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Study Of The Impact Of Circular And Square Openings On Steel Plate Shear Walls Using Finite Element Analysis

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Abstract: The SPSW are lateral load resisting structures which are getting widely used in high rise building structures. The objective of current research is to evaluate the structural and vibrational characteristics of SPSW without any opening type. The FEA structural analysis is conducted on steel plate shear wall using ANSYS simulation package. The FEA analysis is conducted on SPSW structure under static pushover loading conditions. The stresses of high magnitude are obtained at the corner edges of plate. The equivalent stresses are obtained across the entire steel plate and is found to be maximum at the center of mid plate of SPSW. The initial resonant frequencies are obtained for SPSW. The structure is likely to resonate across frontal plate direction which may cause damage to the structure.

Key Words: *SPSW, vibration, stability, Finite Element Analysis*

1. INTRODUCTION

The steel plate shear barrier has been proven to be an efficient & cost-effective lateral force resisting solution to operate even against wind & seismic loads during the three decades using experimental and theoretical methodologies. It is made up of steel plate filling that is one bay long one and storey tall. These infill plates are positioned at either all or a specific storey. These infill plates are joined to the beam and column border by a link that may be rigid or shear. Steel plate shear walls are utilized in high-risk seismic areas because they offer inherent redundancy, high absorption capacity, better elasticity, initial high stiffness, & stable hysteresis loops when they are appropriately built. Older structures could also be upgraded using steel plate shear walls.

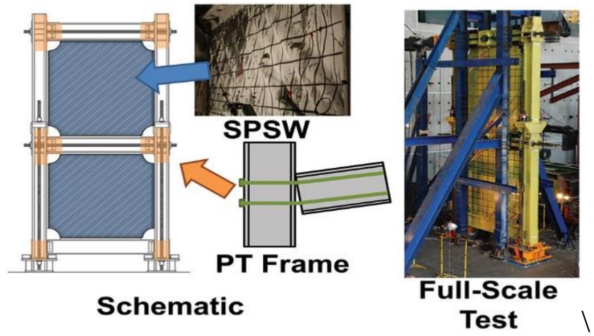

Figure 1: Steel Plate Shear Wall

Scientists have been researching in the use of Steel Plate Shear Walls (SPSW) for the past forty years because of its strong resistance to lateral stresses. Worldwide, in places like the United States and Japan, which are prone to earthquakes, this technique has been successfully applied. SPSW is made up of metal sheets that are surrounded by beams and columns which have been referred to as boundary components [1]. One issue is that SPSW could help to increase plastic energy loss in addition to improving a structure's stiffness, hardness, or elasticity. This device is manufactured using low return point steel and is appropriate for retrofitting structural members.

2. LITERATURE REVIEW

Pachideh et al. [2] an innovative, reduced type known as the "three strip model," in which the SPSWs' infill panels were swapped out for three tension-only strips. The capacities curve of buildings with SPSW that was generated from both experimental tests or computational designs was examined in order to assess the effectiveness of the suggested design. Promisingly, a satisfactory correlation among the findings was attained.

In a different study, according to Gholhaki [3] and Pachideh [4] the SPSWs' impact index premised on Park as well as Ang, lateral displacement, as well as standard 2800 were evaluated. They came to the conclusion that the displaced damage index, when compared to the other 2 indices, has specified the boundary boundaries such that less prohibitions can be classified in collapse avoidance.

Yadegari et al. [5] For the multi-story constructions fitted with hybrid steel plate shear walls, a number of nonlinear seismic evaluations were done. They came to the conclusion that AISC 341-10 often ignores the boundary pillars or reinforced concrete (RC) committee's significant shear capacity for the frames (up to 30%).

Pachideh et al. [6] The influence of subpanel size on the nonlinear behavior of the SPSWs was quantitatively investigated. In order to achieve this, they looked at five SPSW cases—five stiff cases & 5 unstiffened cases—and used a pushover study to gather information on response modification and ductility parameters. According to the findings, the SPSW's nonlinear properties considerably improve as subpanel size lowers.

