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Cyclic Loading Response of Composite Corrugated Steel Plate Shear Walls - Smart Technic

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ABSTRACT

The structural element within the whole structure contains structural elements like beams, slabs, columns and reinforced concrete walls. One of the most vertical structural elements is shear wall that built to giving stability to the building, resisting lateral force such as earthquake and wind and to reduce the building deformations. In present study, the analysis of corrugated vertical steel plate shear walls using finite element method by ABAQUS software is examined. Four different modes are analysed in which the first model is vertical corrugated steel shear wall plate, second is the composite shear wall with full interaction, third is the composite shear wall and finally the fourth model is composite shear wall with gap between concrete panel and steel frame to check out the full performance of different shear wall under the effects of cyclic loadings. Displacement, drift and energy dissipation will investigate throughout analysis. Analysis results indicated that the gap and composite action between steel and concrete panel play an important role on the performance of shear wall under cyclic loading. The decrease in displacement of composite shear wall as compared with the steel shear wall reach 11.86%.

1. Introduction

Composite structural elements were recently adopted in the whole world countries due to the advantageous of this type of composite member (Johansson 1975). Composite shear wall contains concrete, reinforcements and plate with and without steel columns at the ends of shear wall. Steel plate within composite wall either straight or corrugate plate that connected with concrete by shear stud connectors to working as unity. Different configurations of steel plate presences in marketing that use in reinforced shear walls to create composite shear wall. The main classification of steel plates that stiffened and unstiffened and straight or corrugated steel plates. The steel plate has high stiffness, more ductile and high ability to resists lateral loads such as wind or earthquake. Due to the light weight of the steel plate that leads to decrease the dead load that reflects on the load transfer to the foundation become less. This is because of the cross section of the composite wall less than conventional reinforced concrete shear wall. Smart technic in composite shear wall makes a gap between concrete panels at each side of steel plate not connected with steel frame so that at low loads the steel frame only carries out the applied loads but when the load increases the gap close and the composite action working as well. The presence of gap reduces the concrete damage and then when close the strength and stiffness of composite wall become higher.

Behbahanifard et al. [1], studied the performance of steel plate shear wall under the effects of dynamic load. the analysis based on the finite elements approach as explicit analysis. Nonlinearity of material for concrete and steel

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sections was used and the applied cyclic loading was applied as lateral load that represent the load that generated from seismic. The finite elements model was built by ABAQUS software. The analysis results indicated that the steel wall stiffness matched the test results.

Berman and Bruneau [2], revived the approached that adapted for analysed steel plate shear wall and proposed a new analysis method for this type of structure. The proposed analysis was considered the linear behaviour of all shear wall components. The lateral load that represents the seismic loads that transfer from the ground motion and distributed to the floor levels was considered as external loads. Equilibrium, compatibility and Hook low were applied to derive the proposed equations. The analysis results of linear and plastic collapse mechanism that assumed was compared with traditional methods by other researchers and founded close.

Rahai and Hatami [3], evaluated the strength capacity and deformation for the composite shear wall under the influence of cyclic loadings. Experimental and theoretical approached were adapted. Different parameters were considered such as centre to centre shear stud connectors, intermediated beam rigidity and beam – columns connection. Test and numerical results indicated that the significant parameter was the spacing of stud connectors.

Lanhui Guo et al. [4], studied the behaviour and strength of shear walls that connected to the frame beams under the effects of cyclic loadings. The two steel plates were connected to the beams and the lateral load were applied that represent the cyclic loadings to the specimen. The investigation focused on the effect of stiffness on the hysteretic performance of the whole system. The test results showed that the specimen gave more ductility as compared with the traditional shear wall.

Wang et al. [5], investigated the behaviour and strength of straight and corrugated steel plate composite shear walls under the effects of hysteretic load. Total of six specimens were tested and simulated by finite elements software ABAQUS. The specimens consisted of straight and corrugated steel plate in horizontal and vertical positions. Different parameters were adapted such as steel plate configurations and layouts. The specimens were modelled by finite elements approach and the test results compared with the finite elements simulation and founded close. Test results showed that the lateral stiffness and the ductility of composite shear wall gave better results than steel plate shear wall.

Ghassemieh et al [6], studied the methodology to improve the behaviour and strength with little deformations of reinforced concrete shear wall by introduced smart materials. The models were analysed by finite elements ABAQUS software and subjected to seismic loads. The adapted time history analyses are El-Centro and Koyna. The analysis results indicated that the smart materials such as steel bars lead to reduces in residual displacements and reduce the deflections for both walls type.

Najem [7], studied the composite steel plate shear wall by adapted smart solution as gap between the steel frame and concrete wall under the effects of cyclic loadings by finite elements approach. Analysis results pointed out the stiffness and ductility of the composite shear wall increased than the conventional shear wall.

Al-Tameemi [8], studied by numerical finite elements approach the performance of steel corrugated plate shear wall under seismic loadings. The studied evaluated the wall stiffness, strength, energy and ductility. Different parameters were considered such as angle of corrugated steel plate, side length of steel plate and plate thickness. Analysis results indicated that the performance of shear walls become less when the angle of corrugated steel plate more and the wall strength increased in case of steel plate thickness increased.

Kisa et al. [9], studied the behaviour of composite shear wall under the impact of cyclic loadings. Concluded that the composite shear wall has efficient energy dissipation and ductility.

This paper investigates the structural behaviour of steel plate reinforced concrete composite shear walls. A nonlinear finite element model for the analysis of corrugated steel plate reinforced concrete composite shear walls under seismic loadings was developed with smart technic under the effect of cyclic loading. A 3-diminesional finite element was developed using ABAQUS software. Four models are adapted in this study which are shear wall vertical steel corrugated plate, composite shear walls with full interaction, composite shear walls with partial interaction and composite shear walls with gap between steel frame and concrete wall. Displacement, drift and energy cumulative are discussed for all models.

2. Finite element modelling

Models are classify based on the shear wall type that subjected to cyclic loading. The element type for concrete is a C3D10 with 10 nodes quadratic tetrahedron element (with 6 degrees of freedom for each node). This type of element was formulated as second-order tetrahedral elements. In present modelled, the contact between the concrete and other structural elements involved finite sliding with surface-to-surface formulation that is the default method in ABAQUS/Standard for contact enforcement. A S4R with 4-nodes doubly curved shell elements were used to simulate steel sheet elements. A T3D2 with 2-nodes linear 3-D truss element were used to simulate reinforcement of the reinforced concrete shear wall models. The coupling constraint that adopted to simulated the composite shear wall models at interface. The different models with vertical corrugated steel plate listed in Table 1:

Table 1: Models Description

Model	Corrugated plate Thickness (mm)	Concrete Panel	Shear Connecters	Gap (mm)
SW1	1.25	Without	—	—
SW2	1.25	With	—	—
SW3	1.25	With	10mm @ 200 mm	—
SW4	1.25	With	10mm @ 200 mm	32

The aim of simulations of models that mentioned above is to compare of performance between steel shear wall, composite shear wall as full and partial interaction and presence of gap between steel frame and concrete panels. Where the model SW1 is steel corrugated shear wall only without concrete panels, SW2 which is composite steel corrugated shear wall-full interactions and no shear connectors, SW3 which is composite steel corrugated shear wall partial interaction without gap and SW4 is Composite Steel Corrugated Shear Wall Partial interaction same as model 3 with 32 mm gap.

