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Innovative connection in wooden trusses

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HIGHLIGHTS

- A new connection system for traditional timber truss is proposed.
- The new truss is theoretically analysed (FEA), built and tested on a test bench.
- The original connection system is running as expected.
- The new joint withstands forces 4 time higher than design value, without fail.
- It can easily protect a large surface of the sides of the building from precipitation.

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ABSTRACT

An innovation of the traditional timber truss is proposed, designed, built and tested. It is an original joining system to connect the top-chord and the tie–beam. The joint studied enables prolonging the rafter over the linkage with the tie, so as to form overhanging eaves. The behaviour of the connection under loads was analysed either by considerations relating to the possible limit states and by means of Finite Elements Analysis (FEA). In accordance with the design which was theoretically analysed, a prototype was made and it was subjected to loading tests that gave positive results.

1. Introduction

The traditional wooden truss is an old structure that has been used for centuries. The oldest known example of a classical wooden truss is in the Church of Saint Catherine's Monastery on Mount Sinai, dating from the 6th century A.D. [1,2]; in these trusses the king-post is detached from the tie and suspended. The critical node of this system has the task of transmitting the thrust acting in upper-chord to the tie–beam by means of a heel connection.

By its nature this traditional system has the following limits: the rafter cannot continue beyond the point of insertion in the tie–beam, which generally rests inside the bearing wall; furthermore, the length *d* (Fig. 1) is often limited by the thickness of the supporting structure.

Overhanging eaves are normally obtained by putting in place cantilevered bricks or stones and are therefore limited in size; in some situations, to obtain large eaves, more or less complicated additional superstructures are used.

In many cases, for example in the field of agricultural service structures, the designer requires buildings with large eaves. Some of the most significant advantages are:

- achieving efficient protection of buildings from rain; this is very important especially for structures that are delicate in some ways, and that by their nature have a high degree of sustainability, and are therefore suitable for implementation in areas of particular environmental sensitivity: first wooden structures, but also raw earth, straw and similar;
- it contributes to building passive cooling, especially in temperate and tropical zones, causing appreciable energy savings;
- it creates an outdoor space that is not entirely exposed to climatic elements, and therefore is very often useful in buildings that house production processes;

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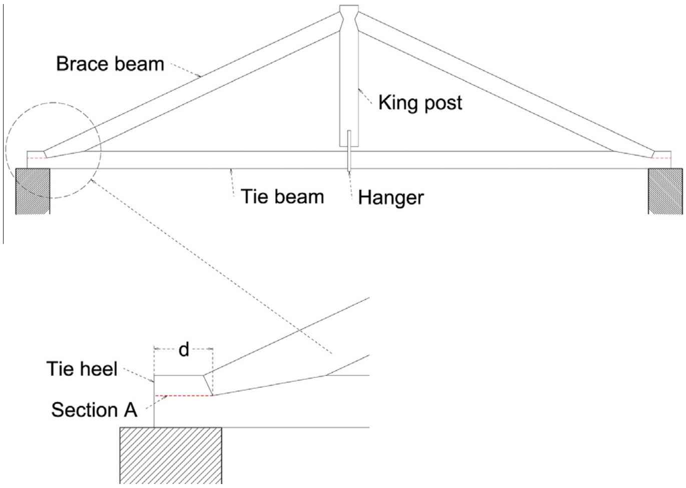

Fig. 1. The simplest classical wooden truss. In evidence the particular of the heel joint and the wood section (A) to be sized (d) for shear stress.

- it increases the covered area with low cost. For many local governments this type of covered area has no costs.

The purpose of this research was to design a solution that meets the following requirements:

- the use of wood mainly as building material, because of its unique sustainability, and its environmental benefits [3];
- the use of the structural layout of the classic truss;
- to enable the extension of the rafters beyond the points of junction with the tie–beam, so as create effective projecting eaves;
- the use of the same resistance mechanism responsible for the stability of the classical truss (disregarding fire resistance), given that this mechanism is certainly reliable for numerous uses and for a very long time;
- simplicity to build.

The next step was to verify mechanical behaviour, in particular the elastic response of the structural system, and its ability to withstand stresses greater than those of current conditions, through the manufacturing of a full size prototype and its testing on a test bench.

2. Material and methods

2.1. Design of the new connection: motivation, characteristics, innovative elements

The new connection system of the truss was designed following these guidelines:

- to use the same operating principle of the classical wooden truss, namely the resistance of wood to the shearing stresses along the grain, also avoiding compressive stress at an angle to the grain different from zero;
- to have the capacity to adapt to the shrinkage/swelling of the wooden parts without suffering significant loss of efficiency;
- to require the use of simple equipment and ordinarily available materials (e.g. simple merchant steel bars, that only need to be cut and drilled);
- to increase safety against shear failure easily, because the shear section may be increased much more than is strictly necessary.

The new connection, presented in Fig. 2, was proposed and designed with the real dimensions (Table 1) and properties of timber (Table 2), chosen to produce a full-size truss to be tested on the universal testing machine.

For the wooden component we decided to adopt the characteristic values of the strength class C30, as indicated in the standard EN 338:2009 [4].

2.1.1. Limit states related to the connection

In order to examine the behaviour of the connection at the serviceability limit states, the following considerations are made:

- the breakdown of the structure as a whole can only occur due to the failure of the connection, because each structural component has been oversized;
- all steel components have been sized in such a way as to always remain in the elastic range and their elastic deformations have negligible values. The limit states of the connection must be sought among wood connections.

The iron-angles transmit forces simultaneously both in the direction parallel to the grain and perpendicularly; it should be noted that the same situation is also present in the classical truss's traditional connection.

2.1.2. Failure of the tie-heel because of shear sliding

This is the ultimate limit state, since overcoming it causes the collapse of the structure as a whole; moreover, it is dangerous because it is a brittle failure, that is to say, it occurs suddenly without strain sensitive warning.

In the classical wooden truss the strength of nodal joints connecting bottom and top-chords is determined mainly by shear failures [5] occurring in heel (section A in Fig. 1), because its length is short for practical reasons [6]. These constraints are also generated by the fact that, in these trusses, the connection must occupy only a part of the thickness of the support wall.

By contrast, in the connection proposed here, the length of the tie-heel does not have the above-mentioned practical constraints, therefore it can be sized in such a way as to reach less dangerous limit states first.

2.1.3. Failure of the wood in the contact area between the iron-angles and the beams

Iron-angles generate in the wood compressive stresses both parallel and perpendicular to the grain both in the rafter and in the tie–beam. The ratio between the values of the two types of stress depends on the geometry of the connection, namely:

- on the tilt angle of the tie-rod;
- on the depth of the notch.

In sum, three cases are possible:

(a) the compressive stress limit is reached first in the perpendicularly solicited grain, and then crushing occurs. In this first case, an irreversible plastic deformation occurs: a general failure of the structure does not occur, but there is a permanent deformation beyond the limit values compatible with the proper functioning of the structure. Within certain limits, this does not lead to ruinous collapse;
(b) the compressive stress limit is reached first in the parallel solicited grain. In this case, two possibilities can occur, depending on the state of compressive stresses on the contact surface:
(I) the tension grows towards the inside of the beam: in this case the L-profile will tend to wedge in the corner of the notch and increase the stress perpendicular to the grain, where it comes to a limit state similar to that described in (a);
(II) the tension grows towards the surface of the beam: in this case the fibres close to the outer surface of the beam, which are the most stressed and unconfined and will therefore collapse due to buckling. The failure of this grain will cause the overturning of the L-profile, giving rise to a general collapse of the structure. In this case there will therefore be a failure of the brittle type.