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Experimental study on perfobond strip connector in steel–concrete joints of hybrid bridges

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ABSTRACT

Perfobond strip (PBL) connectors, consisting of a perforated steel plate with steel rebar passing through the holes and embedded in concrete to transfer the shear action between the concrete and steel components, are increasingly used in composite and hybrid girders and columns. Though many studies on the behavior of PBL connectors can be found in the literature, the load transferring mechanism of PBL still needs further clarification because noticeable discrepancies can be found among the existing equations for predicting the shear capacity of the connectors. This paper presents an experimental study of the structural response of PBL connectors under push-out loading. Twelve push-out specimens fabricated according to the design used for the connectors in the steel–concrete joints in a hybrid cable-stayed bridge have been investigated. The behavior of the connectors, including the failure modes, ductility, and the components of the ultimate shear-resistant capacity, is discussed in depth. The results indicate that the mechanical properties of the PBL specimens are improved due to the bond at the interface between the perforated plate and the concrete. The transverse rebar located in the center of the steel plate hole is important for ensuring the connector's ductility. Furthermore, an analytical model and corresponding equation for predicting the ultimate resistance of PBL connectors with shear failure of the dowel are proposed, and the feasibility of the developed equation has been verified by the experimental results from related references.

1. Introduction

Steel–concrete composite and hybrid structures have been widely used in civil engineering, and shear connectors are the most important element for the transmission of force between steel and concrete. The headed stud is the most commonly used shear connector in structures because it can be automatically welded and produced on a large scale. However, with their wide use in bridges, the fatigue problem of the studs becomes serious [1]. An alternative new connector, called the perfobond strip (PBL), consisting of a perforated steel plate with steel rebar passing through the holes and embedded in concrete to transfer the shear action between the concrete and steel components, was introduced in 1987 [2]. The shear resistance of PBL is comprised of the bonding effects at the interface between the perforated steel plate and concrete, the resistance of the concrete dowel, the resistance of the transverse rebar passing through the holes in the steel plate and the local bearing effects between the end of the steel plate and the concrete. PBL connectors have been widely used in composite structures, particularly in the composite beams and steel–concrete joints of hybrid girder bridges.

The performance of PBL connectors in composite beams has been extensively studied through push-out tests with the standard separated type of specimen recommended in EC. 4 [3] and as shown in Fig. 1(a). Because the effort of separation between the steel girder and the concrete slab caused by the bending moment in composite beams cannot be ignored, lubricating oil is required on the steel flange to eliminate the bonding effect and possible friction in the standard push-out test procedure. The failure mode of PBL by standard push-out tests in previous studies was commonly controlled by the cracking of a concrete slab [4–17].

By comparison, the PBL in a steel–concrete joint of a hybrid bridge is embedded in a thick concrete block, and its failure generally results from the fracture of the dowel of concrete and the transverse rebar caused by the holes on the steel plate. No uplift force is found between the perforated plate and the concrete, and the bonding effects at the interface between the steel plate and the concrete could make a contribution to the shear strength of the connectors. Meanwhile, because a sufficient quantity of PBL is usually adopted to transfer the enormous shear force between the steel components and the concrete in hybrid joints, the effects of the local concrete at the end of the perforated plate are negligible [18]. As a result, the differences between the load transferring mechanism of PBL in steel–concrete joints and composite beams are significant.

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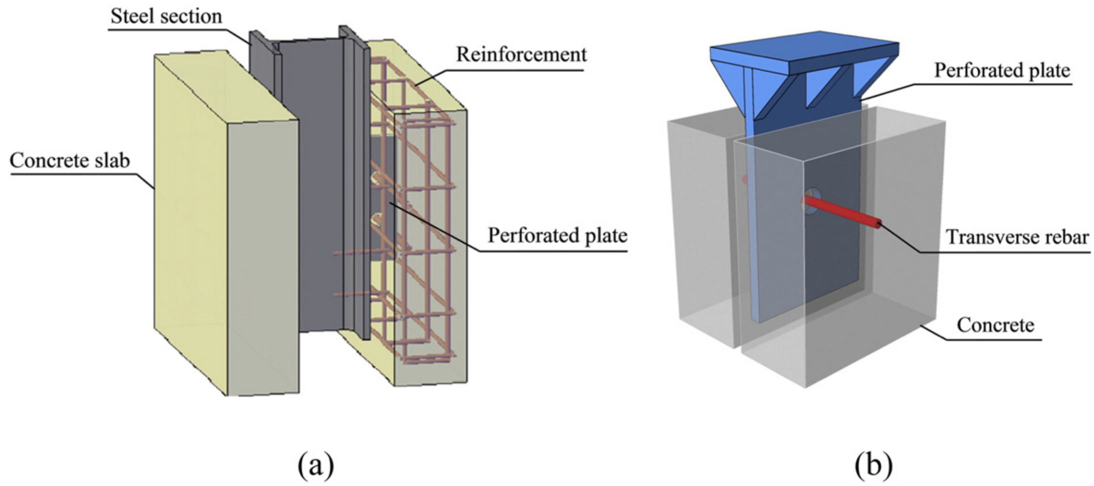

Fig. 1. The push-out test model: (a) The separated type of push-out specimen; (b) The plug-in type of push-out specimen.

