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Economical Shear Connectors with High Fatigue Strength

Connecteurs économiques à haute résistance

Ein wirtschaftliches Verbundmittel mit hoher Dauerfestigkeit

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SUMMARY

This report describes the mechanical model, testing, design criteria and first use of perforated steel strips welded on steel girders to provide composite action between steel girders and concrete slabs.

RÉSUMÉ

Ce rapport contient des informations sur le modèle mécanique, les essais, les critères de dimensionnement et la première application de listeaux métalliques perforés, soudés sur des poutres métalliques et permettant ainsi de réaliser la liaison entre des poutres métalliques et des dalles et béton.

ZUSAMMENFASSUNG

In diesem Bericht werden das mechanische Modell, die Versuche, die Bemessungsrichtlinien und die erste Anwendung von gelochten Stahlleisten beschrieben, die auf Stahlträger geschweisst werden, um den Verbund zwischen Stahlträgern und Betonplatten zu erzeugen.



1. INTRODUCTION

Headed studs are so far considered to be a very versatile and economical means to provide composite action between steel girders and concrete slabs. Local dowel action of the protruding stems of the studs, embedded in the concrete, prevents the relative displacement in the joint between steel and concrete.

The static- and fatigue-strength of the connection depends on a large number of parameters [1]. The evaluation of the strength is simplified for practical reasons and is generally given in terms of a shear strength of the stud cross-section.

Fig. 1 shows the trajectories in the concrete slab. Even though the line of action of the force resultant F at the bottom of the stud is parallel to the edge of the steel girders, the curvature of the trajectories initiates transverse tensile stresses in the slab. These stresses may be counterbalanced by transverse compression due to the externally applied loads. This is why transverse reinforcement is not generally required, but depends on the actual structural system.

The distance between the force resultant F and the edge of the steel girder depends on the strength and stiffness of the concrete. Obviously, there is a bending moment $M = F(a - t/2)$ acting upon the weld influence zone. The stud generally fails due to fissures along the surfaces A-A, B-B or C-C in Fig. 1. The origin of the fissure surfaces B-B and C-C are at the welding notches on the steel surface, obviously, there is a detrimental effect due to tensile stresses in the steel flange.

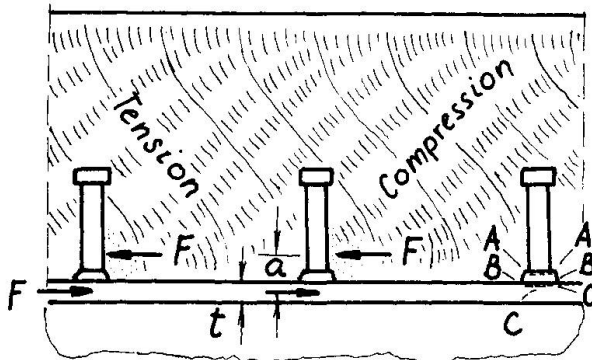


Fig.1 Trajectories in a concrete slab with Stud Shear Reinforcement

Experimental evidence of this detrimental effect results in a three-dimensional interaction model of steel flange stress, stud shear stress and load cycles, as reported by Roik and Holtkamp [2].

Concrete softening due to dynamic loading at the stud support results in an increasing eccentricity (a) of the force resultant F , and thus in an increasing bending moment at the weld. For practical reasons, this effect is not directly accounted for. It is actually hidden in the nominal shear strength of the stud. In order to avoid very high local peak stresses, studs can be closely spaced which results in a more or less continuous shear transfer.

2. DESCRIPTION OF PERFOBOND STRIPS

Instead of very closely spaced studs, the use of steel strips with large, punched holes at close intervals (hence called Perfobond Strips), which are connected upright to the flange by means of thin fillet welds, has been investigated recently [3].

The continuous fillet weld (Fig. 2) can be easily executed and is less harmful to the steel flange than the local stud weld.

The photo Fig. 3 shows a test specimen of Perfobond Strips for push-out tests, where every third hole is punched close to the edge of the strip to build a slot for reinforcement.