The steel frame built as steel beam cross section is W12x26 and for steel columns is W12x120, the mechanical properties of corrugated steel plate, beams, columns and shear stud connector used in the models are lists in Tables 2.

Table 2: Mechanical properties of corrugated steel plate, beams, columns and shear stud connector [8]

Element	Tensile strength fy (MPa)	Ultimate strength fu (MPa)	Modulus of elasticity Es (MPa)	Elongation (%)	Poisson's ratio
Corrugated Steel	282	391	21e+5	8.13	0.3
Beams and Columns	345	483	2e+5	23	0.3
Shear Stud Connector	292	385.9	2e+5	7.18	0.3

The diameter of shear stud connectors is 10 mm at spacing 200 mm and the height of stud is 40 mm. Concrete reinforced concrete wall thickness is 76 mm and the reinforcement is 10 mm @ 102 mm. The corrugated steel vertical plate geometry is shown in Figure 1. Figure 2 shows the layout and dimensions of steel frame.

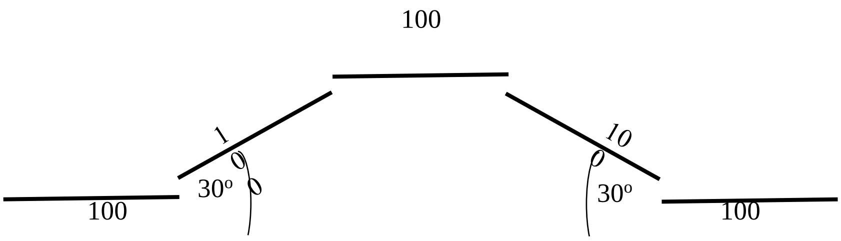

Figure 1. Corrugated steel vertical plate geometry (mm)

Figure 2 show the stress-strain curves for corrugated steel plate, steel frame and concrete shear wall respectively depended in the present analysis. The concrete properties are lists in Table 3.

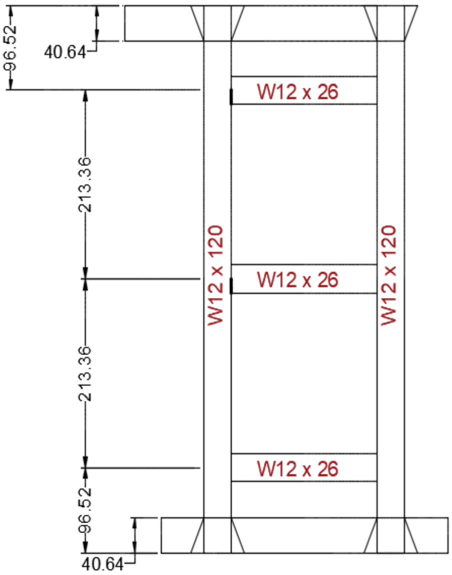

Figure 2. Steel frame Geometry-Dimensions in (cm)

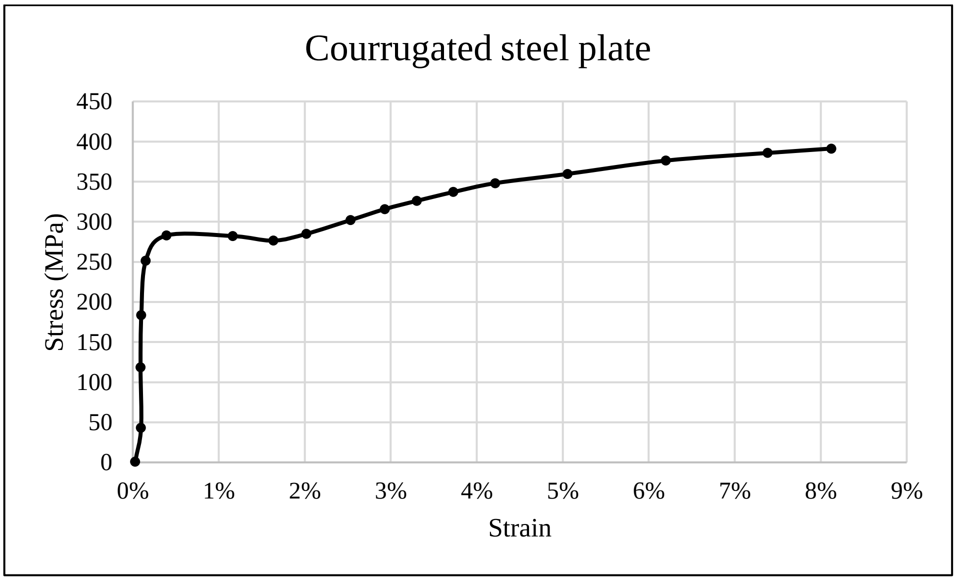

Figure 3. Stress-strain curve of steel plate [7]

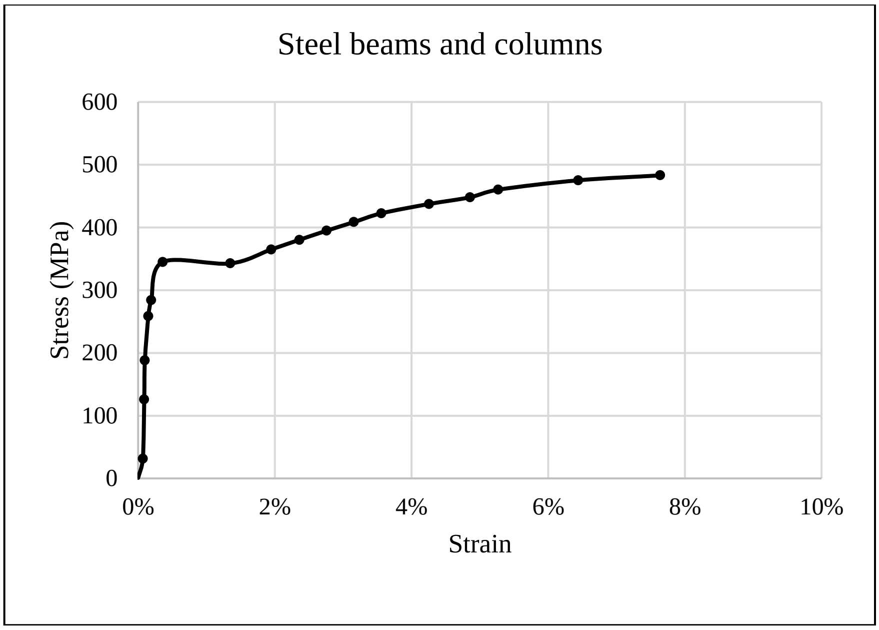

Figure 4. Stress-strain curve of steel frame [7]

