Dicle University
Journal of Engineering
https://dergipark.org.tr/tr/pub/dumf
duje.dicle.edu.tr

Research Article

Experimental Investigation of CFRP-Reinforced Steel Plate Shear Walls Under Cyclic Loadings and the Failure of Connections Between CFRP to Steel

Said DUSAK[1*], Cem Yalçın[2]

[1]Sakarya University, Institute of Natural Sciences, Sakarya, Turkey - sdusak@gmail.com, Orcid No: 0000-0002-6903-1695
[2]Bogazici University, Department of Civil Engineering, Istanbul, Turkey-yalcince@boun.edu.tr, Orcid No: 0000-0003-3142-8125

ARTICLE INFO

Article history:

Received 14 Eylül 2023
Received in revised form 21 Ekim 2023
Accepted 21 Ekim 2023
Available online 31 December 2023

Keywords:

Steel plate shear wall, Composite panel shear wall, CFRP, Energy dissipation

Doi: 10.24012/dumf.1358193

* Corresponding author

ABSTRACT

Steel plate shear walls, as an innovative lateral load resisting system, are widely used in the world. Various configurations have been tried by researchers to increase the shear capacity of steel plate shear walls. In similar studies, it is aimed to obtain better results by changing the material and connection properties of the frame and infill panel. In this study, carbon fiber-reinforced polymer textile (CFRP) is used between two steel infill plates to increase load capacity, ductility and energy dissipation of steel plate shear walls. A specimen of composite plate shear wall through epoxy bonding between two steel plates in a steel frame was prepared, and cyclic loading was applied. The finite element model of the specimen without CFRP textile was prepared, and an in-plane pushover analysis was conducted. The load-displacement curves obtained from the analysis of the model were compared with the experimentally obtained CFRP textile added specimen, and they were found to be in a good agreement. In conclusion, as a result of the addition of CFRP textile to the steel plate shear wall, it was observed that the carbon fiber reinforced polymer delaminated from the plate surface, and its contribution to the system behavior remained limited. The maximum load capacity of the control specimen was 347 kN, 334 kN was obtained in the specimen using CFRP. According to these results, theoretically, the addition of carbon polymer textile to the infill plate increases the strength of the tensile strips, resulting in a higher base shear capacity. However, the expected results cannot be obtained because the adhesive used failure during installation and eliminates the unity of the steel plate and carbon polymer fabric. As a result, it has been observed that to obtain the expected contribution, it is important to ensure that the steel plate and the textile must have full bonding and act as a composite material.

Introduction

From the time when Wagner (1931) first introduced the idea of using thin plates in moment resisting frames having the main principle that thin steel plates continue to carry lateral loads after buckling, studies were carried out on shear walls formed by placing thin steel plates in the frames [1]. Analytical and experimental research on steel plate shear walls has been carried out since the 1970s [2]. The most important feature of steel plate shear walls is that they dissipate energy, and thus, increase the ductility of the steel frames. In order to improve the behavior of thin steel plates, which are subjected to in-plane shear, studies conducted on composite panel shear walls by using steel plates in combination with other high-strength materials. M. K. Poul and F. N. Alahi conducted nonlinear analysis of the steel plate shear wall reinforced with FRP laminated plates and developed the interaction method of the frame and composite panel to determine the shear strength of the composite panels [3]. Although there are many studies on steel plate shear walls, there are fewer studies on composite panel shear walls [4,5,6]. As an innovative method, the use of fibre-reinforced polymer (FRP) together with plate has been investigated through theoretical studies. Due to their lightness, high strength and contribution to rigidity, laminated composite plate shear walls have been developed as an alternative to steel plate shear walls [7]. It is desired that the fiber-reinforced polymer plate or textile provides additional strength to the steel tensile strength, parallel to the tension direction of the steel plate shear wall. In one study, it was reported that the best results were obtained when the FRP strips were placed in the fiber direction of both sides and that the fibers began to transfer load after the steel plate completely yielded, and a 20% increase in shear capacity and 10% increase in rigidity were achieved [8]. There are also studies carried out by placing different types of polymer strips, such as glass fiber reinforced polymer (GFRP) between the double plates. The model was prepared by bonding GFRP strips between two plates in a single-story, single-bay frame, and it was reported at the end of the study that an increase was observed in the shear capacity and rigidity of the steel plate shear wall model and that it improved the hysteresis behavior [9,10]. Openings such as doors or windows are required inside the steel plate share walls, which are an effective lateral load carrying system. In those cases, according to the AISC regulations [11], the tear at the corners must be reinforced by steel plates in order to reduce the stress condensation deteriorated due to the tears. Studies examining the behavior when FRP laminates were utilized as edge reinforcement instead of steel in these window and door openings were carried out. Alipour, Mohamad, and Rahai, Alireza, in their study, demonstrated that the FRP plate prevents stress condensation on the tear corners, provides continuity, and increases the rigidity and strength of the system [12]. Considering the difficulties of steel reinforcements that require welding, this method has been noted to be equally efficient. CFRP plates are used to improve the compressive strength of different geometric structures for reinforcement purposes. 14 different models using CFRP laminates in different thicknesses and angles in cylindrical thin-walled shell structures were developed and subjected to compressive stress from the outer surface. As a result of this strengthening, it was stated that the buckling capacity improved by 77% and the collapse capacity improved by up to 86% [13]. In another study, it was shown that CFRP elements started to buckle at higher load values by using different thicknesses in thin-walled steel storage structures [14]. In a study conducted to demonstrate the interaction of the frame and infill plate in composite FRP-steel plate shear walls, the FRP polymers added to strengthen the infill plate increased the strength, energy damping capacity and secant stiffness of the system, but had no effect on the initial stiffness or had a negative effect. Regarding the frame-infill plate interaction, the use of FRP caused a slight increase in stress in the frame, which increased the effectiveness of the infill wall at the beginning of the loading. In addition, while the use of FRP in single-storey SPSW only affects the behavior of the infill plate, it has been stated that in multi-storey SPSW, it affects both the infill plate and frame behavior because the interaction is high [14,16]. Post-buckling behavior was examined by adding GFRP to steel plate shear walls, which are horizontal load bearing elements obtained by adding wood or steel plates into the moment frames. It has been observed that the benefits in initial stiffness and displacements decrease inversely as the rigidity of the frames increases. The lowest increase in horizontal load capacity was 16% in the stiffest frame with 0° FRP fiber orientation. When the FRP fiber orientation is in the same direction as the tensile rods, the initial stiffness and load capacity reach the highest value [17].

