Behaviour of Steel Plate Shear Wall with Ring Cut-Outs

Lincy Elsa Varughese
M.Tech student, Department of Civil Engineering
AmalJyothi College of Engineering
Kerala, India

Jency Sara Kurien
Assistant Professor, Department of Civil Engineering
AmalJyothi College of Engineering

Abstract*: Steel plate shear walls (SPSWs) are one of the options for lateral load resisting systems for both new and retrofit construction. The factors which make SPSW attractive includes energy dissipation capacity, excellent ductility, constructability, speed of construction compared to concrete shear walls. It has increased inelastic deformation capacity as compared to braced frames. But there prevails buckling. Ring cut-outs are provided in order to reduce buckling. Also, it allows the use of simple shear beam-column connections and lends tenability to the shear wall system. It is more economic, since it required less steel and no moment connections between beams and columns. By considering some input parameters like configuration of cut-outs, thickness of steel plate used, outer radius of the rings, width of the rings, width of the connecting link, aspect ratio of plate, stiffness of column it will be easy to study the buckling and seismic behaviour of steel plate shear wall with ring cut-outs by considering various input parameters. The finite element analysis helps to study behaviour of steel plate shear wall with cut-outs. The load-deformation curve, the strength of the model that was subjected to a monotonic loading, the performance of the panel when the diameter of the rings is varied, investigation of the effect of the ring diameter, deformation and the stress distribution in the panel can be analysed using the finite element analysis method.

Keywords: Steel Plate Shear Wall; Ring Shape; Hysteretic Behaviour; Plate Buckling; Seismic Design

I. INTRODUCTION

A typical steel plate shear wall (SPSW) consists of a thin steel plate, referred to as the web plate, bounded at the sides by columns, also referred to as vertical boundary elements (VBE), and at the floor levels by beams, also referred to as horizontal boundary elements (HBE). This arrangement is shown in Figure 1. Web plates, adequately anchored by the boundary elements, buckle in shear and form a diagonal tension field to resist lateral loads.

The web plate resists horizontal story shear through tension field action of the web plate and dissipates seismic energy as the web plate yields along the inclined tension field direction. Although SPSW can develop significant post-buckling shear capacity, the web plate buckles at small shear force which may even occur during large wind loads. Buckling of the SPSW leads to significant loss of stiffness and a pinched hysteretic behaviour. To mitigate the negative effects associated with SPSW web plate buckling, a surrounding moment frame is required.

The purpose of this study is to develop a new type of SPSW that reduces buckling by utilizing a unique pattern of cut-outs. Additionally, this type of resilient buckling resistant steel shear wall would also exhibit fuller energy-absorbing hysteresis loops without requiring moment connections. Furthermore, as compared to a standard SPSW which has one primary variable being the plate thickness, this SPSW, with a pattern of cut-outs would allow the selection of more independent variables which can be varied to separately tune the strength, stiffness and ductility of the shear wall system. Thus, this specially designed SPSW would lend tunability to the system. It is therefore expected to be a more efficient and better performing alternative to the currently used SPSW.

II. OBJECTIVES

The objectives of this study are to:

- Understand the concept of behaviour of steel plate shear wall with ring shape cut-outs
- Simulate FEA to evaluate the behaviour of steel plate shear wall with ring shaped cut-outs with varying configurations.
- Study optimum design, ultimate load capacity under applied lateral load.

III. CONCEPT

The motivation for the use of rings as the basic unit of the shear wall is to improve the energy dissipation capacity and resistance during load reversals of the steel plate shear wall. The ring-shaped steel plate shear wall (RS-SPSW) includes a unique pattern of cut-outs leaving ring shapes that can mitigate plate buckling. When the wall is subjected to lateral forces, this basic ring unit deforms into an ellipse. The transverse and longitudinal deformations of a circular ring that is being stretched into an ellipse are nearly equal. This implies that for a SPSW made of rings, in the direction perpendicular to the tension field, the slack in the compression diagonal direction will be removed. The removal of slack in the compression diagonal will lead to an almost immediate development of tension field action in the opposite direction upon load reversal. In other words, the RS-SPSW reduces buckling due to the fact that the elongation of the ring in one radial direction will be compensated by the shortening of the ring in the perpendicular radial direction, thus reducing out-of-plane deformation.

