NON-LINEAR SEISMIC ANALYSIS OF STEEL PLATE SHEAR WALL SUBJECTED TO BLAST LOADING

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Abstract. Compared to traditional lateral loading systems, such as steel braced frames, RCC walls and moment- frames, Steel plate shear walls (SPSWs) have affordable detailing pre-requisites, requires lower construction tolerances, allows faster construction and leads to less lateral load. Similar to concrete shear walls, SPSW structures are more versatile and due to their versatility, the designer also needs to have additional flexural rigidity when using SPSW in tall buildings. In spite of all advantages, SPSW are not universally accepted because of typical SPSW arrangements result in huge column sizes and forbid the usage of slender walls while reducing the efficiency of the structure. SPSW allow for less structural wall thickness in comparison to the thickness of concrete shear walls. So, it is necessary to design the thickness of a SPSW required for particular load. This paper would address the above issues with concrete examples and suggest approaches for the creation of the next generation of shear walls made of steel plate. Such approaches would allow SPSWs to be applied efficiently by offering new configuration, different modelling techniques and a more detailed understanding of model behaviour by comparing different SPSW thickness and different patterns in a particular structure. The analysis in this study is done by considering a steel structure. Earthquake data is considered for analysis and it is assigned using time history function in SAP 2000. The paper deals with lateral resistance of a steel structure for a seismic loading with different SPSW thickness and patterns. which showed SS2 type steel plate shear wall configuration performing well in resisting bending moment in both directions.

Key words: Steel Structure, Steel Plate Shear Walls (SPSW), Earthquake Time History, Nonlinear Analysis, Storey Displacement, Storey Drift

1. Introduction
In areas with low to strong seismicity, several “steel buildings are built making the use of ductile lateral load resistance systems. Such structures are also the most complex, prolonged and costly of structural building elements” [2]. Significant economic benefits can be achieved through the use of “SPSW systems to provide the energy and ductility necessary for seismic resistance” [2] the steel structure is modelled and SPSW are provided with different thickness and different patterns. SPSWs provide the ability for equal, if not better, seismic efficiency at a potentially lower construction expense relative to conventional systems. SPSWs have a good strength and makes less lateral load-resistant system, they use moment-resistant beam-to-column links and would only fit for ordinary moment-resistant system and thus have less limitations. Investigation and computational tests have
demonstrated that the column specifications of an SPSW are both nuanced and exceedingly high for traditional systems. “Column flexural requirements arise from the creation of the tension field throughout the infill panel” [2].

2. Methodology
The analysis of the metal structure formulated in SAP 2000 takes into account the different thicknesses of SPSW. Performance is measured by lateral displacement and pressure of structural members. In addition, different SPSW models are used to reproduce the same structure analysis to investigate and compare its performance.

3. Modelling and Inputs
The study will examine typical industrial steel structures on G+4 levels. The three bays in the X direction are equidistant at 5 meters and the three bays in the Y direction are equidistant at 5 meters. The structural geometry and material specifications are shown in the figure 1. Structural steels are FE350 and ISMB 500 class and the cross sections or steel parts used are as per Indian standard.

![Figure 1 Dimensions and details of structure (left) 3D model of structure in SAP 2000 (right)](image)

For the above model steel plate shear walls of thickness 6, 8 and 10 mm are provided in different patterns SS1, SS2, SS3 and SS4 as shown in figure 2. And the comparisons of results are made between them to know the best and economical pattern for particular thickness of wall.

4. Loading conditions
Substantial number of useful works on the static and dynamic activity of SPSWs has been carried out. A great deal of work has been carried out not only to help evaluate the behaviour, reaction and efficiency of SPWs through cyclic and dynamic loading but also to improve advanced study and design techniques for the research community. Here, the structure is analysed with an earthquake time history acceleration data of “El Centro”. Along with that live loads and dead loads are calculated and applied as joint loads of 25 KN.
Figure 2 Steel plate shear wall patterns in Structure modelled in SAP 2000

Figure 3 Plan and elevation of Steel plate shear wall 1 (SS1) modelled in SAP 2000

Figure 4 Plan and elevation of Steel plate shear wall 2 (SS2) modelled in SAP 2000

Figure 5 Plan and elevation of Steel plate shear wall 3 (SS3) modelled in SAP 2000
5. Analysis
Structural analysis is also performed for dead, live loads, super-dead loads and for seismic loads. “All members of the structure are modelled using the ISMB500 section made of IS code steel” [1], with cutting plates 6 mm, 8 mm and 10 mm thick on both sides of the central opening. “The three-dimensional steel structures are modelled using 1D mesh elements for columns and beams and 2D shell elements for slabs. A dimensional mesh element with 6 degrees of freedom at both ends, or a 2D shell element with 6 degrees of freedom at each node” [1].