Considering the studies on this subject, carbon fiber reinforced polymer textile (CFRP) was placed between two steel plates involves the scope of this study in order to contribute to the infill plate properties of steel plate shear walls. A specimen was prepared and experimentally subjected to cyclic loading, in which a pair of steel plates, obtained by using the fiber-reinforced polymer textile between steel plates through epoxy, was attached to the frame as a composite panel. The prepared specimen represents the intermediate floor of a single-story, single-bay, 1/3 scale and multi-story building. The behavior of this specimen under cyclic loads, initial rigidity, ductility, maximum load capacity and energy dissipation capacity have been experimentally and analytically investigated and compared.

2. Test setup and design of specimen

To increase the shear and energy absorption capacity of steel plate shear walls, a panel was obtained by gluing carbon polymer textile between two thin steel plates. This panel was placed in a steel frame as the panel of the steel plate shear wall and cyclic loading was applied. A one-story, one-bay and semi-rigid steel frame was designed. Pinned beam-to-column connection was prepared to be utilized as the test specimen. It was desired to examine the effect of infill plates on the frame. For this purpose, frame sections were selected so that the frame elements would not yield before the steel plates yielded. HEA260 sections were selected for the columns and HEA240 sections for the frame beams. L75x120x12 profiles were chosen for beam-to-column and frame-panel connections. In the frame as infill panel, a panel with bidirectional CFRP textile fixed with epoxy was placed inside double steel plates at a horizontal angle of 90°. In addition, as the control specimen, a comparison was made with the steel plate shear wall, in which only a 1.00 mm-thick single plate was used. The physical characteristics of these specimens are shown in Table 1. In order to clearly understand the contribution of the infill panel to the frame, a semi-rigid beam-to-column connection that acts almost like a pin was preferred.

The connection of the infill panel and the steel frame was made with self-drilling screws. In this way, easy replacement of plates that were deteriorated subsequent to loading would be allowed via only the connection bolts. The use of welded connection was not preferred as it may lead to local heat-related deformations in carbon fiber reinforced polymer textile. Additionally, as it was reported in the studies that the use of self-drilling screws, which did not require a hole preparation prior to the connection, was an alternative method and that it provided sufficient performance, a connection of M6 (6-mm diameter) bolts with 40mm spacing was preferred in the frame and plate joint region [18]. Test specimens were fastened to the concrete foundation with clevises. Experiments were carried out in Bogaziçi University Structural and Materials Laboratories. The laboratory was equipped with 2000kN-capacity reaction wall and a 1000kN-capacity dynamic actuator of with150-mm stroke in both directions. The test setup is given in Figure 1, while the steel plate shear wall specimen with CFRP addition is presented in Figure 2. During testing, out-of-plane deformations of the specimens were prevented via a rigid frame attached to the main setup. Figure 3 shows the preparation of the panel through CFRP textile and lamination used in the CLB specimen that was obtained by fixing between two 0.50 mm plates with epoxy adhesive.

Tension tests were conducted by taking coupons from steel infill plates. Table 2 lists the average and standard deviation values of the material properties. These values are used in the finite element model. S275 steel for frame profiles; S235 quality steel was used in the infill plates. 10.9 class steel was used in the frame bolts.

Carbon fibers have high tensile strength. For this reason, it is used in many areas such as construction, especially in strengthening buildings against earthquakes. Brought together, carbon fibers are used in the form of tape, plaque, strip or fabric. It is possible to obtain very light construction materials with a tensile strength approximately ten times higher compared to steel with an equivalent cross sectional area. In this study, as the steel plate placed in the frame acted as tension strips under shear stress, CFRP textile was used to increase the capacity of those strips. A composite panel was obtained through 600gr/m^2 bidirectional CFRP textile mounted with the help of epoxy between two 0.5mm steel plates. The technical properties of this CFRP textile are given in Table 3.

Table 1 – Test specimens and their properties

Specimen Name	Specimen Details	Panel/Plate Thickness	Infill Property
Control Specimen	Single Steel Plate Shear Wall (TL)	t=1.0mm	1.0mm Steel Plate
Specimen 1	Double Layer Steel Plate Shear Wall with CFRP (CLB)	t=0.5mm+CFRP+t=0.5mm	0.5mm Steel Plate + CFRP Textile + 0.5mm Steel Plate