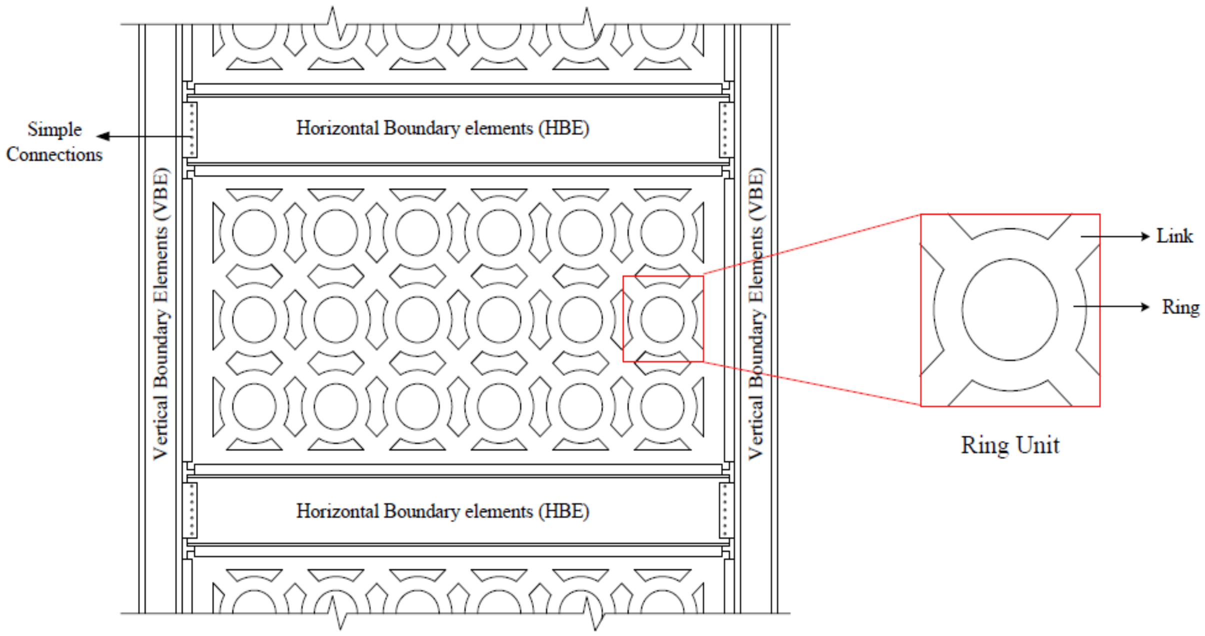


Fig 1: Steel plate shear wall with ring cut-outs and a basic ring unit

IV. FINITE ELEMENT ANALYSIS

The performance of the full panel incorporating ring units was analyzed using ANSYS Workbench (Version 14.5) as subjected to cyclic loading.

A. Modelling

Here different configurations of SPSW are used. The ring diameter, thickness of the steel plate, width of the link is varied. The dimensions of the different configurations are shown in Table 1. The different configurations used are shown in Figure 2.

