AN INVESTIGATION OF FRP COMPOSITE STEEL SHEAR WALLS (CSSW) UNDER CYCLIC LOADING ON LABORATORY

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ABSTRACT :

Composite steel shear wall (C.S.S.W.) is widely used in civil projects because of its good stiffness and deformability. Its main advantage is the deformability due to buckling behavior of the steel sheet. It can be utilized by either laying a concrete layer connected to the steel by shear studs or bonding a FRP sheet to the steel by epoxy resin to form a composite shear wall. This paper defines the effect of FRP layer on steel shear wall (S.S.W.) behavior by numerical & experimental studies. In this regard, 3 experimental specimens involved of steel shear wall, steel plate shear wall composited with FRP layer and flexible frame are built and tested using a rigid frame and actuator under cyclic loading with frequency of 1/60, 1, 2 and 3 Hz. Results show that the FRP plate acts similar to a lateral support for the steel plate. It was indicated that the FRP plate could extend shear stresses to whole area of the steel plate. And so, the FRP layer would increase the stiffness and energy absorption and will be insignificant decreasing the ductility of S.S.W. as compared with C.S.S.W.

KEYWORDS: Composite Shear Wall, Steel Shear Wall, Post buckling, FRP, Cyclic Loading.

1. INTRODUCTION

Steel Shear Wall (S.S.W.) is vastly used as an effective resisting system against lateral loads. The wall stiffness is provided through the diagonal tension field generated in steel sheet accompanied by the frame bending action. In FRP-Composite steel shear wall, a layer of FRP is connected to one or both sides of steel plate to increase the shear capacity due to an increase in the number of diagonal tension fields lines, and also improve the panel bearing against destructive factors such as impulse, explosion etc.

2. LITERATURE REVIEW

During the Last two decades, considerable researches have been carried out on the modeling and seismic behavior of Steel plate Shear Wall (S.S.W.) in North America and Japan.

Thorburn et al. (1983) suggested equations to determine inclination angle of the tension field and controlled its accuracy with some tests.

The researchers of University of Alberta (Timler and Kulak, 1987), (Kulak 1991) and (Driver et al. 1996) did some tests on steel shear walls without stiffening under monotonic and cyclic loadings. The results showed well ductility and high lateral strength of this system.

Sabouri and Roberts (1992), and Roberts (1995) reported the results of tests on 16 S.S.W. panels under diagonal loading with and without opening. The results have a well validation with the elastic response of shear walls.

De Matteis et al. (2003) schematized shear panels as equivalent bracing elements having a suitable hysteretic behavior. They concluded that low-yield steel shear panels provide an apparent reduction in storey drift and damage level of the primary structure.

Bruneau and Bhagwagar (2002, 2004) conducted nonlinear analyses to investigate how structural behavior is affected when thin infill of steel, low-yield steel, or shear-fill fabrics are used to seismically retrofit steel frames located in low and high risk seismic regions. It was found that the use of even very thin steel infill panels can significantly reduce storey drifts without significant increases in floor accelerations, and that low-yield steel behaves somewhat better than standard constructional grade steel under extreme seismic conditions, but at the cost of some extra material.

Alinia (2006) studied the effect of surrounding members on the overall behavior of thin steel plate shear walls. The results show that, unlike the present view, the flexural stiffness of surrounding members has no significant effect, either on elastic shear buckling or on the post-buckling behavior of shear walls.

Two independent research programs performed by Astaneh-Asl and his colleagues (1998-2002) on the ordinary steel and shear wall composited with concrete layer. The results of these researches show very desirable behavior of S.S.W. and also very ductile behavior of composite shear wall system with tension field action. According to published results, concrete layer produces a better distribution of stress in the steel plate developing tension field lines in a wider region.

