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## Methods for Assessing Wood Structures in Place

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### Abstract

The Forest Products Laboratory is developing a comprehensive guideline for assessing the condition of existing wood structures. This paper provides an overview of the current literature on condition assessment that forms the basis of this guideline. We also describe Forest Products Laboratory research on nondestructive testing tools.

### Introduction

Most structures are periodically inspected and evaluated for their ability to function at a desired performance level. This assessment of in-place condition is an important aspect in determining if a wood structure requires rebuilding or renovation. Structures may be evaluated because of a change in use, serviceability problems, deterioration resulting from poor design or lack of maintenance, damage caused by misuse or natural hazards, and/or changes in performance requirements.

Inspectors, architects, and facilities engineers are often called upon to assess the condition of existing wood structures. Though a substantial body of knowledge exists about wood behavior, biodeterioration, and nondestructive testing techniques, comprehensive guidelines are lacking for systematic inspection and evaluation of common wood structures.

At the USDA Forest Service, Forest Products Laboratory (FPL) in Madison, Wisconsin, a program is evolving to develop such guidelines, based on state-of-the-art inspection and evaluation techniques. An important part of this program is an effort to enhance the use of nondestructive testing (NDT) for

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assessing the condition of wood structures in service. This paper will present an overview of this FPL research program.

### **Guidelines for Assessing Existing Structures**

Two basic phases are usually identified with the assessment of existing structures: inspection and evaluation. The inspection should identify material characteristics (species and grade) as well as condition (such as presence of decay) of the structure. The evaluation is based on the results of the inspection. Evaluation includes development of applicable design values along with a structural analysis to determine the effects of load on individual members and connections. This is followed by determination of the ability of members and connections to resist the applied loads. This two-step system typically leads to an assessment of structural adequacy and recommendations for repair or replacement of the structure.

Although much information is available on the inspection and upgrading of wood residential buildings (Sherwood 1975, 1976, 1977; Sherwood and Percival 1983), wood residential military buildings (USAF 1988), and historic buildings constructed of various materials (USDI 1976), no comprehensive guidelines are currently available to both inspectors and facilities engineers for inspecting and evaluating specific components in common wood structures. The most significant publication on the condition assessment of wood structures is the ASCE book *Evaluation, Maintenance and Upgrading of Wood Structures: A Guide and Commentary* (ASCE 1982). This document does an excellent job of providing technical aspects of inspection, evaluation, and repair. However, it lacks adequate coverage of how to apply NDT tools to in-place assessment and inspection rating systems for wood components.

In cooperation with the U.S. Navy, the FPL developed a rating manual for glulam timber beams and heavy timber trusses (NFEC 1985); the manual is oriented toward the evaluation of military wood structures. The condition of wood beams and trusses can be quantified through a rating system, using photographs of members in various stages of distress. Another source for evaluation is a comprehensive manual written by Graham and Helsing (1979) on the inspection of wood poles.

A standard guideline for the condition assessment of buildings constructed of various materials is currently under development (ASCE, in preparation). Although this document covers the assessment of steel, concrete, masonry, and wood materials, it does not provide adequate coverage of the inspection and evaluation phases of assessing the condition of specific wood components. This document also provides little information on how to use NDTs. Another document under development is a manual for the design of timber bridges, which includes inspection and maintenance procedures (Ritter, in press).

Notwithstanding the importance of this body of literature, we feel that information on the assessment of wood structures would prove more useful if compiled into a comprehensive guideline that targets common structures (such as bridges, buildings, wharf and dock structures, and wood utility poles) and

their components (such as trusses, beams, columns, and posts). This guideline would provide the user with a single reference document for most structures encountered in the field.

Often, the person responsible for the inspection and evaluation of a wood structure is not familiar with wood as an engineering material. For this reason, we feel the most useful approach would be to develop a guideline that targets two user levels: inspectors and engineers. Both need guidelines unique to their role in condition assessment. The guideline for inspectors could follow a format similar to that presented in the NFEC manual (NFEC 1985); that is, the use of many examples and pictures to indicate typical problems encountered as well as provision of a method for rating the condition of various components. The guideline for engineers could include accepted engineering practices and assumptions used for evaluating wood structures as well as enough background to familiarize the engineer with wood as a structural material. Also, existing analytical tools and their limitations would be described to aid the engineer in evaluating the structure for the loads likely to be encountered.

### **Nondestructive Testing Tools**

Nondestructive testing tools have been extensively used for the inspection and evaluation of various wood-based materials. We believe that such tools can be particularly useful for the inspection and evaluation of wood structures.

