Condition Assessment of Historic Wooden Ships

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Abstract

This paper summarizes work conducted to assess the condition of members in historically significant timber sailing vessels. Four ship assessments are described, the *USS Constitution*, the *USS Cairo*, and the *Wapama*. Launched in 1797, the *USS Constitution* was nicknamed "Old Ironsides" and was a combat vessal used by the US Navy. "Old Ironsides" is a three-masted heavy frigate with a hull primarily constructed of live oak. The USS Cairo is a city class ironclad river gunboat. It was built in 1861 and commissioned in January 1862. It was used in combat by Union forces during the American Civil War along the Mississippi River and connected waterways and sunk in December 1862. It remained submerged for 100 years and was recovered in 1964. Currently the USS Cairo is on display at the Vicksburg National Military Park. The *Wapama* was launched in 1915 and was used for the Pacific Coast lumber trade and coastal service. It was declared a National Historic Landmark in 1984. It is a wooden steam-powered schooner. Given the historical signifigance of the vessals, it is important that inspection methods employed do not degrade their conditions. Three categories of nondstructive inspection techniques are employed: accoustic based, moisture detection, and micro-drilling resistance. The specific applications of these techniques for each vessel is described.

Keywords: Wood, ships, nondestructive evaluation, acoustic, moisture, micro-drilling resistance, condition assessment.

Introduction

Deterioration of in-service wood can arise for several reasons. Most common are of biological origin, decay fungi and termites, are frequently the cause of deterioration of wood in a variety of structural systems. In-service wood needs to be inspected on a regular basis to ensure that there has not been a significant loss in load carrying capacity. A thorough inspection is particularly important for main load bearing members. The USDA Forest Products Laboratory (FPL) and cooperators have been developing in-field structural condition assessment techniques for use with wood structures since the 1990's (White and Ross, 2014). During our work we have had the opportunity to inspect or provide consultation on the condition of a wide range of timber structures including historic ships (Ross et al. 2001). This manuscript provides a summary of some of the sailing vessels inspected: the *USS Constitution*, the *Wapama*, and the *USS Cairo*. The inspection methods include visual inspection, mechanical inspection by probing, moisture content measurements, stress wave transmission time (SWTT), and micro-drilling resistance.

USS Constitution

The most historically significant ship inspected was *USS Constitution* (Ross et al. 1998; Soltis et al. 1992; Witherall et al. 1992). *USS Constitution*, "Old Ironsides," was launched on October 21, 1797. She carries the distinction of the oldest commissioned ship afloat in the world because a significant portion of the ship's underwater structure is original. Included in this original material are the keel, deadwood, floors, lower planking strakes, and several lower frame futtocks. In the 1990s, FPL assisted the U.S. Navy in conducting an intensive condition assessment. The time of flight of stress wave passing through members perpendicular to the grain were measured using a pitch-catch stress wave timing unit (Ross et al. 2005). Mechanical and decay deterioration was observed, which resulted in the replacement of several members.

A unique aspect of this structure was the wood used in its construction. Much of its hull was constructed from oak wood (*Quercus, sp.*), specifically one of species of oak commonly referred to as live oak. Live oak was widely used in early American shipbuilding. Live oak wood is hard, heavy, and difficult to work with, but very strong. In the days of wooden ships, live oaks were the preferred source of the framework timbers of the ship, using the natural trunk and branch angles for their strength. The frame of the USS *Constitution* was constructed from southern live oak (*Quercus virginiana*) wood harvested from St. Simons Island, Georgia, USA. Dry Southern live oak wood has a specific gravity of 0.88 (Forest Products Laboratory 2021), among the highest of North American hardwoods. Another feature of live oak is that the fibers are "interlocked". Interlocked wood has exceptional strength, specifically perpendicular to the longitudinal axis of the timber.

The density of the wood and its interlocking fiber arrangement allowed it to survive cannon fire, thus earning her the nickname "Old Ironsides". Because of the trees' short height and low-hanging branches, timbers from live oak trees were used in curved parts of the frame, such as knee braces (single-piece, L-shaped braces that spring inward from the side and support the deck), making for exceptional strength. Live oaks were not generally used for planking because the curved and often convoluted shape of the tree did not lend itself to being milled to planking of any length. Red oak and white oak were generally used for planking on vessels, because those trees grow straight and tall, with straight trunks long enough for planks. As a consequence of its interlocking fiber alignment, extensive laboratory work was needed to provide baseline sound transmission values for this species of wood (Ross et al. 1998).

