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Experimental Behavior of Composite Shear Walls Having L Shape Steel Sections in Boundary Regions

S. Bahadır Yüksel, Alptuğ Ünal

***Abstract*—**The Composite Shear Walls (CSW) with steel encased profiles can be used as lateral-load resisting systems for buildings that require considerable large lateral-load capacity. The aim of this work is to propose the experimental work conducted on CSW having L section folded plate (L shape steel made-up sections) as longitudinal reinforcement in boundary regions. The study in this paper present the experimental test conducted on CSW having L section folded plate as longitudinal reinforcement in boundary regions. The tested 1/3 geometric scaled CSW has aspect ratio of 3.2. L-shape structural steel materials with 2L-19x57x7mm dimensions were placed in shear wall boundary zones. The seismic behavior of CSW test specimen was investigated by evaluating and interpreting the hysteresis curves, envelope curves, rigidity and consumed energy graphs of this tested element. In addition to this, the experimental results, deformation and cracking patterns were evaluated, interpreted and suggestions of the design recommendations were proposed.

***Keywords*—**Shear wall, composite shear wall, boundary reinforcement, earthquake resistant structural design, L section.

I. Introduction

In the construction stage of reinforced concrete shear walls, the concrete cannot be placed properly between intensive reinforcements during the pouring of concrete due to dense longitudinal reinforcements in shear wall boundary zones. Shear wall boundary zones should be formed by wrapping intensive vertical reinforcements in boundary zones with frequent-spaced stirrups. This causes difficulty in construction and the shear walls cannot be constructed in accordance with the project. In order to solve this problem, it was considered that composite L-shape structural steel materials might be used in shear wall boundary zone instead of classical reinforcements where intensive reinforcements are present in shear wall boundary zone [1], [2]. Many experimental studies have been carried out for composite shear walls [3]-[8]. To our knowledge no study has been carried out on the CSW having L shape steel sections in boundary regions.

In this study, an experimental research was carried out in order to investigate the seismic behavior of composite shear walls having L section folded plate as longitudinal reinforcement in boundary regions. In this study, CSW with 1/3 geometric-scale having L section folded plate as longitudinal reinforcement in boundary regions were tested under earthquake-simulated reversible repeatable lateral loads and the results obtained were evaluated. The hysteresis curves, envelope curves, rigidity and consumed energy graphs of this tested element is given and interpreted. In the final section, the experimental results, deformation and cracking patterns were evaluated, interpreted and suggestions were made.

S. Bahadır Yüksel is with the Selçuk University, Engineering Faculty, Civil Engineering Department, Konya, Turkey (corresponding author to provide phone: +90-332-223-2646; e-mail: sbahadiryuksel@yahoo.com).

Alptuğ Ünal is with the Selçuk University, Engineering Faculty, Civil Engineering Department, Konya, Turkey (e-mail: alptugunal@gmail.com).

II. Materials and Methods

A. Details of Test Specimens

The dimensions of CSW test specimen with 1/3 geometric scale were designed according to the 1/3 of the dimensions of reinforced concrete shear walls used currently in constructions. For CSW test specimen, the thickness of shear wall is 10 cm, length of shear wall is 100 cm and the height of shear wall is 320 cm. The shear wall boundary zones were determined as 20 cm. Dimensions and reinforcement layout plan of CSW test specimen are given in Fig. 1.

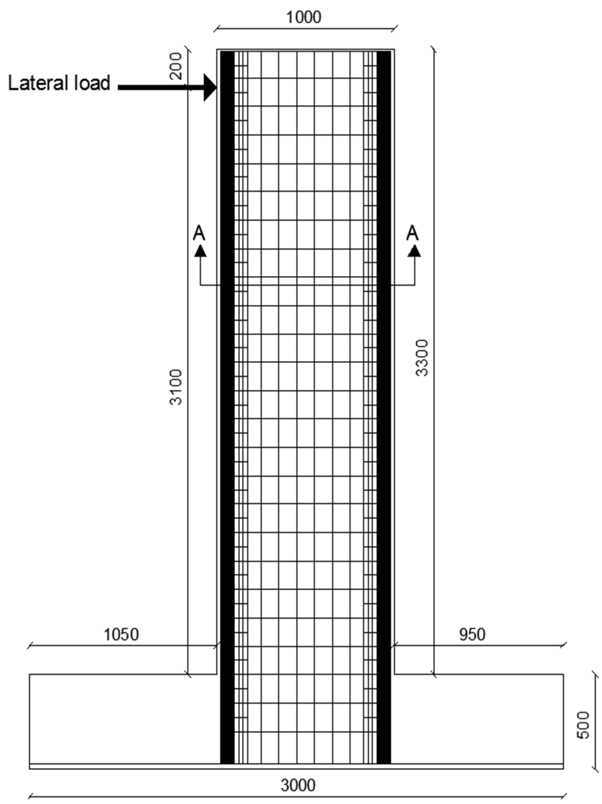

Fig. 1 Dimensions and elevation view of the reinforcement layouts of CSW test specimen (Dimensions are in mm)

