# INSPECTION AND EVALUATION OF WOOD STRUCTURES IN NORTH AMERICA

R. H. Falk R. C Moody

USDA Forest Service, Forest Products Laboratory
One Gifford Pinchot Drive, Madison, WI 53705-2398 U.S.A.

## ABSTRACT

The ability of a structure to perform specific functions may be subject to review periodically. This assessment usually forms the basis for determining whether the structure requires modification, reinforcement, rebuilding, or renovation.

Although extensive research has been undertaken for the design and construction of new wood structures, relatively little work has been performed in support of the assessment of existing structures. As a result, several areas of research need attention.

This paper overviews the state of the art of the inspection and evaluation of wood structures in North America. Methods and techniques used for the assessment of wood structures will be discussed as well as perceived research needs.

## INTRODUCTION

The ability of a structure to perform specific functions may be subject to periodic assessment, which usually determines whether the structure require modification, reinforcement, rebuilding, or renovation.

Structural assessment is usually required because of change in the use of the structure, damage as a result of natural hazards, weakening of structural members caused by deterioration, change in applicable building codes, or serviceability problems caused by foundation settlement, excessive deflection, or vibration (ASCE 1982).

While extensive research has been undertaken for the design and construction of new wood structures, relatively little work has been directed toward the assessment of existing structures. As a result, several areas of research need attention.

The purpose of this paper is to review the present procedures in the United States for the inspection and evaluation of wood structures and to identify research opportunities.

## ASSESSMENT PROCEDURES

Three basic phases are usually identified with the assessment of in-place structures: inspection, evaluation, and repair. In this paper, we will discuss the first two phases.

### Inspection

Typically, structures are inspected to identify the extent of damage or structural disability and to provide insight into the quality and condition of the structural materials. The information derived from a well-organized inspection program can often prevent expensive replacements and extensive loss of operating time during emergency repair. The frequency of inspection depends entirely upon local situations at the structure, such as those necessitated by accidents, existing or potential biological activity, or nature of the structural materials.

A thorough guide for the inspection of glulam arches and heavy timber trusses has been published (NFEC 1985). This document offers the inspector basic information on what properties of wood affect strength, how conditions of use affect durability, and how deterioration occurs. Inspection procedures are outlined based upon this knowledge and provide a system for rating conditions, which outlines the requirements for maintenance or repairs. Specific guidelines for other types of structural members are generally not available.

Traditionally, many techniques have been used for the inspection of wood structures. Obviously, a visual assessment is essential, but such methods as sounding, drilling, and coring can provide helpful, though somewhat limited, information (ASCE 1982).

In general, the inspector must determine the species, grade, and condition of the lumber used in the structure. Depending on the experience of the inspector, the determination of species may require the expertibe of a wood technologist. A licensed lumber grader may be desired to officially classify the material. A professional pathologist may be required to determine the extent of various types of deterioration. The identification of decay can be especially important because small amounts of decay can cause a significant reduction in strength.

More sophisticated nondestructive techniques, such as techniques that utilize stress wave technology, acoustic emissions, and ultrasonics, show promise for establishing the properties and Condition of structures in place. The measurement of parameters such as dynamic modulus of elasticity, energy storage and loss, stress wave velocity, and stress wave attenuation can provide definitive information on in-place properties and condition (Pellerin 1964, Vogt 1985, Anthony and Stewart 1988, Ross and Pellerin 1988, Groom and Polensek 1987, Hoyle and Pellerin 1978, Ned 1985, Hoyle and Rutherford 1987.)

The inspection process will most likely never be simplified to the point where a single device or technique can be used. To assess structural conditions, the inspector will always be required to synthesize the results of visual inspection, nondestructive test methods, and possibly load tests. The inspection process is a very important step in assessing an existing wood structure because the quality of any subsequent structural analysis depends on the accuracy of the information obtained.

---

## Evaluation

Structural evaluation is as important as inspection of a woad structure. This phase in condition assessment determines the capacity of individual members and connections, which leads to an overall definition of structural capacity.

Ideally, one would like to assume that the in situ properties of each member are accurately known from the inspection process and that the overall structure as well as individual components and connections can be precisely analyzed. Unfortunately, most evaluations are oversimplified because of inaccuracy in measuring in situ properties and lack of sophisticated techniques for analyzing connections and the building as a whole.

Current evaluation methods typically rely on only a determination of the species and grade of load-carrying members and components. In-place strength and stiffness properties are then based upon published allowable stresses (Jedrzejewski 1986). The evaluator has little guidance for evaluating members with various degrees of decay or insect attack; thus, the conservative approach is to assume that the members possess no residual strength.

