Seismic Behavior Of Double Steel Plate Composite Wall Under Cyclic Loading

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Abstract - *Double steel plate composite walls (DSPCWs) have gained significant attention in the construction industry due to their exceptional seismic resistance and high ductility. However, the influence of key parameters such as aspect ratio and tie-stud spacing on the cyclic loading behavior of DSPCWs has not been comprehensively investigated. In this study, ABAQUS software is employed to analyze the effects of aspect ratio and tie-stud spacing on the hysteresis response, stiffness and strength degradation, and ductility of DSPCWs subjected to cyclic loading. The analysis is conducted in finite element analysis software ABAQUS CAE of DSPCW models, considering various aspect ratios and tie-stud spacing configurations. The aspect ratio is found to have a significant impact on the hysteresis response, strength degradation, and stiffness deterioration of the walls. Lower aspect ratios tend to promote greater energy dissipation, resulting in enhanced ductility but also increased strength degradation. Similarly, the tie-stud spacing is shown to influence the stiffness and strength degradation, with smaller spacing leading to improved performance.*

***Key Words*: Composite Wall, Cyclic Load, Tie Bar, Steel Plate, Hysteretic Behavior, Stiffness, Strength Degradation.**

1. INTRODUCTION

Double steel plate composite wall consists of two steel plates connected with each other by tie bar and filled with a concrete infill, resulting in a composite section that can withstand a variety of loading conditions. One of the most common types of loading that these walls can face is cyclic loading, which involves the repeated application of loads in opposite directions. Cyclic loading can significantly affect the structural integrity of steel plate composite walls, making it important to understand their behavior under these loading conditions. One of the most primary advantages of using DSPCW is its ability to withstand high loads and stresses. This makes it ideal for use in high-rise buildings, where the weight of the structure and the forces from wind and earthquakes can place significant stress on the building's walls. DSPCW is a highly versatile but durable structural system that offers numerous benefits, including high strength, durability, and resistance to external forces. Its ease of installation and customization make it an attractive option for construction projects of various sizes and applications.

2. NUMERICAL ANALYSIS

In ABAQUS/CAE finite element analysis software, six DSPCW specimens were developed

Table -1: Details of Specimens

Sr. No.	Specimen	Length (mm)	Width (mm)	Thickness (mm)	Tie-Stud Spacing (mm)
1	DSPCW-AR1	3000	3000	230	300
2	DSPCW-AR2	3000	1500	230	300
3	DSPCW-AR3	3000	1000	230	300
4	DSPCW-S150	3000	1500	230	150
5	DSPCW-S250	3000	1500	230	250
6	DSPCW-S300	3000	1500	230	300

DSPCW- Double Steel Plate Composite Wall, AR-Aspect Ratio, S- Tie Stud Spacing

3.1 FINITE ELEMENT MODELLING OF SPECIMENS AND ANALYTICAL STUDIES

3.1.1 Parts and elements of the model

The finite element model was created including steel face plates, top and bottom plates, side plates, shear studs, and infill concrete as shown in figure 3.1 and isometric view of DSPCWAR-1, 2, 3 is shown in figure 3.2.

