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Studying the effect of thickness, diameter, and arrangement of hemispherical ridges in steel shear walls

Siavash Beyranvand [1], Mojtaba Hosseini [*,2]

[1] *MS.c, Department of Civil Engineering, Lorestan University, Khorramabad, Iran.*
[2] *Associate Professor, Department of Civil Engineering, Lorestan University, Khorramabad, Iran.*

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ABSTRACT

Steel shear walls are usually made in two types, hardened and unhardened. All hardened types are more suitable for seismic performance and operational issues. But due to the presence of many hardeners and implementation details, it takes a lot of time and money to make them. Therefore, the idea of corrugated steel shear walls as a replacement for Hardened shear walls has been proposed. These sheets are expected to have Inherent out-of-plane hardness, and high buckling resistance, and are ultimately functional, similar to hardened shear walls. In this research, steel shear walls it has a flat panel and hemispherical protrusions used to evaluate the energy absorption capacity Different models were used, and the amount of formability and energy loss of steel shear wall with interest the above parameters have been checked from ABAQUS finite element software. For this purpose 8 the sample of steel shear wall with hemispherical protrusion was modeled in ABAQUS software a sample of it as a control sample for comparison and verification with the laboratory results of the case A study was done that showed good accuracy for verification. Then the samples were made were subjected to cyclic loading according to the ATC24 regulations.

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1. Introduction

Steel shear walls (SSW) have been proposed and paid attention to in order to depreciate the lateral forces of earthquake and wind in buildings, especially in tall buildings in the last three decades. One of the ways to strengthen and increase the resistance of these walls is to improve their buckling behavior by using hardeners. Hardeners improve their behavior by preventing steel sheet buckling before yielding, and in addition increase hardness, strength, formability and increase energy absorption. A lot of time and money should be spent to make them. One of the ways to reduce these costs without reducing the bearing capacity of the steel shear wall is to use corrugated sheet instead of flat sheet. The idea of using a corrugated sheet in a shear wall is made of beams with corrugated sheets. The first extensive research on the behavior of steel shear wall was done by Takahashi et al. (1973) The aim of this experimental research is to investigate SPSW with and without stiffeners with different element details and stiffness of shear panels under inelastic cyclic loading. In order to determine stability as a system resistant to lateral load. The important results of this experimental research were obtained as follows: a) The energy loss of panels with stiffeners was significant and more than panels without stiffeners. b) Both panels with hardener and without hardener showed stable behavior and ductility. c) Panel with hardener on both sides showed more stable behavior than the panel with hardener on one side. Based on the test results of Takahashi et al., it is recommended that the shear wall be designed with a stiffener so that the shear panel does not buckle elastically. The results of the analyzes performed on the modeled samples show that the use of the metal shear wall system Trapezoidal corrugators are significant due to the amount of load and energy loss and their formability in long spans or frames with high height. Frames with sinusoidal and trapezoidal corrugated sheets with less hardness have higher load capacity and formability than hardened and simple samples, and it will also reduce the cost, speed up and ease the implementation of these structures. (Ahmadi Sangdehi, Syed) Majid, Gholamreza Ghadi Amiri, Siros Gholampour and Mohammad Shamkhi Amiri, 2013) The results of several experiments on steel shear walls with corrugated sheets show that with the gradual increase in the angle of the corrugated sheets from horizontal to Diagonal bearing capacity and hardness decrease and energy loss and formability increased, if it changes from diagonal to vertical, the bearing capacity and hardness will increase and energy loss and formability will decrease. Gholamreza Ghadi Amiri; Mohammad Shamkhi Amiri and Mohammad Ismailpour Languri, 2014) a study showed that creating an opening in the center of the corrugated sheet along with the stiffener in the corrugated shear wall will increase the bearing capacity compared to the simple shear wall.

*Corresponding author Email: Hosseini.m@lu.ac.ir

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The idea of engineering use of steel shear walls originated in aerospace applications where steel panels were used in forms with and without stiffeners. The use of steel shear wall (SPSW) as a primary system resistant to lateral loads in new constructions, as well as to strengthen the lateral load resistance of existing structures, began in the early 1980s in the United States of America and Japan became. In its usual form, the SPSW system consists of a steel shear panel as a filler to the building structure consisting of beams (Horizontal Boundary Element or HBE) and columns (Vertical Boundary Element or VBE) as shown in (Figure. 1) It has been added. The structural frame can be simple or bending resistant and the connection of the steel panel to these boundary elements can be done with screws or welding (usually with a fish plate) and according to the design philosophy, the steel plate panel is also either with a hardener and or used without hardener.