3. NUMERICAL STUDIES

After several trial and error experiments, the optimum dimensions for the F.E. meshes are selected and the shear wall frame and steel plate are modeled. Beam and column meshing is designed so that the boundaries of the steel plate meshes coincide with the beam and column mesh to form a common joint. The elements are chosen to have elasto-plastic behavior so that off-plane buckling of steel plate could be modeled. Convergence criteria for forces and displacements are considered in the above models. So, the "SOLID" element's used for Fiber Reinforced Polymer (F.R.P.) layer. It has 6 degrees of freedom having the capability of warp ping being enforced as the seventh degree of freedom. 3-D “SHELL” element with four nodes and 6 degrees of freedom per node is chosen for steel materials [plates, beams and columns].

3.1. Loading

The specimens are cyclically loaded as shown in Table 1.

Table 1 Cyclic loading time history

Time(second)		Max. Load (KN)	Loading Shape	Frequencies (Hz.)
Start	End			
0	71	0	Cyclic	0
72	180	300	Cyclic	1/60
181	360	500	Cyclic	1/60
361	540	600	Cyclic	1/60
541	576	600	Cyclic	1
577	720	600	Cyclic	2
721	828	600	Cyclic	3
829	858	600	Rectangular	1
859	878	600	Rectangular	2
879	893	600	Rectangular	3

3.2. Numerical results of steel plate shear wall [N]

In this step, numerical models with similar scale to the experimental specimens are generated and analyzed by finite element method. Fig. 1 shows the Von-Misses stress in-plane and off-plane displacement results of 540th second.

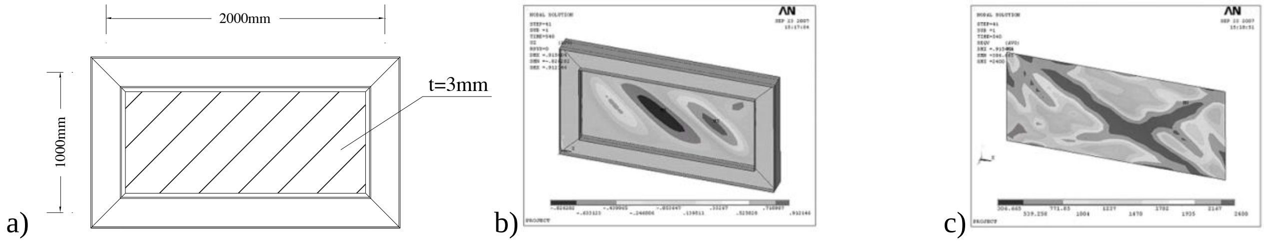


Figure 1 a) Dimension of Panel b) off-plane displacement c) Von-Misses in-plane stress of steel plate shear wall at 540th second

4. EXPERIMENTAL STUDIES

In this step, 3 experimental specimens are prepared and tested. All specimens are connected to the rigid frame & actuator for applying cyclic loading (table 1) as shown in Fig. 2. These specimens are flexure frame [F], steel shear wall [N] and steel shear wall composited with FRP layer [CSF]. Double I shape section steel profile that formed box section (2IPE200) are used strengthened by 12 mm steel plate on both flanges of beams and columns. Thickness of steel plate shear wall is 3 mm. In CSF specimen, there is no connector between the steel plate and the FRP layer other than epoxy resin. Steel and FRP characteristics are shown in Table 2. Thickness and weight per sq. area unite of the FRP layer is 0.176mm and 0.03N respectively. As shown in Fig. 1-a, the specimens dimension is 2 meter width and 1 meter height (Axis to Axis).

Table 2 Steel & FRP Characteristics

	Yield Point	Elastic Modules	Poison's Coefficient
Steel (Beam- Column- Plate)	235 MPa	206 MPa	0.3
FRP (main direct)	3800 MPa	240 GPa	-

