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Shear resistance of the perfobond-rib shear connector depending on concrete strength and rib arrangement

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ABSTRACT

In this study, a perfobond-rib shear connector between steel and concrete mixed girder bridge components is described. Push-out tests were conducted and the results were compared with established shear-capacity equations for perfobond shear connectors. Modified shear-capacity equations that consider the perfobond-rib arrangement, including rib height and spacing, are proposed. The test results were compared with studies of the concrete end-bearing zone, of transverse rebars in the rib holes, and of the shear-capacity equations of perfobond ribs. From the push-out tests, the shear capacity of the perfobond-rib shear connector varies in proportion to concrete strength, as indicated by the increase in the contribution to the shear resistance of the concrete. The ductility of the conductor is related to the flexibility limit of the transverse rebar in the rib hole. The shear capacity of a twin perfobond-rib shear connector was reduced to about 80% that of a single perfobond rib by reducing the shear capacity contributed by the concrete end-bearing zone, the concrete dowel, and the transverse rebar in the rib hole. The perfobond rib can be used as a shear connector in composite or mixed structures since it has sufficient ductility as well as high shear capacity.

1. Introduction

The head stud is the most widely used type of shear connector in composite steel–concrete structures to resist horizontal shear and vertical uplift forces. Studies on stud shear connectors have used push-out and composite beam tests to evaluate shear capacities [1–3].

New composite and hybrid systems, such as precast and composite deck systems, have recently been used in bridge and building construction. These systems provide a greater shear connection in order to improve composite action. However, when head studs are used as shear connectors, many connectors are welded to one intensive area, complicating rebar arrangements at the interface between the steel and the concrete sections. Thus, studies on large stud shear connectors and group stud connections report improved shear capacity compared with general small studs [4]. However, the head stud type can cause cracks in the concrete slab and experience fatigue under service loading conditions. Therefore, various types of shear connectors that have sufficient shear capacity, ductility, and high fatigue resistance have been proposed to substitute for many-head stud connectors.

The proposed shear connector consists of a perfobond-rib shear connector with a high shear resistance capacity, easier installation due to the shape of the ribs, and a high fatigue resistance. A perfobond-rib shear connector developed in Germany consists of a flat steel plate containing a number of holes. This connector resists horizontal shear and vertical uplift forces at the steel–concrete interface by using a concrete end-bearing zone, concrete dowels, and transverse rebars in the rib holes [5].

Studies on the shear capacity and behavior of the perfobond rib have been conducted by using push-out and composite beam tests as well as numerical simulations [6–11]. From these studies, equations for predicting the shear capacity of perfobond-rib shear connectors are proposed and are compared with test results.

As shown in Fig. 1, the shear resistance characteristics of a perfobond-rib shear connector are affected by the shear resistance of the concrete dowel in the rib hole (horizontal and vertical shear) (1, 2), the shear resistance of the transverse rebars in the rib holes (3), and the concrete end-bearing resistance (4). The chemical bond effect does not account for much of the total shear resistance, and its contribution occurs in the bond face between the concrete and the steel plate. This contribution is often ignored due to the difficulty of calculating the bond effect.

In this study, the shear capacity of a perfobond-rib shear connector between the PSC (prestressed concrete) girder and the steel girder, as shown in Fig. 2, was examined. The connection between the PSC and steel girders is very important, and should

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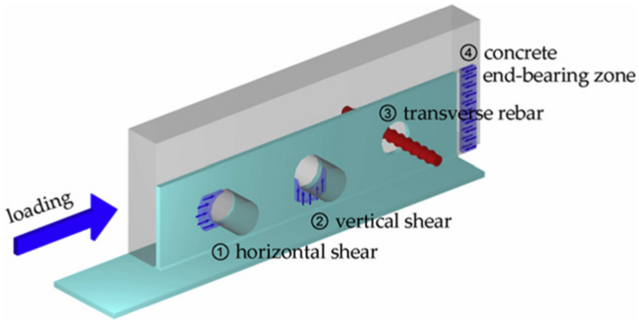


Fig. 1. Mechanical behavior of a perfobond-rib shear connector.

ensure that the two different materials act as a single unit and safely transfer the effective load between the steel and concrete parts. The PSC-steel mixed girder shown in Fig. 2 is connected by multiple perfobond-rib shear connectors to transfer the applied load. Therefore, push-out tests were conducted to evaluate the shear resistance behavior. The goal is to determine the optimum perfobond-rib arrangement and to design a perfobond-rib shear connector for use in PSC-steel mixed girder systems.

The shear capacity of a perfobond-rib shear connector can be affected by the end-bearing zone and the concrete dowel effects as a function of concrete strength, rib arrangement and rib spacing. Thus, the effects of changes in concrete strength and the arrangement of the perfobond ribs in a new shear connector were examined by using a push-out test. The test results were compared with other studies and with numerically calculated shear-capacity equations. Finally, shear-capacity equations that take into account the rib arrangement were derived from the test results and were comparing with the prior shear-capacity equations.

