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Perforated shear connectors on composite girders under monotonic loading: An experimental approach

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ABSTRACT

This paper presents the results of sixteen push-out tests performed at the Civil Engineering Department of the University of Coimbra, Portugal, on perforated steel shear connectors with varying geometries. Eight tests using the previously studied Perfobond and T-Perfobond geometries were initially performed and were followed by another eight tests on two innovative geometries, the I-Perfobond and 2T-Perfobond. The investigated variables included the shear connector geometry and the provision of transverse reinforcement within a shear connector's holes. The results are presented and discussed with a focus on the shear connectors' structural responses in terms of their shear transfer capacity, ductility, stress distribution and collapse modes. Finally, a comparison of the experimental results with existing analytical models of the Perfobond and T shear connectors is also presented to establish their accuracy and applicability.

1. Introduction

The transmission of shear forces between steel beams and concrete decks in a composite girder can be achieved with many types of shear connectors, the most popular being the Nelson or Stud shear connector (Fig. 1a), which is the only shear connector explicitly proposed by the current version of Eurocode 4 [1]. This shear connector's popularity is a consequence of its simple and rapid application, the efficient structural behaviour provided by its anchorage to the concrete, and the simple distribution of reinforcement bars. However, such connectors have certain limitations, especially when fatigue loads are present, because their high flexibility allow for deformations under service loads. In addition, their installation requires a special welding device and high-power generator that may not be available on site, as stated by Vianna [2].

Other widely used types of shear connectors include the channel shear connector (Fig. 1b), studied mainly by Baran and Topkaya [3] and Maleki and Bagheri [4,5] and also referenced by Figueiredo [6] and reported by these authors as presenting ductile behaviour and possessing resistance that can be reasonably predicted by the Canadian Standard [7]; and the Hilti shear connector (Fig. 1c), also capable, according to [6], of attaining the minimum deformation criterion of 6 mm needed to be classified as ductile by Eurocode 4 [1]. A detailed inspection of the results of these references studies revealed that the equations in the US and Canadian standards still cannot accurately predict the load capacity of channel shear connectors.

The current version of Eurocode 4 [1] provides explicit design rules only for stud shear connectors, but ENV 1994 [8], the former version of Eurocode 4, provides design rules for the T-connector, or block connector, depicted in Fig. 2a. In addition to the strong connection provided by this shear connector's geometry with a steel flange bearing in the concrete, this shear connector includes a hooked-shaped rebar to prevent uplift. This shear connector type will be further discussed in this paper because the applicable design rules can be applied, to some extent, to a recently proposed type of shear connector [2] and the innovative types of shear connectors presented here.

Still other alternative shear connectors account for the contribution of the mechanical interlock formed in holes or other indentations drilled in plates or profiles, which are then welded to the beam flange. Among these, Kim et al. [9] have proposed the Hat shear connector (Fig. 1d), consisting of a perforated hollow section welded to the steel girder. Its behaviour appears to meet the recommended ductility criteria, and it has improved resistance when compared to the other geometries studied by these authors. However, the inclined geometry of the shear connector faces causes