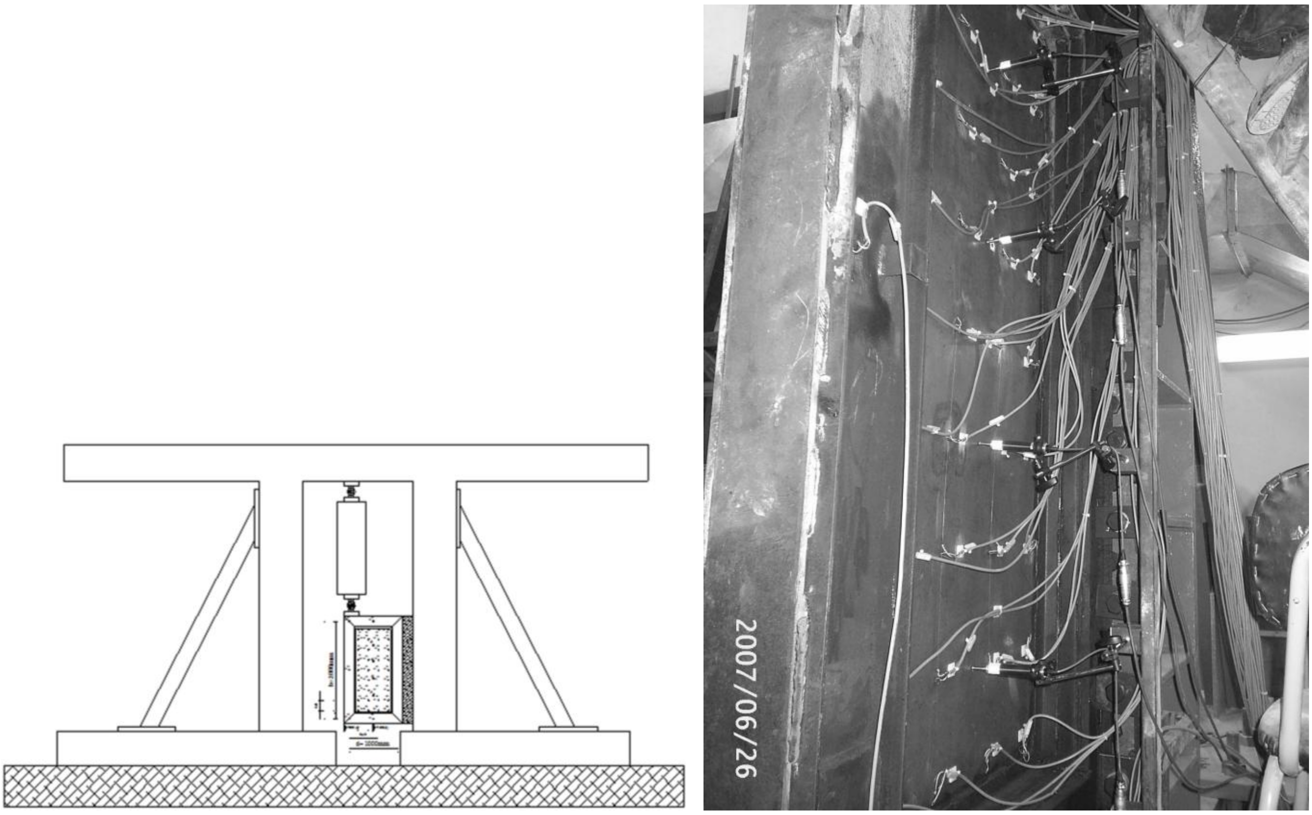
4.1. Experimental Results of Steel plate Shear Wall Specimen [N]

In this specimen, using at least 120 strain gauges and 5 displacement gauges (LVDT) with special cable shield for remittances data of steel frame and plate to data logger and extracted results. In sample N the existence of off-plane buckling and post buckling is visible. Maximum value of off-plane displacement is 8mm, which is quite appreciable; considering the thickness of the steel plate (3mm); however in the other samples, this value is less than 5mm.

