Analytical Study on Trapezoidally Corrugated Steel Plate Shear Wall

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Abstract— Past studies proves that steel plate shear walls (SPSW) as efficient lateral load resisting systems. Its high initial stiffness, strength, energy absorption capacity as well as ductility are some of its advantages. SPSWs may be either stiffened or un-stiffened, based on the type of infill plates. Stiffened SPSWs increases the cost of construction. Recent introduction of corrugated plate with various structural features, created great interest among the researchers, to study about the corrugated SPSWs. On this basis, this paper presents the result of the numerical analysis of trapezoidally corrugated SPSWs. The linear buckling analyses are performed to study the effect of web-plate thickness, aspect ratio and opening percentage. The stiffness, strength and ductility performance of numerous trapezoidally corrugated SPSW under monotonic loading are also investigated. Their behaivour under cyclic loading is also examined.

Key words: Lateral Load Resisting System, Steel Plate Shear Wall, Corrugated Plate

I. INTRODUCTION

Steel plate shear walls (SPSWs) are considered as efficient lateral load resisting structure. SPSW consist of columns known as vertical boundary elements (VBE), beams known as horizontal boundary elements (HBE) and, an infill plate between VBEs and HBEs called web plate. The steel plate shear walls are classified according to web plates ability to oppose buckling. The web plates that are sufficiently stiffened to preclude buckling and to allow the full shear strength of the web to be reached, then these SPSW are known as "stiffened" SPSWs. Even though stiffening increases the effectiveness of SPSW, it is typically not as economical as the use of the "unstiffened" SPSW in which buckling of the web plate is expected. The use of corrugated web plate is a best and economical alternative for stiffening the plate, with its various advantages like ductility, out-of-plane stiffness, buckling strength and higher energy dissipation capacity.

SPSWs are in use since 1970s. But still, it is considered as an emerging system because still many researches are carrying out on SPSW. The first extensive research on the behaviour of steel plate shear wall panels was done by Takahashi et al. (1973) in Japan. He conducted study on various configurations of stiffened shear panels, to determine their suitability for using as a lateral load-resisting system. The researches demonstrated that the stiffened panels dissipated significantly more energy than did the unstiffened panel, but the cost is high. Both have equal ductility.

Mo and Perng (2000) conducted experimental study on framed shear walls made of corrugated steel and concluded that seismic performance was increased over flat plate. Berman and Bruneau(2005) performed study with light-gauge SPSW with flat and corrugated infill plate, and proved corrugated plate can offer higher energy absorption and ductility, at the same time it reduces the column demand. Experimental study on un-stiffened and trapezoidally corrugated SPSWs are conducted by Emami et.al (2013). The behavior of SPSWs with trapezoidal corrugations under monotonic and cyclic loadings was investigated by Emami and Mofid (2014) through detailed numerical simulations. Farzampour et al (2015) conducted numerical study and compared corrugated steel plate and simple steel plate shear walls, with and without openings. In this work, the parameters like plate thickness, angle of corrugation, opening size, and opening placement are studied.

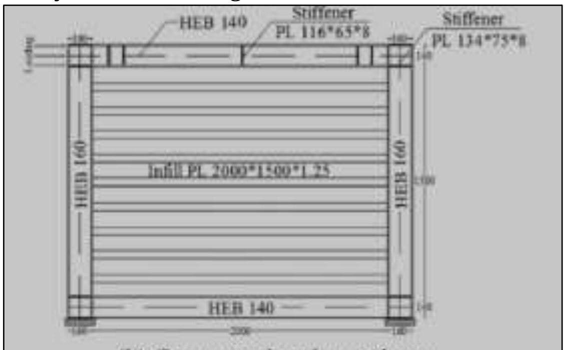
In this paper, various finite element models of single storey single bay trapezoidally corrugated SPSWs are developed by changing various parameters like plate thickness, opening percentage, etc. The performance under monotonic and cyclic loading is considered.

