STRUCTURAL PERFORMANCE OF STRENGTHENED CORRUGATED STEEL PLATE SHEAR WALL WITH IRREGULARITY CONDITION

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Abstract - *In past year's , the corrugated steel plate shear wall (CSPSW) has been widely used as an alternative to simple steel plate shear wall (SPSW). Corrugated steel plate shear wall has various advantages such as higher energy dissipation capacity, ductility, out of plane stiffness and improved buckling stability. This paper presents the analytical investigation on the performance of corrugated steel plate shear wall, with and without opening, in alternative walls. The regular building and irregular building case aligned interiorly and exteriorly 15° were also conducted. Openings like door, window, combination of door and window were used to conduct the study. The finite element models were developed using ANSYS WORKBECH 16.1. Seismic performance on the corrugated shear wall in regular and irregular building were discussed. The study has also demonstrated the importance of providing boundary element around various openings.*

Key Words: corrugated steel plate shear wall, steel plat shear wall, finite element modelling, openings, energy absorption, boundary element.

1. INTRODUCTION

Steel plate shear wall system consist of steel plate wall, boundary columns and horizontal floor beams. Shear walls are the vertical elements of horizontal force resisting system, which were constructed to counter the effects of lateral load acting on the structure. Shear wall are mainly used to resist the shear force and the uplift force and to reduce the lateral sway. The openings and perforations can be provided in shear wall for the force transfer.

Shear walls are ductile and has large energy dissipation capability when designed and detailed properly. Due to relatively small thickness, steel plate shear walls occupy much less space in high rise building. SPSW are much easier and faster to construct. The design of foundation requires special attention and shear wall should be provided along both length and width. Door and window openings can be provided in shear wall, but their size must be small to ensure least interruption to force flow through walls. Shear walls are more effective when located along the exterior perimeter to increase the resistance of the building.

In recent studies on CSPSW with perforations of different shapes shows that, diamond shape has more energy absorption and gives more stiffness [10]. CSPSW with reduced boundary beam section as a promising type of lateral-load-resisting system [1]. The study also shows that the total energy dissipation capacity of the corrugated specimens is 1.52 times higher than the unstiffened specimen. Increasing the web plate corrugation angle from 30° to 90° is effective in improving the cyclic performance and energy dissipation capability of the system [4].

In this study, the corrugated steel plate shear wall of 4.5m x 3.1m length and height is considered for the analysis [1]. The finite element model of the shear wall were developed using ANSYS WORKBENCH 16.1. The strength variation under various opening conditions and irregular building cases were discussed. The purpose of this study is to understand the strength improvement of the shear wall with various opening under the irregular condition of the building. The study also include strength comparison of CSPSW without opening and with opening and the strength is improved by using the necessary boundary elements.

2. FINITE ELEMENT MODEL

2.1 General

CSPSWs are modeled and analyzed using the finite element program ANSYS WORKBENCH 16.1 to investigate the strength improvement of shear wall in irregular building case with door opening, window opening, combination of door and window opening. The system includes infill plates (stiffened or unstiffened) bounded by a steel frame with vertical and horizontal structural elements fig1. RBS-CSPSW is validated with the data available in this paper.

2.2 Geometry

RBS-CSPSW with rectangular shape is adopted for Finite Element Analysis in this paper. The dimension of the corrugated infill plate 4.5m x 3.1m length and height. The geometric modelling was carried out according to earlier specified dimensions. The trapezoidal corrugation with details provided in table 1 is used in the infill plates. Fig 2 shows the axes 1 and 2 indicating the perpendicular and parallel to the corrugation direction, where *b* is the horizontal projection of the inclined panel width and *c* is the inclined panel width [1].

