Исходя из изложенного, мы рекомендуем для определительных испытаний на надежность технологических систем деревообработки по параметру качества продукции «точность» применять индикаторные скобы с ценой деления не более 0,01 мм.

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HOW TO USE A NONDESTRUCTIVE EVALUATION OF TIMBER STRUCTURES

Abstract

A variety of NDE techniques can be employed by an inspector in order to determine the condition of an timber structure. Advances are needed to improve the effectiveness of predicting timber properties and overall structural capacity from various NDE methods. The goal of this paper is to describe a combination of techniques that will provide a more effective prediction of timber structure condition and capacity.

Key words: Nondestructive evaluation, wood properties, timber structures

1 INTRODUCTION

Nondestructive evaluation techniques (NDE) utilizing different methods has successfully been used to improve the assessment of the integrity of wood structures [1]. NDE techniques for wood differ greatly from those for homogeneous, isotropic materials such as metals, plastics, and ceramics. In such materials, whose mechanical properties are known and tightly controlled by manufacturing processes, NDE techniques are used only to detect the presence of discontinuities, voids or inclusions. However, in wood, these irregularities occur naturally and are further induced by degradative agents in the environment. Therefore, NDE techniques for wood are used to measure how environmentally induced irregularities interact in a wood member to determine its mechanical properties. The purpose of this document is to provide guidelines on the application and use of the NDE method in locating and defining areas of decay in timber structure members [2].

Timber bridges are often exposed to harsh environmental conditions. Over time, this exposure can lead to deterioration resulting from decay, insect attack, weathering, and mechanical damage [3]. Early decay is difficult to recognize because it is visually subtle and often occurs on the interior of a timber or below ground. Non visual methods of identifying early decay include culturing the fungus from the infected wood and various physical tests, such as those that indicate a change in strength properties, acoustic changes, and electrical changes.

2 NDE OF TIMBER MEMBERS

Inspection methods are currently a combination of tests for physical detection of decay (for example, sounding, boring), mechanical detection (compression test, splinter test), electrical detection (moisture meter, x-ray), or acoustic detection (acoustic emissions, stress wave time). Laboratory detection methods, such as culturing, microscopy, and serological tests, though definitive for early stages of decay and valuable to the inspection process, have historically not lent themselves to field use [3].

The fundamental hypothesis governing NDE of wood materials was first put forth by [4]. He proposed that the energy storage and dissipation properties of wood materials, which can be measured nondestructively by using any of several vibration-or acoustic-type techniques, are controlled by the same mechanisms that determine the static behavior of the materials. A variety of inspection techniques can be employed to locate damage and decay in timber members in order to maintain structural performance [3]: visual inspection, stress wave / ultrasonic, drill resistance, radiography, microwave / ground penetrating radar, vibration.

2.1 Visual inspection

Visual inspection is the simplest NDE technique, and should be the first step in assessing a timber bridge. Using visual inspection, technical personnel can quickly develop a qualitative assessment of the relative structural integrity of individual members. Obvious deficiencies can be easily identified, Including external damage, decay, crushed fibers in bearing, creep, or presence of severe checks and splits. Results of visual inspection can be employed to guide further NDE.

Visual inspection requires strong light and is suitable for detecting intermediate or advanced surface decay, water damage, mechanical damage, or failed members. Visual inspection cannot detect early stage decay, when remedial treatment is most effective [5].

2.2 Stress wave / ultrasonic technique

Stress wave propagation in wood is a dynamic process that is directly related to the physical and mechanical properties of wood. In general, stress waves travel faster in sound and high quality wood than in deteriorated and low quality wood. By measuring wave transmission time through a timber in the given direction, the internal condition of the tree can be fairly accurately evaluated. If decay is present in the member, the attenuation and propagation time of the stress wave passing through the member is increased. The increase in propagation time, in extensively decayed wood, may be as great as 10 times the propagation time for solid wood [1].

Table 1 summarizes recent research on stress wave transmission times for various species of wood. In general, the reference information can be summarized into two groups: softwoods and hardwoods. Generally, sound travels faster in hardwood species than in softwood species. As a rule in living trees, the baseline transmission time is 1,000 μs/m for softwoods and 670 μs/m for hardwoods [Table 1] [9]. Measured transmission time (per length basis) less than this would indicate a sound wood. A study conducted by [11] demonstrated that a 30% increase in stress wave transmission time implies a 50% loss in strength. A 50% increase indicates severely decayed wood [9]. For timber structures such threshold criteria is still missing.

Table 1: Reference stress wave velocities and transmission times for various species at moisture content 6-12%: sound wood [10], decayed wood calculated according to [11].

