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Experimental and analytical study on channel shear connectors in fiber-reinforced concrete

Shervin Maleki *, Mehrdad Mahoutian [1]

Department of Civil Engineering, Sharif University of Technology, Azadi Ave., Tehran, Iran

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ABSTRACT

This paper investigates, experimentally and analytically, the capacity of channel shear connectors embedded in normal and polypropylene (PP) concrete. Limited testing is used to assess the accuracy of a proposed nonlinear finite element model for typical push-out test specimens. Using this model, an extensive parametric study is performed to arrive at a prediction for shear capacity of channel connectors in PP concrete. An equation, for inclusion in design codes, is suggested for the shear capacity of these connectors when used in PP concrete.

1. Introduction

A composite beam consists of a steel section and a reinforced concrete slab interconnected by shear connectors. The efficiency of composite beams stems from the basic fact that concrete is strong in compression while steel is strong in tension. Concrete can also provide support for compression steel against lateral-torsional and local buckling. Composite beams offer several advantages over non-composite sections; mainly, a reduction in size and deflection of the steel beam and a reduced floor vibration due to higher stiffness.

An essential component of a composite beam is the shear connection between the steel section and the concrete slab. This connection is provided by mechanical shear connectors, which allow the transfer of forces from the concrete to the steel and vice versa and also resist vertical uplift forces at the interface. The shear connectors are usually welded to the top flange of the steel beam before the slab is cast. These connectors ensure that the two different materials act as a single unit.

A variety of shapes and devices have been used as shear connectors and economic considerations continue to motivate the development of new systems. Presently, the headed stud is the most widely used shear connector in composite construction. Its popularity stems from proven performance and the ease of installation using a welding gun. Nonetheless, due to the small load carrying capacity of stud connectors, they have to be installed in large numbers. This usually produces a cluttering effect and an unsafe working place. Therefore, using channel shear connectors could be a good alternative.

The shear capacity of channel shear connectors embedded in concrete has been based on push-out tests. A literature review on composite beam researches from 1920 to 1958 and 1960 to 1970 were reported by Viest [1] and Johnson [2], respectively. Most researches have focused on stud and channel shear connectors that are embedded in normal concrete. An experimental investigation by Ollgaard et al. [3], involving the testing of 48 push-out specimens with 16 mm and 19 mm studs embedded in normal and lightweight concretes revealed that the ultimate strength of the stud shear connector was influenced by the compressive strength and modulus of elasticity of concrete. The test results on channel connectors embedded in normal concrete specimens were reported in the University of Illinois Bulletin by Viest et al. [4] and recently by Pashan [5]. The push-out test results revealed that in addition to concrete strength, flange thickness, web thickness and channel length affected the strength of the composite system.

Based on these investigations, several equations for obtaining the channel shear connector capacity were proposed. After a few years, some of these equations were adopted by the building codes. For example, the current Canadian code [6] suggests the following equation for calculating the strength of a channel shear connector embedded in a solid concrete slab,

$$Q_n = 36.5(t_f + 0.5t_w)L_c\sqrt{f_c} \quad (1)$$

where:
Q_n = Nominal strength of one channel shear connector (N)
t_f = Flange thickness of channel shear connector (mm)

* Corresponding author. Tel.: +98 21 66164266; fax: +98 21 66013201.
E-mail addresses: smaleki@sharif.edu (S. Maleki), mehrdad_mahoutian@mehr.sharif.ir (M. Mahoutian).
[1] Tel.: +98 21 22063932.

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Table 1
Mix proportions.

Specimen no.	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	SP (%)	W/C	PP fiber (kg/m^3)
C1	400	1100	700	152	1	0.38	–
RC1	400	1100	700	152	1	0.38	–
RC2	400	1100	700	152	1	0.38	–
PP1	400	1090	700	152	1	0.38	3.6
PP2	400	1080	700	152	1	0.38	7.2