Fig -1: Geometry of CSPSW panel frame

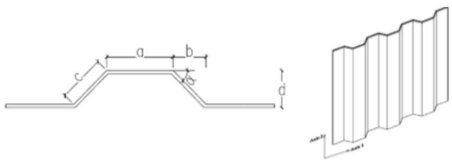


Fig -2: : Geometry of the corrugated plate

Table -1: Corrugated Panel Geometry (see fig-2)

t (mm)	*a* (mm)	*d* (mm)	*α* (deg.)
1.5	100	50	30

The specimen was subjected to lateral loading. The flange width of beam is 398mm and depth is 394mm. The web thickness is 11mm and flange thickness is 18mm for beam. The flange width of column is 432mm and depth is 498mm. the web thickness is 45mm and flange thickness is 70mm for column. The details of the beam and column are given in table 2. The material model behavior given for panel are elastic modulus of 2.09x10^5 Mpa, yield stress and ultimate stress of 341Mpa. The material model behavior given for beam and column are elastic modulus of 2.09x10^5 Mpa, yield stress of 390 Mpa and ultimate stress of 480 Mpa. The material model behavior are given in table3. The important factor which influence the capacity and energy dissipation of the shear wall is the RBS of the beam flange table4. The corrugated shear walls are provided in the alternate walls of the building in all cases. The analysis is carried out for CSPSW with and without opening at wall inclination 0°, wall inclination interiorly 15°, wall inclination exteriorly 15° fig 3. The openings considered here are window, door, combination of door and window. The strength of shear wall with openings are improved by appropriate boundary elements. The strength of shear walls are compared under 4 different categories such as without opening and with wall opening, with wall opening and boundary elements provided around opening, without opening and with boundary elements provided around opening, wall inclination at 0°, interiorly 15°, exteriorly 15°. The CSPSW without opening at various wall inclination is shown in fig3. The CSPSW with different wall opening at 0° is shown in fig 4. Similarly wall inclination 15° inside and 15° outside is analyzed for all opening.

Table -2: Boundary Element cross-section dimensions (all dimensions in mm)

Beam	Flange width	398
	Depth	394
	Web thickness	11
	Flange thickness	18
Column	Flange width	432
	Depth	498
	Web thickness	45
	Flange thickness	70

Table -3: Material Model Behaviour

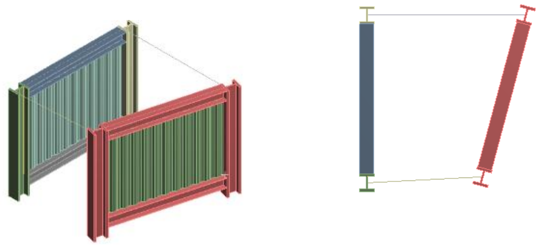
Type	Elastic modulus (Mpa)	Yield stress F_y (Mpa)	Ultimate stress F_u (Mpa)	F_u/F_y
Beam	209000	341	341	1
column	209000	390	480	1.23

Table -4: RBS dimension (all dimensions in mm)

Cut dimensions of the beam flanges (RBS)	Location of cut	199
	Length of cut	256.1
	Depth of cut	99.5
	Radius of cut	132

0°

15° outside 15° outside top view



15° inside 15° inside top view

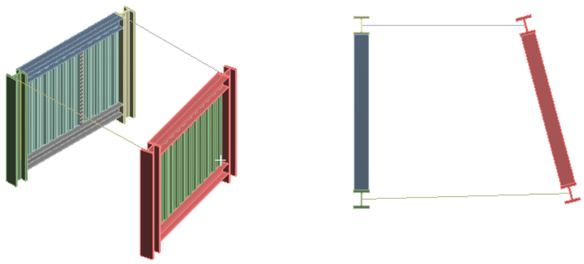
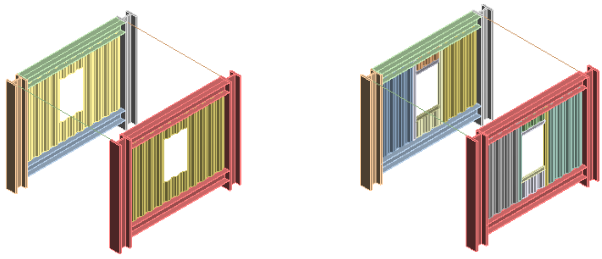
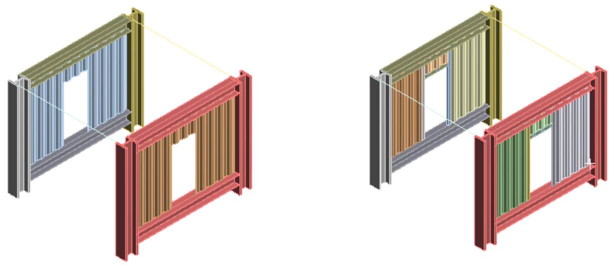