B. Material property

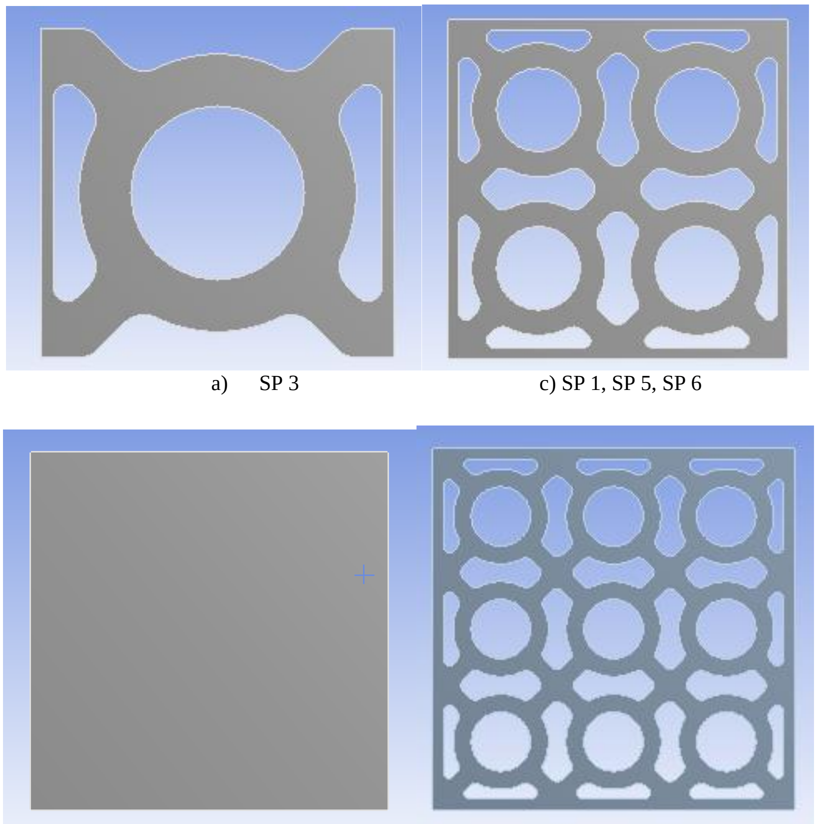
Finite element models using shell elements have been used to model SPSW. The web plate and boundary elements were taken as 4-noded shell 181. Poisons ratio was taken as 0.3. Young's modulus, yield strength and ultimate strength was taken as shown in table 3.

C. Meshing

Meshing is done after modelling and after assigning the material properties. Auto mesh is done here. An example of meshing done on SP 4 is shown in Figure.

TABLE 1:DIMENSIONS OF THE DIFFERENT CONFIGURATIONS USED FOR ANALYSIS OF RS-SPSW

Specimen name	**Basic dimensions**			
	t_w*(mm)*	R_0*(mm)*	w_c*(mm)*	w_l*(mm)*
SP 1	12.7	150	56	56.1
SP 2(solid)	1.9	-	-	-
SP 3	12.7	300	112	112
SP 4	12.7	100	37.3	37.3
SP 5	6.4	150	45.7	56.1
SP 6	6.4	150	56.1	56.1
SP 7	6.4	100	37.3	37.3
SP 8	9.5	100	37.3	37.3



a) SP 3 c) SP 1, SP 5, SP 6

b) SP 2 d)SP 4, SP 7, SP 8

Fig 2: Specimen geometry

TABLE 3: MATERIAL PROPERTIES

Plate thickness(mm)	**Modulus of elasticity(GPa)**	**Yield strength(MPa)**	**Ultimate strength (MPa)**
13	210	331	400
1.9	200	296	365
6.4	210	317	483
9.5	203	296	434

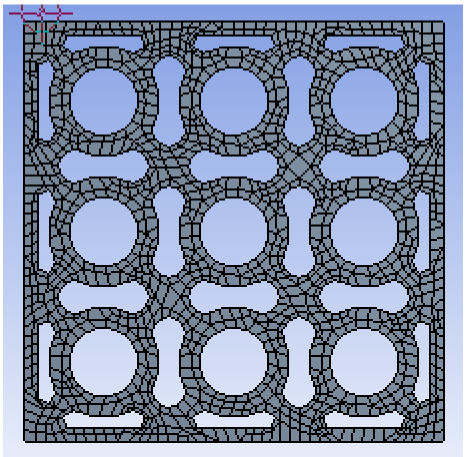


Fig 3: Meshing of SP 4

D. Loading and support condition

The supports are given as shown in figure 4 with:A end- fixed support B, C, D ends- hinged (displacement possible in y- direction only)