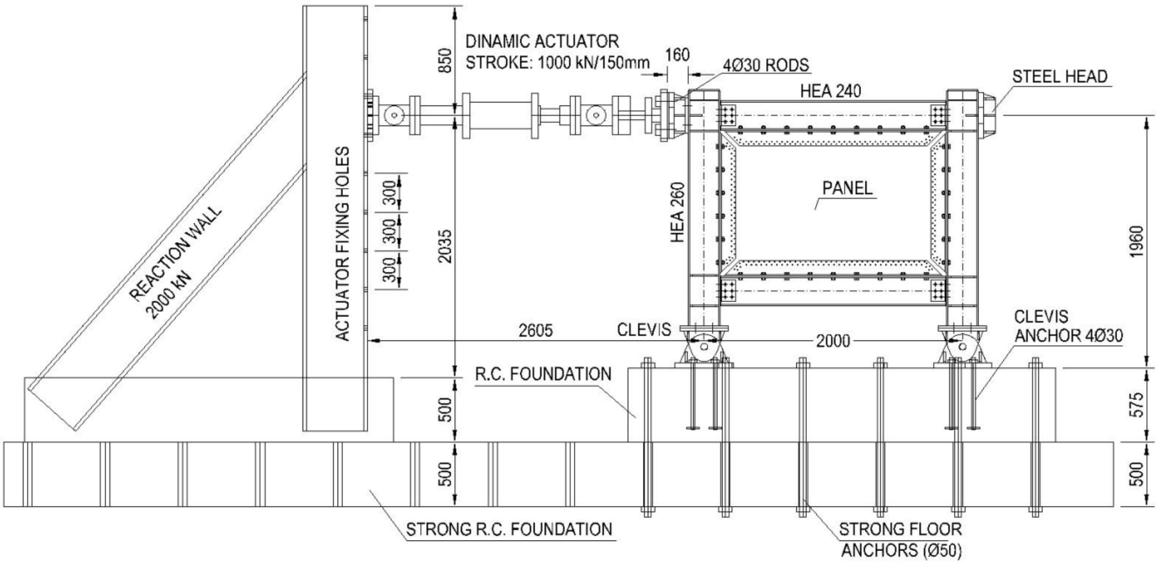


Figure 1. Test Setup (Dimensions are in mm)

Figure 2. CLB specimen double-layer steel plate shear wall with CFRP (+2/3*δy; 4.02 mm)

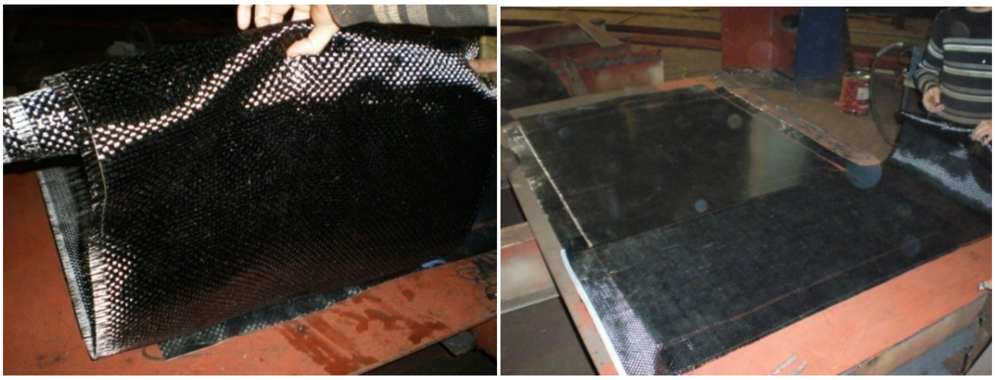


Figure 3. CFRP textile used in the CLB specimen and placing the fabric inside the double steel plates using epoxy

Table 2. Tensile Test Results of Steel Plates plates

Specimen No.	**1**	**2**	**3**	**Mean**	**Standard Deviation**
Thickness (mm)	0.50	0.50	0,50		
Width (mm)	25.00	25.00	25.00		
Yield Stress (MPa)	296	365	330	330.3	34.34
Ultimate Stress (MPa)	416	404	369	396.3	24.51

Table 1. Technical properties of the CFRP textile

Color	Black
Type	Bidirectional fabric textile
Unit Weight (gr/m^2)	600
Mean Thickness (mm)	0.34
Ultimate Stress (MPa)	392
Elasticity Modulus (Mpa)	230 000

3. Finite element model

Finite element model analysis was performed to see how the specimens behave when experimental cyclic loading is applied. In this way, a comprehensive comparison was made with the experimental results. ABAQUS Standard (Hibbit et al.) software [19] was used to prepare the finite element models of non-CFRP specimens. Likewise, the strip model was created using SAP2000 structural analysis software [20]. Since the plate turns into diagonal strips when shear load is applied along its own plane, in the Strip model the strips are defined as pin-ended elements that can only for axial tensile loads.

Equation 1 is a formula used to calculate the inclination angles of steel plates [21]. The inclination angle of the steel plates was calculated as 46° according to this formula. Strip elements were analyzed in this way. The cross-sectional area of each strip is found by multiplying the plate thickness and the width of the tension area.

$$\tan^4\alpha = \frac{1+\frac{t_p L}{2A_c}}{1+t_w h\left(\frac{1}{A_b}+\frac{h^3}{360 I_c L}\right)} \qquad (1)$$

A : Strip angle
t_p : Steel Plate thickness
L : Specimen width
A_c : Column section area
H : Specimen height
A_b : Beam section area
I_c : Column inertia moment

The beam-to-column connection of the bare frame was defined in both models and the analysis results were calibrated with the test results.

Steel plate and sandwich panel shear wall samples were modeled by adding infill plates. Although the presence of fiber polymer material was not taken into account in the modeling process, the difference between the model and test results clearly revealed the contribution of CFRP textile. In the strip model, a total of 11 parallel tension strips with a 200 mm wide tension area are defined as in Figure 4. The strip model was used in specimen design. In the finite element model, the S4R shell element was used to define the column and beam elements of the frame, and the S8R5 shell element was used to define only the thin plates. Figure 5 shows the finite element model. Figure 6 shows the load-displacement curve obtained as a result of the analysis of the model. The specimen representing the plates on both sides of the panel that was obtained by using CFRP acted very similar to the specimen of the steel plate shear wall. Increasing load values were obtained with increasing displacement values in cyclic loading. At the ultimate value, the infill plate was torn and failed. The results obtained from the finite element model will be compared with the experimental results in Section 5.

