Timber Assessment at Quincy Mine Blacksmith Shop, Keweenaw National Historical Park

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Century-old structural members manufactured from old-growth timber have been nondestructively evaluated for deterioration through stress-wave scanning.

The Quincy Mining Company was part of the copper mining boom on Michigan's Keweenaw Peninsula that resulted 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 lb. (384,646 metric tons) of copper. The mine hoist and number two shaft house have been preserved by the Quincy Mine Hoist Association and are open for public tours. The preservation of this century-year-old mine site includes the Quincy Mining Company blacksmith and machine shops (Fig. l), which are part of the Keweenaw National Historical Park. Both structures are slated for renovation in conjunction with the National Park Service. Of great interest in this restoration project is the preservation and use of the remaining roof trusses and floor joists. The eastern-white-pine roof truss timbers have been exposed to weather for several years. The floor joists had been covered by a wood mezzanine that did not provide adequate protection from rain and snowmelt. These roof trusses and floor' joists, manufactured from old-growth timber, are a tremendous resource that should be used appropriately in the renovation of the blacksmith and machine shops.

Condition assessment of the heavy timbers from the blacksmith shop was an important first step in the restoration of this structure. As part of the renovation plan on the Quincy site, the Keweenaw National Historical Park asked the Forest Products Laboratory (FPL) of the USDA Forest Service in Madison, Wisconsin, to assess the quality and structural integrity of these timbers. The FPL, in cooperation with the School of Forestry and Wood Products at Michigan Technological University, formed a team of engineers and scientists to work on this project.

An early on-site assessment revealed that a substantial number of the timbers contained solid wood in spite of visually observed deterioration of parts of the timbers. Carol Clausen and others (1) also conducted a small pilot study on two eastern-white-pine specimens obtained from the blacksmith shop. Immunodiagnosis of wood-decay fungi, stress-wave mapping, and compression-perpendicular-to-grain tests were used to assess the condition of the specimens. The immunodiagnostic wood-decay test diagnosed areas of incipient fungal colonization (meaning no strength loss had occurred yet) in each test specimen. The study also reported that stress-wave nondestructive evaluation (NDE) mapping and compression tests yielded comparable results. It concluded that NDE was a more exact method for

Fig. 1 Historical photograph of Quincy Mine blacksmith and machine shops at Hancock, Michigan. undated. Used by permission Copyright Michigan Technological University Archives and Copper Country Historical Collections. Photo donated by Quincy Mine Hoist Association, ACC 460/8-12-93

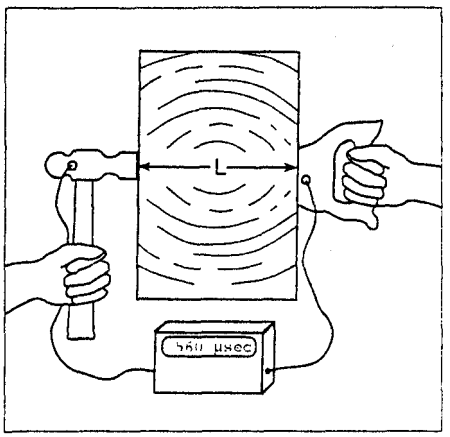

Fig. 2. Stress wave transmission test in a rectangular wood member. Photograph by the authors.

pinpointing the boundary of a deteriorated region, which is desirable when salvaging timbers from a historic structure.

The intent of this study was to follow up on the promising preliminary results of Clausen and others and to further nondestructively evaluate a large sampling of white-pine timbers in the laboratory. The specific objectives were (a) to detect the location and severity of deterioration in 12-by-12-in. (30-by-30-cm) white-pine timbers removed from the blacksmith shop through intensive scanning using a stress-wave transmission technique and (b) to determine how much of the original structural wood from these timbers potentially can be recovered and used in the reconstruction project.

