CONDITION ASSESSMENT OF MAIN STRUCTURAL MEMBERS OF

WAPAMA

- A Historic Steam Schooner

Natural Resources Research Institute
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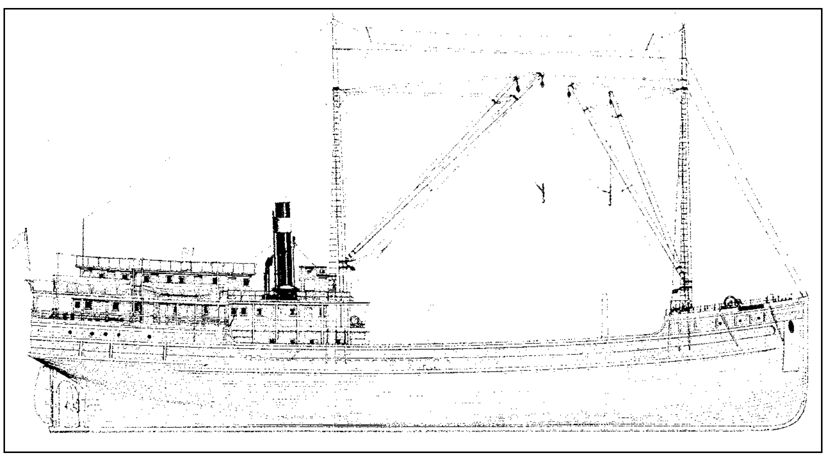

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1. Preface

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 her 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 as a National Historic Landmark (NHL) in 1984.

The wood structure of the WAPAMA has been significantly deteriorated over the years and currently resides on a barge with internal and external structural supports. Portions of the vessel are unsafe for public access. To assist in an effort of stabilizing and rehabilitating this historic vessel, we conducted a field investigation on the current physical condition of the wooden structural members. A variety of nondestructive testing (NDT) methods were employed to locate problem areas and define the severity of deteriorations on key structural members such as keelsons, keel, ceiling planking, hull frames, clamps, and main deck beams etc. This report presents the main findings from this field investigation and demonstrates the use of the state-of-the-art NDT technologies in evaluating physical and biological conditions of historic wood structures.

2. Background

The vessel WAPAMA was built in 1915 and is the last surviving example afloat of some 225 steam schooners specifically designed for use in the 19th and 20th century Pacific Coast lumber trade and coastwise service (Tri-Coastal Marine, Inc. 1986). These vessels formed the backbone of maritime trade and commerce on the west coast ferrying lumber, general cargo, and passengers to and from urban centers and smaller coastal settlements. The men who built them took advantage of plentiful timber and built ships out of wood, long after builders in most of the Western world had shifted to iron and steel construction. These wooden ships were a mainstay of the coastwise carrying trade for decades. As the sole survivor of the once numerous class, the WAPAMA was declared as a National Historic Landmark (NHL) in 1984 due to the international, national, and regional significance.

The WAPAMA is built almost entirely of old growth Douglas-fir timber, and is approximately 217 feet long and 50 feet from keel to house top, with a gross tonnage of 945 GT. The construction is unique in its use of sister frames and lack of steel strapping. The hull is single decked and characterized by a plumb stem, full bows, straight keel, moderate deadrise and an easy turn of bilge (Figure 1).

In 1979, the vessel was removed from her berth at the California State Historical Maritime Park at Hyde Street Pier and moved to a submarine pen at Hunter Point Naval Shipyard. This move to quiet water was to minimize stress on the hull. Prior to building a breakwater in the mid 1980's, the Hyde Street Pier resembled an ocean pier more than a bay pier. Winter storms, in particular, were extremely stressful on the entire fleet.