In different research, Gholhaki et al. [7] incremental dynamic analyses were used to study the over power, ductility, as well as response reduction parameters of the buildings using SPSWs as their lateral load-resisting system. According to the findings, that for high, medium, or low-rise frames response modification ratios need to be close to 8 & 9, correspondingly,

Formisano et al. [8] studied the use of metal shear boards in the technique of seismic retrofitting an existing reinforced concrete building. They initially established the geometry of the shear panels for this goal, and afterwards FE designs were created to evaluate the system's real performance. Though pure aluminum panels are also able of greatly enhancing energy absorption, it was shown that steel shear panels may be regarded as an excellent technique for upgrading [9,10].

Formisano et al. [11] evaluation of the monotonic behavior of stiffened shear panels made of four different metals. So they evaluated pure aluminum, aluminum alloy, mild steel, & LYS steel in their investigation. A parametric study was conducted to examine the impact of the components on the system behavior, which was based on a nonlinear finite-element model. According to the findings, pure aluminum shear panels offer greater efficiency since they make use of their plastic qualities in terms of work hardening & flexibility.

3. OBJECTIVE

The objective of current research is to evaluate the structural and vibrational characteristics of SPSW without any opening type. The FEA structural analysis is conducted on steel plate shear wall using ANSYS simulation package. The FEA analysis is conducted on SPSW structure under static pushover loading conditions.

4. METHODOLOGY

The static pushover analysis is conducted on steel plate shear wall using ANSYS FEA simulation package. Further analysis is conducted on SPSW to determine its vibrational characteristics.

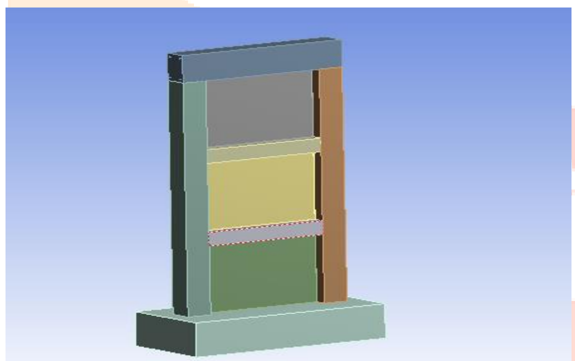

Figure 2: CAD design of SPSW (no opening)

The CAD design of SPSW is developed in design software. The SPSW design is developed using sketch, extrude and pattern tool. The design of SPSW is then imported in ANSYS design modeler as shown in figure 2 above.

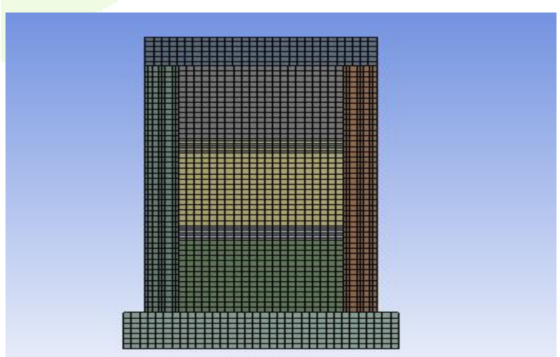

Figure 3: Meshed design of SPSW (no opening)

The SPSW model is then discretized. The discretization is based on geometry type, complexity of the geometry and topological consistency. The geometry of SPSW is discretized with hexahedral element type. The meshing is set to fine type and inflation set to normal.

