

Numerical Investigations on Steel Plate Shear Walls – Stiffened and Un-stiffened

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ABSTRACT: Steel plate shear walls have been one of the most prominently used lateral load resisting system. Research is done on the same for over a decade now. However, there has always been ambiguity in making a choice on kind of shear wall to be used. This work is a contribution to the above mentioned problem. In this work a comparative study has been done of two types of steel plate shear walls. i.e., stiffened and un-stiffened steel plate walls. This thesis consists of modeling of a 10 storey steel plate shear wall, both stiffened and un-stiffened using finite element software Ansys. Both stiffened and un-stiffened steel plate shear walls are subjected to lateral forces. These lateral forces are calculated by modeling a 10 story building with steel plate shear walls in Etabs and analyzing the same for combined effect of earthquake and wind. The most critical load combination is chosen and hence the storey drift and storey shear forces are noted from Etabs. Further these forces are applied in the finite element model of both stiffened and un-stiffened steel plate shear walls and non linear analysis is performed on these models. Three different plate thicknesses 8mm, 12mm and 16mm were used for un-stiffened spsw system and 3mm thick plate was used for comparison of un-stiffened, stiffened spsw with single strut and stiffened spsw with double strut.

KEYWORDS: steel plate shear wall, stiffened and un-stiffened, storey forces, drifts, stress plots

I. INTRODUCTION

Experimental and numerical studies conducted in the past three decades have demonstrated that a steel plate shear wall is an effective and economical lateral load resisting system against both wind and earthquake forces. The system consists of infill steel plates having length of one bay and height of one storey. The infill plates can either be placed at all story levels or some selected story levels. The infill plates are connected to boundary beams and columns of the framed bay. The infill plates can be stiffened or un-stiffened and the beam-to-column connections can be rigid or shear connections. A properly designed steel plate shear wall has superior ductility, high initial stiffness, stable hysteresis loops, inherent redundancy, and good energy absorption capacity. These characteristics make the system attractive in high-risk seismic regions. Steel plate shear walls are much lighter than the commonly used reinforced concrete shear walls, which reduce both the gravity loads and seismic forces. This aspect significantly reduces the foundation costs and makes the system attractive for application in rehabilitation as well as new projects.

The design philosophy of existing steel plate shear wall systems is to prevent shear buckling of infill plate by using either a thick plate or heavily stiffened thin plate. Most existing buildings with steel plate shear walls are stiffened to include considerable amount of out of plane buckling before it reaches its ultimate load carrying capacity. Although the stiffening of the infill plate in steel plate shear walls considerably increases the energy dissipation capacity the cost involved is very high therefore it is prohibited in most of the markets. However it has been demonstrated that buckling is not the limit up to which load is resisted in thin steel plates and the post-buckling strength also plays a considerable role. At the buckling

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point, the load resisting mechanism changes from in-plane shear to an inclined tension field which is developed along the elongated diagonal of the steel plate.

The objective of this thesis is to compare the different parameters of stiffened and un-stiffened steel plate shear walls. Three different plate thicknesses are used for un-stiffened spsw and two types of stiffened plates are compare I.e. single diagonal strut stiffened spsw and double diagonal stiffeners stiffened spsw.

The different parameters compared are the story drifts of each story when un-stiffened steel plate shear wall is used, Maximum storey displacements for different thicknesses of un-stiffened steel plate shear wall and also for stiffened and un-stiffened steel plate shear wall, Out of plane displacements for different thickness of un-stiffened steel plate shear wall and that for stiffened and un-stiffened steel plate shear wall, Stresses like Von Mises and shear stress for different thicknesses of un-stiffened steel plate shear wall. All the above comparison is done for a steel plate shear wall modeled for a 10 story building under same seismic conditions. Because of the expense involved in an experimental program to investigate these parameters, an analytical tool that can accurately predict the behavior of steel plate shear walls is needed. Therefore this thesis is carried out using appropriate analytical software. Finite element software Ansys v14 is used for the analysis of un-stiffened steel plate shear wall and Ansys v15 is used for stiffened steel plate shear wall. Prior to the execution of actual work, Plate buckling analysis is performed for a thin plate subjected to uniaxial compression and simply supported on all four sides. The results are compared with theoretical values to check the reliability of the software and the elements used.