Wapama

The historic American ship *Wapama* is the last surviving example of the wooden steam-powered schooners designed for the 19th- and 20th-century Pacific Coast lumber trade and coastal service. Since its launching in 1915, the *Wapama* has had a long and productive life in plying cargo and passengers along the stormy West Coast from Mexico to Alaska. As the sole survivor of the once numerous class, the *Wapama* was declared a National Historic Landmark in 1984. The wood structure of the *Wapama* has significantly deteriorated over the years and currently resides on a barge with internal and external structural supports (Figure 1). Portions of the vessel are unsafe for public access. Assisting in an effort to stabilize and rehabilitate this historic vessel, we conducted a field investigation on the physical condition of the wooden structural members in January 2006 (Wang et al. 2008).

Our investigation focused on the key structural components that provide the structural integrity of the vessel. Structural components tested that provide for longitudinal integrity are the keelsons (rider keelson, main keelson, assistant keelsons), main deck stringers, waterways, bulwarks, and keel. Structural components tested that provide for transverse integrity are the hull assembly (framing timbers, ceiling, clamps, strakes) at three cross-sections and the main deck beams. Due to limited inspection time, the investigation was not intensively focused on individual members, but instead was conducted with relatively large scan intervals or through spot-checking of suspected areas. Stress-wave timing and micro-drilling resistance were the primary methods used in this investigation, coupled with visual inspection and moisture content determination. It was recommended that the roof structure of the main deck be replaced as it was apparent that the current roof did not effectively prevent rainwater intrusion.

Figure 1–Wapama placed on a barge at the Richmond Reserve Shipyard in Richmond, California.

Figure 2 illustrates the distribution of SWTT (in μs/ft) along the length and the mapping of physical conditions of the rider keelson and main keelson. The keelsons deterioration was concentrated between frames 25 and 42, and most severe decay occurred on the main keelson timber between frames 30 and 39. This is also confirmed by micro-drilling resistance tests. Rainwater likely entered this area through the hatch over the years due to failed weather protection and water remained trapped.

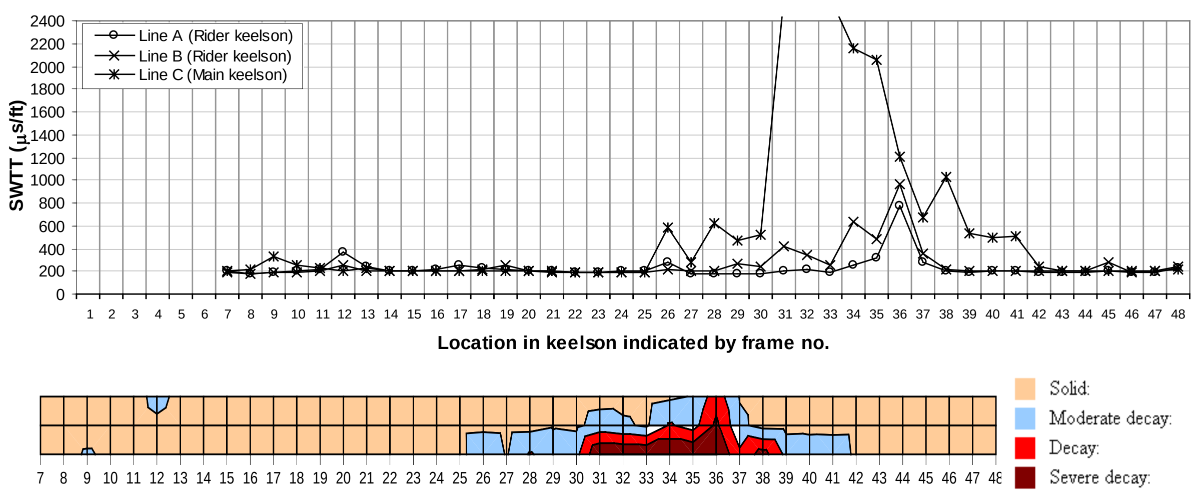

Figure 2–Stress wave transmission time distribution and physical condition map of the keelsons.

Figure 3 is a schematic summary of micro-drilling resistance data collected at hull frame 32. Severe decay was detected at 15 (38%) of the drilling locations, with most of these areas located in the members at the main deck level (stringers and main deck beams) or near the main deck level (clamps, hull frame).