Table 3: Concrete properties [7]

Compression strength (MPa)	28
tensile strength (MPa)	3.22
Density (kg/m3)	2400
Poisson ratio	0.15
Dilation angle	36
Eccentricity	0.1
f_{b0}/f_{c0}	1.16
Viscosity parameter	0.01

In which the parameter f_{b0} and f_{c0} used when defining material properties of concrete damage plasticity model that represent biaxial compressive strength of concrete and uniaxial compressive strength respectively.

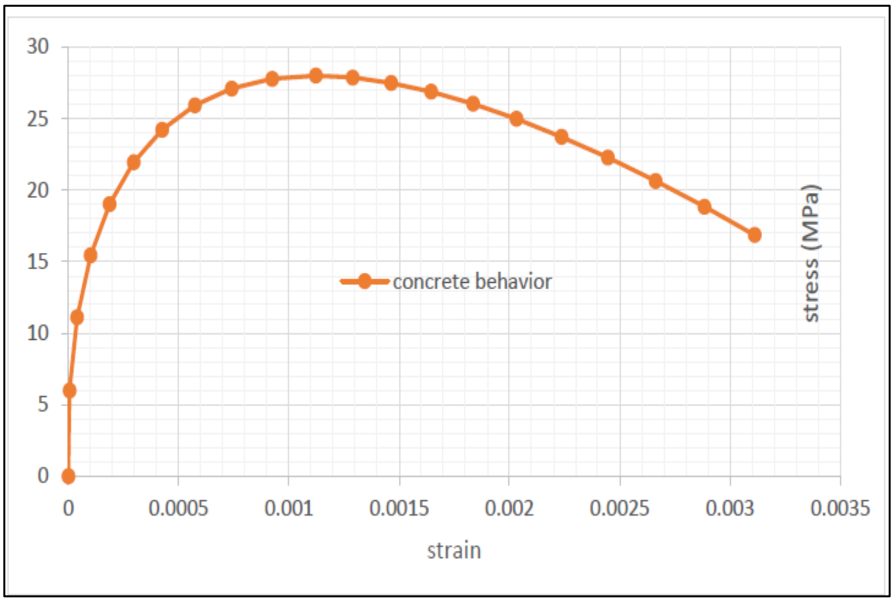

Figure 5. Stress-strain curve for concrete [7]

To simulate the steel plate, S4R element was used. S4R element is a 4-node doubly curved thin or thick shell, reduced integration with 6 degrees of freedom per node. C3D8R element is used to simulate the concrete parts, which is 8-nodes linear brick, reduced integration with 6-degrees of freedom per node. T3D2 element is used to simulate the rebar which is 2-nodes linear 3D truss element with 6-degrees of freedom per node. The cyclic loading considered in this study is shown in Figure 6.

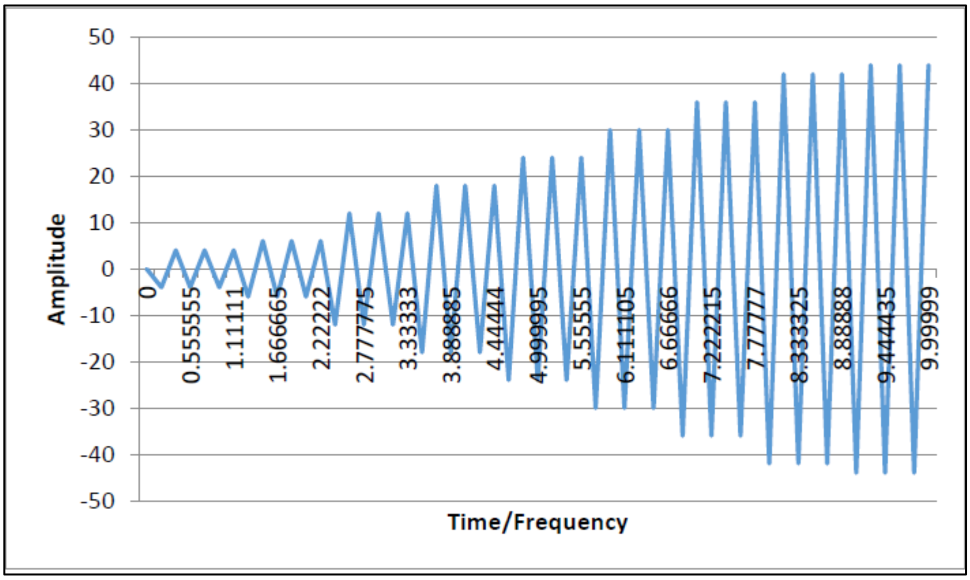

Figure 6. Cyclic loading considered in this study

A buckling analysis was performed in first stage to determine the buckling modes of the steel sections (both local and global buckling was tested), using the buckling modes. An imperfection was introduced to the models to provoke buckling in the model under pushover analysis that was performed (nonlinear static analysis with nonlinear geometry), an automatic virtual stabilizing factors were introduced to stabilize the solution when excessive distortion occurs.

The tie interaction algorithm between steel components was defined and an embedded region algorithm was defined between steel and concrete. The interaction between studs and concrete and between concrete and rebar modeled with infinite slip.

The bottom tie was constraint in all degrees of freedom, and the upper beam was constrained against translation in x and y directions and against rotation around y and z. Loading was applied as a displacement in direction of negative Z axes at upper beam using the amplitude shown in Figure 6.

3. Results and discussions

Analysis results of the four models as drift, displacement and energy variation with time due to applied external load for each model. Energy as cumulative variation with time that represent the energy dissipation for each model.

3.1 Effect of composite on the behavior of plate shear walls

The maximum lateral shear resistance for model SW1 is 222672 N at 0.351 second, corresponding 3.12 mm displacement and energy cumulative 362, while the maximum lateral shear resistance foe model SW2 is 845449 N at time 0.368 second with 3.93 mm displacement and energy cumulative 91667 as shown in Figure 7.

The energy dissipation of model SW2 is higher than model SW1 that is mean the composite shear wall capability to resists the applied cyclic load that represent seismic loadings is higher than the steel shear walls due to the presence of concrete panels that increased the stability, moment of inertia and equivalent modulus of elasticity lead to increase the stiffness of whole system and increase the input energy. Energy input curve represent the cumulative energy of shear wall due to applied load up to last stage of loading.