Further a simple symmetrical rectangular building with 4 shear walls is modeled in Etabs. Story forces are extracted from the same and applied to the model of stiffened and un-stiffened steel plate shear walls modeled in Ansys. The story forces and story drifts are taken as output from Etabs and maximum story displacement, stress plots are taken from Ansys.

II. METHODS OF MODELING AND ANALYSIS

To obtain storey shear forces and base shear, building modeling software Etabs version 9.2 was used. A 10 story symmetrical building was modeled and analyzed in Etabs and further storey forces, storey drifts and base shear were extracted as results from this model. A simple square symmetrical 10 storey building with plan dimensions 15mx15m was modeled. A steel framed structure was chosen. All the sizes of beams and columns were fixed based on trial and error method. A typical I section was used, with the flange width of 400 mm and thickness of 250 mm and the web thickness and depth being 16mm and 500 mm respectively for the beam and 750 mm deep I section was used for columns with the flange width and depth being 500mm and 25mm respectively and the thickness of web section used was 16mm. For un-stiffened steel plate shear wall the plate thickness of 16mm was chosen based on the guidelines specified in IS 800-2000 for shear buckling of plate^[1]. The building was designed for dead load, live load and earthquake load. The building was assumed to be in zone IV and for soil type III (i.e. soft soil). The importance factor and response reduction factors were taken 1 and 3 respectively. The time period was manually calculated using the expression $0.085h^{0.75}$ ^[2]. These earthquake forces were applied in both the directions

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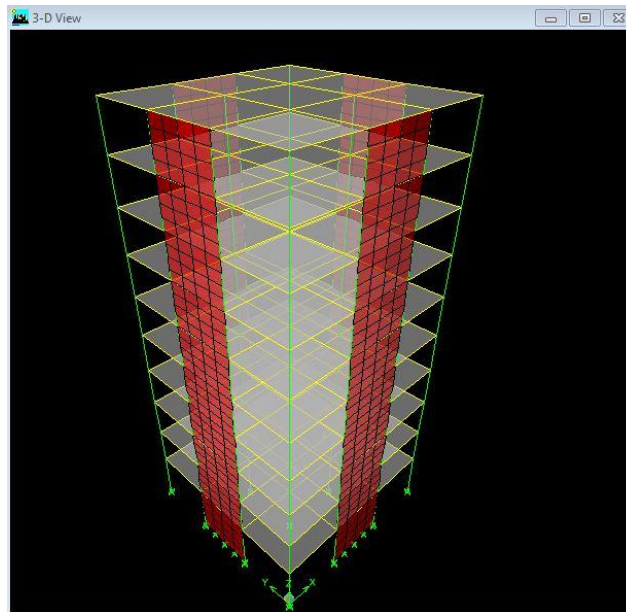


Fig 1: Three dimensional view of the building with shear wall modeled in Etabs

The model was analyzed and checked with the guidelines mentioned in IS 800:1998 for steel frame design. The results obtained from Etabs model were used as input in the Ansys model to carry out further numerical investigations. The 10 storey steel plate shear wall alone was modeled in ansys

Three different types of steel plate shear walls were modeled in Ansys.

1. Un-stiffened steel plate shear wall
2. Stiffened steel plate shear wall with single diagonal strut.
3. Stiffened steel plate shear wall with double diagonal strut.

The modeling of spsw in Ansys involved use of beam element and shell element. The material used was steel with properties as mentioned, the Young's modulus of $2 \times 10^5 \text{N/mm}^2$, Poisson's ratio of 0.3 and yield stress of 250N/mm^2 was used. . Beam188 was used for modeling of beams and columns and shell181 was used for modeling of plate

The plate thicknesses of 8mm, 12mm and 16mm were used for the un-stiffened steel plate shear wall models. The un-stiffened spsw was modeled and meshed using the above details. The storey shear forces that were obtained as a result of analysis of Etabs model was applied on each storey in the ansys model for further numerical investigations. The storey shear forces obtained from Etabs is shown in the table 1. Since, there are two shear walls in each direction only 50% of the storey shear obtained from Etabs was applied on the model in Ansys. Table 1 gives the details of storey forces obtained from Etabs and Fig 3 shows the image of ansys model with applied loads

