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Autor: Kraus, Dieter / Wurzer, Otto

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Bearing Capacity of Concrete Dowels

Dieter KRAUS
Prof. of Civil Eng.
Universität der Bundeswehr
Munich, Germany

Dieter Kraus, born 1941, obtained his civil engineering degree in 1969 and his Dr.-Ing. degree in 1975 at the Techn. Univ. München. Project engineer in a construction company and Professor for concrete Engineering at the Univ. der Bundeswehr München. Dieter Kraus passed away in March 1997.

Otto WURZER
Civil Eng.
Universität der Bundeswehr
Munich, Germany

Otto Wurzer, born 1964, obtained his civil engineering degree at the Techn. Univ. München. After one year, as a member of construction company, he joined the Univ. der Bundeswehr München as a research Assistant.

Summary

The bearing and deformation behavior of a new shear connector called Concrete Dowel was subject of extensive experimental and theoretical investigations introduced at the University of the German Armed Forces during the last years. The main results of these investigations, a new mechanical model and a draft of a design concept are presented in this paper.

1. Introduction

A new shear connector used for composite beams has been developed since 1986 as „Perfobond Strip“ [1] or „Kombi-Dowels“ [2]. The so called „Concrete Dowels“ are built by parts of the concrete slab interspersing circle or drop shaped holes, which are located in steel strips welded upright on I-sectioned steel girders (Fig. 1). It is also possible to locate these holes directly at the upper edge of the web in ⊥-sectioned steel girders (Fig. 2).

The previous level of knowledge about the bearing behavior of Concrete Dowels is mainly based on tests with small holes [1], [2]. In these tests shear yielding of the steel stems remaining between the holes and local damage of the concrete interspersing the holes were observed as failure criterias. As a simple mechanical model, the concrete interspersing the holes may be considered as to build a dowel loaded to shear and extreme local compression. However the general validity of this model has not been sufficiently proved yet.

As well as the strength, the stiffness and the deformation capacity represent further important properties of a shear connector. The characteristic deformation capacity of small Concrete Dowels (width $b_i \leq 43$ mm) does not justify the assumption of a ductile shear connector, while large Concrete Dowels up to a width of 100 mm showed really ductile load-slip-behavior in initial push-out-tests.

Further extensive experimental and theoretical investigations regarding the bearing and deformation behavior of Concrete Dowels have been introduced at the University of the German Armed Forces during the last years. The states of stress and the failure mechanism causing concrete damage are further important subjects of these investigations as well as the main influence parameters. The main results of these investigations and a draft of a new design concept are presented below. More detailed informations about these investigations are given in [3].

