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Analysis on the Behaviour of Stiffened and Unstiffened Steel Plate Shear Walls with Enhanced Performance

Isha Verma[1], Saraswati Setia[2], Parveen Berwal[3], Rajesh Goel[4], Vikram Singh[5]

[1] Assistant Professor, Civil Engineering Department, MDU Rohtak, India
[2] Professor, Civil Engineering Department, NIT KKR, India
[3] Associate Professor, Civil Engineering Department, GCET Greatre Noida, India
[4] Professor, Civil Engineering Department, NICMAR Bahardurgarh, India
[5] Professor, Mechanical Engineering Department, J.C.Bose University Faridabad, India

Abstract: Steel Plate Shear Walls (SPSWs) are utilized for frameworks apposing lateral load for new as well as retrofit developments. For the most part, the shear walls made of thin plates are utilized, however for smaller loads it exhibits buckling resulting in a hysteretic behavior that is highly pinched. So as to lessen the buckling, holes are made in steel plate. Most of the studies provide either a circular or a rectangular hole in the steel plates. Hence we propose an elliptical hole which would improve the performance of the SPSW. This study develops and analyses the performance of a stiffened and unstiffened SPSW model with and without opening in the steel wall.

Keywords: Unstiffened, stiffened, elliptical, buckling, load multiplier

1. Introduction

As of late, there has been a huge increment in the number of tall structures, both residential as well as commercial and the cutting edge pattern is towards taller and thinner structures. Designing the structure of civil engineering is regularly dependant on the prescriptive techniques for construction laws. These structures exhibit an elastic structural behaviour since the loads are generally low. In any case, under a solid seismic occasion, a structure may really be exposed to forces past its limit of elasticity (Shi et al., 2011). Along these lines, the impacts of the lateral loads are achieving more prominent significance and pretty much all the engineers face the issue of giving sufficient strength and stability against horizontal loads. There are various lateral loads opposing framework however shear wall framework is generally adopted for the structures. A shear wall is a auxiliary framework that resists the lateral load. Seismic loads is the ultimate widely recognized horizontal loads that shear walls are intended to withstand (Bahrebar et al., 2016).

Steel plate shear wall (SPSW) is made out of an infill steel plate and a frame. With the merits of high flexible firmness, greater capacity of energy dissipation, stable hysteretic conduct, and malleability, it is a monetary and productive lateral force opposing structure framework in tall structures (Guo et al., 2015). SPSWs are proficient lateral force-resisting frameworks which are usually utilized in the designing and retrofitting of structures. Economical and structural contemplations may bring about the plan of SPSWs with stiffened or unstiffened just as stocky or thin infill plates. Auxiliary conduct and seismic execution of such frameworks are straightforwardly affected by the geometrical and material attributes of the web plates. Among different designs, SPSWs with ridged or potentially punctured infill plates have of late attracted the attention of the scholars and hence numerous investigations have been accounted for in this regard (Nie et al., 2013). As of late, SPSW structure is an exploration hotspot for its incredible execution to resist lateral distortion, so it has been utilized in various skyscraper structures made of steel. Because of huge steel utilization, the low usage productivity of material and poor performance of welding of thick SPSW, thin SPSW structures are given more consideration to current examinations. This sort of structure has a bigger ratio of height to thickness for an infill panel, hence, the application of a horizontal force buckles the steel panel sooner by with bigger out-of-plane deformation. And after that, the strain fields of slender infill plate are shaped, ensuring that the structure continues to oppose the horizontal force. These strain fields are directly transmitted to the casing segments, bringing about a higher effect on columns of the frames (Yin et al., 2019). So as to developed in seismic conduct of lean SPSW structures, inquire about works are primarily centred around two aspects. As of now, numerous researchers have proposed different auxiliary developments of shear walls. This study develops a model of SPSW to analyse its seismic behaviour and the significance of stiffness.

