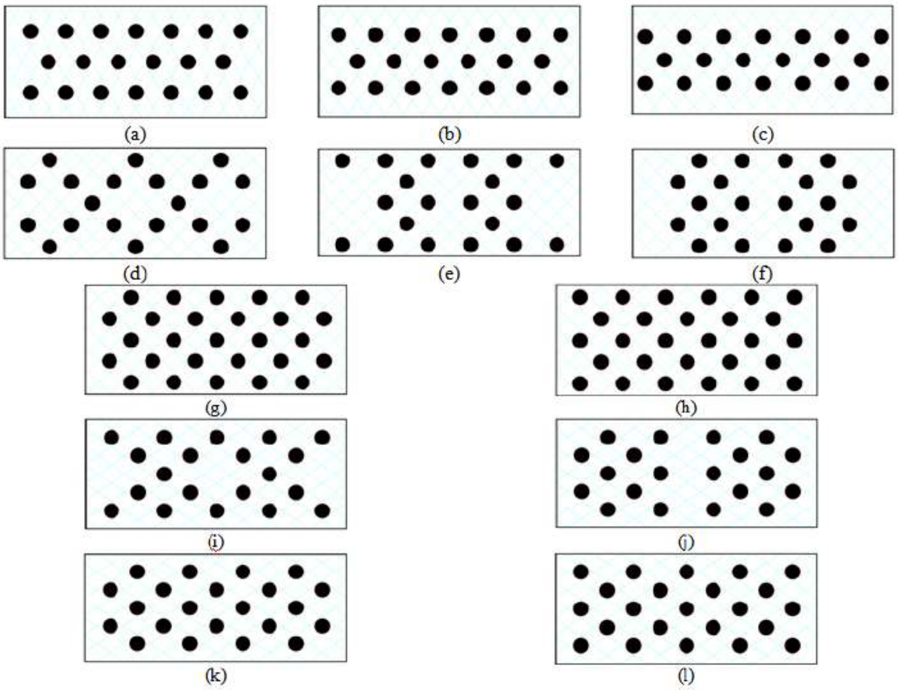
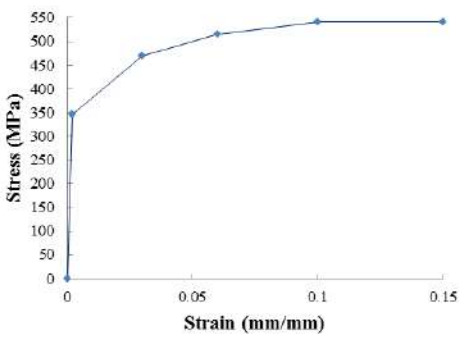


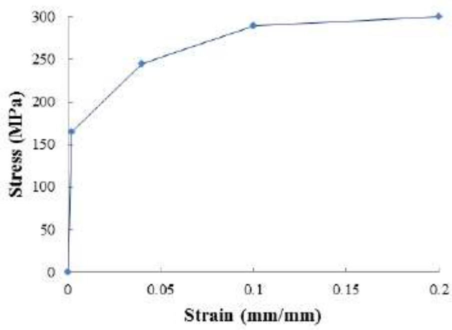
Fig. 2. The perforated pattern: (a) .30°-20, (b) .35°-20, (c) .40°-20, (d) .(45°~50°)-20-I, (e) .(45°~50°)-20-II, (f) .(45°~50°)-20-III, (g) .(45°~50°)-27, (h) .(45°~50°)-28, (i) .(55°~60°)-20-I, (j) .(55°~60°)-20-II,
(k) .(55°~60°)-22, (l) .(55°~60°)-23

3. Material properties

The ASTM-A52 is used as a surrounding frame material with 345 MPa and 540 MPa yield and ultimate stress, respectively Fig. 3-a. Low yield steel with 165 MPa and 300 MPa yield and ultimate stress, respectively is used as infill plate Fig. 3-b. Using of LYS in the infill plate is resulted to the yield of the plate before the boundary elements. For both types of steel, the module of elasticity is 200 GPa and the Poisson’s ratio is 0.3.



(a). Frame members.



(b). Infill plates.

Fig. 3. Material stress-strain curve

4. Numerical modeling

The buckling and cyclic analyses of the models are conducted by ABAQUS. Nonlinear analysis of the models under static, quasi-static and dynamic loading is the ability of this software. The infill plate is modelled by the shell element and all the models are meshed by four node shell elements (S4R). For connecting the infill plate to the boundary elements the CONN2D3 (a kind of Contact which is available in the ABAQUS) is used. Some ties are used to connect the bottom of the column to the base hinge point that cannot move in all directions and cannot rotate around axes 2 and 3.