In order to compare the behavior of reinforced concrete shear wall with CSW behavior, the bearing capacity of reinforcements present in reinforced concrete shear wall boundary zones was calculated and the dimensions of L-shape folded plate structural steel materials corresponding to this bearing capacity were determined. 6ϕ10 longitudinal reinforcement and 2-L-shape steel folded plates with 19x57x7mm dimensions were placed in shear wall boundary zones. Moreover, ϕ8 horizontal reinforcement with 7.5 cm intervals was used in shear wall boundary zones. In the web regions of the shear wall, 12ϕ10 longitudinal reinforcement and ϕ8 horizontal reinforcement with 15 cm intervals were used. Plan view of the reinforcement layouts of the CSW test specimen is given in Fig. 2. L shape steel made-up sections used as longitudinal reinforcement in boundary regions of the CSW test specimen is shown in Fig. 3. For CSW test specimen, the foundation was produced in the dimensions of 50x70x300 cm and a rigid cross section was selected in order to prevent the formation of any damages during experiments.

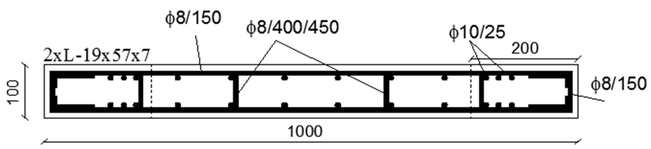

Fig. 2 Plan view of the reinforcement layouts of the CSW test specimen (Dimensions: mm)

Fig. 3 L shape steel made-up sections used as longitudinal reinforcement in boundary regions of the CSW test specimen

CSW test specimen was manufactured in Selçuk University Earthquake Laboratory. It was manufactured in horizontal position and then it was positioned as vertically by means of a lift present in the laboratory. The reinforcement of CSW test specimen was prepared in the laboratory then was placed in steel form. After placing reinforcements, C25 type concrete was desired from concrete plant and the process of concrete pouring into the form was performed in the laboratory. After one week, CSW test specimen was positioned as vertically by means of a lift present in the laboratory. Fig. 4 shows the general view of the CSW test specimen in the construction stage.

(a)

(b)

(c)

Fig. 4 General view of the CSW test specimen in the construction stage

B. Instrumentation and Test Procedure

In order to determine the non-linear behavior of CSW test specimen where intensive reinforcements are present in boundary zones, CSW test specimen was tested under reversible repeatable loadings in Selcuk University Earthquake Laboratory. Test specimens were loaded by means of a hydraulic cylinder having 500 kN compression, 500 kN tensile capacity. Hydraulic cylinder was placed 310 cm above the upper point of the foundation of the shear wall. Since load

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cell should be connected to the hydraulic cylinder for the measurement of the load, a rebate was opened at the end of hydraulic cylinder. By this means, the load data of both compression and tensile from load cell can be transferred to the computer. The capacity of load cell connected to the end of hydraulic cylinder was 500 kN for compression and tensile. In the experiments, the displacements were measured by electronic displacement measurement tools such as LVDT. The measurements together with load values were transferred to the computer by means of data collector and recorded by the software program used in computer. For the measurement of displacements, 8 LVDT were calibrated. Totally 6 LVDT were placed including one which is 1 m above the upper point of foundation, one which is 2 m above the upper point of foundation beam, four which are about 3 m above the upper point of foundation beam. Other LVDTs, on the other hand, were placed in the foundation in order to measure the movements that might happen in the foundation. In the experiments, LVDTs connected to the upper floor can read 300 mm, LVDTs connected to the medium floor can read 200 mm and LVDTs connected to the foundation can read 150 mm. The photograph in Fig. 5 shows the test setup, loading system and Instrumentation of CSW. The loading set-up of experiment, load cell and LVDT placement are shown in Fig. 6. At the end of the experiment, the hysteresis curves, envelope curves, rigidity and consumed energy capacities of the specimens were investigated and interpreted according to the results obtained from load cell and LVDTs.

