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BEHAVIOUR OF DOUBLE STEEL PLATE COMPOSITE WALL

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Abstract

Two steel web plates and two steel flange plates make up the Double Steel Plate Composite Wall (DSPCW), which is then filled with concrete. The web plates are connected at regular intervals by steel tie bars and stiffeners. During the composite process, steel-headed stud anchors (also known as shear studs) may be added to reduce the slenderness of the steel plate and avoid local buckling. Stiffened plates divide the concrete into multiple columns, each of which is independent and resists vertical strain. This paper cites ABAQUS to do a numerical analysis of composite shear walls that include tie bars, stiffened steel plates, and infilled concrete. The purpose of this study is to explore the effects of several factors on double steel plate composite walls, including aspect ratio, tie bar spacings, and the influence of plate stiffeners (DSPCW).

Keywords: Steel Plate, Concrete, Shear wall, Composite behavior, Stiffeners, Shear Stud

1. Introduction

When designing and building high-rise structures, reinforced concrete (RC) shear walls or elevator core walls are frequently used to counteract lateral stresses carried on by an earthquake or wind loads. With height comes a rise in the base shear and overturning forces, necessitating RC walls with large reinforcement ratios. Inadequate concrete placement, compaction, and even building delays are all brought on by these high reinforcing ratios (greater than 2.5%), which result in rebar congestion. Reinforced concrete (RC) shear walls are being replaced with steel plate composite shear walls, a more recent construction material.

For faceplates. The inner sides of the faceplate are welded to steel-headed stud anchors, which are then set into the concrete. Stud anchors enable composite action between the infill concrete and steel faceplates. Two steel faceplates, steel-headed stud anchors, tie bars, and concrete infill make up steel plate composite shear walls. They connect the outer steel faceplates through the concrete infill, providing the stiffness and stability of the empty module illustrated in Figure 1.

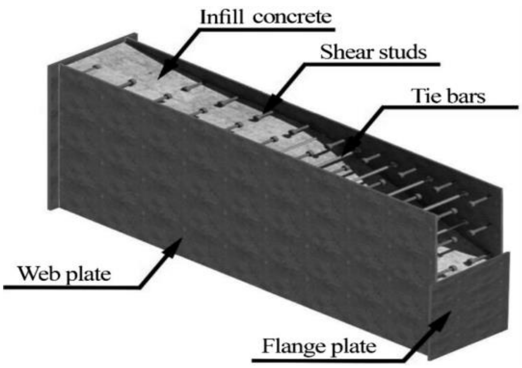

Figure 1: Components of Steel plate composite walls [20]

2. Literature Review

Various studies have proposed several interaction types to create the composite action between steel faceplates and concrete. The stability and loading resistance were creased when steel-headed shear studs, tie rods, stiffeners, and standard studs were used to attach the plate to the concrete.

The plate type and shape of the wall subjected to various loadings is the most important parameter in steel plate composite wall systems design.

Rahai and Hatami [3] investigated the influence of shear stud spacing variation, middle beam rigidity, and beam to column connection method on composite wall behavior experimentally and numerically. The study showed that up to a certain stud spacing, increasing shear stud spacing reduces the slope of the load-deformation curve and enhances ductility. Furthermore, the influence of middle beam rigidity and beam-to-column connection on steel plate composite wall behavior is negligible.

Junming Zhou et al. [4] conducted a Finite Element Analysis to assess the seismic behavior of four steel plate reinforced concrete shear walls. The reversed cyclic horizontal loading was applied to wall specimens. The effect of shear wall thickness, the reinforcement ratio of the shear wall, the thickness of steel plate, and the spacing between shear studs was investigated as test parameters. The study showed that the thickness of steel plate and the spacing of shear studs have a greater impact on the shear force capacity and ductility of shear walls than the thickness and reinforcing ratio of shear walls.