II. FINITE ELEMENT MODELLING AND VERIFICATION

The SPSWs are modeled and analyzed using ANSYS 17.0 finite element software. SHELL181 is selected because it is suitable for analyzing thin to moderately-thick shell structures. It is a four node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. This element can be used in situations of plasticity, stress stiffening, large deflection, and large strain, and is well-suited for modeling SPSWs. To establish the accuracy of the numerical modeling, it is validated by an experimental study done by Emami Et.al, (2013) with horizontal trapezoidal corrugated plate.

A. Experimental specimen details

In this work, half scaled single storey and single bay SPSW was tested. The shear panel was 2000mm wide and 1500 height, with horizontal trapezoidally corrugated infill plate of thickness 1.25 mm. For the boundary frame of the specimen, the top beam section is HE-B 140 and section of column is HE-B 160. The bottom beam section in each specimen is HE-B 200, which is connected to the strong floor beam of the laboratory, as shown in fig 1.



(b) Corrugated-web specimen
(corrugation angle = 30°, web thickness = 1.25 mm, and number of corrugation half-waves = 8)

Fig. 1: Details of the specimen [4]

B. Material properties and boundary conditions

The yield stresses of plate, beam and column components were 207MPa, 288 MPa and 300 MPa respectively. The Young's modulus of elasticity and Poisson's ratio were assumed as 210 GPa and 0.3 respectively. The von Mises yield criteria is adopted for the failure criteria. The multi-linear representation of stress-strain relationship is as shown in fig 2. For the corrugated web plate trapezoidal corrugation with geometric properties as in fig 3 are used.

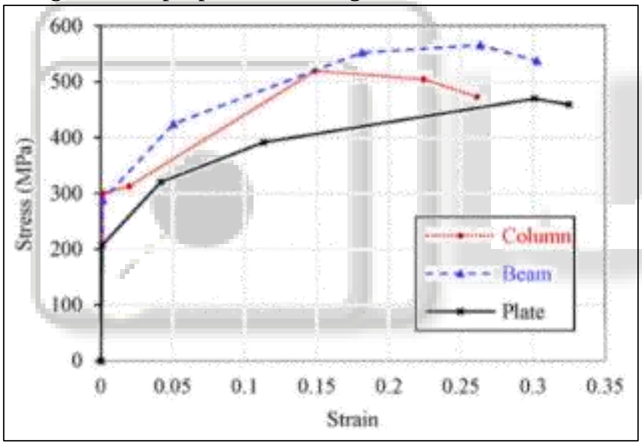


Fig. 2: Stress-strain relationship of steel materials [7]

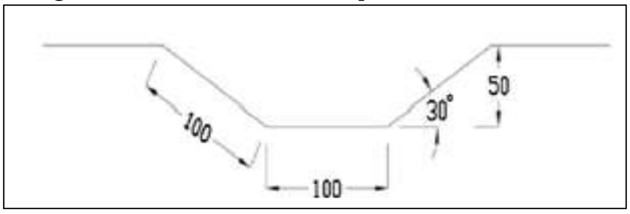


Fig. 3: Geometric properties of trapezoidally corrugated plate (mm) [4]

The boundary condition at the bottom of the shear wall is a fixed support. Out-of-plane displacement at the beam-column joints (moment resisting joints) are restrained.

C. Loading

To implement lateral load and to investigate the behavior of the specimen in lab, quasi- static cyclic load is applied by two horizontal hydraulic jacks on both side at top beam level using AC protocol. Cyclic load history as shown in Fig 4 is applied.

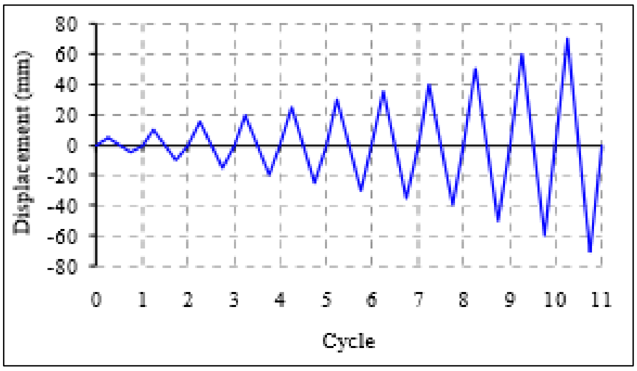


Fig. 4: Cyclic loading protocol [8]

D. Assumptions and validation of modeling

For the validation, SPSW with trapezoidal corrugation is modeled in Ansys Workbench and the corresponding Ansys model are shown in Fig 5. The simulations were performed under displacement controlled loading with the aid of a non - linear static procedure.