Behbahanifard et. al shows that the effect of the initial out of plane imperfection on the results can be neglected if it is limited to the ۰.۰۱ $\times \sqrt{L \times h}$. To consider, the initial imperfection which is appeared by fault construction, at first, a buckling analysis is conducted to find the eigenvalue. The first plate buckling mode is multiplied on the too small displacement (for example 1 mm) and considered as an initial boundary condition for all models.

The plastic behaviour of the material is defined by combined hardening, which is included the kinematic and isotropic hardening. It is noticeable that using of the combined hardening is essential when study on the cyclic behaviour of the metals is the main objective. By this method, both the rigid movement of the system and its yield behaviour (the make the expansion and shortage) are considered.

5. Loading regime

The cyclic loading is defined base on the ATC 24 protocols [7]. For finding the yielding stress and its corresponding displacement and the ultimate stress, an axial buoyancy analysis is conducted. The goal displacement of the cyclic loading is considered equal to ۷σ_y. In Fig. 4. the amplitude is drown against the number of the cyclic of the loading. The other boundary condition is the same as the axial buoyancy analysis, completely.

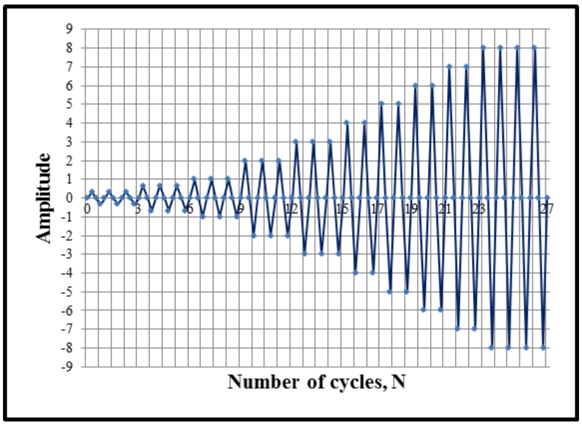
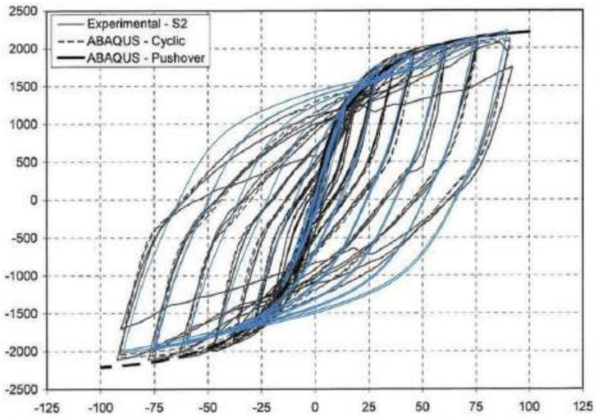


Fig. 4. Loading history

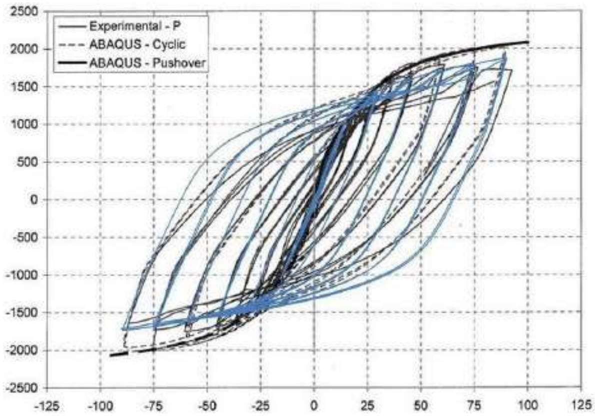
6. Validation and verification of results

Here, two SPSWs that modelled by Vian, Bruneau et al are analysed to evaluate the accuracy of the boundary condition and loading procedure. According to the Fig. 5, the numerical result is almost corresponded to the experimental ones.