Fig. 5 The photograph of the test Setup, Loading System and Instrumentation of CSW

III. Results and Discussion

LVDT and load cell connected to the test specimen was also connected to the computer and the experiments were started after control. The first crack of CSW test specimen in positive direction was formed in +4th cycle at approximately 40 kN load value in the conjunction zone of foundation. The first crack in negative direction was occurred in -4th cycle at approximately 40 kN load value in the conjunction zone of foundation. In the test specimen, bending cracks were started to become at the tip of shear wall at about 120 mm above the foundation with 60 kN load level and bending cracks were continued to become in about 100-150 mm distances after this load level. It was observed that the lengths of these first cracks increased and deflection cracks moved towards the middle of shear wall. Fig. 7 shows the cracking patterns of CSW at 100kN lateral load level. It was also indicated that the cracks formed in negative and positive cycles at about 110 kN load value were integrated in the conjunction zone of foundation and shear wall. Fig. 8 shows the cracking patterns of CSW at 190 kN lateral load level. CSW test specimen at about 200 kN load value reached nominal yield value and displacement-controlled loading was started after this loading level. The distances between first cracks were become more separated with increasing displacement values and it was observed that they bended at about 30° angle towards the web of the shear wall. In positive and negative cycles, crushing of concrete was occurred in compression zones of conjunction between foundation and shear wall at about 55 mm displacement value. The fracture zone of CSW test specimen was obtained with a load where maximum load reached by shear wall decreased at a rate of 20% and by casting of concrete in compression zones. In the test specimen, the maximum load obtained in positive cycles was 194.2 kN and the peak displacement corresponding to this load was measured as 46.16 mm. In negative cycles, on the other hand, the maximum load obtained was 198.05 kN and the peak displacement corresponding to this load was measured as 46.24 mm. Fig. 9 shows the cracking patterns of CSW at failure stage In negative and positive cycles of test specimen, loading was increased until maximum 80 mm lateral displacement and the experiment was terminated by taking into consideration the loss of lateral stability of the test specimen after this value.