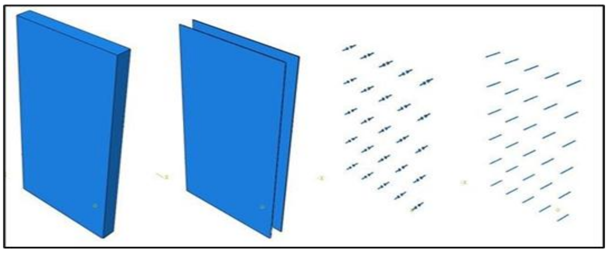


Figure 3.1: Parts and elements of the models

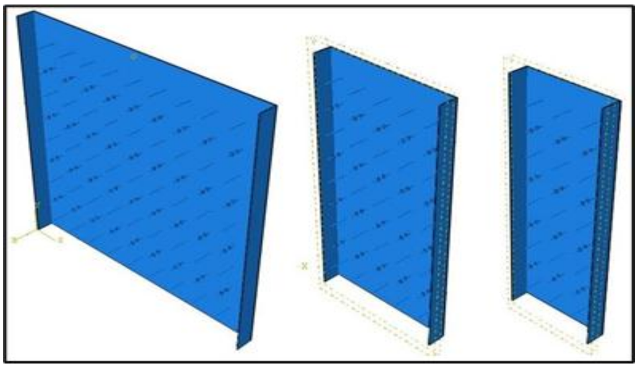


Figure 3.2: Isometric view of DSPCWAR-1,2,3

3.1.2 Assembling of parts and contact properties

In ABAQUS, assembling of parts refers to the process of joining multiple parts together to create a single model. In addition to assembling, contact properties are also an important aspect of finite element analysis in ABAQUS.to neglect the motion between two surfaces tie constraint is used. For the tie bar which is embedded in concrete "Embedded region" constraints are used.

3.1.3 Boundary conditions

The encastre boundary condition constrains is used. all three displacement degrees of freedom (DOF) of the bottom side of the steel supports were restrained.

3.1.4 Meshing

A 'linear eight nodded brick element' type of meshing 60mm was provided to obtain results very accurately as shown in figure 3.3.

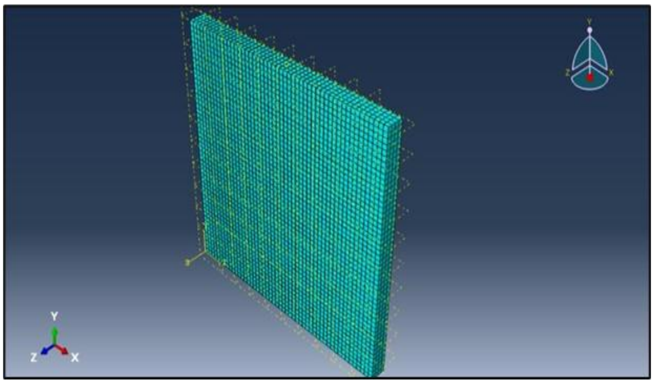


Fig- 3.3: The meshing of specimens

3.1.5 Loading

The RP position is located at the top of the specimen. The prescribed loading was achieved by using the amplitude function at RP as shown in figure 3.4.

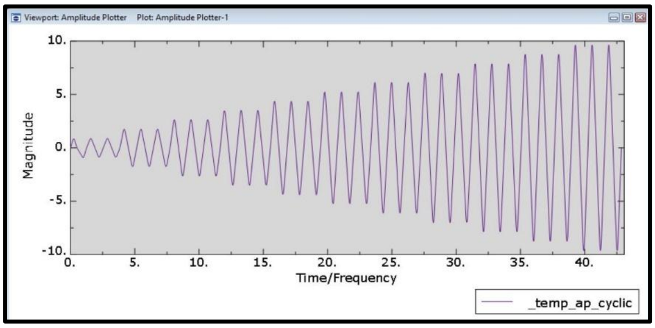


Figure 3.4: The amplitude of loading

Steel plate composite wall, uses two steel faceplates of thickness 10mm and grade of steel as Fe 250, Tie rod is also a connection member that connects the two faceplates and maintains bonding between steel and concrete, here 16 mm diameter, Fe 250 steel tie rod was used. For concrete M50 grade is used shown in table 3.1.

Table 3.1 material properties of wall component

Component	Diameter/thickness (mm)	Modulus of elasticity (MPa)	Density (kg/m^3)	Yield strength (MPa)
Steel Plate	10	$2x10^5$	7860	250
Concrete	230	$35.35x10^3$	2500	2.3
Tie bar	16	$2x10^5$	7860	250
Stud	16	$2x10^5$	7860	250

4. PERFORMANCE ANALYSIS

4.1 Failure mechanism

Common failure modes include steel plate fracture, concrete crushing, shear failure at the plate-concrete interface, and excessive deformations. The damage process under cyclic loading can be simplified as being composed of three major stages: the elastic stage, the yielding developing stage, and the failure stage.

a) Repeated cyclic loading can lead to progressive deterioration of the double steel plate composite wall over time. Fatigue damage can accumulate as the structure undergoes repeated loading cycles, resulting in the initiation and propagation of cracks as shown in fig. 4.1.

b) The initial stiffness of the wall decreases as the steel plates yield, and the concrete infill undergoes micro cracking. The walls first suffered from buckling at the base of the right and left boundary corner and also at top left boundary as shown in figure 4.2.

c) As lateral displacement increases, the existing local buckling is developed and is aggravated as shown in figure 4.3. It was located mostly at the top of the wall.

d) As cyclic loads are applied, shear deformations induced cracking and separation at the interface. Diagonal tension cracking is observed as shown in figure 4.4.