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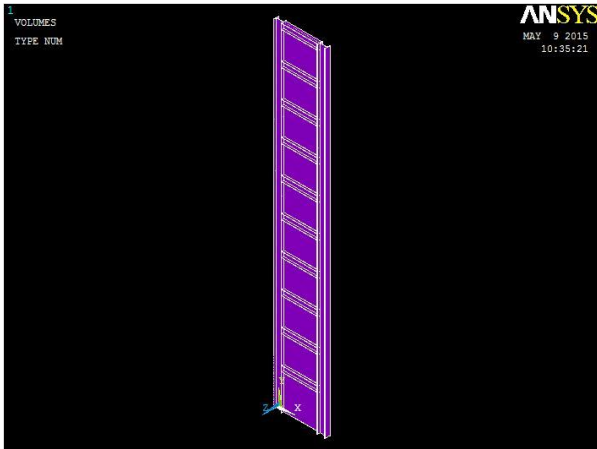


Fig 2: un-stiffened model of spsw in Ansys before meshing

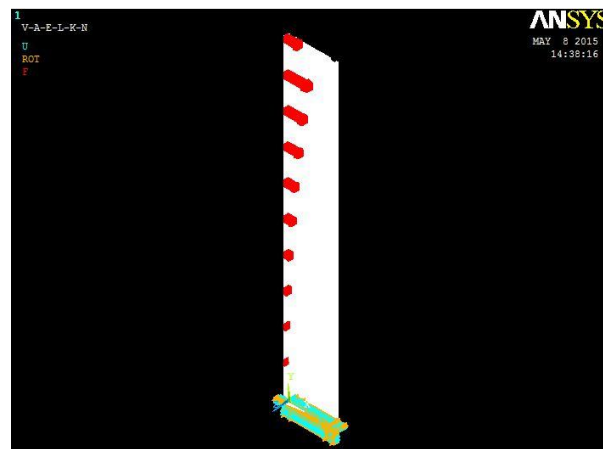


Fig 3: spsw model with applied loads and boundary conditions

story no.	story forces	ansys
STORY10	317.14	158.57
STORY9	548.49	274.245
STORY8	436.31	218.155
STORY7	336.94	168.47
STORY6	250.4	125.2
STORY5	176.69	88.345
STORY4	115.79	57.895
STORY3	67.71	33.855
STORY2	32.45	16.225
STORY1	10.11	5.055

Table 1: storey forces for each storey Obtained from Etabs and that applied in ansys

Further, the modeling of stiffened spsw involved use of link element from the ansys element library. Link180 was used to model the stiffeners. The real constant was defined for the same. For single diagonal strut stiffened spsw the modeling was done along one diagonal of the plate spanning from one corner to the other and for double diagonal strut stiffened spsw the link element was modeled along both the diagonals. Fig 4 and 5 are the images representing single and double diagonal strut stiffened spsw.

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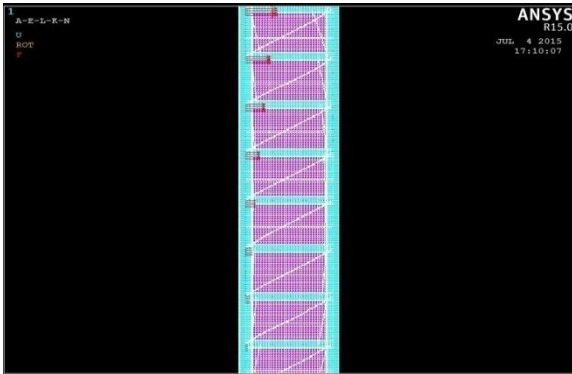


Fig 4: front view of single diagonal strut stiffened spsw with all the loads applied.

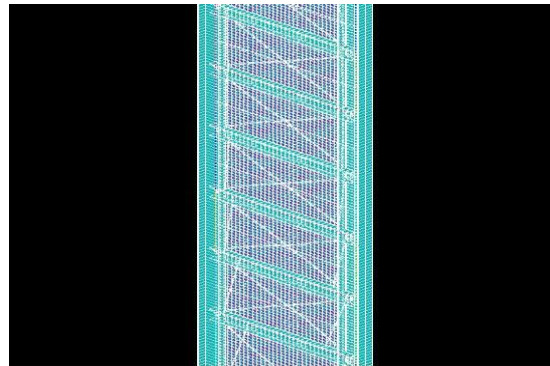


Fig 5: three dimensional view of double diagonal strut stiffened spsw

The stiffeners are used to increase the stiffness of the steel plate shear wall. The stiffener elements are used solely for the purpose of increasing stiffness, it has no contribution in transferring either lateral or vertical loads. Stiffeners have significant effect only when the plate buckling takes place i.e. it reduces out of plane displacements and prevents plate from buckling by taking the diagonal tension and compression and thus avoiding the rupture of plate. To clearly see this effect the plate thickness of 3mm is used for stiffened steel plate shear wall. All the above models were analyzed till the solution converged this was done by trial and error methods.

