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Nondestructive Assessment of Wood Members in a Viewing Tower in Potawatomi State Park, Door County, Wisconsin, USA

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Abstract

The State of Wisconsin's Department of Natural Resources is responsible for operating one of the largest state park systems in the United States. Potawatomi State Park, located on the Door County peninsula, consists of about 1,200 acres of flat to gently rolling upland terrain bordered by steep slopes and rugged limestone cliffs along Lake Michigan's shoreline. A 75-ft observation tower sits atop a 150-ft bluff overlooking Lake Michigan. The USDA Forest Service, Forest Products Laboratory, was asked to conduct an assessment of the main support timbers of the tower. This report summarizes the results obtained from the inspection and assessment. It includes a brief summary of the nondestructive testing techniques that were used, observations, data from tests conducted on the timbers, and recommendations.

Keywords: Nondestructive assessment, decay, moisture, timbers, observation tower

Contents

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Nondestructive Assessment of Wood Members in a Viewing Tower in Potawatomi State Park, Door County, Wisconsin, USA

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Introduction

The USDA Forest Service, Forest Products Laboratory (FPL), was contacted in early 2018 by the Wisconsin Department of Natural Resources (DNR) to assist DNR engineers in assessing the condition of timbers in a historic viewing tower located in the Potawatomi State Park. Located in Door County, the 75-ft observation tower (Fig. 1) sits atop a 150-ft limestone bluff. From its top platform, one can see 16 miles across Lake Michigan's Green Bay.

The DNR periodically examined the structure using visual inspection techniques. Engineers looked for signs of distress, such as failed members and those showing evidence of attack by decay fungi, carpenter ants, or nesting activity of local bird populations.

The objective of the work summarized in this research note was to nondestructively evaluate the quality of timbers that comprise the tower. Several nondestructive techniques were utilized to assess the condition of the large-diameter timber poles and rectangular columns and beams used in the construction of the tower.

History of the Tower in Potawatomi State Park

In 1834, a federal quarry was established on the shores of Green Bay to supply limestone for the building of breakwaters and harbors. This quarry eventually became known as Government Bluff. The land that was to become Potawatomi State Park was purchased from the federal government by the State of Wisconsin in 1928.

Figure 1. Potawatomi Observation Tower: (a) southwest view; (b) southeast view.

In April 1929, the Sawyer Commercial Club donated $500 for the purchase of materials to build a 75-ft observation tower at the peak of Government Bluff, overlooking Sawyer Harbor. Construction of the tower began in late summer of 1931 and was completed by the Wisconsin Conservation Commission. The tower consisted of three platforms supported by four wood poles, each 75 ft in length.

Inspections of the Tower in Potawatomi State Park

In summer 2012, a large crack was discovered on a main support timber and the tower was closed for an extended period because of concerns for public safety. In 2017, inspections of the tower found evidence of decay and movement of the structural wood members. Based upon the 2017 inspections, the Wisconsin DNR contacted FPL and requested a nondestructive inspection similar to the inspection performed by FPL personnel on Peninsula State Park's Eagle Tower in 2016 (Ross and others 2017).

An in-depth, nondestructive inspection of the Potawatomi State Park Tower was conducted on February 6, 2018. Accepted inspection techniques used to assess the condition of the timbers in the tower are discussed in detail by White and Ross (2014). Following are brief descriptions of the techniques.

Visual Inspection

The simplest method for locating deterioration in wood members is visual inspection. An inspector observes the structure for signs of actual or potential deterioration, noting areas that require further investigation. Visual inspection is useful for detecting intermediate or advanced surface decay, water damage, mechanical damage, or failed members. Visual inspection cannot detect early-stage decay or deterioration.

Several key indicators are looked for in visual inspections: fruiting bodies (evidence of advanced decay), staining or discoloration of members (indicators of water damage), evidence of insect activity (holes, frass, and powder posting), plant or moss growth in a member, deep checks or splits, and failed or missing members.

In our inspection of the tower members, we specifically looked for

1. evidence of water intrusion and subsequent damage, especially where the legs of the tower were in contact with concrete pads they rested on and other areas where the exterior of the wood member was compromised, and
2. evidence of structural failure of the timbers.