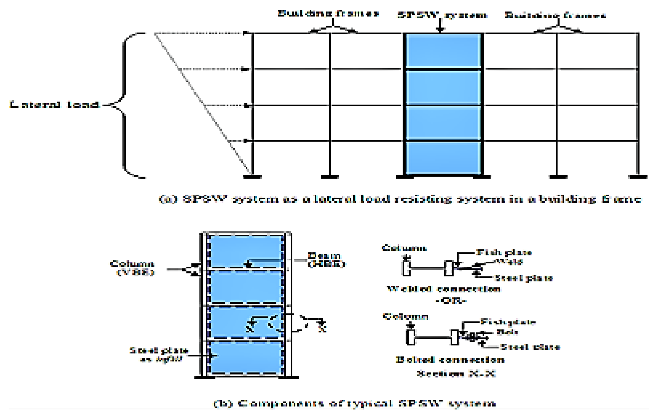

Fig 1. General shape of steel shear wall.

In the 70s and 80s in America and Canada, shear divas without hardener were used in some buildings, steel shear walls covered with a layer of concrete, similar to what we have in composite shear walls. Among this, we can mention a very good example of effective use of steel shear walls with the least vibration but with relatively large wind loads. A 30-story hotel in Dallas, Texas, the structure has a metal bracing system in the longitudinal direction and a steel shear wall system in the transverse section (Figure. 2). Shear walls bear about 60% of the gravity loads and wide wing columns at the border of the walls bear the remaining 40% of the loads. By using steel shear walls as gravity load bearing elements, about one-third of the amount of steel in Weston beams is saved in comparison with steel bending frames. In this structure, the barbed is placed as the basis of the lateral loads and under the design wind load, the maximum relative displacement of the drift floors was 0.0025. The relatively low drift is caused by the stiffness in the relatively high plan of the steel shear walls.

Fig 2. An example of a steel shear wall worked in a hotel in Dallas, Texas.

Steel shear walls are made of steel sheet surrounded by beams and columns. SSW works similar to a steel beam in which the columns are its wings, the floor beams are its stiffeners and the steel sheet is its life. Between the beams and columns can be rigid or simple and unlike the beams in which, due to the weakness of the wings, the wings do not play a significant role in absorbing the forces, in steel shear walls due to the strength of the columns, the columns they can play a good role in load bearing. To prevent the buckling of the steel sheet, especially in the elastic area, the steel sheet can be strengthened with the help of vertical and horizontal stiffeners.

LYP steel, which has recently entered the construction industry and is one of its uses in steel shear walls, has an elasticity modulus equal to that of ordinary steel, 200,000 MPa, and its yield stress is lower than that of ordinary steel, around 100 MPa. The comparison between the stress-strain diagram of normal mild steel and LYP steel is shown in (Figure. 3).

This type of steel has high formability and its energy absorption is more than normal steel (the level below the diagram in (Figure. 3), which has been well demonstrated by its use in steel structures. The results of using steel sheets with low yield stress (LYP) in steel shear walls in Japan show that the ductility and ultimate strain of steels with low yield stress are more than twice the ductility and ultimate strain of ordinary steels.

Therefore, the use of such steels in building members that are used for energy loss will be very effective. The use of steel shear walls is generally based on two points of view, the first is the use of a hardener to prevent the sheet from buckling and the steel sheet from reaching the ultimate stress limit, and the second is the use of the post-buckling resistance and the diagonal stress field of the steel, which is economically The second view is more appropriate. The second point of view raised looks at the wall element as a fuse-like element, which consumes the energy caused by side loads by entering the stage of plastic deformation. In this view, the faster the sheet enters the plastic stage, the faster the depreciation will start and the behavior of the structure will be better, and also the forces applied to the border elements (beams and columns) will be reduced and the overall stability of the structure will not be lost. For this reason, it is appropriate to use LYP sheet in this case. Of course, it should be noted that entering the plastic phase should not be so fast that under small earthquakes, the service of the building will be disturbed.