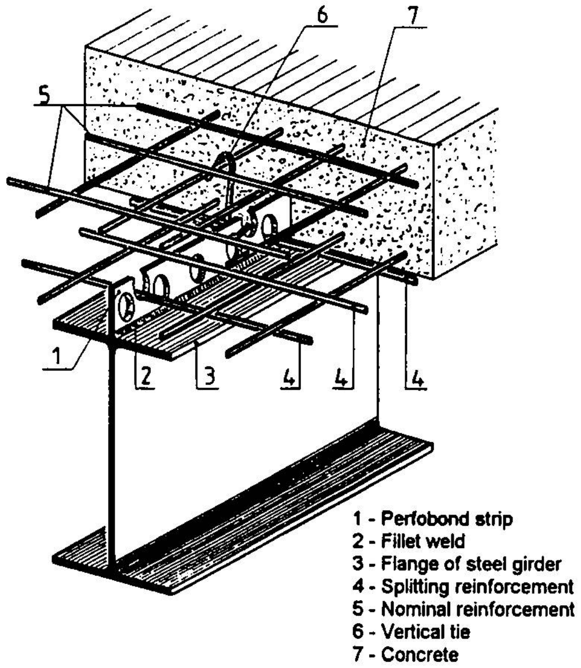

Fig. 1 Composite beam with Perfobond Strip

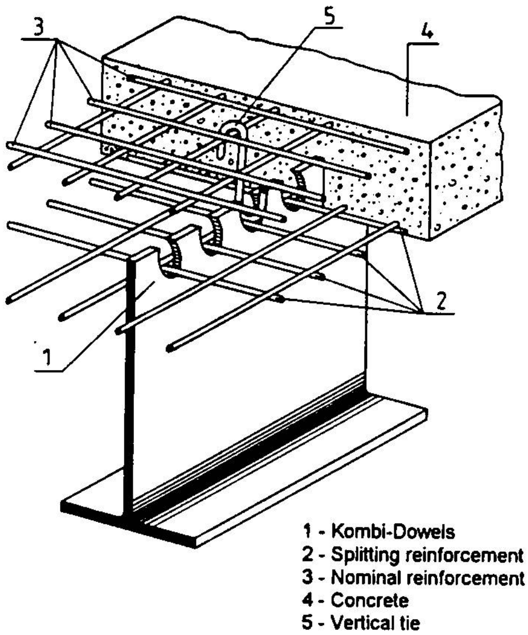

Fig. 2 Composite beam with Kombi Dowels

2. Experimental Investigations

Altogether 42 push-out-tests using large Concrete Dowels ($h = b_i \geq 70$ mm) have been executed and evaluated according to Eurocode 4 [4]. Figure 3 shows the typical test specimens and the investigated variant of Concrete Dowels. The influence of the following parameters has been investigated in these tests: material properties of concrete, dimensions and shape of holes and stems, tranverse reinforcement, loading of concrete slab.

The typical deformation behavior (load-slip-relation) of Concrete Dowels observed in the tests can be divided in three characteristic sections named I, II, III (see figure 4). At lower load steps (section I) only small deformations occur. According to Eurocode 4 [4] 25 load cycles with an amplitude $\Delta P \cong 0{,}35\, P_{max}$ have been introduced in this section to remove the adhesion between steel strip and concrete slab. Longitudinal splitting cracks occur in the concrete slab at a load level $P_{crack} \cong 0{,}75\, P_{max}$, which cause a sharp increase in deformation with further rising load (section II).

The maximum shear resistance P_{max} is reached, when local parts of the slab surface are wedging off close to the Concrete Dowels. After reaching P_{max} shear resistance is decreasing slowly with further deformation and progressive concrete erosion (section III).

At the end of the tests some of the concrete slabs have been longitudinally cutted to examine the condition of the concrete dowels (see figure 5). The concrete interspersing the holes seemed to be local damaged. Wedges of completely compacted concrete, which have been found close to the contact surface, must be particularly mentioned.