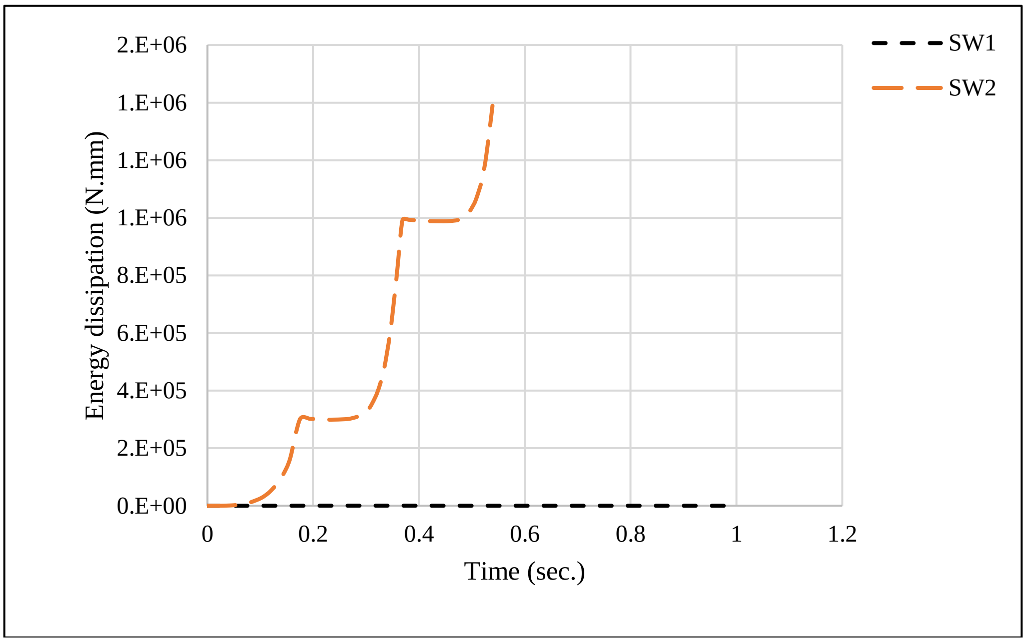

Figure 7. Energy dissipation-time variations of SW1 and SW2 models

The relation of displacement-time same as sine wave and changed in values from positive to negative sign as shown in Figure 8. Displacement of model SW1 under the effect of same applied cyclic load is less than model SW2 due to the absence of concrete panels that make the shear wall more stiffness so that the shear resistance become more but at specific shear capacity of model SW1 the displacement become less in model SW2.

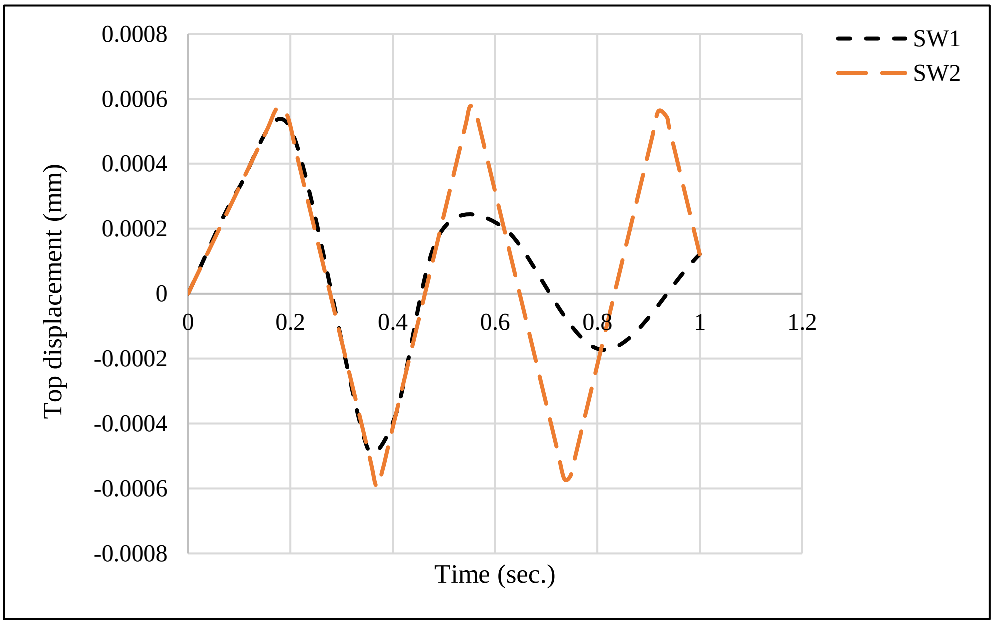

Figure 8. Top displacement-time variations of SW1 and SW2 models

The drift-time variations of SW1 and SW2 models are shown in Figure 9.

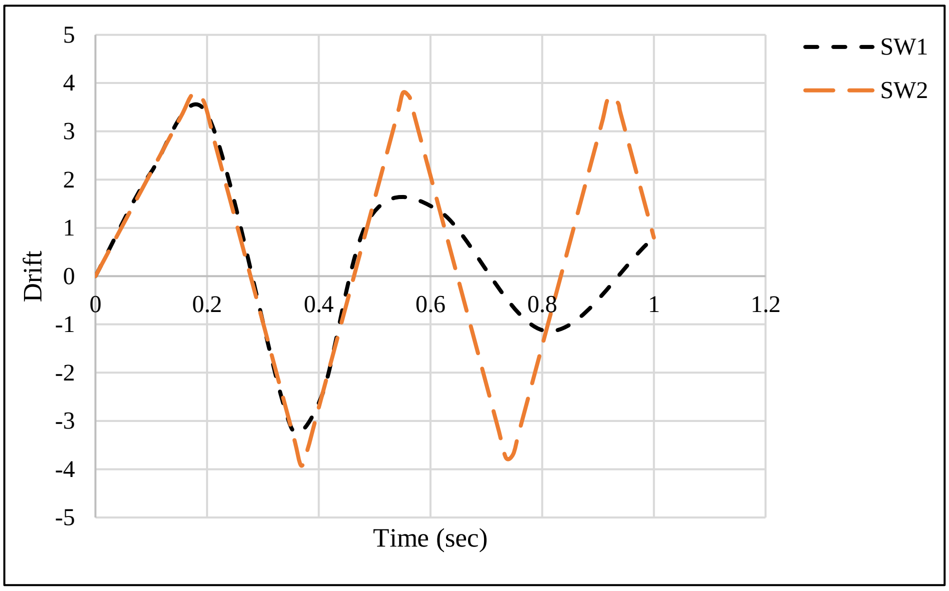

Figure 9. Drift-time variations of SW1 and SW2 models

3.2 Effect of shear connectors on the behavior of plate shear walls

The maximum lateral shear resistance for model SW3 is 230853 N at 0.374 second with 3.82 mm displacement and energy cumulative 111250. Model SW3 same as model SW2 as behavior but the time required to dissipated energy more and also the displacement cycles are more as shown in Figures 10 and 11.

