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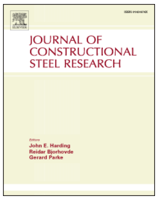

Puzzle-shaped rib shear connectors subjected to combined shear and tension

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ABSTRACT

Open rib shear connectors are increasingly used as shear connectors and anchors between concrete and steel members of composite structures. In many cases, the rib connectors are subjected to combined shear and tension forces. However, until now, the structural response and interaction behavior of rib shear connectors exposed to tension and shear has not been analyzed. The current design guidelines do not provide a recommendation for computing the strength of rib shear connectors (traditionally used as shear connectors) under combined tension and shear. Therefore, the present paper presents systematic studies on the interaction behaviour of puzzle-shaped rib shear connectors, also called composite dowels. Based on tests results gained in a novel test setup and FE-simulations, the interaction properties of composite dowel rib connectors are analyzed and a model approach for the tension and shear interaction is proposed.

1. Introduction

In steel-concrete composite girders, rib shear connectors can be used to transfer shear forces between the concrete slab and the steel section. Rib shear connectors are produced in burning regular recesses into the webs of steel members. After encasing with concrete, the vertically embedded steel dowels and the interstitial concrete dowels ensure a structural, interlocked connection (Fig. 1, a, b). Currently, distinction is made between composite dowels with either open (e.g. puzzle- or clothoid-shaped [1–3]) or closed (e.g. perfobond shape [4–7]) recesses. In this paper, the focus is on the structural behavior of rib connectors with open puzzle-shaped geometry, which are usually called composite dowels or Crestbond connectors, in the literature.

The shear design of rib shear connectors in puzzle (PZ) and clothoid (CL) shape is provided within a technical approval [8], which covers steel failure and pry-out failure. Important preliminary research and models for the assessment of the shear behaviour of rib shear connectors were performed in [9,10] for pry-out failure and in [3,11,12] for steel failure. The impact of transverse cracks on the pry-out resistance of rib shear connectors is investigated in [13]. At present, there are no official guidelines for the design of the tensile strength of rib shear connectors in the codes. However, in [14,15] approaches were developed for the assessment of the tensile resistance of rib shear connectors with concrete break-out failure. These approaches were inspired by the concrete capacity method (CC-method), which is used for the design of headed studs, for instance.

In numerous practical applications, rib shear connectors are neither subjected to pure shear nor pure tensile stresses, but rather to combination of both actions. Besides the shear force transmission, rib shear connectors in steel-concrete composite beams exposed to bending (Fig. 1, b) must also provide sufficient resistance against the uplift of the concrete slab [16,17]. In addition to such inadvertently occurring tensile forces, shear connectors are also systematically used to transfer combined tensile and shear loads. For instance, this is the case where concentrated single loads are applied to the concrete slab of the composite beam, at discontinuities in stiffness along the beam axis e.g. in the region of large web openings [14,18] (Fig. 1, c) or where the tails of external reinforcement elements are anchored to the concrete beam [19,20] (Fig. 1, d).

While the structural behavior of headed studs under combined actions has been extensively researched [21–26], and can reliably be described by models for steel and concrete break out failure, the combined loading of rib shear connectors has so far been largely unexplained. In the literature, only few preliminary tests were carried out under combined actions. As these tests were performed on small-scale composite dowels with slender UHPC concrete slabs [27,28], the assignability of test results to composite dowels with dimensions used in practice and normal-strength concrete is not yet resolved. So far, models for the description of the tensile-shear interaction are completely missing. Therefore, systematic investigations on puzzle shaped rib shear connectors subjected to combined actions are presented in the following. Based on tests and numerical FE-calculations, the structural behavior of composite dowels under