III. RESULTS

1. Storey drifts

The storey drifts for 16 mm spsw are tabulated in the table 2 and the graph 1and 2 represents the variation of storey drift with respect to storey number.

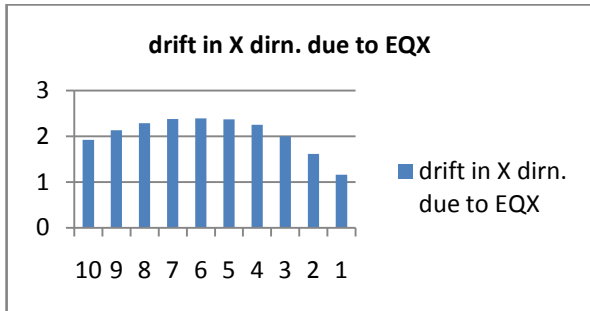
story no.	drift in X dirn. due to EQX	drift in Y dirn. Due to EQY
10	1.9264	2.432
9	2.1344	2.6176
8	2.2848	2.7776
7	2.3776	2.8608
6	2.3936	2.8672
5	2.3712	2.8224
4	2.2496	2.656
3	2	2.3424
2	1.6128	1.8592
1	1.164	1.372

Table 2: storey drifts obtained from Etabs due to EQX and EQY in X and Y direction with respect to the storey number

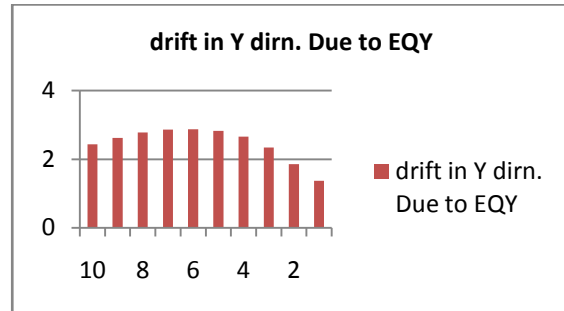
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Graph 1: storey no. v/s storey drift in x direction due to EQX



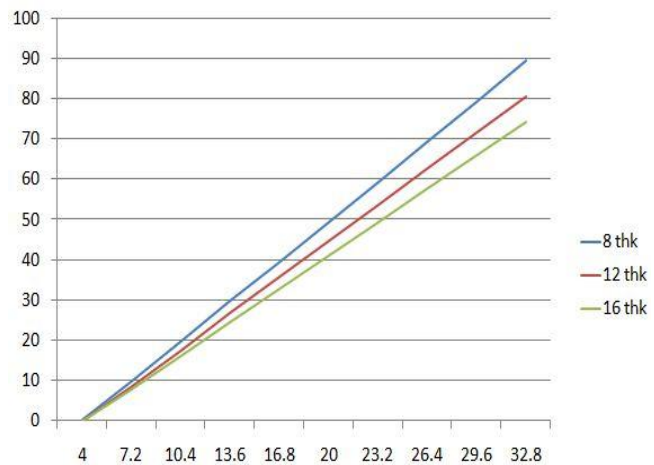
Graph 2: storey no. v/s storey drift in y direction due to EQY

2. Maximum storey displacement

The maximum storey displacements for three plate thicknesses are as shown below in table 3 and graph 3

storey no.	Max Storey displacement		
thickness	8thk	12thk	16thk
1	0.169	0.117	0.105
2	9.752	8.866	8.165
3	19.671	17.843	16.434
4	29.59	26.821	24.704
5	39.51	35.798	32.973
6	49.429	44.775	41.243
7	59.3477	53.753	49.512
8	69.267	62.73	57.782
9	79.1863	71.707	66.051
10	89.493	80.685	74.321

Table 3: maximum storey displacements in mm for three plate thicknesses with respect to storey number obtained from Ansys



Graph 3: variation of maximum storey displacement with storey height

3. out of plane displacements

The out of plane displacement reduces with the increase in plate thickness. For 8 mm plate the maximum out of plane displacement is 0.23 mm. Also, there is a critical stress region in steel plate of 9th storey which initiates slight buckling in the plate. Further, for 12 mm and 16 mm the displacements are 0.075 and 0.069 mm respectively. However, no critical region was found in the stress plots.

