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Study on Diagonally Stiffened Steel Plate Shear Wall with Cutout

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Abstract : *Steel plate shear walls have been identified as an effective option for lateral load resisting system in both retrofit and new constructions. A typical steel plate shear wall consists of a thin steel plate, bounded by columns and beams. In some situations presence of cutout is unavoidable due to architectural reasons or installed cooling and heating systems on the walls. Openings in the web plate leads to improper functioning and decrease in capacity of the systems and also results in an intense variation in stress distribution. A Securing steel plate shear wall system demand to seismic requirements can be achieved by attaching stiffeners to web plate. This paper presents a combination of steel plate shear wall with diagonal stiffeners having a central cutout. The seismic behavior of new system was investigated and compared to the un-stiffened steel plate shear wall with cutout. It can be observed that by the use of proposed stiffening method the deformation and stress of the steel plate shear wall with cutout was achieved close to the un-stiffened steel plate shear wall with cutout. In this paper, the effectiveness of stiffeners with cutout in steel plate shear wall has been studied by performing time history analysis. The effect of diagonally stiffened steel plate shear wall with cutout on displacement and von-mises stress distribution were analysed and discussed.*

Keywords - *Stiffened steel plate shear wall with cutout, Diagonal stiffener, Displacement, Time history analysis, Von-mises stress.*

I. Introduction

Steel plate shear wall (SPSW) is made from thin steel plates which are framed by the columns and beams of structural system. Figure 1 shows the typical steel plate shear wall. A Steel plate shear wall can be idealized as vertical cantilevered plate girder, in which steel plate represents the web, the columns behave as the flanges and the beams behave as the transverse stiffeners. Similar to plate girders, the steel plate shear wall performance are based on taking advantage of post buckling behavior of steel web plates.

The SPSW behaviour are due to development of shear buckling and subsequent formation of diagonal tension field within the web plate. When an increasing lateral load applied to the SPSW, equal tensile and compressive stress will be developed within the plate. The compressive stress can cause local buckling and as a result the web plate develops waves perpendicular to them. If we draw imaginary diagonals on the plate, the diagonal which gets loaded in compression buckles and cannot support an additional load. However, the diagonal in tension continues to take more loads. This behaviour analogous to tension only bracing.

It is obvious that the presence of cutouts on the web plate could disable distribution of tension field and leads the SPSW system to an unstable phase. Considering opening in load resisting part of the structures sometimes due to architectural reasons and/or other parameters are unavoidable. If cutouts are located on web plate, stiffeners can be attached to web plate for restore SPSW to its initial configuration.

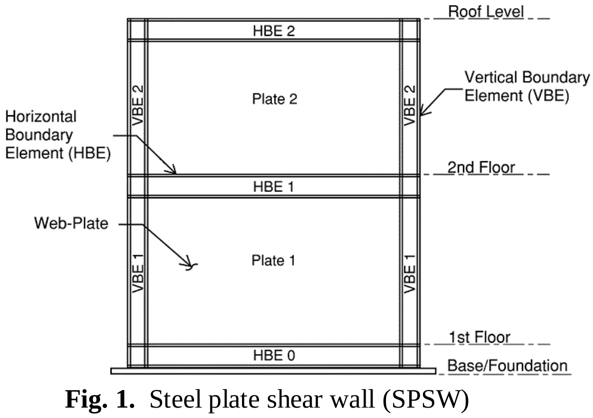


Fig. 1. Steel plate shear wall (SPSW)

II. Literature Review

Steel plate shear wall (SPSW) is rapidly gaining popularity as a very effective lateral load resisting system in highly seismic areas. Even though there was a great amount of experimental works done on this topic, still it requires a detailed study.

Alinia et al. (2009) studied the arrangements of transverse and longitudinal flat stiffeners located in shear plates. Stiffeners can protect shear walls against overall buckling, limit their out-of-plane deflections and increase their elastic buckling strength. Memarzadeh et al. (2010) conducted a study on El Centro earthquake dynamic explicit analysis of steel plate shear wall. Abhishek Verma et al. (2012) carried out a study on unstiffened steel plate shear walls. Steel plate shear wall with relatively larger aspect ratio exhibits the greater deformation capacity and load-carrying capacity. Increase in thickness of steel infill plate leads to increases in ultimate load carrying capacity. Valizadeh et al. (2012) conducted experimental investigation on cyclic behaviour of perforated steel plate shear walls. The creation of cutout decreases the strength and initial stiffness of the system. Farazmand et al. (2012) was found that X shape stiffener has more desirable effect on increase of yield load, ultimate load and capacity to absorb panel energy. Erfan Alavi et al. (2013) conducted experimental study on diagonally stiffened steel plate shear walls with perforation. Jian Guo Nie et al. (2013) conducted experiments on stiffened steel plate shear walls. The test results showed that stiffeners can be used to reinforce the openings. Masoud Ghaderi et al.(2014) conducted a study on stiffened steel plate shear walls. The results of non-linear static analysis demonstrated that the samples which had one horizontal and three vertical stiffer had the most increase of ultimate strength and stiffness.