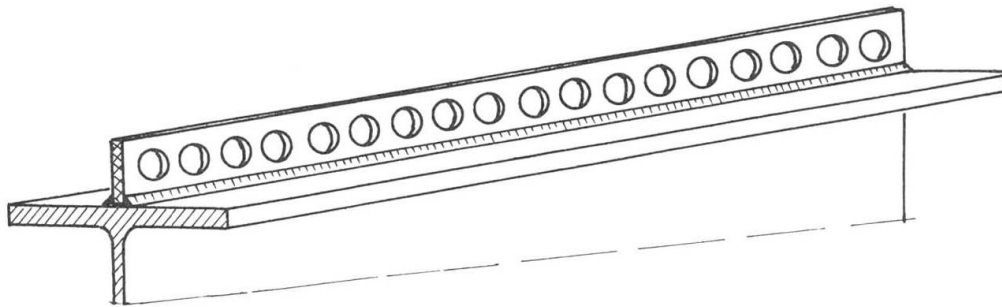


Fig. 2 Perfobond Strip with continuous fillet weld

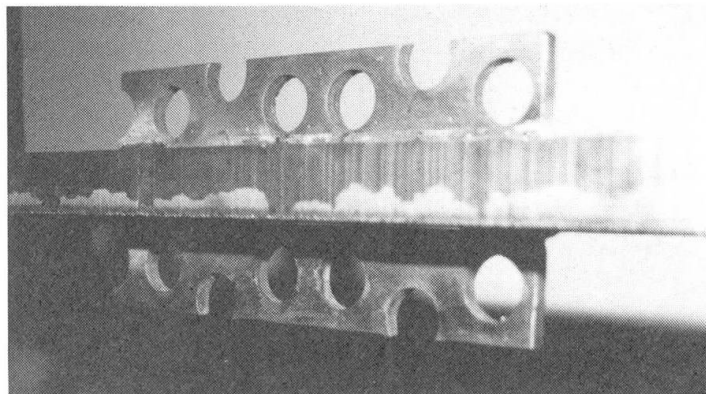


Fig. 3 Test Specimen of a Perfobond Strip with holes and slots

Trajectories in the concrete slab are shown in Fig. 4. Obviously, the point of application of the resultant force F cannot change, even if the concrete softens at the support location. Also, there are no original bending effects.

The confinement of the concrete in the holes of the steel strips increases the concrete strength. Typical push-out tests (Fig. 5) with steel strips $60 \times 12 \text{ mm}^2$ and holes with 35 mm diameter, spaced at 50 mm intervals, showed that the static ultimate shear force per linear metre amounts to

$$t_u = 0,034 \text{ m} \times f_c \text{ [MN/m]}$$

(where f_c is the nominal concrete cube strength) at corresponding displacements of about 5 mm. As shown in Fig. 8, these displacements are due to the ovalizing of the punched holes and to the shear displacement of the strip and surrounding concrete.

Failure is finally due to tearing of the deformed steel stems between the holes, Fig. 6.