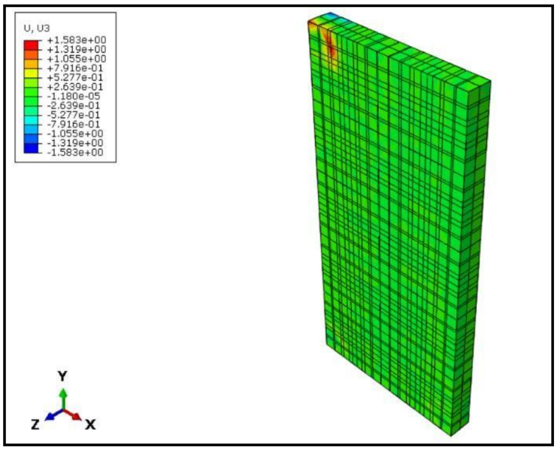


Figure 4.1: Elastic deformation without buckling of steel plate

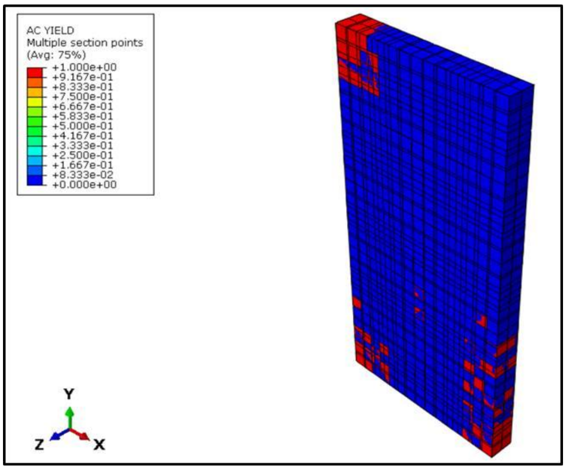


Figure 4.2: yielding of steel plate

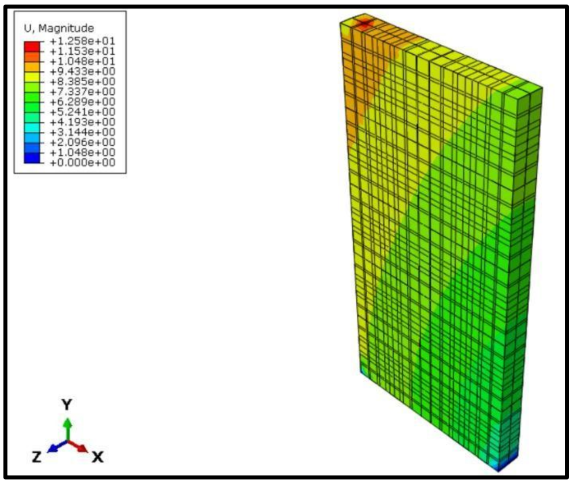


Figure 4.3: buckling of steel plate

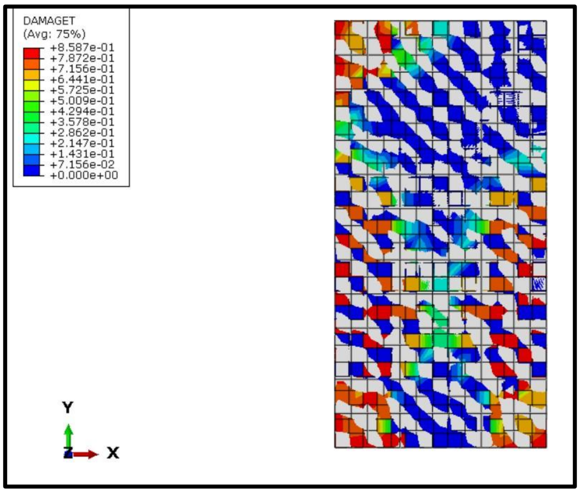
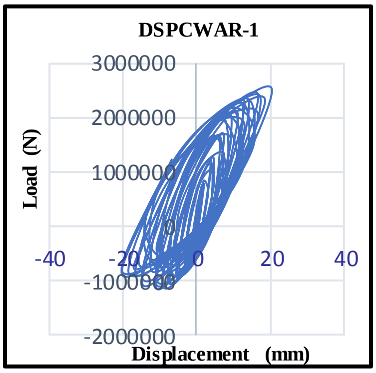


