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"Research Note"

FRACTURE OF CONNECTIONS BETWEEN STEEL AND REINFORCED CONCRETE SHEAR WALLS UNDER THE CYCLIC LOADING*

M. HUSEM** S. PUL, E. YOZGAT AND S. E. GORKEM

Dept. of Civil Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey
Email: mhusem@ktu.edu.tr

Abstract– In steel structures, the effects of horizontal load like earthquake, are more displaced because of the elastic properties of the materials, compared with reinforced concrete structures. Therefore, in steel frame structures, diagonal systems, steel shear walls systems, and reinforced concrete shear walls systems are built for displacements which arise from earthquake or wind effects. In this study in steel frame structures, reinforced concrete shear wall was used. In the experiment samples, different types of connectors were used to connect the reinforced concrete shear walls with steel frame. These shear connectors are single stud, double stud, single I-shape, double I-shape and single U-shape. In these experiments the connections influences were examined by cyclic loading. It is known that currently, stud shear connectors are widely used in composite structural members for composite action between steel and concrete. The experimental results show that the bearing capacity of studs from shear connectors was less than that of other connectors. However, the bearing capacity of shear connections formed with two I-shape steel profiles were bigger than that of other connections.

Keywords– Shear connectors, shear wall, steel frame structure, cyclic loading

1. INTRODUCTION

Concrete, reinforced concrete, timber, steel, masonry and composite structures are built today. Some of the most widespread of these structures are reinforced concrete, steel and composite structures. In steel-concrete composite structures, the compressive strength per unit cost of concrete is higher than that of structural steel. Therefore composite beams, columns and composite slabs are used. Structures must be resistant against the effects of earthquake or wind. So, structures are designed according to earthquake or wind codes. In earthquake or wind codes, building shear walls for the cover of the earthquake or wind loads is generally required.

In steel structures, the effects of horizontal load like earthquake or wind have greater displacement because of the elastic properties of the materials, according to reinforced concrete structures. Therefore, in steel frame structures, diagonal systems and steel shear walls systems, are reinforced concrete shear walls systems built for limited displacement and earthquake or wind effects.

Composite action between steel and concrete implies some interconnection between the two materials which will transfer shear between them. In reinforced concrete members the natural bond of concrete to steel is often sufficient to do this, although cases do arise in which additional anchorage is required [1]. However, sometimes in the repeated loading as earthquake or wind effects, the natural bond of concrete to steel is not sufficient. In such cases, for full shear transfer shear connectors are used in the connections between concrete and steel. One of these shear connectors is studs. Studs are used widely between steel and concrete. Many researchers have studied heated stud shear connectors [2-7]. In these studies

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**Corresponding author

behaviors of stud shear connection between beams and reinforced slabs or beam and column under monotonic or repeated loading were investigated. In the steel frame systems, bracing elements or reinforced concrete shear walls have been widely used to resist the lateral loads such as wind, earthquake or explosion. The reinforced concrete shear walls are located as pre-cast in the steel frame or built as cats-in-situ concrete [8, 9]. In composite members, the shear force transfer is experimentally measured using different techniques. The push-out test is the most common procedure due to its simplicity [10].

In this study, the reinforced concrete shear wall was connected to steel columns by different types of shear connectors. Experiments were performed on the steel frame structures with reinforced concrete shear walls that have different connections. In this experimental study push-out test was under the cyclic loading to compare the effects of shear connectors between steel and reinforced concrete walls with each other. In the results of the experimental study, the type of connection that is more applicable and economic was discussed.

2. EXPERIMENTAL STUDY

a) Materials properties and mix design

In this study, the limestone aggregate was used in concrete production for reinforced shear walls. The maximum aggregate size used was 16 mm. The physical properties and gradations of this aggregate were given in Table 1 and Table 2 respectively. In the production of concrete, CEM II/A-P 32.5 N type cement was used. The mixture proportion of concrete is given in Table 3. In this mixture, a water to cement ratio of 0.50 was used.

Table 1. The physical properties of aggregate

Aggregate size	Loose density (kg/m^3)	Dry density (kg/m^3)	Saturated density (kg/m^3)	Water absorption (%)
Course (>4 mm)	1405	2658	2670	0.42
Fine (< 4mm)	1452	2626	2660	0.52

Table 2. The gradation of aggregates

Gradation class	%, total weight
0.50 mm - 1.00 mm	10
1.00 mm - 2.00 mm	15
2.00 mm - 4.00 mm	20
4.00 mm - 8.00 mm	25
8. 00 mm - 16 mm	30

Table 3. Mix design of concrete

Concretes	W/C	Cement (kg/m^3)	Water (kg/m^3)	Total aggregates (kg/m^3)	Absorbed water (kg/m^3)
OC	0.50	350	175	1829	3.80

In mixing concrete, a concrete mixer having a 250 liter capacity and inclined axes was used. Each granulometric aggregate was weighed and placed into the mixer moistened in advance and mixed for 3 min with the addition of saturated water, for 3 min with the addition of cement, and thereafter, mixed for another 3 min without stopping to add the mixed water. The resulting concrete was placed in a standard cylinder (150 mm x 300 mm) mould and test samples were prepared to investigate the connection between the steel and reinforced concrete shear wall at 3 stages.