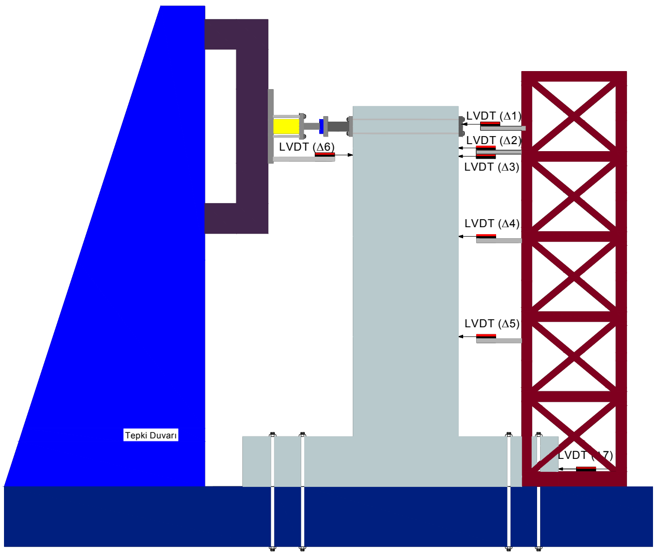


Fig. 6 The test set-up

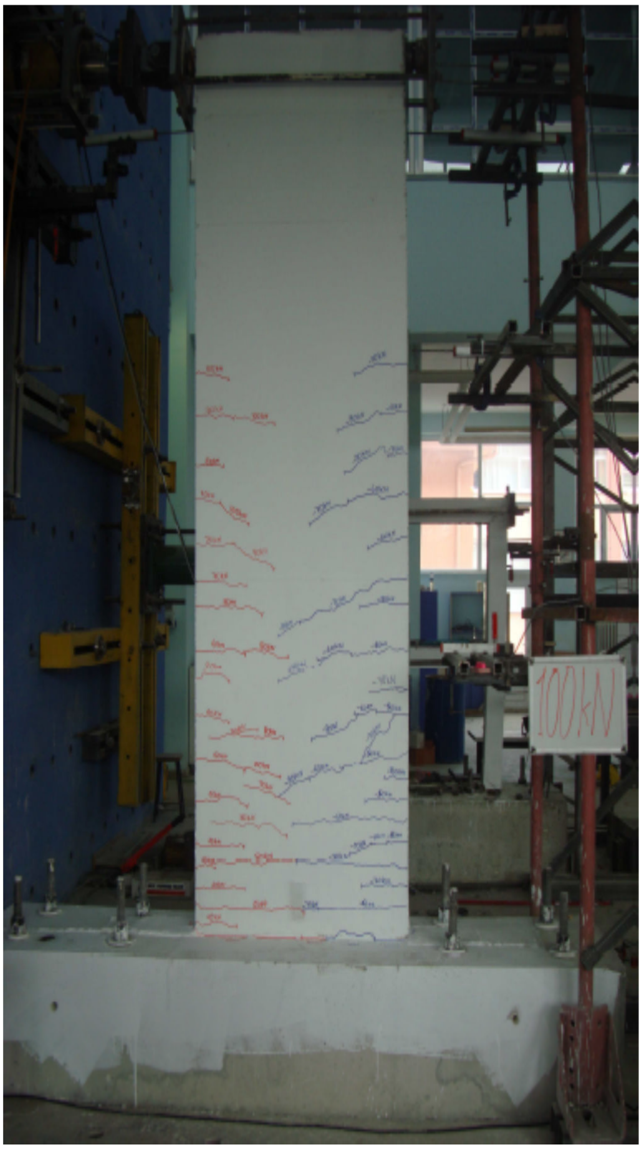


Fig. 7 Cracking Patterns of CSW at 100kN Lateral Load Level

Lateral load-displacement values belonging to each cycle in the test specimens were calculated and hysteresis curves were obtained. The peak points of each cycle in hysteresis curves were united and envelope curves were obtained. The lateral load-peak displacement cyclic hysteresis curve of CSW test specimen is given in Fig. 10 (a) and strength envelope curve belonging to this hysteresis curve is given in Fig. 10 (b). Total drift versus horizontal load of the CSW is shown in Fig. 11. The area under hysteresis curve of each cycle results in consumed energy value. As a result of the experiment, consumed energy values were found by calculating the areas under each hysteresis curve and total consumed energy graph as well as cumulative consumed energy graph is given (Figs. 12 (a), (b)). The slope of the line segment is obtained by uniting positive and negative peak points of each hysteresis curve results in rigidity. Stiffness decrease graph and stiffness rate graph of CSW test specimen are given in Figs. 13 (a) and (b).