The energy input for model SW3 that represent the area under the curve of shear-displacement is higher than model SW2 due to the increased in time due to the shear transfer at the interface between concrete panel and corrugated steel plate that make slip between then but in very small magnitude that reflect on the time or increase in cycles.

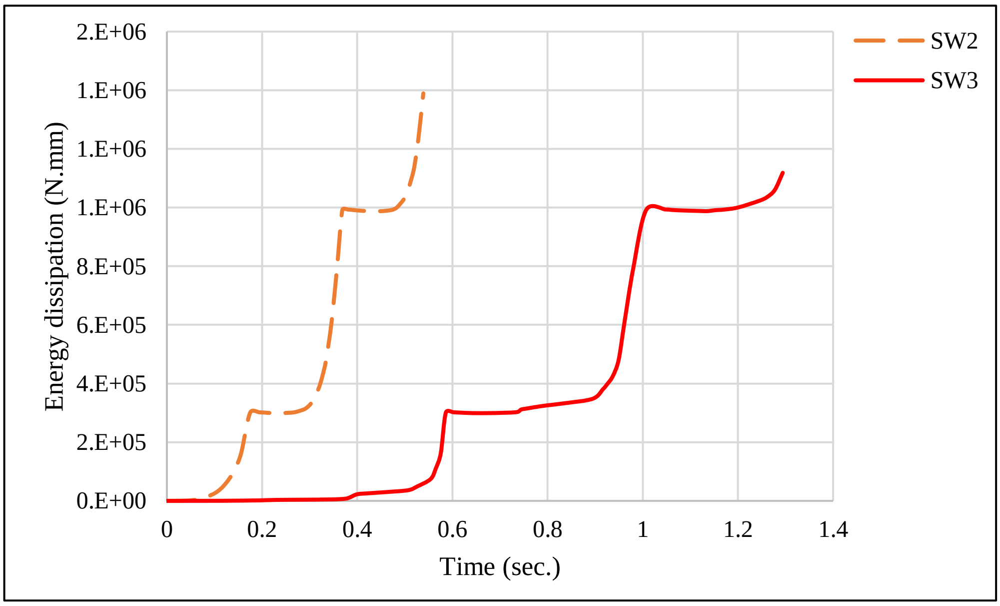

Figure 10. Energy dissipation-time variations of SW2 and SW3 models

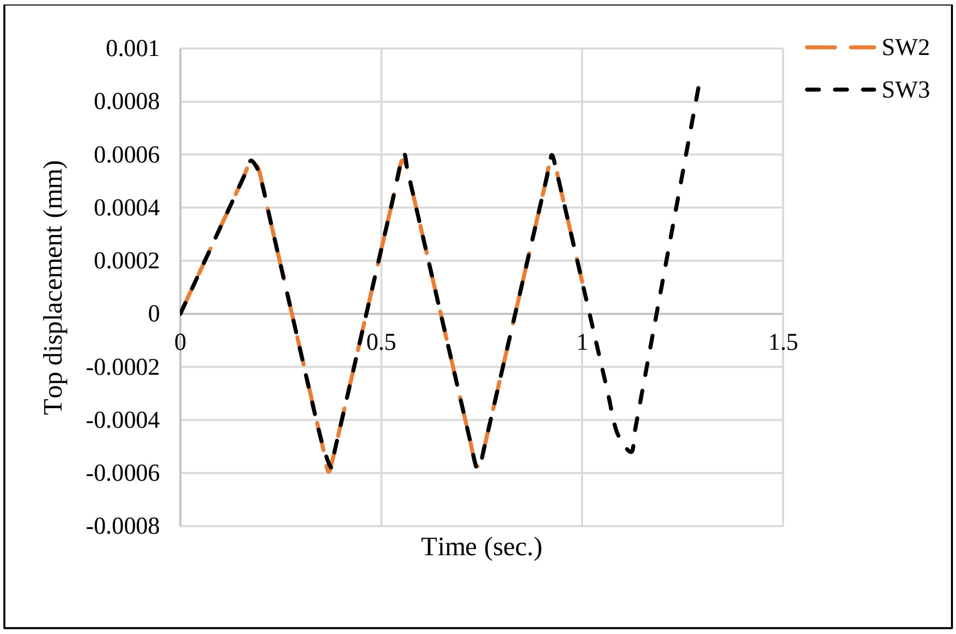

Figure 11. Top displacement-time variations of SW2 and SW3models

The drift-time variations of SW2 and SW3 models are shown in Figure 12.

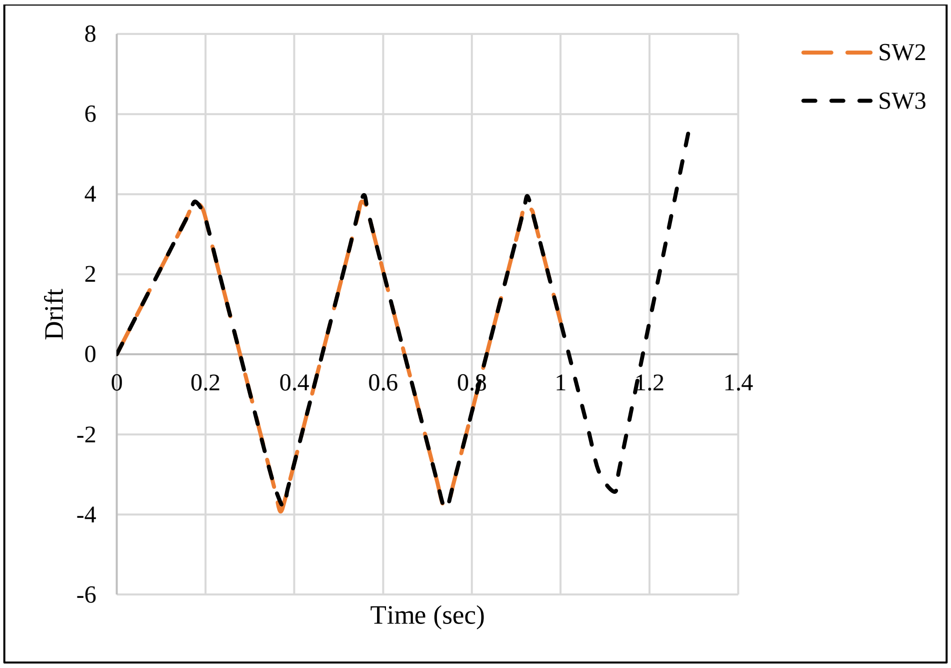

Figure 12. Drift-time variations of SW2 and SW3 models

3.3 Effect of gap on the behavior of plate shear walls

The maximum lateral shear resistance for model SW4 is 417325 N at last cycle with 11.69 mm displacement and energy cumulative 770692 at time 2.591 second. Model SW4 similar to model SW3 in behavior but difference in time range and magnitude of displacement after the 1.25 second in which the displacement increases at 2.40 second as shown in Figures 13 and 14. Initially the steel frame alone carries the applied load due to the presence of gap between the steel frame and concrete panels. After increase in displacement, the steel frame touches the concrete panels so that the concrete has no contribution in carries load up to the gap close and the energy input in case of model SW3 more than model SW4.

