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Condition Assessment of Roof Trusses of Quincy Mine Blacksmith Shop in Keweenaw National Historical Park

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Abstract

Condition assessment is an important first step in the restoration of any historic structure. Immunodiagnosis of wood decay fungi, nondestructive evaluation (NDE) stress wave mapping, and compression perpendicular to grain were used to evaluate white pine roof truss timbers from the Blacksmith Shop of the Quincy Mining Company in Keweenaw National Historical Park. Immunodiagnosis indicated that areas in the timber had been exposed to decay fungi. Stress wave NDE mapping located voids in the timbers tested. Compression perpendicular to the grain correlated with NDE findings.

Keywords: Immunodiagnostic, stress wave NDE, compression testing

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Introduction

The Quincy Mining Company was part of the copper mining boom on Michigan's Keweenaw Peninsula resulting from the discovery of large masses of native copper in the mid-1840s. By 1930, Quincy was the deepest mine in the Western Hemisphere, going down as far as 9,200 ft (2,804 m) below the surface. By the time Quincy closed in 1945, it had produced 848 million pounds (384,646 metric tons) of copper. The Mine Hoist and Number Two Shafthouse have been preserved by the Quincy Mine Hoist Association and are open for public tours. The preservation of this 100-year-old mine site includes the Quincy Mining Company Blacksmith and Machine shops, which are part of the Keweenaw National Historical Park. Both structures are slated for renovation in conjunction with the National Park Service.

Condition assessment of the heavy timber roof trusses of the Blacksmith Shop was an important first step in the restoration of this structure. In addition to visual inspection, the condition of representative timbers exposed to the elements since the removal of the roof was assessed by compression strength perpendicular to grain, stress wave transmission, and immunodiagnosis of wood decay fungi. Recognition of early decay is important for the inspection of wood in service.

Early decay is difficult to recognize because it is visually subtle and often occurs on the interior of a timber or below ground. Visually, macroscopic changes in color or texture provide presumptive evidence of early decay; only the physical presence of fungi is considered definitive. Microscopic examination that reveals hyphae with clamp connections provides definitive evidence of early decay (Zabel and Morrell 1992). Nonvisual 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.

Wood decay caused by brown-rot decay fungi has typically been described as having four stages: incipient, early, intermediate, and advanced. Incipient decay occurs when decay fungi initiate colonization and release enzymes; there is no visible evidence of damage. During early decay, slight changes in color or texture occur, but decay is not obvious. Intermediate decay includes obvious changes in color and texture, although the wood structure still appears intact. Advanced decay is obvious because the wood structure is affected; the wood turns brown and crumbly with a cubical appearance.

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. Because hemicelluloses are rapidly removed by brown-rot fungi during incipient decay, the immunodiagnostic wood decay test was designed to target a hemicellulase enzyme, specifically endo-1,4-ß-xylanase (Clausen and Green 1996). Anti-xylanase antibodies detect minute quantities of xylanase, which indicates the presence of incipient decay. Work to maximum load, toughness, and impact bending are also reported to be sensitive mechanical methods for detecting early decay (Wilcox 1978), and stress wave mapping has been used successfully to locate deteriorated regions in timbers (Ross and others 1997b). The relationship between stress wave transmission and compressive strength in biodeteriorated wood has been demonstrated in Southern Pine (Ross and others 1997a).

The objective of this study was to compare mechanical (compression perpendicular to grain), acoustic (stress wave analysis), and laboratory fungal decay (immunodiagnostic) methods for detecting decay in samples from two eastern white pine timber trusses of the Quincy Mine Blacksmith Shop.

Materials and Methods

Sampling

Two eastern white pine (*Pinus strobus* var. *strobus* L.) specimens measuring 12 in. by 12 in. by 8 ft (30.5 cm by 30.5 cm by 2.4 m) and 7 in. by 9 in. by 10 ft (17.8 cm by 22.9 cm by 3 m) were removed from the site for testing. The 12-in. (30.5-cm) square beam was solid on one end, with a crack near the center of the span. Signs of decay were visible; the opposite end of the beam was hollow. The 7- by 9-in. (17.8- by 22.9-cm) beam was solid on both ends. Initially, decay mapping was conducted on each beam using stress wave nondestructive evaluation (NDE). Both beams were sawn on all four sides to remove up to ¼ in. (0.64 cm) of the outer layer of weathered wood. Weathered wood may harbor contaminants that could result in false positive reactions in the immunodiagnostic wood decay test. Cross sections of each beam were cut at 12-in. (30.5-cm) intervals to test for compression strength perpendicular to grain.