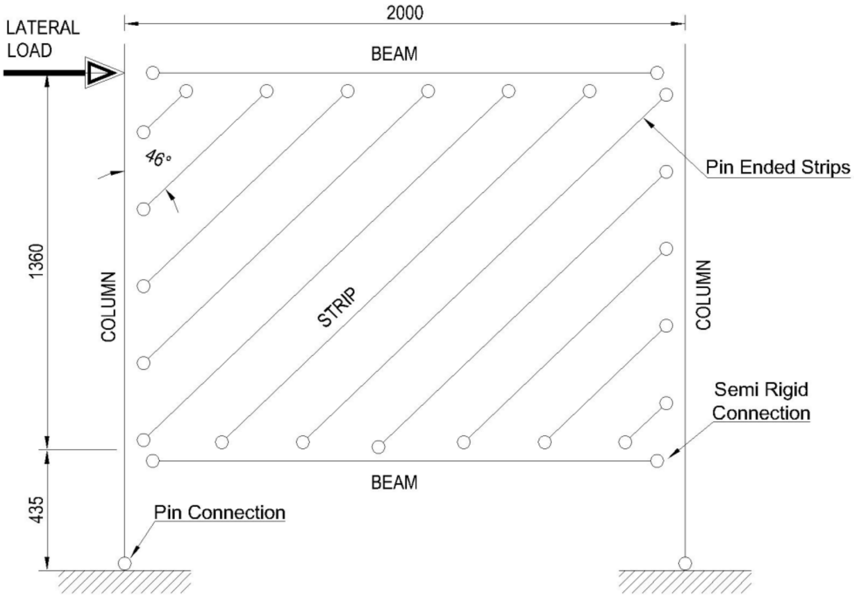


Figure 4. Strip model of Specimen (Dims are in mm)

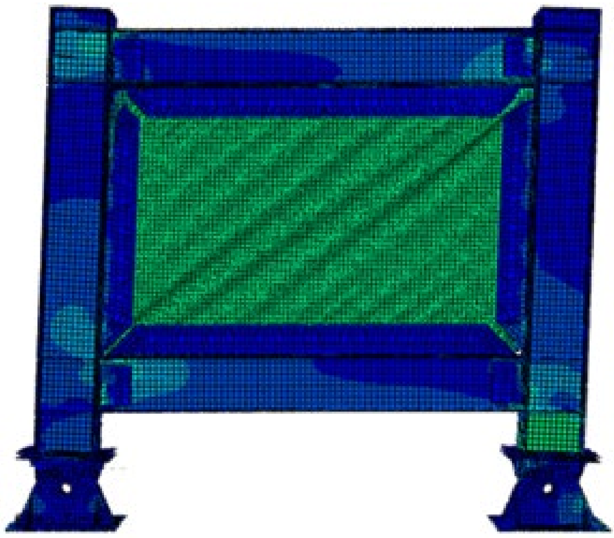


Figure 5. Finite element model of specimen

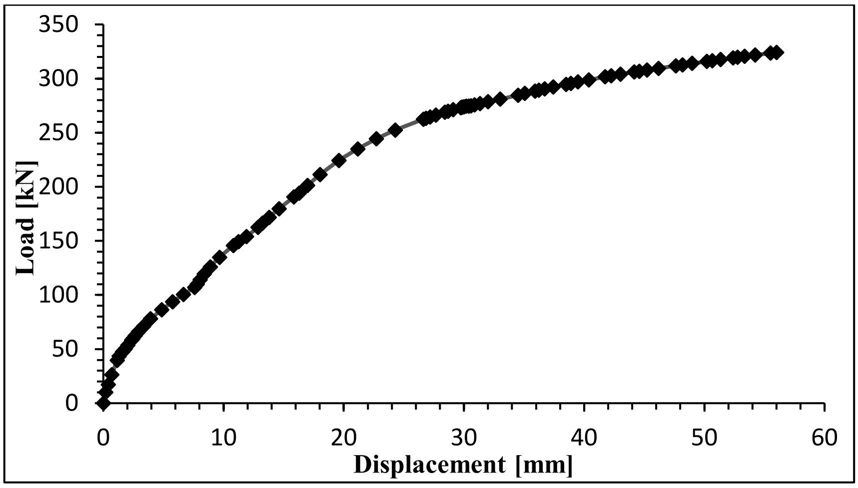


Figure 6. Load-displacement curve of FEM analyses

4. Experimental study and test results

The stresses and displacements obtained during cyclic loading were collected and evaluated. This section introduces the experimental results by discussing the experimental observations and collected outputs. Quasi-static cyclic loading was applied in accordance with ATC-24 regulation [22]. The displacement value, which corresponds to 0.75 times the yield load of the system, was determined as δ*. Cyclic loading increased step by step compared to ATC24. These steps are multiples of δ*. First step; 1/3 of δ*, second step; 2/3 of δ*, third step; it is applied as 1 δ*. The next steps are increased by integer multiples of δ*. A total of three cyclic loadings were applied for each displacement value. The loading protocol is presented in Table 4.

Following the increasing drift values of the experiment, deformations such as separation and crushing were observed between the beam web connection angle and the column flange in the beam-to-column connections. These changes indicated plasticization around the bolt hole on the web of the beam. No deformation was observed in the beam-to-column connection apart from the beam web was yielded around the bolt hole. The test specimen subjected to cyclic loading specified in the loading protocol showed a ductile behavior and was close to the single-plate specimen, which is the control specimen of this study. However, lower initial stiffness and maximum base shear were obtained as the combination of the plate, and polymer fabric did not provide sufficient response. In the first cycles, the specimen showed elastic behavior, and the load-displacement graph in all three cycles followed a very close path to each other. The cyclic graph is given in Figure 7.

At the +1*δy displacement step (0.32% drift; 6.02 mm top displacement), the tension fields became prominent, and there were strains around the screws at the plate-to-fisher plate connection. At this displacement value, base shears of 68.56 kN in push and 82.06 kN in pull direction were obtained in the first cycle. The difference between the load values in the pushing and pulling directions for the first three displacements could be interpreted as the effect of the FRP textile used for these steps. At +5*δy displacement step (1.61%; 30.07 mm), a load of 263.22 kN in push and 255.05 kN in pull direction was obtained in the first cycle. At this stage, it was possible to observe permanent deformation of the plates subsequent to buckling, especially around the bolts and at the corners of the plate. At +9*δy displacement step (2.91%; 54.16 mm), a load of 323.14 kN in the pushing direction and 327.62 kN in the pulling direction were obtained in the first cycle, and tears formed due to repeated loading and repeated deformation of the tension field modes on the plate. Small crushes and tears formed around the bolts enlarged to 20-mm in size, and the tear between the bolts in the lower left corner merged to form a 50mm long tear (Figure 8).