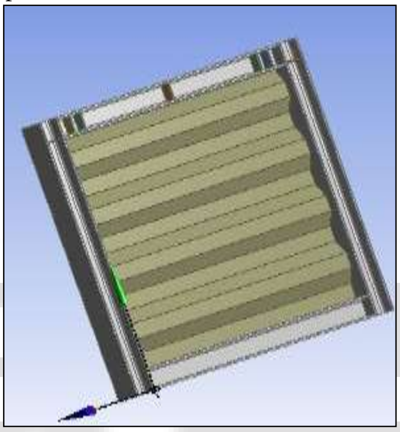


Fig. 5: Ansys models for validation

The hysteresis curve of quasi- static cyclic loading generated from the finite element analysis is compared with the experimental test result. Excellent agreement is observed between analysis and experimental results. The experimental and numerical results are shown in Fig 6 and 7 and tabulated in table 1.

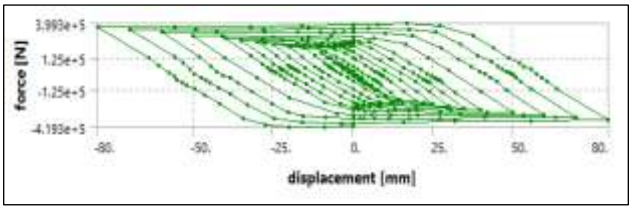


Fig. 6: Hysteresis Behavior of Numerical model

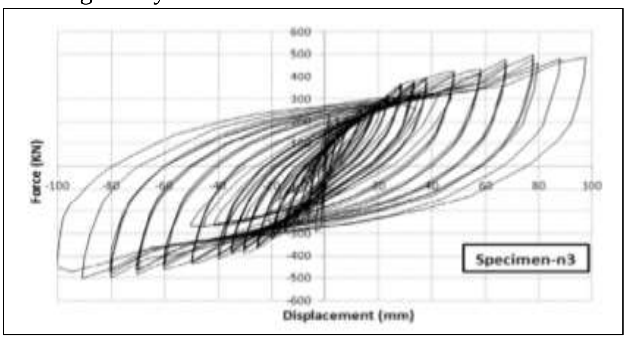


Fig. 7: Hysteresis Behavior of Tested Specimen

	Numerical	Experiment	Num./Exp.
Ultimate strength	419 KN	500 KN	.838
Displacement	80	78	.84

Table 1: Comparison of numerical prediction and experimental results

III. NON-LINEAR STATIC ANALYSIS OF SPSWs

The overall performance of a SPSW depends upon geometric properties of the boundary element as well as infill plates. So, to investigate the performance of SPSW system, parametric studies are conducted by varying infill plate thickness, opening percentage and aspect ratio of SPSW system.

Four different plate thicknesses (1.25mm, 2 mm, 3mm and 4mm) are considered. Four different opening percentages are considered. Three different aspect ratios are considered, 1.33, 1 and 0.75 with infill plate with dimensions 2000mm x 1500mm, 1500mm x 1500mm and 1125mm and 1500mm respectively.

The important properties of structures, which contribute to their performance under earthquakes, are its yield strength, elastic stiffness, ductility, ultimate load and hysteretic energy dissipation capacity.

A. *Effect of thickness*

The variation of ultimate load, ductility and stiffness of horizontally corrugated SPSWs with thicknesses for panel size 2000 mm x 1500 mm are illustrated in chart 1 to 3.