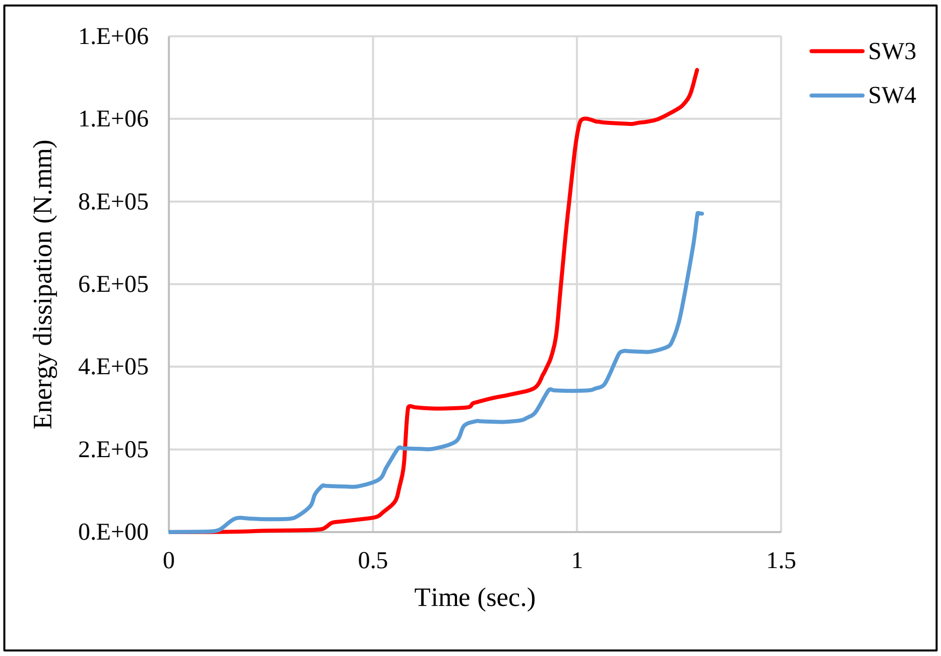

Figure 13. Energy dissipation-time variations of SW3 and SW4 models

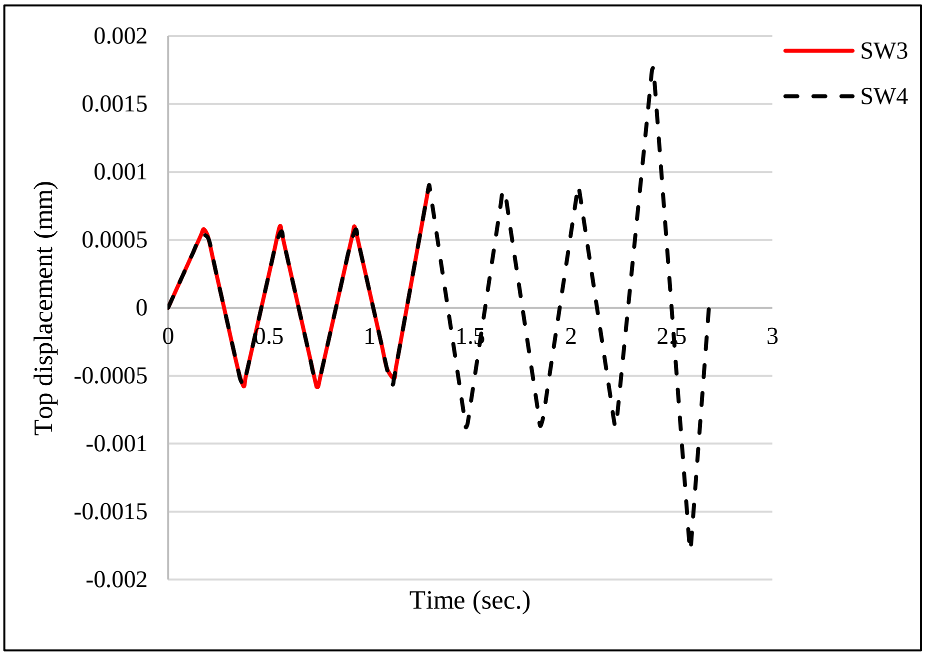

Figure 14. Top displacement-time variations of SW3 and SW4 models

In case of full interaction between steel frame and concrete panel without gap, the shear resistance become higher due to there is no slip will occur at the interface between the two different materials that effects on the displacement as vertical and horizontal. Presence of gap between steel frame and concrete wall lead the interaction between the reinforced concrete panel and steel plate in the compression filed become more active, which caused decrease the lateral shear stiffness for this model. Figure 15 shows the drift-time variations of SW3 and SW4 models.