2. Literature review

Barkhordari et al., (2014) studied the conduct of stiffened SPSWs with the rectangular opening of full height. A progression of multi and single-story SPSWs of different angle proportions, with various features of the opening (for example length and even area) and without openings is examined utilizing the FEM technique to research the changes in framework conduct because of introducing openings with respect to ductility, stiffness and strength. Results demonstrate that features of the opening can importantly affect the conduct of SPSWs with the openings. Introducing an opening that is stiffened consistently lessens the strength of the infill plate and furthermore the underlying firmness and malleability, while it to some degree increases the strength of the casing. It is discovered that the relative decrease in the strength of the infill plate, and the relative decrease in the underlying ductility and stiffness because of introducing openings, can be evaluated reasonably dependent on the relative decrease in the infill plate zone.In view of the outcomes obtained, it can be understood that by expanding the infill plate thickness in proportion to the reduction in the area of the infill plate, the initial stiffness, strength and ductility of SPSWs with the openings would be accomplished near the relating SPSWs without the openings. One of the most significant preferences of SPSW is to make openings with various sizes and self-assertive areas on the infill plate contingent upon their application. In the examination conducted by Sabouri-Ghomi and Mamazizi, (2015), the impacts of two openings on the auxiliary conduct of SPSWs were considered tentatively. Trial testing was performed on three 33% scaled single-story SPSW examples consisting of two opening in the rectangular shape under semi static cyclic loading. The contrasts between the three punctured test examples were the interim between two openings and their closeness to the columns of the frames. The exploratory outcomes were used (a) for comparing the definitive shear strength, firmness and energy absorbed by the examples; (b) to assess the effectiveness of the bottom, top, lateral and central panels. (c) to examine the impact of separation between the columns and openings on the development of hinges of plastic on the flanges of the columns; (d) to assess the conduct of stiffeners around the openings. Test outcomes demonstrated that a definitive shear quality, solidness and energy assimilation were the equivalent in every one of the three punctured examples and the interval among the two openings had no impact on these qualities. Also, the presence of openings prompted a decrease in the structural parameter values.

Shafaei et al., (2017) investigated the nonlinear conduct of cement SPSW (CSPSW) which had an opening. The examination is bifurcated into two separate parts so as to comprehend the impact of an unstiffened opening—areas and sizes. In stage one: four square opening sizes-little, medium, huge, and extremely enormous—are chosen to examine the area of the opening. At the point when the square opening size is fixed, the area is changed over the infill divider. The pattern is additionally rehashed with another size of the square. In stage two: walls with a circular opening at the centre are considered, while the opening proportion shifts from 10% to 65%. In the investigation, the debasements of seismic elements — the underlying solidness, a definitive shear quality, the malleability proportion, and the energy absorbed — with respect to the opening ratio are determined. As per the results obtained, the conduct of CSPSWs with an opening is absolutely unique in comparison to the SPSWs. The introductory versatile solidness of CSPSWs with an opening is autonomous of the opening area and extreme shear strength is marginally influenced by the area. In addition, linear degradation in the underlying elastic stiffness and a definitive shear quality of the infill composite wall is seen because of opening proportion which is increasing in nature. Rassouli et al., (2016) numerically and experimentally studied the conduct of CSPSW with the help of precast concrete panels that are light in weight. Three CSPSW samples were structured, fabricated, for testing. The steel materials and measurements of all samples were identical, but the precast panels made of concrete were distinct. One of the samples, on one of the sides of the infill panel, consisted of a precast concrete panel of normal weight; another sample had a light-weight one. The third sample had two light-weight panels on both the sides of the steel plate. The semi-static cyclic test outcomes demonstrate that CSPSW with a concrete panel of light-weight is a dependable framework for steel structures that resists horizontal loads. Also, the shear limit of the sample with light-weight cement was almost similar to the sample with ordinary weight. Along these lines, it tends to be construed the new framework can decrease the seismic mass and improve the conduct of steel structures. In this investigation, the light-weight concrete panel was 36% lighter than the panel of normal weight. In view of the test information, samples could endure a high level of drift in inter-story in the range of 5.04% and 6.24% until the shear limit decreases to 80% of the highest recorded shear load in the test. It ought to be referenced that the CSPSW infill steel plate is subjected to totally inelastic deformation and disseminates considerable seismic energy via large lateral energy.

Amiri et al., (2018) numerically studied the nonlinear conduct of the hardened SPSW with diagonal stiffeners. After examining the nonlinear pushover, the results of FEM are contrasted and stiffened and unstiffened SPSW, with the vertical as well as horizontal stiffeners. Initially, a FEM model of SPSW is created and approved by utilizing Abaqus programming. In the wake of guaranteeing the conduct of the components at the boundary (columns and sections) and the infill steel plate, the FEM models of the steel shear walls are created and investigated utilizing nonlinear pushover strategy. SPSW models are structured by AISC 341-10 Seismic Provisions. At long last, the obtained outcomes and the conduct of FEM models are contrasted with one another. The significant seismic parameters (elastic firmness, extreme shear quality, and ductility) are determined and the level of changes are examined. In light of the outcomes, the performance of the SPSW comprising of diagonal stiffeners improves as contrasted with unstiffened SPSW. Most of the studies are trying to boost the attainment of the SPSW by incorporating either a circular or rectangular wall. Hence, in this study, we propose to boost the attainment of the SPSW by introducing an elliptical opening.

