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The behaviour of puzzle-shaped composite dowels — Part I: Experimental study

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ABSTRACT

An innovative form of shear connection effected through puzzle-shaped (PZ) composite dowels is studied by means of full scale push-out tests (POST). 19 specimens were subjected to a programme of destructive tests focused on the load bearing capacity of the connection steel part, i.e. the steel dowels. The influence of web thickness, dowel size and steel grade were studied. The design and construction of the test specimens, test procedures, failure mechanisms and test results are presented in detail. On the basis of the test results, it is assumed that in the case of steel S460 and concrete C70/85, at a web thickness of 10 mm steel failure occurs, at 30 mm concrete failure occurs and at 20 mm mixed steel–concrete failure occurs. The steel dowel undergoing plastic deformations is a major factor initiating concrete failure. The tests have proven the thesis [7] that the size of the dowels has no influence on the load bearing capacity of the shear connection unit length. Furthermore, it was discovered that ductility is a linear function of the inverse of dowel size in the case when exhaustion of the load bearing capacity of the steel dowels determines the load bearing capacity of the connection. As the basis of this task, the experimental confirmation of this thesis was paramount. Analysis of the results for a single composite dowel and FEM simulations are presented in the adjoining paper — Part II: Theoretical investigations.

1. Introduction

Composite dowels are a type of shear connectors which have recently been used to build innovative composite structures across Europe. Thanks to such connectors, composite beams can be effectively and economically constructed without using the top steel flange, i.e. by directly connecting the steel beam web and the concrete slab. The intensive research conducted in recent years, especially the international PreCo-Beam project [1], has resulted in the development of principles for designing structures with this type of connection [2–5]. The current relevant knowledge is sufficient to incorporate this type of connection into Eurocode 4. The design principles are based on extensive experimental studies and numerical analyses [6–9], in which the individual researchers focused on specific problems. The load bearing capacity of the concrete part of the connection is presented in [6], while the load bearing capacity of the steel part of the connection is presented in [8]. Finally cutting line developed in Poland [4] using modified clothoide (so called MCL shape, Fig. 2) leading to connectors with a long fatigued life [9], widely introduced into bridge engineering in recent years [5].

The dowels currently in use have been derived from the perfobond strip developed in the 1980s by Leonhardt [10]. The assembly of the reinforcement through insertion into holes proved troublesome and so in the 1990s Wurzer [11] and Zapfe [12] did some research and formulated principles for calculating strips with open cut-outs. However, as was the case with the perfobond strip with holes, this solution still suffered from the drawback that a potential failure would originate mainly from the concrete (hence the name concrete dowels) since the cut-outs in the steel were rather small relative to the total surface area of the strip. The turning point was the use of puzzle-shaped dowels (PZ), which were produced using a single cutting line, so that from one I-bar two T-shaped sections with dowels would be obtained. The T-sections were used to construct the bridge in Pöcking [13], and the typical configurations of girders and shear connection used in the bridge in Pöcking and many other innovative bridges [19] are shown in Fig. 1.

As solution proved effective, economical research was undertaken internationally (mainly in Germany) in order to discover the principles on which the new connectors worked, which led to the launching of the PreCo-Beam project [1]. Various dowel shapes were considered, including the shape (PZ) used in the Pöcking bridge which had the highest potential. Since there existed a simple technology (already tested on an industrial scale) of manufacturing puzzle composite dowels, this type of dowel was given a great deal of attention, especially that the shearing tests carried out for the Pöcking bridge project [13] had shown the PZ dowel to have promising strength characteristics. The results of POST tests carried out on composite dowels of different shapes (Fig. 2), with a thickness of 10 mm, a height of 100 mm and a spacing of 300 m were reported in [2]. Very similar ultimate load bearing capacity values (500–600 kN) were obtained.

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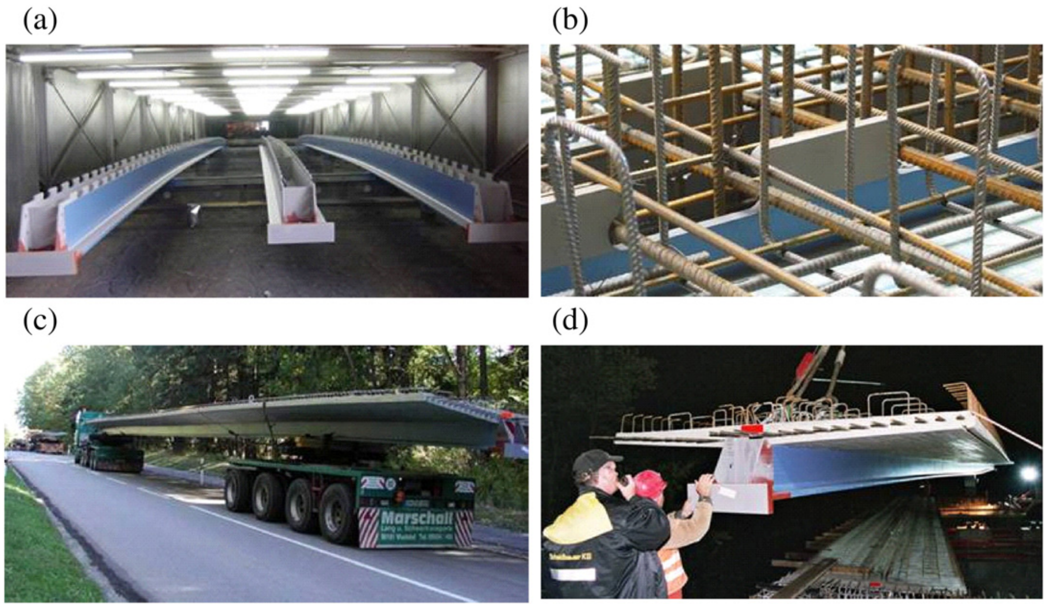

