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Non-destructive assessment, full-scale load-carrying tests and local interventions on two historic timber collar roof trusses

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ABSTRACT

Retrofitting of existing timber roofs may be necessary due to new needs of use or due to the historical significance of the structure. In both cases, a thorough understanding of the existing structure must be available in order to decide the best intervention method. This understanding requires both the assessment of the present state of conservation of the structure, as well as its original and present structural performance.

In this paper, two collar trusses belonging to an old building were surveyed and assessed by means of non-destructive methods and evaluated structurally by full-scale load-carrying tests made at the laboratory. The trusses were first tested until failure in their present condition and then tested again after applying two different types of repairs. The interventions consisted on the strengthening of the support regions and local repairs at the failure areas of the rafters using either screwed timber elements or metal plates. The strengthening of the support regions allowed to obtain a higher load level compared to the initial conditions, while the local repair of the timber rafters allowed to partially regain the original load bearing capacity of the trusses compared to results obtained prior to the rafters initial failure.

1. Introduction

The geometry of a timber truss, the structural system, the formation of the joints are directly related to its structural purpose, as well as to the building knowledge and technology of the culture that constructed and used it. Unfortunately, several examples of deteriorated and damaged trusses are presently found due to poor maintenance, while many did not survive. Thus, very often they were replaced, mainly due to lack of knowledge from the architects and engineers, concerning the assessment and repair/reinforcement methods that could be used.

Different intervention methods may be used to maintain, repair or reinforce these structures. Therefore, a thorough recording and analysis of their conservation state and moreover a thorough understanding of their original and present structural behaviour must be available to define the more suitable and compatible for each intervention case. However, testing the overall behaviour of timber roof trusses is often not possible and few studies deal with such topic. Parisi and Piazza [26] tested a full-scale roof truss (king-post truss superimposed above queen-post truss) of Silver fir (*Abies alba* Mill.), of mid-19th century, to validate and calibrate a numerical model developed for the analysis of timber structures subjected to seismic forces. [4] investigated the behaviour of two traditional king-post trusses on a full-scale load-carrying test under symmetric and asymmetric loading, to identify suitable reinforcement methods. More recently, [3] tested a full-size prototype of a traditional timber truss, to verify the mechanical behaviour of an original joint connection system between the top-chord and the tie beam. The numerical modelling of timber joints on structural heavy timber trusses was also analysed by Rumlová and Fojtík [28]. Regarding biological deterioration, the structural behaviour of a king-post truss was probabilistically analysed in Brites et al. [7], whereas Bastidas-Arteaga et al. [2] analysed the performance of a truss subjected to very aggressive climate variations through a time dependent reliability design.

In this paper, two collar roof trusses are assessed, tested and analysed and the results of full-scale load-carrying tests with different test setups and repair interventions are presented. The collar truss was developed in order to provide a larger internal room height without increasing the overall height of the roof and the building. For this reason, the collar truss is constituted by a tie beam at mid-height resisting to the rafter separation. It has also a different connection system to the inclined rafters compared to

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the tie beam of a traditional king-post truss, which was usually placed at the level of the supports at the masonry walls [6,21].

Different methods of repair and reinforcement of the structural performance of timber beams are summarized in Franke et al. [15]. Regardless of the intervention technique, the final choice greatly depends on the structure itself. The method must comply with the original conception of the structure or with its present/future use, as discussed by Munafò et al. [25] concerning the analysis of the failure of historic king-post trusses. The conservation state of the structure, for both structural elements and joints, has to be taken into account when deciding the repair or strengthening technique and methods, since it may influence the final performance of the intervention.

Other works, such as Branco et al. [4,5], also presented the results from full size scale tests on roof trusses which were preceded by a thorough visual inspection and non-destructive testing, complemented with tests of local repairs using screwed and bolted elements. However, the novelty of this work is that, after the diagnosis phase, different intervention methods used for the repair of the rafters of one of the collar trusses were tested. The interventions consisted on the strengthening of the support region and local repair at the failure areas of the rafters using either screwed timber elements or metal plates. The initial results of the experimental campaign and interventions may be found in Cibecchini et al. [9] for the local repair of a truss' rafters.