3. Proposed Methodology

For studying the behaviour of the SPSW, its model is developed using finite element analysis techniques. The structure of SPSW consists of edge columns and beams, connections between the columns and beams and the infill panel as illustrated in figure 1 below. The infill panel and the frame in the shape of H are modelled using ABAQUS so that the phenomenon of shear locking is avoided. The residual stress has little effect on the SPSW behaviour hence it is not considered during the process of modelling. The patterns of loading as well as the boundary conditions are as per common tests. The procedure of loading contains two stages. First, to the top of the edge columns the vertical loads are applied for simulating the axial forces and the effect of 2nd order impact is considered Second, the displacement Δ or P- horizontal load is applied on the beam for simulating the seismic loading that is horizontal.

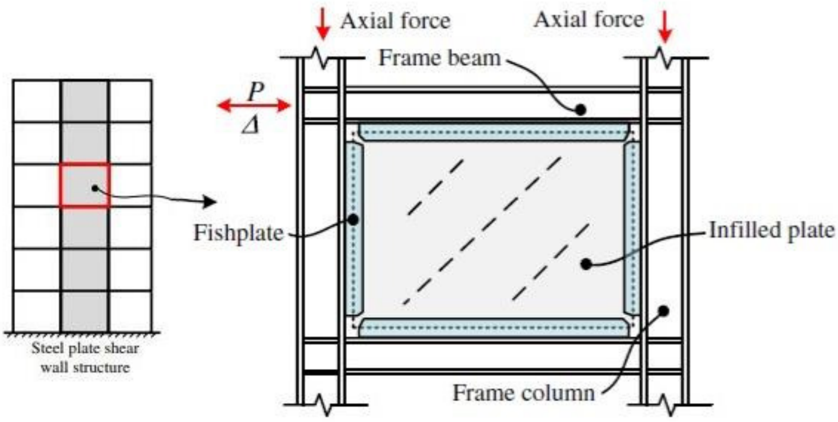

Figure 1. SPSW structure

The structure modelled above is seismic analysis to study its behaviour. Then the SPSW structure is modelled with openings of different shapes viz. Rectangular, circular, vertical and horizontal ellipse at the centre of the steel plate and then these structures are analysed for their capacity to carry loads, energy dissipation, fracture behaviour of the corner welds and the infill panel, ductility, failure mode and the effect of tension field on the columns. The following are the cases considered for the analysis.

- Analysis of seismic behavior of Steel plate shear wall (plane)
- Analysis of seismic behavior of Steel plate shear wall (With a hole in the center)

- Diagonally stiffened steel plate shear wall having elliptical opening (Vertical manner)
- Diagonally stiffened steel plate shear wall having elliptical opening (horizontal manner)
- Analysis of Rib type, steel plate thickness
- Elliptical opening having inline and staggered arrangements

The above discussed SPSW structures are modelled for a single-story as well as two-story buildings, the results of which are presented in the next section.

4. Simulation Results and Performance Evaluation

The SPSW structures are modeled and analyzed for different cases mentioned in the previous section. The figure 2 below illustrates the stiffened model developed using ANSYS for analyzing the SPSW structure without any opening. The figure 5 illustrates the solid model of the structure in figure 2.

