



# Structural Condition Assessment of In-Service Wood

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Wood is used extensively for both interior and exterior applications in the construction of a variety of structures (residential, agricultural, commercial, government, religious). The deterioration of an in-service wood member may result from a variety of causes during the life of a structure. It is important, therefore, to periodically assess the condition of wood used in structures to determine the extent of deterioration so that degraded members may be replaced or repaired to avoid structural failure. An assessment is especially critical for building officials in municipalities affected by catastrophic events, such as hurricanes Katrina and Rita (Fig. 1).

## What is a Structural Condition Assessment?

Assessment of the condition of wood in a building can be conducted for a variety of reasons. Code compliance, historic preservation, or alternative uses of a structure are

frequently cited reasons for conducting a condition assessment. A structural condition assessment consists of the following: 1) a systematic collection and analysis of data pertaining to the physical and mechanical properties of materials in use; 2) evaluation of the data collected; and 3) providing recommendations, based on evaluation of the collected data, regarding portions of an existing structure that affect its current or proposed use. Such an assessment relies upon an in-depth inspection of the wood members in the structure. A wide variety of techniques are used to assess the condition of wood in structures. Visual, resistance drilling (probing), and stress wave or ultrasound-based techniques are all used either individually or in combination to inspect in-service wood.

## Visual Inspection

Visual inspection is the simplest method for locating

deterioration in timber structures. The inspector observes the structure for signs of actual or potential deterioration, noting areas for further investigation. 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. During an investigation, the following signs of deterioration should be carefully investigated.

Fruiting bodies provide positive indication of fungal attack but do not indicate the amount or extent of decay. Some fungi produce fruiting bodies after small amounts of decay have occurred; whereas others develop only after decay is extensive. When fruiting bodies are present, they almost certainly indicate serious decay problems.

Sunken faces or localized surface depressions can indicate underlying decay. Decay voids or pockets may develop close to the surface of the member, leaving a thin, depressed layer of intact or partially intact wood at the surface.

Staining or discoloration indicates that members have been subjected to water and potentially high moisture contents suitable for decay. Rust stains from connection hardware are also a good indication of wetting.

Insect activity is visually characterized by holes, frass, and powder posting. The presence of insect activity may also indicate the presence of decay.

Plant or moss growth in splits, cracks, or soil accumulations on the structure indicates that adjacent wood has been at a relatively high moisture content suitable for decay for a sustained period of time.

### Resistance Drilling

Resistance drilling, an automated form of mechanical probing, is being used increasingly in the field to characterize wood properties and to detect abnormal physical conditions in structural timbers. A commonly used tool (the Resistograph) is a mechanical drill system that measures the relative resistance (drilling torque) of the material as a rotating drill bit is driven into the wood at a constant speed. It produces a chart showing the relative resistance profile for each drill path. Because it can reveal the relative density change along the drill path, it is typically used to diagnose the internal condition of structural timbers.

The drill resistance  $R_D$  (Nm s/rad) is defined as:

$$R_D = \frac{T}{\omega}$$

where  $T$  = drilling torque (Nm);  $\omega$  = angular speed (rad/s).

A Resistograph tool consists of a power drill unit, a small-diameter drill bit, a paper chart recorder, and an electronic device that can be connected to the serial interface input of any standard PC. The diameter of the drill bit is typically very small, from 2 to 5 mm, so that any weakening effect of the drill hole on the wood cross section is negligible.

Resistance drilling is generally used to confirm suspected areas of decay identified by visual inspection or a stress wave transmission test. When decay is detected,



**Figure 1.** — *Flooding in the aftermath of Hurricane Katrina, which caused severe damage to structures in New Orleans.*