Figure 4.4: tensile damage of concrete

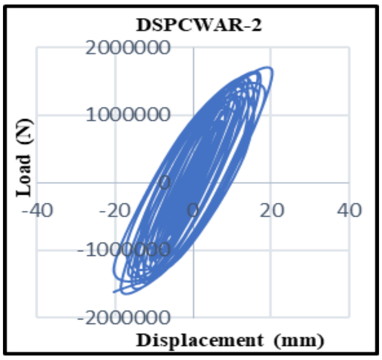
5. RESULTS OF FINITE ELEMENT ANALYSIS:

5.1 Hysteretic behavior in load deformation form

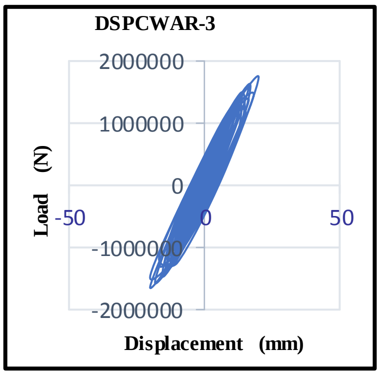
The hysteresis curve shows the energy dissipation and deformation characteristics of the material under cyclic loading. The hysteresis curve for a higher aspect ratio wall is exhibiting larger loops, indicating greater energy absorption capacity. The hysteresis curve for a lower aspect ratio as in figure 5.1 wall shows smaller loops, indicating lower energy absorption capacity. The lateral load carrying capacity of all six wall is shown in figure 5.2.



(a)



(b)



(c)

Figure 5.1: Hysteresis loops of lateral force versus displacement of DSPCW (aspect ratio)

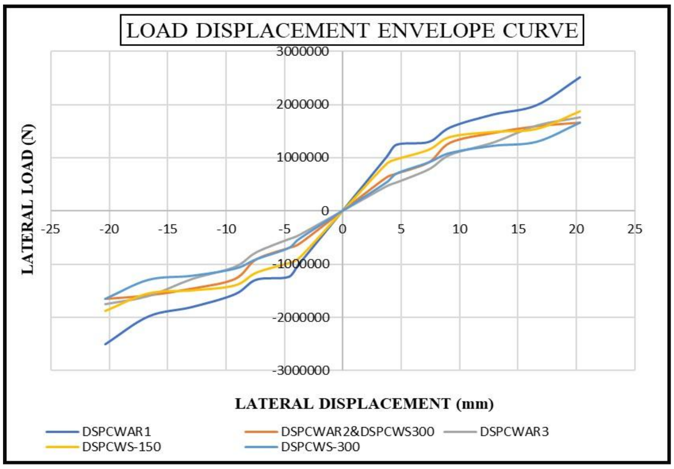


Figure 5.2: Lateral load-lateral deformation graph

5.2 Stiffness and strength degradation

A strength degradation factor ηj was calculated using Eq. (1),

$$\eta_J = \frac{P_j^i}{P_j^{i-1}} \qquad .....(1)$$

Stiffness kj is calculated by using equation (2),

$$k_j = \frac{|P_j^+| + |P_j^-|}{|\Delta_j^+| + |\Delta_j^-|} \qquad .....(2)$$

where Pj+ and Pj- are maximum push and pull lateral load at the Jth loading level and Δj+ and Δj- are lateral displacement corresponding to Pj+ and Pj-respectively.

