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Case study

Safety assessment of historic timber structural elements

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ABSTRACT

Dealing with the safety assessment of existing buildings engineers often have to face the diagnosis of old timber structures. The current standards framework does not provide clear prescriptions about the evaluation of these kinds of structures, so the principal aim of this work is to outline an alternative methodology that leaves the concept of "Knowledge Level" and "Confidence Factor", usually applied for existing buildings. An experimental campaign carried out on old timber joists supplied a sample of homogeneous data that were the support to the theoretical reasoning.

1. Introduction

The assessment of existing structures is dealt by several studies. Starting from the assumption that Confidence Factor (*CF*) values do not rest on solid theoretical foundation, Alessandri et al. [1] proposed a method for the calculation of two types of *CF*, one for the geometry and one for the materials. The subject of [1] was the reinforced concrete, for which the codes do not make a distinction between the two materials involved, that are completely different in terms of behaviour and in terms of techniques of investigation. The calibration of these new kinds of *CF* is done by using the Bayesian method that allows the inclusion of prior information and ex-post results (investigations on the materials and on the structural elements). This procedure is interesting because it gives the adequate relevance to the non-destructive tests that can be carried on existing structure. Franchin et al. [8] investigated the soundness of the *CF* by a simulation of the entire assessment procedure and the evaluation of the distribution of the assessment results on the acquired knowledge. Based on this distribution, a criterion is employed to calibrate new *CF* values. This procedure was applied to three reinforced concrete frame structures of increasing sizes, employing the nonlinear static and dynamic analysis methods and considering all Knowledge Levels (*KLs*). An analysis of the reliability of the *CF* for seismic safety assessment was proposed in [18]. Such a study outlines a procedure for the assessment of the material properties by combining different sources of information. By using a Bayesian framework and considering the case of normal distributed strength, the obtained results lead to the conclusion that, when the prior knowledge and the new test data are in agreement, the necessary *CF* decreases as compared to the value obtained in the absence of a prior knowledge. An extensive literature is available on testing old timber elements. As an example, Piazza et al. [17] presented an experimental campaign on disassembled old roof beams, whereas [15,3,7] deal

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with the correlation between non-destructive and destructive methods for the evaluation of timber properties. A testing activity on 130 years old timber beams can be found in [2]. Machado et al. [19,20] reports a review of the application of Visual Strength Grading (*VSG*) and the way the information obtained can be combined with information provided by other NDT/SDT methods and [21] presents an experimental campaign on 20 old chestnut beams in order to define the correlations between bending modulus of elasticity in different scales of timber members in combination with visual grading analysis.

The aim of this paper is to define an alternative method for the safety assessment of old timber structures. As just the first step for the processing of a new methodology, this work has the objective of outlining the general way to progress, so some hypotheses are restrictive and some parameters are not taken into account. This work starts with an experimental activity based on destructive tests on old timber joists which were recovered from existing buildings. Before samples were tested it was performed the *VSG* according to the current Standards. The *VSG* was carried out in a more accurate way with respect to the prescriptions of the Standards in order to take into account some aspects that are relevant during the assessment *in situ* of timber members. Both bending and compression tests were carried out. The results of the tests were elaborated in order to determine their characteristic values on the basis of the prescriptions given in [23,25,26]. Then it was possible to perform a statistical analysis in order to evaluate the variance of the strength results for each type of test. The values obtained by tests were used as a support for the development of a new method for the evaluation of the design strength of old timber elements. A procedure based on the concept of "Knowledge Levels" (*KL*) and "Confidence Factors" (*CF*) is proposed based on the combination of *VSG* and the direct determination of strength provided by experimental tests on the samples [24].

It is important to remark that the proposed approach is directed to evaluate the design values of the strength based on two possible strategies: The first one through experimental test on samples extracted from the existing structure and the second one through the visual grading. The calibration of the coefficients involved in these two procedures is based on a study case; nevertheless, further study cases will improve the calibration itself in a future development of the research program. Finally, in order to promote a deeper comprehension of the material properties and to improve the reliability of the design parameters, a combined (mixed) procedure will be proposed. By this "third way", the design values are determined by using both the tests and the visual grading, so that the uncertainties and, in turn, the consequent *CF*s will be reduced, thus increasing the design strength.

2. Confidence Factors

2.1. The significance of the Confidence Factors

Once all the investigations on the structures have been carried out the main task becomes the definition of the design values. Concerning existing timber structures there is not a defined standardization, for this reason we refer to the Italian Standards [27]. The prescriptions of the Italian Standards [27] for the assessment of existing building are based on the concept of *KL*, that is defined by the quantity and the quality of the information gained. Depending on the *KL*, the *CF* plays the role of an additional safety coefficient that contains the uncertainties about the existing structure in terms of geometry, details and materials. In order to understand the physical significance of *CF* it is necessary to focus on the difference between the determination of the design value in case of new buildings and in case of existing buildings. The design value for new structures f_d is obtained by the ratio between the characteristic value f_k of the material and the safety coefficient γ_M

$$f_d = \frac{f_k}{\gamma_M}. \tag{1}$$

On the other hand, for the assessment of existing buildings the mean value f_m is used instead of the characteristic value, and it is reduced by the *CF*

$$f_d = \frac{f_m}{\gamma_M CF}. \tag{2}$$

The safety coefficient γ_M assumes the same value in both cases. By comparing (1) and (2) it is clear that the ratio f_m/CF for the existing structures should be the equivalent of the f_k for the new

$$f_k = \frac{f_m}{CF}. \tag{3}$$

Eq. (3) shows that *CF* should account for both the standard deviation of the material strength as well as the incomplete knowledge of the structure. As a matter of fact, the *CF* value defined by standard codes does not account for the strength variance, so that it results inappropriate. Since it was at the Authors' disposal a homogeneous sample of old timber joists, some destructive tests have been carried out in order to calculate the actual standard deviation of mechanical properties and to estimate the subsequent value of *CF* according to Eq. (3).