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Composite dowels as shear connectors for composite beams – Background to the design concept for static loading

Maik Kopp [a,*], Kevin Wolters [a], Martin Claßen [b], Josef Hegger [b], Max Gündel [c], Joerg Gallwoszus [d], Sabine Heinemeyer [e], Markus Feldmann [a]

[a] Institute of Steel Construction, RWTH Aachen University, Germany
[b] Institute of Structural Concrete, RWTH Aachen University, Germany
[c] Wölfel, 97204 Höchberg, Germany
[d] Kempen Krause Ingenieure GmbH, 53879 Euskirchen, Germany
[e] Kempen Krause Ingenieure GmbH, 52072 Aachen, Germany

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ABSTRACT

Composite dowels are known as powerful shear connectors in steel-concrete-composite girders. More and more they are used in practice, especially for prefabricated composite bridges. Compared to headed studs they provide an increased strength. They also show a good deformation capacity even in high strength concrete. Furthermore, the application in steel sections without upper flange is very simple. Nevertheless, missing standards for composite dowels with the economic clothoidal and puzzle shape have led to hesitations in application which is often due to delays in the approval process. Hence, the aim of the finished German research project P804 funded by FOSTA – Research Association for Steel Application was to solve open questions concerning these innovative shear connectors and to prepare a general technical approval [1] available for any design office or construction company. Since May 2013 the composite dowels with clothoidal and puzzle shape are regulated in the technical approval. This paper presents the background information to the derived technical rules for ultimate limit state, structural design principles and instructions for production and construction and provides further background information.

1. Introduction

Composite dowels (CD) are shear connectors for composite beams, which consist of steel dowels and concrete dowels (see Fig. 1), replacing headed studs for the transference of shear forces between steel section and concrete slab. They are either made of steel plates welded on the upper flange of steel beams or fabricated directly out of the web of steel beams by gas cutting. The main advantage compared to headed studs is the higher load-bearing capacity and a sufficient deformation capacity even in high strength concrete, so that they can be classified as ductile shear connectors acc. to EN 1994-1-1 [2]. Furthermore, composite dowels are particularly suitable and economic for composite sections with steel profiles without upper flange. By this, any steel parts next to the neutral axis can be reduced to a minimum. Another application area is the arrangement of composite dowels in concrete T-beams as external reinforcement. Nevertheless, the absence of technical rules led to uncertainties on the part of the design office and building authority during the construction process and to some reluctances of clients. Still, owing to the technical advantages, composite dowels are more frequently used for buildings as well as road and railway bridges. In several European countries (e.g. Germany [3–5], Austria [6], Poland [7,8], Romania [9,10] and the Czech Republic [11]) about 38 composite bridges are built.

The aim of the finished national research project P804 [12] funded by FOSTA, the Research Association for Steel Application, was to solve unanswered questions regarding these innovative shear connectors and to prepare a German technical approval available for any design office or construction company. The German general technical approval Z-26.4-56 "composite dowels" [1] from May 2013 covers the composite dowels with clothoidal (CL) and puzzle (PZ) shape (see Fig. 1).

2. State of the art

2.1. Overview

The beginning of development of composite dowels dates back to the 1980s. The starting point can be traced back to the research of Andrä and Leonhardt, which led to the development of the Perfobond strip (see Fig. 2, a) [13,14]. At the same time Bode developed the

* Corresponding author.
E-mail address: m.kopp@stb.rwth-aachen.de. (M. Kopp).

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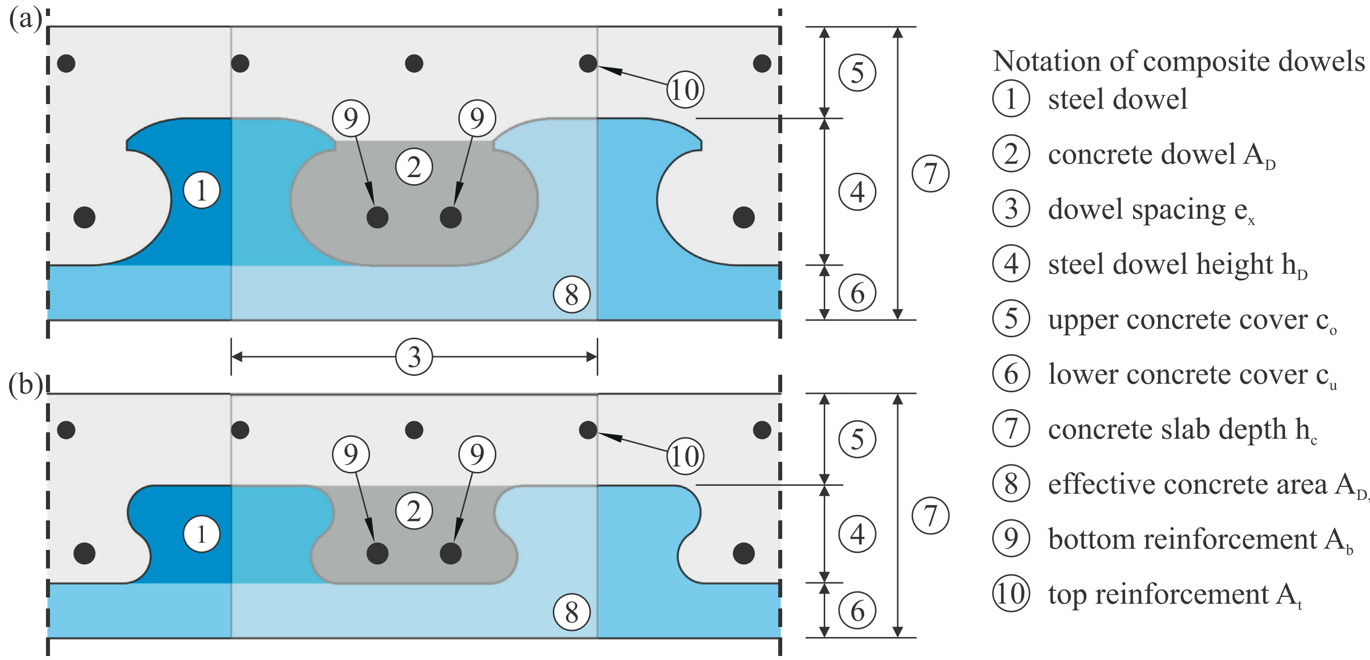

