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COMBINE USE OF NDT/SDT METHODS FOR ASSESSMENT OF STRUCTURAL TIMBER MEMBERS

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Combine information from visual and NDT/SDT methods

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Abstract Visual strength grading (VSG) standards are generally the most common non-destructive method used for assessing the mechanical properties of timber member in situ. The limitations of the full application of visual grading rules to timber members in situ lead to the necessity to provide a set of simplified rules for this task. However given the subjectivity and the limitations related to the application of visual grading the results can be supported/validated by complementary information provided by non and semi-destructive testing (NDT/SDT) methods. The present paper discusses how VSG information can be optimized facing a particular timber member and how its information can be combined with other type of NDT/SDT information.

Background

Structural evaluation of ancient or recent timber structures presents particular problems (related to inherent wood material properties) and difficulties. In situ evaluation (without damaging) of timber structural elements represents an initial and crucial step for the success of the rehabilitation process. Support for non-destructive inspection works includes nowadays a variety of tools offering valuable information about the quality and biodeterioration status of timber elements.

Appraisal and repair of ancient timber structures has become a major topic of interest in the last decades. This renewed interest considerably increased the number of technical interventions and design developments. Conservation or rehabilitation of existing timber structures imply extensive knowledge about the properties of materials from which the structure is made. This knowledge constitutes the support for short-term structural behaviour assessment as well as to foresee the continuous adaptation and capacity of response of the material under long-term actions.

Due to the high variations intra and inter species, a large volume of wooden material is needed to be tested to characterize its mechanical properties with a

minimum level of confidence [1]. Quality control and preservation of artistic value were considered important issues leading to the development of some non-destructive and semi-destructive test methods (NDT/SDT) for wood, which sometimes were used in the evaluation of the mechanical and physical properties of other materials [2]. Combined with a visual grading survey, these evaluation methods are an excellent complement to achieve a good level of reliability in the structural analysis, diagnosis and inspection of existing constructions.

Visual Strength Grading

The evaluation of a timber structure begins by conducting a preliminary survey that includes an appraisal of the general quality of the timber members. This evaluation consist in examining directly, and preferably at close distance, checking and registering wood features, signs of damage or deterioration, sometimes with the help of simple instruments (knife, chisel, hammer, etc.), providing a rapid means of identifying areas that may need further investigation. This is an essential part of diagnosis but the results depend severely on the experience of the person carrying out the task.

Since modern design standards require quantitative more than qualitative parameters, visual inspections, as the basis of any visual strength grading (VSG) appraisal, are crucial in the inference of mechanical properties. Visual grading is done mainly based on national standards trying to optimize the grading results for the timber resources of the country, taking into account growth conditions, local preferences for certain cross sections, silviculture differences, and historical developments concerning structural applications [3]. All the VSG standards are based on indirect visual methods focus in understand the effect of important macroscopic strength-reduction reducing characteristics, such as knots and slope of grain, upon the basic quality of a timber member, defined by the properties of its clear wood zones. Therefore mechanical properties of wood elements are highly dependent on the inherent wood properties of each species as well as on the presence and type of defects [4].

Appraisal in situ includes the identification of the wood species, selection of a proper VSG standard and consequent allocation of suitable reference mechanical properties in terms of allowable stresses, characteristic values or strength class. VSG was the first non-destructive testing method to be applied for the sorting of sawn timber according with their mechanical characteristics. The simplicity of its application, not requiring any special equipment, made this method also the one first adopted for the in situ assessment of structural timber members. However in this preliminary survey other NST/SDT methods are already used as support to VSG results (e.g. moisture meters).

Such properties are then used for a first structural analysis. If results showed that structural failed complied with the ultimate state requirements then a more detailed evaluation – detail survey – of the timber members should be carried out or

the structure demolished [5]. The focus of this second evaluation is on critical members of the structure (more stressed or involved in failure has shown by the first structural analysis results).

Recent publications address the way VSG should be adapted to on site conditions [5, 6, 7, 8]. These publications try to optimize the grading process (optimal visual grade) by considering the most important defects present in a timber member and the type of stress applied. The use of NDT/SDT methods to ensure a more reliable prediction of timber member's properties is vaguely mentioned. For instance, [7] establishes criteria for the diagnosis of old timber elements and strength grading can be performed using both on site inspections and NDT techniques.

Prepared in the scope of COST Action IE0601, [5] proposed a first harmonized method for determining the structural grade based on visual grading appraisal supported in the current European procedures and standards. Although NDT for strength prediction is presented as an option in some cases, the level of reliability was thought to provide always an over conservative prediction (safe side).

This document is also the reference document for the WG 10 of the CEN/TC 346/WG 10 activity (Conservation of cultural heritage - Historic Timber Structures) aiming the final preparation of a harmonised visual strength grading methodology that could be approved by CEN.