The techniques that utilize NDT tools differ greatly for homogeneous, isotropic materials such as metals, glass, plastics, and ceramics, and a material such as wood. In nonwood-based materials, whose mechanical properties are known and tightly controlled by manufacturing processes, NDT techniques are used to detect the presence of discontinuities, voids, or inclusions. In wood-based materials, these irregularities occur naturally, and they may also occur because of degradative agents in the environment. Hence, in determining the mechanical properties of wood, NDT techniques are used to measure how natural and environmentally induced irregularities interact in a wood member.

The fundamental hypothesis governing NDT of wood materials was first put forth by Jayne (1959). 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. As a consequence, useful mathematical relationships between these properties and static elastic and strength behavior should be attainable through statistical regression analysis methods.

To elaborate on Jayne's hypothesis, consider how the microscopic structure of clear wood affects its static mechanical behavior and energy storage and dissipation properties. Clear wood is a composite material composed of many tube-like cells cemented together. At the microscopic level, energy storage properties are controlled by orientation of the cells and their structural composition, factors that contribute to static elasticity and strength. Such properties are observable as frequency of oscillation in vibration or speed of sound transmis-

sion. Conversely, energy dissipation properties are controlled by internal friction characteristics, to which bonding behavior between constituents contributes significantly. Measurements of the rate of decay of free vibration or acoustic wave attenuation are frequently used to observe energy dissipation properties.

Verification of the hypothesis with wood subjected to different levels of deterioration by decay fungi, which are frequently found in wood structures and have a detrimental effect on the mechanical properties of wood, has been limited to studies that have employed only energy storage parameters. For example, Wang and others (1980) found that the frequency of oscillation of small eastern pine sapwood cantilever-bending specimens was significantly affected by the presence of decay. Pellerin and others (1985) showed that stress wave speed could be successfully used to monitor the degradation of small, clear wood specimens exposed to brown-rot fungi. They showed a strong correlative relationship between stress wave speed and the compressive strength parallel to the grain of exposed wood. Rutherford (1987) showed similar results. He also revealed that modulus of elasticity perpendicular to the grain, measured using stress wave NDT techniques, was significantly affected by degradation from brown-rot decay and could be used to detect incipient decay. Chudnoff and others (1984) reported similar results from experiments with several hardwood and softwood species using an ultrasonic measurement system. Recently, Patton-Mallory and DeGroot (1989) reported similar results from a fundamental study on the application of acousto-ultrasonic techniques. Their results also showed that energy loss parameters may provide useful information on early strength loss from incipient decay caused by brown-rot fungi.

Acoustic emission techniques have also been investigated for detecting decay. Using a small sample of clear white fir specimens infected with brown-rot fungi, Beall and Wilcox (1986) showed a relationship between selected acoustic emission parameters and radial compressive strength.

Several researchers have published results of their efforts to use NDT tools for existing wood structures. Pellerin (1989) summarized his results and those of others (Browne and Kuchar 1985; Hoyle and Pellerin 1978; Hoyle and Rutherford 1987; Neal 1985; Renyer 1988) on successful use of stress wave methods for in-place detection of decay in wood structures. All used energy storage parameters obtained from simple stress wave time of flight-type measurement systems. These reports cite the successful in-plane evaluation of structures such as bridges, foot-bridges, grandstands for spectator activities, piers, laminated arches in school buildings, and the largest wood structure in the world, TRESTLE.

Anthony and Bodig (1989) reported on the use of sonic spectral analysis techniques they developed and used for inspection of wood structures. These authors developed equipment based on their study results and have successfully evaluated in-service wood utility poles and large, wooden cooling towers.

Murphy and others (1987) and Dunlop (1983) used acoustic and vibration techniques for evaluating wood poles. The technique developed by Murphy and others (1987) involves measuring the vibrational response of a pole

after the pole is tapped by a rubber mallet. The resonant frequencies of the pole, which are indices of energy storage parameters, were identified and analyzed to determine key parameters. Dunlop (1983) used an electronic system, sweeping through a selected range of excitation frequencies, to develop an acoustic signature of a pole. Resonant frequencies and their bandwidths were examined for use as NDT parameters. Other techniques such as pick tests, sounding, and utility impact-type devices have also been used with some success.

At FPL, we are investigating and developing relationships between fundamental NDT parameters and the residual strength and stiffness of wood members subjected to a wide range of degradation agents. Parallel studies are aimed at the design and implementation of new measurement techniques.

From a reliability standpoint, a great advantage of using NDT tools to measure in-place properties is that the direct measure of in-place resistance reduces the variability of total resistance. In theory, an exact measurement of resistance reduces the variability of resistance to zero. This approach is being taken in current research on upgrading the load limits on timber bridges.

### **Concluding Remarks**

The large body of information on the inspection and evaluation of wood structures needs to be consolidated into comprehensive guidelines that can be easily used by inspectors and facilities engineers. The FPL plans to develop such guidelines. The FPL is also conducting research on NDT technologies and their application to the condition assessment of existing wood structures.

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