III. Scope

Recently there is large increase in the number of tall buildings, thus the effect of lateral loads like earthquake forces are attaining increasing importance. SPSW have became more widespread during these days and are much efficient than reinforced concrete (RC) shear walls. Openings may need to be created within the steel web plate to accommodate for architectural purposes, structural reasons and/or passing utilities. Stiffeners can be used to modify the properties of steel plate shear wall, hence a study regarding the seismic response of steel plate shear wall with stiffeners are also necessary. In this paper, analysis of steel plate shear wall under non-linear time history analysis is studied.

IV. Objectives

To analyse and compare the single storey steel frame with diagonally stiffened and unstiffened steel plate shear wall with different size and shape of cutouts.

V. Finite Element Analysis

The steel plate shear wall was modelled using the software CATIA V5 and analysis was done by using the finite element analysis software ANSYS14.5.

5.1 Description of the model

Geometric and material properties for the present study were collected from the journal titled investigation of the behaviour of stiffened steel plate shear walls with finite element method by Masoud Ghaderi. Geometry of the specimen was shown in figure 2 and the material properties were shown in table 1.

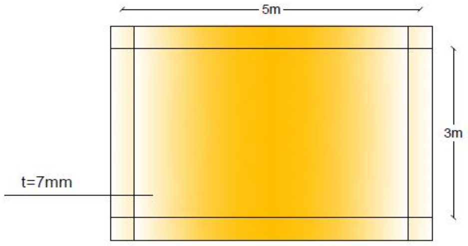
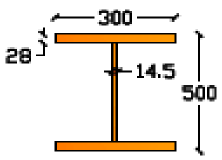
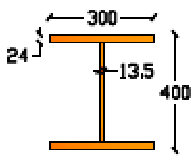


Fig. 2. Geometry of the specimen



Column Section



Beam Section

Table 1. Material properties

Steel material	Elastic modulus (MPa)	Yield Strength (MPa)	Poisson's ratio
Beam, Column, Stiffener, Web plate	2.1 x 10^5	240	0.3

5.2 Modelling of the frame using ANSYS14.5

For the present study diagonally stiffened and unstiffened steel plate shear wall with 1000 (i.e,1/3rd of the panel depth) and 1500 (i.e,1/2 of the panel depth) mm circular and square cutouts were considered. In the case of stiffened SPSW, stiffeners of X shape along with the stiffeners at the boundary of opening attached to the web plate were considered. The thickness and width of stiffeners were chosen as 8 and 80 mm respectively. The web plate and boundary elements of the frame were modelled using shell element of 4-node plastic 181. The boundary condition provided for the single storey frame was fixed at the bottom end. The loading provided as dynamically in order to produce a dynamic effect on the frame. El Centro earthquake ground-motion records in terms of acceleration time history were taken as input dynamic loading. The duration of time were taken from one to 30.84 seconds.

5.3 Non-linear dynamic Analysis/Time History Analysis

This type of analysis was conducted to observe the dynamic response of the structure due to the action of any time dependant loads. It incorporates the real earthquake ground motions , hence this analysis gives the true picture of the collapse mechanism and possible deformation in a structure. The acceleration time history data were collected from the website "www.vibrationdata.com" taken as the input for the dynamic loading.

VI. Result and discussions

During this study effectiveness of stiffeners in steel plate shear wall with cutout on seismic behaviour of single storey frame were investigated. By reviewing the journal, Asheena et al. (2015) made the following conclusions, "The unstiffened SPSW with circular cutout of diameter upto 828 mm are within in the safe drift limit and also unstiffened SPSW with square cutout of size upto 763 mm are within in the safe limit .The lateral load resisting capacity of SPSW are not existing when the cutout size in web plate are beyond 2/3 of the panel depth. When the opening size of web plate is more than 1/3 of the panel depth, stiffener can be provided suitably to limit the displacement ". Hence for the present study stiffeners are providing to web plate having opening size of 1/3 and 1/2 of the panel depth. In order to achieve the objective, stiffened and unstiffened SPSW with 1000 (i.e,1/3rd of the panel depth) and 1500 (i.e,1/2 of the panel depth) mm circular and square cutouts are taken into account for the study. The effect of diagonally stiffened steel plate shear wall (DSSPSW) on displacement and stress graph was analysed and discussed. The displacement graphs obtained from the time history analysis were shown in figure 3 and 4.

