NDT to identify biological damage in wood

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Abstract

Nondestructive techniques are widely used to assess existing timber structures. The models proposed for these methods are usually performed in the laboratory using small clear wood specimens. But in real situations many anomalies, defects and biological damage are found in wood. In these cases the existing models only indicate that the values are outside normality without providing any other information.
To solve this problem, a study of non-destructive probing methods for wood was performed, testing the behaviour of four different techniques (penetration resistance, pullout resistance, drill resistance and chip drill extraction) on wood samples with different biological damage, simulating an in-situ test. The wood samples were obtained from existing Spanish timber structures with biotic damage caused by borer insects, termites, brown rot and white rot.
The study concludes that all of the methods offer more or less detailed information about the degree of deterioration of wood, but that the first two methods (penetration and pullout resistance) cannot distinguish between pathologies. On the other hand, drill resistance and chip drill extraction make it possible to differentiate pathologies and even to identify species or damage location.
Finally, the techniques used were compared to characterize their advantages and disadvantages.

Key words: Nondestructive testing, probing, biological damage, identification.

Introduction

In the evaluation of existing structures, either in rehabilitation or consolidation works, non-destructive probing techniques can be of great help in decision-making. The application of these techniques to estimate physical and mechanical properties, especially density, requires knowledge of the characteristic values of each technique for each genus or species.

Many authors propose different models of density estimation for different tools, species and origins (Greaves, BL et al. 1996; Watt, MS et al. 1996; Walter, ITG et al. 2005 and Bobadilla et al. 2007, 2009).The models proposed for these methods are usually performed in the laboratory using small clear wood specimens. However, in real situations when these techniques are applied in-situ, many anomalies, defects and biological damage are found in wood. In these cases the existing models only indicate that the values are outside normality, without providing any other information.
But non-destructive methods are actually often used in addition to characterise wood, detecting and evaluating diseases or damage (Ross and Pellerin, 1994; Machado and Cruz, 1997; Casado et al. 2005; Lladró et al. 2006; Gallego and Bobadilla, 2011; Henriques et al. 2011). Analysis is complex due to the variability of results, since they depend on test location, timber anisotropy and density, the percentage of late wood, defects or decay, and the operator (Bonamini, 1995).

The main aim of this work is to organize and complete existing information on the use of non-destructive or semi-destructive probing methods in the detection and characterization of disease and damage in timber pieces, based on 10 years' professional experience and previous research works.

Materials, Equipment and Methods

Testing Material

Eighty six coniferous wood specimens with different types of biological damage were subjected to simulated in-situ testing. Wood samples were obtained from existing Spanish timber structures with biotic damage caused by borer insects, termites, brown rot and white rot, with different levels of damage.

Equipment and Methods

Firstly the pathology was identified, quantifying damage in the wooden pieces and determining the local density in the working area of the material tested.
Once the piece was tested the extent of attack and degradation depth was checked using an awl and gauge.
To quantify damage, visual inspection of the test zone was performed, distinguishing 4 depth damage groups: healthy wood (no degradation), surface degradation (1 to 10 mm depth), medium degradation (11 to 30 mm depth) and deep degradation (over 30 mm depth) (Bobadilla et al. 2009).
For local density calculation 8 cm^3 samples of the damaged tested areas as well as healthy wood of the same wood pieces were obtained. The density of the whole piece was measured by dividing its mass by its volume. The densities of the 4 damage classes (healthy wood, surface, medium and deep degradation) of the timber pieces tested were obtained in this way.

Penetration tester
The Penetrometer instrument (Pilodyn 6J Forest, Proceq, Switzerland) consists of a calibrated spring that drives a steel needle into timber. Depth of pin penetration can be used to evaluate the level of damage to the timber, depending on surface hardness and density (Hoffmeyer, 1978).

Screw Withdrawal Resistance Meter

Screw withdrawal resistance is measured using a test device designed specifically to record the maximum load required to extract a screw previously inserted into the timber. The assumption is that the greater the force needed to extract the screw, the higher the density of the timber (Iñiguezet al. 2010).

The screw withdrawal test was performed using the portable Screw Withdrawal Resistance Meter (SWRM), designed by Fakopp (Hungary). A 4 mm diameter 70 mm long Heco-Fix plus type screw with a penetration depth of 20 mm was selected for this study. Resistance can be used, as in the previous case, to evaluate the level of damage to the timber.

Resistograph

IML RESI F400S (IML, USA) drill equipment was used in this study. This equipment measures the torque or drill resistance applied to a 2.5 mm diameter drill bit in order to maintain constant penetration velocity into the wood piece. Density variations in the wood material will correspond to variations in the torque and result in a resistance drill profile down the depth of the wood element (Morales-Conde et al. 2014). This method involves obtaining and analyzing the drill resistance profile in the damaged wood area.