Stress Wave NDE

Decay mapping consisted of recording a series of stress wave measurements taken at 6-in. (15-cm) intervals over the length of the span and at multiple sites on two faces of the beam. Readings on each face were taken at approximately 2-in. (5-cm) intervals to produce a grid of readings, as indicated in Figure 1a. Readings exceeding 600 µs were designated as representative of decay.

Immunodiagnosis

Samples were taken at 6-in. (152-cm) intervals along each specimen by drilling to the center of the beam with a 0.25-in. (0.64-cm) drill bit and collecting sawdust for testing. Fifty milligrams of each sawdust sample was extracted in 2 mL water plus 0.01% Triton X–100 (Sigma, St. Louis, MO) for 2 h at 77°F (25°C) with agitation. Following extraction, each fluid was tested with the immunodiagnostic wood decay test (Clausen 1994, Clausen and Green 1997), with results recorded as positive (**+**) or negative (**–**) for decay on the sampling diagram (Fig. 1).

Compression Perpendicular to Grain (ASTM D143)

Compression perpendicular-to-grain tests were conducted on samples taken at 12-in. (30.5-cm) intervals and tested in accordance with ASTM D143–94 (ASTM 1998). Sampling sites and results are indicated on the beam diagram (Fig. 1a).

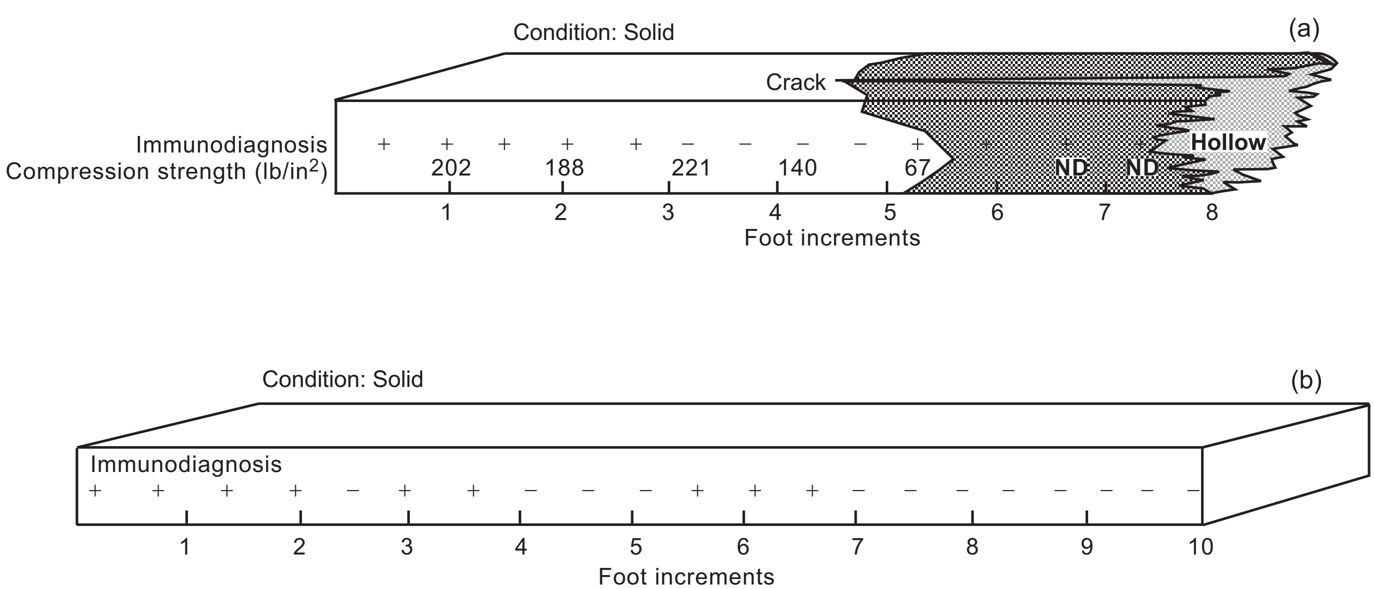

Figure 1—Results of tests on eastern white pine roof trusses: (a) 12-in. by 12-in. by 8-ft (30.5-cm by 30.5-cm by 2.4-m) truss; shaded area indicates deterioration detected by stress wave mapping; ND designates areas not sampled for compression strength because of advanced visible decay; (b) results of immunodiagnosis of 7 in. by 9-in. by 10-ft (17.8-cm by 22.9-cm by 3-m) roof truss; no deterioration or voids were detected by NDE mapping.

Results and Discussion

Eastern white pine roof trusses from the Blacksmith Shop of the Quincy Mining Company were evaluated for deterioration as part of the restoration of this historic structure. The 12-in. by 12-in. by 8-ft (30.5-cm by 30.5-cm by 2.4-m) timber specimen was solid on one end, with a crack forming near the center of the span; signs of decay were visible along the span, and the other end of the specimen was hollowed by decay. Assessing this timber permitted evaluation of each test method for sensitivity to detect incipient decay along the length of the span as decay visibly progressed. Positive reactions to the immunodiagnostic wood decay tests were observed in samples up to 2.5 ft (76 cm) from both ends of the specimen. In the early stages of decay, rapid strength losses associated with brown-rot are due to the damaging effect of extracellular enzymes that diffuse away from the hyphae creating damage beyond the colonized cells, which occurs during incipient decay. Immunodiagnostic tests specifically detect the presence of brown-rot fungal enzymes during incipient decay, prior to strength or weight loss, as reported in this study (Clausen and others 1991, Clausen and Ferge 1995, Clausen 1997).