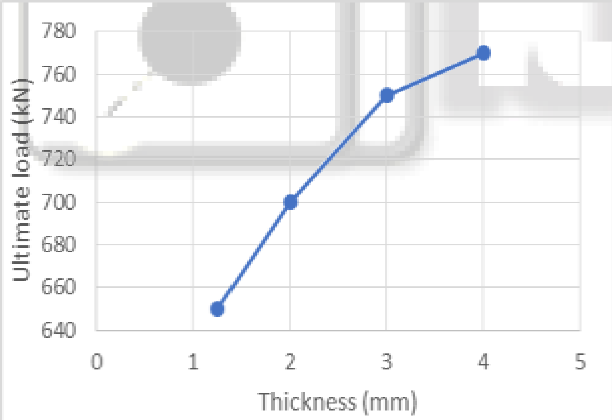


Chart 1: Ultimate Load Vs Thickness Curve

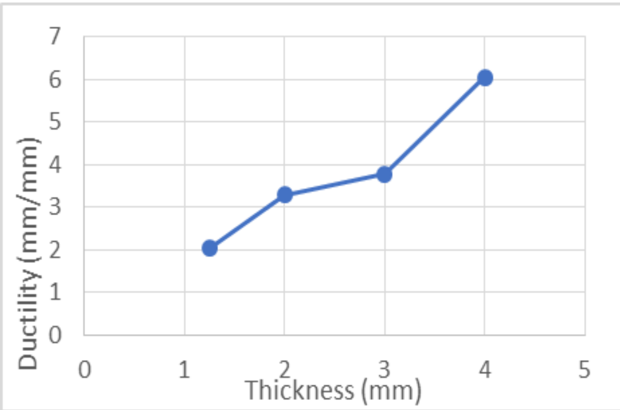


Chart 2: Ductility Vs Thickness Curve

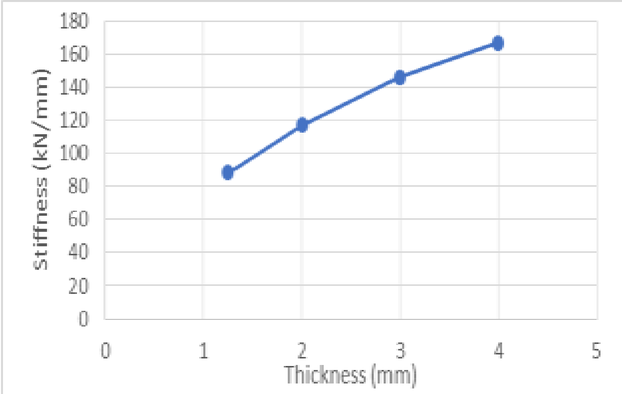


Chart 3: Stiffness Vs Thickness Curve

B. *Effect of opening percentage*

The variation of ultimate load and stiffness of horizontally corrugated SPSWs for five different opening percentage (0%, 5%, 10%, 15% and 25%), with 1.25mm thick panel of size 2000 mm x 1500 mm are illustrated in chart 4 to 5.

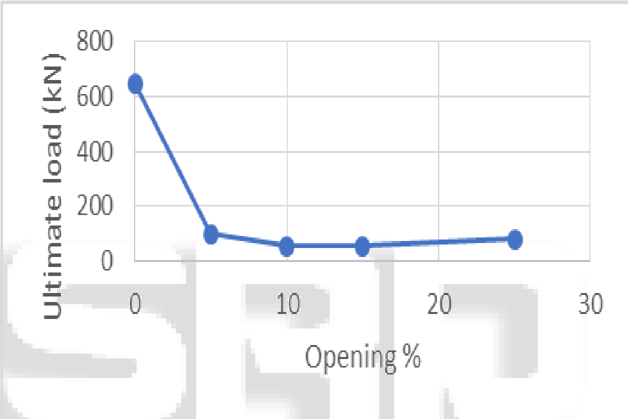


Chart 4: Ultimate load Vs Opening percentage

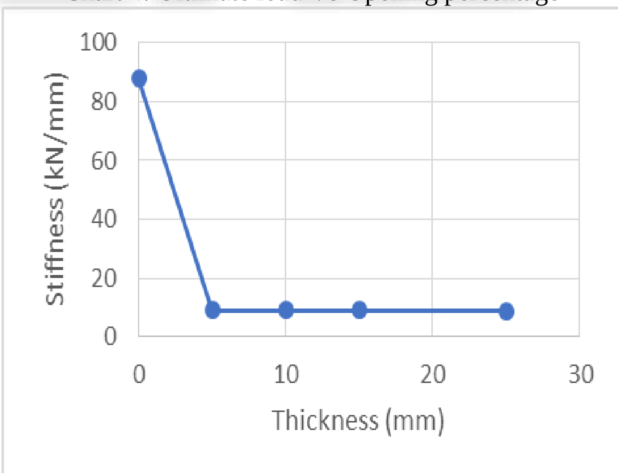


Chart 5: Stiffness Vs Opening percentage

C. *Effect of Aspect Ratio*

The variation of ultimate load, ductility and stiffness of horizontally corrugated SPSWs for three different aspect ratios (1.33, 1 and 0.75), for thickness of 1.25 mm is illustrated in chart 6-8.