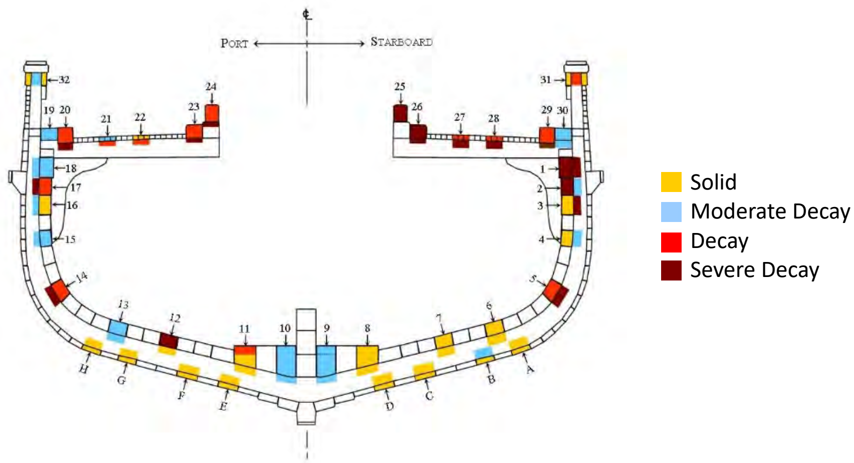

Figure 3–Cross section physical condition map at frame 32 based on micro-drilling resistance.

USS Cairo

The *USS Cairo* was one of a group of Civil War gunboats that were designed specifically to perform in the swift and shallow rivers of the Mississippi River basin. Known as the City Series gunboats, *Cairo* and her six sisters were the first ironclads launched in the Western Hemisphere. Each boat had three keels and flat bottoms that enabled them to glide over the often-shallow rivers. *Cairo* and her sisters were each 175-ft long, 51-ft. wide, and mounted 13 guns. The forward casemate was covered with 2 ½ inches of armor plating which also covered portions of the starboard and port sides. When fully loaded they weighted 880 tons, yet only drafted 6-ft of water. Commissioned on January 15, 1862, *Cairo* had a complement of 175 officers and men and was commanded by Lt. Cmdr. Thomas O. Selfridge, Jr. She was sunk in December 1862 and was salvaged in 1964. In 1980, a covered shelter and mass timber crib structure was built to display and support the *Cairo* (Figures 4a and 4b).

a. b.

Figure 4–USS Cairo **a)** Displayed at Vicksburg National Military Park **b)** Timber crib support

The Forest Products Laboratory (FPL), and Mississippi State University were contacted in 2023 by Vicksburg National Military Park to assist in assessing the condition of a timber crib built to support the *Cairo*. The assessment did not include the *USS Cairo* itself as it is preserved in its current condition because if its historical significance. An inspection utilizing visual, acoustic-based and probing nondestructive testing techniques was conducted on October 24 and 25, 2023 (Senalik et al. 2024). Condition assessment of the *USS Cairo* glulam crib began with a visual inspection to identify obvious areas of decay within the glued laminated (glulam) structure. Overall, the condition of the glulam crib supporting the remains of the *USS Cairo* is in good condition. No areas of surface decay were identified.

The second step of our condition assessment was determination of moisture content (MC) within the wood. Moisture is necessary for wood decay. As moisture content decreases below wood fiber saturation, the likelihood of wood decay decreases. Fiber saturation is species specific, but 20% MC by weight is generally considered below the fiber saturation point. The percentage MC corresponds to the level of concern for the presence or potential of decay. Levels were set at low (below 17%), moderate (17% to 20%), and high (above 20%). At first glance, the underside of glulam beams appeared damp, but it was determined that this was residual oil used in the original pentachlorophenol treatment and moisture readings with a pin-type moisture meter ranged between 8-15% MC, with most values falling within the 10-13% range. These ranges of MC are slightly elevated but still below the 20% and above MC range to promote growth of mold and decay fungi (Forest Products Laboratory 2021). The MC measurements are summarized in Figure 5.