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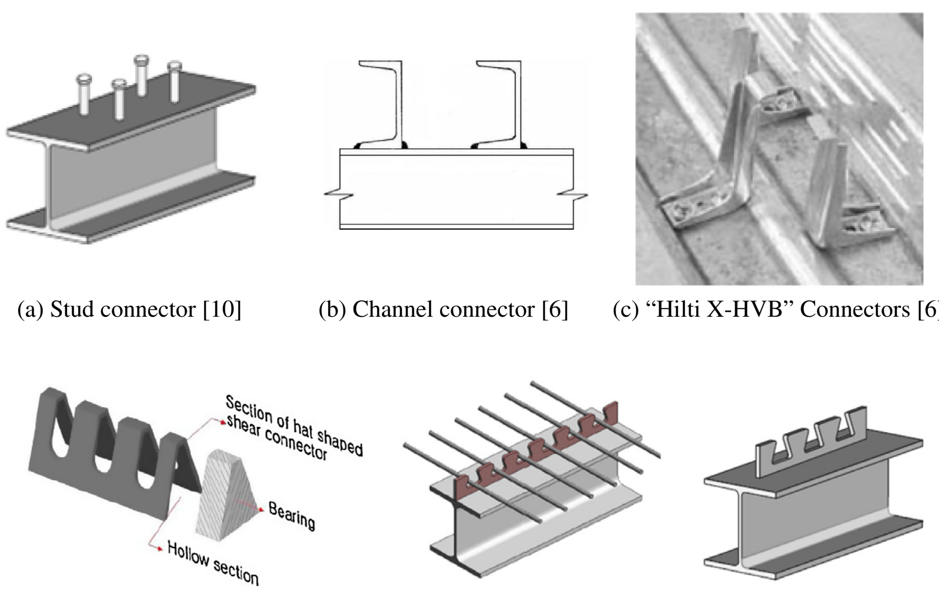
List of symbols

A_{cc}	longitudinal concrete shear area per shear connector (mm^2)
AR	reinforcing bar diameter at the shear connector holes (mm)
A_{tr}	concrete slab transversal steel reinforcement area (mm^2)
b_f	steel section flange width (mm)
D	shear connector hole diameter
f_{ck}	characteristic concrete compressive strength (MPa)
f_{cm}	mean concrete compressive strength (MPa)
f_y	concrete slab steel reinforcing bar yield stress (MPa)
h_c	concrete slab height (mm)
h	shear connector height (mm)
l	shear connector length (mm)
L_c	contact length between the concrete slab and the steel section flange (mm)
n	number of transverse reinforcing bars in the concrete slab
P_{Rk}	characteristic test resistance (N)
P_{test}	maximum experimental load (N)
$P_{rk,norm}$	normalised characteristic test resistance (N)
q_u	Perfobond shear connector nominal shear strength (N)
t_c	concrete slab thickness (mm)
t	shear connector thickness (mm)
δ_u	shear connector slip capacity (mm)
δ_{uk}	shear connector characteristic slip (mm)

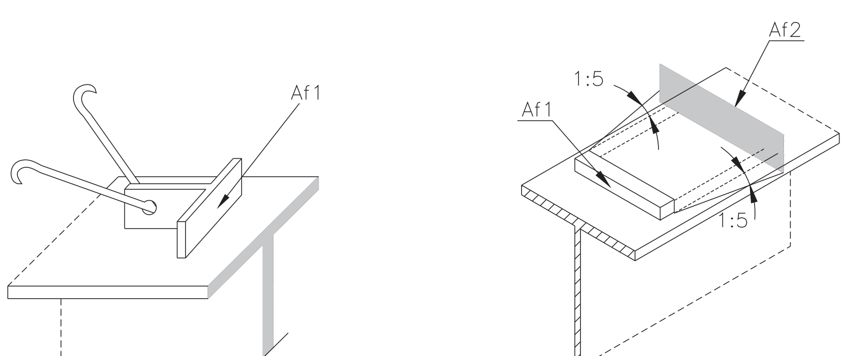
undesirable slip patterns that may be attenuated with transverse rebar, as concluded by Kim et al. [9]. An alternative geometry proposed by Veríssimo et al. [10] consists of a continuous or localised steel plate welded to the steel girder, with indentations, as shown in Fig. 1e, and is called the Crestbond shear connector. The advantage identified by these authors is the improved ability



(a) Stud connector [10] (b) Channel connector [6] (c) "Hilti X-HVB" Connectors [6]

(d) Hat connector [9] (e) Crestbond connector [10]

Fig. 1. Examples of shear connectors.



(a) T-shape block type connectors (b) A_{f1} and A_{f2} area definitions

Fig. 2. T-connector, Vianna et al. [20].