6. Results and Comparisons
Modelled metallic structure, analysis and results obtained from SAP 2000 are:

6.1 Base shear
In the table 1 we can see that base shear is gradually decreasing with increasing thickness of the steel plate. And also the base shear is decreasing from pattern type 1 to type 4. Energy is observed by steel plate shear wall provided over there for every pattern. Shear transferred by frame to frame is supported
by the steel plates in both the directions as the thickness increases. Shear is less where the centre bay is provided with shear wall.

### Table 1 - Max Base Shear in X and Y-Direction

| Pattern type | X Direction | Y Direction |
|--------------|-------------|-------------|
|              | 6mm | 8mm | 10mm | 6mm | 8mm | 10mm |
| 1            | 22036 | 18496 | 15647 | 19365 | 15236 | 11250 |
| 2            | 39563 | 36569 | 31253 | 34562 | 30215 | 26325 |
| 3            | 34698 | 29658 | 27569 | 27635 | 23651 | 21536 |
| 4            | 27689 | 24365 | 21986 | 25002 | 21563 | 17596 |

### 6.2 Max Displacements

From the table 2 we can see that the displacement is minimum in pattern of fully provided steel plate model and that will continue decreasing with increase in thickness of steel plate. Other than this type of structure, the structure containing type 4 pattern of steel plate shear wall results in less displacement when compared to other structures. As the bending moment and shear force decreases with the increase of thickness of shear wall displacements along X and Y directions are also decreased since thickened plate take more load than the other. Displacements are less when the building is provided with shear wall at centre bays i.e. when the shear wall provided is nearer to centre of gravity of building.

### Table 2 - Max Displacements in X and Y-Direction

| Pattern type | X Direction (mm) | Y Direction (mm) |
|--------------|-----------------|-----------------|
|              | 6   | 8   | 10 | 6   | 8   | 10 |
| 1            | 138 | 132 | 125 | 130 | 123 | 106 |
| 2            | 181 | 169 | 161 | 168 | 158 | 147 |
| 3            | 165 | 154 | 146 | 150 | 143 | 139 |
| 4            | 152 | 145 | 137 | 141 | 135 | 130 |

### 6.3 Max Column Forces

From the table 2, the value of ‘P’ is increasing with the increase in thickness of the shear wall. The value of moment ‘M2’ is very less when compared to moment ‘M3’ and it is increasing with the increase in thickness of shear plate. And also moment ‘M3’ is found to be increasing with thickness. As the thickness of steel plate shear wall increases self-weight also increases but the frame dimensions can be minimised since the shear wall provide more support in resisting loads and transferring forces from member to member.
Table 3- Max column forces for different patterns

| Pattern type | Forces | 6mm     | 8mm     | 10 mm   |
|--------------|--------|---------|---------|---------|
| P (kN)       | 3965.35| 4602.32 | 5445.125|
| M2 (kNm)     | 38.698 | 43.655  | 472.664 |
| M3 (kNm)     | 896.368| 986.322 | 1049.027|
| P (kN)       | 4036.36| 3799.23 | 3568.33 |
| M2 (kNm)     | 25.369 | 28.36   | 31.653  |
| M3 (kNm)     | 542.35 | 654.32  | 786.322 |
| P (kN)       | 4630.3 | 4325.35 | 4025.236|
| M2 (kNm)     | 41.32  | 37.56   | 35.256  |
| M3 (kNm)     | 1002.2 | 963.25  | 843.365 |
| P (kN)       | 4835.36| 4532.33 | 4436.256|
| M2 (kNm)     | 44.12  | 42.65   | 41.365  |
| M3 (kNm)     | 1032.2 | 968.365 | 945.32  |

Figure 8 Response spectrum curves for a model with 10mm thick shear wall

Figure 9 Variation of stresses in steel plate shear wall
7. Conclusions

From the above study it can be concluded that the steel plate shear wall thickness used in the structure played a vital role in reducing the displacement, base shear, column forces, etc. structure with 10mm steel plate shear wall is performed well, since it can observe more load. Among the different SPSW patterns, SS1 and SS4 has performed well compared to other two, but we can say, the number of steel plate provided may also helped to SS4 for better performance, in SS3, even though the number of plates used are less, change in position of plates has helped. SS2 Type steel plate shear wall is very good in lateral load resisting system as the steel plate is provided at the periphery which reduces seismic demands on beams and columns significantly. Displacement is least for the SS1 Type steel plate shear wall configuration due to the higher stiffness. Wider steel plate shear walls are more effective than a few short ones. SS2 Type steel plate shear wall configuration shows lesser bending moment values in both directions of the building. SS1 Type steel plate shear wall configuration is also found to be good in resisting the axial force induced in the building. It is better to provide a shear wall at the centre bay rather than providing at the corner. Where the centre of gravity is nearer to shear wall.

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