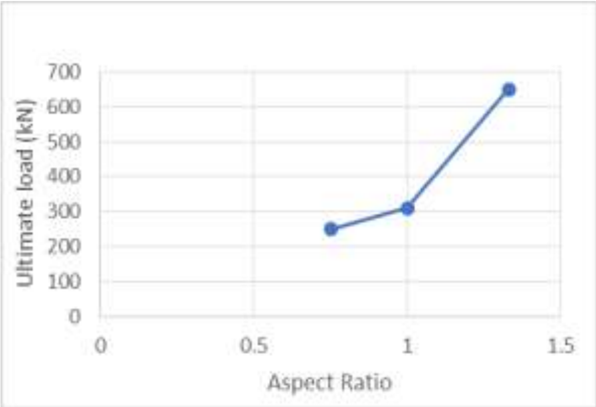


Chart 6: Ultimate load Vs Aspect Ratio

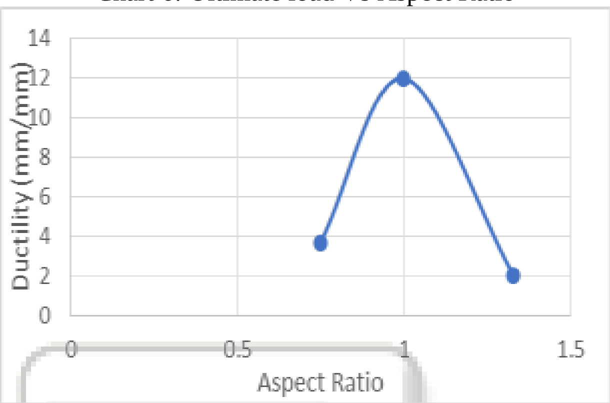


Chart 7: Ductility Vs Aspect Ratio

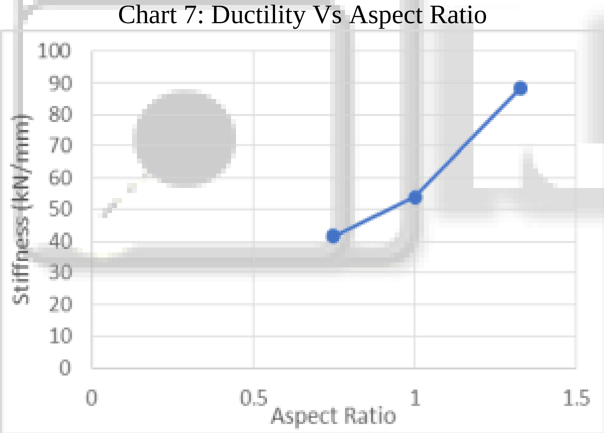


Chart 8: Stiffness Vs Aspect Ratio

IV. EIGEN BUCKLING ANALYSIS OF SPSW

Eigen buckling analysis was performed on ten samples of SPSWs. The relevant shapes and results are listed below. The buckled shape of corrugated SPSW is as shown in Fig 8.

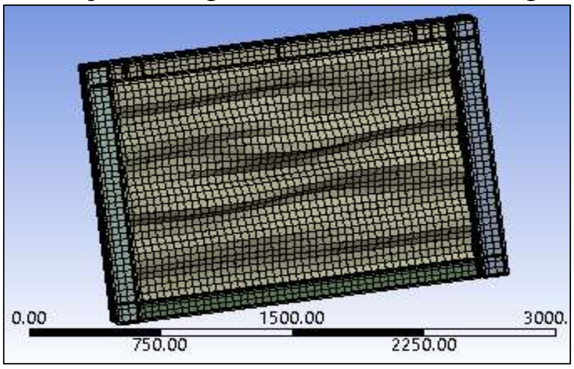


Fig. 8: First buckled mode shape of corrugated SPSW model

A. Effect of thickness

The variation of buckling load with various thicknesses, for panel size 2000 mm x 1500mm is represented in chart 9.