Once an allowable design stress is established, the National Design Specifications (NDS) (NFPA 1986) provides guidance in structural analysis methods for timber structures. A load duration factor may need to be applied to the allowable stress. If the load history of the structure suggests previous high loading for a long period, a factor on the order of 0.90 may be applicable.

Structural analysis is a very important part of the evaluation process and is used to determine (1) the types and magnitudes of forces that are applied to individual components, members, and connections, and (2) the stresses and deformations produced in various elements by applied forces. To perform the analysis, the structure must be modeled in a way that realistically reflects the response of the entire assembly to the applied loads.

## Research Needs and Opportunities

Nondestructive inspection techniques, such as sonic stress waves and acoustic emissions, offer great potential as means of determining in situ material properties and the levels of decay in the members of wood structures. However, discontinuity in structural members, such as splits, checks, and mechanical fasteners, may affect in-place inspection capability. Also, the extent to which nondestructive devices are sensitive to the detection and quantification of incipient levels of decay needs further investigation.

Modal annlysis techniques have been used for determining the stiffness and strength of wood utility poles in place (Murphy and others 1987). These techniques monitor the frequency content of the pole and operate on the principle that stronger and stiffer poles vibrate at higher frequencies than do poles degraded by wood decay. Frequency content can be related to pole condition and hence to expected remaining life. Additional research is needed in this area to examine the vibrational characteristics (energy storage and dissipation) of the wood member in regard to its strength while accounting for the presence of knots, splits, grain deviations, decay, and other defects.

Analytical methods have been developed for various wood building components, such as walls, roofs, and floors, but no comprehensive model exists for the annlysis of a complete building (Polensek 1976, Vanderbilt and others 1974, Tuomi and McCutcheon 1978). The analysis of wood structures is complicated by not only the complex interaction between the separate components but also the interaction between individual framing members, sheathing, and connecting fasteners used to construct the components.

Research efforts also need to be directed towards a better understanding of the factors that affect the in-place properties used as input to structural analysis. These factors include the effects of duration of load on wood members, of cyclic temperature and humidity on wood properties, of decay on lumber strength and stiffness, of aging, and of fire and wood-preservation treatments.

In 1976, Madsen and Barrett determined that the effect of duration of load may be a function of material strength, with smaller effects for low-strength material. More recently, Gerhards (1988) studied the effects of duration of load on several grades of Douglas-fir lumber. No significant difference was found between grades.

Gerhards (1985) also determined the residual lifetime of beams (time remaining under load until failure) as part of a study to determine the time-dependent deformation (creep) of nominal 2- by 4-in. (5.08- by 10.16-an) beams. Using this methodology, Gerhards suggested that inspection of beams in existing structures for excessive deflection and levels of distress might indicate the probability of a beam surviving a set level of load for a desired period. This proposition may have more theoretical than real value because the necessary load history of a given member in a unmonitored structure would be difficult, if not impossible, to obtain. Also, the level of damage accumulated in a member is probably very small throughout most of the member's lifetime and only rises to measurable levels just before failure.

The effects of cyclic humidity and varying moisture contents on full-size members and on long-term deflection needs further investigation. Designers currently use rules of thumb to prevent excessive deformations, but they have no method to account for environmental changes.

No quantitative information is available on the strength loss caused by fungal decay for in-service wood structures. Most evaluations generally assume that members affected by decay or insect attack have no residual strength. Laborntory studies have shown that for brown-rotted softwoods, a 5 to 10-percent weight loss corresponds to a 20- to 80-percent strength property loss (Wilcox 1978). The determination of strength reduction before detectable weight loss requires quantification. The dynamic characteristics of wood members are also affected by biodeterioration. The ability of timber fender piles (used in dock structures) to dissipate the energy of impact is greatly reduced by the presence of decay (Lee 1982). Methods are needed to detect incipient levels of decay before significant strength, stiffness, and energy-absorption characteristics are lost. Because decay can be localized, determining which parts of a structure can tolerate some degree of property loss is important (DeGroot 1980).

Most evaluations of in situ wood structures assume that the strength and stiffness of wood members are unaffected by age. Although some studies have indicated that age has little effect on wood properties (Jessome 1965, Bendtsen 1974), work by Attar-Hassan (1976) showed that the strength and stiffness of white pine in service for 141 years were dependent on age. The Canadians have proposed an age modification factor of 0.90 for deflection and strength calculations based upon limited short-term test data on aged wood members (Suter 1982). This area needs further investigation.

## Concluding Remarks

The determination of in-place condition is an important aspect of rood structure evaluation. Although many techniques have been used to estimate existing conditions, additional work is needed to more accurately and consistently determine in-place strength as affected by cyclic humidity, load duration, biodeterioration, and age of structural members. Coupling this knowledge with refined structural analysis techniques will allow engineers to more accurately and confidently determine the actual condition and performance of wood structures.