4.2. Experimental Results of Steel plate shear Wall Composited with the FRP [CSF]

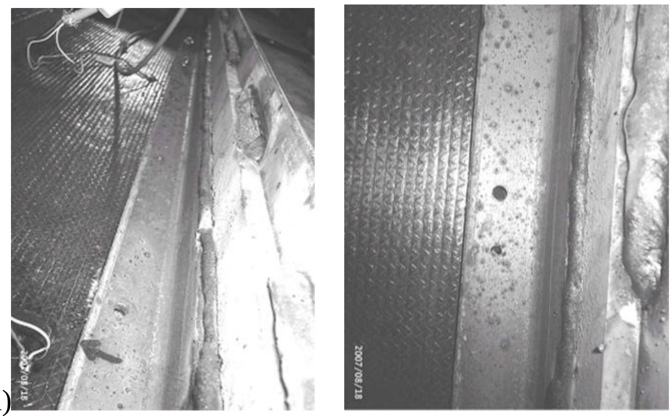
In this strengthen plate; the steel plate is roughened by sand blasting before being covered with the FRP layer is then superimposed to both sides of the steel plate laterally and longitudinally. Epoxy resin plus hardener with a certain ratio are used to glue the carbon fiber to the plate and care was taken to eliminate the air bubbles while gluing. Then, the steel plate composited with the FRP layer is placed inside the steel frame and sandwiched between two layers of pre-prepared L sections flanges, which are fastened together using 6mm bolts with 150mm spacing all around the composite plate.

As shown in Fig. 3-a, in sample CSF, the damage and destruction is little particularly in beam-column junctions. The destruction is even less than what is achieved in sample N, which indicates the stress distribution on steel plate. But in connections of the FRP-steel plate to boundary frame, some bolts are cut.



a) Test setup

b) Specimens
Figure 2


a)


b)

Figure 3 Demolition of connection in specimens a) FRP composite shear wall[CSF] b) Flexural Frame [F]

The existence of the FRP composite does not get involve in energy transfer of the frame, however it contributes positively in stress distribution over the steel plate. This involvement and distribution will have an increasing effect as the steel plate deformation progresses.

All displacement gauges in sample CSF that shows off-plane displacements, indicates that plate behavior is shifting towards post buckling condition, therefore post buckling behavior together with increasing energy absorption and its expansion can be expected to establish as loading increases.

4.3. Experimental Results of Flexural Frame [F]

As shown in Fig. 3-b, in sample F, the damage and destruction is huge particularly in beam-column and flexural frame junctions. The destruction is even more than what is achieved in sample N, which indicates the stress concentration in junctions. This destruction is due the extraordinary loading of the sample F.

5. COMPARISON OF THE NUMERICAL & EXPERIMENTAL RESULTS

5.1. Displacement of Steel Plate Results

Comparing the results numerical analyses with the experimental ones, numerical models were verified for analysis and modeling of samples with experimented scale. Figs. 4 & 5 compares the load-displacement of the numerical analysis with the experimental specimens in the end of top beam up to 540^{th} second for specimens of F & N. Note that the jump at the end of the experimental curve is due to entering the loading phase with high frequency. Recording the results similar to other data's because of data logger accuracy was not possible.

As shown in Fig. 5, the load-displacement curves up to 540^{th} second are plotted for comparison the experimental results. Relative area under hystersis curve of samples CSF, N and F is 0.6206, 0.4177 & 0.3431 respectively. Note that the Relative area under hystersis curve is reduced for samples N & F. This value in sample F is about %45 at compared with the sample CSF.

The discrepancy between lateral displacement in the 540^{th} second of loading in samples F (21.5mm) and N (8.9mm) is 12.6mm that this value is absorbed by steel plate. In fact, the steel plate and frame has absorbed about %37 & %63 of displacement respectively. This is in spite of having about %155 stiffness of sample N at compared with sample F. Also, the lateral displacement in sample CSF at this time (6.1mm) is %150 more than sample N.