Fig. 1. Notation for the section along a composite dowel, (a) clothoidal and (b) puzzle shape.

"Kombi-Verdübelung" (see Fig. 2, b) [15,16]. These shaped geometries transfer the shear forces between the steel beam and the concrete slab by vertical steel plates with holes. Both design concepts are based on the mechanical model for shear failure of the concrete dowel. In the following years important knowledge about the bearing behaviour of composite dowels was gained at the Bundeswehr Universität München [17,18]. From this, mechanical models for the exceedance of the partial area pressure of concrete in the opening and concrete prying-out for composite dowels next to the concrete surface were obtained [20,23].

In recent times composite dowels with puzzle and clothoidal shape evolved. The development of composite dowels with puzzle strip (Fig. 2, c) were pushed by research projects at RWTH Aachen University [24,25,78]. They led to a further development of the pry-out model and new models for steel failure. Seidl [21] developed design models for overlapping effects on concrete pry-out and vertical splitting of composite dowels in concrete T-beams. The beginning of the clothoidal strip (Fig. 2, b) – an optimization for fatigue loading - can be found in [26,27]. Both, the puzzle and the clothoidal geometry enable the manufacturing of two composite dowels with one gas cut and none or little waste of material. Moreover, the open geometry allows for easy installation of the reinforcement leading to reduced production costs and time.

An extensive description of the main steps in the development of composite dowels can be found in [12].

2.2. Failure modes

Literature and experiences based on own tests have shown various failure modes originating from static loading. Generally, there are two types of failure modes: concrete and steel failure. In the area of concrete failure, 3 types are known (see Fig. 3). Concrete shearing can occur through double shearing of the concrete dowel (cp. Fig. 1, "2"). This failure mode is decisive for small openings, large steel plate thicknesses and no resp. less dowel reinforcement A_b. A low distance between concrete dowel and concrete surfaces (top or bottom concrete cover) leads to the concrete prying-out. This failure mode is similar to the concrete prying-out of anchors subjected to shear forces. In beam-type sections with composite dowels as external reinforcement failure of the concrete web can occur. For thin concrete webs, splitting tensile forces can exceed the concrete tensile stress, which results in a horizontal crack at the height of the composite dowel (vertical splitting).

In addition to the concrete failure modes for small plate thickness and low steel strength, plastic steel failure of the steel dowel can occur. This failure mode is caused by a combined shear-bending mechanism, which leads to a horizontal crack in the steel plate.

3. Methods

Different methods of investigations are used to develop mechanical models, which describe the load-bearing behaviour (failure modes) of composite dowels. Based on experimental results from literature, a database (chapter 3.1) is prepared. The database is divided into different load types (static and cyclic) and respectively into concrete (shearing, prying-out) and steel (shearing) failure modes. The own tests (chapter 3.2) performed in [12] are added to the database. The experimental tests are supported by numerical simulations (chapter 3.3).

3.1. Database

In order to resolve open issues regarding load-bearing behaviour of the composite dowels, a database is composed on the basis of available research results from literature. Therein, only those results have been considered which are reproducible without restrictions, where the failure mode is distinct (no block dowel effects) and all necessary parameters are documented. With the help of this data, occurred failure modes of the composite dowels are identifiable. The result, amongst others, is that the design model for concrete shearing can be transferred to different dowel geometries. Therefore, this failure mode has not been investigated in own tests. Another result is the existence of a considerable stock of test results under static loading of the puzzle shape. Due to the lack of knowledge of the clothoidal shape, this aspect has been given a special amount of attention during the execution of the own tests.

The databases of the presented failure modes (chapter 4) are shown in the related chapters.