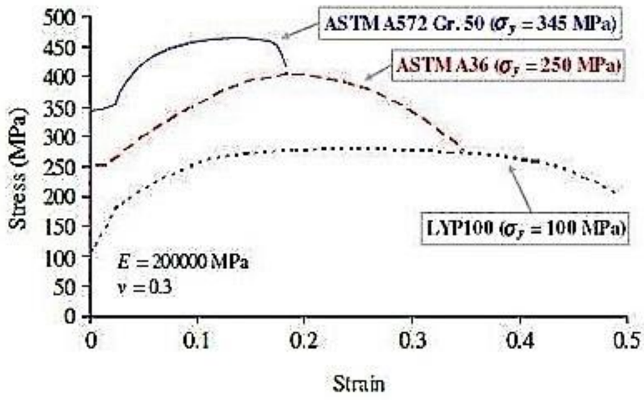

Fig 3. Comparing the stress-strain diagram of ordinary mild steels with LYP.

2. Material and Methods

In order to properly understand the behavior of steel shear wall, it is necessary to be familiar with issues such as stability, stress distribution and nonlinear behavior criteria. In this section, an attempt is made to present the theoretical issues with an overview in a compact manner, in order to finally obtain a general view of what happens in the process of force transmission by a steel shear wall in different stages of loading. The issue of sheet buckling is one of the important issues in facing the shear wall against lateral forces. According to the theories of structural stability, after the shear stress in the sheet exceeds a certain limit, the phenomenon of buckling occurs. The amount of this stress depends on the thickness of the sheet. And it has its boundary conditions. The phenomenon of buckling in components such as beams and columns is considered as the ultimate limit of resistance, but in sheets, by redistributing stresses and creating a diagonal tension field, the sheet can show resistance far beyond the force that causes it to buckle. The mechanism of the diagonal tensile field is such that the stiffness of the panel and the distribution of the internal forces of the panel are affected by its formation, and factors such as: 1- panel geometry (opening length and floor height) 2- column stiffness 3- panel thickness 4- tilt angle The diagonal tensile field plays a significant role in this effect.

In the upcoming modeling, ASTM A572 steel is used for the border elements and LYP100 steel is used for the sheet element, and the stress-strain diagram of these two types of steel is shown in (Figure. 3). Von Mises yield criterion and composite hardening model are considered in the modeling of steel behavior. In the following, the mechanical specifications of the steel shear wall system components, including the filler plate and boundary elements (beams and columns), are given in Tables 1, 2 respectively.

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Table 1. Mechanical characteristics of used steel

Modulus of elasticity (Kg/cm²)	2100000	
Poisson's ratio	0.3	
Plastic properties	Yield stress	Plastic strain
	3400	0
	4400	0.08
	4900	0.17
Weight mass	0.00786	

Table 2. Mechanical characteristics of the plate

Modulus of elasticity (Kg/cm²)	2100000	
Poisson's ratio	0.3	
Plastic properties	Yield stress	Plastic strain
	870	0
	2211	0.04
	2820	0.17
Weight mass	0.00786	

Four different components have been used for modeling: Horizontal boundary elements or beams, vertical boundary elements or columns, middle sheet and spheres, all these elements are defined as shells. The reason for choosing this element is that the behavior of this element includes bending and shear stiffness, which is able to transfer shear forces and bending moment to its surroundings. Also, if there is bending in two planes in the steel shear wall system, it is necessary to consider the out-of-plane bending stiffness in addition to the shear stiffness. For this reason, it is appropriate to use the shell element. If the shell element is used, the analysis time of the system, especially in wheel loads, is less compared to the solid element, while it does not have much effect on the accuracy of the answers, and in most references and authoritative articles such as Zirkian, the shell element is used for modeling the wall components. They suggested a steel blade and found it suitable.

After defining the building materials and required sections in the property module and assigning them to the elements, it is time to assemble the model, which can be done in the assembly module with the help of software features. After assembling the main structure, to facilitate the analysis, the structure is integrated with the help of the Merge command and a new part is created. In the continuation of this section, in order to mesh the structure in the best possible way, partitions should be considered in the parts of the structure where there are sudden changes in the cross-section. For the advanced structure, these partitions should be considered in the reduced section of the beam and also in the parts where there are spherical excesses. In the following, one of the partitioned shapes is shown. In the next part, the stages and types of analyzes are specified and the required outputs are extracted. For the advanced analysis, the main outputs are the cutting of the base and the change of the location of the load application. Also, the outputs related to energy will be needed for some investigations.

According to (Figure. 4), meshing technique will be structured as much as possible for ease of solving equations, but free technique is used in areas where redundancies are present. In order for the best collection of points to happen, the meshes are reduced by trial and error process. The dimensions of the mesh for meshing the steel shear wall system in the software are also considered to be 21 cm. Of course, it should be noted that too fine meshes make the answers diverge and the results become unreliable. Also, the explicit module is used in wheel analysis and the elements used will be S4R.