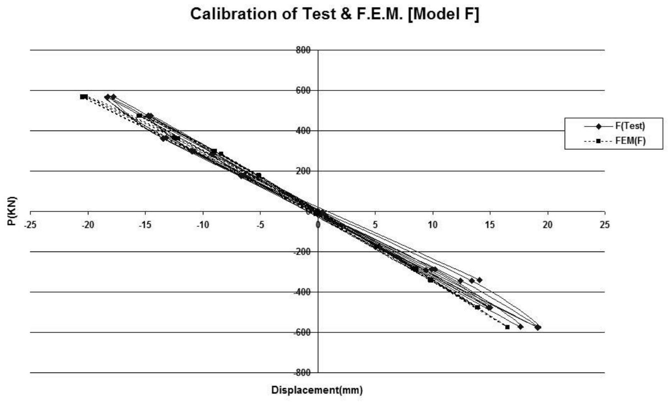


Figure 4 Comparison of experimental & F.E.M. results [F]

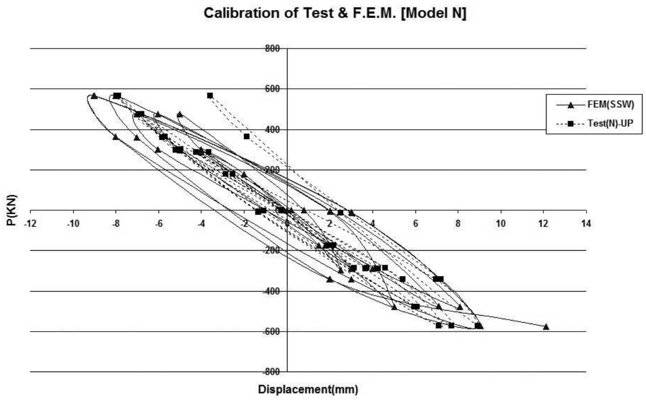


Figure 5 Comparison of experimental & F.E.M. results [N]

5.2. Displacement of Steel Frame Results

As shown in Fig. 6, in experimental sample F, in which all the forces and displacement are carried by the flexural frame, the displacement at middle of right column (near the actuator) is about 62 micro strain less than the sample CSF (408 micro strain), and in sample N (-41 micro strain). Also at middle of left column, the displacement of sample F is -157 micro strains, sample CSF is -9 micro strains and sample N is 48 micro strains. Hence comparing these points indicate the axial displacements of opposite columns in the frame. These two columns act as coupling force, transferring the load from the jack to the supports and the plate.

Hence, the maximum displacement and deformation is in the column, close to the lateral loading point. The axial displacement only occurs in sample CSF, i.e. interaction between the frame and composite plate exacerbates the frame deformation.

However in sample N, this axial deformation is reduced about %33. Also at the middle left column that is further away from the loading point, not only the axial deformation has been eliminated, but the column has been shortened to the same extent.

So, it is meaning that the plate has not managed to prevent the stress concentration in this phase of loading due to the destruction of the plate-frame junction. Also due to the separation of plate to frame junction all the forces in the plate-flexural frame is dissipated, in addition the potential of the columns is used appropriately, and the columns do not provide coupling action, therefore this stress concentration caused failure and rupturing of the junction bolts. At middle of top beam, in samples F, CSF, & N, axial deformation is -143, -150, & 55 micro strain respectively, i.e. at the time of maximum elastic displacements (540th second), this data on the F is under 143 micro strain compression, This value in sample N in conjunction with the steel plate, is changed to 55 micro strain of tension. This indicates the positive interaction between frame and the plate (Fig. 6).

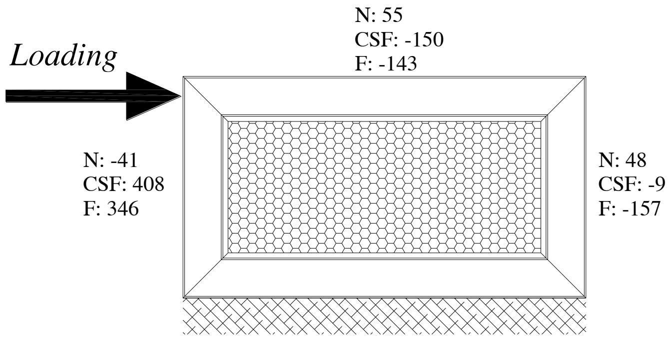


Figure 6 Displacement of experimental steel frame in middle of beam & column (Micro Strain)at 540th second of cyclic loading in samples N, CSF & F