Wood species	**Stress wave transmission time** (μs.m^{-1})		
	Sound wood [10]	Moderate decay [11]	Severe decay [11]
Spruce	700-930	910-1209	1000-1375
Fir	625-1070	940-1390	1085-1605 (1574 [10])
Pine	1075	1390	1610 (1640 [10])
Oak	570-645	740-835	855-970
Beech	600	780	900
Maple	670	871	1005

Because wood is an organic substance, the speed of wave propagation varies with grain direction. The speed of sound across the grain is about one-fifth to one-third of the longitudinal value. [9]. Remember that longest transverse-to-grain transmission time is found at a 45° orientation to the annual rings. The shortest is in the radial direction; stress wave speed is about 15-30% faster than that in the tangential directions. [9] Stress wave transmission time (TT, μs.m^{-1}) is given by:

$$TT = 10^6 c^{-1} = 10^6 (E/\rho)^{-1/2} \quad (1)$$

where c – stress wave velocity (m.s-1), E – modulus of elasticity (N.m-2), ρ – wood density (kg. m^{-3}).

2.3 Drilling resistance

Drill resistance is a quasi-nondestructive test that has been used to determine density end detect decay in trees and timber. It is classified as quasi-nondestructive because a small diameter (1.5mm - 3mm) hole remains in the specimen after testing. However, this hole is small enough to have only negligible structural effects on the remaining cross-section and may be sealed to prevent access for agents of decay. Drill resistance (RD, Nm.s.rad-1) devices operate under the premise that resistance to penetration is correlated with material density. Drill resistance is determined by measuring the power required to cut through the material:

$$RD = T / \omega \quad (2)$$

where T – drilling torque (Nm), ω – angular speed (rad/s).

Plotting drill resistance versus drill tip depth results in a drill-resistance profile that can be used to evaluate the internal condition of a tree or timber member and identify locations of various stages of decay. The resistance profile can also be used to estimate member density and compares favorably with radiographic.

Due to the invasive nature of the drill resistance technique, and the fact that it provides a vary localized measure of density, this technique maybe best employed if used in conjunction with NDE methods that provide qualitative condition assessment (e.g., visual inspection) or regional condition assessment (e.g., stress wave or ultrasonic inspection). In such a scenario, visual or stress wave inspection could be used to locate expected regions of decay. Drill resistance measurements could then be taken at a limited number of key locations to determine the through-thickness condition of the wood. These measurements could be combined to predict MOE and possibly member strength.

An overall analysis of data from different timber specimens led to the development indices of decay for the test specimens. It seems to be difficult to distinguish between different stages of decay within narrow range of 0-25% [Table 2].

Table 2: Deterioration assessment based on drilling resistance (indices represents nearly 85% of the specimens tested) [8].

Drilling resistance (Nm.s.rad^{-1})	**Deterioration index**
25-100%	Sound wood
10-25%	Moderate deterioration
0-10%	Severe deterioration

3 QUANTIFICATION OF BIODEGRADATION

Another attempt there is to develop an NDE methodology whereby the presence and extent of biodegradation could be quantified [6]. It is easy to add an additional constraint to the objectives since we wanted to develop the technique in such a way that it could quantify biodegradation at inaccessible locations.

Since in exterior use we cannot control the environmental variables, such as temperature and moisture content, for in-situ measurements, we needed to develop an NDE which can quantify the biodegradation while at the same time is insensitive to temperature and moisture variations.

In a general form, e.g. the vibration signal output (V), is assumed to be a function (f) of a number of major material and environmental variables. In mathematical form [7]:

$$V = f\,(D, B, M, T, G, C, ...) \qquad (3)$$

where D – density, B – biodegradation, M - moisture content, T – temperature, G – geometry, C - boundary condition.

In the final form the biodegradation is quantified by a decay ratio (DR). The decay ratio is defined as the fraction of decay occupying the cross section. Based on the above outlined criteria the final form of the mathematical prediction model chosen is [7]:

$$DR = a+b\,(P/S) + c(G) \qquad (4)$$

where P - NDE parameters, S - species parameter, G - geometry parameter, a, b, c - numerical constants.