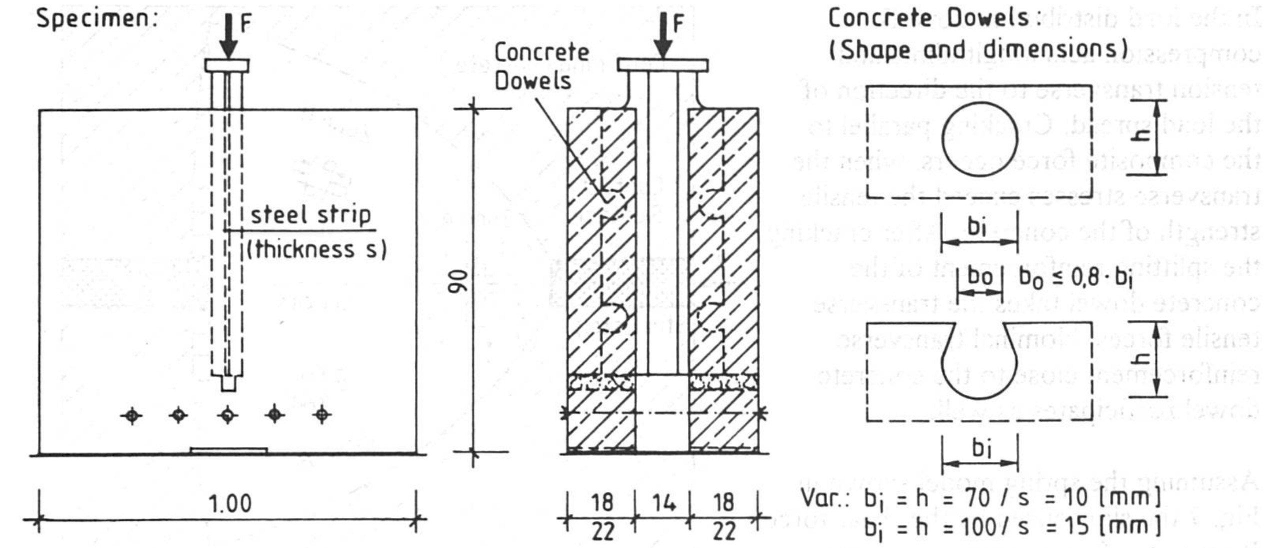

Fig. 3 Push-out test specimen and investigated variants of Concrete Dowels

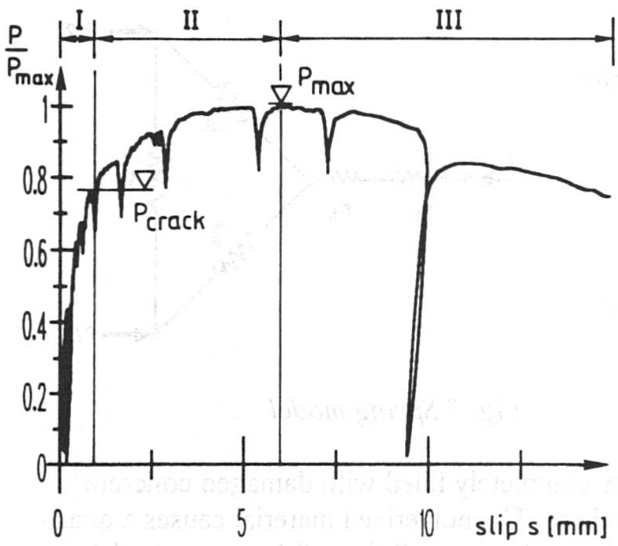

Fig. 4 Characteristic deformation behavior

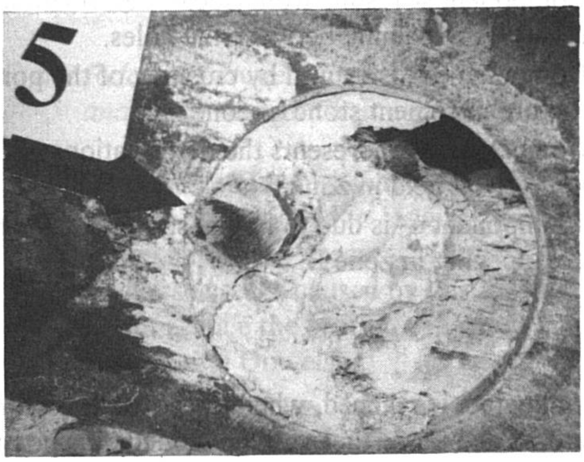

Fig. 5 State of damage

3. Mechanical Model

The composite force is transmitted from the steel strip to the concrete slab by extreme local compression (effect of partial area loading), which acts at the contact surfaces of the hole. The area, where the load spread is taking place in the concrete dowel, may be separated in two main parts named zone A and zone B (see Fig. 6).

In the load transmission zone A concrete is confined causing triaxial compression. There the bearing and deformation behavior of the concrete depends mainly on the pore structure of the cement stone. Above a critical load step crushing of pore sides occurs caused by the triaxial compression. Afterwards damaged concrete material fills up the pores.

In the load distribution zone B compression acts longitudinal and tension transverse to the direction of the load spread. Cracking parallel to the composite force occurs, when the transverse stresses exceed the tensile strength of the concrete. After cracking the splitting reinforcement of the concrete dowel takes the transverse tensile forces. Nominal transverse reinforcement close to the concrete dowel participates as well.

Assuming the spring model shown in Fig. 7 the slip caused by the shear force P consists of four components (see equation (1))

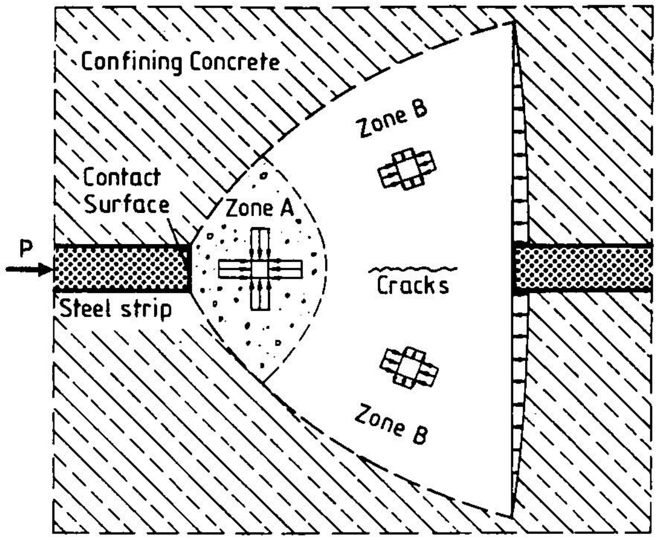

Fig. 6 Loading of a Concrete Dowel

$s_{(P)} = s_S + s_A + s_B + s_C$ (1)