As the failure of PBL in steel–concrete joints differs from the connectors in composite beams, the push-out test with the separated type of specimen is not appropriate for simulating the failure mode of PBL connectors in hybrid joints. Su et al. [19] suggested a push-out test procedure, using the plug-in type of specimen composed of a concrete block and a single perforated steel plate with transverse rebar passing through the hole, as shown in Fig. 1(b), to simulate the performance of the PBL in the steel–concrete joints of hybrid girder bridges. On the bottom of the specimen there is no support at the end of the steel plate to eliminate the local bearing for the steel plate. This plug-in type of push-out specimen was used by Q.H. Zhang et al. [20], L. Xiao et al. [21] and W.M. Wu [22] to study the behavior of PBL with the shear failure modes of the concrete and/or transverse rebar dowels crossing the holes in the steel plate.

The recently completed Nujiang bridge, as shown in Fig. 2(a), located in Yunan, China, with a single pylon and a single cable plane as well as a span arrangement of 81 m + 175 m, is a cable-stayed bridge with a hybrid girder consisting of three parts: the Prestressed Concrete (PC) girder, the steel girder and a 2 m long steel–concrete composite joint. The joint is composed of a steel back bearing plate and several steel cells filled with concrete, and PBL connectors are installed in the steel cells to transfer the shear force between the concrete and the steel plates, as shown in Fig. 2(b) to (d). Based on the geometric configuration of the connectors in this bridge, a test was conducted to simulate the mechanical properties of PBL connectors in steel–concrete joints.

Though there have been studies of PBL in steel–concrete joints, few were focused on the bonding effects at the interface between the perforated plate and the concrete or on its load transferring mechanism in hybrid joints. In this paper, the push-out test using the plug-in type specimen is introduced, and based on the experimental results, the effects of the interface bond, the dowels of concrete and the transverse rebar in the hole on the properties of PBL, as well as the suitability of the existing equations for predicting the resisting capacity of PBL are

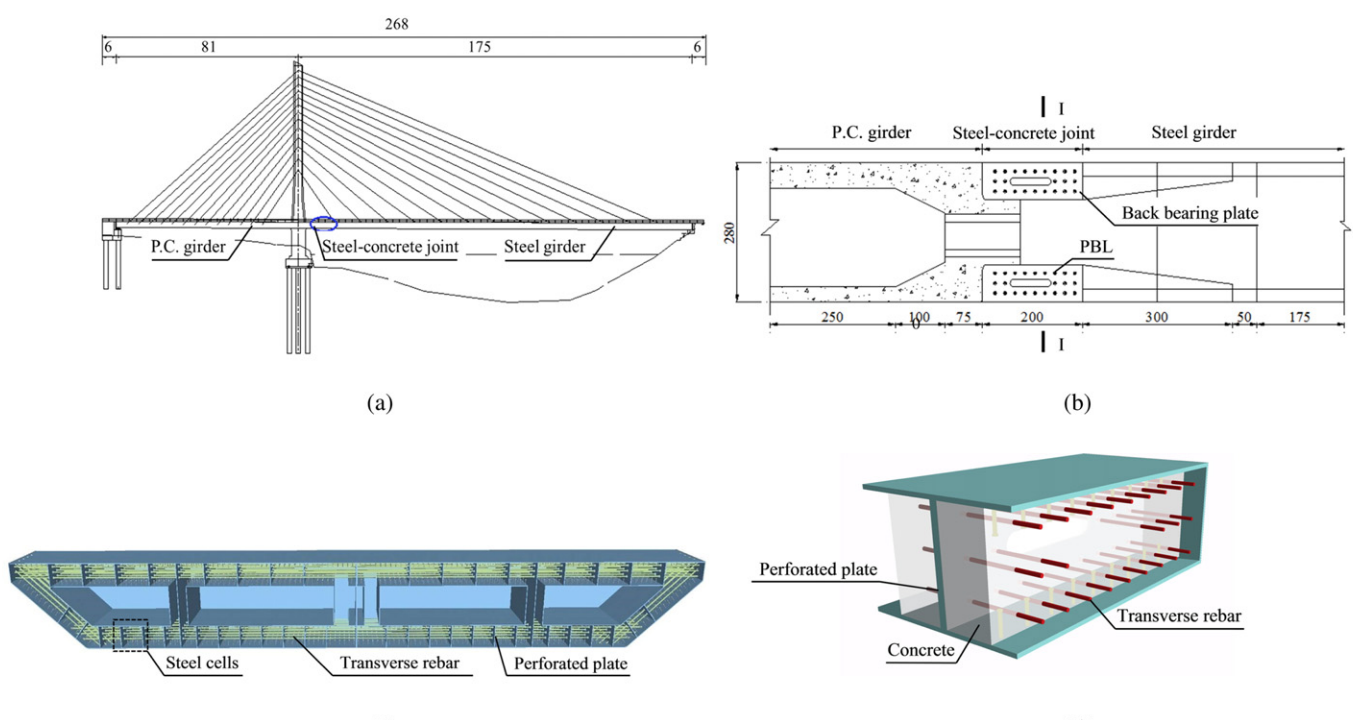

Fig. 2. Nujiang bridge: (a) Elevation view (unit: m); (b) Steel–concrete joint part (unit: cm); (c) Section of I–I; (d) PBL connectors in the steel cells.