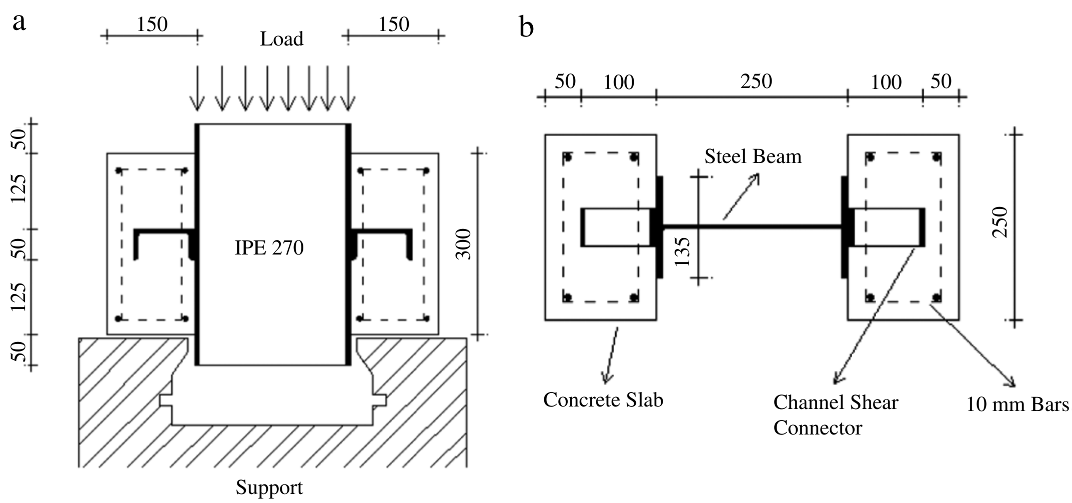

Fig. 1. RC1 push-out specimen (a) front view (b) plan view.

Table 2
Compressive strength of tested specimens.

Mix no.	C1	RC1	RC2	PP1	PP2
Tested Compressive Strength (MPa)	27.5	38.6	28.8	31.1	27.1

Table 3
Steel properties used in push-out specimens.

Specimen	C1	RC1	RC2	PP1	PP2
Channel UNP100 Length (mm) ($F_y = 240$ MPa)	50	50	30	50	30
10 mm Stirrup ($F_y = 300$ MPa)	No	Yes	Yes	No	No

t_w = Web thickness of channel shear connector (mm)
L_c = Length of channel shear connector (mm)
f_c = Specified compressive strength of concrete (MPa)

As mentioned, up until now, most of the push-out tests were performed on normal and lightweight concretes. However, Li [7] has investigated the behavior of stud shear connectors and Maleki et al. [8] studied the strength of channel shear connectors embedded in ECC (Engineered Cementitious Composites). Maleki et al. [9] also proposed a finite element model for channel connectors in normal weight concrete.

Since normal concrete and steel have a brittle and ductile behavior, respectively, these elements have no proper interaction together. It seems that by enhancing the ductility of concrete, behavior of these materials become more alike and could improve the shear capacity of channel connectors. Adding fibers such as polypropylene to concrete is one way of improving the ductility of concrete. In addition, using polypropylene fiber in concrete has the beneficial effect of reducing the shrinkage and thermal cracks.

Composite beams are usually provided with minimum shrinkage and temperature steel in the slab. This reinforcement is not identical to the reinforcement commonly used in the push-out tests. Therefore, the shear capacity of channel shear connectors (as prescribed by the design codes) is valid only when the channel is embedded in normal concrete confined by steel bars.

In this paper, the results of some monotonic push-out tests on normal concrete and polypropylene fiber-reinforced concrete are reported. These results are used to calibrate a proposed nonlinear finite element model. Using this calibrated model, a parametric study is conducted to arrive at an equation to predict the ultimate capacity of channel shear connectors embedded in PP concrete.

2. Experimental program

2.1. Materials and mix proportions

Five specimens with different mix proportions were considered for testing in this study. Details of mix proportions are presented in Table 1. Natural sand with limestone base with a maximum nominal size of 4.75 mm was used as fine aggregate in mix proportions. Fine aggregate had a fineness modulus of 3.1 and specific gravity of 2.7 g/cm^3. Coarse aggregate with 2.6 g/cm^3 specific gravity and maximum nominal size of 12 mm was also used in mixes. The cement used in all mixes was normal Portland cement, which corresponds to ASTM type II. The W/C ratio is kept at 0.38 and is kept constant for all mixes. To achieve a good workability, superplasticizer (SP) with Polycarboxylate base was added to all mixes. The two PP concrete specimens utilized polypropylene fiber with a density of 0.91 g/cm^3 and a length of 12 mm. Only in the two RC specimens confining steel bars with nominal diameter of 10 mm and yield stress of 300 MPa were used. The channel connector was UNP100, with 100 mm depth and a web and flange thickness of 6 and 8.5 mm, respectively. The nominal yield strength of these channels is 240 MPa. The channels with 30 and 50 mm lengths were used in the tests.

2.2. Compressive strength

Following ASTM C39 for compressive strength test, three standard 150 × 300 mm cylinders were cast from each mix. The specimens were cured in water at a temperature of 23 ± 1 °C. After curing, the cylinders were tested in compression with a loading