Sound Transmission

A significant volume of research has been devoted to the use of sound waves for locating areas of deterioration in timber structures, and a practical set of guidelines for their use has been prepared by FPL (Ross and others 1999). In summary, the transmission of sound in wood is affected significantly by the presence of deterioration. Consequently, ultrasound and stress-wave-based technologies have been developed and are widely used to inspect wood structures (Allison and others 2008; Brashaw and others 2005; Clausen and others 2001; Emerson and others 2002; França and others 2015; Ross and others 1999; Ross and Wang 2005; Ross and others 2006) and have been used for the assessment of culturally significant historic ships and artifacts (Ross and others 1998; Wang and others 2008; Dundar and Ross 2012).

A simple, commercially available sound transmission nondestructive testing device was used in the inspection. With this device, sensors were placed on opposite sides of a timber. The timber was then impacted, generating a stress wave. The time it took for the wave to travel between the sensors was measured by the device and recorded. Transmission times for wood in good condition from several species are known and were used as a baseline. Transmission times significantly longer than baseline values indicate the likely presence of deteriorated wood.

Micro-Drilling Resistance

Simple mechanical tests are frequently used for in-service inspection of wood members in structures. Drilling and coring are the most common tests used to detect internal deterioration. Both are used to detect the presence of voids and to determine the thickness of the residual shell when voids are present.

Micro-drilling resistance is a commercially available inspection technique originally developed for use by arborists and tree care professionals to evaluate the condition of urban trees and to locate voids and decay. It is now commonly used to identify and quantify decay, voids, and termite galleries in wood beams, columns, poles, and piles (Brashaw and others 2005). The underlying premise for this technique is that degraded wood is relatively soft and will have low resistance to drill penetration and that voids will have no resistance to drill penetration.

Micro-drilling resistance tests were conducted in areas of the timbers that were believed to contain deteriorated wood, based on results from the visual assessment and sound transmission testing.

Results

The condition assessment of the Potawatomi Observation Tower was performed on February 6, 2018. Figures 1a and 1b show the tower on the day of the inspection. The assessment began with a visual inspection. Deterioration of structural and nonstructural wood members was evident in the tower. Numerous deep splits and cracks within many of the members, and several deep splits on the main load bearing support columns, were observed. Holes, probably resulting from nesting activities of birds, were observed. Of concern were splits and deterioration in the vicinity of connections and the evidence of lateral movement of the upper sections of the tower.

After the visual inspection was completed, sound transmission and micro-resistance drilling tests were performed. Figure 2a shows the southwest tower support pole near ground level. Note the large patched area sealing a previous woodpecker hole. Similar patches were present on all four support legs of the tower. The pink attached notes indicate sites where micro-resistance drilling inspections were performed. Figure 2b shows the resistance drilling tool positioned for use, and Figure 2c shows the results of the inspection. The diameter of the pole at the inspection site was 17 in. The measured resistance noticeably decreases between approximately 7 and 10 in. from the edge. The decrease indicates the presence of interior decay or a void, or both.

Figure 3a shows the steel collar securing the first platform to the southwest support. The steel collar had displaced relative to the location of the support approximately 3-1/4 in., causing noticeable damage (Fig. 3b). The displacement was sufficiently deep to completely penetrate through the surface preservative treatment. Figure 3a also shows surface deterioration on the south side of the support. The wood at that location was easily penetrated by a probe with minimal effort, indicating the presence of advanced decay. Figure 3c shows the results of the micro-resistance drilling at location no. 5, 10 in. above the steel collar (as shown in Fig. 3b). The resistance profile showed sign of decay for the outer 1-1/2 in. in this location.

Figure 4a shows the southeast support of the tower. The diameter of the support pole at the location shown is 17 in. Micro-resistance drilling at location no. 3 is 37 in. above the footing. The resistance profile shown in Figure 4b reveals center decay of 1 in. diameter and multiple internal cracks.

Figure 5a shows the southeast support pole at the first platform. Micro-resistance drilling was performed at location no. 7, 58 in. above the platform, where the diameter of the support pole was 15 in. Large patched cracks of unknown depth are observed on this timber. The resistance profile results shown in Figure 5b reveal an internally sound support with some surface deterioration (marked red in the resistance profile).