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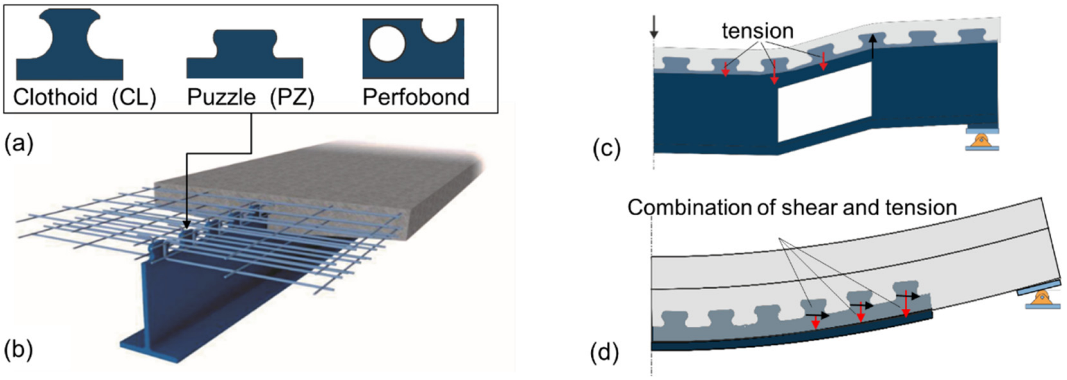


Fig. 1. Composite beam with composite dowel rib shear connectors (left), combined tensile and shear loading (right).

combined loads is analyzed and an engineering model for the determination of the tensile-shear interaction is derived.

It is important to note, that the following investigations and models presented in this paper only cover cases where the tensile-shear interaction leads to a concrete failure of the rib shear connectors. However, especially if using thin steel sheets for the dowel and constructional steel with low strength (e.g. S235) but high strength concrete slabs with large embedment depths and heavy reinforcement, the steel dowels are likely to fail. Here, the global interaction of shear and tensile forces at the rib connector will lead to local stress interactions within the steel dowel. These stress interactions will certainly influence and alter the structural behavior and failure process compared to pure shear or tensile loading of the connector. However, investigations of these interaction processes in the steel are not in the scope of this paper. Nevertheless, in the future the experimental and theoretical methods presented in this paper, can be used to analyze the behavior of rib shear connectors under combined tensile-shear loading in case of steel failure, as well.

2. Experimental investigations

2.1. Test campaign

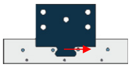
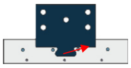
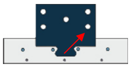
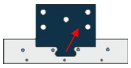
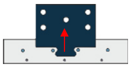
Table 1 presents the test program. This was aligned with the systematic investigation of the structural behaviour of composite dowels with puzzle geometry in normal-strength concrete under combined tensile and shear loads. Besides the test designation, the number of individual tests *n* performed per series as well as the dimensions and the arrangement of the reinforcement of the test specimens are given herein. Within the tests, the angle α of the load applied to the composite dowels was systematically varied between 0° (pure shear) and 90° (pure tension).

2.2. Test specimen and materials

Fig. 2 shows the dimensions and the setup of the test specimen. Here, puzzle-shaped steel dowels with a longitudinal spacing of $e_x = 15$ cm, a dowel height of 4 cm and a web thickness of 1.1 cm were used. This dowel geometry represents the smallest possible dimensions, which is covered by the technical approval for composite dowels [8]. The concrete slab's height was 10 cm and its square area had edges of 50 cm each. The embedment depth of the steel dowels in the concrete slab was chosen to set the concrete cover c_u to 3 cm between the bottom of the steel dowel and the bottom of the concrete slab (cf. Fig. 2). At the straight outer edges of the steel plate the transfer of compressive stresses between steel and concrete was prevented through inserting PU-foam blocks (Fig. 2).

The transverse reinforcement of the concrete slab, throughout all tests, was composed of crossbars (Fig. 2, top, Pos. 1, Ø 12 mm), which were placed in the center of the top puzzle fillet, and closed stirrups (Fig. 2, top, Pos. 2, Ø 10 mm), which were positioned at mutual distance

Table 1
Test program of tensile-shear-tests.

Test	Parameter	Angle [°]	n	Reinforcement		l/b h_c/c_u	Remark
			–	Transversal bars strirrups	Longitudinal reinforcement	[cm]	
ZS1		0°	2	4∅12 ∅10/15 cm	8∅12	50/50/ 10/3	Pure shear (Reference shear test)
ZS2		22.5°	3	4∅12 ∅10/15 cm	8∅12	50/50/ 10/3	Predominantly shear
ZS3		45°	2	4∅12 ∅10/15 cm	8∅12	50/50/ 10/3	Shear and tension
ZS4		67.5°	3	4∅12 ∅10/15 cm	8∅12	50/50/ 10/3	Predominantly tension
ZS5		90°	4	4∅12 ∅10/15 cm	8∅12	50/50/ 10/3	Pure tension (Reference tensile test)