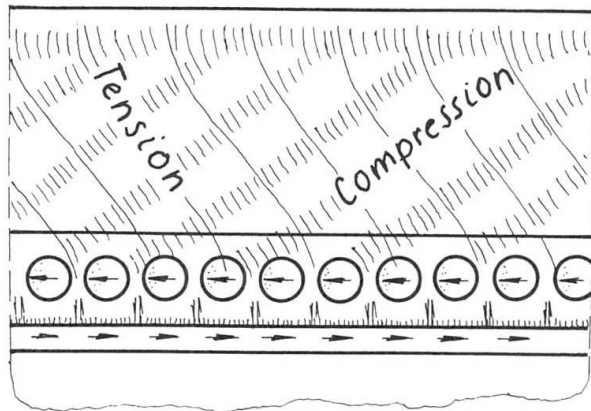


Fig. 4 Trajectories in a concrete slab with Perfobond Shear connectors

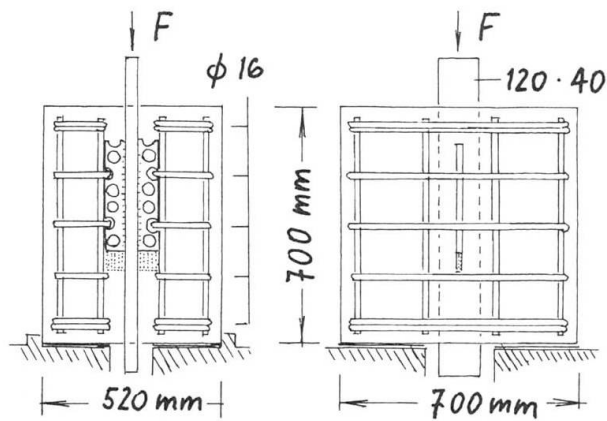


Fig. 5 Typical push-out test specimen

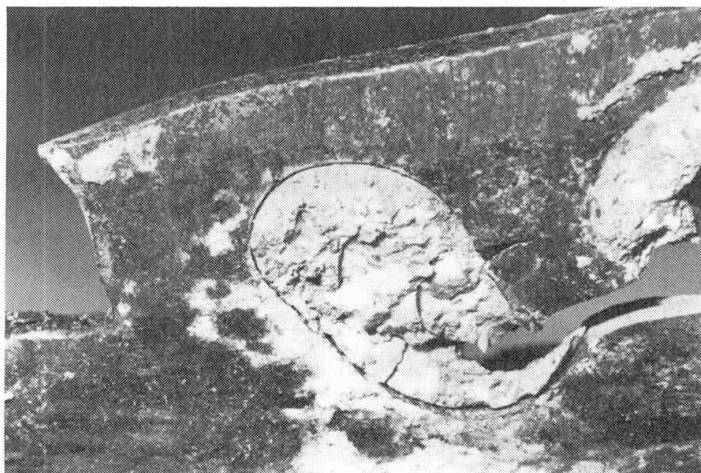


Fig. 6 Ovalling holes of Perfobond Strip after failure of the connection

3. DIMENSIONS AND DESIGN

According to [4], the strip dimensions given in Fig. 7 ensure steel failure of the steel strip rather than concrete shear failure.

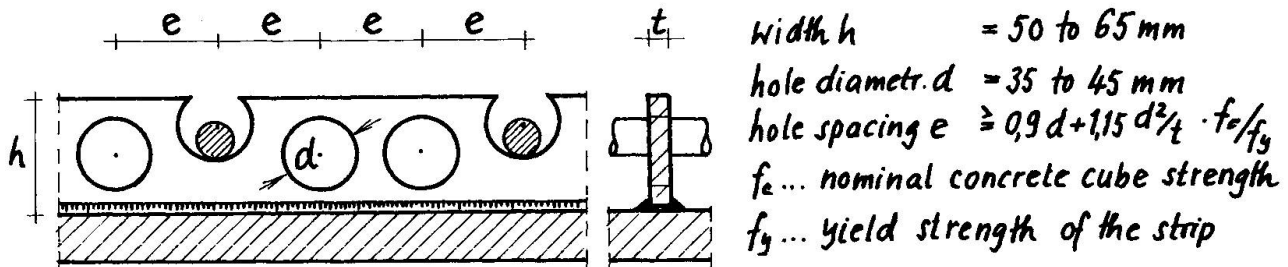


Fig. 7 Perfobond strip dimensions

The concrete interspersing the holes in the strip may be considered to build concrete dowels with two shearing planes. A conservative approach for the static strength of the concrete dowel is

$$T_u = 1,26 \times d^2 \times f_c.$$

It is expected, that the statistical evaluation of further tests will prove, that the dowel strength is even higher.