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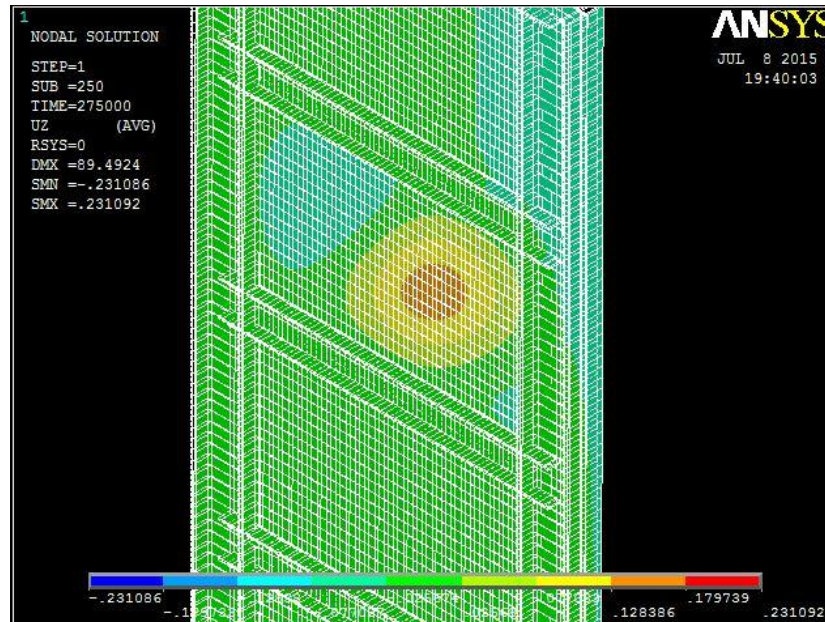


Fig 6: critical stress region for out of plane displacement in 8 mm thick plate

4. Shear stress

It is observed that the shear stress is solely taken by plate and the beams and columns take very negligible amount of it. Shear stress is most critical in the bottom most storey and goes on decreasing for the higher stories. The maximum shear strength of the plate is given by $\sigma_y/\sqrt{3}$. Therefore, the maximum shear strength of the plate is 144.34 N/mm^2 . The maximum shear stress in the 8 mm thick plate is 36.34 N/mm^2 , for 12 mm plate it is 25.9 N/mm^2 and that for 16 mm plate is 20.25 N/mm^2 . Therefore, the plate thickness chosen are safe against the shear criteria. Fig 7 shows the shear stress plot for 8 mm thick plate, such similar but less critical plots were obtained for higher thickness of plates.

5. Von Mises stress

The beams being axially rigid take no amount of stress, column is the most stressed and plate takes little amount of stress. Critical region is at the base of the column due to the fixity at bottom. The maximum value of Von Mises stress is 171.39 N/mm^2 for the 8 mm thick plate and the values of 12 and 16 mm thick plate being 156.21 N/mm^2 and 144.62 N/mm^2 respectively. Since all of these values are less than yield strength of the material i.e. 250 N/mm^2 . The members are safe from yielding. Fig 8 represents the Von Mises stress plot for 8 mm thick plate and such similar and less critical plots were obtained for higher thickness of the plates.

