Assessing Wood Members in the USS *Constitution* Using Non-Destructive Evaluation Methods

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The USDA Forest Service, Forest Products Laboratory, contributed to the development of an inspection methodology to evaluate the condition of fasteners and the general condition of the wood on the oldest floating commissioned ship in the U.S. Navy.

Introduction

The USS *Constitution,* known as "Old Ironsides," is the oldest floating commissioned ship in the world and still a part of the U.S. Navy. Launched on October 21, 1797, the ship was recently in dry-dock, being prepared for the 200th anniversary of her launching (Fig. 1). Personnel from the U.S. Navy responsible for maintaining the ship have investigated a variety of non-destructive testing techniques to assess the condition of its wood.

The sophistication of these tests ran the gamut from signs of deterioration observed through visual inspection to instrumented probes and advanced chemical analyses. Radiography and ultrasonic techniques were used to assess the condition of copper pins used as fasteners. Stress-wave non-destructive evaluation (NDE) techniques were used to locate areas of degradation in the wood.

These techniques are widely used in assessing wood structures. They utilize relatively low-cost equipment (approximately $3,500) that can be readily obtained from manufacturers. With minimal training an inspector can use these techniques and obtain consistent results. They provide a relatively quick method for locating large deteriorated areas in wood members that can then be probed and are a valuable addition to conventional visual and probing techniques. The objective of this paper is to describe the stress-wave techniques utilized and present results obtained from their use.

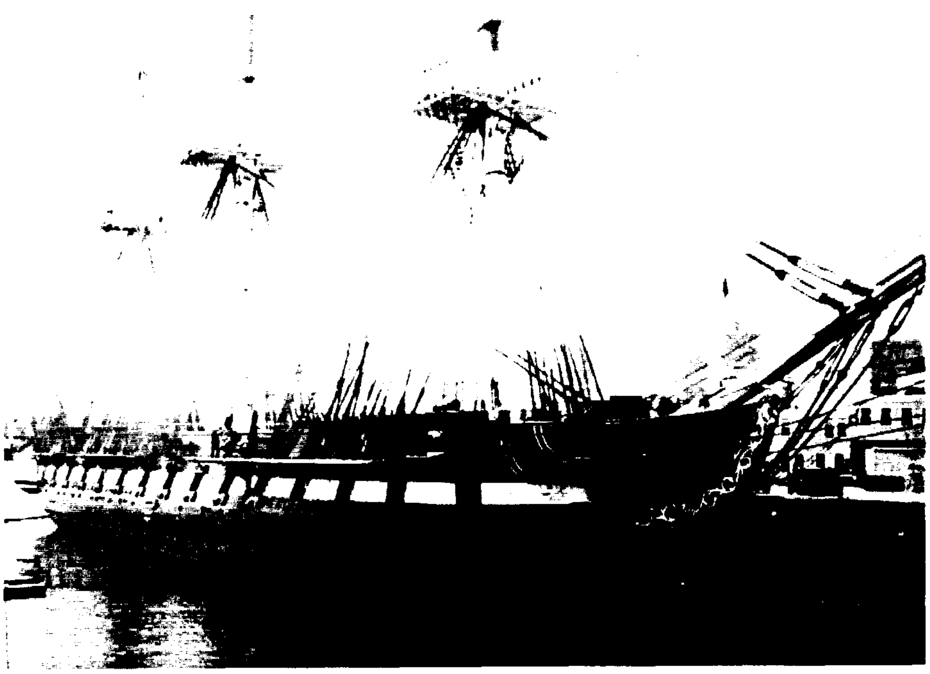

Fig 1. The USS *Constution.* All ililustrated by authors.