For the use in design codes with global safety factors, as for example in Germany, the brittle dowel failure is accounted for by further reduction of the characteristic dowel strength, e.g. in the relation of the global safety factors

= 1,7 (ductile failure), and = 2,1 (brittle failure), hence

$$T_u = 1,26 \times d^2 \times f_c \times 1,7/2,1$$

$$T_u \approx 1,0 \times d^2 \times f_c$$

where d is the hole diameter [mm] and f_c the nominal concrete cube strength [N/mm^2].

The Interpolation between test data of dynamic tests with 10^5 to 10^7 loadcycles indicates the relationship between fatigue strength T_N and the static strength T_u shown in Fig. 8.

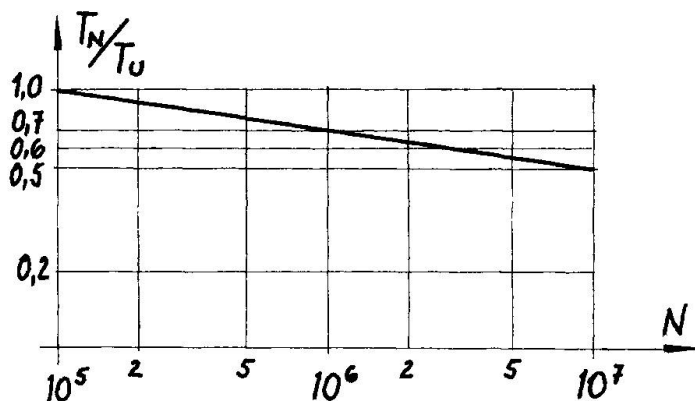


Fig. 8 Fatigue strength of the Perfobond Connection

The transverse reinforcement (splitting reinforcement) required amounts to

$$a_{s,trans} = 1,1 d^2 \times f_c / (f_y \times e) \quad (1)$$



at least 1/3 of this reinforcement has to pass through the holes or notches. The distance b between two parallel strips shall not be less than

$$b \geq 3 h, \text{ with} \\ h_b \geq h + 0,5 b.$$

Further details are given in the approval certificate on the basis of [4]

4. FIRST APPLICATION OF PERFOBOND STRIPS

Perfobond Strips instead of shear studs are used for the bridge across the river Caroni at Ciudad Guayana, Venezuela. The bridge carries a single track railway and two 10,8 m wide carriageways, with a main span of 213,75 m and side spans of 82,5 m and 45 m respectively. The deck slab and the bottom chord in the area of negative moments are out of reinforced concrete.

The steel structure of the two half bridges is completely assembled behind the abutments and afterwards launched using an auxiliary truss girder. A stay cable system is used for force redistributions such that the deadweight of the steel structure and the concrete bottom chord acts onto the corresponding composite section, see Fig. 9.

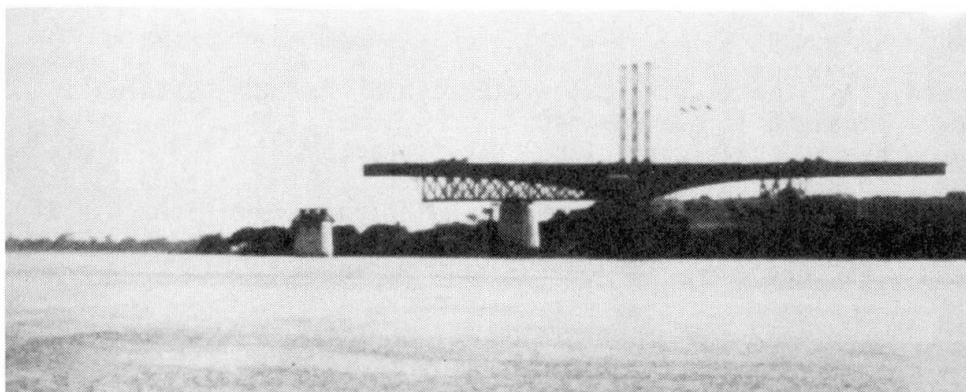


Fig. 9 Bridge across the river Caroni, erection stage 1989

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