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Experimental investigation and modelling of the structural behaviour of confined grouted interfaces for a new steel–concrete connection

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ABSTRACT

Confined interfaces between cement grout and other materials such as embossed steel or rough concrete are formed in an innovative new steel-concrete connection for composite bridges. This article presents the experimental study of such interfaces and investigates the laws obtained from an analytical study, which describe the behaviour of those interfaces subjected to shear loading, static and cyclic, under different levels of constant normal stress. The laws describing the interface behaviour in monotonic shear loading are: (a) the relationship between the ultimate shear and the normal stress acting on the interface, i.e. the failure criterion, (b) the shear stress–slip relationship of the interface, called hereafter the constitutive law and (c) the relationship between the transverse separation (uplift) of the interface and the slip in the interface, called hereafter kinematic law. Concerning cycle shear loading, tests on interfaces enabled damage determination due to repeated loading. This damage is expressed by the development of an accumulated residual slip in the interface. Results indicate that as long as the applied shear stress in the interface, during cyclic loading, remains inferior to the elastic shear limit for static loading, the residual slip stabilizes with the number of cycles. A safe fatigue failure criterion is proposed relating the accumulated slip with the value of the slip at shear failure of the interface for static loading. The proposed laws together with the law describing the development of the confinement constitute the necessary input for a model to predict the behaviour of an innovative connection consisting of such confined grouted interfaces.

1. Introduction

In steel–concrete composite bridges construction with prefabricated slab elements, the traditional solution to apply the composite action between the slab elements and the steel girders is concreting the openings (shear pockets) of the slab elements in which shear studs are enclosed. Studs are typically welded on the upper part of the flanges of the girders. However, this method presents several disadvantages. The supplementary work in situ for concreting the pockets increases the overall construction time. Due to the development of shrinkage in the concrete of the shear pockets and due to stress concentration, cracks appear at the perimeter and at the corner of the shear pockets. Corrosion agents such as de-icing salt may enter the cracks decreasing the durability of the structure and damaging the connection. Those disadvantages are overcome using a new type of connection such as the connection by adhesion, interlocking and friction [1] which is favourable for prefabrication and help guarantee long term durability.

Fig. 1 presents the connection by adhesion, interlocking and friction. The steel girder is provided with a pair of longitudinally connecting plates. Those embossed steel plates are welded together and are also welded longitudinally to the upper flange of the steel girder. The deck consists of precast reinforced concrete segments which are fabricated with an inner rib at the lower part. The width of the trapezoidal rib is, for constructional reasons, equal to 6 cm in the top and 8 cm in the bottom, so that at least 1 cm of cement grout exists between the concrete and the steel plates, even in the case of slightly asymmetric positioning. The surface of the rib is roughened by using a retarding agent during casting, followed by hydro-jetting and sandblasting. The aggregates are exposed but firmly attached to the concrete mass. The slab segments are positioned over the steel connector and the void is filled by injecting a high strength cement grout. Once the cement grout is cured the connection composite action can be achieved.

The resistance of the connection to longitudinal shear is based on the shear resistance that is developed at two types of interfaces, as illustrated in Fig. 1. The two types include an interface between the embossed steel and the cement grout and an interface between cement grout and the material of the inner rib of the deck

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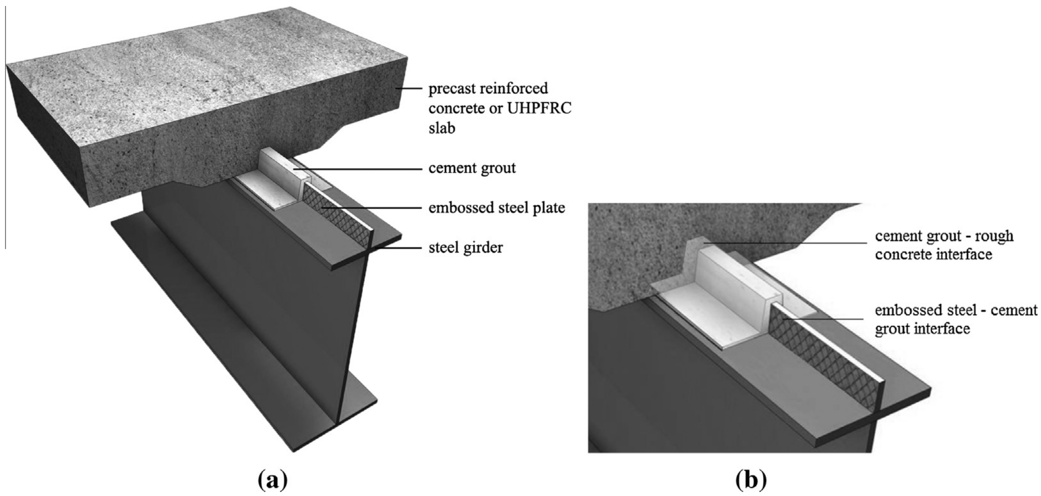