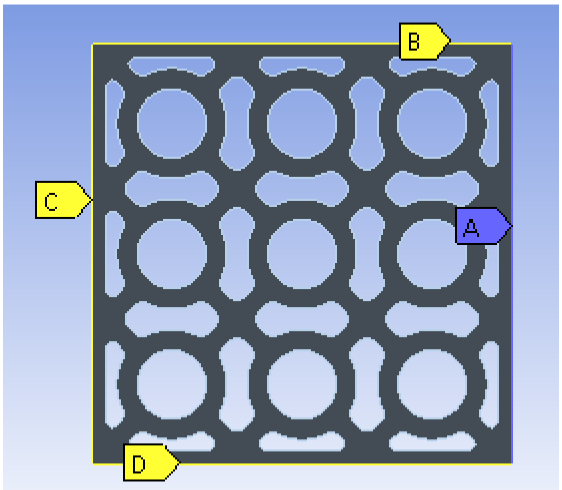


Fig. 4. Applied boundary conditions

The loading is applied as cyclic loading. A graph of the applied cyclic loading is shown in figure 5.

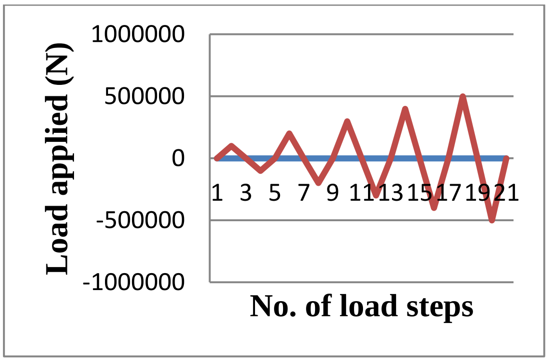


Fig 5: Load applied vs no. of load steps

The load is applied as cyclic load on the side of the SPSW as shown in figure6.

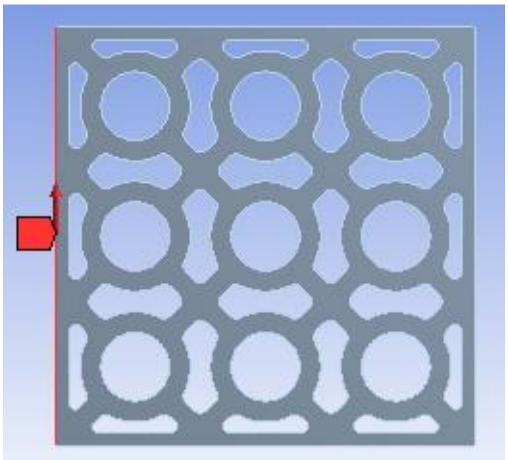


Fig 6: Load applied

E. Analysis

After applying loads and boundary conditions, the model is analysed in ANSYS Workbench (Version 14.5) and the required results are obtained.

V. RESULTS AND DISCUSSION:

The results of the eight shear panels were studied. The ultimate load carried and the deformation caused by each panel was found out and studied (Table4).

TABLE 4: ULTIMATE LOAD CARRIEDAND DEFORMATIONS OF DIFFERENT CONFIGURATIONS OF SPSW

Specimen Name	Ultimate load carried(kN)	Deformations (mm)
SP 1	262	0.685
SP 2	246	1.13
SP 3	156	1.886
SP 4	500	1.1 e-3
SP 5	125	2.629
SP 6	126	3.63
SP 7	100	1.97
SP 8	150	2.16

It is seen that the specimen SP 4 carries the highest load of about 500kN and the deformations caused is 1.1e-3 mm.The deformed shape of SP 4 is shown in figure 7.