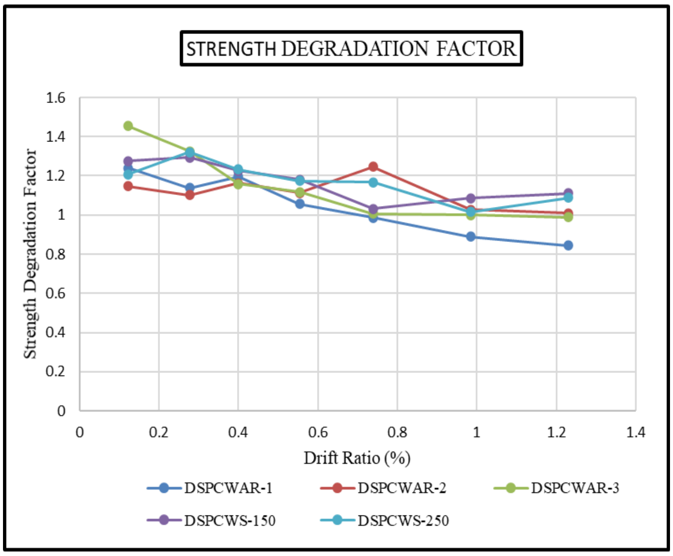


Fig 5.4: Strength degradation curve

From the figure 5.4 and figure 5.5, the lateral strength degradation increases with the decreases in the drift ratio. DSPCW with an aspect ratio 1 shows the large stiffness than DSPCW with tie stud spacing 150 mm have better performance. The DSPCWAR-3 shows less stiffness and strength.

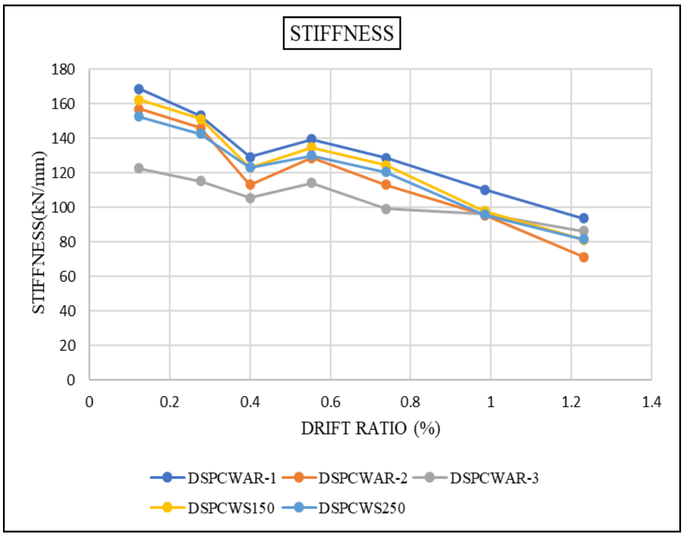


Fig. 5.5: Stiffness curve

5.3 Energy dissipation and displacement ductility

Energy dissipation is nothing but the area enclosed by the hysteretic loop at corresponding deformation From fig. 5.6, energy dissipation for model with aspect ratio 1 is 7 to 10 % more as compared with the models with aspect ratio 2 and 3. For tie-stud spacing of 250 mm the energy dissipation is 7 to 10% more from another tie-stud spacings.

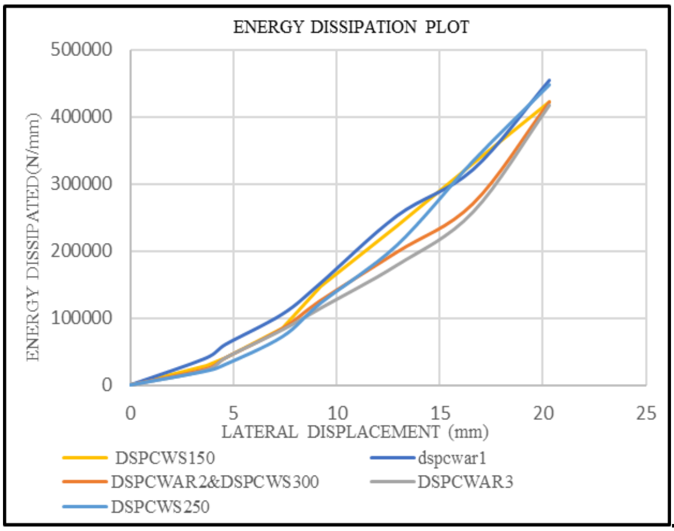


Figure 5.6: Energy dissipation plot of models

Ductility ratio μ is defined as the ratio of ultimate displacement to yield displacement. From table 5.2 the displacement ductility ratio for DSPCWAR-1 is smallest among all the models. Bigger for DSPCW with aspect ratio 3. The stress in model 1 is 20 % less as compared to model 3 and 20 % more as compared to model 2. As the tie-stud spacing increased from 150 to 300mm the stress value decreased 15 to 20 %. Figure 5.7 and 5.8 shows the percentage comparison between DSPCW specimen for aspect ratio and tie stud spacing for all mechanical properties.