2. Description of the collar roof trusses

2.1. General information

The two timber trusses evaluated in this work were salvaged during the restoration works of the Chimico Laboratory's roof, a Portuguese neoclassic building, built at the end of the 18th century. In total, four Maritime Pine (*Pinus pinaster*) timber trusses with 14.2 m span were retrieved from a two pitched roof structure. An iron tie rod at the level of the support area on the masonry walls was present on these two trusses (Fig. 1). During the restoration works, the trusses were brought down and a geometrical survey was made [23]. The geometrical survey was complemented by means of pin penetration and drilling resistance tests in order to determine the extent of decay of the timber elements. Based on those results and on a structural analysis, the trusses were considered unsuitable for the new use of the building and they were replaced by new timber trusses. The old timber trusses were then disassembled and stored. Afterwards, two trusses (trusses T1 and T2) were moved to the Laboratory of the Civil Engineering Department of University of Minho, in Guimarães, and reassembled with the aim of evaluating their structural performance under load-carrying static tests.

2.2. Geometrical survey

The dimensions of the cross section (height and width) of each element of the two trusses were measured every 40 cm. The results were consistent with the previously obtained in [23]. Due to the biological attack found on the surface of the elements, significant coefficients of variation (CoV) were found pertaining to the cross section dimensions. Moreover, extensive wane was found affecting the rectangular section of the elements. This was especially found on the rafters and collar beams. Taking into consideration the exterior cross section dimensions, and therefore the nominal value, the cross section of the rafters had approximate dimension values of $19 \times 25\ cm^2$ (CoV = 18%) and the collar beam values of $19 \times 19\ cm^2$ (CoV = 18%). The approximate nominal dimensions of the post were $19 \times 26\ cm^2$, whereas the diagonal dimensions were $19 \times 20\ cm^2$. The variation of the cross section geometry along the length of the post and diagonals was significantly lower (5%) compared to the rafters and collar beam.

In order to complement the geometric survey, non-destructive tests were made in order to evaluate decay and its depth, and to obtain a database for correlation with the results of the load-carrying tests. Moreover, the results of these non-destructive tests would verify if the decay process continued after the removal of the trusses from the building's roof. The results of the non-destructive tests are presented in detail in the following paragraphs.

3. Non-destructive evaluation

3.1. Visual inspection – strength grading

The main reasons to conduct a visual inspection in timber structures is to detect and to characterize the natural defects in order to evaluate the strength class of the timber members, the deterioration and the level of damage present in the elements. In timber elements, natural defects include features such as knots, slope of grain, deformation, wane and seasoning checks, whereas deterioration includes damage from insect infestation or fungal decay. Moreover, special attention must be given to the assessment of the joints since their level of preservation, and their structural performance, is critical for the overall behaviour of the whole roof.

In this work, the timber trusses were visually inspected taking into consideration the premises of the Italian Standard UNI 11119 [30]. This standard establishes objectives, procedures and requirements for the diagnosis of the state of conservation and

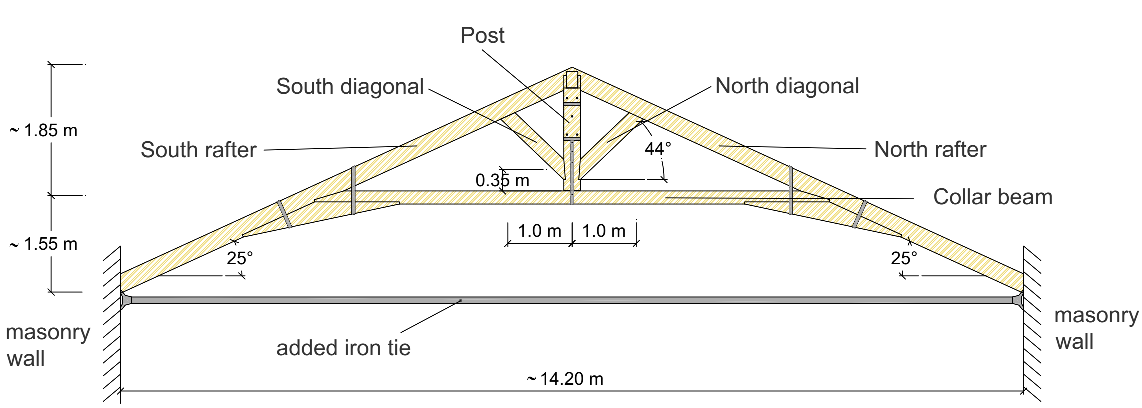

Fig. 1. Section of the studied trusses as found onsite.