Baseline Information

Stress-wave NDE techniques are used frequently to inspect large timber structures [1]. 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. As an introduction to the stress-wave technique, a schematic of the stress-wave concept for detecting deteriorated areas within a rectangular wood member is shown in Fig. 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 timer. A second accelerometer, which is coupled to the member, then responds to the leading edge of the propagating stress wave and sends a step signal to the timer. The elapsed time for the stress wave to propagate between the

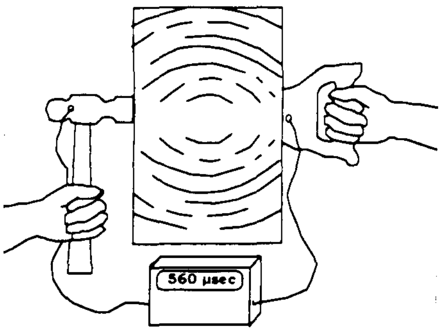

Fig. 2. Test setup used to locate deteriorated member.

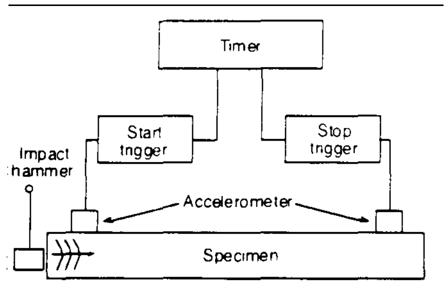

Fig. 3. Test setup used to establish speed of stress-wave transmisson parallel to gram in live oak specimens.

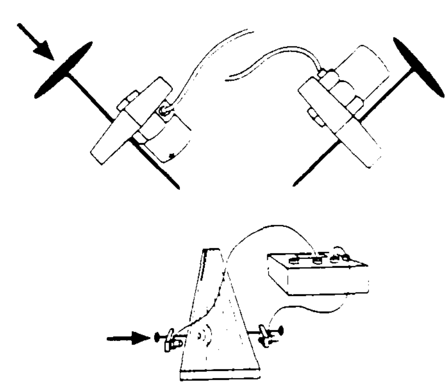

Fig. 4. Test setup used to measure speed of stress-wave transmission perpendicular to grain in live oak specimens

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.

For example, it has been shown that a stress wave travels at speeds that are significantly slower in deteriorated wood when compared with sound wood. Consequently, this technique has proven to be an effective method for locating large, degraded areas in timbers. Table 1 summarizes published applications of these techniques for locating deteriorated regions in timbers. Note that previous efforts were aimed at locating degraded areas in softwood timbers. No information was found on the use of these techniques for assessing degradation in hardwood timbers. In addition, limited baseline information exists on speed of stress-wave transmission values for hardwood species (Table 2).

Smulski reported on speed of stress-wave transmission values parallel to the grain for sugar maple, yellow birch, white ash, and red oak [5]. Armstrong and others determined speed of stress-wave transmission values, both parallel and perpendicular to the grain for birch, yellow poplar, black cherry, and red oak [6]. McDonald measured speed of stress-wave transmission for three hardwood species (beech, hickory, and red oak) in longitudinal, radial, and tangential directions [17].

Many timbers in the USS *Comtitution* are from live oak, a hardwood species. Consequently, baseline information on speed of stress-wave transmission in live oak was needed before using the stress-wave technique. Thus, a series of laboratory experiments was conducted to determine baseline speed for live oak specimens prior to inspecting the ship.

To determine speed of stress-wave transmission values parallel to the grain. eighty 0.5-by-0.375-by-12.0-in. (0.01-by-0.01-by-0.30-m) live oak specimens were tested, using the experimental setup shown in Fig. 3. All specimens were conditioned to approximately 12% equilibrium moisture content. An average value of 105 microsec/ft (9,524 ft/sec) was found. Values for these specimens ranged from 71 to 151 microsec/ft (6,622 to 14,085 ft/sec).

To determine speed of stress-wave transmission values perpendicular to the grain, 20 5- by 12- by 12-in (0.1- by 0.3- by 0.3-m) live oak specimens were tested, using the setup illustrated in Fig. 4. An average value of 278 microsec/ft (3,597 ft/sec) was found. Values for these specimens ranged from 210 to 476 microsec/ft (2,101 to 4,762 ft/sec).

