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

Editors:
José Saporiti Machado and Mariapaola Riggio

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Assessment through NDT of the state of timber structures of the historic buildings of Catalonia

Marcel Vilches Casals, Carles Labèrnia Badia and Vladimir Rodríguez Trujillo

M. Vilches Casals · C. Labèrnia Badia · V. Rodríguez Trujillo

Catalan Institute of Wood (INCAFUST). Lab. and Technical unit of Lleida. Parc Científic i Tecnològic. Edifici H2 • E-25003 Lleida, Spain

e-mail: marcel.vilches@incafust.org,

C. Labèrnia Badia

e-mail: c.labernia@caatlleida.net

V. Rodríguez Trujillo

e-mail: vladimir.rodriguez@incafust.org

Abstract The wood was the material most commonly used for the construction in cities and towns of Catalonia in the past, for this reason, nowadays a lot of diagnosis in timber structures are performed. The NDT, in the diagnosis of ancient buildings, help to complete the inspections, therefore in some diagnosis NDT were used, like Microsecond timer or drilling resistance device, to improve the assessment conditions of the structure. In order to NDT are reliable, previous studies of laboratory should be made, for getting warranty correlations. These correlations presented by different authors have been used in some inspections of ancient buildings in Catalonia, in which timber roofs and the floors of the buildings are analyzed with NDT. These methods have been a complement for deciding the strength class of the timber placed in the ancient buildings.

Keywords Nondestructive techniques, timber structures, diagnosis, ancient buildings, Catalonia

Introduction

Historically, the timber has been the material most used for construction of the resistant structures (roof, floors, …). For this reason, many rehabilitations of catalan historic buildings are performed in timber structures, that can be degraded by biotic agents. Nowadays, the development of the NDT for the evaluation of properties of timber also are used in the inspection of the structures as a complementary tool for deciding the strength class of timber.

The main advantage of the NDT is that they do not produce damage in the examined sample and the timber elements were can continue using. The acoustic methods are most used in the diagnosis of timber, permitting to predict the modulus of elasticity with the transfer speed of the wave. The densitometers are also employed as NDT for determining the density of timber, so this physic property is a good indicator of the mechanic properties. In this case, the estimations are in a point and its information is complemented by other methods, as ultrasonic or vibration techniques for calculating dynamic modulus of elasticity, which is a good estimator of the real elasticity of the material.

Technicians and researchers, before using the NDT in the inspections, first have performed several studies in a laboratory for obtaining good correlations between the values of the nondestructive methods and the properties of timber (MOR, MOE and density). Normally, the acoustic methods are correlated with the dynamic modulus of elasticity[1] and the MOE[2] and MOR[3], but the Pearson correlation coefficients do not exceed the 80% [2, 5, 6, 8, 11]. Although it is difficult to find higher correlations that give better warranties, it should be taken into account that these techniques must be a help to the inspections of timber structures. The case of the densitometers is similar, inasmuch as the correlations between density and the values obtained with the tool used can vary between the 50% and 80% [1, 4, 6, 7, 9, 10, 12].

Methodology

Specie identification

The wood species identification of the inspections is performed through a macroscopic identification of a sample extracted in situ. The macroscopic description includes the observation of several characteristics of the timber to the naked eye or with the help of a magnifier of 10×. The structure, size and form of the tissues are different in almost all timber species, so that each one species can be identified. Xylotheque samples are used for the macroscopic description, with the three cutting plans: transversal, radial and tangential.

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[1] $E_{dyn}=\rho(v^2)$ (ρ=Density, v=wave speed)

[2] $MOE=A+B\cdot E_{dyn}$

[3] $MOR=A+B\cdot E_{dyn}$

Moisture content

The moisture content in the inspections is determinate with a xylohygrometer of electrical resistance (FMW), which permits obtaining the moisture content of the timber quickly with a microprocessor. This tool has a sensor on top and measures the moisture content holding the sensor on the timber element. The measuring range of the humidity is 2 to 30%, with a resolution of 0.1% and an accuracy of 0.5%. The measuring depth is 10 to 20 mm, adjustable to intervals of 1 mm.