**Figure 2.** — *Field inspection using a resistance drilling device to locate areas of deterioration.*

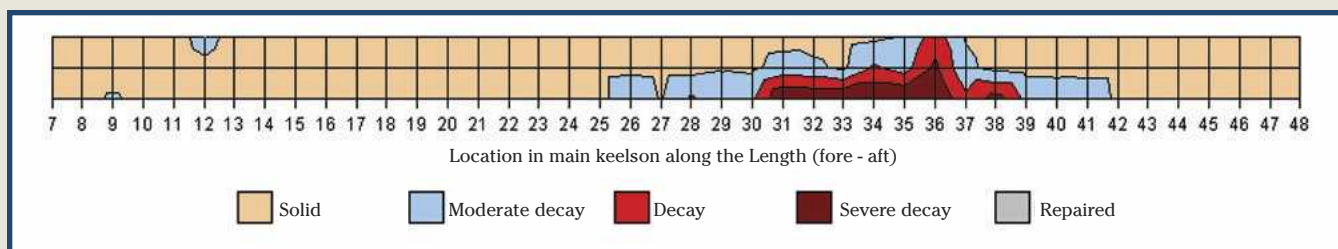
drilling can help inspectors to further define the decay's extent and limits (Fig. 2).

### Stress Wave or Ultrasound Techniques

Stress wave transmission techniques are used in decay detection in a variety of wood structures. The concept of detecting decay using this method is that stress wave propagation is sensitive to the presence of degradation in wood. In general terms, a stress wave travels faster through sound and high quality wood than it does through wood that is deteriorated or of low quality. The time-of-flight (or transmission time) of the stress wave is typically used as a predictor of the physical conditions inside the wood. By measuring the time-of-flight of a stress wave through a wood member perpendicular to the grain, the internal condition of the member can be determined.

The use of stress wave velocity to detect wood decay in timber bridges and other structures is limited only by access

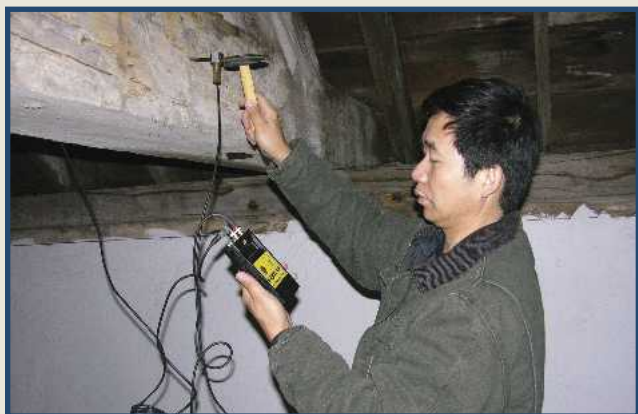




**Figure 3. — Results obtained from a typical stress wave scan of an in-service wood member.**

to the structural members under consideration. It is especially useful for large timbers or glulam timbers  $\geq 89$  mm (3.5 in.) for which traditional hammer sounding is not effective. Access to both sides of the member is required. Because timber is an organic substance, material properties and strength vary in accordance with the direction timber is impacted relative to the cell structure orientation. This impact creates a stress wave in the material. Impacting the end grain of a beam or post will cause a primarily longitudinal shock wave along the length of the cell structure in the timber. Impacting the side or top of the beam will cause a wave across, or transverse to, the timber cells. The timber cells are arranged in rings around the center of the tree. The velocity at which a stress wave propagates in wood (as well as other physical and mechanical properties) is a function of the angle at which the fibers of wood are aligned. For most structural members, fibers of the wood align more or less with the longitudinal axis of the member.

Stress wave transmission times on a per-length basis for various wood species have been given in the *Wood and Timber Condition Assessment Manual*. Stress wave transmission times are shortest along the grain (with the fiber) and longest across the grain (perpendicular to the fiber). For Douglas-fir and southern pine, stress wave transmission time parallel to the fiber is approximately 200  $\mu\text{s}/\text{m}$  (60  $\mu\text{s}/\text{ft}$ ). Stress wave transmission time perpendicular to the fiber ranges from 850 to 1000  $\mu\text{s}/\text{m}$  (259 to 305  $\mu\text{s}/\text{ft}$ ). When a stress wave propagation method is used to detect localized decay in timbers, measurements should be made in transverse paths (perpendicular to the grain). Parallel-to-grain travel paths (longitudinal direction) can bypass regions of decay and therefore are not effective. Figures 3 and 4 show the testing results and the use of stress wave/ultrasound testing equipment to detect wood decay.



