Engineering Structures 160 (2018) 133–146

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Shear performance of a novel demountable steel-concrete bolted connector under static push-out tests

Fei Yang, Yuqing Liu*, Zhibo Jiang, Haohui Xin

Department of Bridge Engineering, Tongji University, Shanghai 200092, China

ARTICLE INFO

Keywords:
Steel-concrete composite structure
Demountable bolted connector
Push-out test
Shear bearing capacity
Load-slip curve
Shear stiffness

ABSTRACT

Bolted connectors could be an alternative to replace conventional welded headed studs between steel girders and concrete slabs, which may benefit prefabricated construction and replacement of concrete slabs considering the life-cycle design of steel-concrete composite structures. In this paper, a novel steel-concrete bolted connector, consisting of a short bolt, a long bolt and a coupler, is proposed. Compared with other bolted connectors, this bolted connector could render the dismantling of concrete slabs more convenient. To investigate the failure mode and fundamental mechanical behaviour of novel bolted connectors and to compare their shear performance with that of conventional welded headed studs, static push-out tests were implemented on four groups of bolted connector specimens and one group of welded stud specimens. The test results demonstrate that the failure mode of novel bolted connectors is that shanks of short bolts are sheared off directly without local concrete crushing phenomenon under couplers. The shear bearing capacity is about 0.8 times of the tensile strength of short bolts, and the peak slip of the steel-concrete interface grows as the bolt shank diameter increases. The exponential expression which generally describes load-slip curves of welded stud connectors simulates the test load-slip curves of novel bolted connectors well. The clearance between bolt shank and bolt hole has a significant effect on the shear stiffness of novel bolted connectors.

1. Introduction

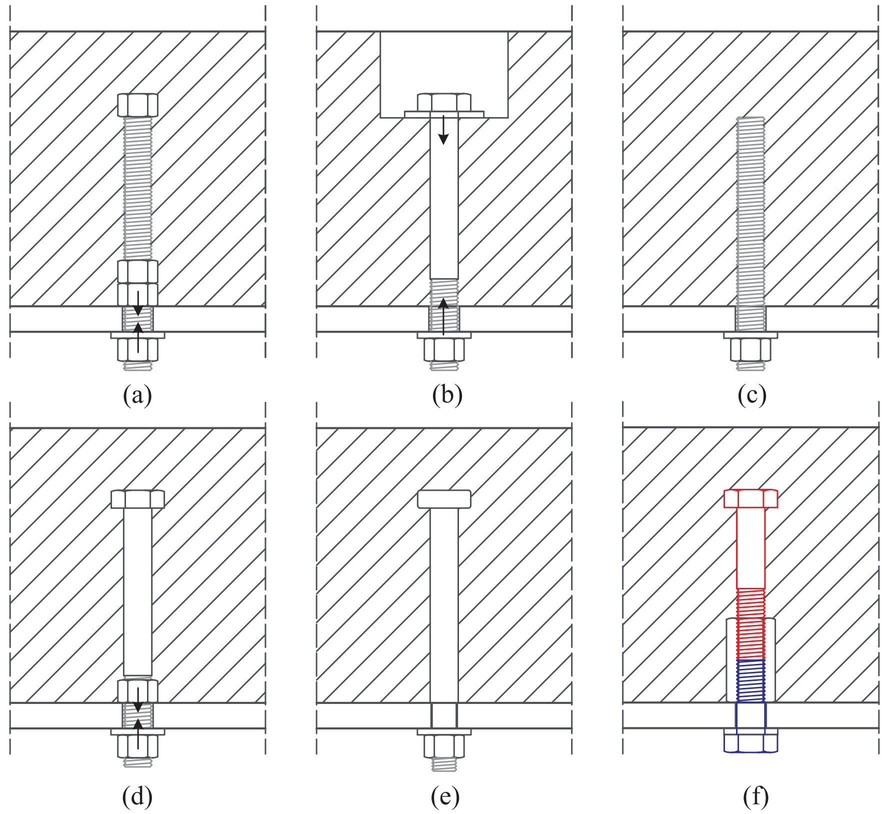
Recent decades, steel-concrete composite bridges have been widely constructed around the world for the benefits of combining two different constructional materials and exerting each advantage, especially in short and medium span girder bridges [1–3]. Among various steel-concrete connectors, welded headed studs have become the most practical shear connector for achieving the composite action between steel girders and concrete slabs due to their rapid welding procedure, outstanding mechanical performance and comprehensive research achievements [4–16].

However, concrete slabs of the composite bridge are facing a major challenge with deterioration, especially for reinforcement corrosion caused mainly by freeze-thaw cycles and various chemicals. Replacement, rehabilitation or strengthening of deteriorated concrete slabs could extend the service life of composite bridges and have become a research hotspot [17–19]. Compared with conventional welded stud connectors, concrete slabs connected to steel girders with bolted connectors could be easily dismantled to allow the rapid replacement of deteriorated concrete slabs, which contributes to reduce the structural life cycle cost and to improve the structural sustainability of steel-concrete composite bridges. In addition, bolted connectors also benefit prefabricated construction of concrete slabs, which could shorten the construction period and reduce the construction cost. Due to lack of comprehensive research and design specifications, bolted shear connectors are currently rarely used in the construction of steel-concrete composite bridges. Recently, there has been some research work relating to using bolted shear connectors to achieve the composite action between steel girders and concrete slabs. Fig. 1 exhibits six different geometry configurations of bolted shear connectors and will be introduced in detail as follows.

