THE USABILITY OF TURKISH EARTHQUAKE RESISTANT STEEL BAR AS A SHEAR CONNECTOR IN COMPOSITE STRUCTURES

*Mehmet Alpaslan KÖROĞLU, *Ali KÖKEN
*Department of Civil Engineering, Selcuk University, 42075 KONYA/TURKEY
Tel: +90 332 223 26 67 Fax: +90 332 241 06 35

ABSTRACT

The composite behavior of two or more structural members joined together by using different materials is called "a composite structure". Shear connectors are used to avoid potential slippings between steel and concrete and slippings due to deformations on concrete plate. Many materials having different shapes and dimensions are tested as shear connectors. Headed stud shear connectors are commonly used to ensure composite action due to its fast manufacture.

In this study, availability of earthquake resistant steel bars manufactured in the same length as headed studs are investigated. For this purpose, 4 push-out tests accomplished to the composite beams with profiled steel sheeting in which earthquake resistant steels are used as shear connector and 4 push-out tests accomplished in which headed studs are used as shear connector. Earthquake resistant steel is a steel reinforcement bar used in concrete and produced by a heating process during hot rolling with the ribs on it to increase the adherence between concrete and steel. It is abundantly manufactured in recent years with an increasing use in reinforced concrete constructions due to its advantages in terms of ductility, weldability, adherence, corrosion resistance and strength. In the experimental section, 8 push-out tests performed on 16 specimens with different slab height, different number and arrangement of shear connectors. The dimensions of the test specimens were taken in appropriate to the dimensions of the push-out test procedure given in European Standards of Eurocode-4 according to which the steel profiles welded with shear connectors by using laminated steel plates were proposed to be HE260, and the slab dimensions were taken as 600 x 600 x 150 mm. As a result of the tests, earthquake resistant steel can be suggested to be used as an alternative material for the shear connectors. Consequently, performing more number of tests will give more accurate results for earthquake resistant steel use as a shear connector.

1. INTRODUCTION

The composite behavior of two or more structural members joined together by using different materials is called "a composite structure". Each material of a composite structure usually has a superior property effectively used for providing the composite behavior of the materials. Although several materials are used as the shear connector of a composite structure, "headed stud" shear connectors are generally used in constructions due to their practicality [1].

After the invention of composite structures, many types of shear connectors were used [2]. Alexander C. (1998) studied on "Standoff Screw" shear connector in Virginia Technical University' Materials and Construction Investigation Laboratory. It is screwed on laminated steel plates by using screw guns that 106 small-scale push-out tests formed with 11 groups were carried out in order to investigate the usability of "Standoff Screw" as a shear connector [3]. Kim B., Wright H. and Cairns R. (2001) experimentally studied the behaviors of shear connectors in composite beams prepared on steel plates. They produced three specimens, made discussions on the test results and modeled push-out tests biaxially and triaxially. The objective of their tests was to determine the load-displacement relationships, maximum shear load capacity and failure types of the shear connectors (headed studs of 13mm diameter and 65mm length) at composite beams [4]. Roddenberry M. D. R. began to make investigations on the resistance and behavior of shear connectors against shear after they were used in composite members. Therefore, push-out test devices were produced to perform today's mostly used method, "push-out test", in order to examine the behaviors of the shear connectors. 24 reinforced concrete push-out tests, 93 composite slab push-out tests and 3 composite beam tests were performed in this study, and the test results were compared with the standards of American Code, Canadian Code and Eurocode-4 [5]. Valente I., Cruz P. (2004) made 12 push-out tests in 4 groups to investigate the behavior of perfobond steel used as the shear connectors of lightweight concrete composite slabs [1].

The behavior of the headed studs used in composite beams together with laminated steel plates depend on the strength, dimensions and directions of studs, the geometry of laminated steel plates and the strength of concrete [6]. Ellobody E., Young B. (2005) made 13 and 18 push-out tests with laminated plates and composite slabs welded each other by φ19mm and φ16mm shear connectors, respectively. The shear occurred during the tests were measured with precise instruments and compared with Eurocode-4 and American Code standards [7].

