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Stress transfer mechanism investigation in hybrid steel trussed–concrete beams by push-out tests

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ABSTRACT

Results of push-out tests carried out on Hybrid Steel Trussed–Concrete Beams (HSTCBs) before and after the concrete casting are presented and interpreted. Firstly, in order to check the ability of weldings before casting, tensile tests were performed on specimens reproducing different types of welded joints. Simplified design formulae were used to predict their ultimate strength. Secondly, results obtained by push-out tests on specimen representative of the beam before and after the concrete casting are presented and discussed. Finally, simplified analytical models proposed by the current European building code were adapted to the specific typology to roughly predict the ultimate strength obtained by push-out tests on specimens complete with concrete casting.

1. Introduction

Hybrid Steel Trussed–Concrete Beams (HSTCBs) are a typical Italian structural typology constituted by a precast steel truss embedded into a concrete core generally cast in situ. The adoption of HSTCBs within reinforced concrete frames is a structural solution for light industrialization in use in the Italian construction industry since 50 years due to high construction speed with minimum site labour, the possibility of covering wide spans with low depths as well as economical convenience.

In spite of the widespread use of this beam typology due to both the easy manufacturing operations and the possibility of covering wide spans, to date few studies are present in the literature about this topic [1–9]. Some of these studies refer to a beam type similar [4,5,7] or identical [6,9] to that considered in this paper.

Among several existing HSTCB typologies, this study concerns beam types made up of:—a steel plate placed at the bottom of the beam that acts as the bottom chord of the truss (it also plays the role of a mould during the concrete casting);—coupled steel bars constituting the upper chord;—steel inclined web bars (V-reverse) welded to the two chord elements. In the first phase of the realization process (phase I), only the bearing capacity of the steel truss is often utilized in order to reduce or to eliminate the supports before and during casting. After cure and maturation of the concrete (phase II), bearing capacity is evaluated by considering the composite beam made of steel and concrete. Reinforcement is provided by the steel truss, and reinforcing bars are added at the end zone of the beam to guarantee the stress transfer to the beam-to-column joint panel.

The mechanical behaviour of HSTCBs was usually modelled by employing the classical models and rules developed for reinforced concrete or for steel–concrete composite beams [10,11]. Notwithstanding, due to the widespread use of HSTCBs in practice, current Italian building code makes a clear reference to this structural typology, requiring the adoption of specific design criteria and calculus methods derived by means of design by testing procedure. Mainly in the last decade a significant research activity has begun. The main topics covered by the scientific community involved in such research program have regarded evaluation of flexural and shear strength of the beam [8], behaviour of the steel to concrete connection [7,9], the study of the buckling of steel trusses before, during or after the concrete cast, the cyclic behaviour of beam-to-column joints, and the issues related to the creep.

Concerning to HSTCB behaviour after the concrete casting, the beam can be viewed as steel–concrete hybrid beam with deformable shear connection represented by the web members of the steel truss welded to the steel plate at the bottom [7]. Thus, in most of the problem related to behaviour in phase II a decisive role is played by the transfer mechanism of the stresses from the steel truss to the concrete core. As a matter of fact, experimental tests on shear critical HSTCB showed that the collapse can arise from three different mechanisms: collapse for diagonal tension, or shear compression [8], or failure of the shear connection [7,9].

The paper herein presented mainly deals with this last topic of paramount importance for the behaviour of HSTCBs both under serviceability and under ultimate loads.

Particularly, the paper is focused on the investigation of the stress transfer mechanisms in HSTCBs occurring in experimental push-out tests carried out on specimen representative of the aforementioned beam typology before and after the concrete casting. As far as there is not a standardised experimental procedure to evaluate the resistance

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and the stiffness of the steel–concrete shear connection, the slip–load curve is usually characterized by means of push-out tests inspired to the classical tests developed for steel–concrete composite beams according to Eurocode 4 [10]. Even if the load conditions of such a test do not reproduce the load condition of the beam under combined shear and flexure action, as in steel–concrete composite beams, these results are needed to evaluate strength and stiffness of the connection in order to recognize if the full flexural strength [7,9] or the shear strength [8] can be reached in the beam.

The tests were carried out at the University of Palermo, Italy, in the framework of the abovementioned research program addressed to validating methods and criteria for structural design of this beam typology.

Firstly results of tensile tests performed on specimens reproducing different types of welded joints are presented in order to investigate their bearing capacity which is a requirement of paramount importance in the phase before casting, when self-bearing capacities are exploited. The joints are different from the ones which are normally used due to the coupling of different steel types and complex geometry involving rebar bent with large curvature. Simplified design formulae of structural codes [12] are used to predict the ultimate strength of welded joints for each different typology, according also to results and discussions of a larger extensive experimental test survey on strength of this typology welded joint presented in Colajanni et al. [13].