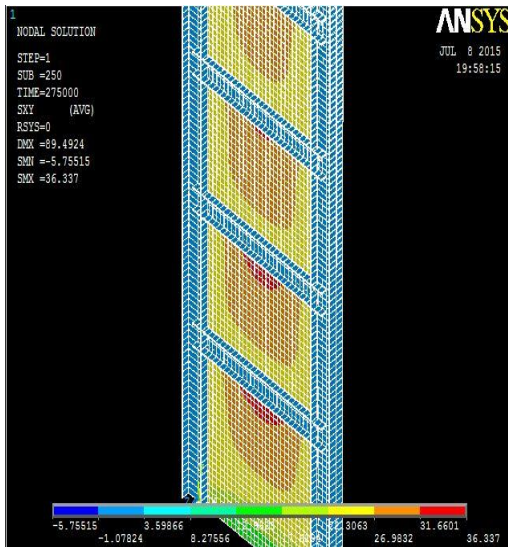


Fig 7: shear stress plot for 8 mm thick plate

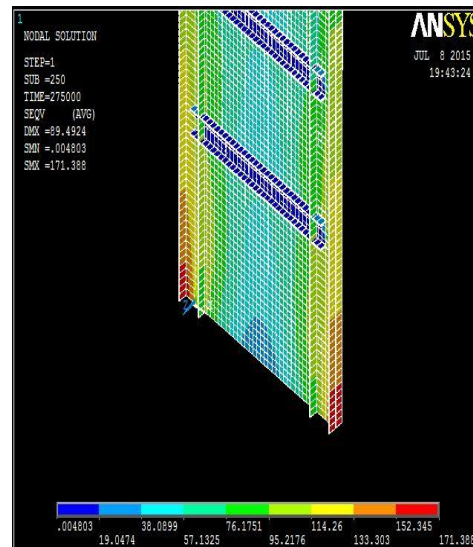


Fig 8: Von Mises stress plot for 8 mm thick plate

6. Results for stiffened spsw

Since the out of plane displacements are the ones that vary significantly when stiffeners are provided, in this paper that is the only parameter being considered for comparison of stiffened spsw.

The in-plane maximum lateral displacement of un-stiffened steel plate shear wall is 102.5mm and that for single diagonal strut stiffened and double diagonal strut stiffened is 102.8mm and 101.5 mm respectively. Therefore, it can be seen that the diagonal struts whether single or double does not have any effect on the maximum lateral displacement of the steel plate shear wall.

The out of plane deflection for un-stiffened steel plate shear wall ranges from -7.87mm to 7.89mm, for single diagonal strut stiffened steel plate shear wall it ranges from -6.29mm to 2.7mm and that for double diagonal strut stiffened steel plate shear wall it ranges from -0.098mm to 0.098mm. Therefore, it is observed that in case of single diagonal strut stiffened steel plate shear wall, the out of plane deflections are arrested in only one direction. In the other direction it almost remains same as that of un-stiffened case. Whereas in case of double diagonal strut stiffened steel plate shear wall the out of plane deflections are completely arrested. Hence, it can be concluded that there is no possibility of buckling in case of double diagonal stiffened steel plate shear wall.

IV. CONCLUSIONS

1. In this study it is found that storey drift is minimum for the first floor and it goes on increasing until sixth floor, where it is found to be maximum and it again starts decreasing from there on until the last floor. This can be seen in graph 1 and 2. Therefore, here it can be concluded that in a 10 storey building subjected to lateral loads the storey drift is maximum at sixth floor.
2. The maximum storey displacement varies linearly with the increase in height of the building i.e. it is found to be minimum for the first storey and further goes on increasing with the increase in storey number or height of the building. This can be compared to a vertical cantilever which has zero deflection at fixed end and maximum deflection at free end.
3. The maximum storey displacement decreases with the increase in thickness of the steel plate.

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4. It has to be noted that there was a slightly stressed region in the ninth storey for 8 mm plate thickness having deflection of 0.23mm as shown in fig 6. Further, the out of plane deflections also goes on decreasing with the increase in plate thickness.
5. It is observed that the percentage decrease in out of plane deflection when plate thickness increases from 8mm to 12mm is 67.9% where as that for increase of plate thickness from 12mm to 16mm is only 6.75%. Therefore, from these observations it can be drawn that 12mm plate is effective as compared to 8mm or 16mm plate.
6. From the shear stress plots it is observed that the shear stress is majorly taken by the steel plate alone. Columns and beams have zero contribution in taking any shear stress.
7. From the above observations it can be stated that the shear wall system behaves analogous to the plate girder. The columns in shear wall system behaves like flanges in plate girder, plate in shear wall system behaves like web in plate girder and the beams behave like transverse stiffeners placed certain distance apart.
8. Diagonal stiffeners are used to reduce the out of plane deflections. For plate thicknesses 8mm, 12mm and 16mm the out of plane deflections are not very large it is not advisable to use stiffeners. Therefore, for a comparative study the plate thickness for stiffened case is reduced to 3mm.
9. From the observations for out of plane deflection in stiffened spsw, it can be concluded that in case of earthquake where the direction of lateral force is uncertain it is not suggested to use single strut diagonal stiffeners. Even though the double diagonal strut stiffeners are considered efficient in all cases the cost involved can be the issue depending upon the importance of structure.
10. From this study, overall it can be concluded that for a building of upto ten storeys plate thickness above 8 mm can be used. If the plate thickness is to be reduced then double diagonal stiffeners of appropriate dimension should be used.

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