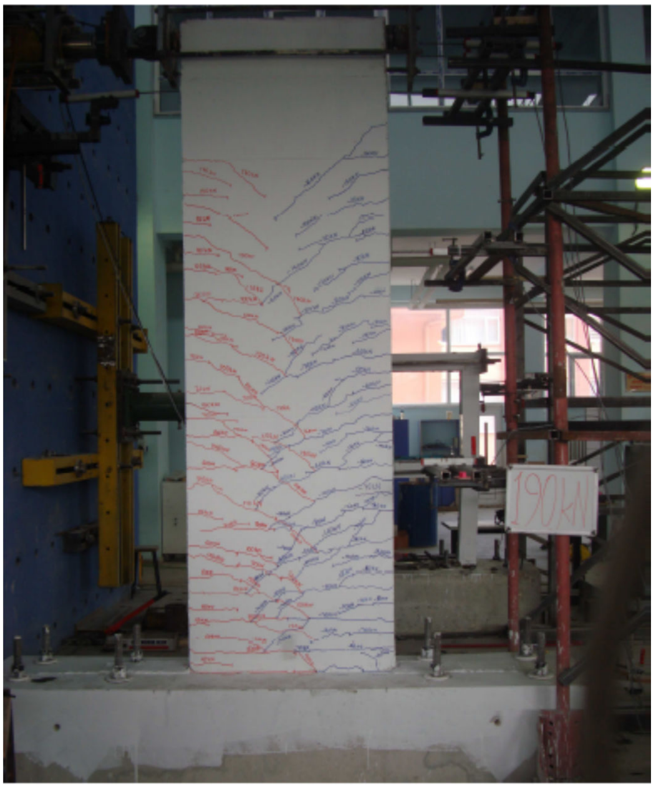


Fig. 8 Cracking patterns of CSW at 190 kN lateral load level

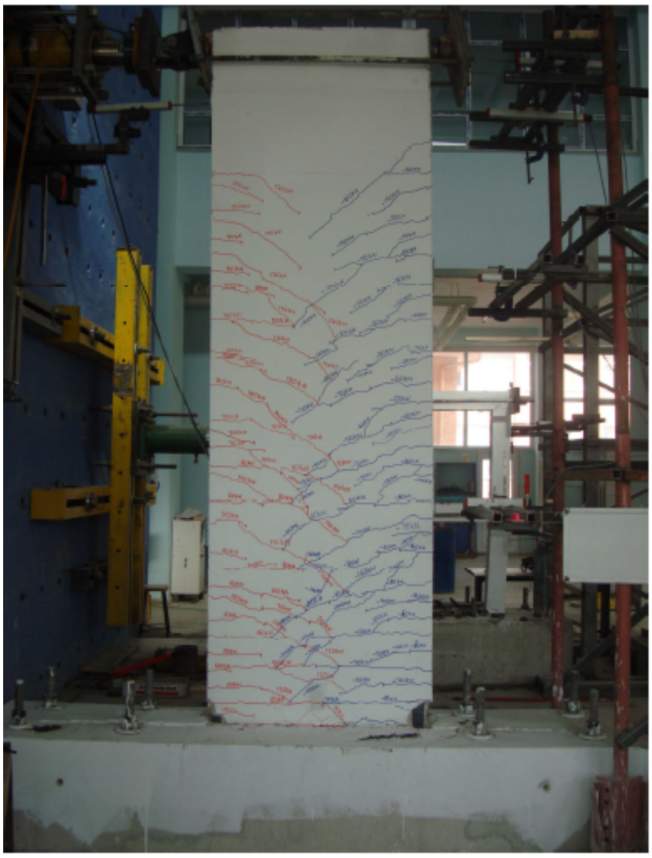
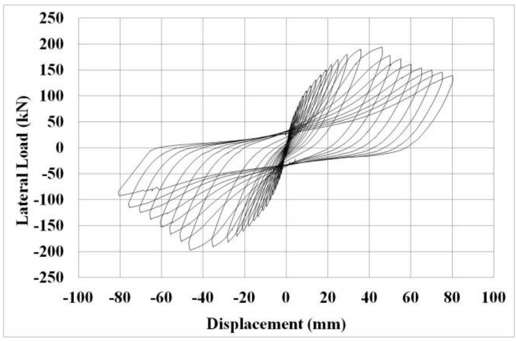
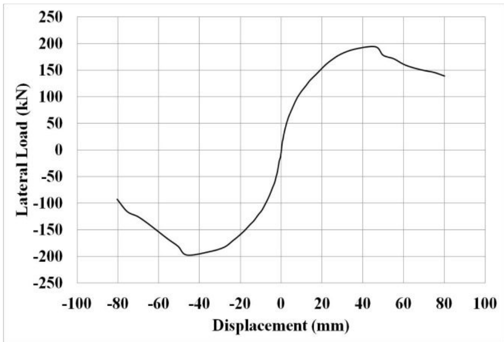


Fig. 9 Cracking patterns of CSW at failure stage

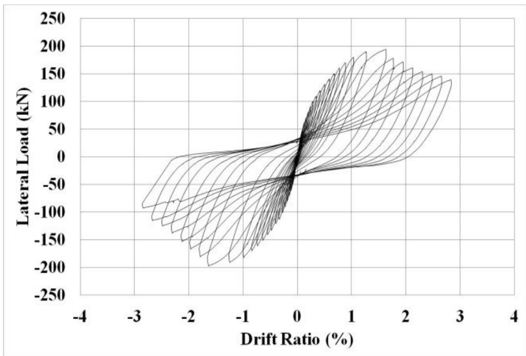


(a)

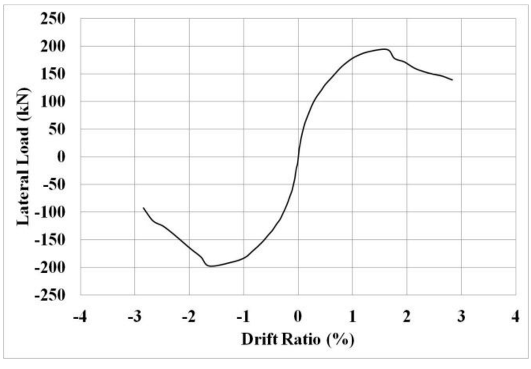


(b)

Fig. 10 Lateral load-peak displacement of CSW (a) cyclic hysteresis curve (b) envelope curve