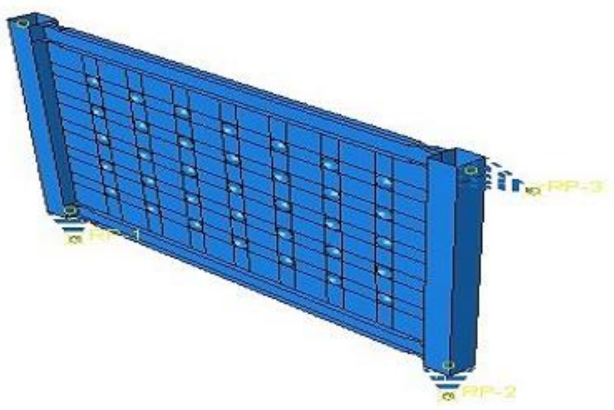

Fig 4. A view of the partitions considered for the SSW.

2.1. Design of SSW

Two determining factors in systems resistant to lateral loads, such as bracing systems and steel shear walls, are their hardness and resistance, which are determined with the help of a diagram (load-lateral displacement).

In (Figure. 5) an example of this diagram is shown in a general outline. In the above diagram, the slope of the line OA is called the hardness of the resistant system and Fu is the ultimate resistance. The relationship between load and lateral displacement in the elastic region is as is below:

$$F = KU \tag{1}$$

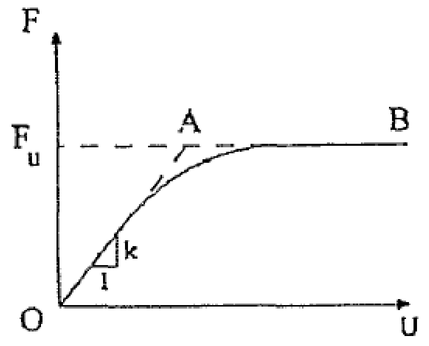

Fig 5. Overview of the load diagram - lateral displacement of the system.

Considering the need to control lateral displacement in buildings, the hardness of systems resistant to lateral loads is of particular importance. Among the factors in relation to which the need to control lateral displacement plays an essential role, P-Δ effect can be mentioned. When lateral loads are applied to the structure, the structure is slightly displaced, and as a result, the vertical loads, like dead load, are off-centered with respect to the axes of the frames and walls. Subsequently, the structure is subjected to the effect of additional anchoring. Additional displacement causes anchoring the interior will be more balanced with the anchor due to the vertical loads. This effect of the vertical load P on the lateral displacement Δ is called the P-Δ effect. Now, if the structure is flexible and its weight load (vertical load) is high, it is in a critical state. The additional force caused by this effect may increase the stresses in some members beyond the permissible limits and cause the destruction of the structure by creating instability. So here again the importance of using a lateral resistant system that has greater hardness against lateral forces and naturally changes the lateral location is less, it is clearly evident and it is very effective in controlling this effect.

In (Figure. 6), the diagram mentioned for the steel sheet and the frame is drawn separately, which are shown with the letters W and F, respectively. Also, two diagrams which are actually the load diagram - changing the shear location of the panel in the mentioned figure with the letters P is indicated.

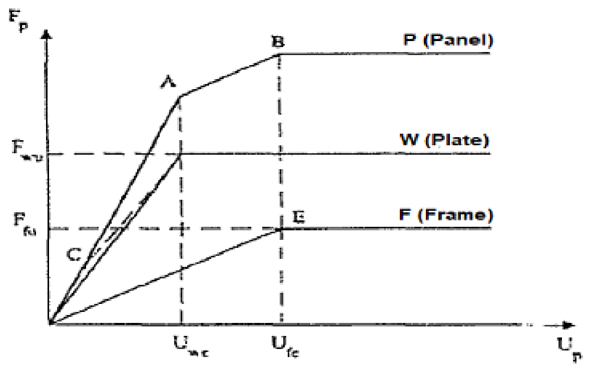

Fig 6. Diagram F_p-U_p of shear location of the panel.

