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Performance of dowel-type fasteners and notches for hybrid timber structures

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A B S T R A C T

One of the most popular Timber-Concrete connection types is the dowel type fastener, due to many factors, such as for example, simplicity, low cost and adequate performance in most conditions. This connection type was traditionally used in timber structures and was adopted for composite structures from the early ages. The basic phenomena governing the mechanical behavior of timber-timber and timber-concrete connections with dowel type fasteners are similar, however, the last show some relevant specificities due largely to the presence of concrete. Such specificities have a non-negligible influence in the performance and consequently in modelling and design. In this paper such specificities are discussed, as well as, their consequences in the modelling. Based on this analysis proposals are made for models to estimate the connections' load carrying capacity and slip modulus. Additional the existing knowledge about the performance of notched connections is summarized. Therefore, also values for important design parameters such as minimum values for the geometry, values for the slip modulus and possible failure modes of a notched connection are given.

1. Introduction

Timber-concrete structures have become increasingly popular all over the world in both rehabilitation and new construction [1,2]. One of the critical components of this composite system are the connections, which shall transmit the load between timber and concrete with the minimal deformation [3]. From the early ages of Timber-Concrete Composites (TCC) the adoption of timber-timber connection solutions was an option, namely the dowel-type fasteners. Different dowel type fasteners have been tried and used in TCC, namely, screws, dowels, nails or bolts [4]. These are simple, relatively cheap and available everywhere, being suitable in a wide range of applications [5], leading to a significant use in practice. Nevertheless, they also have some shortcomings such as for example the relatively low stiffness. To minimize these difficulties innovative TCC connection systems such as notches have been adopted. Notched connections need no special skills beyond the typical knowledge of carpentering connections. These have a high stiffness but usually low ductility or axial loading capacity [6]. The combination of these two connection systems emerged as a natural solution widely used in high demand applications such as for example bridges [7].

The design methods available for timber-timber connections have also been adopted. The mechanical performance of the TCC connections is, however, different from the one from timber-timber connections, mostly due to the concrete behavior. This has necessarily a direct influence in the modelling and design of TCC connections.

The first proposals were based in the data from experimental tests, that later evolved to standard configurations with tabulated data [6,8]. In the Canadian bridge code two notches configurations are given for using in bridge decks [9]. In Oceania also two connection configurations are indicated for with elastic design values are provided [10]. In the current version from Eurocode 5 guidelines are given for the determination of the load carrying capacity and stiffness of dowel type fasteners [11]. Namely the stiffness of TCC connections made with dowel type fasteners is determined as steel-timber connections, assuming no deformation on concrete side [12]. In Eurocode 5 for notched connections no information for the determination of corresponding values are provided yet.

In the last decades, various research works and analysis have been developed dealing with the analysis and design of TCC connections. The load carrying capacity of dowel type fasteners is analysed in a comprehensive way by Dias et al. as well as stiffness [13].

The notches performance has been comprehensively addressed in various parts of the world such as for example in New Zealand [14] or in Germany [15]. Various research studies from literature and available experimental test results on notched connections were compiled and

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analysed in a Short Term Scientific Mission (STSM) performed in the frame of Cost Action FP1402 by Katrin Kudla [16]. In general, for the evaluation of test data and references, special attention has been paid to slip modulus, load carrying capacity and failure modes of the notched connection.

A wide compilation of the information and data available for TCC connections around the world was done in a State of the Art Report made within the WG4 – Hybrid Structures from Cost Action FP 1402 [17].

This paper will discuss the available models for the determination of TCC mechanical properties, including the proposal that will be made within the work undergoing regarding the preparation of the next generation of Structural Codes.

2. Mechanical performance

2.1. General

The basic phenomena involved with the performance of TCC connections do have significant similarities with the ones of timber-timber connections, namely regarding the load transmission mechanisms which are rather similar. As mentioned before the most significant differences are related to the concrete mechanical behavior. Concrete is a brittle material, with low plastic deformation capacity, associated with a high elasticity modulus when compared with that of timber. The ratio between timber and concrete modulus of elasticity is generally higher than 2 leading to completely different deformation levels in the two materials. Another difference with implication in the performance is the production, usually the fastener is cast in concrete side and inserted after predrilling in timber side. This leads to a perfect fitting in the concrete side and to a partially fitting in timber side.

Fig. 1 shows two TCC connections after being tested, evidencing the damage in timber and concrete.

