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Design and experimental verification of an innovative steel–concrete composite beam

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ABSTRACT

This paper deals with the design method and the experimental verification of a new type of steel–concrete composite beam under static and fatigue loading. The connection is an alternative solution for steel–concrete composite bridges suitable for prefabrication and fast erection, while guaranteeing durability. The composite action of the beam is established through an innovative shear connection by adhesion, interlocking and friction. The resistance of the connection to longitudinal shear is based on the development of shear stresses in the confined interfaces that form the connection. The interfaces include a steel–cement grout interface and a rough concrete–cement grout interface. Confinement is provided by the reinforced concrete slab that encloses the connection. A composite beam was designed according to the design method for such type of composite beams in order to resist cyclic loading and to guarantee in the sequence its bearing capacity at ultimate limit state. The beam was initially subjected to cyclic loading and did not present signs of important damage after five million cycles. The damage on such type of connections is expressed by the development of a small residual slip in the interface which with the appropriate design stabilizes with the number of cycles. Finally the composite beam was statically loaded up to failure. The results show the capability of such a composite beam to develop its plastic moment at ultimate limit state.

1. Introduction

In steel–concrete composite bridge 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 which enter the cracks might decrease the durability of the structure and damage the connection. Those disadvantages are overcome using a new type of connection by adhesion, interlocking and friction [1] which is favorable for prefabrication and help guarantee long term durability. The new connection, in comparison with other new innovative solutions, as for example steel dowels created on the steel web by cutting a steel profile [2,3] or connections with perfobond ribs [4], present the advantage that allows for prefabrication without supplementary cast in place concrete for the deck. Fig. 1 presents the connection by adhesion, interlocking and friction. The steel girder is provided with a pair of longitudinal embossed steel plates on it. These 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 a rib at the lower part. The surface of the rib is roughened by using a retarding agent during casting, followed by hydro-jetting and sandblasting. The aggregates on the rib surface are exposed but firmly attached to the concrete mass. The slab segments are positioned over the steel connector and are connected together by prestressing, see Fig. 2. The void between the connector and the concrete deck is then filled with a high strength cement grout by injection. Once the cement grout is cured the connection is activated and composite action can be achieved.

The resistance of the connection to longitudinal shear is based on the shear stresses that are developed at two types of interfaces, which are an interface between the embossed steel and the cement grout and an interface between cement grout and the concrete deck, as illustrated in Fig. 1. Due the development of the longitudinal shear, τ, in the connection, interfaces tend to slip, see Fig. 3. Because of 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 by the creating normal stress, σ, due to the surrounding concrete slab (confinement effect). An equilibrium state is developed with tension in the concrete and in the reinforcement of the concrete slab over the rib and normal compression stresses developed on the interfaces. The equilibrium state caused by the uplift in the embossed

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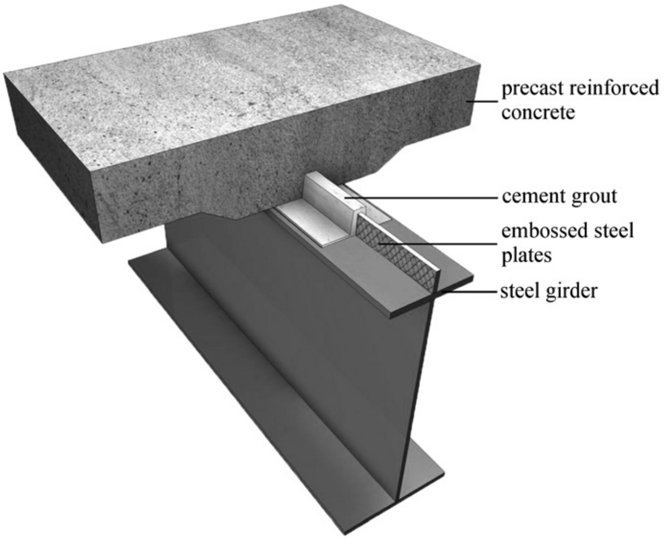

Fig. 1. Connection by adhesion, interlocking and friction.