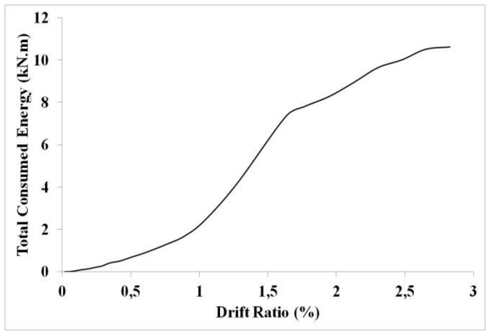


(a)

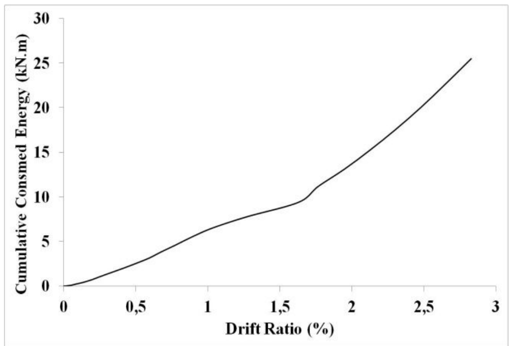


(b)

Fig. 11 Total drift versus horizontal load of the CSW (a) cyclic hysteresis curve (b) envelope curve

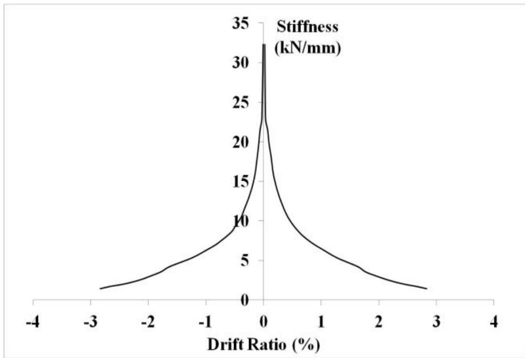


(a)

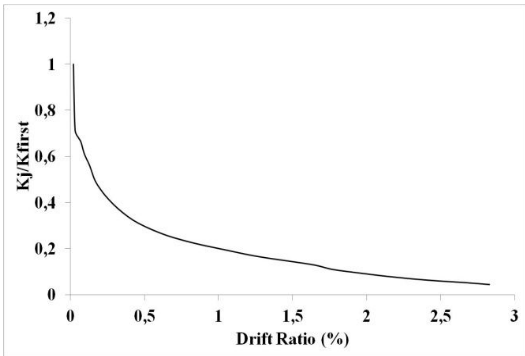


(b)

Fig. 12 Energy graph of CSW (a) total consumed energy graph (b) cumulative consumed energy graph



(a)



(b)

Fig. 13 Stiffness graph of CSW (a) Stiffness decrease graph (b) stiffness rate graph

IV. Conclusion

This study was performed in order to investigate the seismic behaviors of CSW having L section folded plate as longitudinal reinforcement in boundary regions. For this purpose, the CSW with 1/3 geometric-scale having L section folded plate as longitudinal reinforcement in boundary regions were tested under earthquake-simulated reversible repeatable lateral loads and the results obtained were evaluated. The cracks and damages occurred in test specimen presented that the test specimen indicated bending behavior. As it can be observed from hysteresis and envelope curves of test specimen, horizontal load bearing capacity of CSW reached a maximum when relative floor shift was about 1.5%. When relative floor shift rate was about 3%, the experiment was terminated. After CSW reached its maximum lateral load, a sudden decrease did not occur in load and it was observed that it displayed a more ductile behavior than reinforced shear walls. This indicates the positive effect of L-shape folded plate structural steel materials on shear wall behavior. When rigidity graphs are considered, it was observed that the value of rigidity decreased with the formation of damages and cracks although rigidity was approximately constant until the formation of first crack in test specimen. When the rate of relative floor shift is about 3%, rigidity curves became parallel to horizontal axis. This means that the test specimen lost its horizontal stability at the end of the experiment. Energy consumption increased in test specimen with the progress of the experiment. The cracks formed in test specimen served the energy consumption to increase. Loss of strength and adherence problem in reinforced concrete shear walls where intensive reinforcements are present in shear wall boundary zones were developed out of concrete pouring. These problems were overcome with CSW produced by using tip reinforcements made of L-shape structural steel materials. It was observed that CSW produced by using boundary reinforcements made of L-shape folded plate structural steel materials displayed a similar behavior like reinforced concrete shear walls in terms of strength, stiffness and energy consumption.

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