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Prospective study on the behaviour of composite beams with an indented shear connector

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ABSTRACT

This paper presents a prospective study on the behaviour of steel and concrete composite beams in which a linear indented continuous shear connector, called Crestbond, is used to establish the connection between the steel beam and the concrete slab and ensure the joint behaviour of these two elements. The work includes an experimental campaign developed at the Structural Laboratory of University of Minho, Portugal, and a numerical study developed with the ATENA 3D software.
The experimental tests and the numerical models were developed to evaluate the behaviour of the composite beam and particularly the indented shear connector in analysis. The tested specimens consist on a steel beam with a continuous indented connector, positioned on the upper flange of the beam and continuously welded in its development, and a reinforced concrete slab, in a total span of 3000 mm. During the tests, the connector provided high stiffness and a full interaction between the concrete slab and the steel beam. The beams failure was determined by crushing on the upper part of the concrete slab.

1. Introduction

1.1. The Crestbond shear connector

By the end of the 80s, the poor performance of stud connectors under fatigue motivated the search for new connection mechanisms for steel and concrete composite structures. Several alternative connectors were developed consequently, and some of them were based in the concept of a steel plate with slots that are filled by concrete. One of the first examples of these connectors is the Perfobond, developed by Leonhardt Andrä und Partner [1], with a focus on bridges and viaducts applications, which was the object of several subsequent research studies across the globe [2], [3], [4], [5], [6], [7], [8]. Nonetheless, constructive and structural aspects still motivate the search for better performance solutions resulting in the continued development of many other connectors based on the dowel-effect concept [9–37].

While researchers from Northern Europe focused their studies on bridges and viaducts [1,2,3,9,10,17–21], Canadians [4, 5], Brazilians and Portuguese [13–16, 28, 29], studied solutions for building structures. In the first studies, the failure mechanism observed was associated with the failure of the concrete by shear at the openings of the connectors. For this reason, for a while, these connectors were called concrete dowels. Subsequently, other studies have demonstrated the possibility of other failure modes, including failure of the steel due to the force exerted by the concrete on the protrusions of the connector. From this, these connectors came to be called composite dowels (Fig. 1).

Different connector shapes were analyzed within a European project called PreCo-Beam (prefabricated composite beam) [22, 23]. This project involved researchers from Germany, France, Belgium, Sweden, Poland and Luxembourg, as well as partnerships between universities and construction companies. The studies carried out consider the behavior of the connectors under static and cyclic loadings for application in industrial floor systems and bridges. After extensive investigation, three connectors stood out due to their structural performance: (a) the puzzle-shaped connector (Fig. 1.n); (b) the clothoidal connector (Fig. 1.p) and (c) the saw-tooth connector (Fig. 1.o). Further studies on puzzle-shaped connectors and clothoidal connectors were developed by other authors and analytical approaches were derived, [30–37].

Crestbond is a notched steel-plate connector with a configuration that facilitates its fabrication and the disposition of transversal reinforcement [13,14,15],. In addition, it is a very rigid connector for service loads and ductile in ultimate limit state, constituting an interesting alternative for steel and concrete composite structural systems subjected to cyclic loads, or for those with a limited installation space for

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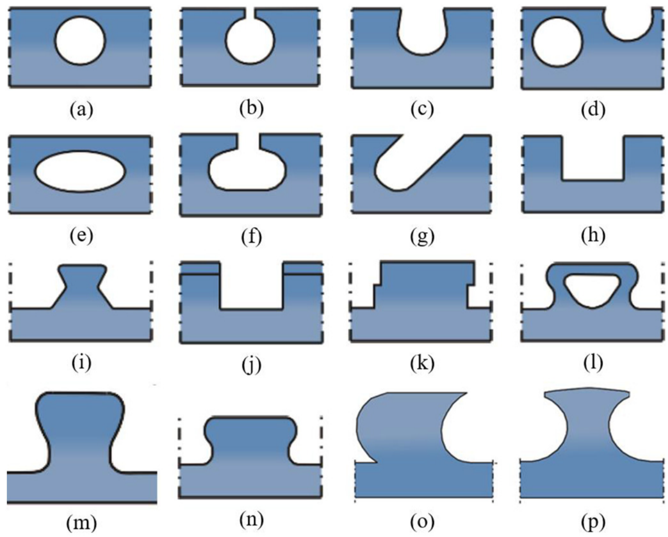

Fig. 1. Composite dowel shear connectors [22]. The Crestbond connector (Fig. 1.m and Fig. 2) was developed by Veríssimo [13,14], in this context.