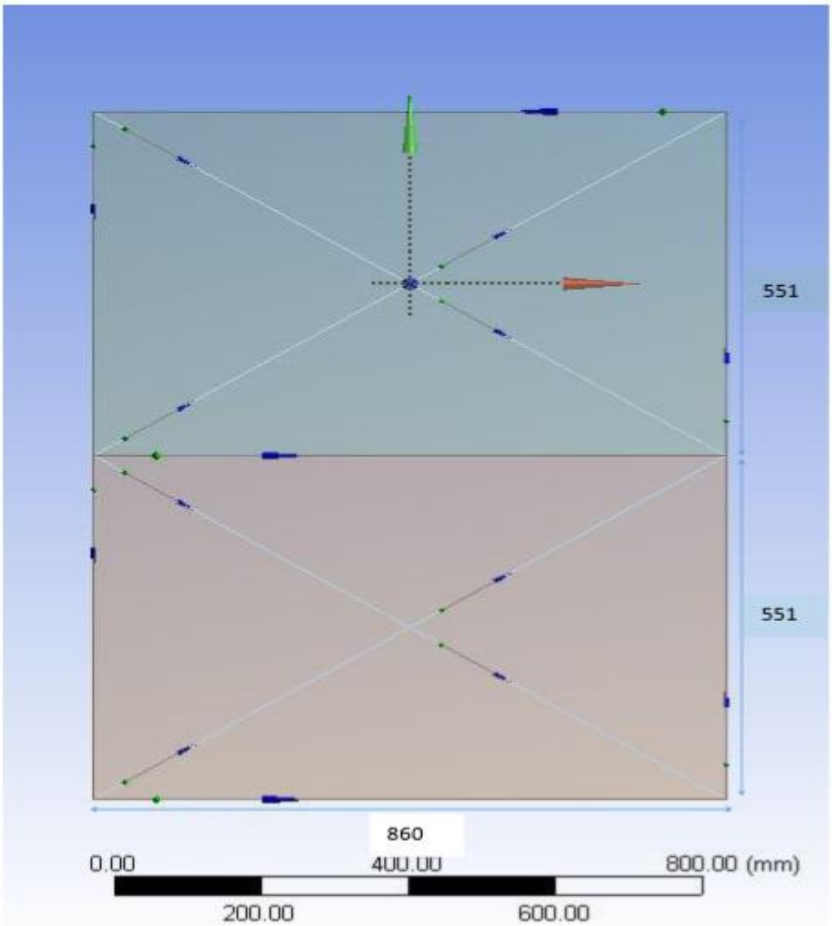

Figure 2. Dimensions of stiffened SPSW structure without any opening

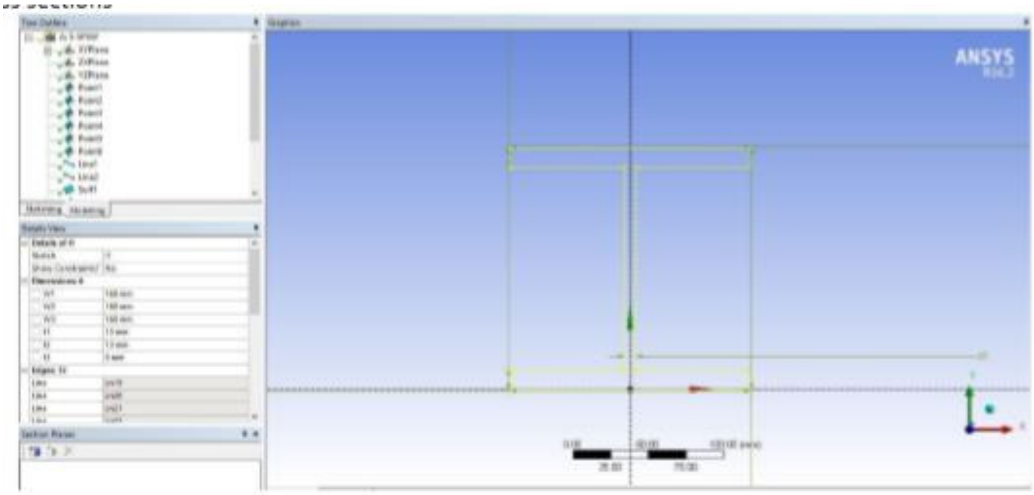

Figure 3. Cross-section of I – beam

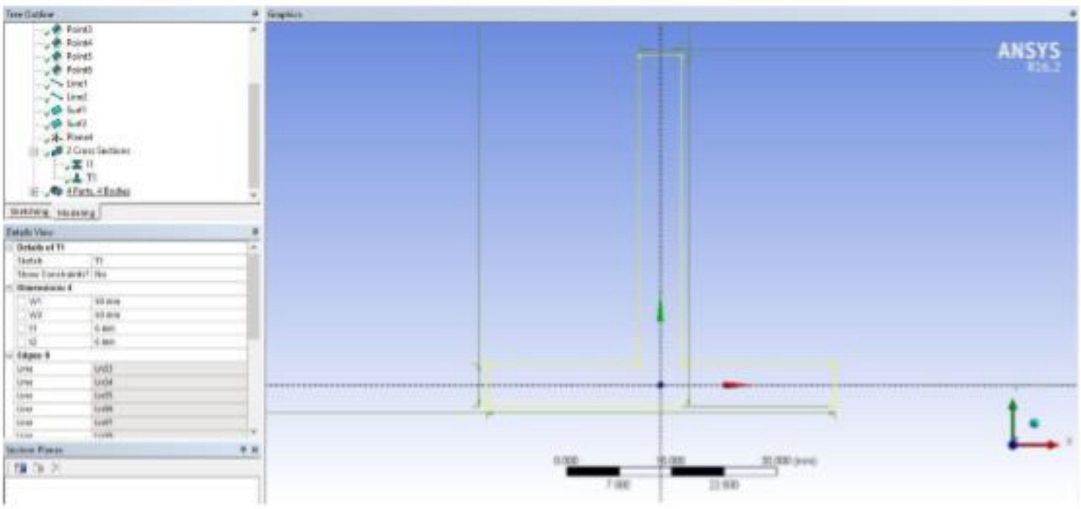

Figure 4. Cross-section of T – beam

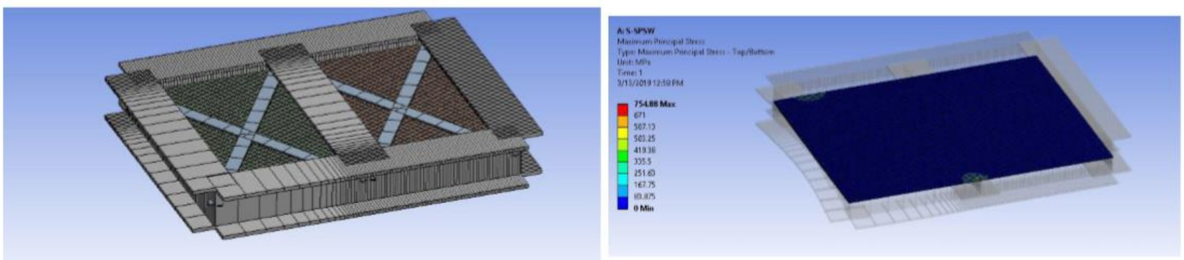

Figure 5. Stiffened Solid model

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The unstiffened