COST Action FP1101 Assessment, reinforcement and monitoring of timber structures

State of the Art Report
WG 1 / TG 2

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

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Reference conditions and modification factors for the standardization of nondestructive variables used in the evaluation of existing timber structures

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Abstract

The aim of this paper is to define the reference conditions and to propose modification factors to standardize the nondestructive variables recorded by different NDT, in order to gain uniform practical data and to develop a procedure for the standardization of timber structure assessment..

Introduction

The standardization process consists of the development of a common NDT procedure for the evaluation of structural timber properties. This process could be based on previous works (Íñiguez-González et al. 2013) and should include the following features:

- Compilation of nondestructive test results from different research groups and studies, taking into account the species studied and devices used;
- The creation of a standardized data sheet to compare results, based on the adjustment factors proposed;
- Standardized equations.

This paper therefore focuses on the second and third features.

Background

2.1 Nondestructive variables

The following variables are usually measured for the in situ assessment of timber properties by means of nondestructive techniques:

Time of flight (or equivalent velocity)

The propagation of stress waves through material can be used to estimate its mechanical properties, mainly stiffness. Time of flight (TOF) or the equivalent velocity, is the main parameter measured. Attenuation can also be recorded and is related to strength properties. Two types of waves are used: sonic stress waves for frequencies within the audible range, and ultrasonic stress waves at frequencies above 20 kHz.

Natural frequency

In this method timber pieces are made to vibrate longitudinally or transversely by means of an impact in the corresponding direction. The vibration of the piece occurs primarily in the system Eigen frequencies. These frequencies are related to the stiffness properties of the piece and its dimensions/geometry. In the case of longitudinal vibration, it is also possible to obtain the equivalent velocity of stress wave transmission.

Pullout resistance

The pullout resistance method consists of the measurement of the withdrawal force of a screw with a known diameter inserted into a timber piece to a certain depth. This force is related to the density of the timber.

Penetration depth

This method is based on a similar principle to that of material hardness measurement, and it consists of measuring resistance to the penetration of a hard solid piece. Penetration depth is related to the timber density in the outer part of the piece of wood.

Drill resistance

This method mainly focuses on gathering data on the internal condition of timber members and trees. It uses a small diameter drill (1.5-3.0 mm) to bore into timber members while measuring resistance to penetration (energy consumed at constant velocity). Resistance to drilling is proportional to density.

2.2 Factors affecting nondestructive variables

Moisture content

The moisture content (MC) of timber depends on the hydrothermal conditions of the surrounding air. In a normal dry condition inside a building the MC of timber is from 8 to 12 %; this is slightly higher, 10 to 16 %, if the building is close to the coast. MC can be measured with electrical resistance equipment, according to the EN 13183-2:2002 standard. A reference value of 12% MC is usually adopted. Under usual conditions the range of MC variation is about ±4% (12±4%).

Temperature

In general, the mechanical properties of wood decrease when it is heated and increase when it is cooled. However, in the practical range from -10 to 50 ºC the effect is negligible; for example, in structural mechanical timber design it is assumed that the properties of timber do not change and are not affected by temperature below 50 ºC. Consequently, the effect on measured nondestructive variables is very small.

Size/length

The size effect may have an influence on some local nondestructive variables such as pullout resistance and penetration depth, as a consequence of the sawn pattern and cross-section size of the piece. In the case of large cross-sections, the outer wood of the cross-section usually has narrow rings, and the direction of probe penetration is more radial than it is tangential. On the other hand, small or narrow cross-section pieces may have juvenile wood in the outer part of cross-section, so that tangential penetration is possible.

Wave velocity propagation is independent of frequency. But different commercial devices work at different wave frequencies, and the means used to detect signal start and stop may differ. The result is influenced by signal attenuation and therefore depends on the length and size of the piece. It is more difficult to establish a reference value for the size and length factors.

Positioning of sensors/angle to the grain

This factor affects the measurement of time of flight (or the equivalent wave propagation velocity). The best positioning of sensors for measurements is at each end of the piece, obtaining the velocity parallel to the grain.

This is not possible in practice in existing structures because the ends of pieces are not accessible. It is therefore common practice to take measurements at an angle to the grain, positioning the sensors on opposing faces at the maximum possible distance or, in the central portion of a span, obtaining the velocity for a certain angle. For frequent dimensions of timber pieces and cross-section slenderness (width/thickness = 1-2) and length (length/depth of the beam = 17-22) the angle with respect to the grain varies from approx. 2 to 6 º. In some situations only the lower face of the piece is accessible, and in this case sensors are placed on the same face, obtaining velocity parallel to the grain but under special conditions.