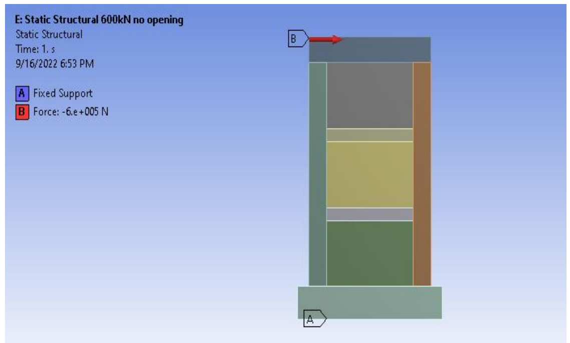

Figure 4: Lateral load application on SPSW

The structural loads and boundary conditions are applied on the structure as shown in figure 4 above. The applied boundary conditions are based on static pushover analysis (SPO) analysis. For SPO analysis, the base of the structure is applied with fixed support and top left end of the structure is applied with force of 60kN.

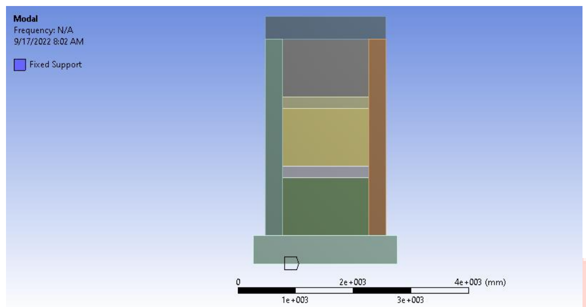

Figure 5: Boundary conditions for modal analysis

The modal analysis boundary conditions are applied on the structure. From the modal analysis, the vibrational characteristics of SPSW is determined. The number of modes extracted from the analysis is 6. The modal analysis is run to determine natural frequencies and mode shapes.

Table: Types and Parameters of Models Used

Model Type	Opening Type	Dimensions of SW	Material Properties	Boundary Conditions	Analysis Type
SPSW without Openings	None	Height: 3000 mm	Young's Modulus: 210 GPa	Fixed at bottom, free at top	Static Pushover, Modal, Response Spectrum
		Width: 1500 mm	Poisson's Ratio: 0.3		
		Thickness: 10 mm	Density: 7850 kg/m³		
SPSW with Circular Openings	Circular	Height: 3000 mm	Young's Modulus: 210 GPa	Fixed at bottom, free at top	Static Pushover, Modal, Response Spectrum
		Width: 1500 mm	Poisson's Ratio: 0.3		
	Diameter: 300 mm	Thickness: 10 mm	Density: 7850 kg/m³		
SPSW with Square Openings	Square	Height: 3000 mm	Young's Modulus: 210 GPa	Fixed at bottom, free at top	Static Pushover, Modal,

		Width: 1500 mm	Poisson's Ratio: 0.3		Response Spectrum
	Side: 300 mm	Thickness: 10 mm	Density: 7850 kg/m³		

5. RESULTS AND DISCUSSION

The FEA simulation is run static pushover loading conditions. The lateral deformation of the structure is determined at 60kN load as shown in figure 6. The topmost region of the SPSW exhibited maximum lateral deformation. The lateral load tends to distort the SPSW structure. This load tends to induce stresses at the corners and mid plate of the structure.

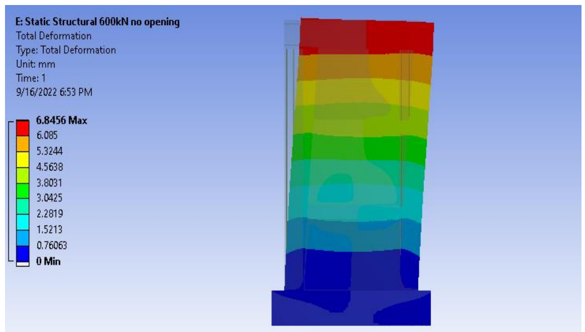

Figure 4: Total deformation induced on SPSW (no opening)

The base of the structure has shown minimum deformation as shown in dark blue colored region whereas the topmost region of the structure has shown higher deformation of more than 6.08mm as represented in red colored zone.