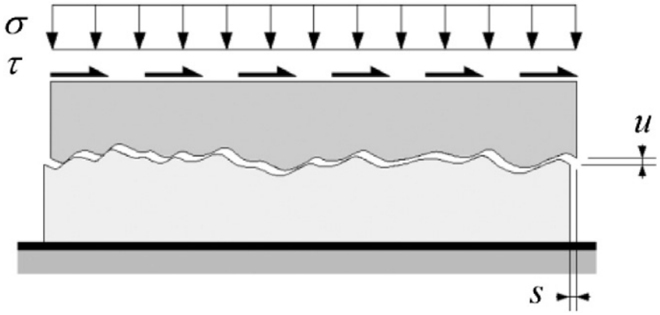

Fig. 3. Definition of interface parameters.

steel–cement grout interface is illustrated in Fig. 4. Uplift is developed also between the roughened concrete and cement grout but is not presented in this figure. The confinement effect which is provided by the slab on the interfaces of the connection becomes even more significant when, in addition, the normal forces resulting from the transversal bending of the slab are also considered. The interface behavior, described by three laws which relate the slip, s, the uplift, u, and the shear stress, τ, in an interface and the relationship describing the confinement effect were presented by the authors in previous papers [5,6]. Thomann [7] has proposed a model in order to take into account the interaction of such relationships in order to predict the resistance of such connections. The model of Thomman [7] was used by the authors, as basis to predict the bearing performance of the new connection. In the updated model developed by the authors [1,6] more detailed interface laws were introduced with validity to a higher level of confinement like the one expected in real structures. Furthermore a new more general relationship for the confinement effect was introduced, which takes into account the connection geometry, the uncracked and cracked state of the concrete enclosing the connection, the mechanical characteristics of the concrete of the slab and the reinforcement details.

This paper presents the experimental verification of a steel–concrete composite beam fabricated with the new connection and designed based on the new model [1,6] so as to withstand fatigue while preserving its capacity for the ultimate limit state. The mechanical characteristic of the materials the fabrication of the steel–concrete composite beam and the design method are presented in Section 2 of the paper. The experimental investigation is deployed in Sections 3–5. The experimental program contains two steps. Initially the composite beam was subjected to a five million cycle fatigue loading followed by a static loading up to failure. In the same section the results are presented and commentated. Conclusions and recommendations for the engineering practice are finally stated in Section 6.

2. Design materials and fabrication of the steel–concrete composite beam

2.1. Materials and fabrication

The composite beam is assembled by the following parts:

a) Steel beam profile is HEA 500, in the upper flange of which, the connector is welded longitudinally. The connector consists of two embossed steel plates welded together. The steel plates are of steel quality S235 and of type BRI 8/10 according to the Swiss Tables of steelwork construction [8]. Steel of the section profile is of quality S355 J0-M [9]. The total length of steel profile used is 9.50 m. Coupons were cut from a part of the same initial steel profile; two from each flange and three from the web, in order to define the precise stress–strain curves for the analysis. Fig. 5 illustrates the steel profile HEA 500 with the welded connector on it, where Fig. 6 illustrates the geometrical characteristics of the steel cross sections, for the span and at the supports with the stiffeners.

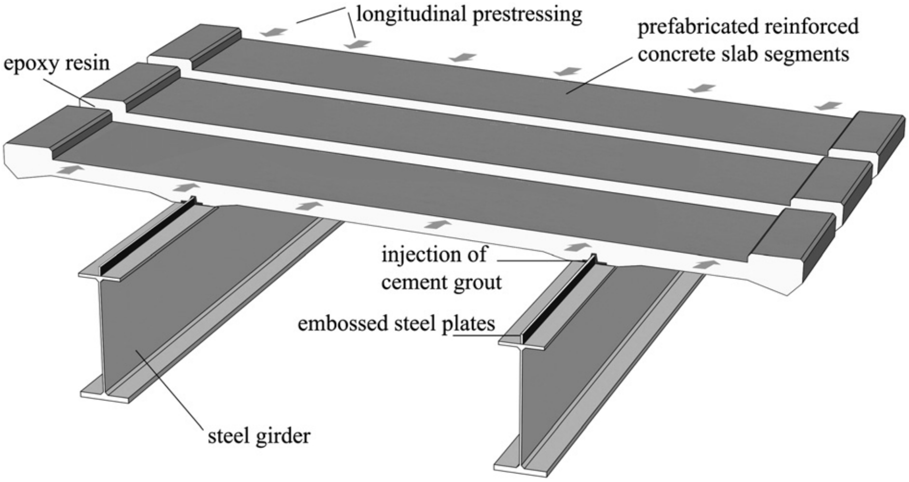

Fig. 2. Typical cross section of a highway steel–concrete composite bridge realized with the connection by adhesion, interlocking and friction.