Reliability based robustness of timber structures through NDT data updating

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Abstract This work presents a framework for reliability-based assessment of timber structures / members using data gathered from non-destructive test results. These results are used for modeling an update of the mechanical characteristics of timber, using Bayesian methods. Results gathered from ultrasound testing, Resistograph® and Pilodyn® conducted on chestnut wood specimens were used, as well as correlations between those results and compression strength parallel to the grain tests' results. The resistant characteristics are also updated assuming deterioration models applied to specific key elements of the structure, thus, being possible to evaluate reliability based in time dependent factors, as well to categorize that structure in terms of robustness. For exemplification of the underlined concepts, three different types of structures are studied.

Keywords timber, NDT, reliability, Bayesian methods, existing structures

1. BACKGROUND

Timber is a rather complex construction material, not only due to its anisotropic behavior and dependence on defects, but also due to the influence that different environmental conditions may have on its mechanical properties. The probability density functions of timber's mechanical properties are defined in various codes and guidelines and may be updated with the results of mechanical tests. When dealing with existing structures, data updating may be regarded as an important tool in the assessment of its reliability parameters. For that purpose, Bayesian methods are often applied to implement new information into a probabilistic structural assessment due to their simplicity of use.

2. METHODOLOGY

When assessing existing structures a variety of information may be gathered from distinct sources, which may be available or can be made available at a given cost. In the assessment of existing structures, this information can be taken into account and combined with prior probabilistic models resulting in so-called posterior probabilistic models.

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In this paper, the updating data is obtained through results collected from non-destructive tests' (NDT) using ultrasound testing, Resistograph® and Pilodyn®, conducted upon a batch of chestnut wood specimens, as well as from tests allowing to estimate the correlations between those results and the compression strength parallel to grain, $f_{c,0}$. The uncertainties connected to the NDT methods are modeled and included in the assessment through a Maximum Likelihood method.
To assess the evolution of the timber elements deterioration, a bi-parametrical idealized decay model was considered. The two parameters correspond to an initial propagation period of the deterioration phenomenon and an annual penetration ratio.
For indication of the level of robustness, measures related to structural redundancy were used, as well as a time dependent indicator when deterioration was considered significant.

3. EXAMPLES

Three example cases are presented: (i) simple supported beam; (ii) column; and (iii) planar truss structure. In those examples, the structural reliability was calculated in both design and assessment phases. After updating the resistant properties, deterioration models were implemented and robustness indicators were considered.
The first example consists in a simple supported beam with uniformly distributed loading along the beam length. For that structure, a deterioration model was assumed regarding different climatic conditions. Further on, a hypothetical trial of tests with a Resistograph® device was assumed for model updating, where different degrees of information led to different reliability parameters. Since the deterioration phenomenon has a constant activity, also the reliability decreases in time and therefore robustness may also be considered to be decreased. Redundancy index and the redundancy factor are not suitable to be considered for this example since this is not a redundant structure.
The second example consists in a column with concentrated loads applied at the top. According to the NDT data, three updated models were made with respect to each type of test. The results obtained denoted higher values of reliability for the models updated with NDT data when compared to the reference models. This is mainly due to the consideration of $f_{c,0}$ as a function of the correlation given between the destructive and NDT. The data with respect to the Pilodyn® tests presented very similar values to one of the reference models.
The third example consisted in a planar timber truss. The structure was assumed to be constructed with chestnut and two strength classes were considered for design. In this example it was found that different strength classes of timber, even for the same design considerations, led to different reliability and robustness levels. Also, not always a higher reliability index produces higher indicators of robustness, depending in the nature of the structural failure that is associated.
Determining the key elements was found to be a fundamental step in order to understand the level of robustness of this particular structure. By changing the design of key elements, different load paths and consequently different structural systems may be found. In that case, a parallel system may be turned into a series system with great interest specially to increase the reliability of the structure. The structural system may, also, influence both the reliability of the system as well as its robustness level.
Although model updating is a useful method for safety assessment of existing structures, NDT data updating does not increase or decrease robustness. The objective of NDT data updating is to allow for a better definition the characteristics of the structural elements, with special regard to the key elements of a structure. From the deterioration model analysis, it is concluded that different indicators for robustness assessment should be used depending in the type of possible actions / loads that might influence the structure.

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