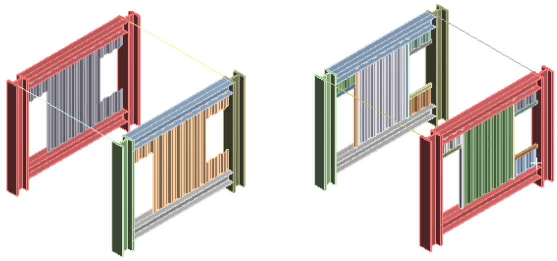
Fig -3: CSPSW without opening at various wall inclination



Window Window with boundary element



Door Door with boundary element



Door window Door window with boundary Element

Fig -4: CSPSW with different wall opening at 0°

2.3 Meshing

Meshing is the most important part of analysis and essential to achieve accuracy in results. Meshing divides the entire component into finite number of meshes as small as possible. The entire component is converted into a finite element model after meshing. In this analysis, meshing is done to achieve maximum accuracy in results.

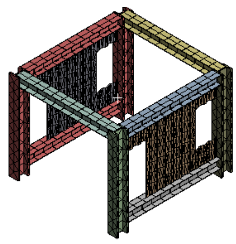


Fig -5: Meshed view

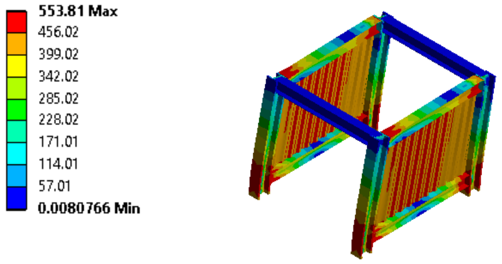
2.4 Loading and Boundary Condition

To simulate the real condition, the columns were modeled with fixed end condition. The load was applied only in one direction and rotation was allowed in X and Z axis. The behavior of shear wall under lateral loading was studied by ANSYS.

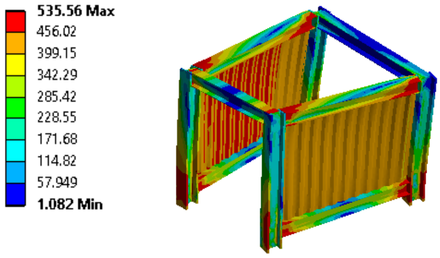
3. ANALYTICAL RESULT AND DISCUSSIONS

3.1 Lateral Loading

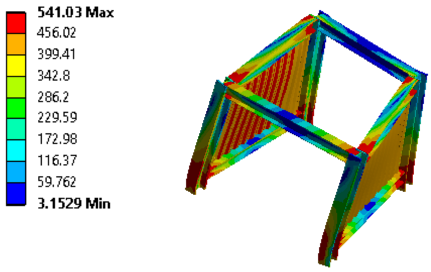
Lateral load was applied at the top of column only in one direction, incremented from zero upto failure. Lateral loading is one of the most important factor at zones of high seismic risk



0°

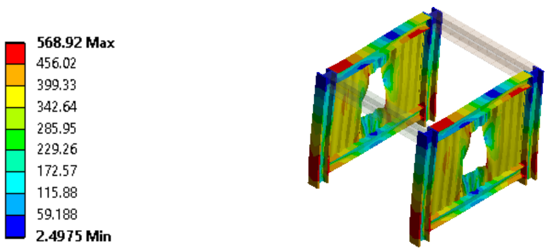


15° outside

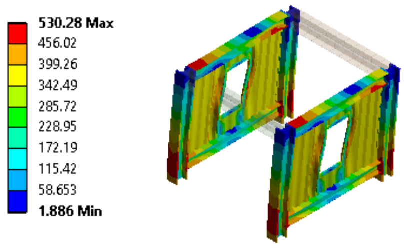


15° inside

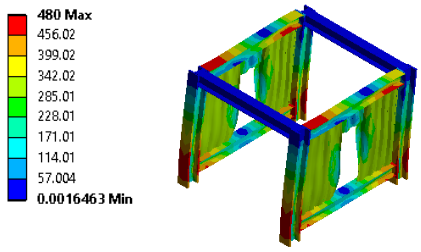
Fig -6: von-mises stress diagram of CSPSW without opening at various wall inclination