Secondly, results obtained by push-out experimental tests on specimen representative of the beam before and after the concrete casting are presented and discussed. Push-out tests are carried out first in specimens before concrete casting, and then on specimens completed with concrete, allowing local problems regarding the stress transferring mechanism between different materials to be investigated. More precisely, the stress transferring between steel elements (of different steel types also) in phase I, and the stress transferring between steel truss elements and concrete in phase II are analysed. Furthermore, the behaviour of the steel truss before concrete casting was investigated with the focus on buckling phenomena occurring in both web bars and the upper chord [14]. Finally, some simple analytical models proposed by the current European building code, Eurocode 2 [11], were adapted to the specific typology aiming at interpreting the strength values obtained by experimental tests. All these results are part of a more extensive experimental and theoretical research carried out in order to investigate the seismic behaviour of HSTCBs in framed structures [6].

2. Experimental program

In Fig. 1a) a photo showing the beam typology to which this study is addressed is presented before concrete casting, and in Fig. 1b) the specific slab truss beam used in this experimental program is reported; for this beam typology the self-bearing capacity of the steel truss in phase I is not exploited.

The experimental tests related to phase I investigate the bearing capacity of welded joints, verifying their overstrength among steel elements by means of tensile tests on welded joints (Fig. 2). Moreover, the efficiency in phase I of inclined web bars is investigated by push-out tests on bare steel trusses. Tests were carried out on specimens of beam segments similar to those usually utilized for traditional steel–concrete composite beams, according to Eurocode 4 [10] (Fig. 3).

Afterwards, push-out tests on specimens completed with concrete representing the beam in phase II were carried out in order to investigate the stress transfer mechanism between steel and concrete, following again the procedure suggested in Eurocode 4 [10].

In all the examined cases the plate located at the bottom is constituted by S355 steel having nominal yield stress 355 N/mm^2 and the rebars by steel B450C with nominal yield stress 450 N/mm^2. Weldings are made according to recommendations in the ISO Code [15].

Preliminarily, the material strength values of coupling elements were evaluated by axial tensile tests on steel bars and steel plates according to code provisions [16]. Three tests on specimens extracted from the 5 mm thick steel plate of HSTCB and six tests on pieces of bars, three for each diameter used in HSTCB (12 mm and 16 mm for web bars and upper chord respectively) were performed. Table 1 shows the mean values of test results in terms of stress and corresponding strain at yielding (f_y, ε_y) and the ultimate values at peak (f_u, ε_u).

To carry out the tensile tests a universal testing machine with a 600 kN load carrying capacity was utilized.

In the next sections, first tests performed on welded joints, and secondly push-out tests in phase I and phase II are presented. Specifically twelve tensile tests on welded joints, two push-out tests on bare truss specimens and three push-out tests on complete truss specimens were carried out.

3. Welded joints

In this section the results of experimental tests on weldings together with a simplified calculus of their bearing capacity are reported. Butt welded joints of web bar to bottom steel plate and fillet welding joints of inclined web bars to top chord bars were tested. Test on these joint configurations is performed since they are different from the ones which are normally involved in concrete or hybrid structures due to the coupling of different types of steel and complex geometry involving rebar bent with large curvature. Such investigation is of paramount importance when the steel truss is employed exploiting its self-bearing

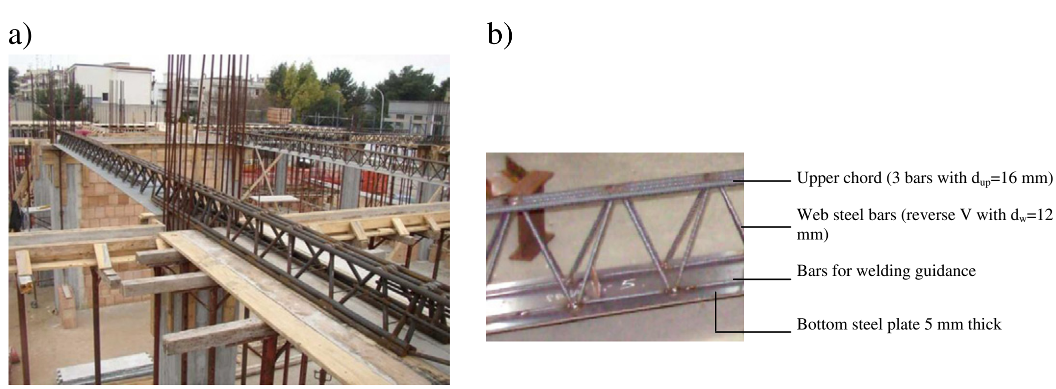

Fig. 1. Typology of hybrid steel trussed–concrete beam: a) photo before concrete casting in r.c. framed structure; b) steel truss type utilized in experimental investigation.