Inspection of Members

All deck beams (four decks of approximately 32 beams each), various knees, the stern post, the stem keelson, and the keel were examined using the setup

Table 1. Summary of Research on Use of Stress Wave Technique for Decay Detection in Timber Structures

Reference	Type of structure	Type of wood product	Test procedure	Analysis
[2]	Bridge	Douglas Fir, glulam, creosote pressure treated	Speed of stress wave perpendicular to grain, across laminations at 1-ft transmission	Sound wood: 90 microsec/ft Moderate decay: 557 microsec/ft Severe decay: 741 microsec/ft
[3]	Football stadium	Douglas Fir, solid-sawn, creosote pressure treated	Speed of stress wave transmission perpendicular to grain, inspected in vicinity of connections	Sound wood: 260 microsec/ft Incipient decay in center of members: 389 microsec/ft 1.5-in (0.04-m) thick shell of solid wood: 649-778 microsec/ft Decayed member: >1300 microsec/ft
[4]	School gymnasium	Douglas Fir, glulam arches	Speed of stress wave transmission perpendicular to grain, inspected in vicinity of end supports	Sound wood: 133 microsec/ft Decayed wood: 267 microsec/ft

Table 2. Summary of Research on Speed of Stress Wave Transmission Values for Various Species of Sound Wood

Reference	Species	Moisture content (% ovendry)	Speed of stress-wave transmission parallel to grain ft/s (microsec/ft)		Speed of stress-wave transmission perpendicular to grain ft/s (microsec/ft)		Comments
[5]	Sugar Maple	12	12,790–16,820	(78–59)			Laboratory study
	Yellow Birch	11	14,270–18,020	(70–55)			
	White Ash	12	13,000–16,680	(77–60)			
	Red Oak	11	12,440–16,280	(80–61)			
[6]	Birch	4–6	17,090	(58)	4720	(212)	Laboratory study
			(15,384–18,800)	(65–53)	(4589–4851)	(218–206)	
	Yellow Poplar	4–6	17,910	(56)	4920	(203)	
			(16,930–18,890)	(59–53)	(4592–5248)	(218–190)	
	Black Cherry	4–6	16,900	(59)	5020	(199)	
			(15,980–17,820)	(63–56)	(4758–5282)	(210–189)	
	Red Oak	4–6	16,530	(60)	5410	(185)	
			(14,430–18,630)	(69–54)	(5082–5738)	(197–174)	
[7]	Several	11	16,000–19,700	(62–51)			Laboratory study
[8]	Red Oak Veneer	12	10,800–14,400	(92–69)			Laboratory study
[9,10]	Several species		12,000–17,100	(83–58)			Laboratory study
[11]	Stika spruce clear 2x4's	10	19,400	(52)			Laboratory study
	Southern Pine clear 2x4's	9	16,800	(60)			
[12]	Douglas Fir clear 2x8's	10	16,200	(62)			Laboratory study
[13]	Southern Pine clear 2x2's	10	17,000	(59)			Laboratory study
	Southern Pine knotty 2x6's	10	16,800	(60)			
[14]	Douglas Fir	12			3,000–5,260	(333–190)	Laboratory study
[3]	Douglas Fir	11			3,854–5,494	(259–182)	Inspection of college football stadium
[4]	Douglas Fir	—			7,500	(133)	Inspection of gymnasium
[15]	Southern Pine	9	16,390–19,231	(61–52)			Field study of decay
[16]	Northern Red White Oak	Green			4,464 < 2,500 (224 > 400)		Laboratory study of bacterially infected lumber