Many types of composite slabs formed with steel plate profile models laminated in various ways are used for the construction of buildings and bridges. Kim Y. H., Jeong Y. J. prepared 17 composite slab specimens produced with reinforced lightweight concrete by using "perfobond" shear connectors on the laminated galvanized steel plates, and full-scale slab tests and push-out tests were made on these specimens [8]. Larbi A., Ferrier E., Jukiewiez P. and Hamelin P. (2007) used epoxy and polyurethane as the shear connectors. The dimensions of the specimens used for push-out tests were specified by using the reference of Eurocode-4 standard. During the specimen preparation stage, three different connection thicknesses and two surface behaviors were investigated, and 100x100mm dimensions were selected for the areas on which the plates (surfaces) were connected [9].

In this study, the usability of Turkish Earthquake Resistant Steel Bars in composite slabs as a shear connector was studied in the light of assuming this type of shear connectors to be more durable and more economic than the alternatives.

2. EXPERIMENTAL STUDY

According to Eurocode-4 standard, the variables considered in push-out tests are geometrical and mechanical characteristics of concrete slabs, shear connectors and reinforcements. Additionally, failure loads, failure types and load-displacement performances are all determined by the help of push-out tests.

IPE240 profile was used in this study on which 80 mm long shear connectors (both headed stud and earthquake resistant steel bar) were welded with laminated steel plates. As given in Figure 1, the slab dimensions were taken as 650 x 650 x 120 mm for the first 8 specimens and 650x650x100 mm for the rest 8 specimens by taking the previous studies as reference (Figure 1).

Figure 1. A photo of a specimen prepared for the tests

2.1. Details of Test Specimens

The most significant difference among the test specimens is the varying type of shear connectors. Headed stud as the shear connector was used in 8 specimens which have a widespread use due to its mass production, and φ20 earthquake resistant steel bar was used in 8 specimens due to its economy and geometry.

Earthquake resistant steel bar is a steel reinforcement bar used in concrete and produced by a heating process during hot rolling with the ribs on it to increase the adherence between concrete and steel. It is abundantly manufactured in recent years with an increasing use in reinforced concrete constructions due to its advantages in terms of ductility, weldability, adherence, corrosion resistance and strength.

The earthquake resistant steel bar of minimum 500 N/mm^2 yield strength behaves considerably ductile due to its higher uniform elongation under maximum loading and its higher ratio of yield strength to tensile strength, i.e. f_s/f_y.

To increase workability, i.e. increase the ability of giving shape, reinforced concrete steels are subjected to heating process after which the carbon amount is adjusted according to demanded steel type in order to provide the easy shaping of the earthquake resistant steel bar during heat treatment.

The earthquake resistant steel bar is more favorable material than other concrete construction steels due to its resistance against corrosion and weldability characteristics resulted from the processes applied on earthquake resistant steel bar again during the heat treatment. As a result of its weldability property, the earthquake resistant steel bar is mostly used at the plates on which welded connectors are applied [10].

The notches made on ribbed steel surface during the production stage provide tight adherence between concrete and reinforcement. The earthquake resistant steel bar with its higher clutching property depending on rib angles and rib heights is more superior with respect to other reinforcement steels. The earthquake resistant steel bar welded to steel profile can be seen in Figure 2.

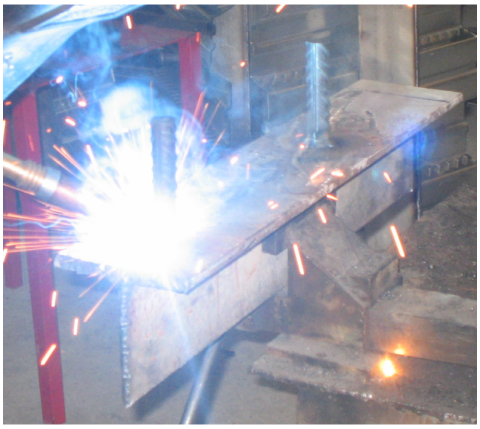

Figure 2. Earthquake resistant steel bar welded to the profile

In order to determine the mechanical characteristics of earthquake resistant steel bar bars used for the production of test specimens, twelve φ20 earthquake resistant steel bar bars were subjected to tensile test. Then, the average tensile strength test results are given in Table 1.