Figure 6a shows the northwest support pole at the second platform. Micro-resistance drilling was performed at location no. 10, where the support pole diameter was 12 in. Figure 6b shows visible surface deterioration on the east side of the support. The resistance profile shown in Figure 6c reveals an internally sound support.

Figure 7 shows the central rectangular timber supporting the staircase at the second platform. The stress wave timing tool is shown in Figure 7a. Results of the stress wave timing measurement were significantly high. Any measurement of greater than 300 µs/ft is indicative of internal decay. The measurement across the support was 853 µs/ft, indicating severe decay. In addition, Figure 7b shows visible decay. The extent of the decay on the support was such that the wood could be removed by hand with little to no effort.

Conclusions

The following conclusions are based on the visual inspection and nondestructive testing of the tower components:

1. The tower contained support members that were deteriorated. Surface decay is present on all four support poles. The southwest support contains internal and surface decay over a significant length. The central stair support is decayed.
2. The inspections performed revealed several areas of decay in the tower. Given the current state-of-the-art in timber inspection, it would be difficult to accurately determine, in-place, the extent to which the deterioration has spread. Although it can be stated with certainty that the load-carrying capacity of the tower has been compromised, the residual load-carrying capacity is unknown.
3. It is difficult to estimate the quantity or quality of recoverable material from the timbers. Many of the members were deteriorated, and they should not be reused in any load-bearing application.
4. Several of the same deficiencies that were observed with the Potawatomi Observation Tower were observed during the 2015 assessment of the Eagle Tower. Both structures were of similar construction and age, so this is to be expected.

Implications

The presence of deterioration caused by decay has a significant effect on various properties of structural timber. The following sections summarize the effect of decay on various strength properties of wood. Table 1 summarizes early scientific literature on the topic.

Toughness (Impact Bending)

Toughness (the ability of a wood member to withstand shock loading) is generally considered to be the strength property most affected in early stages of decay. Research dating to 1954 indicates a loss of toughness of 50% with a corresponding loss of only 1% loss in weight.

Static Bending

Research dating to the 1930s has been conducted on modulus of elasticity, modulus of rupture, and work-to-maximum load. Reported results indicate a significant loss in modulus of rupture (strength) with decayed wood.

Table 1—Estimated values for strength losses in softwoods and hardwoods at early stages of decay (indicated by weight loss) by brown-rot and white-rot fungi as a percentage of the value for non-decayed samples[a,b]

	Strength property loss (%)										
			Static bending								
Approx. weight loss (%)	Toughness	Impact bending	General bending strength	Work to max. load	MOR[c]	MOE[c]	Compression perpendicular (radial)	Compression parallel	Tension parallel	Shear parallel	Hardness
Brown rot											
Softwoods											
1	57	20–38	—	—	—	—	—	—	—	2	—
2	—	20–50	5	27	13–50	4–55	18–24	10	23–40	—	—
4	75	25–55	—	—	—	—	25–35	—	—	6	7
6	—	62–72	16	—	61	66	48	25	60	—	—
8	—	78	—	—	—	—	48–60	—	50	15	21
10	—	85	36	—	70	—	66	45	—	20	—
Hardwoods											
1	—	6–27	—	—	—	—	—	—	—	—	—
2	36	31–50	—	54	32	—	6–10	—	56	—	—
4	—	60–70	—	69	49	—	—	—	—	—	—
6	—	80	—	75	61	—	16–25	—	—	—	—
8	—	9–89	13–34	—	—	—	19	—	82	—	—
10	60	70–92	—	—	—	—	—	—	—	—	—
White rot											
Softwoods											
1	55	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	10–20	—	4–38	—	—
4	—	—	—	—	—	—	—	—	8–43	—	—
6	75	—	—	—	—	—	32–61	—	10–49	—	—
8	—	—	—	—	—	—	—	—	14–58	—	—
10	85	—	—	—	—	—	—	—	20–63	—	—
Hardwoods											
1	—	21	—	—	—	—	4	—	—	—	—
2	—	26	—	28–35	13–14	4	5	—	22–42	—	—
4	70	44	—	38	20	—	—	—	17–44	—	—
6	75	50	—	45–53	20–27	10	12–27	14	12–58	—	18
8	—	—	—	—	—	—	—	—	14–49	—	
10	85	60		58	24	14	35	20	20–50		25