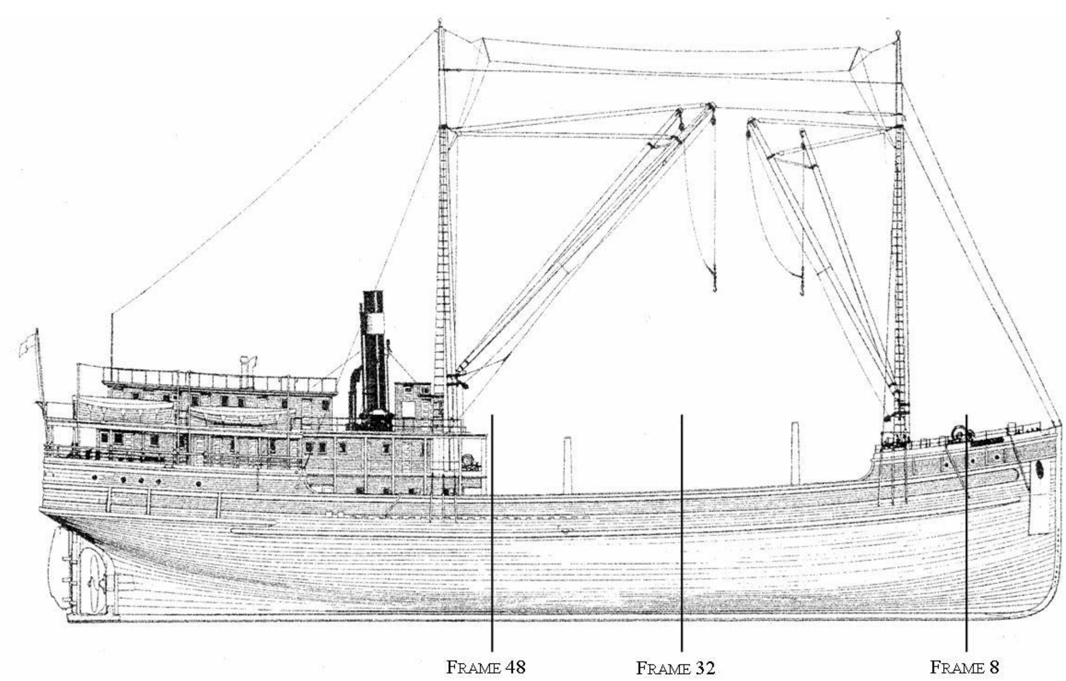


Figure 1. Starboard elevation of the WAPAMA.

In 1980, the vessel can no longer remain afloat due to severe deterioration and was hauled out of water and placed on Barge 214, berthed at Pacific Drydock Co., Alameda. Since that time she has remained on the barge and received limited maintenance. Currently, the vessel resides on Barge 214 in a flooded graving dock at the Richmond Reserve Shipyard in Richmond, California and is unsafe for public access (Figure 2).

In an effort to stabilize and rehabilitate the vessel, the National Park Service tasked the Architectural Resources Group (ARG) to undertake a condition assessment of the vessel and provide preservation recommendations.

Figure 2. A recent photo of the WAPAMA placed on Barge 214 at Richmond Reserve Shipyard in Richmond, California (Photo taken on January 2006).

3. Scope of Work

In response to the request from the Architectural Resources Group (ARG), an architectural firm based in San Francisco, CA, the Natural Resources Research Institute (NRRI) at University of Minnesota Duluth has signed a cooperative research agreement with the ARG for conducting an on-site condition assessment of key wooden structural members of the vessel. This work is aimed to assist a structural engineering analysis process on determining the possibility of stabilizing and rehabilitating the vessel.

In a recent condition survey of the vessel and barge, BMT Designers & Planners, Inc. provided visual assessment in terms of safety and stability of the vessel and conducted a preliminary structural analysis of the vessel's main features and support structures. The intent of this on-site investigation was to physically test the key wooden structure elements that were deemed structurally in critical state or unknown condition and provide scientific evidence of WAPAMA's deterioration.

On January 10, 2006, the first day on WAPAMA, the inspection team had a meeting with the following personnel who are involved in the preservation project:

Gee Hechscher, Structural Engineer, Architectural Resources Group.

Steve Hyman, Historic Preservation Specialist, San Francisco Maritime NHP, National Park Service.