Wood extractor

The Wood Extractor is a device coupled to a commercial power drill to collect all the chips that are produced during drilling in a one-use paper bag filter (Bobadilla et al. 2013). This technique establishes a known volume of removed wood, at a constant setting of drill diameter (8 mm) and penetration (47 mm). After drilling, the collection of chips in the filter is studied for biological damage using a stereo microscope, and the percentage of small particles (<0.85 mm) is measured to discriminate between healthy and damaged wood.

Results and Discussion

Since the performance, behavior and information obtained with each tool is very different, analysis has been divided into three categories to clarify the results: Damage detection, quantification and identification.

Penetrometer

Damage detection: wood damage is detected when higher than normal penetration values for the analyzed species or family are obtained. If an existing density estimation model is applied, estimated density values are below the normal ones for healthy wood. It is only possible to detect damage of surface areas (up to 40 mm), as this is the measurement range of the equipment.

Quantification: with this tool, damage quantification is limited to the external area of the pieces. The degree of attack is well correlated with loss of density and increased needle penetration. The density of healthy and damaged areas of the same pieces was estimated using any of the existing models (Bobadilla et al. 2007, 2009), and the values obtained were compared. Thus surface degradation is difficult to detect due to measuring equipment variability, but in pieces with medium degradation, penetration values were duplicated for relatively low losses of density (17%), and in pieces with deep degradation, penetration is four times greater due to density loss of approximately 44%. Some of these results can be seen in Table 1. Another limitation of the penetrometer is that existing density estimation models do not work properly with deeply damaged timber, as they were designed for healthy wood.

Identification: Finally, with the information provided by this equipment it is not possible to identify the organism that caused the damage. Data provided by this tool is only about loss of wood density and hardness.

Table 1 - Results obtained with the Pilodyn in conifer wood pieces with different degrees of degradation. The density estimation model used is the one proposed by Bobadilla et al. 2007. (*) the density estimation models used do not work properly with deeply damaged timbers, as they were designed for healthy wood.

Sample	Mean penetration depth (mm)	CV (%)	Estimated density (kg/m^3)	CV (%)	Real density (kg/m^3)	CV (%)
Surface degradation	13	13.9	472	7.9	444	11.3
Medium degradation	16	26.0	414	20.5	436	12.8
Deep degradation	33	28.8	Out of range (*)	-	295	12.8
Healthy wood	8	20.6	570	6.2	528	8.5

Screw Withdrawal Resistance Meter

Damage detection: damage is detected when resistance values or estimated densities are below normal for the analyzed species or families. As in the previous case, the tool only detects damage in the outer part of pieces, because the range of use is 0 mm to 20 mm, although this could be increased if another type of screws is used and insertion depths are higher.

Damage quantification is achieved by the relationship between loss of withdrawal resistance and loss of density. Thus, the density of healthy and damaged areas of the same pieces has been estimated using one of the existing models (Bobadilla et al. 2007) and the values obtained have been compared. As happened with the penetrometer, this tool is not very precise about surface degradation due to the variability of the measuring equipment, but in pieces with medium degradation, resistance values decrease more than a half (53%) at relatively low losses of density (17%), while in pieces with deep degradation resistance drops by over 80% and density decreases by approximately half (44%). Some of these results are shown in Table 2. Similar results were obtained by other authors (Casado et al. 2005).

Table 2 - Results obtained with the Screw Withdrawal Resistance Meter in conifer wood pieces with different degrees of degradation. The density estimation model used is the one proposed by Bobadilla et al. 2007.

Sample	Mean withdrawal force (kN)	CV (%)	Estimated density (kg/m^3)	CV (%)	Real density (kg/m^3)	CV (%)
Surface degradation	1.20	28.3	421	8.8	444	11.3
Medium degradation	0.73	32.4	370	7.1	436	12.8
Deep degradation	0.25	92.9	317	8.0	295	12.8
Healthy wood	1.56	25.6	460	9.5	528	8.5

Identification: as in the previous case, with the information provided by this equipment it is not possible to identify the organism that caused the damage.