Table 1. Tensile strength test results of earthquake resistant steel bar

Area (mm^2)	**Yield Force** (kN)	**Tensile Force** (kN)	**Rupture Force** (kN)	**Yield Strength** (N/mm^2)	**Tensile Strength** (N/mm^2)	**Rupture Strength** (N/mm^2)	**Elongation Percentage**
314	144,55	221,15	191,60	460,4	704,3	610,2	0,32

3. TEST RESULTS

Eight tests performed in this study were classified into four groups named as “tests with one shear connector” and “tests with two shear connectors” for each type of shear connector (headed stud/earthquake resistant steel bar). The specimens with one and two shear connectors were labeled by using “1” and “2” respectively in front of the names of the specimens. The specimens with 10 cm and 12 cm slab thicknesses were labeled by writing “10” and “12” respectively at the end of the names of the specimens. If earthquake resistant steel bar was used as a shear connector, “E” is placed between these two numbers (10 or 12), and similarly if headed stud was used as a shear connector, “K” is written between the numbers.

3.1. Specimens with One Shear Connector

The load-displacement relationships and the concrete types of the specimens with 10 cm and 12 cm slab thicknesses both of which have the shear connectors of earthquake resistant steel bar and headed studs were compared with each other.

When 10 cm thick slabs with one shear connector are considered, the maximum loads acting on the connectors were obtained as 75 kN and 63 kN for the specimens with earthquake resistant steel bar and headed stud, respectively. 1E10 specimen produced with earthquake resistant steel bar carried

7% more load than 1K10 specimen. Both specimens failed with tensile shear cracking at the concrete around the shear connector.

When 10 cm thick slabs with two shear connectors are considered, the maximum loads acting on the connectors were obtained as 79 kN and 70 kN for the specimens with earthquake resistant steel bar and headed stud, respectively. 1E12 specimen carries 2% more load than 1K12 specimen (Figure 5).

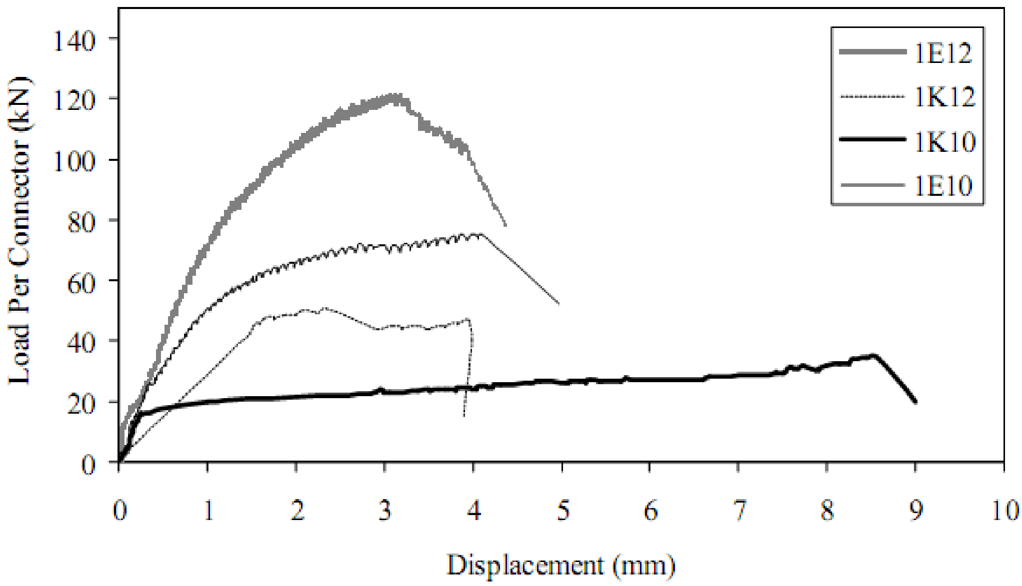

Figure 5. Load-displacement diagram of the specimens with one shear connector until the failure (cracking) load was reached

3.2. Specimens with Two Shear Connectors

When 10 cm thick slabs with one shear connector are considered, the maximum loads acting on the connectors were obtained as 62 kN and 58 kN for the specimens with earthquake resistant steel bar and headed stud, respectively. 1E10 specimen produced with earthquake resistant steel bar carried 4% less load than 1K10 specimen (Figure 5). Both specimens failed with tensile shear cracking at the concrete around the shear connector.