Allen C. Rawl, President, Allen C. Rawl, Inc.

Trung-Son T. Nguyen, Architect, Pacific Great Basin Support Office, Facility Management Team, National Park Service.

Michael R. Bell, San Francisco Maritime NHP, National Park Service.

Per the discussion in this meting, we decided that our NDE inspection should be focused on the key strength members. With the input from Mr. Steve Hyman and Mr. Allen Rawl, we identified following features as priority target for a four-day-long on-site inspection:

1. Keelsons
2. Assistant keelsons
3. Keel
4. Ceiling planks
5. Hull frames
6. Clamps
7. Main deck beams
8. Main deck stringers
9. Waterways
10. Hanging knees
11. Pointers
12. Main supporting columns

4. Inspection Methodology

The general physical condition of the WAPAMA has been assessed and monitored at periodic intervals since the acquisition of the vessel by the State Maritime Historical Park in 1957. The inspection in previous surveys and studies were mostly done by visual observation and wood borings. The in-depth information on the deterioration levels of structure elements is limited. The focus of this investigation was to nondestructively determine the internal physical condition of the key structural elements of the vessel that are usually difficult to assess by visual inspection. Two state-of-the-art nondestructive evaluation methods that were employed in our investigation are 1) stress wave (acoustic wave) transmission technique and 2) resistance micro-drilling technique.

4.1 Stress Wave Transmission Technique

Stress wave transmission technique has been successfully used in decay detection in a variety of wood structures (Forest Products Laboratory 2000). The concept of detecting decay using this method is that stress wave propagation is sensitive to the presence of degradation in wood. In general terms, a stress wave travels faster through sound and high quality wood than it does through wood that is deteriorated or of low quality. The time-of-flight (or transmission time) of the stress wave is typically used as a predictor of the physical conditions inside the wood. By measuring the time-of-flight of a stress wave through wood member perpendicular to grain, the internal condition of the member could be determined. Detailed information on the principles of stress wave transmission technique and the guidelines for use and interpretation are given in FPL-GTR-119 (Appendix E).

4.2 Resistance Micro-Drilling

Resistance micro-drilling is also called Resistograph test. This method is being used increasingly in the field to characterize wood properties and detecting abnormal physical conditions in structural timbers. The Resistograph tool is a mechanical drill system that measures the relative resistance (drilling torque) of the material as a rotating drill bit is driven into the wood at a constant speed. It produces a chart showing the relative resistance profile for each drill path. Because it can reveal the relative density change along the drill path, it is typically used to diagnose the internal condition of structural timbers.

The drill resistance R_D is defined as

$$R_D = \frac{T}{\omega} \qquad \text{(Nm s/rad)}$$

where T is drilling torque (Nm), ω is the angular speed (rad/s).

A Resistograph tool typically consists of a power drill unit, a small-diameter drill bit, a paper chart recorder, and an electronic device that can be connected to the serial interface input of any standard PC. The diameter of the drill bit is typically very small, from 2 to 5 mm, so that any weakening effect of the drill hole on the wood cross section is negligible.

5. Inspection Procedure

5.1 General Procedure

On-site inspection of the WAPAMA was conducted by the inspection team between January 10 and 13, 2006. Following general procedure was followed during the inspection:

- Identify critical areas and key structural elements (sampling);

- Examine moisture content (moisture meter);
- Perform stress wave scanning tests in key strength members (Fakopp Microsecond Timer);
- Perform resistance micro-drilling tests on key strength members (Resistograph tool).
- Photographic documentation of inspection process and ship conditions.

Stress wave scanning and resistance micro-drilling were two primary means we used to determine the internal physical conditions of the wood members.

5.2 Stress wave scanning

Stress wave transmission test requires access of two opposite sides of a timber for attaching sensor probes. Therefore, the stress wave scanning in the WAPAMA was only conducted on the structural members that have both sides exposed and are within the reach of the inspectors. Such members included keelsons, keel, stringers, main deck beams, vertical supporting members, pointers, and hanging knees. Stress wave transmission tests were performed on these members using a Fakopp Microsecond Timer.