model developed using ANSYS for analysing the SPSW structure without any opening is shown in the figures below.

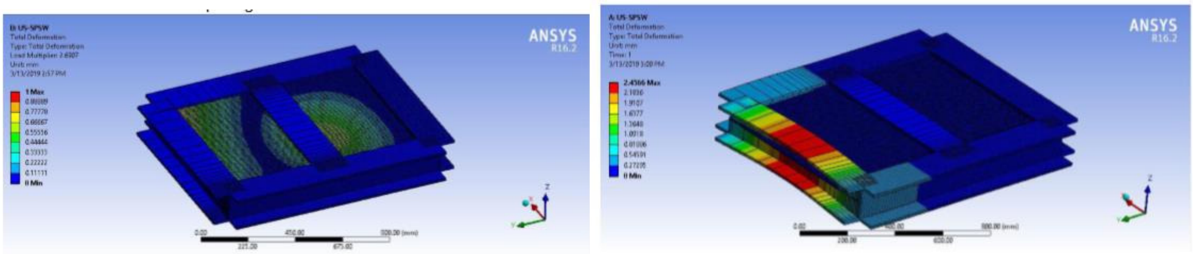

Figure 6. Unstiffened Solid model of SPSW

4.1 *Analysis of the SPSW structure with circular opening*

The figure 7 below gives the dimensions of the stiffened SPSW structure with circular opening and the solid models for the same is given in figure 8.