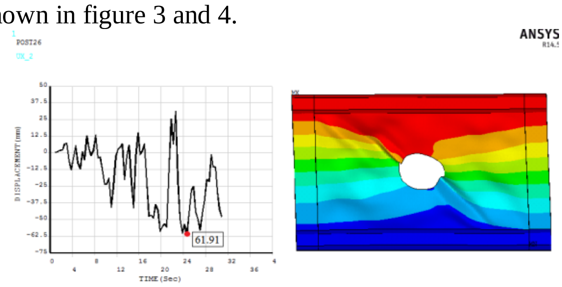


Fig. 3. Displacement graph of SPSW with 1000 mm dia circular cutout at MX

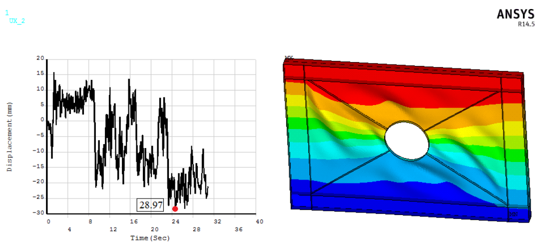


Fig. 4. Displacement graph of DSSPSW with 1000 mm dia circular cutout at MX

The comparison of displacement of unstiffened and diagonally stiffened steel plate shear wall with circular and square cutout of varying size were shown in table 2.

Displacement was reduced around 53 % by the use of stiffeners in SPSW with cutout. By reviewing the journal, Asheena et al. (2015) made the following conclusions, "As per FEMA 310, maximum drift limited to 51mm". From the finite element analysis, it is observed that displacements of diagonally stiffened steel plate shear wall with cutouts are below 51 mm. Hence Stiffener dimensions can be suitably refined to get the displacement nearer to 51 mm.

Table 2. Comparison of displacement of SPSW and DSSPSW with hole

Cutout size (mm)	Max. displacement (mm)		Percentage reduction (%)
	SPSW with hole	DSSPSW with hole	
1000-circular cutout	61.91	28.97	53.2
1500-circular cutout	73.49	34.51	53.04
1000-square cutout	65.06	29.9	54.02
1500-square cutout	76.71	35.10	54.24

The von-mises stress graph obtained from the time history analysis of stiffened and unstiffened SPSW with 1000 and 1500 mm circular and square cutouts are also taken into account for the study. The stress graphs obtained from the time history analysis were shown in figure 5 and 6.

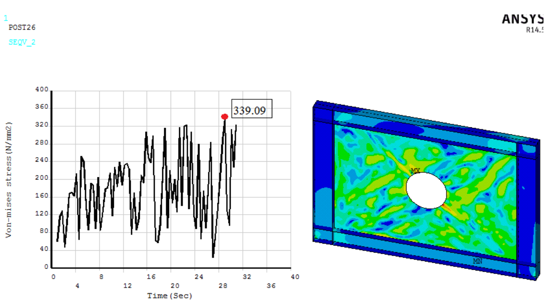


Fig. 3. Von-mises stress graph of SPSW with 1000 mm dia circular cutout at MX

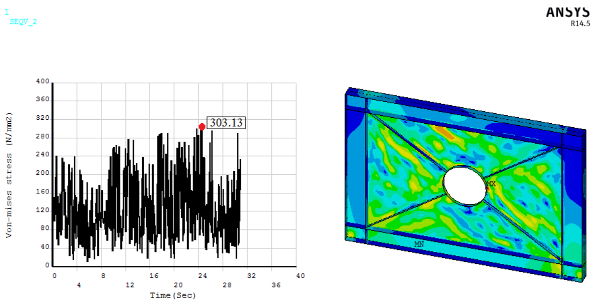


Fig. 4. Von-mises stress graph of DSSPSW with 1000 mm dia circular cutout at MX

The von-mises stress of unstiffened and diagonally stiffened steel plate shear wall with circular and square cutout of varying size were shown in table 3.

Table 3. Comparison of von-mises stress of SPSW and DSSPSW with hole

Cutout size (mm)	Von-mises stress (N/mm^2)		Percentage reduction (%)
	SPSW With hole	DSSPSW With hole	
1000-circular cutout	339.09	303.13	10.6
1500-circular cutout	357.33	313.88	12.15
1000-square cutout	349.54	308.44	11.76
1500-square cutout	381.86	315.11	17.48

Von-mises stress was reduced around 11 to 17% by the use of stiffeners in steel plate shear wall with cutout when compared with steel plate shear wall with cutout.

VII. Conclusions

A finite element model of the structure was subjected to the El Centro earthquake and was analysed using the non linear dynamic procedure. During this study the effectiveness of stiffeners with cutout in steel plate shear wall has been studied by performing time history analysis. This study was conducted by considering variety of openings. Stiffeners were provided in order to reduce the displacement.

This study leads to following conclusions:

- When the opening size is more than 1/3 of panel depth, stiffener can be provided suitably to reduce the displacement and von-mises stress.
- By considering the architectural aspects, the shape of the cutout can be retained by the use of stiffeners.
- The diagonal stiffening is an appropriate strengthening method for the steel plate shear walls with a central opening.

The present study was focused on examining the effects of varying the size of circular and square cutouts and effectiveness of the stiffeners in steel plate shear wall with cutouts, by time history analysis. The above work can be extended by considering different shape of cutouts, different aspect ratio of rectangular cutouts and varying the position of cutouts in the web plate of a steel plate shear wall. Also the work can be extended by conducting a study on optimization of thickness of steel web plate and dimensions of the stiffeners in steel plate shear wall with cutouts. The present study is purely based on finite element analysis using the software ANSYS14.5. Experiments are also required and can be done to validate the concept.

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