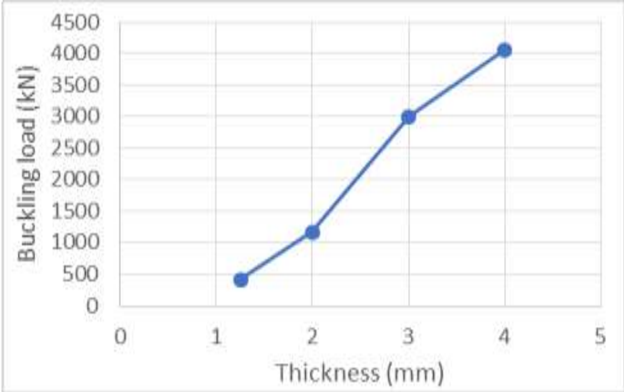


Chart-9: Buckling load Vs Thickness Curve

B. Effect of opening percentage

Chart 10 shows how the opening percentage effect the buckling load of SPSW with aspect ratio 1.33 and thickness 1.25 mm.

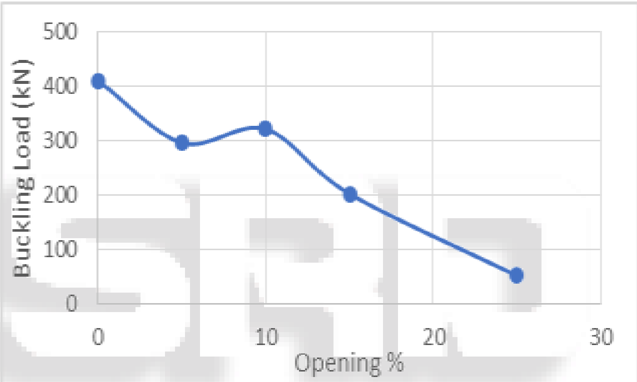


Chart 10: Buckling load Vs Opening Percentage Curve

C. Effect of Aspect Ratio

The variation of buckling load for various aspect ratio are demonstrated in chart 11.

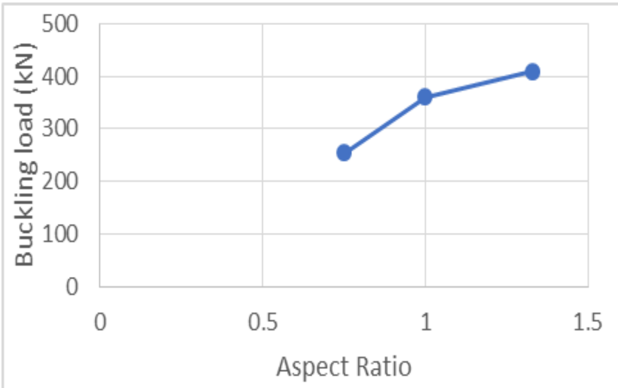
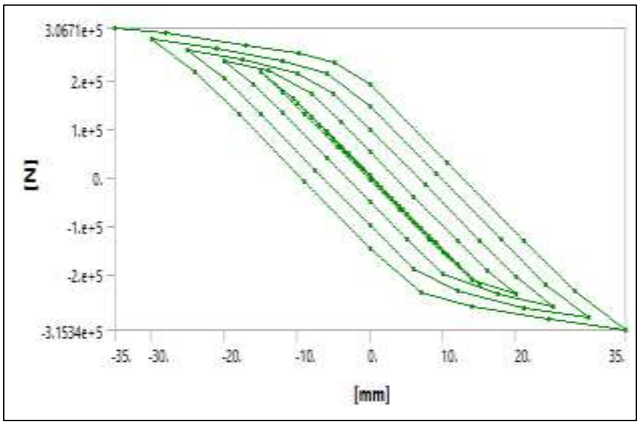