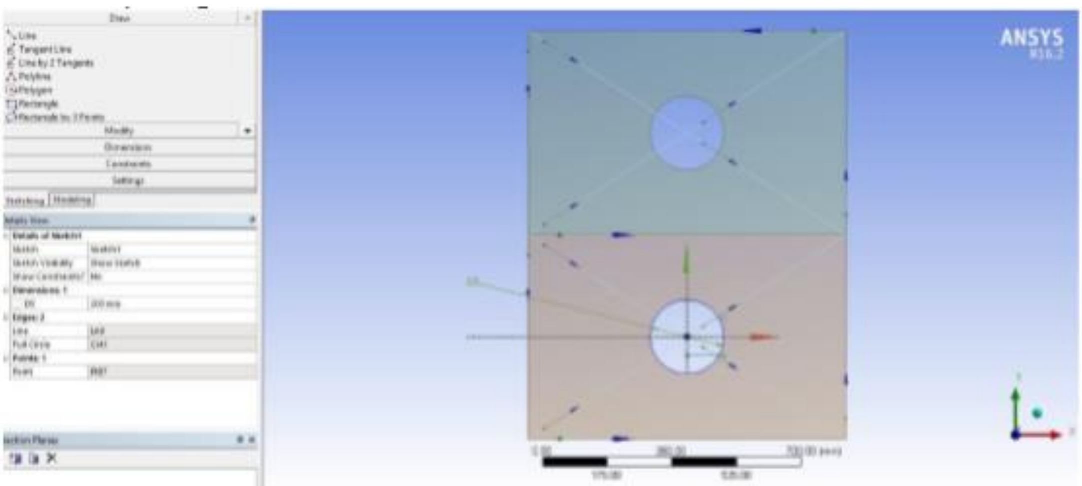

Figure 7. Dimensions of stiffened SPSW structure with circular opening

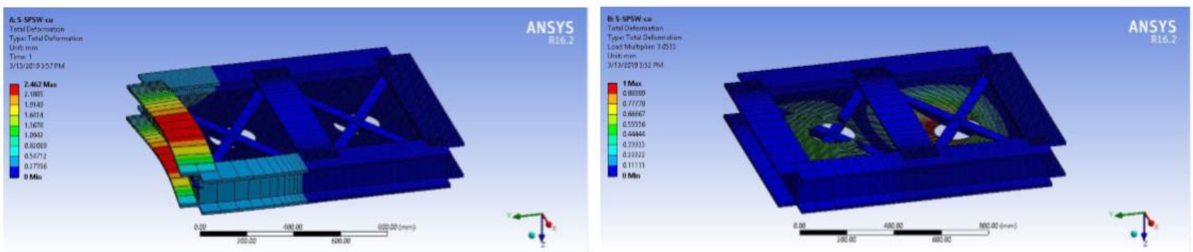

Figure 8. Stiffened Solid modelwith circular opening

4.2 Analysis of the SPSW structure with rectangular opening

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The figure 9 below gives the dimensions of the stiffened SPSW structure with rectangular opening and the solid models for the same is given in figure 10.

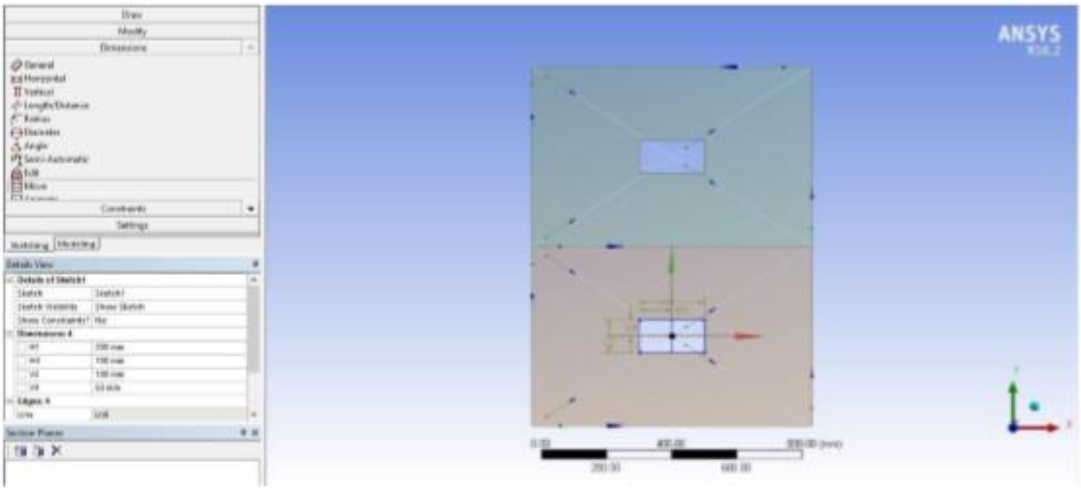

Figure 9. Dimensions of stiffened SPSW structure with rectangular opening

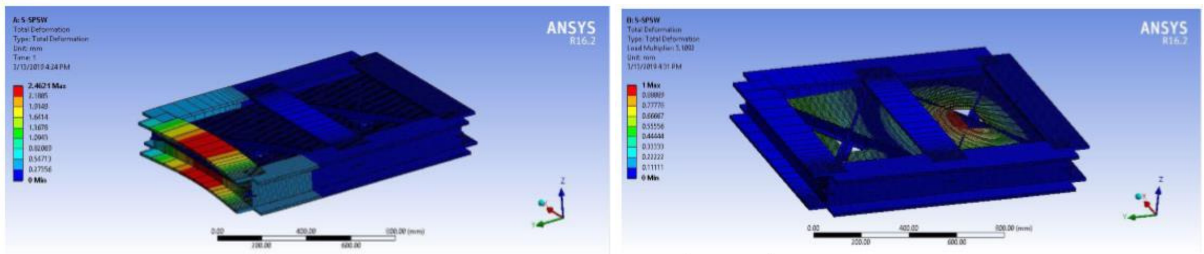

Figure 10. Stiffened Solid model with rectangular opening

4.3 Analysis of the SPSW structure with elliptical opening

The figure 11 below gives the dimensions of the stiffened SPSW structure with elliptical opening and the solid models for the same is given in figure 12.