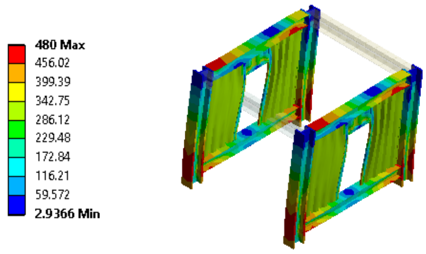
Window



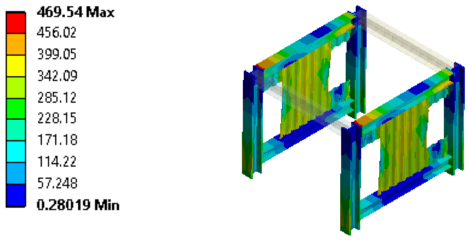
Window with boundary element



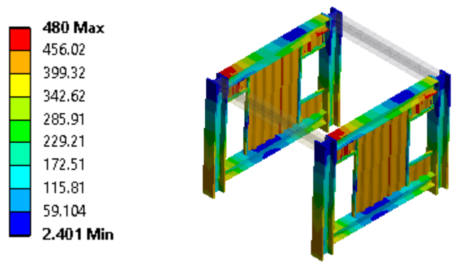
Door



Door with boundary element



Door window



Door window with boundary element

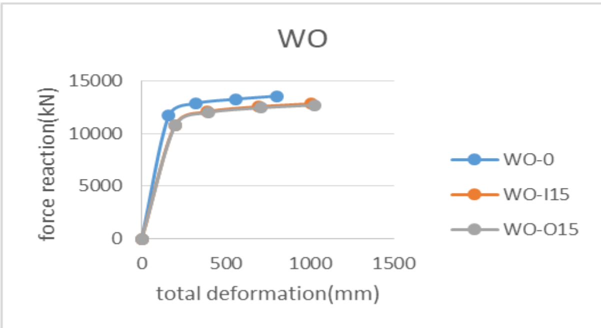
Fig -7: von-mises stress diagram of CSPSW with different wall opening at 0°

The von-mises stress diagram of CSPSW without opening at various wall inclination is shown in fig6. The von-mises stress diagram of CSPSW with different wall opening at 0° is shown in fig 7. Similarly the analysis is done for the wall inclination at inside 15° and outside 15°. On comparing the strength variation, without opening(WO) and opening without boundary element(BE), the shear wall with window opening(without BE) when inclined outside 15°(W-O15°) shows 1.76% strength improvement than shear wall without opening. Except the shear wall with window opening (without BE), all other conditions have less strength than shear wall without opening. The shear wall without opening shows 7.48% strength more than the door(D) at 0° wall inclination(D-0°), 4.19% more strength than D at 15° outside(D-O15°), 6.22% more strength than D at 15° inside(D-IN15°). The shear wall without opening shows 3.48% strength more than the window(W) at 0° wall inclination(D-0°), 0.38% more strength than W at 15° inside(W-IN15°). The shear wall without opening(WO) shows 7.54% strength more than the combination of door(D) and window(W) at 0° wall inclination(DW-0°), 3.77% more strength than DW at 15° outside(DW-O15°), 6.01% more strength than DW at 15° inside(DW-IN15°).