The samples, which were taken out the day after, were kept in water at 22±2˚C for 21 days. They were kept at 23˚C and 75% relative humidity until the time of the test. The specimens were 28 days old at the time of the tests.

b) Preparation of test samples and testing

The dimensions of the reinforced concrete shear walls are 110 mm x 480 mm x 700 mm. I-shaped steel columns used in the tests were formed by welding from two sides of a double U-shaped steel having 140 mm height. So the height and width of the flange of the formed I-shape steel columns are 140 mm and 120 mm respectively. In the tests three different types of shear connectors were used. These are stud, U-shape steel profile and I-shape steel profile. Shear connectors were welded with 100 mm space on the flange of the steel column. These connectors were designed with five different types of test samples. These are single and double stud, single and double I-shape steel profile, and single U-shape steel profile (Fig. 1). The double stud and double I-shape steel profile was fixed as zigzag. In the reinforced concrete shear walls, reinforcement having 8 mm diameters with 70 mm spaces horizontally and vertically were used. A test set up was prepared for these tests. In this test set up, a hydraulic cylinder having 800 kN loading capacity was used. The load-cell in the capacity of 500 kN was used to read the applied load. The test results were recorded by a data-logger that could record 8 data in a second. The linear potentiometer displacement transducer (LPDT) was used to measure the slip between the steel column and reinforced concrete shear wall. In the tests cyclic loading was done with 5 kN steps in the compression and tension. The test set up is shown in Fig. 2.

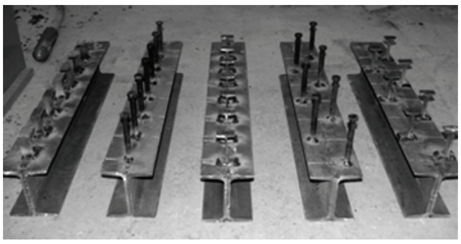

Fig. 1. Shear connectors using tests

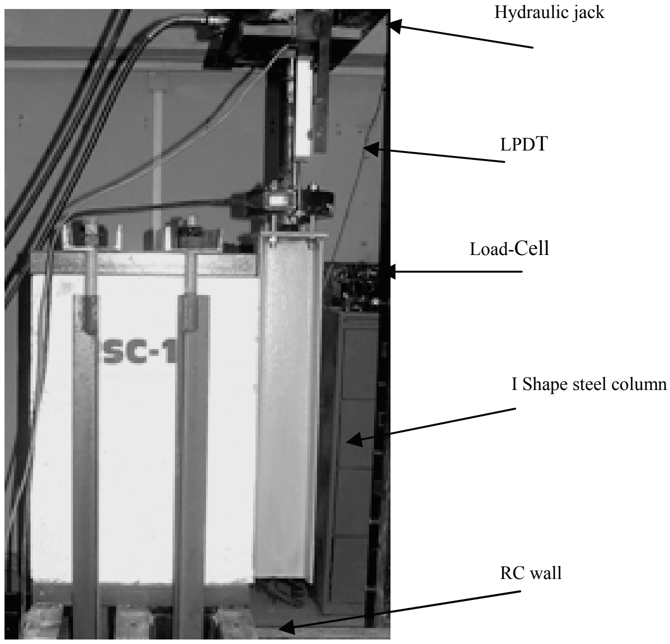

Fig. 2. Test set-up

3. Results and discussion

In this study, fracture behavior of the connections between the steel columns and reinforced concrete shear walls was investigated experimentally under cyclic loading. The obtained results from the tests were given in Table 4, together with the concrete average compressive strength (f_c). The average compressive strength of the produced concrete for the investigation of the connection between steel and reinforced concrete shear walls is 35 MPa.

As seen in Table 4, when double stud, single I-shape, double I-shape and single U-shape profiles are used as shear connectors, maximum load bearing capacity was obtained 37%, 13%, 67% and 10% more than single stud shear connectors respectively.

Table 4. Test results

Type of connectors	f_c (MPa)	Maximum cyclic load (kN)	Slipping versus max. cyclic loading (mm)	Ultimate slipping (mm)
Single stud	35.6	206	10	16
Double stud	34.8	283	13	18
Single I-shape	35.1	233	9	17
Double I-shape	35.4	344	10	23
Single U-shape	34.5	226	10	17

When double I-shape profile is used as the shear connector, the load bearing capacity increased 48% according to single I-shape profile. When the increasing ratio between single stud shear connector and double stud shear connector is 37%, the increasing ratio between the single I-shape shear connector and the double I-shape shear connector is 48%. Therefore, using double shear connectors instead of single shear connectors increased the load bearing capacity and double I-shape shear connectors had the highest load bearing capacity.

After the tests, types of failure for some test samples were given in Fig. 3. The slipping versus loading curves obtained tests for single stud, double stud, single I-shape, double I-shape and U-shape steel connectors were given in Fig. 4-8.