Stress-Wave Transmission Techniques

Stress-wave transmission techniques frequently are used to inspect large timber structures. A wide range of structures has been evaluated with these techniques, including bridges, piers, sports stadiums, utility poles, cooling towers, large testing structures, and residences (2). The propagation of a stress wave in a wood member is basically a mechanical phenomenon. As an introduction to the technique, a schematic of the stress wave transmission concept for detecting deteriorated areas within a rectangular wood member is shown in Figure 2.

A stress wave is induced by striking the member with an impact device that is instrumented with an accelerometer that, in turn, emits a start signal to a timber. A second accelerometer, which is coupled to the member, then responds to the leading edge of the propagating stress wave and sends a stop signal to the timer. The elapsed time for the stress wave to propagate between the accelerometers is displayed on the timer.

The underlying premise of this technique is that the speed, hence the transmission time, at which a stress wave travels through a wood member is indicative of the member's condition. It has been shown that a stress wave travels at significantly slower speeds in deteriorated wood than in sound wood (3, 4, 5). Consequently, this technique has proven to be an effective method for locating deteriorated regions in timbers.

Stress-Wave Scanning

Fifteen 12-by-12-in. (30-by-30-cm) white-pine timbers removed from the Quincy Mine blacksmith shop in Keweenaw National Historical Park were transported to FPL on August 2,2001 (Fig. 3). These timbers were part of the original roof structures and had been exposed to weather for several years. The timber specimens ranged from 25.5 to 50 ft. (7.8 to 15.2 m) in length. Thirteen of them were about 50 ft. (15.2 m) long and originally were used as tension members in the roof trusses. Three of them were from 26 to 34 ft. (7.9 to 10.4 m) long and probably were used as pitched chord or web materials.

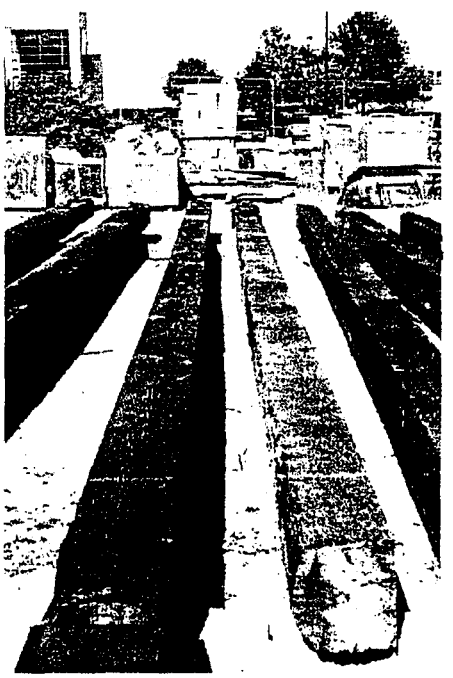

Fig 3 Fifteen 12-by-12-in (30-by-30-cm) white-pine timbers removed from the Quincy Mine blacksmith shop. Photograph by the authors

Decay was a primary concern in assessing the structural integrity and residual strength of the timbers, as advanced decay was apparent. Surface decay was found either on the surface of any part of the timber, or on the ends (Fig. 4). Other defects included splits, ring shake, notches, and mechanical damage.

Figure 5 shows a typical scanning diagram that we used to conduct stress-wave transmission tests. The timbers were supported on two beams. Each timber was stress-wave scanned perpendicular to grain along three lines on the side surfaces (A, B, and C). Since the ends of the timber usually were considered to be areas with a high risk of deterioration, stress-wave transmission tests were performed more intensively at the ends than at other parts of the timber. The intervals between two scanning points in the longitudinal direction changed from 6 in. (0.15 m) at the ends to 1, 2, and 4 ft. (0.3, 0.6, and 1.2 m) as the scanning position approached the middle of the timber.

A commercially available stress-wave timing unit was used to measure wave transmission time, perpendicular to grain, at the series of points described. Three stress-wave readings were taken at each scanning point, and the average wave transmission time for each point was used as an indicator of the soundness of wood in that area. Depending on how intensively a timber is being scanned, the stress-wave scanning process may take from thirty minutes to an hour to test one 12-by-12-in. timber that is 50 ft. in length.