From the figure the formation of the two plastic hinges can clearly be seen as predicted from Johansen model [18]. But also for the notches the damage is visible in both materials, but clearly it is much more significant in timber side. Significant embedding takes place on timber while on concrete side only some crushing signs are visible.

Another important aspect is the pull-out of the fastener in both timber and concrete side. For dowel type fasteners, no signs of pull-out can be found in any of the materials, which is perfectly in line with the observations and measurements from the experimental tests on which, no significant pull-out could be identified [3]. In this particular situation the dowel used was obtained from profiled steel bars, developed to increase the anchor forces in concrete. Similar tests were performed with smooth bars and similar behavior was observed. On the other hand, in timber the dowels were inserted into tight fitting predrilled holes. In these conditions the bar profile could increase the damage in the timber and lead to a lower pull-out capacity, but such situation could not be observed in the tests [3].

Push-out tests with notched connections conducted in Stuttgart [15] and [19] showed a ductile failure due to buckling of the wood fibers in front of the notch, combined with shear cracks in concrete (see Fig. 1). Displacements up to 20 mm were measured at the notches. Shear failure in front of the notch did not occur. However, different push-out tests with notched connection showed a brittle timber shear failure in front of the notch [20].

2.2. Load carrying capacity

The load carrying capacity of dowel-type fasteners is mostly governed by the development of the bending-shear transmission mechanisms. In spite of that, other phenomena such as the friction or the rope effect do also contribute.

The basic load transmission is similar in timber-timber and TCC connections. There are, however, two main differences: the lower deformation in concrete side and the crushing of concrete. The lower deformability in concrete side leads to a more effective load transmission and consequently to a collapse for a higher load level. Additionally, the crushing of concrete leads to a fastener length without contact with concrete and consequently to a less effective load transmission.

In terms of secondary transmission mechanisms, the friction component also increases with the higher contact which results from the lower deformability. Similarly, the higher axially load carrying capacity and low axial deformation contributes to increase the rope effect in this type of connections. This can be observed in both experimental and numerical results. Fig. 2 presents results from numerical simulation in a TCC connection with different levels of friction/axial boundary in the fastener [21] together with results from dowel type fastener connections with different fastener configurations (smooth, profiled and screwed) [3,22]. In order to allow a direct comparison, the loads were divided by the yield load carrying capacity of each of the connections.

The results show a clear convergence between experimental and numerical results. The smooth bars do show slip values similar to those of the numerical simulation with a steel-timber coefficient of friction from 0,1. On the other hand, the simulations with a coefficient of friction equal to 0,9 are quite close to a lag screw with a significant axially load carrying capacity. In between these limits is the result from a dowel type fastener made with reinforcement profiled bars.

Another important aspect is the ratio between the yield load and the ultimate load. Up to a maximum displacement of 15 mm (limit slip defined in EN 26891 [24]) the ratio varies between around 1.5 and 3

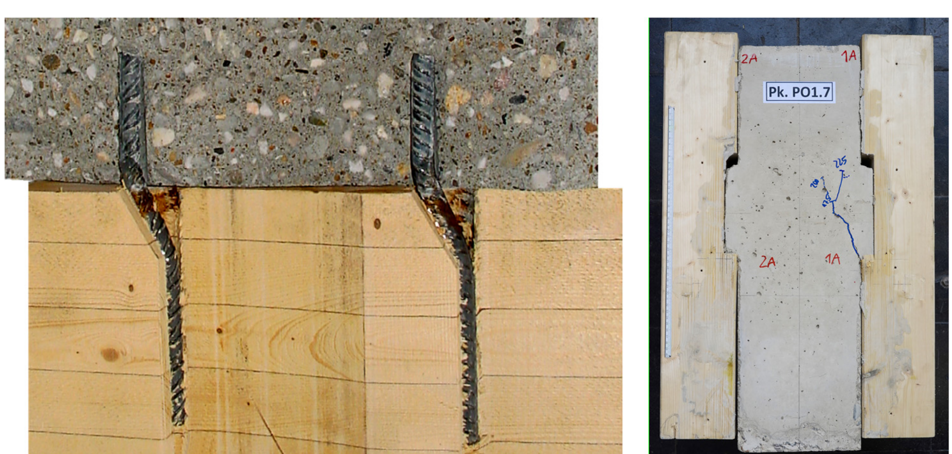

Fig. 1. Tested TCC connection (a) Dowel type fastener; (b) Notch [15].