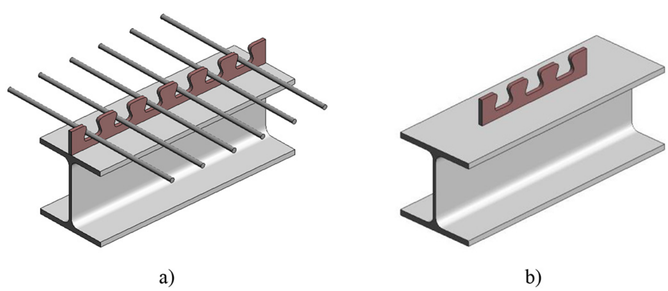

Fig. 2. The Crestbond shear connector: (a) continuous; (b) non-continuous.

shear connectors [14,28]. Its resistant mechanism is mostly related to the concrete's work in the connector's slots region. The concrete that fills these slots works as virtual dowels that, interlocked with the connector, prevent or limit the slip between steel and concrete, as well as the uplift. In recent years, the research on Crestbond connector's behaviour has been developed by means of semiempirical models and numerical simulation [16, 29].

Although similar to the puzzle, Crestbond has different geometry (Fig. 3) and different structural behaviour.

1.2. Research significance

Several push-out experimental tests have already been performed with Crestbond connectors [14 [15],. Although a push-out test provides insight regarding the load-slip relation for the connector, its configuration is very different from that of a composite beam. In bending tests, it is possible to investigate the connector's behaviour with geometric proportions and stress configuration typical of composite beams, which are the most common structural application elements in real structures. In a push-out test, the slabs' and steel profile's dimensions are such that the connector tends to be the less resistant element. Besides, the tendency of slip between steel and concrete is imposed directly by the applied load. The steel section and the slab are both under compression. Comparatively, in composite beams the predominating effect is the bending of the structural element. The tendency of slip between concrete slab and steel beam comes from the bending moment's action in each material separately. In composite beams, the stress distribution in the steel profile, the concrete slab and the connector depends on the geometry of these components, on their physical properties and on the connection's strength. The study on the behaviour indented connectors in experiments with composite beams enables the analysis of parameters that cannot be investigated in push-out tests.

The main objectives of this study are to make a prospective assessment on the experimental behaviour of the proposed indented connector in composite beams subjected to bending and, at the same time, to develop a numerical model that is able to simulate new cases by varying certain parameters that influence the beams' structural behaviour. The tests performed so far show that the geometry of the shear connector studied is suited for composite beams used in residential or office building floors, where fatigue phenomenon is less relevant.

2. Preliminary design

In the present work, the aim is to complement previous studies developed with the Crestbond connector in push-out tests [13, 14], with new experimental tests performed on composite beams.

Initial assumptions were established in order to guarantee that the connection was subjected to a high level of shear stress. The aim was to evaluate the behaviour of Crestbond connector within the structural element. The influence of the connector behaviour on the composite beams overall response was also a main concern. One of the mentioned assumptions was to find a cross section geometry that could guarantee a maximum effectiveness of the used materials by considering the steel section totally under tensile stresses and the concrete section under maximum compressive stresses. In this assumption, the neutral line position is close to the interface between concrete and steel sections and, during a large part of the bending test, the inferior zone of the concrete slab is not cracked. Therefore, concrete cracking was not affecting the connector behaviour and its load capacity in this phase.

The beams geometry was preliminarily studied with the software ATENA 2D (Fig. 4). Relevant parameters were established as constant or variable, depending on the geometrical limitations of the test frame and the steel profiles available in the Portuguese market. The beam span and the concrete cross section were defined as variable parameters within some limiting values. The steel profile was defined as IPE200 and strength class S275, the concrete type was chosen as C25/30 and the

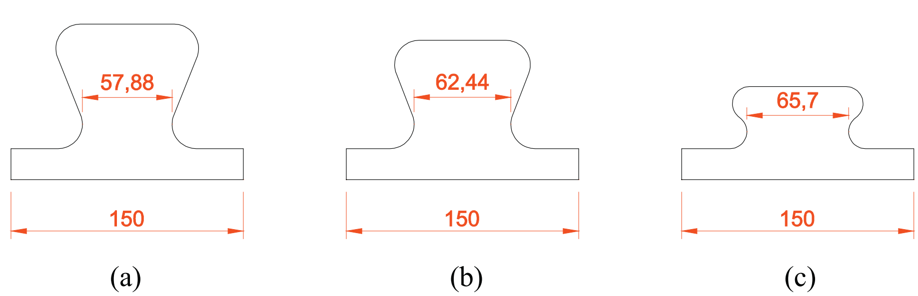

Fig. 3. Differences between Crestbond and Puzzle connectors: (a) Crestbond A; (b) Crestbond B; (c) Puzzle.