Top Displacement, Δ (mm)

(a). SPSW with solid plate

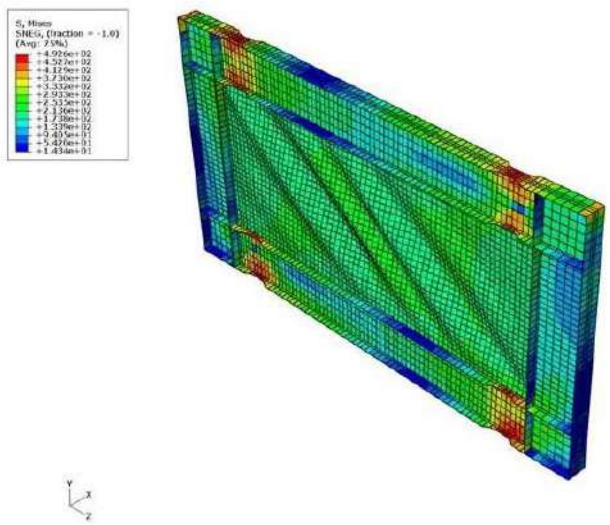


Top Displacement, Δ (mm)

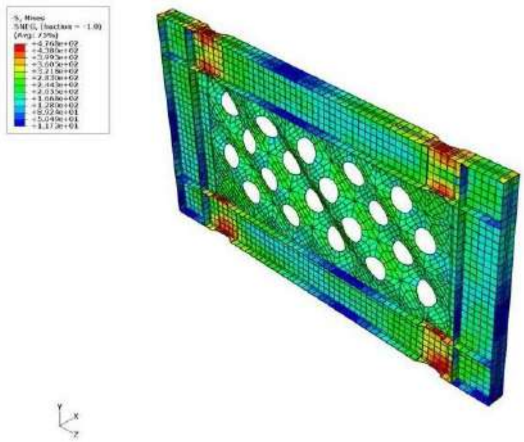
(b). SPSW with perforated plate

Fig. 5. Model hysteresis

In the Fig. 6 the deformation of the unstiffened steel plate shear wall, perforated steel plate shear wall (these models are presented by Vian, Bruneau previously) and the model 45°-28 are shown. In Figures 7 to 11, the force-displacement diagrams of each model are shown. In the table 1, the stiffness and strength of the models are presented. $V_{y.total}/V_{y.total}(S)$ and $K_{total}/K_{total.S}(S)$ are the stress and stiffness ratio of the system with perforated plate to the plate without any holes, respectively.



(a). SPSW with solid plate



(b). SPSW with perforated plate

Fig. 6. Deformed shape of FE models at 3% drift (et al. Vian, Bruneau [19])