When 10 cm thick slabs with two shear connectors are considered, the maximum loads acting on the connectors were obtained as 73 kN and 48 kN for the specimens with earthquake resistant steel bar and headed stud, respectively. 1E12 specimen carried 37% more load than 1K12 specimen (Figure 6). Since welding crack occurred during the test of the specimen produced with headed studs, any reliable comments could not be done for the relevant specimen. The primary cause of the welding cracks experienced during some of the push-out tests was determined as the insufficient welding strength against very high shear loads.

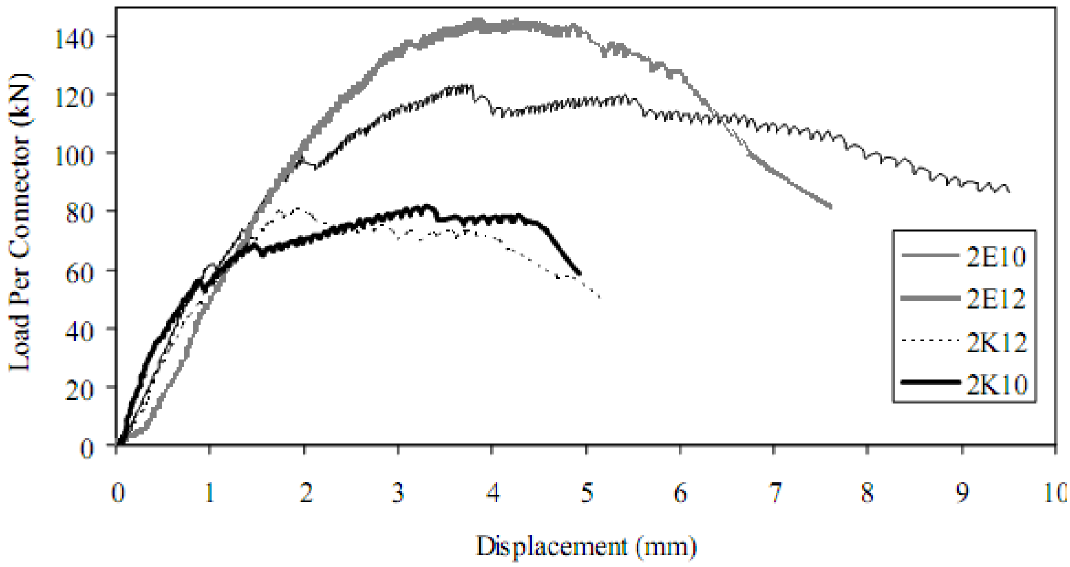

Table 3. Failure (cracking) types of test specimens, maximum load acting on a shear connector, maximum load acting on the head, head displacement at the instant of failure (cracking), and load-bearing ratios of earthquake resistant steel bar / headed stud

Group	Specimen	Maximum Load Acting on	Maximum Load Acting on	Head Displacement at the instant	Load-Carrying Ratio of
1	1E10	75	150	4,1	1,07
	1K10	63	126	8,5	
	1E12	79	178	3,2	1,02
	1K12	70	140	3,5	
2	2E10	62	248	3,8	0,96
	2K10	58	232	4,6	
	2E12	73	292	4,1	1,37
	2K12	48	192	4,5	

The characteristics of crack type, maximum load acting on a shear connector, maximum load acting on a head, head displacement at the instant of the crack formation and the bearing capacity ratios of earthquake resistant steel bar/headed stud for all test specimens are given in Table 3. The areas of the shear connectors were taken into consideration for the calculation of the bearing capacity ratios.

4. Results of the Experimental Studies

The most important inference of the push-out tests was the usability of earthquake resistant steel bar as a shear connector in composite slabs and composite beams. Due to its good weldability, high tensile strength and geometry providing good adherence with concrete, the earthquake resistant steel bar was supposed to be an alternative for the headed studs.

The specimens prepared with earthquake resistant steel bar and headed studs were compared with each other by the aid of the experimental results, load-displacement diagrams, crack types and crack formations obtained from the tests, past studies of literature and current codes.

The comparisons were made according to three different variables, i.e. the type of shear connector, the number of shear connector and the thickness of slab concrete.

Both types of shear connectors presented similar behaviors during the experimental study.