[a]From Wilcox (1978). Values obtained from published experimental results and adjusted to equivalent weight loss levels.
[b]Sources: Brown (1963), Cartwright and others (1931), Gillwald and Michalak (1963), Hartley (1958), Henningsson (1967), Kennedy (1958), Kennedy and Ifju (1962), Kubiak and Kerner (1963), Mizumoto (1966), Mulholland (1954), Pechmann and Schaile (1950), Richards (1954), Scheffer (1936), Toole (1971), and Wilcox (1968).
[c]MOR, modulus of rupture; MOE, modulus of elasticity.

Other Strength Properties

Research has shown that compression perpendicular to the grain, compression parallel to the grain, tension parallel to the grain, shear parallel to the grain, and tangential hardness are also impacted by deterioration caused by decay.

Recommendations

1. If the tower is dismantled and reuse of the materials is desired, then each member should be evaluated using advanced nondestructive assessment procedures.
2. The FPL has no data or published reports on, and can therefore make no recommendation related to, bonding of deteriorated wood.
3. None of the members should be reused in any load-bearing application.
4. Reuse of any recovered materials should be limited to non-load-bearing applications (for example, as interior paneling in offices, signage, or craft-type products).

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Figure 2. Southwest support pole at ground level. (a) View of southern side of support. The attached pink notes indicate locations of micro-resistance drilling test. The black patch is the location of a sealed woodpecker hole. (b) Micro-resistance drilling test at location no. 1, 32 in. above the footing. (c) Resistance profile for location no. 1 reveals a 3- to 4-in. center deterioration, which was likely caused by water entering through the woodpecker hole 1 ft above.