Jianguo Nie et al. [7] investigated the seismic performance of two specimens of two-bay and five-story steel plate shear walls under cyclic loading. One specimen is unstiffened and bolted whereas the other is stiffened and welded. The study showed that unstiffened specimens with bolted connections had high ductility and energy dissipation performance. But that in the serviceability condition, a slip at the bolted connections and buckling of steel panels reduced stiffness. The stiffened and welded specimen had higher elastic stiffness and a high energy dissipation capability.

Siamak Epackachi et al. [8] investigated the seismic performance of four rectangular conventional and steel plate composite walls subjected to cyclic loads. The aspect ratio of the wall specimen was 1.0. A pre-tensioned bolted baseplate was used to anchor the specimens to a concrete foundation. The wall thickness, reinforcement ratio, stud spacing, and tie bar spacing were investigated as test parameters. The study showed that the damage to the infill concrete was concentrated around the level of the first row of tie bars, and the distance between the first row of the tie bars and the base of the wall has a significant influence on the post-peak load behavior.

Kurt and Varma et al. [11] investigated the seismic performance of eight steel plate composite walls subjected to cyclic loads with aspect ratios ranging from 0.6 to 1.0. The wall aspect ratio, reinforcement ratio, and wall thickness were investigated as test parameters. The study showed that decreasing the aspect ratio and increasing the wall thickness boosted the composite wall’s lateral load capabilities. Cyclic yielding and local buckling of the steel faceplates and compression crushing of the concrete infill determined the behavior and failure.

3. Numerical Study

Eight FE models were developed using the ABAQUS/CAE finite element software as shown in table 3.1.

Table 3.1. Details of Specimens

Specimens	Length (mm)	Width (mm)	Thickness (mm)	Tie-Stud Spacing (mm)	Stiffener-Stud Spacing (mm)
DSPCW-AR1	3000	3000	230	300	-
DSPCW-AR2	3000	1500	230	300	-
DSPCW-AR3	3000	1000	230	300	-
DSPCW-T150	3000	1500	230	150	-
DSPCW-T250	3000	1500	230	250	-
DSPCW-T300	3000	1500	230	300	-
DSPCW-S150	3000	1500	230	-	150
DSPCW-S250	3000	1500	230	-	250

3.1. Model Overview

3.1.1 Part and Element of the FE Model

The finite element model was created in six parts using linear hexahedral element (C3D8R) including steel face plate, top and bottom plates, side plate, stiffeners, shear stud and infill concrete as shown in figure 3.1.1. and figure 3.1.2.

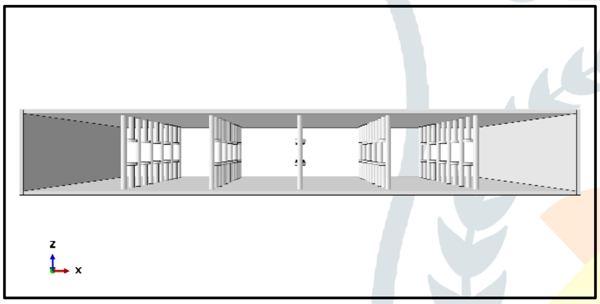

Fig.3.1.1. FE model showing wall with tie bars.

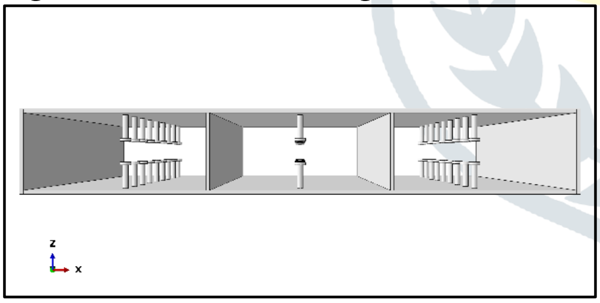

Fig.3.1.2. FE model showing wall with stiffeners.