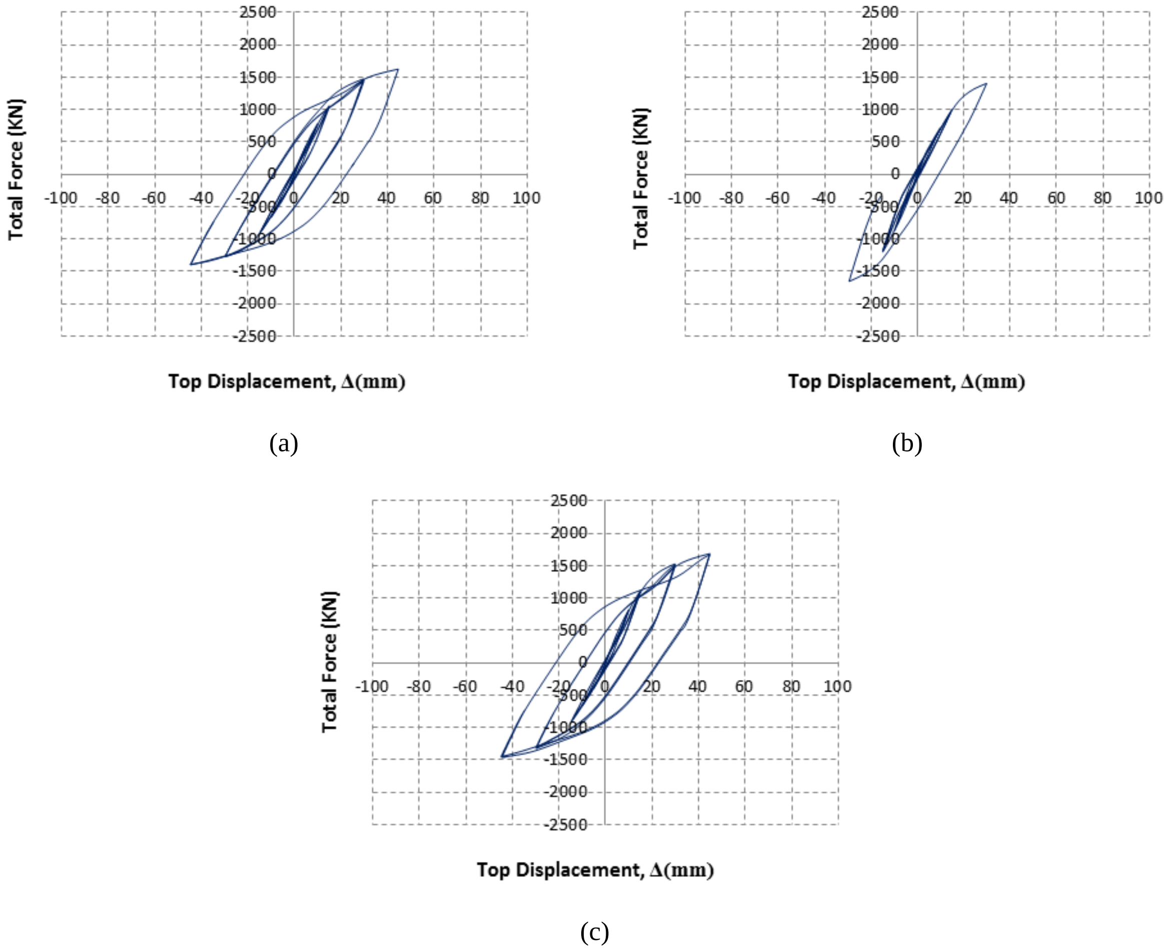
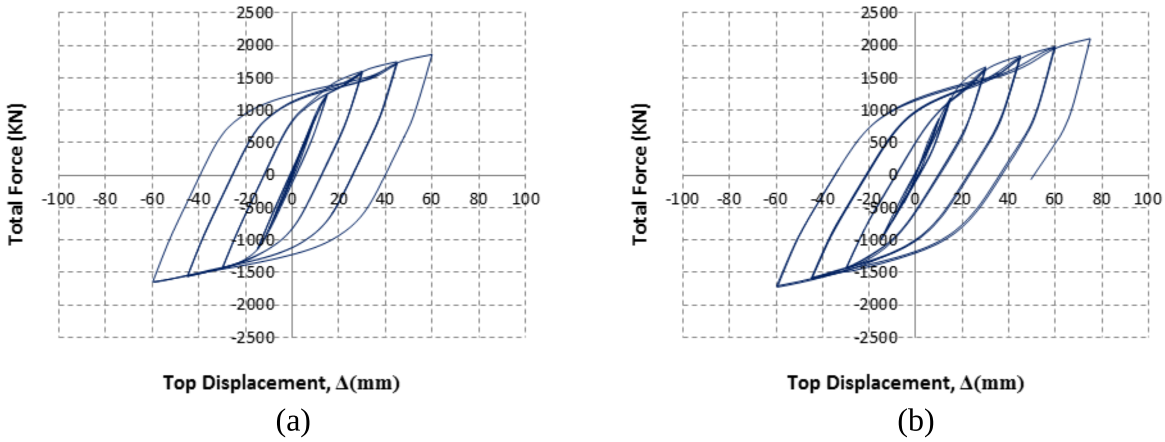
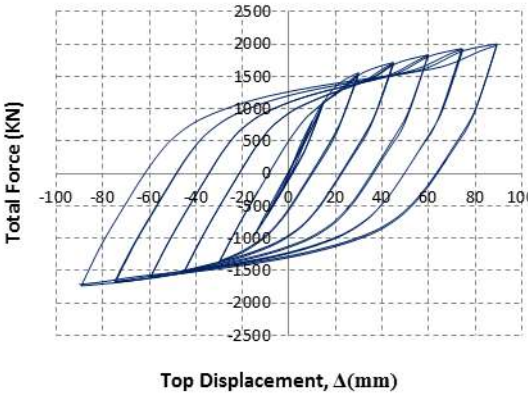
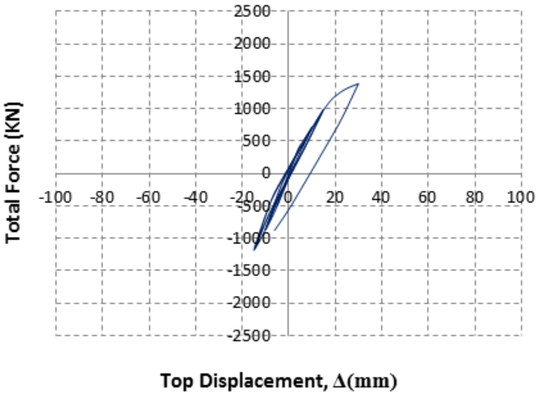