2. Push-out tests of the perfobond-rib shear connector

2.1. Shear-capacity equations of the perfobond-rib connector

A perfobond rib, which consists of a flat plate with a number of holes punched through it, resists horizontal and vertical forces by concrete end-bearing resistance, dowel action, and transverse rebars in the rib holes. Shear-capacity equations of perfobond ribs are expressed by using these contributing parameters [7,8,12–15].

Oguejiofor and Hosain performed push-out tests with perfobond ribs and proposed two regression analysis equations for predicting the shear capacity of perfobond-rib shear connectors. The first equation, Eq. (1), overestimates the shear capacity of a perfobond rib because it over-evaluates the contribution of end-bearing resistance as well as the contribution of the rebar in the concrete slab. The second equation, Eq. (2), which considers the height and thickness of the rib, was proposed by Oguejiofor and Hosain [7,8] after the numerical analysis of the push-out tests.

$$Q = 0.590A_c\sqrt{f_{ck}} + 1.233A_{tr}f_y + 2.871nd^2\sqrt{f_{ck}} \quad (1)$$

$$Q = 4.5h_{sc}t_{sc}f_{ck} + 0.91A_{tr}f_y + 3.31nd^2\sqrt{f_{ck}}, \quad (2)$$

where Q is the shear capacity at the shear connector (N), f_{ck} is the compressive concrete strength (MPa), A_c is the shear area of the concrete slab (mm^2), A_{tr} is the area of the transverse rebars in the rib holes (mm^2), f_y is the yield strength of the transverse rebar (MPa), n is the number of rib holes, d is the diameter of the rib hole (mm), h_{sc} is the height of the rib (mm), and t_{sc} is the thickness of the rib (mm).

These shear-capacity equations were initially proposed in Japan [12,13]. Eq. (3) applies to a case where the rib hole is without a transverse rebar and Eq. (4) applies to situations in which the rib hole contains a transverse rebar. The welding details of the perfobond rib should be checked for any developed tensile stress due to shear force and moment at the shear connection [12,13].

$$Q_{\text{rib}} = 3.38d^2(t/d)^{1/2} \times f_{ck} - 39.0 \times 10^3, \quad (3)$$
$$\text{with } 22.0 \times 10^3 < d^2(t/d)^{1/2} \times f_{ck} < 194.0 \times 10^3,$$

$$Q_{\text{rib}} = 1.45 \times ((d_2 - \phi_{st}^2) \times f_{ck} + \phi_{st}^2 \times f_{st}) - 26.1 \times 10^3, \quad (4)$$
$$\text{with } 51.0 \times 10^3 < (d_2 - \varphi_{st}^2) \times f_{ck} + \varphi_{st}^2 \times f_{st} < 488.0 \times 10^3,$$

where Q_{rib} is the shear capacity at the rib hole (N), φ_{st} is the diameter of the transverse rebar in the rib hole (mm), and f_{st} is the tensile strength of the transverse rebar (MPa).

Sara and Bahram proposed another equation, Eq. (5), for predicting the shear capacity of perfobond-rib shear connectors. The equation included the effect of the chemical bond between the steel and the concrete face in the equations of Oguejiofor and Hosain [7,8,14].

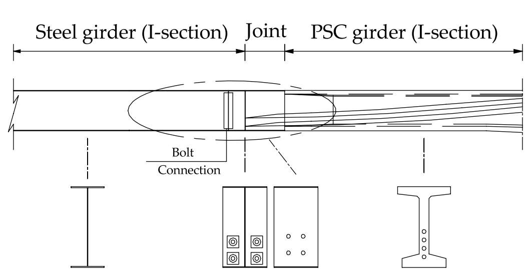
$$Q = 0.747bh_{\text{ecs}}\sqrt{f_{ck}} + 0.413b_fL_c + 1.66n\pi\sqrt{f_{ck}}(d/2)^2 + 0.9A_{tr}f_y, \quad (5)$$

where b is the thickness of the concrete slab (mm), h_{ecs} is the distance between the end of the perfobond rib and the end of the concrete slab (mm), b_f is the width of the steel beam flange (mm), and L_c is the contact length between the concrete slab and the steel beam flange (mm).

Verissimo et al. proposed a modified shear-capacity equation, Eq. (6), based on that of Oguejiofor and Hosain [15,16].

$$Q = 4.04\frac{h_{sc}}{b}h_{sc}t_{sc}f_{ck} + 2.37nd^2\sqrt{f_{ck}} + 0.16A_{cc}\sqrt{f_{ck}} + 31.85 \times 10^6(A_{tr}/A_{cc}), \quad (6)$$

where A_{cc} is the longitudinal concrete shear area per connector (mm^2).



(a) Steel and concrete mixed girder.

(b) Detail of shear connections (test model).

Fig. 2. New mixed girder and connection detail.