**Figure 4. — Field inspection using stress wave/ultrasound equipment.**

### Short Training Courses for Practicing Engineers and Inspection Professionals

Since 1995, the USDA Forest Products Laboratory (FPL) has worked cooperatively with the American Society of Civil Engineers (ASCE) and others (University of Minnesota Duluth, Washington State University) to develop and teach a short course that focuses on assessing the condition of existing structures. This course is an extensive overview of material evaluation practices and procedures used for assessing structural conditions, and covers as many aspects of evaluating in-service wood, metals, and concrete as possible. The state-of-the-art information on visual inspections, destructive and nondestructive testing (NDT), and the hands-on experience provided in this seminar are essential for those involved in evaluating the structural integrity of existing structures. ASCE has provided overall coordination of our efforts and marketing support (Fig. 5). The resulting course has been presented over 80 times throughout North America with over 1,000 attendees.

### Wood and Timber Condition Assessment Manual

The Forest Products Society (FPS), in cooperation with the American Forest & Paper Association, published the *Wood and Timber Condition Assessment Manual* in 2004 (Fig. 6). The objective of the *Manual* is to provide a comprehensive guide to the state of the art in inspection methods. It contains chapters on visual inspection methods, probing techniques, and stress wave/ultrasound tools. Each chapter contains numerous color photographs taken from actual inspections. Information such as equipment vendor addresses and equipment operating procedures is contained in each chapter. An entire chapter is dedicated to inspection and evaluation of fire-damaged wood. A sample inspection report and summary reports from several inspections are also included.

### Web-Based Community of Practice for Inspection of Historic Structures

Current communications regarding inspection are mostly via technical and scientific presentations, publications, equipment brochures, and a limited number of short courses. We found that these approaches are limited by time and resources. Consequently, with funding from the USDA Forest Service Wood Education and Resource Center (WERC) and Northern Initiatives (Marquette, MI), we developed a web-based community of practice specifically



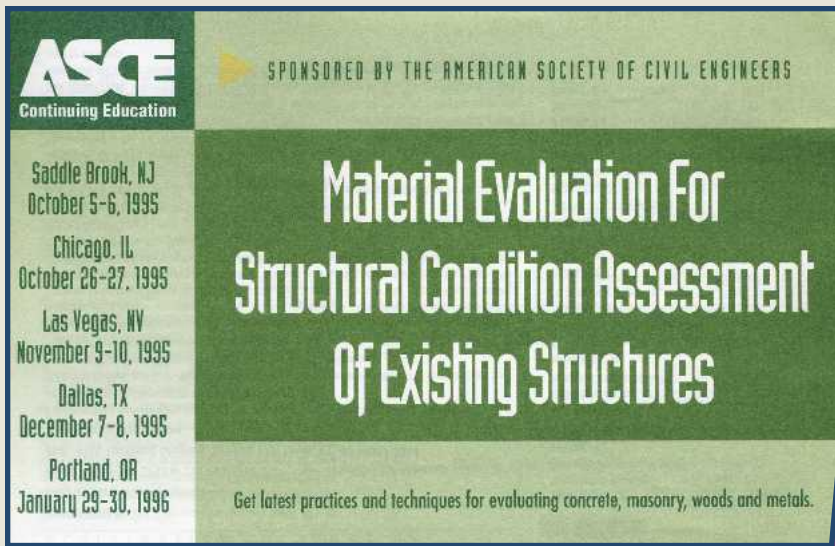


Figure 5. — Marketing brochures for American Society of Civil Engineers short courses on structural condition assessment.