Fig. 7. Model hysteresis: (a) 30°-20, (b) 35°-20, (c) 40°-20

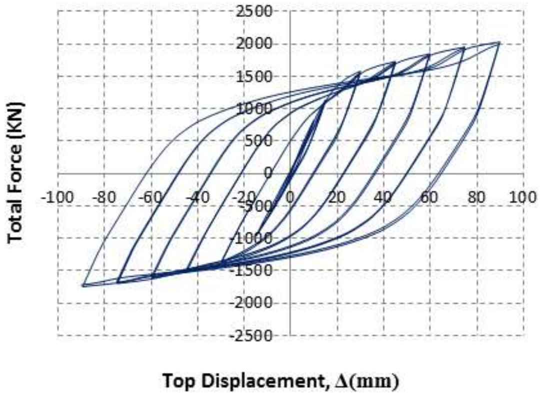




(c)

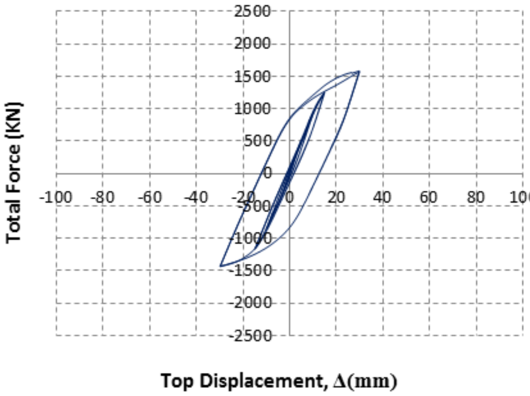


(d)

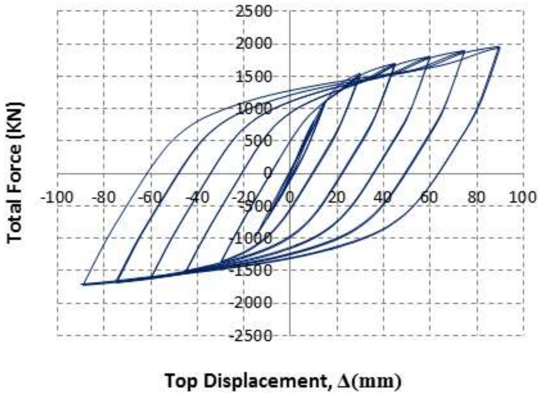


(e)

Fig. 8. Model hysteresis: (a) 45°-20-I, (b) 45°-20-II, (c) 45°-20-III, (d) 45°-27, (e) 45°-28



(a)