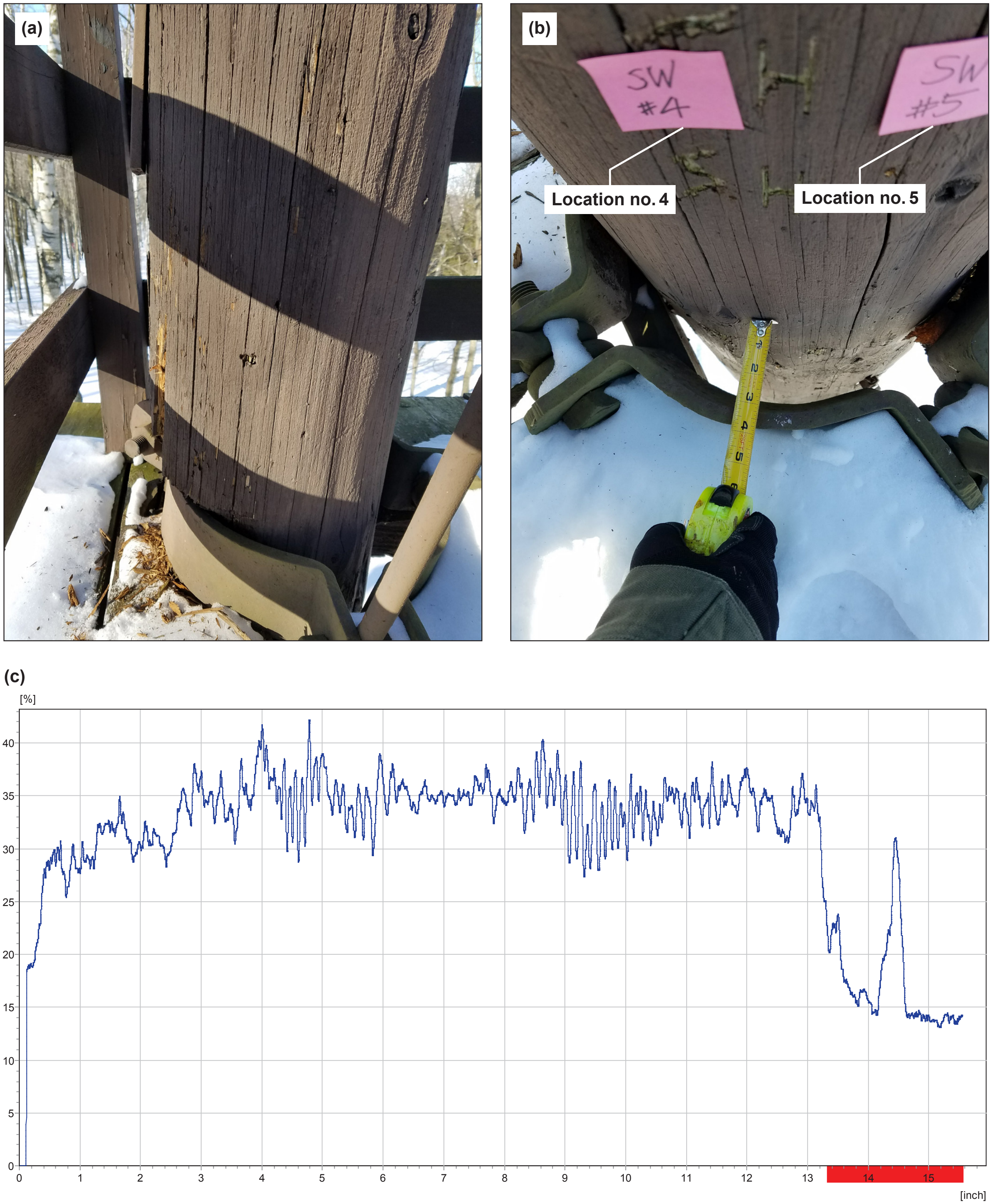


Figure 3. Southwest support pole at platform 1. (a) Steel collar securing the first platform to the southwest support. Displacement of the collar has damaged the support and penetrated the surface layer of preservative. Deterioration is apparent where the clamp has damaged the support. (b) Steel clamp has displaced 3-1/4 in. The attached pink notes show micro-resistance drilling locations no. 4 and no. 5, 10 in. above the collar. (c) Resistance profile for location no. 5 shows 1-1/2 in. of surface decay.