3.1.2. Assembling of Parts and Contact Surfaces

Position constraints were utilized to assemble the whole model. For the simulation of the interface between steel sheets and concrete core, the option of having contact surface and also surface tie constraint was used. For normal contact behavior, the default option for ‘‘Constraint enforcement method’’ was considered and the ‘‘Hard’’ contact option was used. For tangential contact behavior, the friction between steel plate and concrete core was considered as 0.5. Tie constraints are used to tie bottom and top steel plates to the main wall surface together for the duration of a simulation. In MPC constraint, each node on the slave surface is constrained to have the same motion as the point on the master surface at top of the wall. For the tie bar which is embedded in concrete “Embedded region” constraints are used.

3.1.3. Boundary Conditions

The out-of-plane displacement of the steel frames at both sides was restrained to take into account the concrete confinement. Also, all three displacement degrees of freedom (DOF) of the bottom side of the steel supports were restrained.

3.1.4. Meshing

Partitioning was done at each tie bar and stiffener connection using six datum planes to mesh the member properly. A 'linear eight nodded brick element' type of meshing 50mm was provided to obtain very accurate.

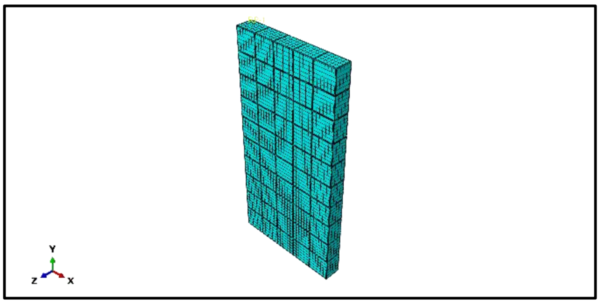

Fig.3.1.2. Meshing of DSPCW-AR2 model

3.1.5. Loading

The loading was achieved by defining a Reference Point (RP) and assigning a 7000 KN lateral load to the RP. The RP position is located at the top of the specimen. The prescribed loading was achieved by using the amplitude function.

3.1.6. Material

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 3.2.

4. Analysis Results

The analysis was performed in step-1 (Dynamic, Explicit), a step after the initial step. Automatic increment and one second total ''Time period'' were chosen.

4.1. Lateral Load Deformation Behavior and Comparison

The lateral load-deformation responses of all the tested specimens summarizes in figure 4.1, figure 4.2 and figure 4.3.

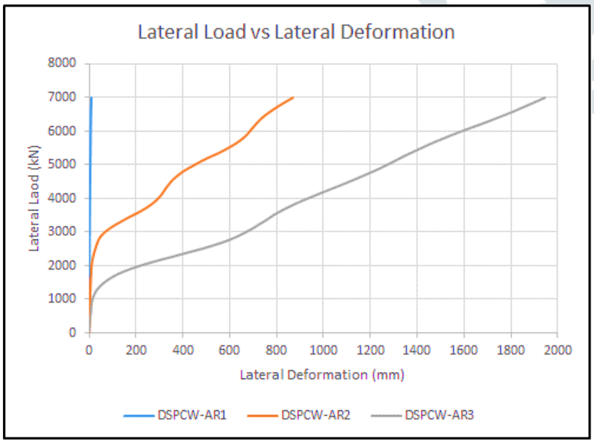

Fig. 4.1 Lateral Load-Lateral Deformation graph of different aspect ratios.

Table 3.2. Properties of Materials

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

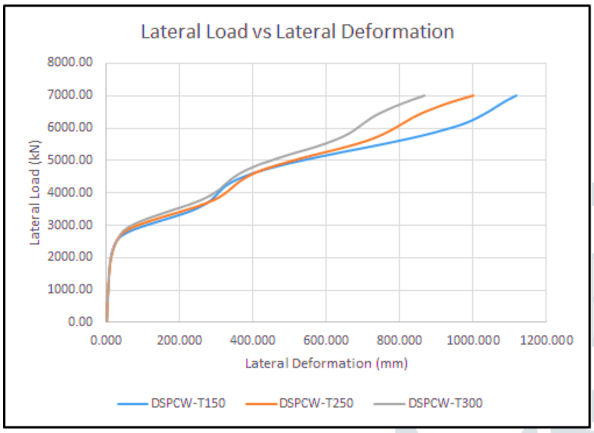

Fig. 4.2. Lateral Load-Lateral Deformation graph of different Tie-Stud Spacing.