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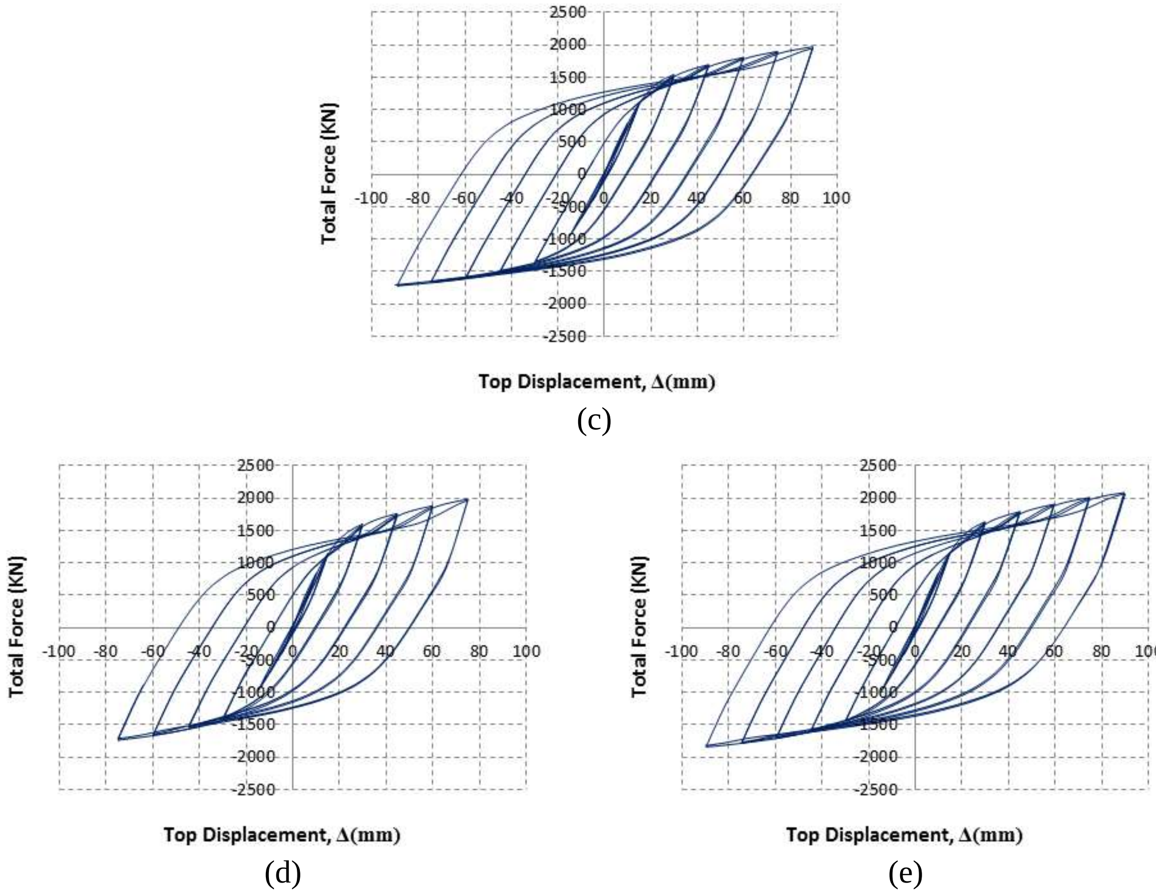
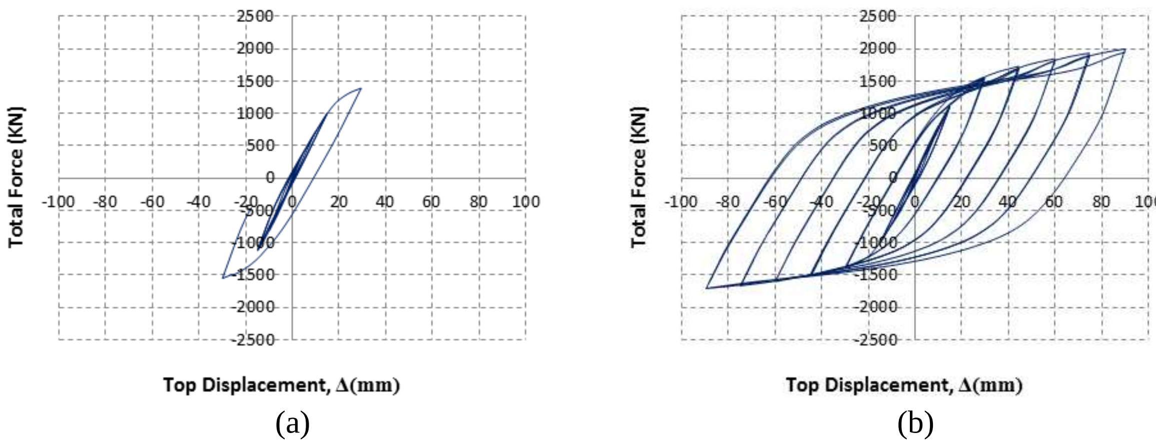
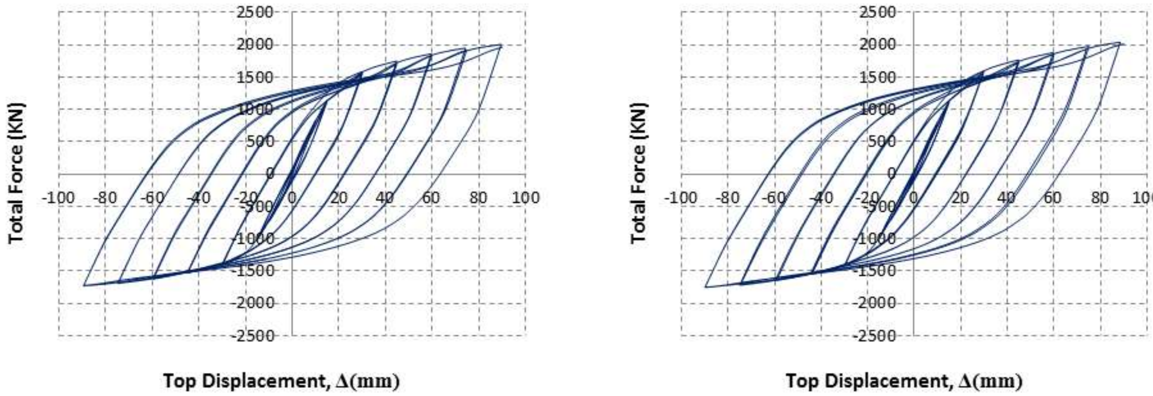