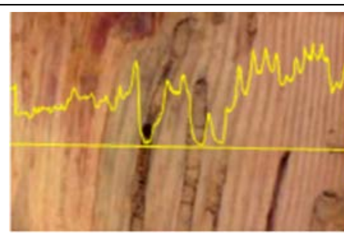
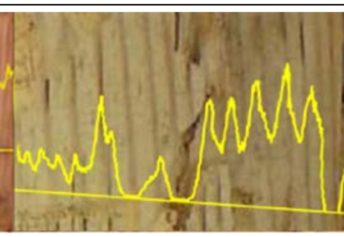
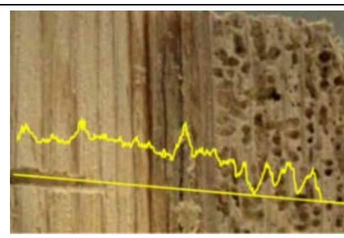
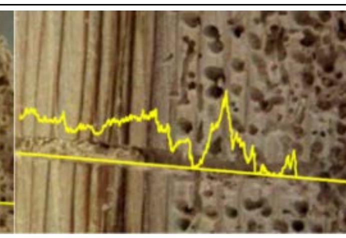
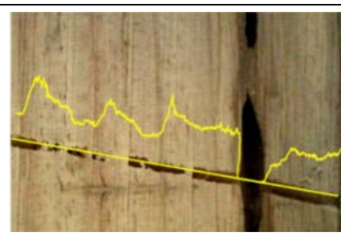
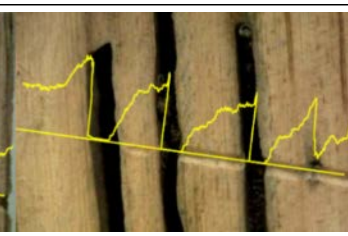
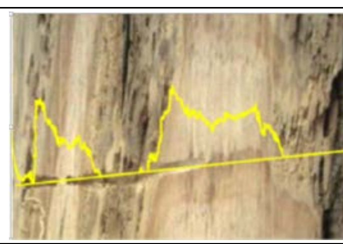
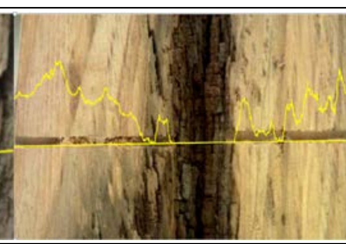
Resistograph

Damage detection: this is done by looking at abnormally low resistographic profiles. With this equipment it is also possible to compare densities through the values obtained using any of the regression models proposed by various authors (Machadoand Cruz, 1997; Lladró et al.2006; Gallego and Bobadilla, 2011). Some authors estimate that losses in density of from 3% to 12% can cause decreases in mechanical strength from 20% to 45% (Henriques et al. 2011).

Damage quantification is based on study of low resistographic profile surface locations affected by abnormalities in wooden pieces.

This tool now makes it possible to identify the pathogen affecting wood. This requires analysis of the shape and location of anomalies within the resistographic profile. Each destructive agent produces a characteristic attack, causing typical damage to timber and a different tool response.

Table 3 – Characteristic damage profiles and corresponding graphics produced by the most common pathogens in conifer timber.

<table>
<tr><th>Pathogens</th><th>Attack location</th><th>Shape</th><th colspan="2">Pictures</th></tr>
<tr><td>Long horn beetle (Cerambicidae)</td><td>Sapwood</td><td>U</td><td></td><td></td></tr>
<tr><td>Furniture beetle (Anobiidae)</td><td>Sapwood</td><td>V</td><td></td><td></td></tr>
<tr><td>Termites (Reticulitermes spp)</td><td>Sapwood and Heartwood</td><td>|_/</td><td></td><td></td></tr>
<tr><td>Brown and white rot</td><td>Sapwood and Heartwood</td><td>__/</td><td></td><td></td></tr>
</table>

Given the characteristics of each of the pathogens taken from the study of such damaged wood samples, damage profiles were obtained for each of the different diseases. Table 3 shows the profile shape found and its most likely location in wood for each type of attack.

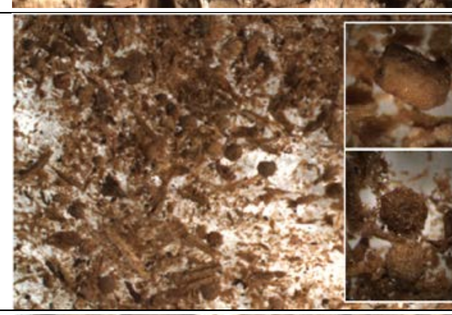
As a limitation of this method it should be noted that although profile analysis can provide some degree of information about pathogen type, it is still a complex and subjective method of identification. Furthermore, if different overlapping damage is found in the same piece, analysis and identification become more complex.