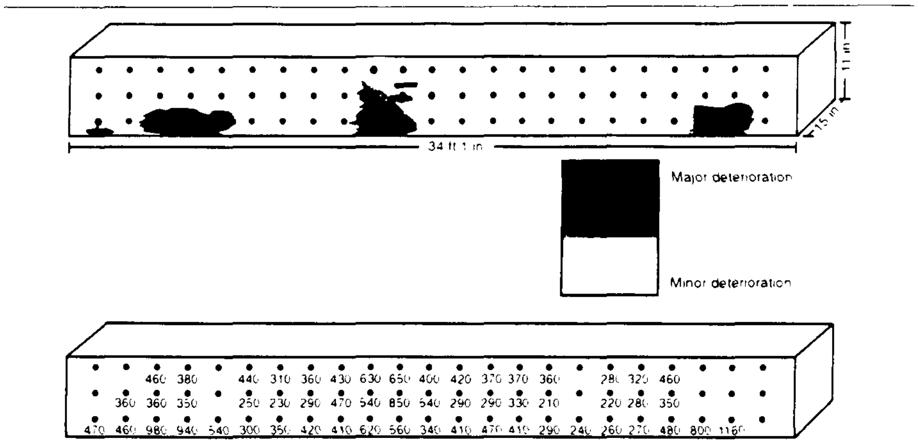

Fig. 5. A beam removed from the USS *Constitution.* Note the significantly lengthy transmission times in regions containing deterioration.

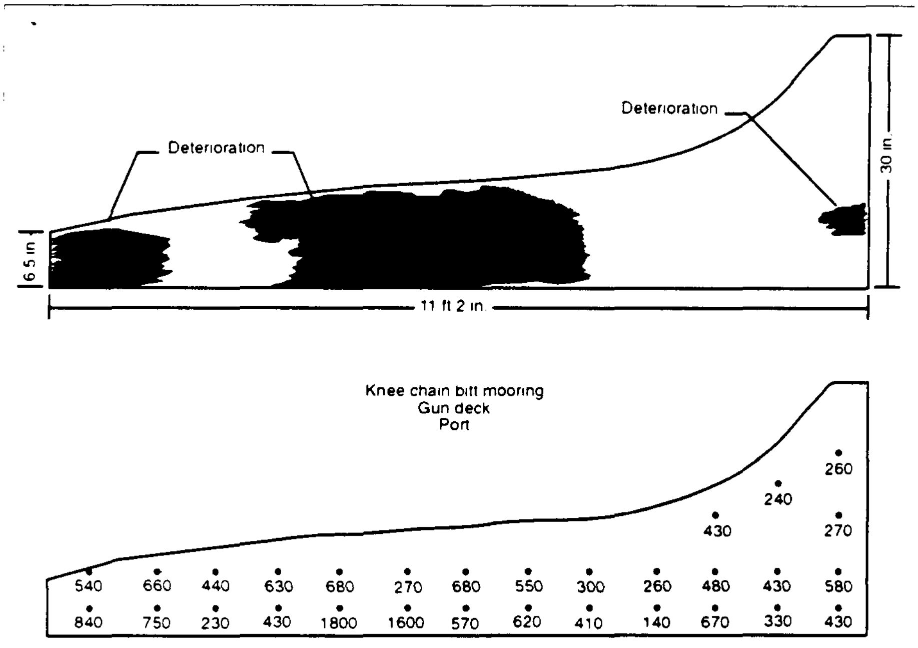

Fig. 6. Knee chain bitt mooring from the USS *Constitution.* Note the difference in stress-wave transmission time and values of 260 microseconds observed m sound wood. Deteriorated wood yielded values in excess of 600 microseconds

illustrated in Fig. 2. Baseline stress-wave transmission times for sound live oak were calculated for the thickness of various members. Significantly lengthy transmission times indicated the presence of deterioration.

Figures 5 through 8 illustrate the results. Note that the numbers on the drawings represent the stress-wave transmission time for that particular point in the member. Significantly longer transmission times were indicative of deteriorated wood. Inspection of these members after they were removed from the ship revealed that the severity of degradation corresponded to increases in transmission times. This finding is in agreement with previously reported results.