According to the cracking (failure) load and the load acting on a shear connector in each test where the earthquake resistant steel bar was used, 7% and 2% more loads were respectively obtained for 10 cm and 12 cm slab thicknesses of first group specimens, and 4% and 37% more loads were obtained for the second group specimens of 10 cm and 12 cm slab thicknesses, respectively.

After comparing the load-displacement curves of the specimens at which earthquake resistant steel bar and headed studs were used as shear connectors, the behavior of the slabs with earthquake resistant steel bar was more rigid than the other specimens produced with headed studs.

After the completion of the tests, when shear connectors were demounted from the concrete parts of the test specimens, the amount of flexural deformations occurred at the center of the shear connectors during the tests was observed to be more for headed studs than that of earthquake resistant steel bars.

It was concluded that the earthquake resistant steel bar had good adherence with concrete and it was difficult to draw it from concrete.

After examining the cracks of the slabs in which headed studs were used and the ultimate loads were reached, the slabs were observed to have tendency of cracks perpendicular to the laminated axes of the steel plates. This tendency can be explained with the increasing width geometry at the top sections of the studs with which the specimens were produced.

After the completion of the test and removing the connectors from concrete, most of the earthquake resistant steel bars had concrete particles on their surfaces, while headed studs did not have any.

5. Discussion of Results and Suggestions

As a result of the tests, earthquake resistant steel bar can be suggested to be used as an alternative material for the shear connectors. Consequently, performing more number of tests will give more accurate results for earthquake resistant steel bar use as a shear connector. In the light of this study, the following suggestions can be made for further studies that will be carried out with the same loading mechanism and measuring technique;

> The further push-out tests should be done by using shear connectors of different diameters and lengths for different concrete strengths.

By changing the diameters of the shear connectors in push-out tests, the variation between the load-bearing capacities of slabs/beams and the diameters of the shear connectors should be researched.

- The slabs should be tested with and without upper-reinforcement.
- The usability of automatic welding method (used for headed studs) for earthquake resistant steel bar should be supported with experimental studies.
- Welding operations should be carried out with great care.

Acknowledgement

This research was prepared from MS Thesis by Mehmet Alpaslan KÖROĞLU named ” Kompozit döşemelerde kayma bağlayıcısı olarak eksismik çeliğinin kullanılabilirliği” and supported by Selcuk University BAP Office (SU-BAP 06201071).

REFERENCES

1. Valente I., Cruz P., 2004. “Experimental Analysis of Perfobond Shear Connection between Steel and Lightweight Concrete” Journal of Constructional Steel Research 60 (2004) 465–479.
2. Ellobody E., Young B., (2005), “Performance of Shear Connection in Composite Beams with Profiled Steel Sheeting” Journal of Constructional Steel Research, 66 (2005) 245-253
3. Alander C. C., 1998. “Standoff Screws Used in Composite Joists”, Ph. Master Thesis Virginia Polytechnic Institute and State Univ., Blacksburg.
4. Kim B., Wright H., Cairns R., 2001. “The Behavior of Through-deck Welded Shear Connectors: An Experimental and Numerical Study” Journal of Constructional Steel Research 57 (2001) 1359-1380.
5. Roddenberry M. D. R., 2002. “Behavior and Strength of Welded Stud Shear Connectors”, Ph. D. Thesis Virginia Polytechnic Institute and State Univ., Blacksburg.
6. Anonymous. 1992. Design of Composite Steel and Concrete Structures, ENV 1994-1-1. European Prestandard, Chapter 7. (Eurocode-4)
7. Ellobody E., Young B., (2005), “Performance of Shear Connection in Composite Beams with Profiled Steel Sheeting” Journal of Constructional Steel Research, 66 (2005) 245-253
8. Kim B, Wright HD, Cairns R. (2001) The Behaviour of Through-Deck Welded Shear Connectors: an Experimental and Numerical Study. Journal of Constructional Steel Research;57:1359–80.
9. Larbi A., Ferrier E., Jurkiewiez P., Hamelin P., 2007. “Static behavior of steel concrete beam connected by bonding” Engineering Structures 29 (2007) 1034–1042.
10. Köroğlu M. A., Kompozit döşemelerde kayma bağlayıcısı olarak eksismik çeliğinin kullanılabilirliği, Selçuk Üniversitesi, Fen Bilimleri Enstitüsü, Konya Türkiye, 2007 (In Turkish)