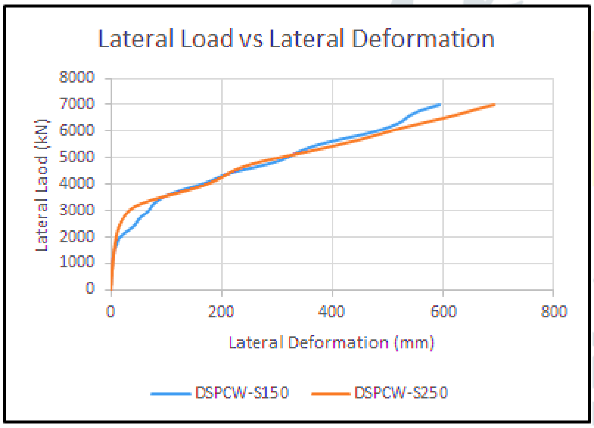

Fig. 4.3. Lateral Load-Lateral Deformation graph of different Stiffener-Stud Spacing.

4.2. Comparison of Key Parameters

The characteristic parameters include the Lateral Load capacity and Deformation up to yielding.

4.2.1 Aspect Ratio

As the aspect ratio increased, the lateral load capacity and stiffness of DSPCW walls declined. Additionally, as the aspect ratio increases, the deformation corresponding to the force increases as shown in figure 4.4.

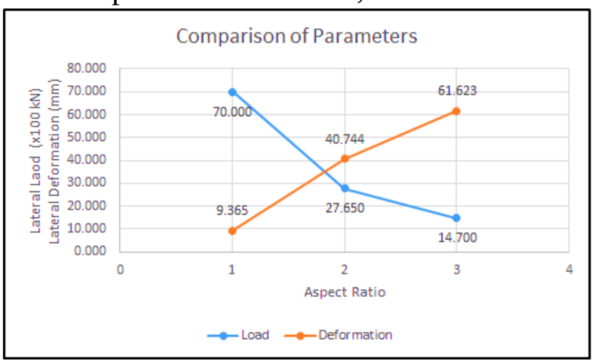

Fig. 4.4. Comparison of Key Parameters: Aspect Ratio.

4.2.2. Tie-Stud Spacing

The lateral load capacity and deformation of the wall are enhanced with the increase of the confinement. Increasing the confinement could improve the flexural rigidity of the wall and the section area of the steel. The steel plate in the wall could resist most of the lateral force. The lateral load capacity and deformation are improved significantly with the increasing confinement shown in figure 4.5.

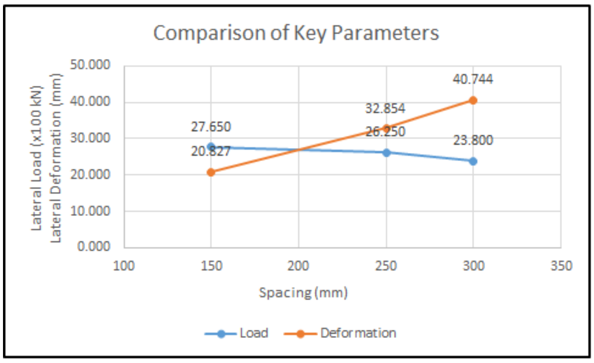

Fig. 4.5. Comparison of Key Parameters: Tie-Stud Spacing.

5. Failure Mechanisms.

Due to the load transfer mechanism, the force applied to the top of the DSPCW wall resulted in an overturning moment and a shear force at the base, which resulted in a combination of normal and shear stresses. As a result, the wall experienced both in-plane flexure and in-plane shear.

Under monotonic loading, the damage process can be divided into three key stages: the elastic stage, the yielding developing stage, and the failure stage.

a) The elastic stage started with the initiation of loading and ended when the specimens yielded. At this stage, the specimens almost elastically deformed. As the lateral displacement increased, it had a linear relationship with the horizontal force. There was no local buckling seen as shown in figure 5.1.