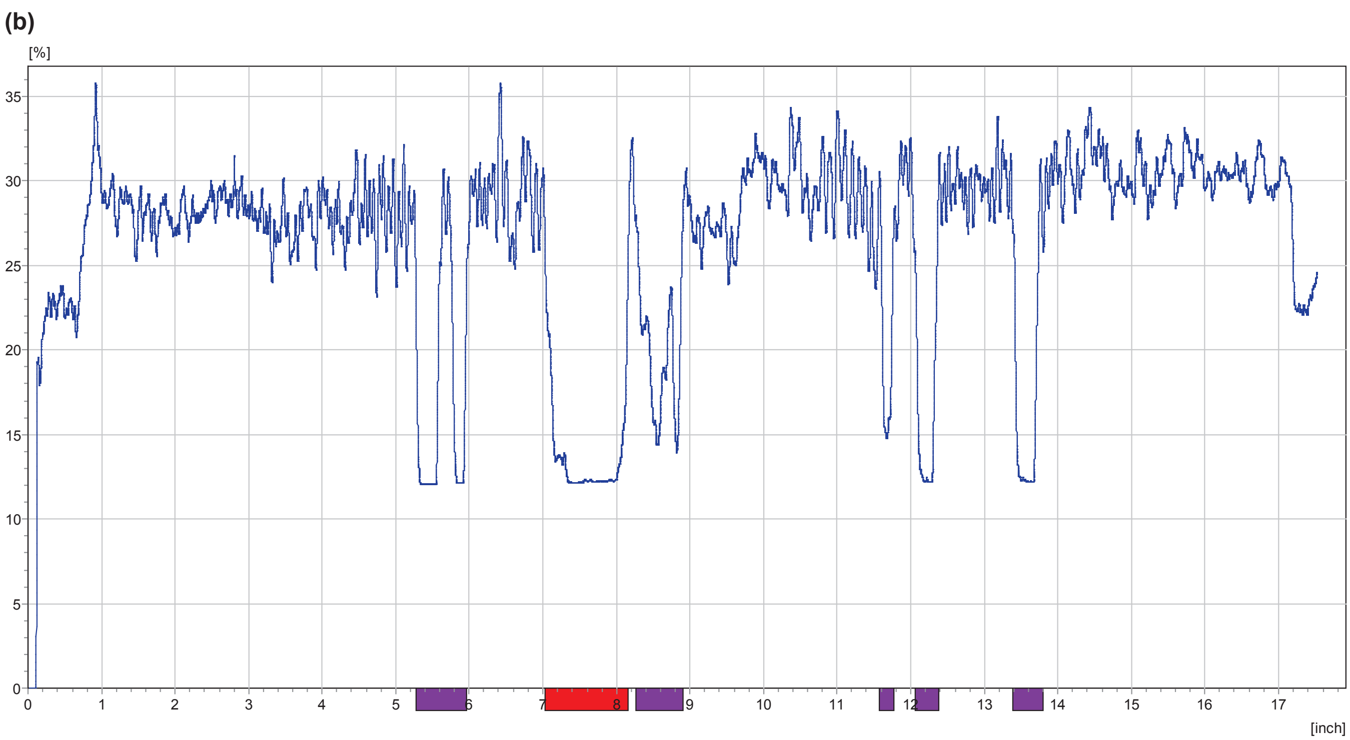
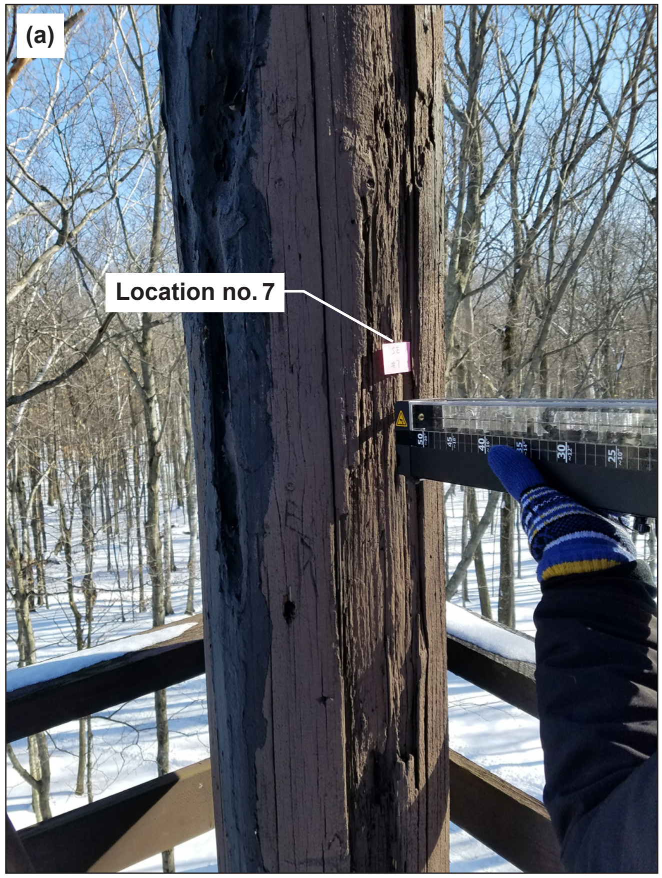


Figure 4. Southeast support pole at ground level. (a) Micro-resistance drilling test at location no. 3, 37 in. above the footing. The support diameter is 17 in. at this location. (b) The resistance profile reveals center deterioration (marked red) of 1 in. diameter and multiple internal cracks (marked purple).