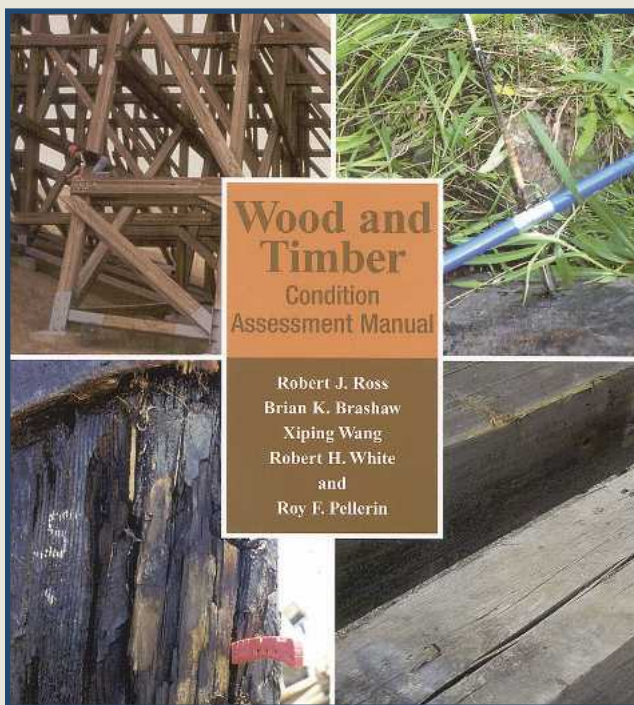
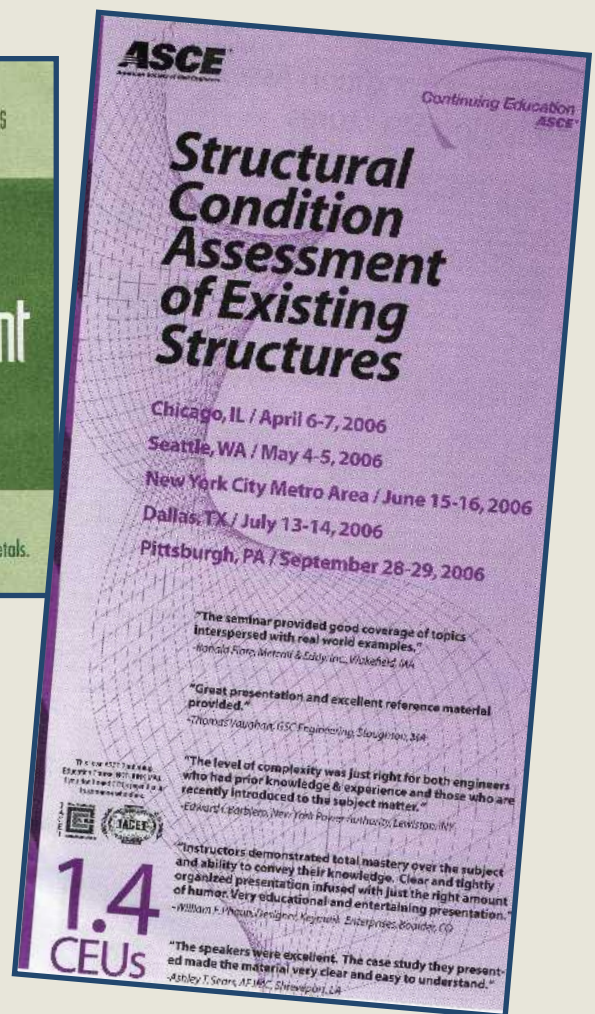


Figure 6. — The Wood and Timber Condition Assessment Manual published by the Forest Products Society.

focused on inspections of historic wood structures. Hosted by the Northern Tier High Technology Corridor of Bemidji State University, this public community will have open membership and will allow individuals to share and transfer information related to inspection of historic wood structures when it becomes fully operational.<sup>1</sup>

Within this web community, inspectors, engineers, and other interested individuals will find valuable information to help them plan and conduct inspections of historic wood structures. We have developed a section outlining inspection equipment information and demonstration videos, along with vendor links. An extensive library of technical publications, books, and presentations has been compiled and a moderat-



ed discussion board is available. Interfaces have also been created for conducting online seminars and short courses. Figure 7 shows the home page of the web community.