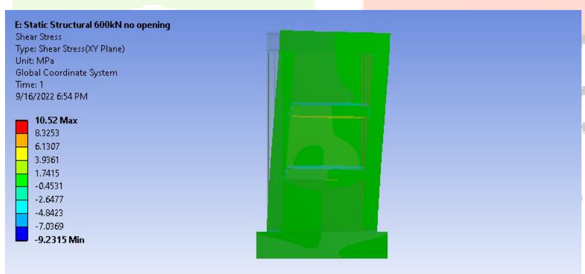

Figure 5: Shear stress induced on SPSW (no opening)

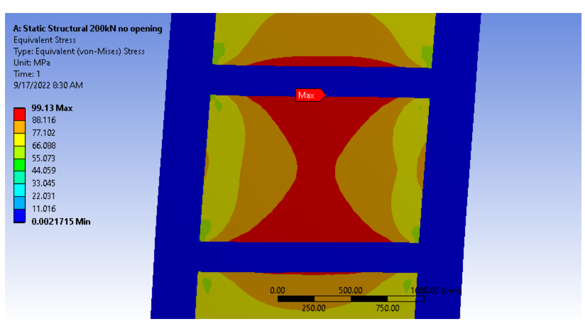

Figure 6: Equivalent stress induced on SPSW (no opening)

The equivalent stress distribution plot is evaluated for SPSW. The equivalent stress is higher at the mid plate of the SPSW. The equivalent stress at the mid plate is higher than 89MPa. The equivalent stress at the corner region is uniform with magnitude of 66.08MPa.

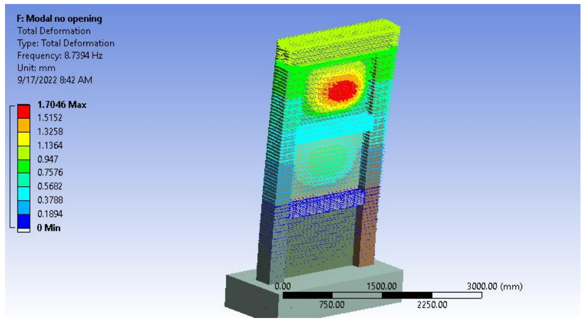

Figure 7: 1st mode shape plot of SPSW

The modal analysis is conducted on SPSW to determine mode shape of the structure. The mode shape represents zone of maximum and minimum deformation. The SPSW comprises of 3 different plates and the topmost plate of SPSW has shown highest deformation wherein the magnitude is more than 1.57mm.

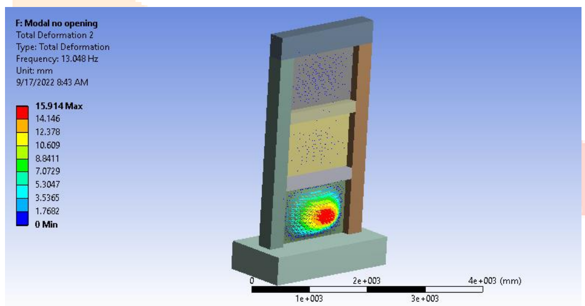

Figure 8: 2nd mode shape plot of SPSW frequency

For 2nd mode shape, the deformation is maximum at the bottommost plate of the SPSW. The deformation is higher than 8.84mm. The deformation on other regions is negligible.

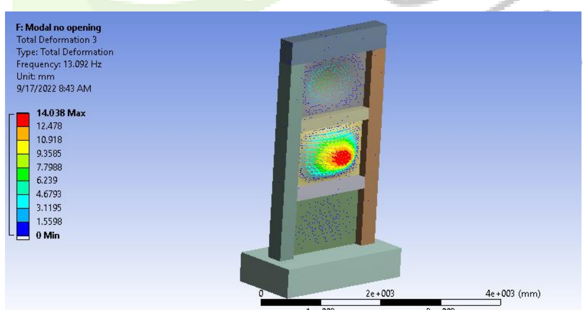

Figure 9: 3rd mode shape plot of SPSW frequency

For 3rd mode shape, the deformation is maximum at the mid-section plate of the SPSW. The deformation is higher than 9.35mm. The deformation on other regions is negligible.