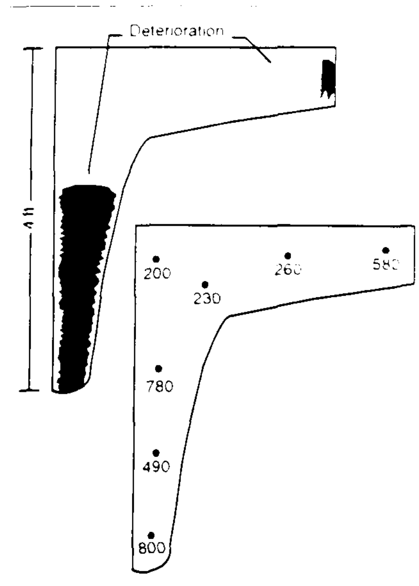

Fig. 7. A knee brace removed from the USS *Constitution.*

Conclusions

Stress-wave non-destructive evaluation techniques were used to successfully locate deteriorated wood in the USS *Constitution.* A stress wave was induced in the member in question, and the time it took to flow through the member, perpendicular to the grain, was monitored. Significantly longer transmission times were observed when deteriorated wood was present.

ROBERT J. ROSS, Ph.D., research engineer, USDA Forest Service, Forest Products Laboratory, is currently working on the development of non-destructive evaluation procedures for wood structures, including "Old Ironsides."

LAWRENCE A. SOLTIS, Ph.D., research engineer, USDA Forest Service, Forest Products Laboratory, works on the application of structural analysis and design technologies to wood structures.

PATRICK OTTON, technical writer, U.S. Navy, led the restoration effort for "Old Ironsides."

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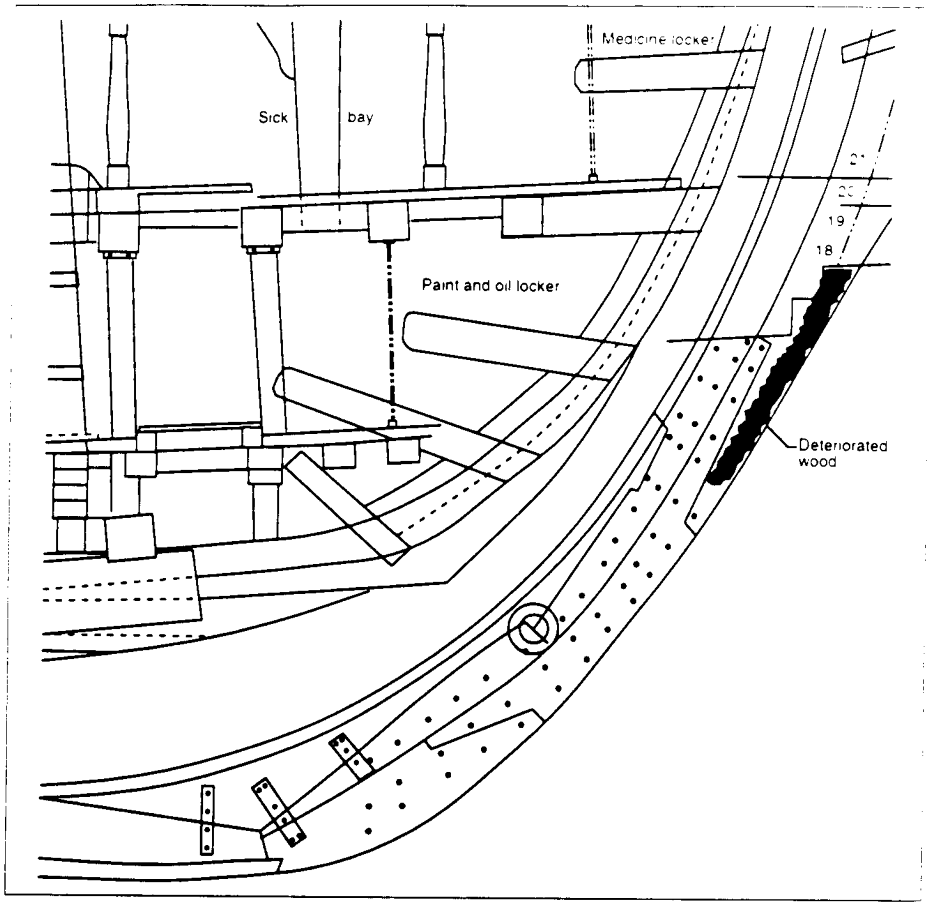

Fig. 8. Stem from the USS *Constitution*.

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