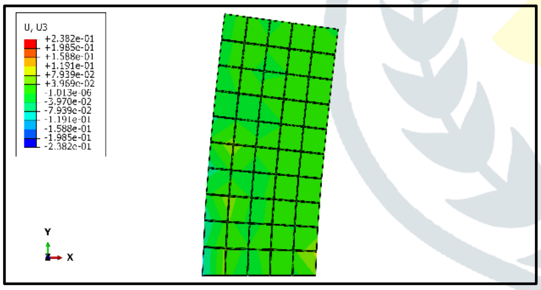

Fig. 5.1. Specimen showing elastic deformation without buckling of steel plate

b) The yielding development stage began with the yielding to the peak load of the specimens as shown in figure 5.2. The walls initially buckled at the base of the right border corner. With increasing loading, the local buckling became more visible and extended as shown in figure 5.3.

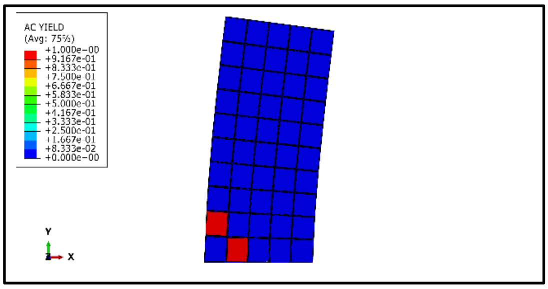

Fig.5.2. Specimen showing yielding of steel plate

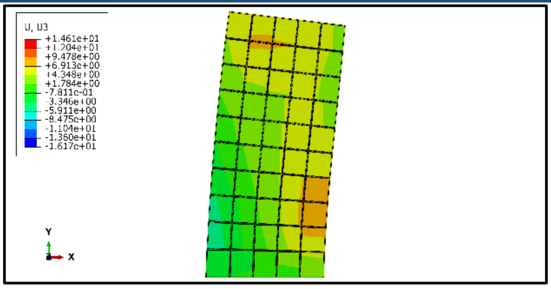

Fig.5.3. Specimen showing buckling of steel plate

c) The failure stage began with the peak load and ended at the specimen's failure point. As the lateral displacement increased, the existing local buckling became more severe and increased. It was usually found between the wall's base and the first row of studs. On further loading, concrete tensile damage was seen as shown in fig 5.4. A fracture caused by considerable buckling began at the right corner and spread across the depth of the wall. Finally, the specimens lost their ability to support the lateral load and had a total failure known as loss of convergence in the numerical analysis.

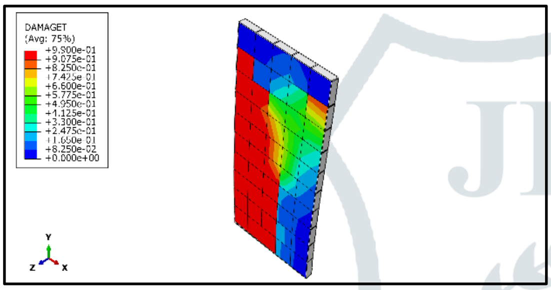

Fig.5.4. Specimen showing tensile damage of concrete.

6. Conclusion

Numerical study on behavior of double steel plate composite wall (DSPCW) was studied using finite element software Abaqus CAE. Lateral load carrying capacity and deformation of wall with different aspect ratio and different tie-stud, stiffener-stud spacing and effect of stiffeners were studied. The main conclusions are listed as follows:

a) As the specified aspect ratios increased, the lateral load carrying capacity and resultant deformation of Double Steel Plate Composite Wall (DSPCW) walls decreased.
b) The lateral load capacity and deformation of the wall increased as the confinement of the tie bar stud increased.
c) The lateral load-carrying capacity of the wall is increased and the deformation of the structure is decreased by about 30% when steel plate stiffeners are used.

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