(b)

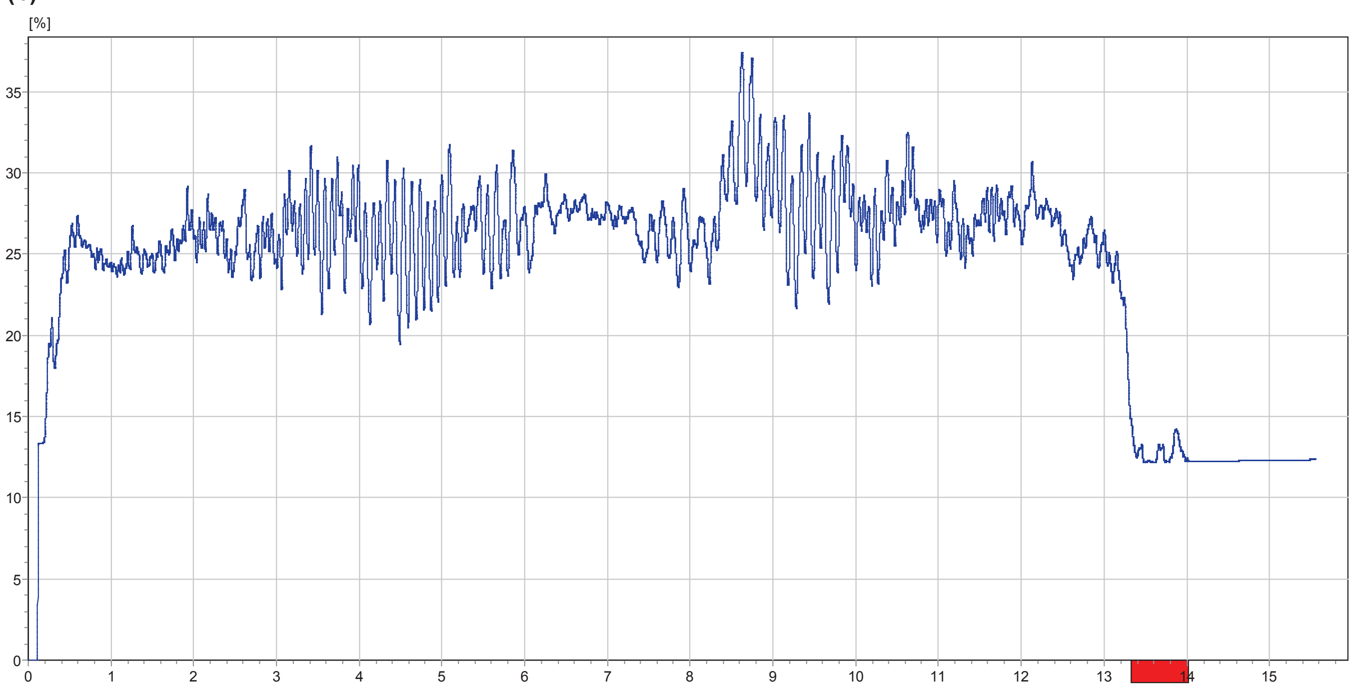
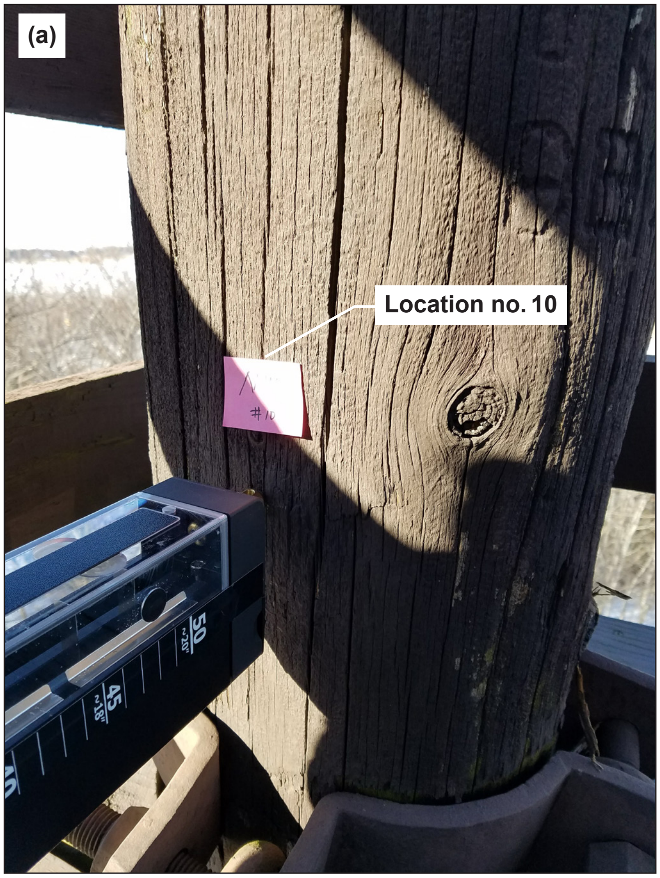


Figure 5. Southeast support pole at platform 1. (a) Micro-resistance drilling test at location no. 7, 58 in. above the platform. The support diameter is 15 in. Large patched cracks of unknown depth can be observed on this timber. (b) The resistance profile reveals an internally sound support with surface deterioration.