For the longitudinal strength members such as keelsons, assistant keelsons, keel, and main deck stringers, stress wave transmission tests (perpendicular to grain) were conducted along one, two, or three lines on the side surface. The intervals between two scanning points in the longitudinal direction varied for different members: 2 ½ ft for keelsons, 5 to 6 ft for keel and main deck stringers. Figure 3 shows a typical scanning diagram for inspecting and mapping longitudinal members with stress wave transmission times.

For vertical supporting members, pointers, main deck beams, and hanging knees, stress wave transmission tests were conducted as a spot check due to the limited available time on the ship.

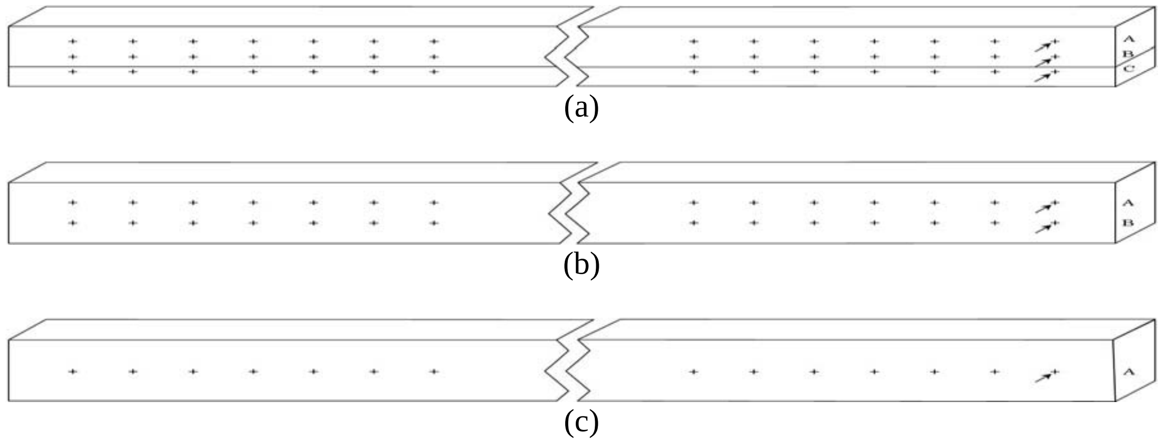


Figure 3. Scanning diagram of longitudinal strength members - (a) keelsons; (b) keel; and (c) main deck stringers.

5.3 Micro-Drilling Test

A Resistograph tool (IML-RESI F400) was used to conduct micro-drilling tests and obtain relative resistance profiles for the key structure elements. The purpose of conducting micro-drilling test was two-folds: 1) to confirm and determine the extent of the decay in critical locations or areas that have been identified by stress wave scanning; and 2) to determine the internal conditions of the key structure elements that can not be scanned using stress wave transmission techniques.

The drill was oriented so that its drilling path was perpendicular to the exposed face of the wood members. During each dill test, the relative resistance was recorded on a wax paper graph and also stored in an electronic unit. Each resistance chart was properly coded to track its drilling location in a specific member. The electronic files were transmitted to a computer after testing for further analysis. The maximum drilling depth of the tool we used is 15 inches, so the internal condition of wood beyond this depth can not be revealed.

Ceiling planks, assistant keelsons, hull frames, clamps, waterways, bulwark, and assistant stringers are the key strength members that cannot be evaluated with stress wave transmission techniques. To assess the physical conditions of these members, we selected three main sections along the length of the vessel for detail inspection with the Resistograph tool (Figure 1). The three sections selected are 1) section at frame 8; 2) section at frame 32; and 3) section at frame 48. The drilling locations at these sections are illustrated in Figures 4, 5, and 6.