- Component s_S results from (local) deformation of the steel stems remaining between the holes.
- Component s_A is caused by crushing of the pore structure in cement stone of zone A
- Component s_B represents the deformations of the compression field in zone B
- Component s_C is due to lateral strain, cracking and crack opening in zone B

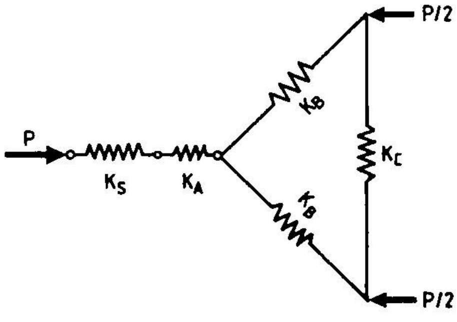

Fig. 7 Spring model

A limit state is reached, when the pores in zone A are completely filled with damaged concrete material and no further volume reduction is possible there. The pulverized material causes a quasi-hydrostatic pressure on the confining concrete, which may lead to splitting of the concrete slab and finally to local wedging off of parts of the slab surface close to the dowels.

The validity of the presented mechanical model has been successfully proved using nonlinear finite element analyses. The main conditions and results of these FE-analyses are given in [5].

4. Significant parameters

The tests resulted a nearly linear relation between the compressive strength f_{cm} and the shear resistance P_{max} of Concrete Dowels (see figure 8). Figure 8 shows as well the effect of an increase in transverse reinforcement A_{sq}, which rises the shear resistance P_{max} of Concrete Dowels. Reinforcing bars positioned inside the holes take most effect there.

The shear resistance P_{max} of Concrete Dowels rises with increasing dimensions. Assuming the mechanical model described in chapter 3, the shear resistance P_{max} depends considerably on the area A_L of the contact surface, where load transmission acts between steel strip and concrete slab.

Therefore the depth h of the holes and the thickness s of the steel strip must be considered as the essential dimension parameters. However, in the presented tests a decrease of the ultimate local compressive stresses f_{cc} transmitted in the contact surface has been observed with increasing A_L. As shown in figure 9 as well, the ultimate values f_{cc} of large Concrete Dowels have not been considerably influenced by the shape of the holes.