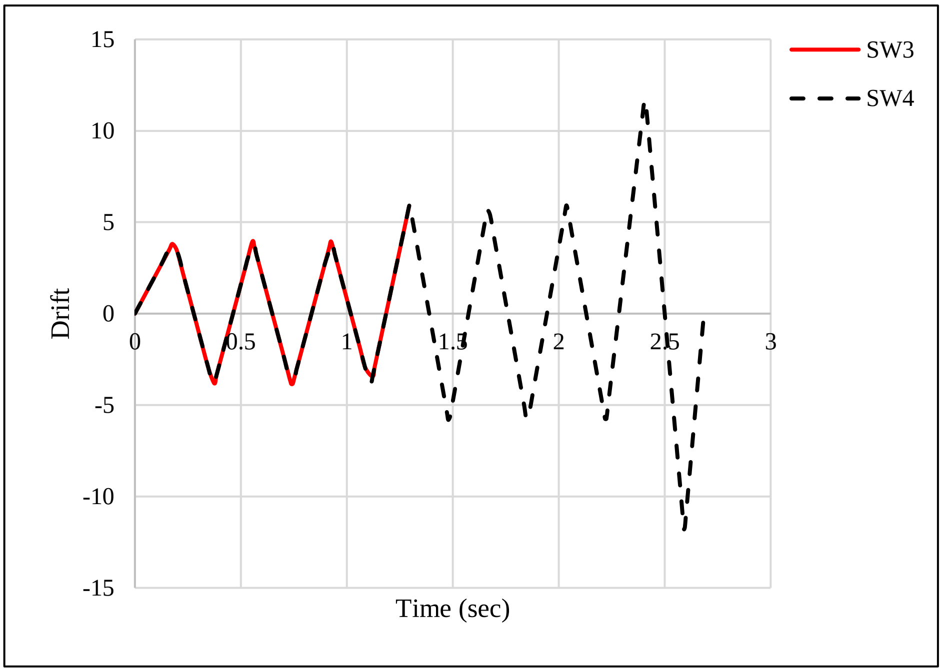

Figure 15. Drift-time variations of SW3 and SW4 models

Figures 16 to 18 shows the results of all models for drift, top displacement and energy dissipation. The hysterias cycles for each model differ in loop as large or small loops that depend on the model resistance as stiffness in which the composite action between corrugated steel plate and concrete gave more equivalent modulus of elasticity and high moment of inertia that load to increase the stiffness of the wall against the applied load.