However, there are several restrictions to the full application of visual grading standards to timber members in situ. VSG standards were developed having in mind the grading of sawn timber at sawmill yards. The full application on site of the rules applied at the sawmill yard is not possible or logical and leads to gross underestimation of the real mechanical performance of timber members. Considering the biased and subjectivity of the grading process, dependent upon human judgment, and variability associated to each visual grade, it is expected that a large proportion of the pieces real resistance would be largely underestimated [9, 10]. However the estimation of the serviceability properties of timber constructions, by means of the VSG standards, is not entirely reliable due to the many factors:

- timber is a highly anisotropic material – heterogenetic material;
- specific to a particular wood species and provenance, the possibility of extrapolation to other wood species and origins is not certain – correlation inaccuracy;
- susceptible to human error, given the limitation of its full application in situ – measurement error.

VSG principles can be differentiated between those following the concept of characteristic values [11, 12] and those following the concept of allowable working stress [7, 13, 15].

Since VSG is a group classification based on a heuristic approach with limited support from models (e.g. statistical), limited options remains for a possible upgrade of a timber member. In fact, in the absence of the data used for defining the grades of a certain VSG standard, the only option is to shift a timber member from one grade to another (lower or upper), not being possible to derive intermediate grades.

For making these changes significant, the data used for the derivation of the visual strength grades or at least a probabilistic model adjustable to the timber species under analyse, needs to be available [16].

When no grading standard is available to a certain species, it is selected one appropriate to a species showing similar wood anatomy and wood density. For example, while [12] establishes different grading criteria for different timber groups, [7] applies the same grading criteria to all species.

In-situ diagnosis of ancient timber structures has been described by several authors [5, 17, 18, 19, 20]. All the authors state that an initial visual inspection of the entire structure and of the singular elements is required in order to determine the original timber characteristics and the changes suffered due to service conditions. This survey follow several steps, beginning with the purpose of a general prediction of mechanical properties and ending in a thorough examination using NDT/SDT. But an important characteristic of several ancient timber structures is that they can effectively bear higher loads than expected [21], which stresses the need of adequate procedures for diagnostic and assessment of the real bearing capacity, which cannot be obtained with a simple visual inspection.

Combine visual and NDT/SDT methods

Recent guidelines propose the upgrading of preliminary VSG application by conditioning it upon the stress condition and position of defects in relation to applied stress. As referred, and based on this, recent standards and studies establish that strength grading can and should be performed using both on site inspections and NDT techniques [1, 5, 22, 23].

Thus, NDT/SDT can be used to increase the precision of the prediction of the mechanical properties provided by visual grading. Generally these methods are used as validation of visual information and not combined in the sense of a fusion process between the data obtained from visual observation and other type of information (NDT/SDT methods). Usual applications of these methods are related with the prediction of:

- the element residual section by analyzing abnormal density variations in the element, generally associated with mass loss;
- density;
- important mechanical properties (bending, shear, tension and compression strength, local and global stiffness) by measuring one or more indicative parameters that can be correlated with it.

There are several NDT/SDT that can be applied to wood and wood composites namely: thermography [24, 25], sonic stress waves [26], X-Ray [27, 28], isotope method [29, 30], hardness tests [31], drilling resistance [20, 32, 33], moisture content meter and core drilling [34, 35, 36].

Among these, core drilling, the moisture content meter and drilling resistance currently play key roles in the preliminary survey. The large majority of research and in-situ application relies on the use of NDT/SDT results to support or confirm visual grading measurements. Drilling resistance is the most often used method to get information about the presence of hidden features and their extent (e.g. knots, decay and fissures). Other NDT/SDT methods (e.g. dynamic modulus of elasticity or penetration resistance) are used as independent variables in regression models.

The upgrading of VSG information (reference properties) using other types of information (NDT/SDT methods) is limited to a few studies.

The development of these methods is in fast progress; however, owing to safety concerns, high costs involved, technical issues, etc., their use has been quite limited in structural timber evaluation. One of the main constrains continues to be the lack of generalized procedures or standards concerning the application of NDT/SDT methods, although recent publication attempt to harmonize the way these methods are used [37, 38, 39]. Although some publication shows the advantages of combining (joining) information from VSG with those from NDT/SDT methods [40] very few present methods that can be used for a true combination of information [41, 42].

Conclusions

VSG will remains as the basic method for assessing the mechanical performance of timber members in situ. However several studies agrees on the fact that the sole use of these method can lead to the demolishing of safe structures and that other NDT/SDT methods should be used to ensure a proper assessment procedure. The question about how to combine this information is still under study but will probably depend upon many variables (e.g. type of structure, load stresses involved, type of evaluation) making that the expert will have to make the final decision upon which method to use and how to use all the methods and data for taking a final decision.

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