At +10*δy displacement step (3.19%; 59.36 mm), in the first cycle, the load increased in the pushing direction to 334.12 kN, and decreased in pulling to 264.70 kN. In response to the decrease in load, tears on the bolt connection and plate increased in the pulling direction, while no tears were formed at this scale in the pushing (Figure 9). In the second and third cycles, there was a decrease of 51% (from 238,59 kN to 165,65 kN) in the pushing, while in the pull direction, it decreased to 181.15 kN and 153.35 kN, respectively, and there occurred a 53% decline in the value of maximum load capacity. These sudden load drops coincide with the tearings on the plate. Although the maximum load capacity decreased by more than 50% at the end of the third cycle in the previous displacement step, the experiment was continued one more step by increasing the displacement to see the possible effect of the CFRP textile between the two plates. At +11*δy displacement step (3.53% drift; 65.75 mm top displacement), values of 163.85 kN, 139.69 kN, 130.49 kN in push direction, and values of 135.03 kN, 96.77 kN, 93.86 kN in pull direction were obtained in last three cycles. The plate was torn 150 mm from the lower right and left corners. At this stage, the plates were mostly torn from the connection screws and repeated buckling area and acted similarly to the single-plate specimen. The test was terminated at this stage, as the load obtained in the last cycles of this displacement value decreased by 61% in the push and by 72% in the pull directions of the highest values reached during the loading.

The view of the single plate, which is the control specimen, at a displacement of +5*δy is shown in Figure 10. The single-plate specimen showed less crushing and tearing at the same displacement step than that of the specimen reinforced with carbon fiber polymer textile fabric.

Table 4. Cyclic loading histories of the CLB specimen

Displacement Steps	Number of Cycles	Cumulative Num. of Cycles	Relative Disp. Ratio to δ_y (Δ/δ_y)	Relative Disp. [mm]	Top Disp. [mm]	Drift (%)
1	3	3	0.34	1.45	1.98	0.11
2	3	6	0.67	2.93	4.02	0.22
3	3	9	1	4.39	6.02	0.32
4	3	12	2	8.77	12.02	0.65
5	3	15	3	13.13	17.99	0.97
6	3	18	4	17.57	24.07	1.29
7	3	21	5	21.95	30.07	1.61

8	3	24	6	26.52	36.33	1.95
9	3	27	7	30.74	42.11	2.26
10	3	30	8	35.14	48.14	2.58
11	3	33	9	39.53	54.16	2.91
12	3	36	10	43.33	59.36	3.19
13	3	39	11	48.00	65.75	3.53

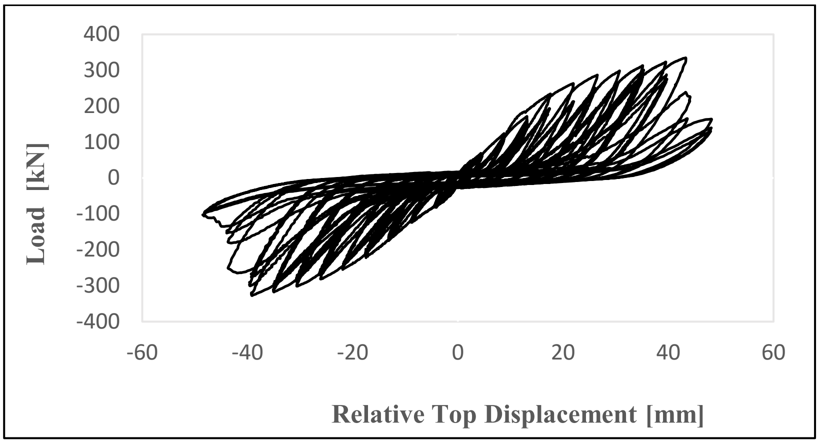
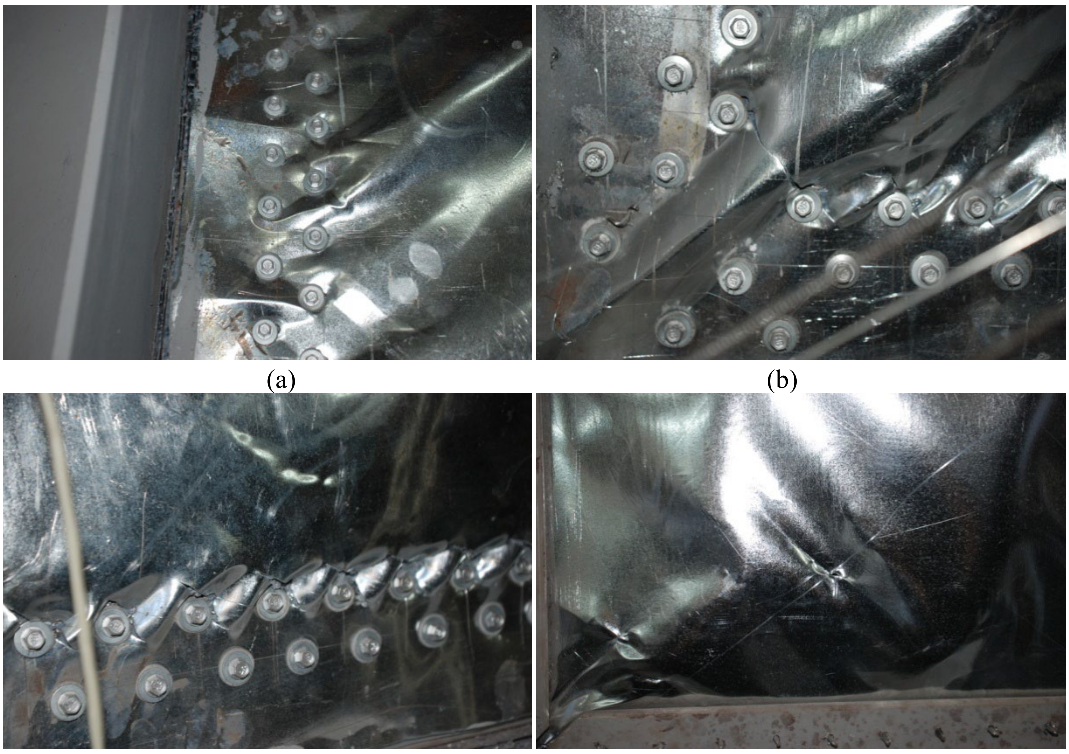


