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Review

Static behavior of stud shear connectors in elastic concrete–steel composite beams

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ABSTRACT

Elastic concrete was first introduced into steel–concrete composite beams due to its superior deformability. The static behavior of stud shear connectors embedded in elastic concrete is studied in this paper. Eighteen push-out tests were conducted to evaluate the load-slip behavior, bearing capacity and ultimate slip of shear studs. Four different rubber contents, 0%, 5%, 10% and 15% were taken into consideration. Test results show that the ductility of stud improves significantly with the increasing rubber content. Especially, when the rubber content reaches 10%, the shear stud has relatively high bearing capacity, better deformation and better ductility. In specimens with 5% rubber content elastic concrete, shear stud shows a more ductile behavior embedded in lower compressive strength elastic concrete and the diameter has little influence on ductility and stiffness of studs. The equations provided by AASHTO LRFD, Eurocode-4 and GB50017-2003 can still apply to shear studs embedded in elastic concrete. Compared with the experimentally obtained bearing capacities, AASHTO LRFD is confirmed to be the closest one.

Contents

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1. Introduction

Steel–concrete composite beams have been widely used in the field of bridge and building structures for decades [1]. As an important component of steel–concrete beams, stud shear connectors transfer the longitudinal shear force on the surface between steel and concrete. The deformation ability of shear stud is a decisive factor to evaluate its ductility. Hence, it is of great importance to find a method to improve the deformation capacity of shear studs without sacrificing its bearing capacity. To this end, elastic concrete is introduced into composite beams in this paper.

Elastic concrete, also called crumb rubber concrete or recycled tire rubber-filled concrete, is a new environmental material in the last few years. According to previous studies, the deformability of concrete increases significantly after adding rubber crumb to it. Elastic concrete has ductile failure and better crack resistance. Moreover, it has superior acoustical properties, wearing resistance and aging resistance to ordinary concrete [2–4]. Nowadays elastic concrete is used in the paving of tennis courts and parking lots due to its superior properties, but it has never been used in composite beams. Hence, it is significant to study the performance of the elastic concrete and steel composite beams.

This paper presents an investigation on the shear studs in the elastic concrete and steel composite beams through push-out test. The push-out test has proven to be an effective method of determining the ultimate strength and deformation capacity of shear connectors. Since the first push-out test was devised in Switzerland in the 1930s [5], many experimental tests of shear connectors have been studied by numerous researchers. Viest [6] conducted 12 push-out tests and proposed the conception of "critical load". He suggested that the shear bearing capacity of studs should be the load value when load-slip curves just entered nonlinear stage or the residual slip was 0.762 mm. Chapman [7] and Johnson [8] measured the shear performance of studs and developed a calculation model based on push-out tests. In 1966, Slutter and Fisher [9] tested the fatigue behavior of shear connectors and proposed the fatigue design formula. In 1971, a design formula of static behavior of shear studs was proposed by Ollgaard [10] based on the push-out test results. The structure of the formula was adopted by most of national codes for nominal strength of studs. Changsha Railway Institute [11] conducted 15 push-out tests of studs based on Wuhu Bridge in China. An [12] investigated the different behaviors of studs between normal strength and high strength concrete through push-out tests. The results showed that the concrete compressive strength significantly affected the shear capacity of studs.

Recently a number of researchers have focused on the different aspects of studs. In 2004, Lee and Shim [13,14] investigated the static and fatigue behavior of large stud shear connectors up to 30 mm in diameter, which were beyond the limitation of current design codes. A new stud system fastened with high strength pins was investigated experimentally by Tahir [15]. Pavlović [16] studied the different behaviors between bolted shear connectors and headed studs. W Xue [17] conducted 18 push-out tests to show the static behavior of single-stud. D Xue [18] investigated the different behaviors between single-stud and multi-stud connectors. According to the aforementioned research, the shear bearing capacity of studs depends on many factors, including the material and diameter of the stud itself and properties of the surrounding concrete slab. These factors are all included in several national codes [19–22].

People pay more attention to the bearing capacity of the shear studs, however few researchers have addressed the relationship between the deformation capacity of shear studs and the properties of the surrounding concrete. This paper will focus on this point. Moreover, the optimum efficiency of rubber content can be found after the experimental study.

The remainder of the paper is organized as follows. In Section 2, we present an introduction to the material properties of elastic concrete used in push-out tests. Section 3 details a total of 18 push-out tests analyzing failure modes, bearing capacity and ultimate deformation of studs. Three influence factors on the static behavior of studs, including rubber contents, elastic concrete compressive strengths and stud diameters are discussed in Section 4. The actual stress mechanism of studs in push-out tests and the comparison between the test results and three national codes regarding nominal strength of studs are also presented in this section. Section 5 presents some concluding remarks of this current paper.

Table 1
Proportions of elastic concrete with different rubber contents.

Group	Rubber content	Crumb rubber (kg)	Cement (kg)	Stone (kg)	Sand (kg)	Water (kg)	Water reducing (kg)
1	0%	0	295	1087	839	165	2.174
2	5%	50	400	703	1004	169	2.391
3	10%	100	590	1230	412	168	6.522
4	15%	150	590	1230	412	168	7.39
5	5%(S)	50	550	703	1004	169	5.652

2. Material properties of elastic concrete

Before push-out tests, the material properties of the different rubber mixed elastic concrete were studied experimentally. Note that the mixture ratios of elastic concrete discussed below were the same of those used in push-out specimens, introduced in Section 3 of this paper.

Fig. 1. Raw materials and concrete test cubes.