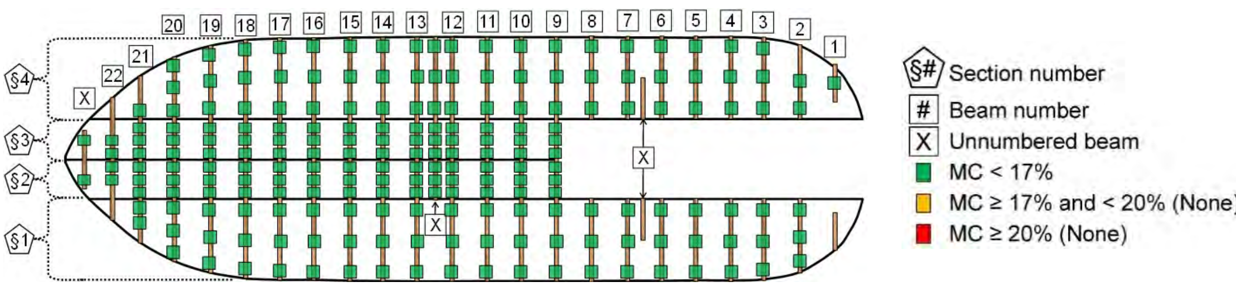

Figure 5–Moisture content of glulam crib underneath the USS Cairo. Measurements taken using pin moisture meter. All values fell below 17%. The four sections, left to right, are port, port/center, starboard/center, and starboard. The photograph shows how moisture measurements were taken.

Average moisture content and coefficient of variation (COV) for the four sections of the *USS Cairo* were determined and recorded in Table 1. Overall, moisture content in all four sections was below what is required for decay fungi to grow (>25%). However, there were some instances especially in Section 4 where the moisture barrier between the concrete structure and glulam housing the *USS Cairo* was showing elevated moisture readings (15%). This could be a result of the moisture barrier failing which is allowing elevated moisture readings at these spots. Specific instances of higher moisture readings occurred in Section 1 (port) and Section 4 (Starboard).

Table 1–Average moisture content by section [a]

Section	Average MC (%)	COV (%)
1 (Port)	11.9	10.7
2 (Port/Center)	10.9	9.3
3 (Starboard/Center)	10.8	8.9
4 (Starboard)	11.7	9.9

[a] Triplicate readings were measured for each of the glulam structures housing the USS Cairo. Average MC was obtained from the entire length of each section.

One area of particular concern is the white oak bulkhead located below the steam pistons attached to the aft paddle wheel assembly. There was evidence of extensive decay and some beginning of structural failure as shown in Figure 6. It is recommended that this area be at a minimum filled with a two-part wood epoxy or similar material to consolidate the member as well as seal off the damage the prevent further biodegradation.