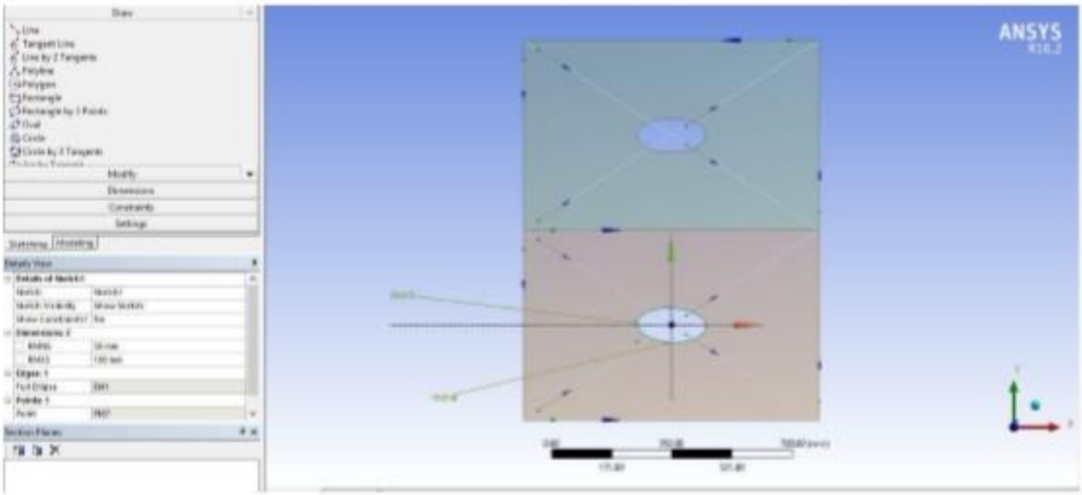

Figure 11. Dimensions of stiffened SPSW structure with elliptical opening

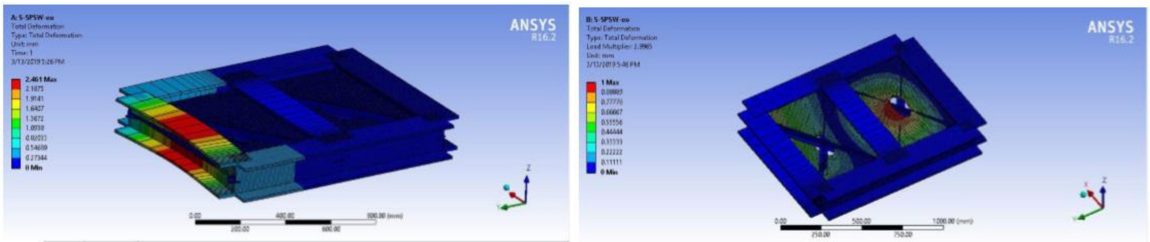

Figure 12. Stiffened Solid model with elliptical opening

4.4 Results for load and seismic analysis

All the models with circular, rectangular and elliptical openings are subjected to loading and seismic analysis. A steady load of 450KN is considered for the buckling analysis and for the seismic analysis a transient displacement varying from zero to 50mm in a time interval of 0 to 35 sec is considered. The table 1. Below gives the results obtained for the load analysis which implies that the elliptical opening is the best among all the configurations, hence the further analysis is carried out for this configuration only.

Table 1. Results of load analysis

Thickness	Load factor			
	Circular opening	Rectangular opening	Elliptical Opening	
			Vertival major axis	Horizontal major axis
1	0.00769	0.0030900	0.96248	0.10245
4	0.14471	1.568400	1.52520	1.57600
5	0.46881	2.026900	1.95510	2.05530
6	1.39150	2.658900	2.54770	2.70490
8	4.13300	4.457900	4.22830	4.52200

Since the elliptical model is the best, elliptical horizontal model is subjected to seismic analysis in steel frames. This model includes the ribs and a load of 900KN is applied. The results are as follows.