Kwon et al. [20–22] put forward three types of post-installed shear connectors for developing composite action in existing non-composite bridges which were built in America before the 1970s. Those three types of bolted connectors were called Double-Nut Bolt (Type I, Fig. 1(a)), High-tension Friction-Grip Bolt (Type II, Fig. 1(b)), and Adhesive Anchor (Type III, Fig. 1(c)), respectively. The pretension in Type I bolted connector was only induced on the bolt shank between upper and bottom nuts. Besides, there were double nuts embedded in the concrete slab, and the increased bearing surface could help to delay concrete crushing in front of the bolted connector. Type II bolted connector used through high strength bolt to attach the concrete slab to the

* Corresponding author.
E-mail address: yql@tongji.edu.cn (Y. Liu).

https://doi.org/10.1016/j.engstruct.2018.01.005
Received 5 August 2017; Received in revised form 30 December 2017; Accepted 4 January 2018



(a) **Type I** Double-nut bolt (b) **Type II** High-strength friction-grip through-bolt (c) **Type III** Adhesive anchor
(d) **Type IV** High-strength friction-grip bolt (e) **Type V** Headed stud bolt (f) **Type VI** Novel bolted connector

Fig. 1. Configurations of bolted connectors.

steel flange, and the concrete near the bolt shank would bear local compressive stress induced by the pretension of the high strength bolt. The bolt in Type III bolted connector could not be pretensioned because of its geometry configuration. In the research work by Kwon et al. [20–22], those three types of 22 mm diameter post-installed connectors were examined under static and fatigue loading. Besides, five large-scale non-composite beams were constructed, and four of them were retrofitted with the post-installed shear connectors and tested under static load. Parametric studies on the use of the post-installed shear connectors for strengthening non-composite bridges were carried out, and preliminary design recommendations were also given.

Pavlović et al. [23,24] believed that casting of high strength bolted shear connectors in prefabricated concrete slabs could improve the competitiveness of prefabricated composite structures. The configuration of the bolted connector examined by Pavlović was Type IV (Fig. 1(d)) bolted connector, and M16, M24 high-strength friction-grip bolts were used in the push-out test. Moynihan and Allwood [25] pointed out that a demountable connection would achieve composite action but also permit reuse of both components at the end of their service life. Three composite beams of 2 m, 5 m and 10 m length, which were constructed using M20 Type IV demountable bolted connectors, were implemented in static loading tests for investigating their mechanical performance. Chen et al. [26] considered that a suitable shear connection configuration was needed to achieve composite action between steel girders and precast concrete panels for the accelerated construction of steel-precast concrete composite bridges. Therefore, through-bolt connectors with three bolt diameters (12.70 mm, 15.88 mm and 19.05 mm), whose configurations just like the High-tension Friction-Grip Bolt (Type II, Fig. 1(b)) proposed by Kwon, were examined under static push-out tests. Dai et al. [27] reformed the conventional 19 mm welded headed studs into demountable bolted shear connectors which are depicted in Fig. 1(e). The main geometry characteristic of Type V bolted connector was that its shank diameter in the bolt hole and of the threaded part was 1–3 mm less than the diameter of the shank embedded in concrete slabs. Liu et al. [28,29] thought that use of innovative demountable high-strength friction-grip bolt shear connectors (Type II, Fig. 1(b)) in composite beams could greatly enhance the sustainability of building infrastructures. Practical design recommendations were proposed for predicting the ultimate strength and the load-slip relationship of the bolt shear connector.

The former five types of bolted connectors in Fig. 1 have the following common characteristics: (1) The bolted connectors, except for Type III connector, need to be installed on the steel flange from the concrete slab side and a nut below the steel flange is needed to fix the bolted connector. (2) The bolt shank in the bolt hole has threads which would penetrate into the wall of the bolt hole in the ultimate shear state. (3) The nut below the steel flange should be removed and then concrete slabs could be lifted up with the embedded bolted connectors when concrete slabs need to be dismantled. Therefore, the replacement process of concrete slabs would be feasible but rather complicated. For facilitating the dismantling process and preventing bolt threads from penetrating into the wall of the bolt hole, a novel steel-concrete bolted connector is proposed, as illustrated in Fig. 1(f). This bolted connector consists of a short bolt, a long bolt and a coupler. During bridge construction, the short bolt and the coupler should be installed before the long bolt. The shank length without threads of the short bolt is designed equalling the steel flange thickness added with the washer thickness to prevent bolt threads from penetrating into the wall of the bolt hole. When dismantling concrete slabs, screwing out the short bolt from the underside of the steel flange could separate steel girders and concrete