In the nonlinear dynamic analysis of steel shear walls, the mathematical model of their hysteresis curves should be defined. The aforementioned model and generally this kind of theoretical models are based on laboratory results in which the system is subjected to reciprocating loads (cyclic loading). Is defined. In relation to corrugated steel shear walls, considering their use in different conditions, the defined mathematical model must be responsive to all the mentioned conditions. If there is no opening and hardening in the corrugated shear panel. Therefore, the final shear force of the panel when flowing according to the principle of the sum of effects of forces is:

$$F_{pu} = F_{fu} + F_{wu} = \frac{4M_{fp}}{d} + bt\left(\tau_{cr} + \frac{\sigma_{ty}}{2}\sin 2\theta\right) \quad (2)$$

Where θ is the angle of the tensile field and σ_{ty} is the stress caused by the tensile field.

2.2. Shear capacity of SSW

The shear capacity of steel shear walls can be calculated using the methods carried out in the regulations, especially AISC (1999), which is obtained for sheet beams. As an appendix for these equations, you can refer to SSRC and SSEC guidelines written by Theodore Galambos. The shear capacity of steel shear walls in the paste state is $\varphi_v V_n$, which φ_v=0.9 and V_n is determined as follows:

a) For compressed shear walls

$$V_n = 0.6A_wF_{yw} \quad (3)$$

b) For non-compressed and thin shear walls

$$V_n = 0.6A_{iv}F_{yw}\frac{1-C_v}{1/15\sqrt{1+(\frac{a}{h})^2}} \quad (4)$$

Where:

$$K_v = 5 + \frac{5}{(\frac{a}{h})^2} \quad (5)$$

$$C_v = \begin{cases} 1.1\dfrac{\sqrt{\frac{K_vE}{F_{yw}}}}{\frac{h}{t_w}} & 1.1\sqrt{\frac{K_vE}{F_{yw}}} \le \frac{h}{t_w} \le 1.37\sqrt{\frac{K_vE}{F_{yw}}} \\ 1.51\dfrac{K_vE}{\left(\frac{h}{t_w}\right)^2 F_{yw}} & \frac{h}{t_w} > 1.37\sqrt{\frac{K_vE}{F_{yw}}} \end{cases} \quad (6)$$

And also A_w in the above equations is the shear area of the plate which is equal to d_wt_w, V_n is the minimum shear capacity of the base of the wall to determine the minimum yield strength.

In the designs, the condition V≤φ_vVn where V is the shear stability factor obtained from the analysis Host should be satisfied. After designing the steel sheet, the accepted shear capacity V_{ne} should be calculated according to the actual shear area of the wall and the accepted yield strength. Boundary columns are also used and are calculated as follows:

$$V_{ne} = \frac{F_u+F_y}{2F_y}R_yV_n \quad (7)$$

In this regard, R_y is a factor for uncertainty in the specific value of F_y and is obtained by AISC. According to AISC, the R_y value for steel shear walls is suggested as 1.1.

3. Results

In this section, the effect of using LYP steel as the main material in middle plates instead of traditional steels in steel shear wall structures is investigated and compared. In the following, the effect of the presence of hemispherical protrusions on the cyclic behavior of steel shear walls is investigated by examining several different models.

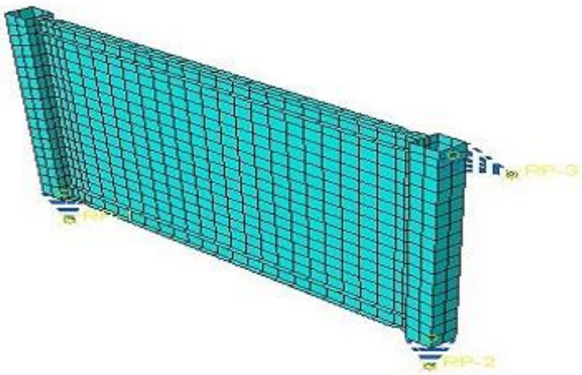

Fig 7. The model made for the first and second analysis in ABAQUS.

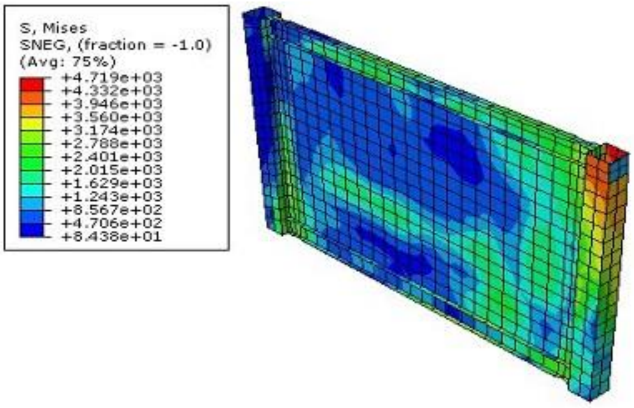

Fig 8. Von Mises stresses for the first investigated model.