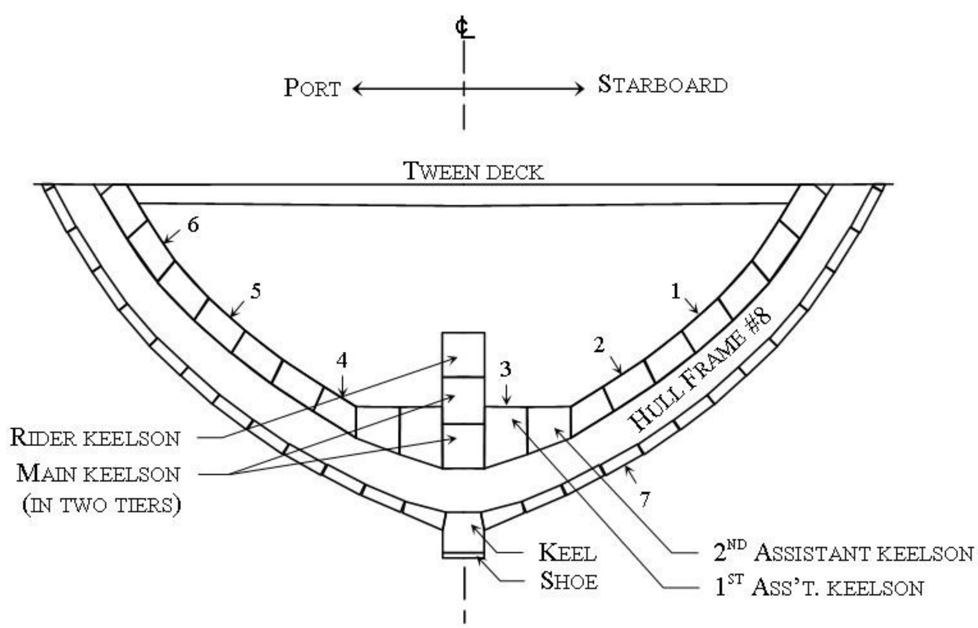


Figure 4. Schematic of drilling locations for the cross-section at frame 8.

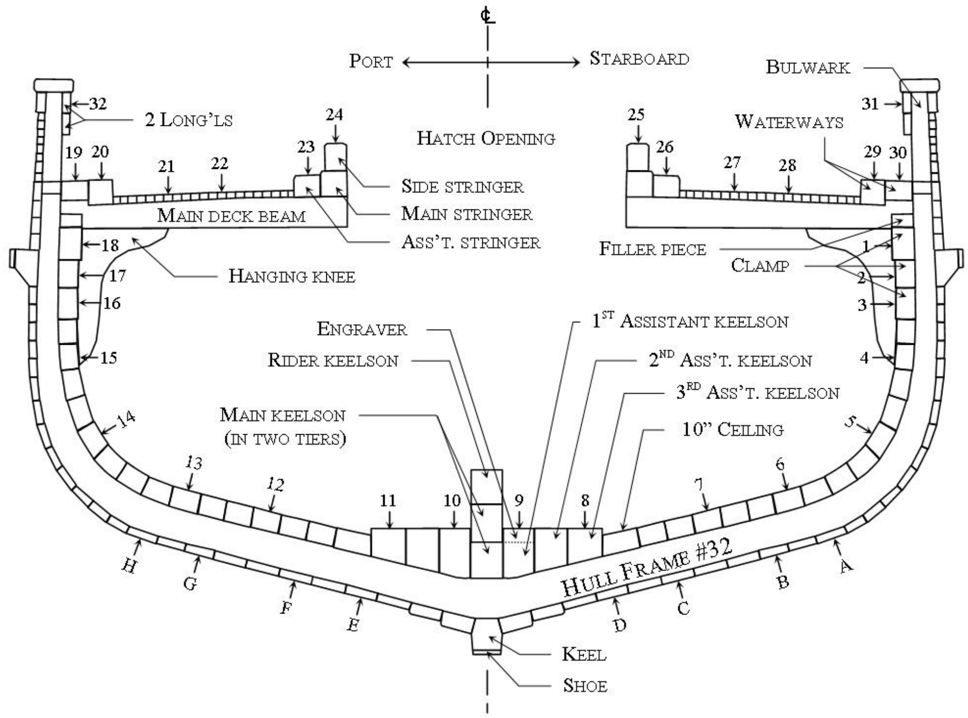


Figure 5. Schematic of drilling locations for the cross-section at frame 32.