5.3. Stiffness, Ductility & Energy Absorption of Panel

As shown in Fig. 7, load-displacement push over diagram is plotted for specimens of N & CSF from numerical results. The stiffnesses, ductility & energy absorption of all specimen using the maximum load and maximum displacement at the end of loading is shown in table 3. In fact, the steel plate despite having 35.6 % of the stiffness, contributes in sustaining only 26 % of the displacement of the whole panel. Also, as shown in table 3, stiffness, ductility & energy absorption ratio of CSF / N is 1.5, 0.92 & 1.37 respectively.

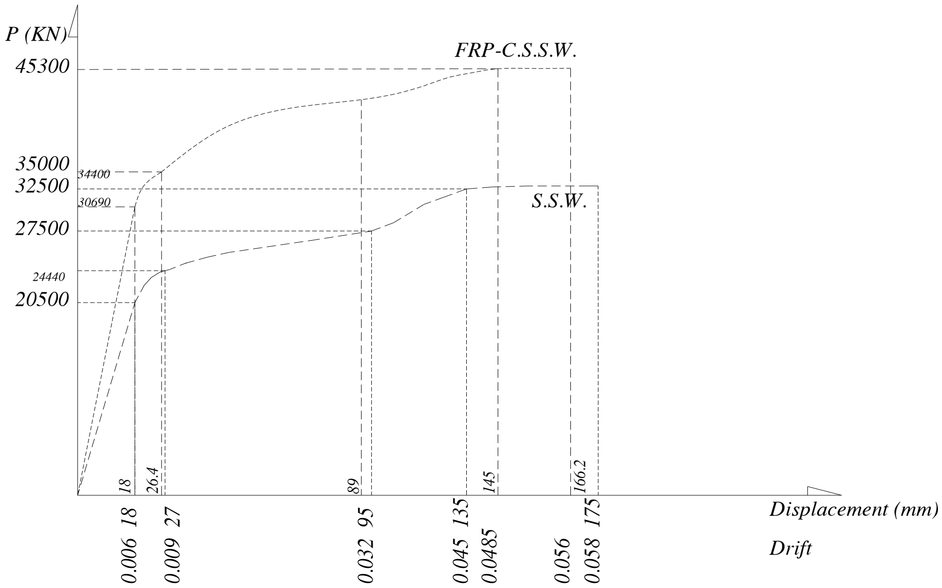


Figure 7 Numerical load-displacement push over diagram in specimens N (SSW) and CSF (FRP-CSSW)

Table 3 Comparison of Stiffness, Ductility & Energy Absorption

Specimen	F	N	CSF	Steel Plate	CSF / N
Stiffness; $K = \frac{F}{\Delta}$ (KN/mm)	733.5	1139	1705	405.5	1.5
Ductility	3.4	8.14	7.48	-	0.92
Energy Absorption (KN.mm)	1175383	4369670	5963999	-	1.37

6. CONCLUSION

In this paper two parallel experiments with numerical and experimental models were studied. In this regard, 3 models of steel shear wall (S.S.W.), steel plate shear wall composited with fiber reinforced polymer (C.S.F.) & flexible frame (F) was built as 2meter width & 1meter height using the finite element method (F.E.M.). So, these walls are tested with laboratory equipments under cyclic loading. The FRP plate can lead the global tension field action towards the local flexure of the steel plate, effectively contributes more in resisting the shear stresses, extension of post buckling lines in steel plate and formation of composite shear wall. Through analyzing the influence of the FRP layer on behavior of S.S.W., indicated that this FRP layer, acts as stiffener on the steel plate of shear wall, would increase the stiffness and energy absorption of C.S.S.W. by a factor of 1.5 & 1.37 respectively as compared with S.S.W. Therefore, adding the FRP layer would reduce the value of the steel off-plane displacement and maximum normal stress on steel plate. And so, The FRP layer will be insignificant decreasing (about %8) the ductility of S.S.W.

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