## REFERENCES


ASCE (1982): Evaluation, maintenance and upgrading of wood structures: A guide and commentary. Alan Freas, Chairman, American Society of Civil Engineers.

Anthony, R.W.; Stewart, A.H. (1988): Applications of nondestructive evaluation to wood structures. Vol. 1, Proceedings of the 1988 International Conference on Timber Engineering, Seattle, WA, September 19–22, pp. 701–707.

Attar-Hassan, G. (1976): Aging effect on eastern white pine. Association for Preservation Technology Bulletin 8(3), 64–73.

Bendtsen, B.A. (1974): Bending strength and stiffness of bridge piles after 85 years in the Milwaukee river. Research Note FPL-0229. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI.

DeGroot, R.C. (1980): Quantifying potential for wood decay, How the environment affects lumber design: assessment and recommendations. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI.

Gerhards, C.C. (1985): Time-dependent bending deflections of Douglas-fir 2 by 4's. Forest Products Journal 35(4), 18–26.

Gerhards, C.C. (1988): Effect of grade on load duration of Douglas Fir lumber in bending. Wood and Fiber Science 20(1), 146–161.

Groom, L.; Polensek, A. (1987): Nondestructive prediction of load-deflection relations for lumber. Wood and Fiber Science 19(3), 298–312.

Hoyle, R.J.; Pellerin, R.F. (1978): Stress wave inspection of a wood structure. Proceedings of the Fourth Nondestructive Testing of Wood Symposium, Washington State University, Pullman, WA.

Hoyle, R.J.; Rutherford, P.S. (1987): Stress wave inspection of bridge timbers and decking. Final Report, Research Project Y-3400, Task 10, Washington State Department of Transportation, July.

Jedrzejewski, M.J. (1986): A method for determining the allowable strength of in-place wood structural members. Building Performance: Function, Preservation, and Rehabilitation, ASTM STP 901, G. Davis, Ed., American Society for Testing and Materials, Philadelphia, pp. 136–151.

Jessome, A.P. (1965): Strength tests on specimens from wood trusses in service for 97 years. Report of the Forest Products Laboratory, Department of Forestry, Ottawa, ON, Canada.

Lee, T.L. (1982): Biological and physical deterioration of timber fender systems. Structural Use of Wood in Adverse Environments, R.W. Meyer and R.M. Kellog, Eds., Van Nostrand Reinhold.

Madsen, B.; Barrett, J.D. (1976): Time strength relationship for lumber. Struc. Res. Ser. Rep. No. 13, The University of British Columbia, Dep. of Civ. Eng.

Murphy, M.W.; Franklin, D.E.; Palylyk, R.A. (1987): A nondestructive testing technique for wood poles. B.C. Hydro Research and Developement, Surrey, BC.

NFEC (1985): Inspection of wood beams and trusses. Naval Facilities Engineering Command NAVFAC MO-111.1. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI.

NFPA (1986): National Design Specifications. National Forest Products Association, Washington, DC.

Neal, D.W. (1985): Establishment of elastic properties for inplace timber structures. Proceedings of the Fifth Nondestructive Testing of Wood Symposium, Washington State University, September, Pullman, WA.

Pellerin, R.F. (1964): A vibrational approach to nondestructive testing of structural lumber. Forest Products Journal 14(9), September.

Polensek, A. (1976): Finite element analysis of wood stud walls. Journal of the Structural Division, ASCE, 102(ST7).

Ross, R.J.; Pellerin, R.F. (1988): NDE of wood-based composites with longitudinal stress wave. Forest Products Journal 38(5), 39–45.

Suter, G.T. (1982): Evaluation of in situ strength of aged timber beams. Structural Use of Wood in Adverse Environments, R.W. Meyer and R.M. Kellog, Eds., Van Nostrand Reinhold.

Tuomi, R.L.; McCutcheon, W.J. (1978): Racking strength of light frame nailed walls. Journal of the Structural Division, ASCE, 104(ST7).

Vanderbilt, M.D.; Goodman, J.R.; Criswell, M.E. (1974): Service and overload behavior of wood joist floor systems. Journal of the Structural Division, ASCE, 101(ST1).

Vogt, J.J. (1985): Evaluation of the tensile and flexural properties and internal bond of medium density fiberboard using stress wave speed and attenuation. MS thesis, Washington State University, Pullman, WA.

Wilcox, W.W. (1978): Review of literature on the effects of early stages of decay on wood strength. Wood and Fiber 9(4), 252–257.


In: Proceedings, 2d Pacific timber engineering conference; 1989 August 28–31; Auckland, New Zealand. Auckland: Centre for Continuing Education University of Auckland; 1989: 181–183.Vol. 2.