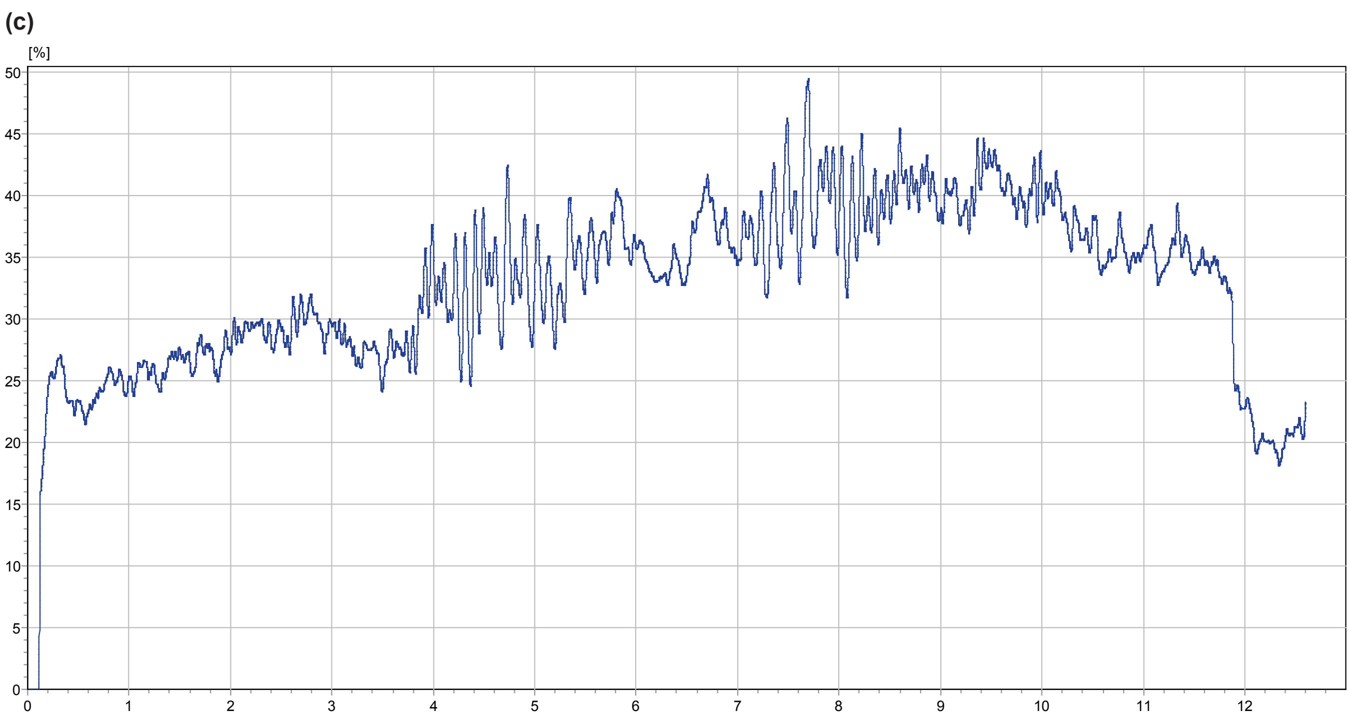


Figure 6. Northwest support pole at platform 2. (a) Micro-resistance drilling test at location no. 10. (b) Visible surface deterioration. (c) Resistance profile reveals an internally sound support.

Figure 7. Central stairway support at platform 2. (a) Stress wave timing measurement showed significantly high readings (426 μs, equivalent to 853 μs/ft), indicating severe decay. (b) Visible deteriorated wood.