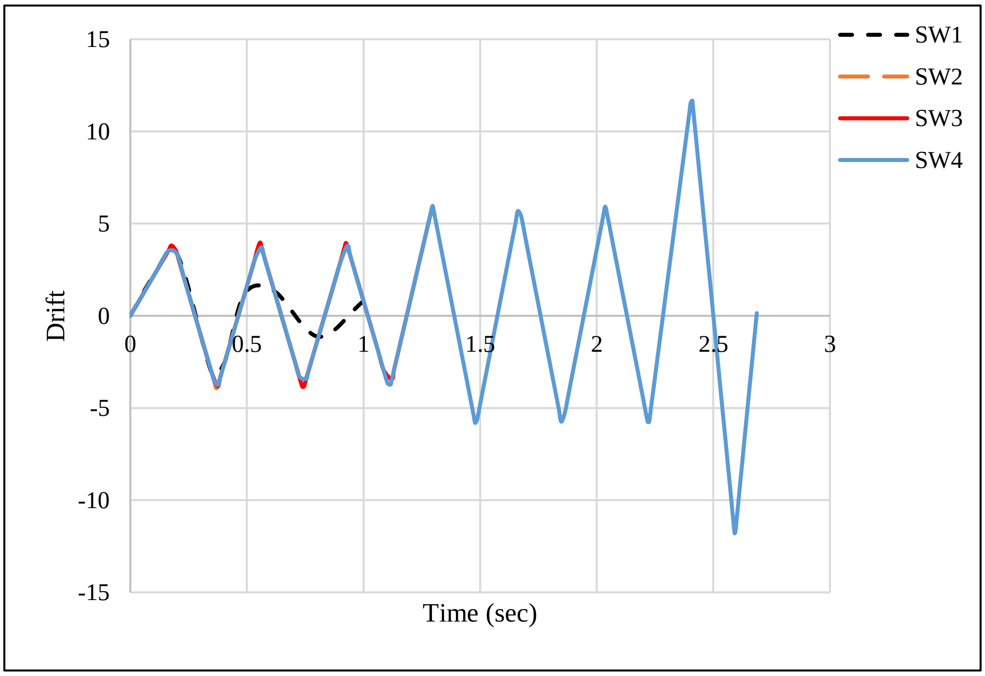

Figure 16. Drift-time variations for all models

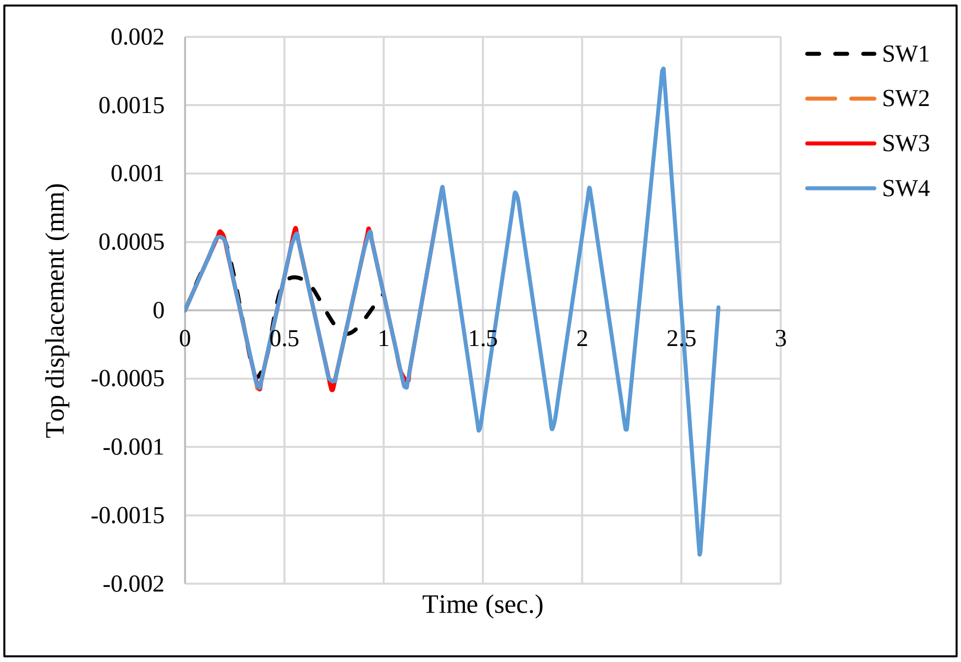

Figure 17. Top displacement-time variations for all models

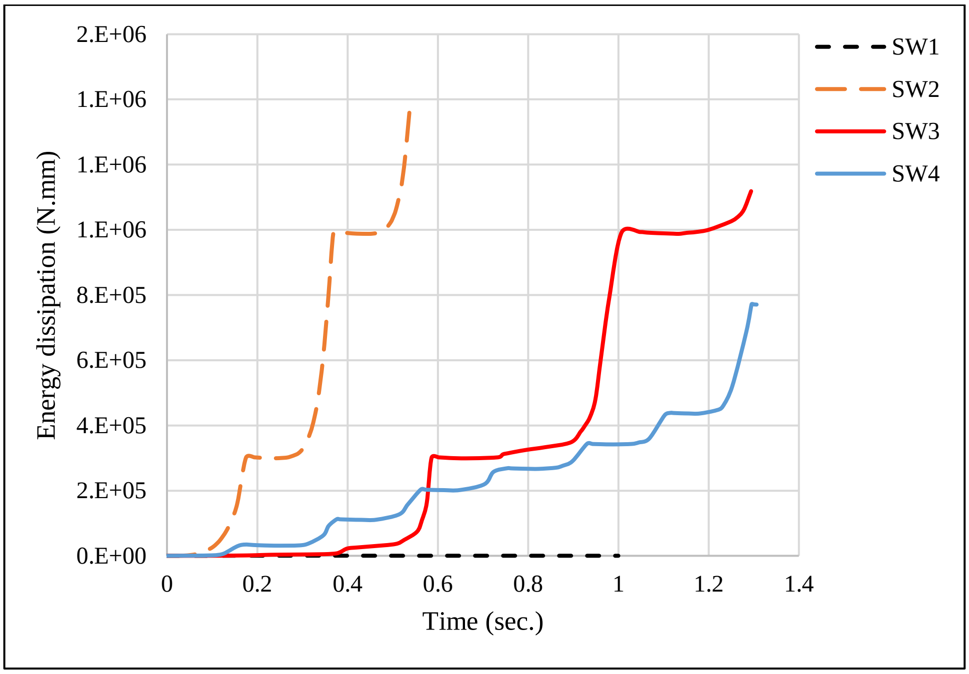

Figure 18. Energy dissipation-time variations for all models

Table 4 lists the analysis results for all models, the displacements decrease in case of composite shear walls when compare with the steel shear wall.

Table 8: Analysis results for all models

Model mark	Displacement (mm)	Time (second)	%Decrease in displacement
SW1	3.12	0.35	---
SW2	2.97	0.35	4.81
SW3	2.90	0.35	7.05
SW4	2.75	0.35	11.86

Displacement at top of SW1 model less than other models because the shear force is less than other models that reflect on the energy cumulative that is become less. In case of composite shear wall, the shear yield capacity of a steel plate alone is significantly more than its capacity of concrete to resist shear in yielding due to diagonal tension filed. The presence of concrete panel increases the stiffness of the wall due to increase in equivalent modulus of elasticity and moment of inertia that lead to decrease the displacements and increase in resistance later load. Figures 19 to 22 shows the drift for all models.

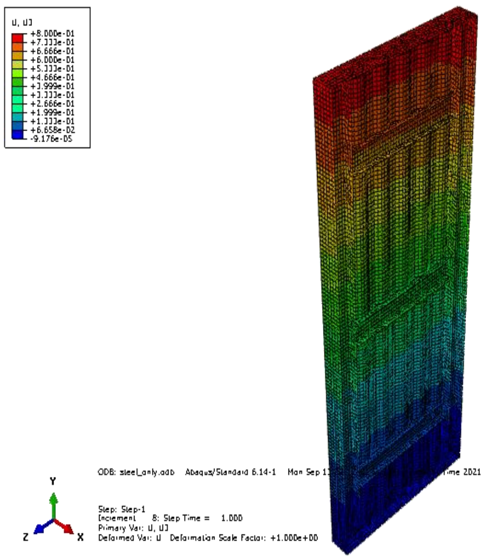

Figure 19. Drift of SW1

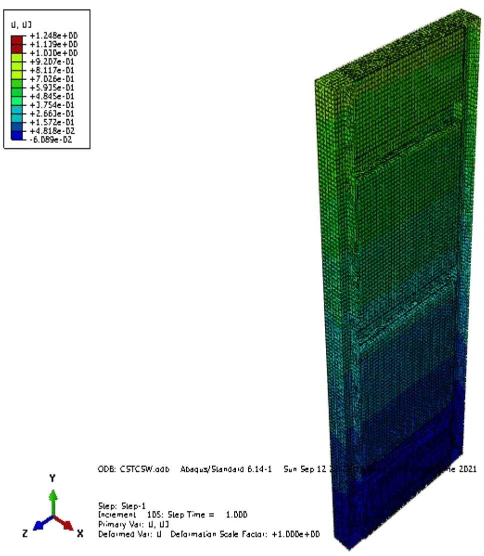

Figure 20. Drift of SW2

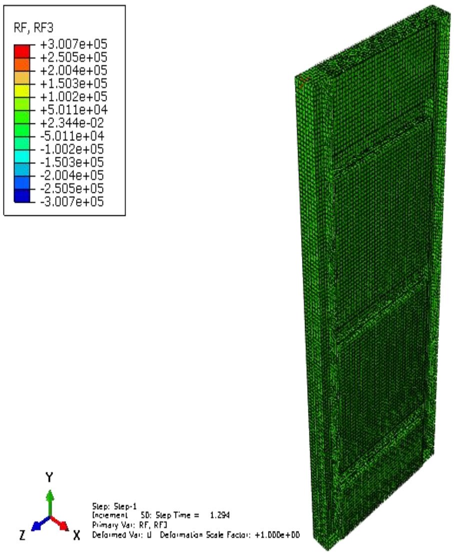

Figure 21. Drift of SW3

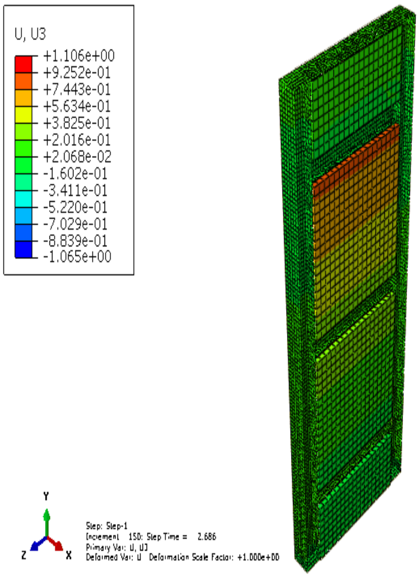

Figure 22. Drift of SW3

4. Conclusions

According to the analysis results presented in this study, the conclusions drawn from this work can be summarized as follows:

1. Composite wall showed better energy dissipation as compared with steel shear wall.
2. Composite shear wall has higher resistance to the applied lateral load compared with the steel wall only that is mean the lateral force bearing capacity of composite shear wall are higher than the lateral force of steel shear wall.
3. Presence of gap gave more shear strength capacity compared with the composite shear wall without gap.
4. The stiffness of the model was more in case of composite shear wall and presence of gap due to increase in modulus of elasticity as equivalent of concrete and steel and increase in moment of inertia.

5. The main function of presence of gap to separate concrete wall form steel frame so that under low applied load, the steel frame with plate and boundary element provides strength, stiffness and ductility so that the concrete panel to provide out-of-plane bracing for the steel plate.
6. The energy dissipation capacity of composite shear wall (model SW2, SW3 and SW4) is stronger than the steel shear wall.
7. Decreased in displacements of composite shear wall as compared with steel shear wall. Models SW2, SW3 and SW4 reduce in displacement as 4.81, 7.05 and 11.86% when compared with model SW1.

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