Determination of density

Drilling resistance device, model IML Resi F300S, is used for the determination of density. This tool is an electrical drill, which introduces a needle in the timber with a constant speed, and it measures the degree of resistance offered by the wood. It is a good technique for the inspection of structures in service. The drill does holes of 3 mm of diameter. Normally, it is used to verify the status of certain critical points, as the inspection of hidden sections of beams that are sensitive to the material loss, due to accumulation of humidity.

Determination strength properties

Another tool used is the Microsecond Timer (FAKKOP), which is based on the generation of the impact waves, with a frequency of resonance of 23 kHz. The function of this tool is based on the higher absorption capacity of the impact waves of the wood degraded and the sound wood. The impact waves are generated with the mechanical hammer impact on an electrical transmitter. The mean of the wave speed is performed with a timer and an electronic receptor that detects the transit time.

Case study

Ancient Building at the Pyrenees

This building presented as a case study, where scholar activities were performed, is from the beginning of 19^{th} century, located in the town of La Seu d'Urgell. Nowadays, it is the cultural center of the town. The building is distributed in ground floor, first floor, second floor and penthouse floor. Structurally it is built with walls of load and horizontal floors with timber beams (Figure 1).

Fig. 1 Exterior building front view and beams of the second floor

In the inspection was observed that all timber of the structure was performed with the same species, for this reason a wood piece of a beam was extracted for the specie identification. The identification showed that the genus of the specie was *Pinus* sp., probably *Pinus sylvestris*. The moisture content was determined with a contact hygrometer, obtaining humidity around 10% of the timber elements. So that, the characteristic values of elasticity will be modified for the 12% of humidity.

The density, used for determining the dynamic modulus of elasticity, was determined in the laboratory with beams that were not of the case study building. Drilling resistance curves were made in areas free of defects, in eight beams of Scot pine, with similar dimensions and characteristics to the beams of the inspected building. These eight elements were available in the laboratory for an own characterization project and they were used for this analysis because the drilling resistance curves were not made on the beams of the inspection *in situ* by unavailability of the drilling resistance device. The moisture content of the eight beams in the moment of drilling was approximately of 12% and the mean value of coefficient of growth was of 6 mm by ring in each beam. With mean values of the drilling resistance and the correlation obtained by Acuña *et al*. [1], for *Pinus sylvestris*, a density of 411 kg/m^3 was consider for the inspected timber (Table 1).

Table 1 Density values obtained with the mean values of the drilling resistance of different timber elements of *Pinus sylvestris*

Timber elements	Mean values of Drilling resistance (%)	Density values[a] (kg/m^3)
Pinus sylvestris 13	23.34	412.53
Pinus sylvestris 21	38.06	423.71
Pinus sylvestris 22	18.52	408.87
Pinus sylvestris 23	25.51	414.18
Pinus sylvestris 81	15.42	406.51
Pinus sylvestris 81b	12.24	404.10
Pinus sylvestris 82	25.75	414.36

Pinus sylvestris 83	14.25	405.62
	Mean	411.24

[a] ρ=394.797+0.7598·Drilling resistance Mean Value (r^2 = 0.82) [1]

With the density value obtained the MOE_{dyn} can be calculated, but this density will not be considered for the assignation of the strength class because in this case the density value is not limiting for the strength class that will be assigned to the timber beams of the building, according to the standard EN 338:2010. For this reason, in order to estimate the strength class of the timber inspected it was decided to consider only the MOE and the MOR obtained with the impact waves (Table 3).

The timber structure of *Pinus sylvestris* analyzed showed a good condition of conservation, which has given an excellent structural functionality. Only in some beams of the first floor were found excessive deformations. This was originated by the prolonged action of humidity of the water tubing of the top floor. The other beams near the water pipings did not observe any degradation signs of the timber. In the penthouse was not found any kind of alteration.

Once the condition of the timber structure was valued positively the assignation of the strength class was performed with the help of the time-of-flight of ultrasonic waves values. Six pieces of timber were analyzed, two bottom chords, which formed the trusses of roof, two beams of penthouse and two beams of the second floor, and in each of them were measured three readings wave speed (Figure 2). The measures were performed on the central part of the timber pieces, with a distance between sensors of approximately two and three meters (Table 2).