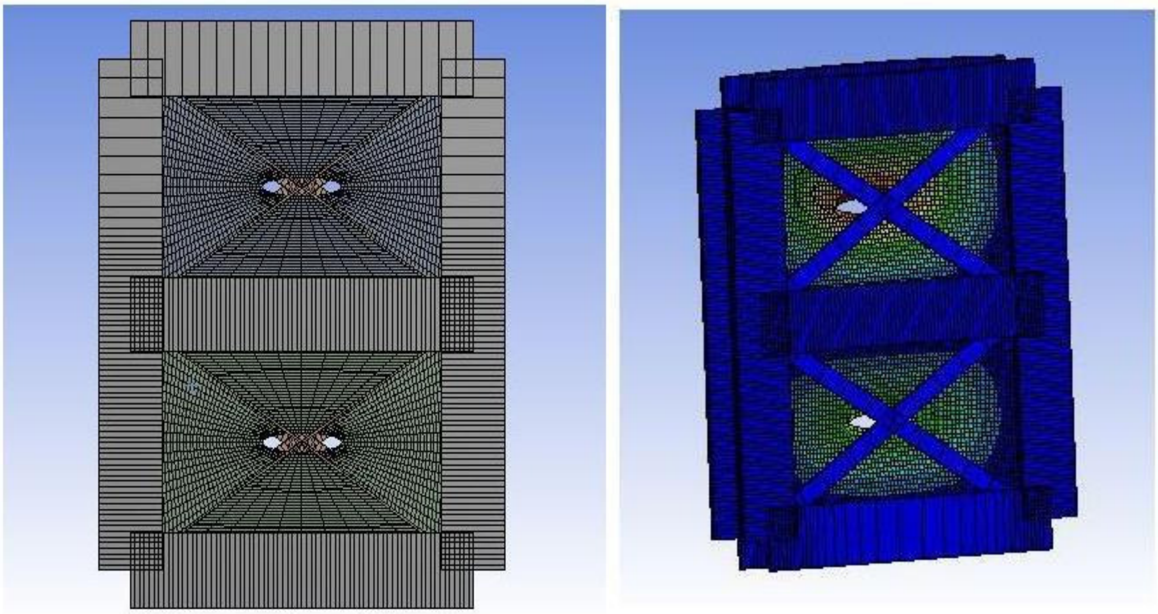

Figure 13. Seismic analysis of elliptical (horizontal axis) model

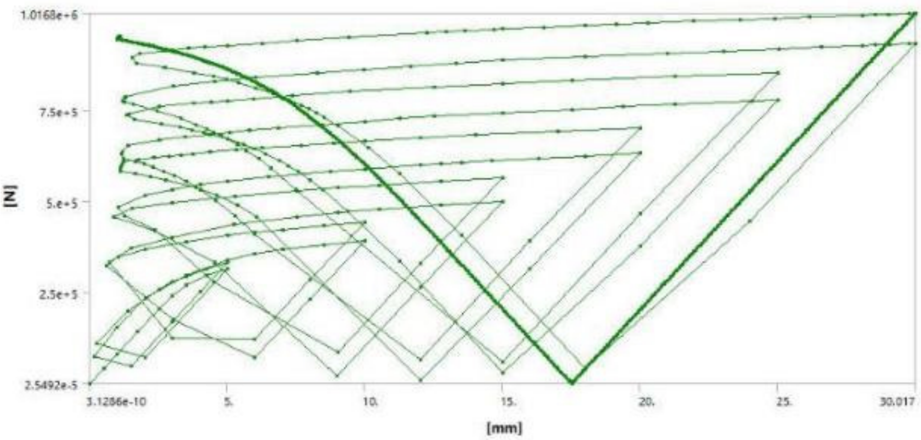

Figure 14. Hysteresis curve for the elliptical profile

From the above graph it can be observed that the load generated by the seismic waves on the structure with respect to the displacement of the building during the wave. The table 2 below gives the results of the seismic analysis conducted on the elliptical model

Table 2. Results of Seismic Analysis

Thickness	Load factor	Maximum bending moment (N- mm) in beams (*10^6)
1	0.15000	9.85000
4	2.17270	9.01000
5	2.84170	8.85000
6	2.86330	8.72980
8	4.13000	8.54000

The table 3 below gives the comparison of the load multiplier for the stiffened and the unstiffened SPSW structure with horizontal elliptical opening. Load multiplier is an integer that mentions the percentage of the applied load that the considered model can withstand making it independent of the load applied. Hence in spite of the changes in load the load multiplier gives the maximum load at which the buckling will occur indicating that the buckling depends on the stiffeners and the materials and not the loads being applied.

Table 3. Results of Seismic Analysis

Thickness	Load Multiplier	
	Unstiffened load applied 450KN	Stiffened load applied 900KN
1	0.102	0.150
4	1.576	2.176
5	2.055	2.842
6	2.705	2.863
8	4.133	4.150

5. Conclusion

In this study we developed a stiffened and unstiffened SPSW model and evaluated its performance with and without opening in the steel wall. We proposed an elliptical opening and compared its performance with that of a rectangular and circular opening. The load analysis indicated that the SPSW model with an elliptical opening was the best and further its seismic analysis was carried out for a load of 450KN (unstiffened) and 900KN (stiffened). The results implied that the buckling depends on the stiffeners and the materials and not the loads applied.

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