As an education component, web-based seminars (webinars) will be presented bimonthly and will feature a detailed inspection of a historic wood structure. The first webinar, held in May 2006, featured the inspections and

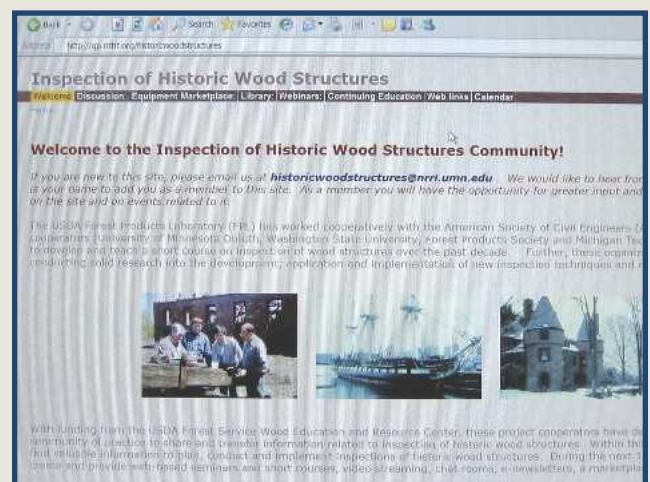
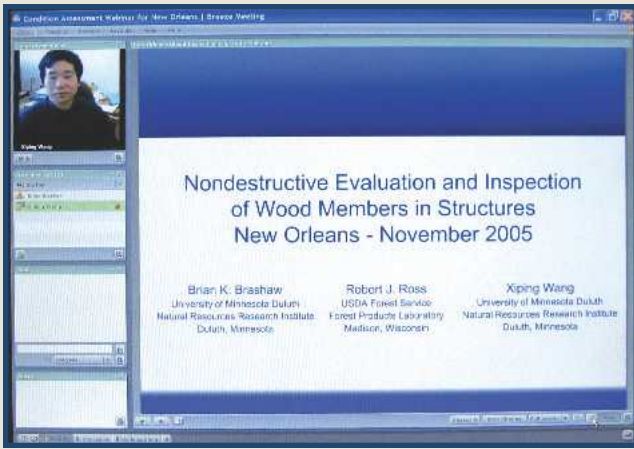


Figure 7. — Home page for web-based community of practice for inspection of historic wood structures.

<sup>1</sup> Northern Tier High Technology Corridor. 2006. Bemidji State University, Bemidji, MN. www.ntht.org.





**Figure 8. — Web meeting room used to conduct online presentation for the City of New Orleans Department of Safety and Permits.**



**Figure 9. — Testing a timber bridge using vibration techniques.**

renovation of Grey Towers, the Pennsylvania home of Gifford Pinchot, the first Chief of the USDA Forest Service and Governor of Pennsylvania (photo shown on cover of this issue). Future webinars will detail inspections, equipment, and case studies of a historic log cabin on the edge of the Boundary Waters Canoe Area Wilderness; the Quincy Mine Site in Hancock, Michigan; the Wapama wood schooner in San Francisco, California; and others. These webinars are conducted using Macromedia Breeze, a web communication system that provides high-impact online meetings, training, and presentations that everyone can access instantly, through any web browser.

The web community and its software tools also provide the opportunity to host meetings and presentations to address specific needs and requests. For example, as a result of the damage caused by Hurricane Katrina and the resulting flood in New Orleans, our project team was asked to provide a webinar for the City of New Orleans, Department of Safety and Permits. Team members provided a targeted online presentation for 12 inspectors in New Orleans in November 2005. The presentation focused on specific condition assessment recommendations for inspections, equipment, and evaluation of flood-damaged structures. Figure 8 shows an image of a Breeze web-based meeting room used for conducting online training and

webinars. The video portion shows a presenter who is being taped using a web-camera in his office (see the upper left corner of the image). A powerpoint presentation is utilized to conduct the training, and instant chat features are available to ask real-time questions. The audio portion can be conducted using traditional telephone or streaming audio over the Internet.

### Recent Research Developments

The methods currently used to assess the condition of wood in service are based on techniques that evaluate individual members or small areas within a wood member. Recently, an extensive series of experiments was conducted to examine the feasibility of testing, in-place, entire structural wood systems. The results to date have shown that it may be possible to assess the in-place stiffness of some types of structural systems (e.g., short-span timber bridges and floor systems within buildings) using vibration techniques (Fig. 9).

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