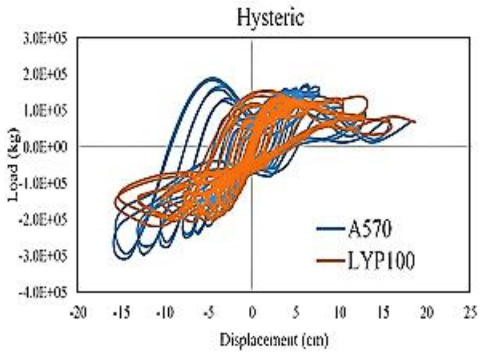

Fig 9. Comparison of hysteresis curves for two models with A57 and LYP100 steels as the middle plate.

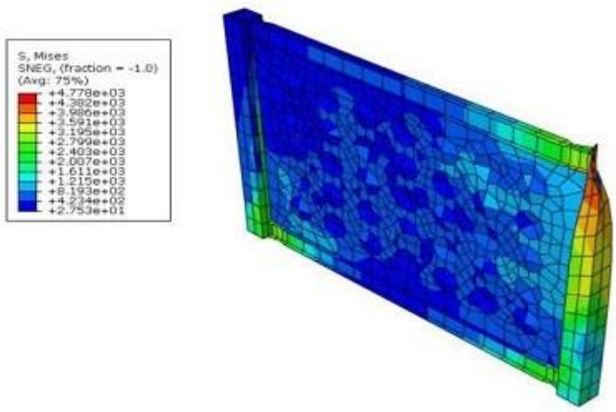

Fig 10. Von Mises stresses for the state of uniform arrangement, first case.

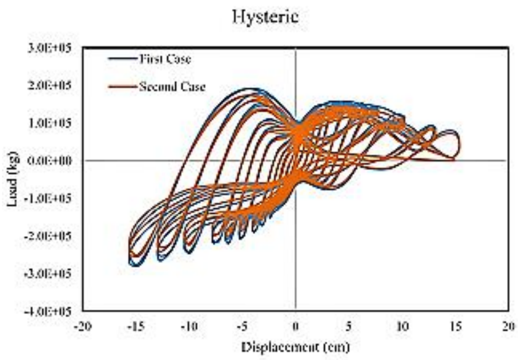

Fig 11. Cyclic analysis results for the first and second cases in the case of uniform arrangement.

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4. Conclusion

One of the most important points in the design of structures is proper bearing and formability against lateral loads. Traditionally, steel structures have elements called braces in various shapes (cross, chevron, divergent, etc.) for the resistance of the structure against lateral loads is used. One of the new techniques for resisting lateral loads is the use of shear walls, which has been more common than using steel shear walls until today. Steel shear wall has entered the world of construction industry with the same concepts as steel shear wall, but due to architectural reasons and devices such as less thickness at the same time as appropriate resistance and also far less weight, it has become popular and used.

In this research, the study of steel shear walls in which spherical excesses are used to increase the power of nonlinear deformations and as a result increase energy consumption, the main results of this research are as follows:

1- By placing these redundancies in a diagonal arrangement, the energy consumption in the structure is increased and also the lateral stiffness and ultimate strength of the structure is increased compared to the state of the normal sheet.

2- The increase in the diameter of the excesses is related to the decrease in the amount of energy consumption and lateral stiffness, and with the increase of this diameter, the depreciation and lateral stiffness of the system also decreases. Also, it should be noted that by increasing this diameter too much, the structure becomes vulnerable to gravity loads and there is a possibility of buckling out of the plane of the middle sheet.

3- According to the investigations, placing the spheres in a uniform and crosswise manner with a diameter of 25 cm in the structure causes a failure mechanism and as a result, the structure goes out of orbit sooner.

4- The use of spheres uniformly throughout the sheet, due to the reduction in hardness, is not economical compared to the diagonal and cross modes and will result in additional costs.

5- The use of diagonal arrangement leads to an increase in the area under the curve of the hysteresis cycle, which proportionally leads to an increase in the amount of absorbed energy. It can be said that the use of this model has led to the improvement of cyclical and continuous behavior.

Conflict of interest

There is not conflict of interest.

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