Figure 7.Cyclic load graph of the CLB specimen (double layer steel plate shear wall with CFRP)



(a) (b)

(c) (d)

Figure 8. CLB specimen (+9*δy) step (a) tears around the lower left bolt connection (10mm) (b) merging tearing around the lower left bolt 50 mm (c) tears around the lower bolt edge (20mm) (d) tears from the lower left plate

(a) (b)

Figure 9. CLB specimen (+10*δy) step (a) 80 mm tearing from the lower left edge (b) no tearing at the lower right edge

Figure 10. General view of the TL specimen at the +5*δy displacement step (30.13 mm)

5. Result's Comparison and Discussion

The data obtained as a result of the experimental study were compared with the analysis results obtained from the analytical study. The cyclic load-displacement envelope curves of the 1.00 mm thin single-plate TL specimen [23], which was the control specimen, and the specimen with two 0.5 mm thin steel plates, in which a carbon fiber reinforced polymer textile (CFRP) was placed, are compared in Figure 11. It was seen that it acted similarly to the single plate TL, which was the control specimen. For all displacement steps, similar stiffness and load values were obtained, following close paths in both directions. The load values obtained in the first cycles of each displacement step for the CLB specimen are given in Table 5. In the CLB sample, 0.5 mm thin plates yielded around the bolt at lower load values than 1.00 mm thin single plates. For this reason, they lost their maximum load capacity from very early values.

As a result of this comparison, it was concluded that the contribution of the CFRP test specimen to the initial stiffness and load values remained limited when compared with the single steel-plate specimen following the cyclic loading. The infill plate of the control specimen failed at a larger displacement than the specimen with CFRP. Therefore, in this study, it was concluded that the addition of fiber polymer textile did not increase the base shear capacity of the steel plate shear wall. If better combination is achieved, fiber polymer fabrics can be used. The maximum load capacity of the specimen under the load applied is given in the table created for certain drift ratio values, comparing it with the control specimen (Table 6).

The cyclic envelope curve of the push directions of the CLB specimen obtained as a result of the experimental study and the curve obtained from the analytical study are shown in Figure 12 on the same graph. Experimental and analytical curves of load-displacement relationships were very close to each other, and the analytical model curve remained below the experimental curve after 5δy displacement value. It can be concluded that the analytical results for this model were congruent with the experimental results within sufficient approximation. The load, where the system lost its load capacity, was obtained at a degree of 3% closeness in the analytical solution.

The graphs of the energy absorbed by the composite plate shear wall, which was the area scanned by the cyclic load-drift graph, were drawn. The energy dissipation capacity of buildings under lateral loads is the basis of performance-based design [18]. Hence, energy dissipation amounts under cyclic lateral loads, which were administered in accordance with the loading protocol of the test specimens, were one of the most important parameters used in the comparison of the results. Along with the control specimen of the test result, the cumulative dissipated energy of the first cycles is presented in Figure 13 according to the drift ratios. A significant increase in the dissipated energy was observed after the 9th cycle when yielding began. Yielding by tearing the plates around the bolt connections, energy was consumed.

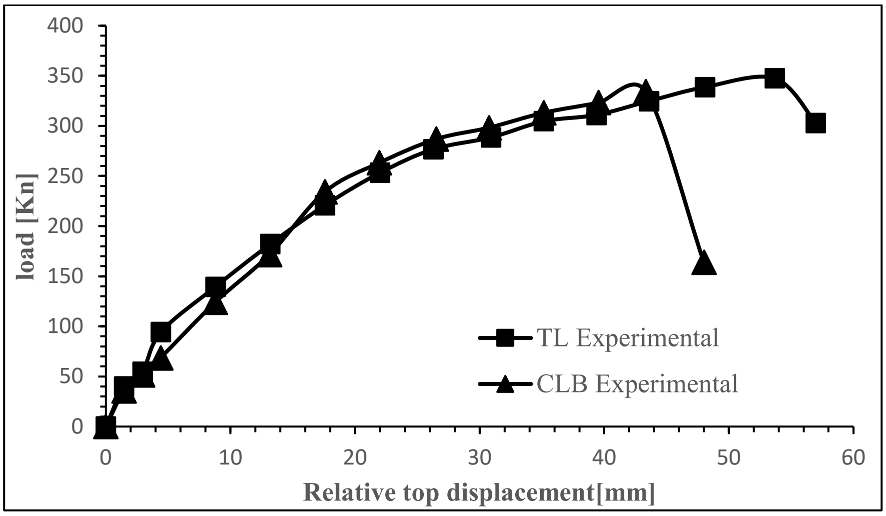


Figure 11. Comparison of push direction cyclic envelope curves of TL and CLB test specimens

Table 5. Displacement – load values of the CLB specimen in the push direction

Drift (%)	Relative Displacement[mm]	Load [KN]
0.00	0.00	0.00
0.11	1.45	35.44
0.22	2.93	51.42
0.32	4.39	68.57
0.65	8.77	123.96
0.97	13.13	171.71
1.29	17.57	234.13
1.61	21.95	263.22
1.95	26.52	286.89
2.26	30.74	298.21
2.58	35.14	313.14
2.91	39.53	323.15
3.19	43.33	334.13
3.53	48.00	163.85