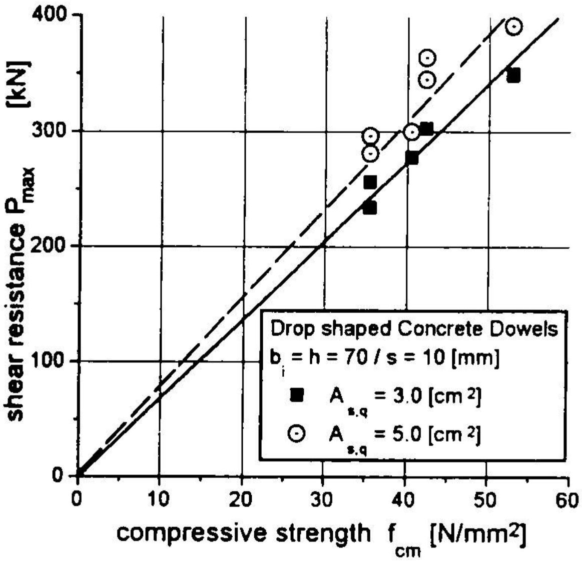

Fig. 8 Relation between concrete strength and shear resistance

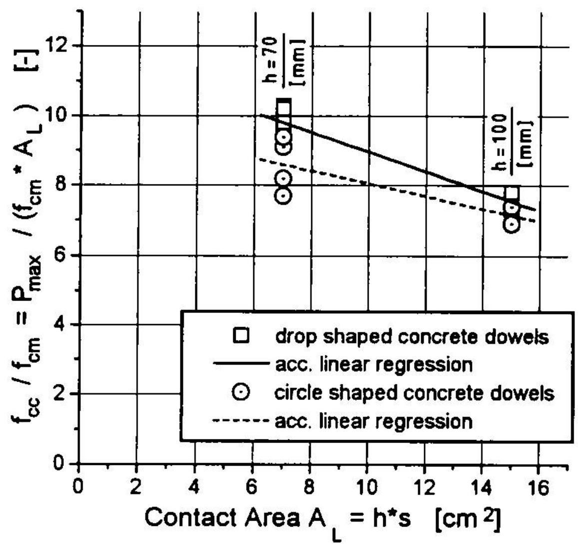

Fig. 9 Relation between dimensions and shear resistance

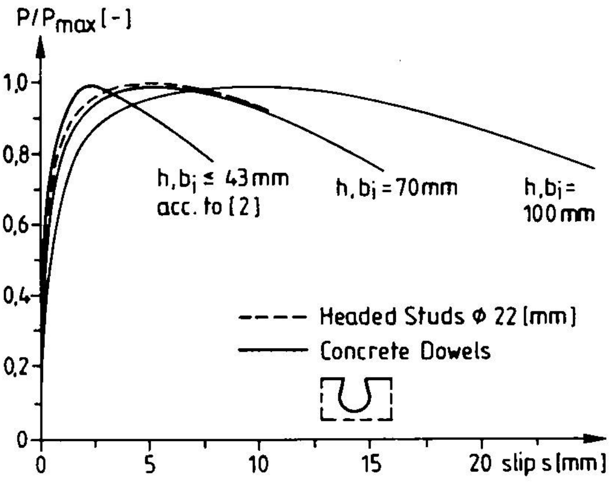

Fig. 10 Characteristic load-slip-relations

In addition some push-out-tests with concrete slabs loaded to longitudinal tension have been executed. But the transverse cracks caused by this loading did not reduce the bearing capacity P_{max} of the Concrete Dowels.

The loading of the concrete slab by a (negative) transverse bending moment rises the bearing capacity of Concrete Dowels similar to the conditions of stud shear connectors. A transverse bending moment m_q = -19,0 [kNm/m] loaded to the concrete slabs of some specimens caused a 35% increase in bearing capacity P_{max} of Concrete Dowels.

In the presented investigations the pore volume of the cement stone was recognized as an important parameter for the deformation behavior of Concrete Dowels, but no influence of the compressive strength f_{cm} of concrete was observed in these tests.

The deformation behavior of Concrete Dowels was getting more ductile with increasing dimensions (see figure 10). Concrete Dowels with dimensions h = b_i = 70 [mm] showed a similar deformation behavior like stud shear connectors with a diameter ø= 22 mm. But only a small influence of the shape of the holes was found especially for large Concrete Dowels.

The results of the push-out tests were evaluated according to Eurocode 4 [4]. The characteristic deformation capacity δ_{uk} amounts about 8,0 [mm] for the Concrete Dowels with h = b_i = 70 [mm] and $\delta_{uk} \cong 10$ mm for the one with h = b_i = 100 [mm]. Therefore a Concrete Dowel with dimensions h = $b_i \geq 70$ [mm] may be considered as a ductile shear connector, because it fullfills the criterion $\delta_{uk} \geq 6{,}0$ [mm] according to [4].

All other parameters (transverse reinforcement, loading of concrete slab) showed only small influence on the deformation behavior of the Concrete Dowels.

5. Design Concept

Based on the mechanical model presented in chapter 3 the design shear resistance P_{Rd} of Concrete Dowels in the ultimate limit state (acc. to [4]) can be determined from equation (2). The factor η in equation (2) depends on the dimensions and the shape of the Concrete Dowels and also on the transverse reinforcement. For example $\eta = 6.8$ was evaluated for drop shaped Concrete Dowels with h = b_i = 70 [mm], $b_o/b_i = 0{,}8$, s = 10 [mm], which requires a transverse reinforcement determined for the tensile force $F_s = 0.5\, P_{Rd}$.

$$P_{Rd} = \eta \cdot f_{ck} \cdot h \cdot s \cdot \frac{1}{\gamma_v} \tag{2}$$

where:

- f_{ck} the characteristic cylinder strength of the concrete
- h height of the holes of Concrete Dowels
- s thickness of the steel strip
- γ_v partial safety factor; $\gamma_v = 1{,}25$ according to [4]
- η factor, found by statistical evaluation of test results

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