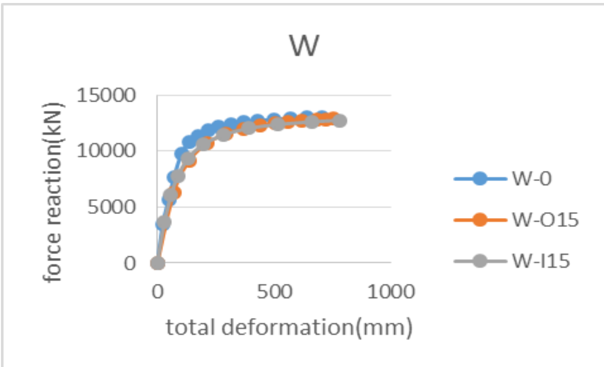
On comparing the strength variation, without opening(WO) and opening with boundary element(BE), the shear wall with door opening(D-BE) shows less strength variation than shear wall WO at all wall inclinations. WO has 4.86% more strength than D-0°-BE. WO has 1.72% more strength than D-O15°-BE. WO has 3.65% more strength than D-IN15°-BE. The shear wall with window opening(W-BE) shows more strength variation than shear wall WO at all wall inclinations. WO has 0.18% more strength than W-0°-BE. WO has 5.55% more strength than W-O15°-BE. WO has 3.21% more strength than W-IN15°-BE. The shear wall with combination of door and window opening(DW-BE) shows more strength variation than shear wall WO at all wall inclinations. WO has 2.81% more strength than DW-0°-BE. WO has 5.39% more strength than DW-O15°-BE. WO has 3.25% more strength than DW-IN15°-BE.

On comparing the strength variation, with opening and opening with boundary element(BE), the shear wall with boundary element provided around opening shows more strength variation than shear wall without boundary element around opening at all wall inclinations. D-0°-BE has 2.83% more strength than D-0°. D-O15°-BE has 2.58% more strength than D-O15°. D-IN15°-BE has 2.74% more strength than D-O15°.W-0°-BE has 3.79% more strength than W-0°. W-O15°-BE has 3.72% more strength than W-O15°. W-IN15°-BE has 3.6% more strength than W-O15°. DW-0°-BE has 11.2% more strength than DW-0°. DW-O15°-BE has 9.52% more strength than DW-O15°. DW-IN15°-BE as 9.85% more strength than DW-O15°.

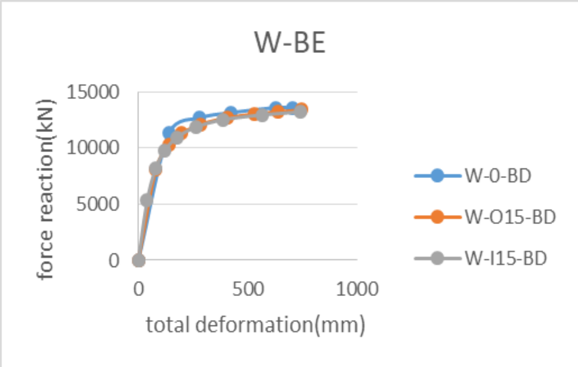
On comparing the strength variation for different wall inclinations without opening, with window opening, with door opening, with door and window opening, the shear wall inclined 15° inside without opening shows 0.95% more strength than shear wall inclined at 15° outside without opening. On comparing the strength performance of shear wall at 15° inclination inside and outside, Except the above condition, all other cases shows better strength performance when the shear wall inclined 15° outside. The SW WO shows 6.74% more strength at 0° inclination than O-15°. The SW WO shows 5.73% more strength at 0° inclination than IN-15°. The SW with D-0° shows 3.07% more strength than D-O15°. The SW with D-0° shows 4.3% more strength than D-IN15°. The SW with D-O15° shows 1.19% more strength than D-IN15°. The SW with D-0°-BE shows 3.33% more strength than D-O15°-BE. The SW with D-0°-BE shows 4.4% more strength than D-IN15°-BE. The SW with D-O15°-BE shows 1.04% more strength than D-IN15°-BE. The SW with W-0° shows 1.25% more strength than W-O15°. The SW with W-0° shows 2.44% more strength than W-IN15°. The SW with W-O15° shows 1.18% more strength than W-IN15°. The SW with W-0°-BE shows 1.31% more strength than W-O15°-BE. The SW with W-0°-BE shows 2.63% more strength than W-IN15°-BE. The SW with W-O15°-BE shows 1.3% more strength than W-IN15°-BE. The SW with DW-0° shows 2.5% more strength than DW-O15°. The SW with DW-0° shows 4% more strength than DW-IN15°. The SW with DW-O15° shows 1.41% more strength than DW-IN15°. The SW with DW-0°-BE shows 4.13% more strength than DW-O15°-BE. The SW with DW-0°-BE shows 5.28% more strength than DW-IN15°-BE. The SW with DW-O15°-BE shows 1.1% more strength than DW-IN15°-BE.