Table 6. Load values by drift ratio (kN)

Drift [%]	Specimen TL	Specimen CLB
0.25	67,02	56.90
0.50	118.89	99.01
0.75	153.09	139.59
1.00	185.64	178.29
1.25	215.66	226.08
1.50	241.48	252.92
1.75	263.10	272.80
2.00	279.06	288.71
2.25	287.75	297.83
2.50	300.27	309.27
3.00	315.65	326.80
3.50	337.21	
4.00	344.67	

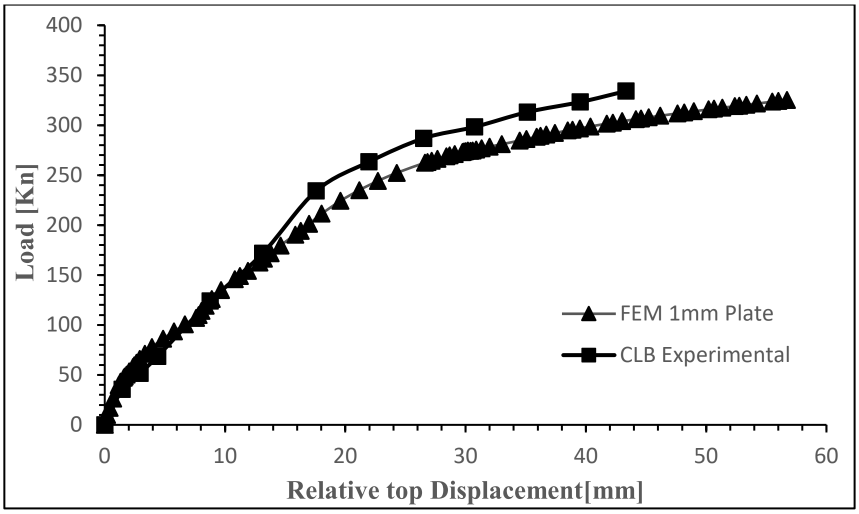


Figure12.Comparison of experimental envelope curves of the specimen with analytical results

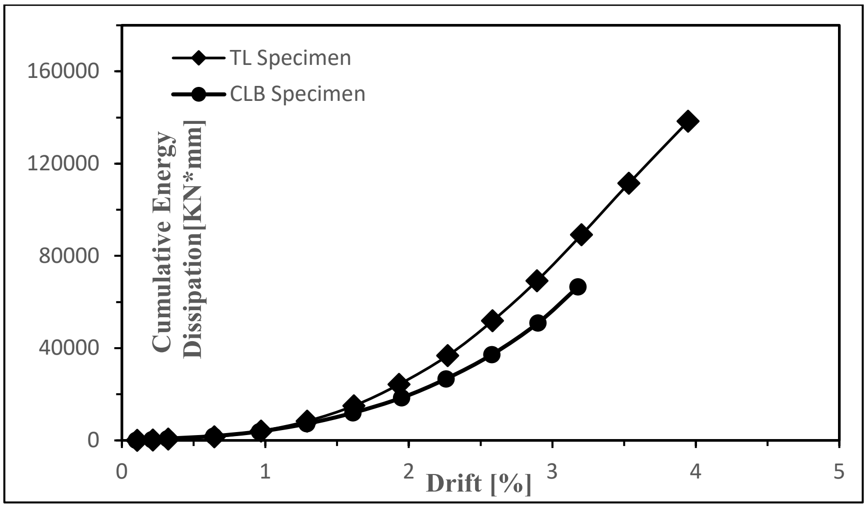


Figure 13. Comparison of the cumulative dissipated energy

6. Conclusions

In this study, a double plate with the same total thickness as the control specimen and a bidirectional CFRP textile bonded between the two plates was used. In the event that the CFRP textiles were used together with steel plate share walls, the effect of the CFRP on the system behavior by moving in the same direction while the steel plate acted as a tension strip was investigated. The stiffness, maximum load capacity, dissipated energy amount and other outputs obtained from the experimental studies were compared with the analytical study results, and in the light of the data, the system behavior during the experiment phase was evaluated. A consistency was found between the FEM analysis results and the experimental results. In the CLB specimen, a double plate with the same total thickness as the other specimens, and on which bi-directional CFRP textile was placed by epoxy bonding between the two plates, was used. In this way, in the event that the CFRP textiles were used together with steel plate share walls, the effect of the fibers on the system behavior by moving in the same direction while the steel plate acted as a tension strip was investigated. According to the load displacement graph obtained, for the same drift ratio compared to the 1.00 mm single-plate specimen, the failure load was reached earlier, and it was observed that the fibre-reinforced polymer was delaminated from the plate surface and its contribution to the system behavior remained limited. The control specimen and the specimen using CFRP were compared in terms of initial stiffness, load and dissipated energy. The control specimen carried 315 kN for 3% drift, while the specimen using CFRP carried 326 kN. While the maximum load capacity of the control specimen was 347 kN, 334 kN was obtained in the specimen using CFRP. While the initial stiffness of the control specimen was 27,43 kN/mm, it was calculated as 24,50 kN/mm for the specimen using CFRP. While the cumulative energy dissipated at 3.2% drift in the control specimen was 89.230 kNmm, it was found to be 66.627 kNmm in the specimen using CFRP. The similarity of these values showed that the effect of CFRP addition on the system behavior was limited. The reason for the low values is that the thin steel plates of the CLB specimen is torn at a lower load. Here, as in the single-plate specimen, the failure mode of the system was realized as the screw edge crushed at the plate-to-frame connection and torn from the screw connection net section. In conclusion, the important findings obtained from our study can be summarized as follows: carbon fiber polymer or similar reinforced textiles with higher tensile strength can be used to provide the behavior of tension strip adjacent to the plates, but very high base shear strengths can be obtained by improving the connection conditions to the plate and the frame.