Fig. 3. Types of failure for some test samples

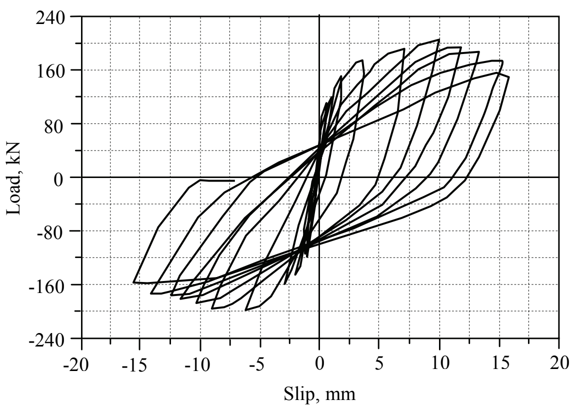

Fig. 4. Slip versus load for single stud connectors

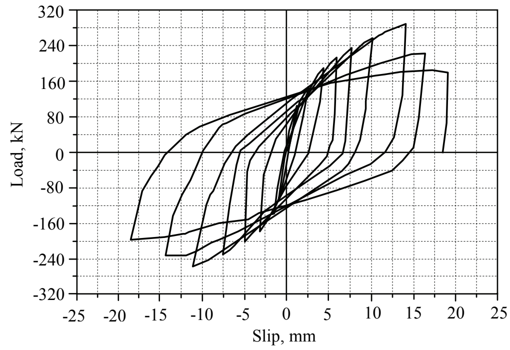

Fig. 5. Slip versus load for double stud connectors

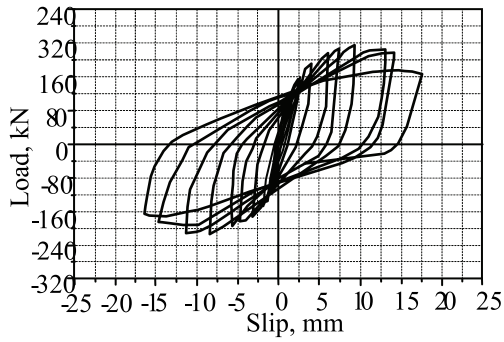

Fig. 6. Slip versus load for single I-shape steel connectors

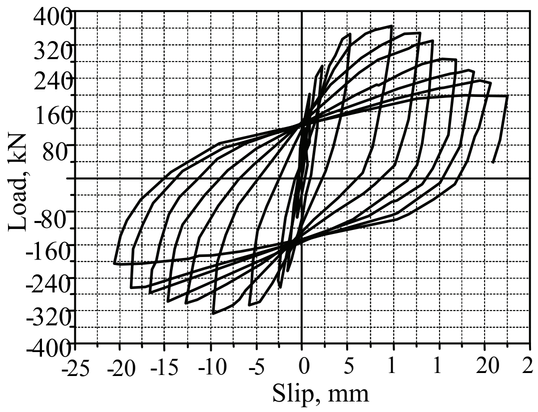

Fig. 7. Slip versus load for double I-shape steel connectors

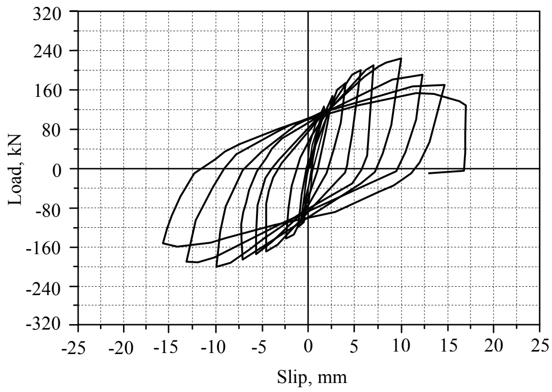

Fig. 8. Slip versus load for single U-shape steel connectors

In the experiments, ultimate slipping was 60% more for single stud shear connectors, 38% more for double stud shear connectors, 89% more for single I-shape shear connectors, 130% more for double I-shape shear connectors and 70% more for single U-shape shear connectors than slipping versus maximum cyclic loading. It showed that double I-shape shear connectors had a higher capacity of energy absorption besides having higher load bearing capacity.

It is observed that in these tests, the fracture was due to the slipping of shear connectors. The slipping versus maximum loading for all of the test samples was approximately the same. However, according to slipping versus the maximum loading behavior of the test samples, the double stud connection was more ductile than that of other shear connections. From the point of applicability, in spite of single stud and double shear connectors being more applicable than that of others, double I-shape shear connectors were more suitable from the point of bearing capacity and ductility.

4. CONCLUSION

The double I-shape steel shear connector, which was one of the shear connectors used in this study, demonstrated better behavior than that of the others in point of bearing capacity and ductility (slipping capacity). Because of the elastic properties of used shear connectors, ductility was greater than that of other connectors.

In the tests, the single stud connectors slipped, not reaching bearing capacity because of cracks that occurred in the concrete with the effects of cyclic loading. Because of the flange of the I and U-shaped steel connectors, slipping was obtained later than that of the stud connectors, even if they were concrete cracks. But using U-shape steel connectors between the steel columns and the reinforced shear walls can cause holes to occur because of the flanges of U-shape steel. In these types, shear connectors must be proved to place of concrete as without holes.

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