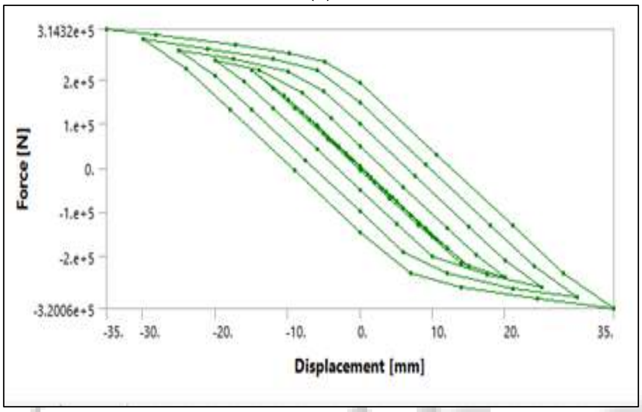
Chart 11: Buckling load Vs Aspect Ratio Curve

V. SPSW UNDER CYCLIC LOAD

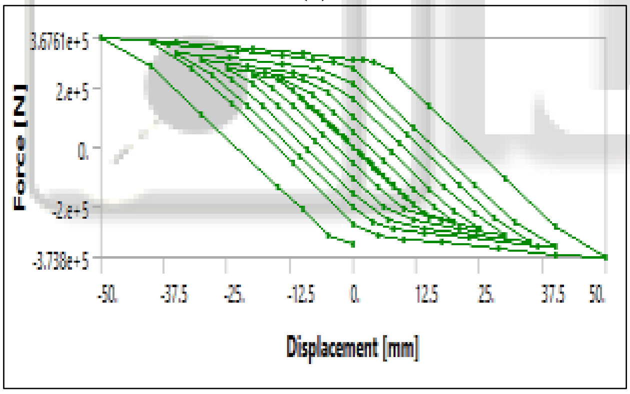
In order to study the behavior of SPSW under the cyclic loading, the hysteresis loops are considered. The hysteresis loops for various opening percentages are shown in fig 9.



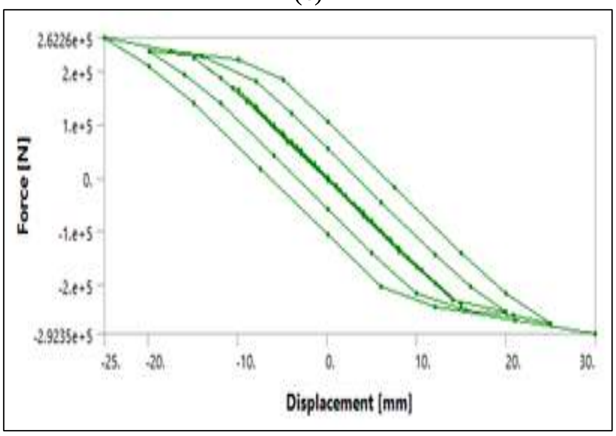
(a)



(b)



(c)



(d)

Fig. 9: Hysteresis loop for (a) 5%, (b) 10%, (c) 15% and (d) 25% opening

VI. CONCLUSION

In this study, numerous finite element models of SPSWs with varying thicknesses, aspect ratio and opening percentages are considered. From the results of the analyses, following conclusions can be drawn.

- The infill plate thickness is found to be an important parameter which affects the buckling load as well as ultimate load. The buckling load shows almost a linear variation with thickness. As the thickness increases, the ultimate load, stiffness as well as ductility increases. The rate of increase of ultimate load is small when the thickness changes from 2 mm to 3 mm.
- A large reduction of strength as well as stiffness can be observed in SPSWs with openings, but the variation is small for SPSWs with different percentage (5%, 10%, 15% and 25%) of openings.
- Similar trend of variation of ultimate load and stiffness are observed for SPSWs with different aspect ratio.
- Ductility is found maximum for SPSW with 1 as aspect ratio. A reduction of ductility is observed after aspect ratio 1. But the buckling load is found to increase with aspect ratio. The rate of increase is less after aspect ratio of 1.
- No significant reduction in column demand (reaction force) is observed due to the presents of openings. From the hysteresis curves, it is concluded that the ductility increases with opening percentage. But for 25% opening a reduction in ductility and strength is observed.

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