Line A

Line B

Line C

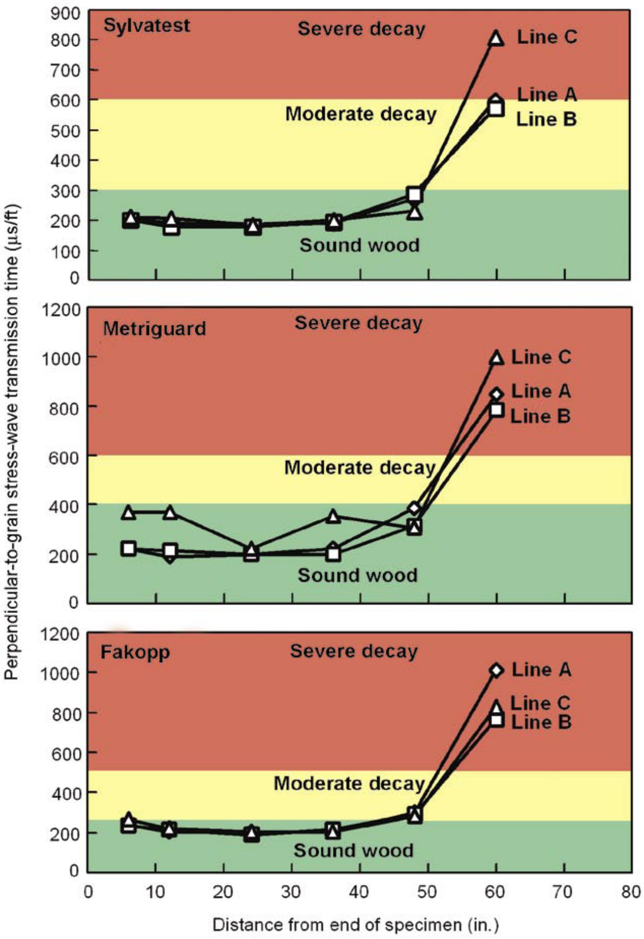

Figure 1: Assessment of wood deterioration (Douglas-fir) by several stress-wave tools [12].

The above decay ratio is computed at several orientations at a given cross section. This way the decay location can be mapped to scale. Note that the process can be repeated more times rotating the measurements at some degrees each time. The decay ratio approach gives excellent results between actual and NDE-predicted decay ratios.

One example of application of above mentioned approach there is comparison of stress wave transmission plots and interior photographs of wood specimen revealing areas of different grade of deterioration (Figure 1). Figure 1 illustrates results obtained from a specimen that showed mostly sound wood with a pocket of moderate–severe deterioration at approximately 240 mm from the specimen end after being cut open. Nearly all measured stress-wave transmission times were within the sound to slightly moderate decay zones. However, the stress-wave transmission time measured was in the severe to slightly moderate decay zone for one device, whereas it was in the severe decay zone for another devices [12]. Anyway, a good approximation of threshold criteria distinguishing a sound and deteriorated wood there is the stress-wave transmission time around 1000 $\mu s.m^{-1}$ (softwoods) and 700 $\mu s.m^{-1}$ (hardwoods). For more details refer to [10].

Results on comparative performance characteristics such as accuracy, reliability, and ease of use in detecting internal decay in the timber structures provide good potential for interpretation of the testing results. Regardless of the unit used, the user must be careful to differentiate the presence of decay from internal splits, cracks, or ring shake in the timbers. It is recommended that an increment corer or resistance drill be used to confirm the exact levels and locations of decay [12].

4 CONCLUSION

Professionals may be satisfied to produce a report on the conducted NDE research. However, eventually a question is raised whether the results could be used to produce a tool that can be put to practical application. While the professional may not be the one who produces the NDE tool, he or she should be familiar with the questions raised by the one who will consider the feasibility of such an undertaking. Some of the more important elements of the feasibility evaluation are discussed in the paper:

• Stress-wave timing technologies can be used successfully to detect the presence and level of internal decay for timber bridge components.

• Stress-wave timing measurements perpendicular to the grain provide an excellent tool to assess the extent of internal decay in timber bridge components.

• There were, however, differences in the level of variability and the decay thresholds for different equipment.

• Any nondestructive testing tool or device must be used as part of a comprehensive condition assessment that incorporates an in-depth visual inspection, knowledge of prior use of the structure, and a working knowledge of fundamental engineering properties of structural wood products.

• When used with visual and probing techniques, NDE technique provides a very accurate description of the internal condition of timber structures.

ACKNOWLEDGMENT

This paper was elaborated with the financial support of Ministry of Education, Youth and Sport of Czech Republic, No. MSM 6215648902.

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ЭЛЛИПТИЧНОСТЬ БРЕВЕН И ОПТИМАЛЬНЫЕ РАЗМЕРЫ ПИЛОМАТЕРИАЛОВ

ELLIPTISITY OF LOGS AND THE OPTIMUM SIZES OF SAWN TIMBER

Практически каждое бревно в поперечном сечении имеет отклонение от формы круга. У пиловочника хвойных пород полученного из нижней и средней части ствола, взаимно-перпендикулярные диаметры различаются на 3,1…3,7%. При среднем диамет-