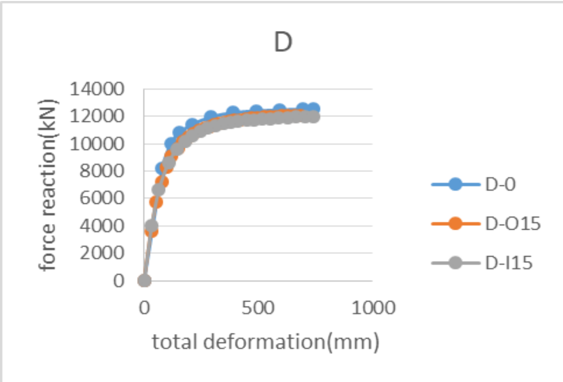
Without opening



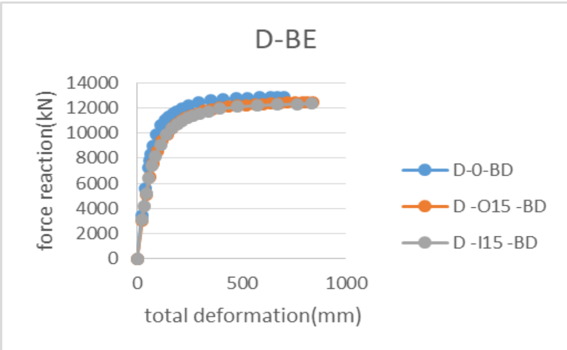
Window opening



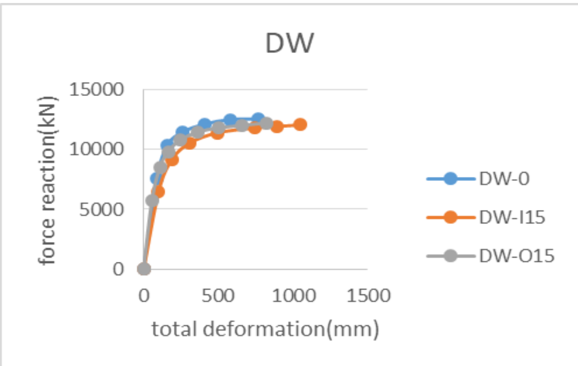
Window opening with boundary element



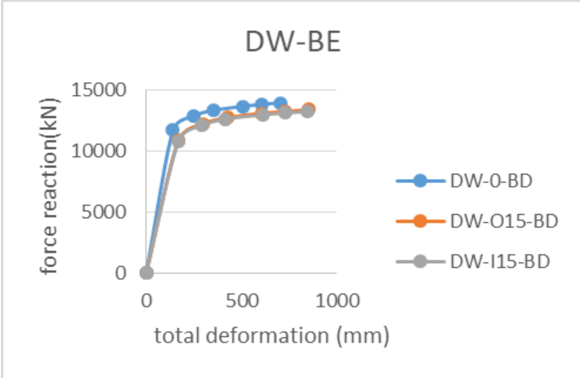
Door opening



Door opening with boundary element



Door-Window opening



Door-Window opening with boundary element

Chart -1: Variation of strength under different opening

From the above graphs we can conclude that the strength of shear wall with various opening at different wall inclination can be achieved by providing boundary elements around the opening. This paper focuses on how to obtain the strength of shear wall without opening at different wall inclinations in shear wall with various opening sizes by providing boundary element and the result indicates that the strength obtained in shear wall with boundary element around various openings is in the range of strength of shear wall without opening. Also from the result, it is obtained that the combination of door and window opening with boundary element has better performance than the other openings.

4. CONCLUSIONS

Based on the results and discussions made on CSPSW, the following conclusions are drawn:

- This paper investigates the structural performance of strengthened CSPSW with irregularity condition.
- The strength of CSPSW with various opening at different wall inclination are improved using boundary elements.
- The strength obtained in shear wall with boundary element around various openings is in the range of strength of shear wall without opening.
- The combination of door and window opening with boundary element has better performance than the other openings.
- The strength of shear wall with wall inclination outside shows better performance than the shear wall with wall inclination inside.

The strength of shear wall at 0° wall inclination has more strength than other inclinations.

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