Stress-Wave Mapping of Timbers

An effective way to illustrate the scan results of timbers is to map the whole length of the timber with the measured stress-wave transmission times. Figure 6

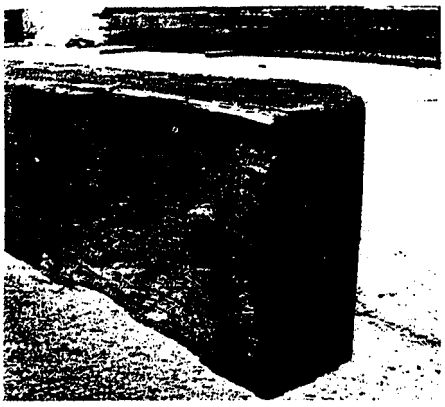

Fig. 4. Surface deterioration on White-pine timber. Photograph by the authors.

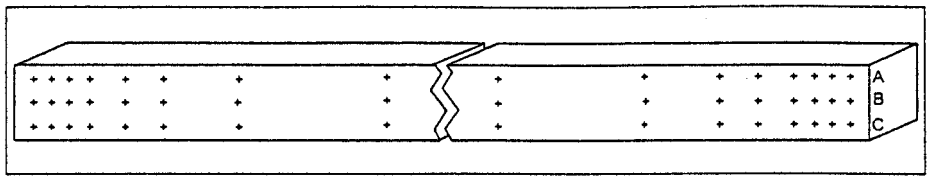

Fig. 5. Scanning diagram, indicating points where tests were conducted, for nondestructive evaluation of 12-by-12-in. (30-by-30-cm) white-pine timbers. Photograph by the authors.

shows typical stress-wave maps from stress-wave scanning of two timbers. The stress-wave transmission time, perpendicular to grain, was measured in microseconds (µs). Given the same width of 12 in. (30 cm) for all timbers, the stress wave data also can be deemed as values in a unit of microsecond per foot (µs/ft). The scan results for all 15 timbers can, therefore, be conveniently compared with the baseline data given in previous publications (1, 2, 6, 7, 8).

Stress-wave transmission times may vary from species to species, but they are mainly controlled by the soundness of wood. For most species, stress-wave transmission time perpendicular to grain ranges from 180 to 400 µs/ft (591 to 1,312 µs/m) for solid wood (6). This baseline range was used as an evaluation standard to assess scan results obtained from the fifteen 12-by-12-in. (30-by-30-cm) white-pine timbers.

The scan results indicated that these white-pine timbers were in various conditions, ranging from solid to fully deteriorated. As mentioned earlier, the deterioration was mainly caused by decay (surface and internal), splits, and mechanical damage. Stress-wave mapping of each timber can distinguish whether deterioration occurs in the external shell or the internal core, because stress-wave transmission times obtained from three scan lines (A, B, and C) are plotted on the same graph for each timber (see Fig. 6).

The amount of solid wood in each timber was determined by comparing scan results with the baseline data of stress-wave transmission times for solid wood. The approximate length of solid wood in each timber with potential structural use was also determined. A summary of the potential recovery of solid wood from all tested white-pine timbers is shown in Table 1.

From the scans and Table 1, it was found that a substantial amount of solid wood could be recovered from these timbers except for one short timber, FPL-12, which was almost fully deteriorated. For the rest of the timbers, the potential recovery rate could be as low as 16 to 17 percent due to severe deterioration (such as FPL-4 and FPL-8). It could also be as high as more than 90 percent (such as timber FPL-3 and FPL-10). Overall, an average of 61 percent of total materials (discounting FPL-12) potentially could be recovered from these white-pine timbers and used in the reconstruction phase of the project.