3. STANDARDIZATION PROPOSAL

3.1 Reference conditions

Moisture content

12% moisture content of timber is proposed as reference value to correct the non-destructive measurements (stress wave, ultrasound wave velocity and penetration depth). This value corresponds to the target MC for coniferous timber in service class 1 according to Eurocode 5 (EN 1995-1-1:2004). Service class 1 is characterized by a MC in the materials corresponding to a temperature of 20ºC and a relative humidity of the surrounding air only exceeding 65% for a few weeks per year.

Temperature

20ºC is the reference value proposed in general, and according to the definition of mechanical properties in Eurocode 5. But considering its low effect on nondestructive variables this correction may be neglected in frequent variable conditions (-10 to 50ºC).

Size

The effect of size is considered here in terms of length, and 2.7 m is the proposed reference length to correct nondestructive measurements (stress wave and ultrasound wave velocity). This value is based on standard bending test slenderness (span/depth = 18) and the reference depth for bending strength of solid timber in Eurocode 5 (150 mm, 18•150 = 2700 mm). In practice length may usually be in the range from 3 to 6 m, and considering the reference value of 2.7 m the maximum effect would be a 7% variation in velocity.

Sensor positioning

The end to end positioning of sensors, measuring the velocity parallel to the grain, is the proposed reference position of sensors and reference angle. In practice the angle may usually be in the range from 2 to 6º, so the maximum effect would be a 6% variation in velocity.

3.2 Modification factors

Moisture content

The reference velocity of stress wave propagation, v12 (referred to 12% MC) may be obtained by equation 1, from velocity at H % MC, vH,

$$v_{12} = \frac{v_H}{1-(H-12)\,k_H} \qquad (1)$$

Where k_H is the adjustment factor for MC obtained as the ratio between the linear variation of velocity relative to MC (Δvelocity/ΔMC) related to velocity at 12% MC. A preliminary value of 0.01 (1% velocity decrease for every 1% MC increase) is proposed for this, as it is a common result in several research works.

The reference depth penetration of the Pilodyn 6J Forest, P12 (referred to 12% MC) may be obtained by equation 2 from depth penetration at H %, P_H,

$$P_{12} = \frac{P_H}{1 + (H - 12)\, k_P} \tag{2}$$

Where k_P is the adjustment factor for MC obtained as the ratio between the linear variation (depth/MC) related to depth penetration at 12% MC. A preliminary value of 0.02 is proposed (approx. 2% depth penetration increase for every 1% MC increase) for this factor. There are other experiences suggesting that its effect be neglected for practical purposes.

Temperature

The reference velocity of stress wave propagation, v_{20} (referred to 20 ºC temperature) is obtained by equation 3 from velocity at T ºC temperature, v_T,

$$v_{20} = \frac{v_T}{1 - (T - 20)\, k_T} \tag{3}$$

Where k_T is the adjustment factor for temperature obtained as the ratio between the linear variation of velocity relative to temperature (Δvelocity/ΔT) related to velocity at 20 ºC. This factor has been obtained in several research works with a value close to 0.00075 (a 0.075% velocity decrease for every 1 ºC temperature increase). In practice the temperature may usually be in the range from 5 to 35 º C, and considering the reference value of 20 ºC the maximum effect would be 1.12 % of variation in velocity.

Size/length

The reference velocity of stress wave propagation, $v_{2.7}$ (referred to a reference length of 2.7 m) is obtained by equation 4 from velocity at L length in m, v_L,

$$v_{2.7} = \frac{v_L}{1 - (L - 2.7)\, k_L} \tag{4}$$

Where k_L is the adjustment factor for length obtained as the ratio between the linear variation of velocity relative to length (Δvelocity/ΔL) related to velocity at reference length 2.7 m.

Positioning of sensors/angle of the grain

The reference velocity of stress wave propagation, v_0 (parallel to the grain and end to end) is obtained by equation 5, from velocity angle α in sexagesimal degrees ($\alpha \leq 10^{o}$), v_α,

$$v_0 = \frac{v_\alpha}{1 - \alpha\, k_\alpha} \tag{5}$$

Where k_α is the adjustment factor for angle obtained as the ratio between the linear variation of velocity relative to angle (Δvelocity/Δα) related to velocity parallel to the grain and end to end. This factor was obtained in several studies with a value close to 0.01 (a 1% velocity decrease for every additional grade increase in angle deviation) for ultrasound waves (at 22 kHz).

Finally, if velocity is measured only using sensors in the lower face of the piece, these values should be divided by a factor of 0.972 to obtain the velocity v_0.

4. CONCLUSIONS AND FUTURE WORKS

Given the lack detected in the state of the art, research work compiling nondestructive testing values measured in coniferous and deciduous species is being undertaken in Spain. This has the purpose of collecting existing test results measured in raw material and existing structures with different devices and procedures. A testing protocol has also been designed and proposed in order to make the results of future nondestructive tests by different researchers comparable. Although this study does not yet include sufficient material to propose a grading method of timber based on nondestructive testing results, it does mark the route to this goal.

Acknowledgments

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