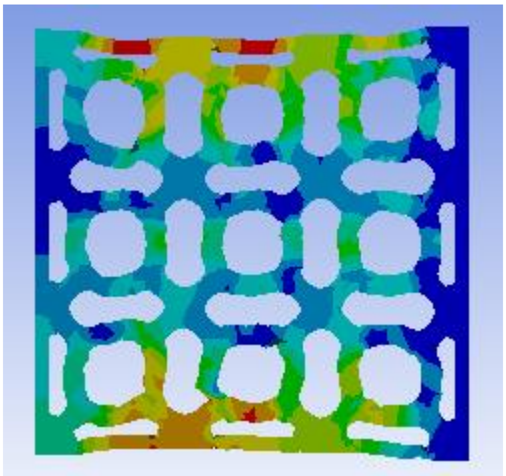


Fig 7: Deformed shape of SP 4

The observations that were made during the analysis were:

- Thickness of the web plate plays an important role in all the behavioural aspects of RS-SPSW. A thicker plate does not experience substantial strength and stiffness reduction. This results in relatively much larger energy dissipation. A thinner plate experiences buckling at earlier stage and therefore exhibits a much smaller energy dissipation ratio. Needless to say, thicker web plates also result in higher strength and stiffness.

- As expected, the behavior of RS-SPSW is highly sensitive to the size of the ring units. This is because the ring size is a major factor in determining the type of buckling the web-plate will experience. It was concluded that smaller radii rings resulted in global tension field buckling of the plate.

- The only major advantage of using a larger radius ring is the reduced cutting cost. It was observed that decreasing the ring radii exponentially increases the cutting cost of RS-SPSW. However, in all other aspects web-plates with smaller radii exhibit much better behaviour.

VI. CONCLUSIONS

Some general conclusions drawn from the study are presented below.

Conventional steel plate shearwalls (SPSW) have small stiffness and energy dissipation capacity as they act like tension-only bracing after shear buckling occurs at small shear force.A ring-shaped steel plate shear wall (RS-SPSW) is proposed thatlimits out of plane buckling by the mechanics of how the circular ring deforms into an ellipse. An analytical study was conducted on eight approximately 1 m x 1 m shear panels to validate the RS-SPSW and investigate the effect of the geometric parameters on cyclic shear behavior.

The concept of RS-SPSW was validated. The hypothesis regarding the ring deforming into an ellipse to reduce buckling works to a large extent. However, since this “ring effect” is an idealized concept, it was found to not to fully prevent buckling. The major reason why RS-SPSW does not fully prevent buckling is due to the inelastic deformation of the links joining the rings. This results in non-uniform distribution of stresses in a ring unit which hinders the perfect elongation of the ring.

REFERENCES

[1]. Egorova, N., Eatherton, M. R., and Maurya, A., (2014). ‘Experimental study of ring-shaped steel plate shear walls’, *J. Constructional Steel Research*, pp.179-189.

[2]. Choi, I. and Park, H.,(2011). ‘Cyclic loading test for reinforced concrete frame with thin steel infill plate’, *J. Structural Engineering*, pp.654-664.

[3]. Berman, J. W., and Bruneau, M., (2005). ‘Experimental investigation of light-gauge steel plate shear walls’, *J. Structural Engineering*, pp. 261-267.

[4]. Berman, J. W., and Bruneau, M., (2003). ‘Plastic Analysis and Design of Steel Plate Shear Walls’, *J. Structural Engineering*, pp. 1448-1456.

[5]. Driver, R. G., Kulak, G. L., Elwi, A. E., and Kennedy, D. J. L., (1998). ‘FE and simplified models of steel plate shear wall’, *J. Structural Engineering*, pp. 121-130.

[6]. Caccese, V., Elgaaly, M., and Chen, R., (1993). ‘Experimental study of thin steel-plate shear walls under cyclic load’, *J. Structural Engineering*, pp. 573-587.