Conclusions

Fifteen 12-by-12-in. (30-by-30-cm) white-pine timbers removed from the Quincy Mine blacksmith shop in Keweenaw National Historical Park were nondestructively evaluated through

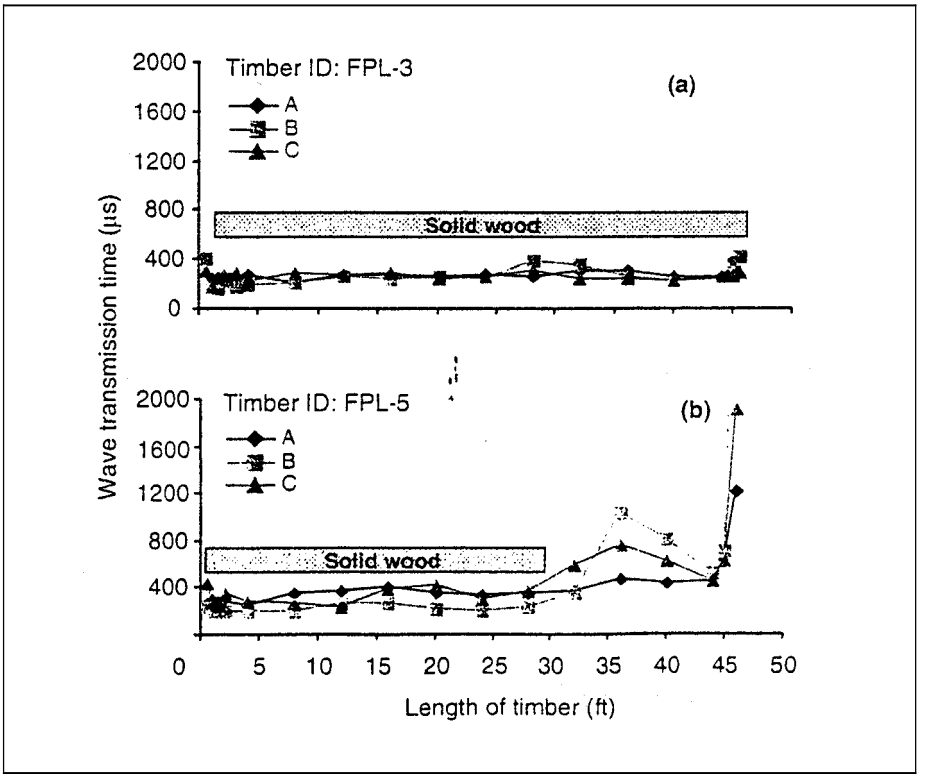

Fig. 6. Typical stress-wave mapping of 12-by-12-in. (30-by-30-cm) white-pine timbers: (a) 98 percent recoverable (b) 59 percent recoverable (1 ft. = 0.3048 m). Photograph by the authors.

Table 1. Potential recovery of solid wood from 12-by-12-in. (30-by-30-cm) white-pine timbers

Timber ID	Length of timber (ft.)a	Length of solid material (ft.)a	Potential recovery (%)	Major defects of timber
FPL-1	50	39	78	Decay on end, notch
FPL-2	48.4	28	58	Split on surface
FPL-3	45.8	45	98	
FPL-4	50	8	16	Severe decay, split, notch
FPL-5	47.8	28	59	Decay on end, surface split, notch
FPL-6	50	42	84	Decay on end, surface split, notch
FPL-7	50	26	52	Decay, notch
FPL-8	46	8	17	Severe surface decay
FPL-9	50	42	84	Surface split, notch
FPL-10	48.3	44.5	92	Surface decay on one end
FPL-11	so	24	48	Severe decay, notch
FPL-12	25.5	0	0	Severe decay, split, notch
FPL-13	33.8	22	65	Big split on ends
FPL-14	32	16	so	Decay and split on ends, notch
FPL-15	50	24	48	Severe decay, notch

[a] 1 ft. = 0.3 m

intensive stress-wave scanning. The scan results indicated that some timbers or parts of timbers were seriously deteriorated and had lost structural integrity. It was also found that most of the timbers still contained a substantial amount of solid wood and that some timbers were only slightly decayed or mechanically damaged on the ends. Further data analysis indicated that 61 percent of the total white-pine timbers potentially could be recovered and used in the reconstruction project. Based on the preliminary results obtained from the 15 white-pine timbers, it may be concluded that stress-wave scanning is an effective inspection method for deterioration detection in timbers. The procedure employed in this study can be used to determine the location and severity of deterioration that might occur in the rest of the structural members.