Fig. 1. Girders for viaduct in Pöcking (Germany) with puzzle-shaped dowels [13]: a) steel sections, b) steel dowels with reinforcing bars, c) transportation of girders, and d) montage of girders at construction site.

The sharp notch at the back of the SA-shaped dowel is the point where fatigue cracks would start [17]. Hence such asymmetric shapes were eliminated from further consideration for application in bridges, where fatigue is a problem. Attention was drawn to stress concentration in the steel dowel, and not only the ultimate load bearing capacity, but also the behaviour of the connection under the operational load. The state of stress in the dowel began to be analysed.

The push-out test (POST), described in [18], is one of the ways of testing the shear connection affected by means of composite dowels. It has been shown that the POST test is a good tool for analysing the ultimate load bearing capacity, but it is not suitable for assessing the behaviour of the connection in the elastic range because of the non-uniform loading of the dowels (Fig. 3). Other testing methods are used in the latter case [18].

The finite element method (FEM) is used for numerical simulations of composite dowel connections. Advanced FEM numerical simulations of the POST test (shape SA), taking into account the physical nonlinearity of steel and concrete, the geometric nonlinearity and the contact problem, were carried out [15]. It has been shown that regardless of the non-uniform strain of the dowels, the material begins to yield under loads significantly below the characteristic load bearing capacity according to Euro-code 4 (Fig. 3) and the ratio of the yield force in the critical point of the dowel to the ultimate load bearing capacity depends on the shape of the dowel and its height/length ratio [7].

In extreme cases the shear connection may fail due to the failure of the steel dowels or the concrete dowels, but usually due to a mixed mechanism, as illustrated in Fig. 3 [7]. Assuming that the structural element to be optimized is the steel part of the connection [7], it is essential to determine the load bearing capacity of this part and the character of the slip–force curves conditioned by the failure of the steel in the context of the connection ductility and the dowel yield forces. As the parameters depend on the dowel shape and proportions, the geometry of the dowel also needs to be optimized [7].

This paper presents an extensive programme of tests carried out to identify the behaviour of puzzle-shaped dowels (part I), which is followed by analyses leading to the development of design guidelines (part II).

2. Composite dowels at the background of the other shear connectors

Comparison of designed shear capacity between headed studs and composite dowels can be done using formulas (1) and (9) concerning steel resistance (what is the scope of the paper). Considering area of shear connector as the only criterion for comparison, welded studs ensure higher resistance, but they require a steel flange to be welded to. Much effort is needed for the realisation of welded studs and a big advantage of composite dowels is that steel dowels are fabricated fully automatically. Direct comparisons can be made when assessing the bridges presented in [19] with typical bridge solution using studs. Herein composite dowels at the background of the other continuous shear connectors are presented and discussed. Since the development of the perfobond rib [10], many researches focused on investigations of concrete failure design, which was typical for this type of shear connection. One disadvantage of the perfobond rib was the difficulty to position the slab reinforcement, when the steel bars have to cross the connector openings. However, perfobond strip (Fig. 4a) evolved [11,12] towards kombi connection (Fig. 4b) with opened holes. In such a case, steel failure and increased ductility started to be noticeable. Finally, for composite dowels (Fig. 4c) obtained with symmetric cutting line [1] steel failure mechanism is of the utmost importance in design of connection because constructional steel is the most expensive part of composite a girder structure and must be optimized. Extensive studies of different shapes of dowel and a list of references developed by

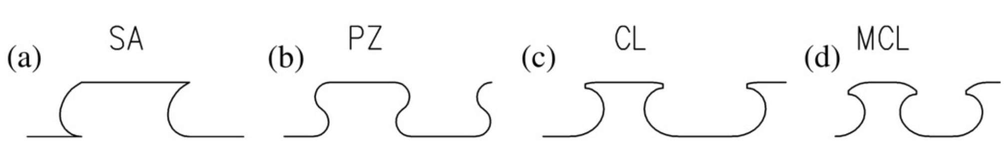

Fig. 2. Shapes of composite dowels a) fin (SA), b) puzzle (PZ), clothoidal (CL), and d) modified clothoidal (MCL).