To summarize, this study was carried out to increase the energy absorption and load carrying capacity of steel plate shear walls. For this purpose, it was desired to benefit from the high tensile strength of carbon fibers. These carbon fibers are added to the steel plates in the steel frame with a strong adhesive between the two plates. When the steel plate shear wall specimen was subjected to cyclic loading, the adhesive failed and from then on the steel plate and carbon fibers behaved independently of each other. Based on the data and analysis results obtained from the experimental study, the infill plate could not be strengthened by gluing. By developing different combination conditions in steel plate shear walls, the high tensile strength of carbon fibers can be utilized.

Acknowledgements

The authors would like to thank the friendly staff of Boğaziçi University Structure and Materials Laboratory, where we carried out the experimental studies. We would like to thank ArcelorMittal RZK for providing all steel profiles free of charge and Çağla Mühendislik for manufacturing the samples. The authors would like to thank Sakarya University Scientific Research Projects Unit for the project support numbered 2007-50-02-022.

References

[1] Wagner, H., 1931. Flat sheet metal girders with very thin metal webs, part I-General theories and assumptions, Technical Memorandum, No. 604, National Advisory Committee for Aeronautics, Washington, DC.

[2] Mimura, H. and Akiyama, H., 1977. Load-deflection relationship of earthquake resistant steel shear walls with a developed diagonal tension field, Trans., Arch. Inst. Of Japan, Tokyo, Japan, 109-114.

[3] M. K. Poul and F. N. Alahi, "Theoretical and numerical study on the strengthened steel plate shear walls by FRP laminates," IJE Transactions C, vol. 25, No. 1, 2012.

[4] Elgaaly, M., and Liu, Y., 1997, Analysis of Thin Steel Plate Shear Walls, Journal of Structural Engineering, ASCE Vol. 123 No. 11 pp. 1487-1496, November

[5] Driver, R.G., 1997, Seismic behavior of steel plate shear walls. Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada

[6] Thorburn, L. J. and Kulak, G. L., 1983, Analysis of steel plate shear walls, Structural Engineering Report, 107, University of Alberta, Edmonton, Alta, Canada

[7] Arafa El-Helloty. "Free Vibration Response of Laminated Composite Plate Shear Walls." International Journal of Engineering Research and Development, vol. 13, no. 09, 2017, pp. 28–38.

[8] Rahai A.R. and Alipour M., 2011, Behavior and Characteristics of Innovative Composite Plate Shear Walls, The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction, Procedia Engineering, 14, 3205–3212

[9] Nateghi-Alahi F. and Khazaei-Poul M., 2013, Analytical Study on the Strengthened Steel Plate Shear Walls by FRP Laminate, The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering, Procedia Engineering, 54, 377 – 386

[10] M. K. Poul and F. N. Alahi, "Finite element investigation of steel plate shear walls with infill plates strengthened by GFRP laminate," JSEE, vol. 14, No. 3, 2012.

[11] AISC (2005b). Specifications for Structural Steel Buildings, American Institute of Steel Construction, Chicago, IL., USA.

[12] Alipour, Mohamad & Rahai, Alireza. (2011). Perforated Steel Shear Walls WithFrp Reinforcement Of Opening Edges. Australian Journal of Basic and Applied Sciences. 5.

[13] Maali M., Kılıç M., Yaman Z., Ağcakoca E., Aydın A.C., Buckling and post-buckling behavior of various dented cylindrical shells using CFRP strips subjected to uniform external pressure: Comparison of theoretical and experimental data, Thin-Walled Structures, Volume 137, 2019, Pages 29-39, ISSN 0263-8231, https://doi.org/10.1016/j.tws.2018.12.042.

[14] Aydin A.C., Yaman Z., Ağcakoca E., Kiliç M., Maali M., Aghazadeh Dizaji A., CFRP effect on the buckling behavior of dented cylindrical shells, International Journal of Steel Structures 20, 425-435,

[15] Seddighi, M., Barkhordari, M.A. & Hosseinzadeh, S.A.A. The Wall–Frame Interaction in Composite FRP-Steel Plate Shear Walls. Iran J Sci Technol Trans Civ Eng 46, 133–156 (2022). https://doi.org/10.1007/s40996-021-00592-0

[16] Seddighi, M., Barkhordari, M. A., & Hosseinzadeh, S. A. A. (2019). Behavior of FRP-reinforced steel plate shear walls with various reinforcement designs. Steel and Composite Structures, 33(5),729–746. https://doi.org/10.12989/SCS.2019.33.5.729

[17] Ülger T., Tension Field Performance of GFRP Plate Shear Walls, Celal Bayar University Journal of Science, Volume 18, Issue 2, 2022, p 149-160. Doi:10.18466/cbayarfbe.1015437

[18] Vatansever C. and Yardimci N., 2011, Experimental investigation of thin steel plate shear walls with different infill-to-boundary frame connections, Steel and Composite Structures, Vol. 11, No. 3, 251-271

[19] Hibbit, Karlsson, Sorenson, Inc., (HKS), ABAQUS / Standard Theory Manual, Student Edition 6.13. Pawtucket, R.I.

[20] SAP2000 V14, Computers and Structures, Inc. 1995 University Ave. Berkeley, CA.

[21] Timler, P. A. and Kulak, G. L., 1983. Experimental study of steel plate shear walls, Structural Engineering Report, 114, University of Alberta, Edmonton, Alta, Canada.

[22] Dusak, S., Yalçın, C., Yelgin, A. N. "Experimental Investigation of Using Sandwich Panels as Infill Plate in a Steel Plate Shear Wall". Technical Journal 31 (2020): 10413-10439

[23] ATC-24, (1992). "Guidelines for cyclic seismic testing of components of steel structures." Applied Technology Council, California.