Fig. 9. Model hysteresis: (a) .50°-20-I, (b) .50°-20-II, (c) .50°-20-III, (d) .50°-27, (e) .50°-28





(c) (d)

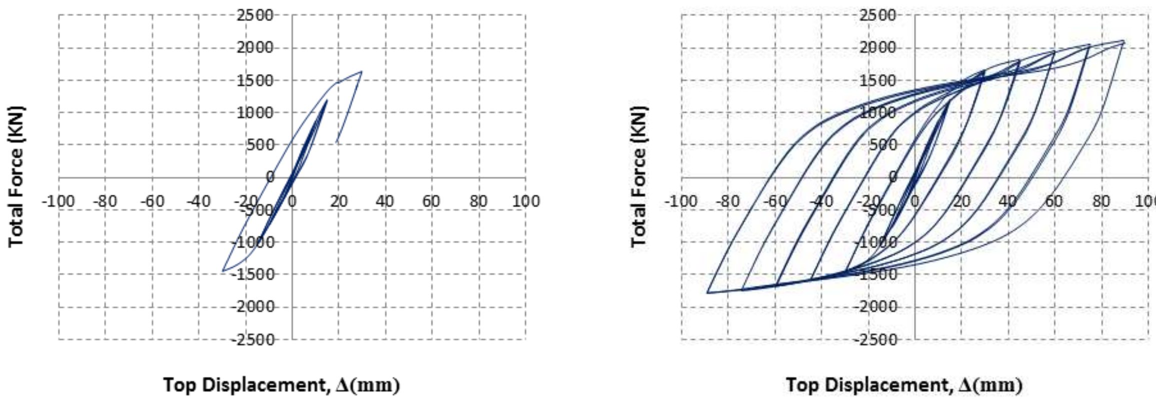
Fig. 10. Model hysteresis: (a) .55°-20-I, (b) .55°-20-II, (c) .55°-22, (d) .55°-23

7. Discussion of Results

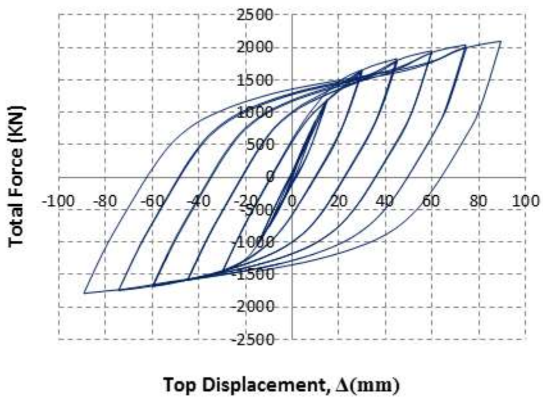
Finding the proper pattern of the perforated plate in order to improve the energy absorption ability of the system is the main aim of this paper. According to the figures 7 to 11, Because of the suddenly collapse and reducing of the ultimate loading capacity in the initial cycles, the performance of the models is undesirable if the angle is smaller than 45. The hysteresis diagrams of the I ، 45°-20-II ، 45°-20-III ، 45°-27 and 45°-28 are shown in Fig. 8. By study in these models, it can find that when the perforated pattern is centrally symmetry with uniform distribution, the cyclic loops are more stable compare to the asymmetry and non-uniform ones (Fig. 13). A little bending will be induced in the transfer strip if the distribution of the holes is not uniform, so for the strip with asymmetry holes, based on eccentrically of the axial load, more stress is resulted on the same loading condition compare to the symmetry ones (Fig. 13).

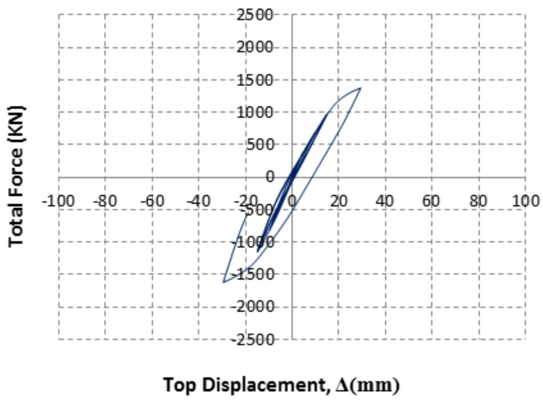
The performance of the type II such as 45°-20-II ، 50°-20-II ، 55°-20-II ، 60°-20-II are better than the type I. But it is undesirable too because the distributions of the holes are not uniform.