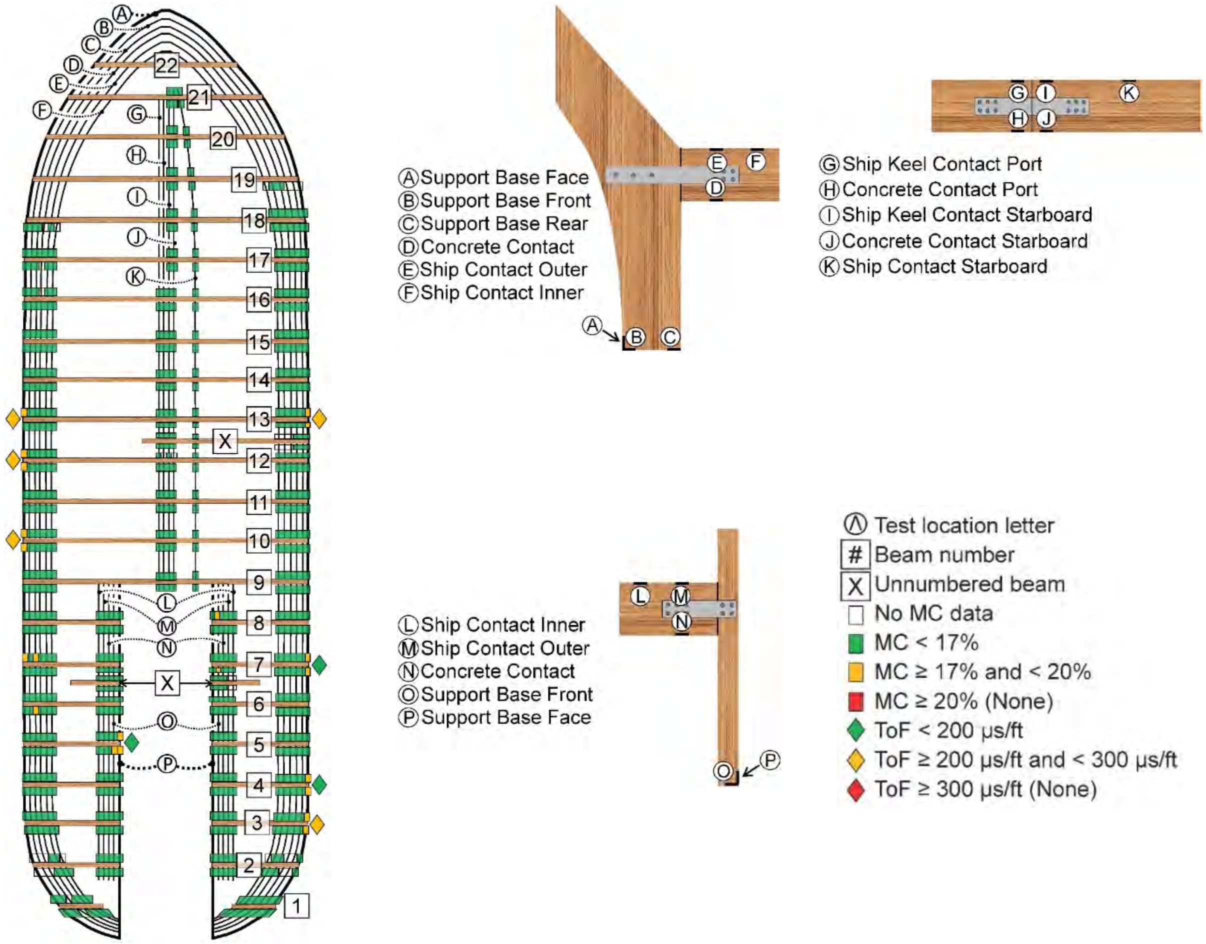

Figure 6–Moisture content (MC) and time of flight (ToF) of glue laminated timber support structure for U.S.S. Cairo. Test locations identified by beam number and location letter provided on diagrams to the right. Locations where MC was at or above 17% were also measured using stress wave ToF. Advanced decay was not found but stress wave ToF revealed locations that should be monitored going forward.

Measurements were taken at contact points between the glulam structure and either the concrete substructure or the historic timbers of the *USS Cairo*. Moisture can become trapped at points of contact and promote wood decay. Wood / concrete contact is particularly prone to decay as the porous concrete absorbs water which is then drawn into wood. Wicking is greatest when the wood end grain is in direct contact with concrete. A thin, barrier layer was placed at each wood-concrete contact point to prevent direct contact between the two materials. The barrier layer minimized transfer of moisture from the concrete to the wood. No areas of MC above 20% were found.

Moderate concern locations (17% to 20% MC) were further tested using stress wave time of flight (ToF). Stress wave time of travel was measured using Fakopp Microsecond Timer from Fakopp Enterprise Bt.

Mechanical waves (sound or mechanical impact) travel faster in sturdy wood than decayed wood. ToF less than 200 µs per foot (µs is a microsecond which is one-millionth of a second) indicate sturdy wood; ToF between 200 µs/ft and 300 µs/ft should be monitored; ToF above 300 µs/ft indicate decay. The Wagner L610 Digital Lumber Moisture Meter and Fakopp Microsecond Timer. No ToF above 300 µs/ft were observed. Several areas where MC was between 17% and 20% had ToF between 200 and 300 µs/ft.

The following conclusions were drawn from the inspection. Based upon visual inspection, moisture measurement, and time of flight tests it can be concluded that the high humidity and restricted air flow environment have not caused the development of advanced decay. Areas of moderate concern were identified and should be regularly monitored for the development of advanced decay. Increasing air flow around the contact between the glulam supports and the concrete substructure will reduce absorption from standing water. The high humidity environment will continue to be a source of moisture that can potentially lead to the development of advanced decay.

Acknowledgments

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Campinas, São Paulo, Brazil
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International Union of Forest Research Organizations

Abstract

The 23rd International Nondestructive Testing and Evaluation of Wood Symposium was hosted by the School of Agricultural Engineering of the Universidade Estadual de Campinas (FEAGRI/ UNICAMP) and the Brazilian Association of Nondestructive Testing and Evaluation (ABENDI). The symposium was held in Campinas, São Paulo, Brazil, on September 17–21, 2024. This symposium was a forum for those involved in nondestructive testing and evaluation (NDT/NDE) of wood and brought together many international researchers, NDT/NDE users, suppliers, representatives from various government agencies, and other groups to share research results, products, and technology for evaluating a wide range of wood products, including standing trees, logs, structural lumber, engineered wood products, and wood structures. Networking among participants encouraged international collaborative efforts and fostered the implementation of NDT/NDE technologies around the world. The technical content of the 23rd symposium is captured in these proceedings. Full-length, in-depth technical papers for most of the oral presentations and several of the poster presentations, along with abstracts for all the oral and poster presentations, are published herein. Although the authors may have conducted peer reviews for their own papers, the papers were not peer reviewed for the proceedings and are reproduced here as they were submitted by the authors.

Keywords: Nondestructive evaluation, nondestructive testing, wood properties, wood products, logs, trees, wood structures

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