CUMULATIVE MASS FRACTION	RATIO EFF.MASS TO TOTAL MASS
0.990351	0.287342
0.996271	0.171765E-02
0.998471	0.638066E-03
1.00000	0.443761E-03
1.00000	0.701410E-12
1.00000	0.231703E-12
	0.290141

Figure 10: Mass participation factor of SPSW

The mass participation factor is obtained for SPSW without opening as shown in figure 10. The maximum mass participation factor is obtained along y direction i.e. along the frontal plate direction. The higher mass participation factor along this direction would likely to cause resonance which would lead to amplitude buildup and thus incur damage to the structure.

Table: Comparison of SPSWs with Circular and Square Openings

Analysis Type	**Metric**	**SPSW without Openings**	**SPSW with Circular Openings**	**SPSW with Square Openings**
Static Pushover Analysis	Maximum Stress	High	Moderate	High
	Deformation	Low	Moderate	High
	Stress Distribution	Uniform	More uniform	Less uniform
Modal Analysis	First Natural Frequency	High	Higher than square openings	Lower than circular openings
	Mode Shapes	Stable	More stable	Less stable
Response Spectrum Analysis	Maximum Deformation	Low	Moderate	High
	Stress Concentration Points	Minimal	Few	Several
	Seismic Performance	Excellent	Good	Fair

Key Observations:

Static Pushover Analysis:

Maximum Stress: SPSWs with circular openings show a reduction in maximum stress compared to those with square openings.

Deformation: Circular openings cause moderate deformations, whereas square openings lead to higher deformations.

Stress Distribution: Circular openings provide a more uniform stress distribution compared to square openings.

Modal Analysis:

Natural Frequencies: SPSWs with circular openings have higher natural frequencies than those with square openings, indicating a stiffer structure.

Mode Shapes: Circular openings result in more stable mode shapes compared to square openings.

Response Spectrum Analysis:

Maximum Deformation: SPSWs with circular openings experience moderate deformations under seismic loads, while square openings result in higher deformations.

Stress Concentration Points: Circular openings exhibit fewer stress concentration points compared to square openings.

Seismic Performance: SPSWs with circular openings perform better under seismic conditions than those with square openings.

6. CONCLUSION

The FEA is a viable tool in determining structural characteristics of SPSW subjected to lateral loading. The results obtained from structural analysis enabled to identify the critical regions of high stresses on SPSW. The static pushover analysis is conducted to investigate the lateral behavior of SPSW under different loads i.e. 200kN, 300kN, 400kN, 500kN and 600kN. The effect of opening type on shear behavior of SPSW is analyzed under static and dynamic loading conditions. The detailed findings are:

1.From static pushover analysis, the lateral deformation is maximum at the topmost zone of SPSW and reduces towards the bottom region of SPSW.

2. The lateral deformation of SPSW increases with incorporation of opening.

3.The lateral deformation obtained for SPSW with circular opening is 31.27% higher than SPSW without opening.

4.The lateral deformation obtained for SPSW with square opening is 11.47% higher than SPSW without opening.

5.From the modal analysis, the natural frequency and mode shapes of SPSW with and without opening are determined. The incorporation opening increases the natural frequency of SPSW.

6.From the modal analysis, the maximum deformation is obtained at the central region of SPSW without opening. For SPSW with openings, the maximum deformation is observed at the vicinity of opening.

7.From response spectrum analysis on SPSW with circular opening, the maximum stresses are observed at the center regions of each corner edge. High stresses are also observed at the corner of circular opening.

8.From response spectrum analysis on SPSW with square opening, the maximum stresses are observed at the center regions of each corner edge.

9.From response spectrum analysis, the equivalent stress is maximum for SPSW with square opening. The maximum equivalent stress is obtained at the corner regions of steel plate.

10.From the response spectrum analysis, the deformation of SPSW is obtained. The deformation is minimum for SPSW without opening and is maximum for SPSW with square type opening.

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