Model 45°-20-III and 50°-20-III have a suitable performance under cyclic loading because the perforated pattern is centrally symmetry and the holes distribution are uniform unless near the columns. However it is noticeable that this pattern is not the optimum ones.



(a) (b)





(c) (d)

Fig. 11. Model hysteresis: (a) .60°-20-I, (b) .60°-20-II, (c) .60°-22, (d) .60°-23

However the distribution of the holes in models 45°-27, 50°-27, 55°-23 and 60°-23 are uniform, but they are not reasonable performance under cyclic loading because the transfer loading strip is not centrally symmetry (Fig. 13). So, after some initial cycles, the strength of the models will drop and the imperfect loop of energy absorption will be appeared. In models 45°-28, 50°-28, 55°-22 and 60°-22, the transfer strip is centrally symmetry, so the stable hysteresis loop will be formed. Moreover, the distributions of the holes are uniform; therefore the stress distribution will be uniform over the strip and the explained bending is removed. The performance of these models is appropriate under cyclic loading based on these reasons.

According to the table 1, the infill plate has a noticeable effect on the lateral stiffness of the system. And this effect is also seen in the perforated steel plate shear walls.

8. Conclusion

Recent studies show that the buckling of infill plate improves the energy absorption ability of the system. So using of too thin steel plate is essential that produce some construction problems. Using of a perforated steel plate shear wall can be an appropriate solution of this problem. But there is not any code that presented a pattern of the perforated plate. In this paper, for achieving to the suitable pattern of the holes location, 21 perforated steel plate shear walls are analysed under cyclic loading by ABAQUS. The results show that using of the centrally symmetry strip with uniform distribution lead to form of the more stable hysteresis loop compare to the un-symmetry strip with not uniform distribution of the holes. They also show that the angle between the direction of the holes line locations and the vertical axes should be equal or greater than the design angle of the steel plate shear wall (almost 45 degree).

Table 1

Comparison of peak result with simplified perforated panel models

Models	$\%V_{y.total}/V_{y.total}(S)$	$\%K_{total}/K_{total.S}(S)$	K_{Panel} (N/mm)	$\%K_{Panel.S}$
Solid	-	-	93749	-
30°-20	86.2	78.3	64331	68.6
35°-20	86.9	92.6	83710	89.3
40°-20	84	79	65272	69.6
45°-20-I	86.8	93.1	84391	90
45°-20-II	87.7	93.6	85114	90.8
45°-20-III	87.1	93.7	85277	91
45°-27	85.7	92	82850	88.4
45°-28	85.5	91.7	82532	88
50°-20-I	87.8	92.7	83860	89.4
50°-20-II	87.4	85	73521	78.4
50°-20-III	87.5	85.6	74258	79.2
50°-27	85.8	78.8	64999	69.3
50°-28	86.5	91.3	81985	87.4
55°-20-I	87	85.4	73937	78.9
55°-20-II	86.7	92.3	83271	88.8
55°-22	86.2	92.1	82991	88.5
55°-23	87.4	92.86	84059	89.7
60°-20-I	86	85.6	74256	79.2
60°-20-II	86.6	77.9	63776	68
60°-22	86.6	83	70621	75.3
60°-23	86.6	92.9	84157	89.7

Assume K_{Frame} =42 KN/mm, $K_{Panel} = K_{Total}$-K_{Frame}

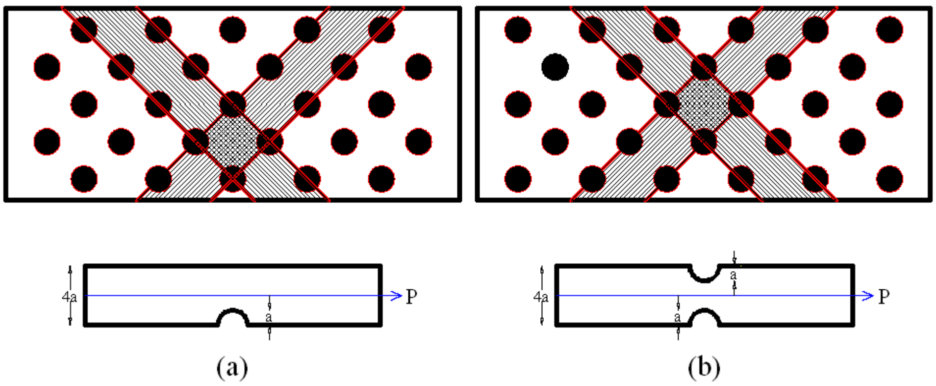


Fig. 13. (a). Unsymmetry ،(b). Symmetry

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