Stress wave readings on the 12-in. by 12-in. by 8-ft (30.5-cm by 30.5-cm by 2.4-m) timber specimen indicated decay beginning near the deep crack in the center of the span and progressing to the hollowed end of the specimen. Stress wave NDE measures the speed (transmission time) at which stress waves travel through a wood member (Ross and others 1994, Ross and Pellerin 1994). NDE locates voids in wood caused by insects, decay fungi, or other physical defects. It does not specifically distinguish between active decay, voids, ring shakes, or other defects (Wilcox 1978). In defect-free timbers, research has shown that stress wave signals are slowed significantly in areas containing deterioration compared to sound wood, and this method has been used successfully to locate deteriorated regions in timbers (Ross and others 1997b). In the 12-in. by 12-in. (30.5-cm by 30.5-cm) specimen, decay was mapped and differentiated from sound wood by NDE (Fig. 1a).

Of the many strength properties used to measure the effects of decay on wood, work to maximum load, toughness, and impact bending are reported to be the most sensitive methods to detect early decay (Wilcox 1978). For the 12-in. by 12-in. by 8-ft (30.5-cm by 30.5-cm by 2.4-m) timber, tests on compression perpendicular-to-grain indicated a decrease in compressive strength in the same location as did NDE. The relationship between stress wave transmission and compressive strength in biodeteriorated wood was previously demonstrated in southern pine (Ross and others 1997a). NDE and compressive strength compared favorably as methods to predict the residual strength of a specimen.

The 7 in. by 9-in. by 10-ft (17.8-cm by 22.9-cm by 3-m) specimen was solid throughout, but it showed three distinct areas of positive reaction to the immunodiagnostic wood decay test along the length of the span, which is indicative of incipient decay (Fig. 1b). Except for a single reading at 0 in., no stress wave reading exceeded 600 μs for this timber. Deteriorated pine yields readings in excess of 600 μs; therefore, compression tests were not conducted.

Conclusions

In this study, the immunodiagnostic wood decay test diagnosed areas of incipient fungal colonization (that is, prior to strength loss) in each test specimen. Compressive strength and stress wave NDE mapping showed areas of early decay; these results were comparable. NDE was a more exacting method for pinpointing the boundary of a deteriorated region, which is desirable when salvaging specimens from an historic structure. These results represent a small pilot study. Future studies are needed to evaluate a large sampling of specimens.

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