Table 5.2: The displacement ductility ratio for model

Model	Yield Load (Py)	Yield displacement (Dy)	Ultimate Load (Pu)	Ultimate Displacement (Du)	Displacement Ductility (Du/Dy)
DSPCWAR1	1125530	4.61538	2048180	9.23077	2.000002
DSPCWAR2	616841	3.69231	1396548	12.9231	3.500004
DSPCWAR3	532621	4.61538	1599520	16.6154	3.600007
DSPCWS-150	975638	4.61538	1396548	10	2.166669
DSPCWS-250	699277	4.61538	1087860	10.738	2.326569
DSPCWS-300	616841	3.69231	1396548	12.9231	3.500004

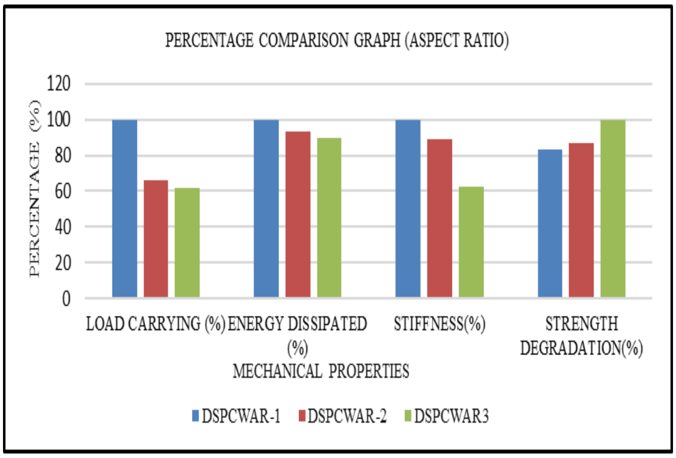


Figure 5.7: Percentage comparison graph for aspect ratio

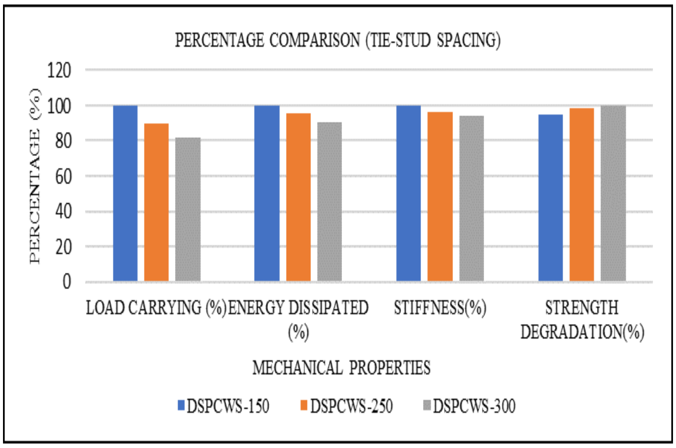


Figure 5.8: Percentage Comparison Graph for Tie Stud Spacing

6. CONCLUSION:

1) The wall with aspect ratio 1 had minimum deformation than wall with aspect ratio 2 and 3. wall with 150 mm tie-stud spacing provided lesser deflections than wall with 300 mm tie-stud spacing hence have more load carrying capacity.

2) As the aspect ratio increased, the lateral stiffness of the wall decreased. A higher aspect ratio led to a larger wall section, results in enhanced strength and resistance to lateral deformations. A smaller spacing increased the overall stiffness of the wall, reducing the deflections and deformations under applied cyclic load.

3) The wall with aspect ratio 3 had large deformation hence, the ductility of DSPCWAR-3 is high. A lower aspect ratio and smaller tie-stud spacing contributed to improved ductility in a double steel plate composite wall subjected to cyclic loading.

4) The wall with lower aspect ratio and lower tie stud spacing had large energy dissipation capacity.

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