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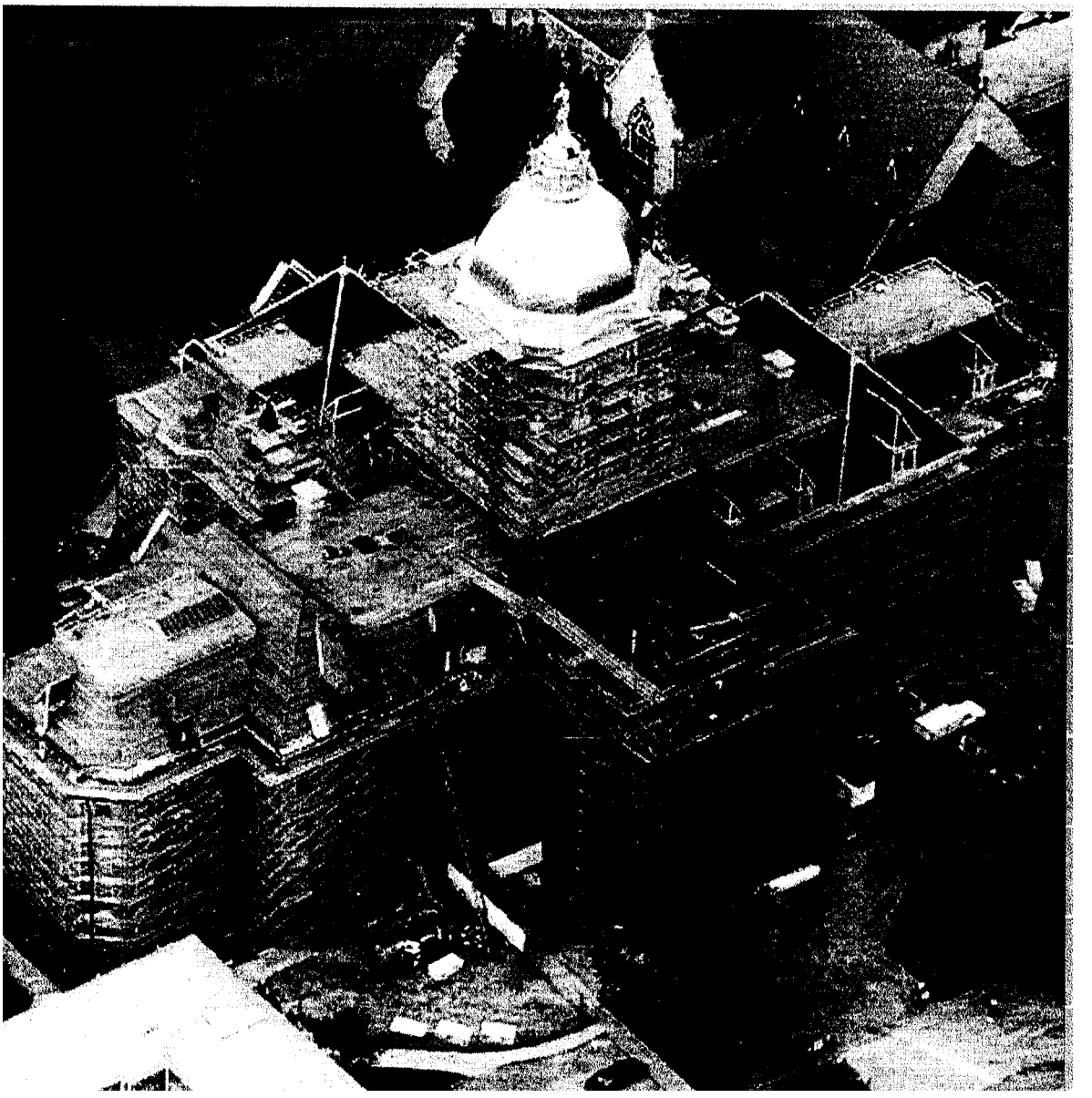

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