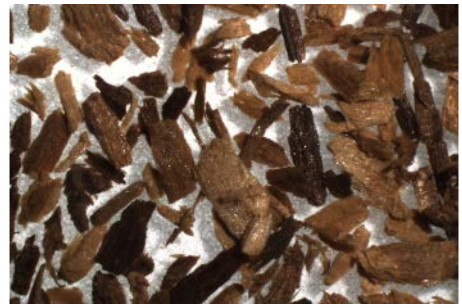
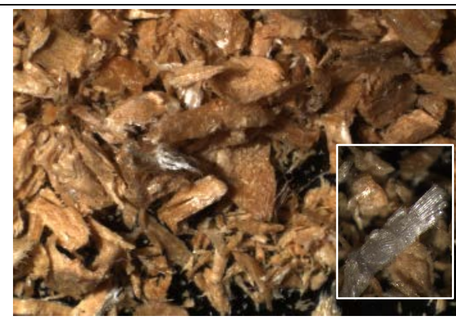
Wood Extractor

Damage detection begins with the feeling of loss of resistance to the drill. This loss of strength is transmitted to the hands of the technician continuously or discontinuously, depending on the type of damage to the wood. In a second phase, estimation of an abnormally low density based on the existing models or the appearance of the chips removed can also raise alarms (Bobadilla et al. 2013).

Degree of damage quantification estimates the above-mentioned density and greater or lesser amount of powder (minute debris<0.85 mm) in the extracted sample. The higher the small particle content and the lower the density, the greater is the damage. Table 4 presents the data obtained.

Table 4–Results obtained using the Wood Extractor on conifer wood pieces damaged by the most common timber pathogens.

Sample	Drill resistance feeling	Powder content	Distinctive feature on the extracted sample	Sample appearance	Pictures (X6)
Clear wood	Normal	15% Low	Wood scent	Splintery	
Borer insects (Cerambicidae, Anobiidae, Curculionidae… etc)	Low with gaps	40% High	Insects pellets	Powdery	
Termites (Reticulitermes spp)	Normal with gaps	30% High	Mud	Muddy powdery	

Brown rot	Low	40% High	Prism shaped bits	Powdery	
White rot	Low	30% High	Fiber shaped bits	Powdery fibrous	

As with the resistograph, one of the advantages of this equipment is that it allows the identification of disease causing damage. To do this, quantification study of powder content (minute chips) and visual analysis of the presence of detritus (pellets), hyphae or characteristic remains of each pathogen in the extracted sample must be done (Bobadilla et al. 2008, 2013). Identification is therefore based on the detritus left by the degrading agent.

This technique is more effective and reliable than the resistograph in identifying different degrading agents, even if they overlap in the same piece of wood.

Finally, Table 5 shows a comparison of the techniques used.

Table 5 – Comparison of the different methods used in the study. Categories: Poor, Medium-Poor, Medium, Medium-Good and Good.

	Equipment cost	Handiness	Damage detection range	Damage quantification	Damage identification
Pylodin	Medium	Good	Surface 0 a 40 mm	Poor-Medium	-
Screw Withdrawal	Medium	Medium	Surface 0 a 20 mm (Depends on the screw)	Medium	-
Resistograph	Poor	Medium-Poor	All section (Depends on the tool)	Good	Medium-Good (Type, Family)
Wood extractor	Good	Medium-Good	Surface 0 a 50 mm (Depends on the drill bit)	Medium	Good (Family, sometimes Species)

Conclusions

The four probing and drilling tools and methods tested in this paper have proven their effectiveness for the detection and quantification of damage in construction timber. All the methods discussed objectively detect density losses caused by destructive agents, although detection is more reliable for medium or deep damage (affecting more than 1 cm below the surface).

Damage quantification reliability will depend on the method used, but they all allow estimation of abnormally low density, which is a clear indicator of the deterioration of wood.

The resistograph and wood extractor often also allow the identification of pathogens in wood. The resistograph does so by analyzing the shape of the graphic profile obtained, while the wood extractor does so by visual analysis of the sample taken with a magnifying glass.

The Screw Withdrawal Resistance Meter, Pilodyn and Wood extractor have an important limitation in terms of the test area, as this varies from 2 to 5 cm in depth in wooden pieces.

For better and more reliable analysis of damaged wood, and taking into account the fact that the characteristic values for each wood species and method used are not always known, the authors recommend testing areas of healthy and is free of defects wood in the same pieces tested in-situ and using the results obtained as a reference for comparison.

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Abstract

The 19th International Nondestructive Testing and Evaluation of Wood Symposium was hosted by the University of Campinas, College of Agricultural Engineering (FEAGRI/UNICAMP), and the Brazilian Association of Nondestructive Testing and Evaluation (ABENDI) in Rio de Janeiro, Brazil, on September 22–25, 2015. This Symposium was a forum for those involved in nondestructive testing and evaluation (NDT/NDE) of wood and brought together many NDT/NDE users, suppliers, international researchers, representatives from various government agencies, and other groups to share research results, products, and technology for evaluating a wide range of wood products, including standing trees, logs, lumber, and wood structures. Networking among participants encouraged international collaborative efforts and fostered the implementation of NDT/NDE technologies around the world. The technical content of the 19th Symposium is captured in these proceedings.

Keywords: International Nondestructive Testing and Evaluation of Wood Symposium, nondestructive testing, nondestructive evaluation, wood, wood products

Contents

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