Fig. 2 Evaluation of the bottom chords of the trusses of roof with the Microsecond timer

Table 2 Values of time transmission, the mean value of the time and the wave velocity in each timber element analyzed

Element	Floor	Time 1 (µs)	Time 2 (µs)	Time 3 (µs)	Mean value (µs)	Distance (cm)	Wave Velocity (m/s)
Bottom chord DEF	Penthouse	480	482	480	480.60	215	4473.57
Bottom chord LLLM	Penthouse	434	435	435	434.60	217	4993.10
Beam 4	Penthouse	315	314	315	314.60	171	5435.47

Beam 5	Penthouse	331	332	331	331.30	177	5342.59
Beam 11	Second	634	630	632	632.00	290	4588.61
Beam 13	Second	664	663	662	663.00	283	4268.48

These values of time-of-flight of ultrasonic waves were used for determining the dynamic modulus of elasticity and later, with this value, allocate the strength class using the equations of bending strength (MOR) and modulus of elasticity (MOE), published by Íñiguez [8] for Scots pine. The bottom chord obtained a characteristic value of the bending of 23.49 N/mm^2, of 35.14 N/mm^2 for the beams of penthouse and of 20.83 N/mm^2 for the beams of the second floor, assigning them respectively a class C22, C35 and C20, according to the standard EN 338:2010. In return, the elasticity values limited the strength class of the inspected elements, obtaining characteristic values of 7404 N/mm^2 for the bottom chords, 9403 N/mm^2 for the beams of penthouse and 6541 N/mm^2 for the beams of the second floor, assigning them respectively a class C14, C18 and C14 (Table 3).

Table 3 Values of modulus of elasticity and bending strength for each individual element. Characteristic values of modulus of elasticity, bending strength and strength class assigned for each kind of timber element

Element	Floor	MOE$_{dyn}$[a] (N/mm^2)	MOE[b] (N/mm^2)	MOR[c] (N/mm^2)	MOE[d] (N/mm^2)	MOR[e] (N/mm^2)	Strength class
Bottom chord DEF	Penthouse	8230.09	6655.74	23.14	7403.78	23.49	C14
Bottom chord LLLM	Penthouse	10252.63	8151.82	30.02			
Beam 4	Penthouse	12149.83	9555.19	36.47	9402.92	35.14	C18
Beam 5	Penthouse	11738.13	9250.65	35.07			
Beam 11	Second	8658.79	6972.85	24.60	6541.59	20.83	C14
Beam 13	Second	7492.75	6110.33	20.64			

[a] $E_{dyn}=\rho(v^2)$ (ρ=411kg/m^3, v=wave speed)

[b] MOE=A+B·E_{dyn}=579.5+0.7548·E_{dyn} (r^2 = 0.74) [5, 8]

[c] MOR=A+B·E_{dyn}=-4.84+0.0034·E_{dyn} (r^2 = 0.60) [5, 8]

[d] Mean values

[e] 5th percentile values

The visual grading was not used for allocating the strength class because the timber elements of the penthouse were hidden by the ceiling, which did not permit to see the singularities of timber. The beams of the first and second floor were painted and the defects of timber were not visible.

CONCLUSIONS

Nowadays the speed of the wave transmission is, together with visual classification, the NDT technique more used. The disadvantage of these methods are the low correlations, because they don't fulfill with the expectative. The predicted values of elasticity and resistance, with the nondestructive variables, have a deviation of 40% and 70% respect the actual mechanical properties and the estimation of the strength, with these devices, must be more approximate with the true values. Even so, these techniques are a good complement for rehabilitation of buildings with timber structure to estimate a strength class of timber elements.

The drilling resistance device is a good tool for predicting biotic degradations in hidden areas and the difficult access areas, as the timber beams ends embedded in masonry walls. This tool also serves like estimator of the timber density, using the mean value of the drilling resistance curve as indicator [3, 11]. The results obtained by the authors, reinforce the utility of this tool in the inspections, but it is necessary to use different NDT techniques in order to get an adequate diagnostic.

In inspections, like this study, where the timber beams are hidden or the defects cannot be easily seen, the diagnostic is difficult to evaluate. So that, with an inspection of the critical areas of the building (areas with water pipings or places where there can be filtrations of water), the NDT devices and with the experience of working with ancient timber beams, conclusions with warranties of the strength capacity of the timber structure of the edifice can be obtained.

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