Fig. 1. Connection by adhesion, interlocking and friction: (a) general view, (b) detail.

(fabricated from either roughened concrete or ultra high performance fibre reinforced concrete UHPFRC). Due to the development of the longitudinal shear, τ, in the connection, interfaces tend to slip, see Fig. 2. Due to the roughness of the interface, this slip, s, is accompanied by a separation of materials, called uplift, u, at a direction normal to the slip, s. This uplift, u, is however restrained due to the confinement effect, normal stress, σ, created by the surrounding concrete slab. An equilibrium state is developed with tension in the concrete and in the reinforcement of the concrete slab and normal compression stresses developed on the interfaces. Fig. 3 illustrates the equilibrium state caused by the uplift in the embossed steel–cement grout interface. Equally, uplift between the roughened concrete and cement grout is also developed but not presented in this figure. The confinement effect provided by the slab on the interfaces of the connection becomes even more significant if, in addition, normal forces resulting from the transversal bending of the slab are considered.

In order to predict the connection behaviour under static and cyclic loading a necessary first step is to develop laws that describe the behaviour of interfaces subjected simultaneously to shear loading and normal stresses and second step to develop the law for the confinement effect and the interaction of this law with the interfaces laws. This papers answer to the first step proposing laws for describing the governing behaviour of the confined interfaces under static and cyclic loading.

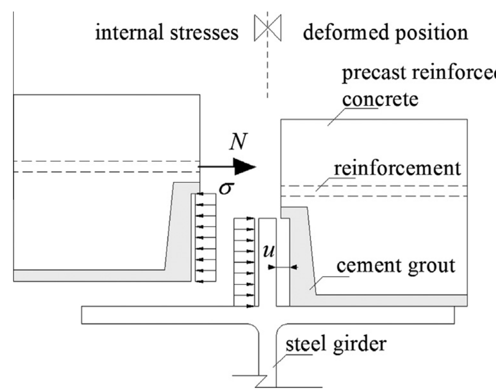

Fig. 3. Development of confinement due to uplift.

2. Experimental investigation

2.1. Specimens and materials

The two types of interfaces, the interface between embossed steel–cement grout and the interface between roughened concrete–cement grout, which are present in the new connection, were initially studied. Additionally, a third type of interface, the interface between artificial roughened UHPFRC and cement grout was studied for the cases that the slab deck is made of this material.

Interface behaviour – i.e. the relationships between slip, s, uplift, u, shear stress, τ, and normal stress, σ – in an interface, see Fig. 2, are investigated by a large number of direct shear tests. The principal of the direct shear tests used is described in the Fig. 4. The force V, is applied to the specimen simultaneously with a normal force, resulting in uniform normal stresses, σ. The specimens are constituted of a block of cement grout which is casted between two embossed steel plates or two concrete or two UHPFRC plates. The vertical force V passes through the developed interfaces to the support of the specimen.

Three types of specimens are tested; their characteristics are presented in Figs. 5 and 6. For tests with concrete blocks, plates'

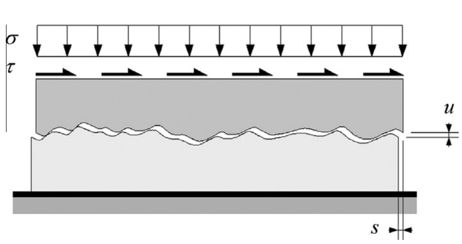

Fig. 2. Definition of interface parameters.

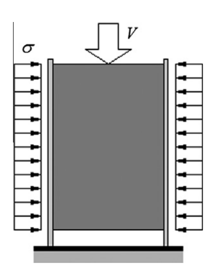

Fig. 4. Principal of the direct shear test.