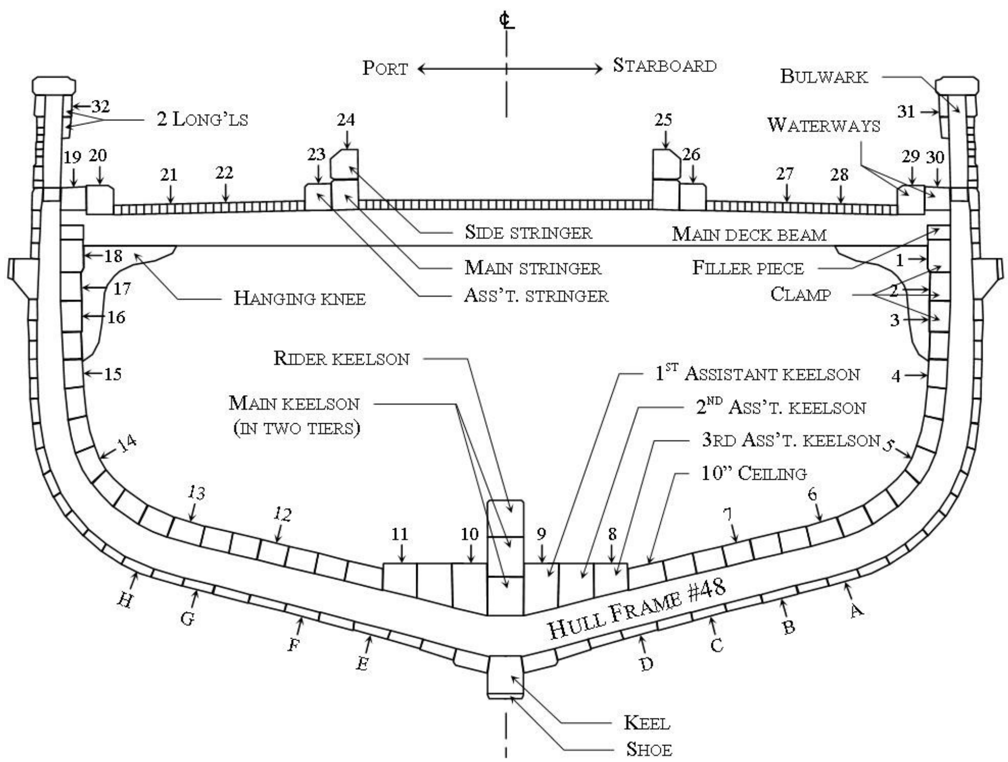


Figure 6. Schematic of drilling locations for the cross-section at frame 48.

In assisting the on-site inspection efforts, we also took a series of photographs and short videos to document the inspection process and the physical conditions of the key structure features. Photos are shown in Appendix A. Videos are recorded in a DVD accompanied with the report.

6. Main Findings

6.1 Keelsons

Keelsons are key longitudinal strength members and form the main backbone of the vessel. The keelson members in the WAPAMA include rider keelson (20 x 17 ½ in.), main keelson (20 x 37 in. in two tiers), and three assistant keelsons, port and starboard. The rider keelson and part of the main keelson (upper portion) are exposed above the top surface of the assistant keelsons and therefore are readily available for stress wave scanning. The assistant keelsons, on the other hand, only have the top face exposed. Therefore the internal condition of the assistant keelsons can only be evaluated through micro-drilling tests.

6.1.1 Rider Keelson and Main Keelson

The rider keelson and main keelson (above the top surface of the assistant keelsons) in the cargo hold were stress wave scanned along three lines (Figure 3a). Line A and B were on the rider keelson and line C was on the main keelson. The portion of the keelsons tested is between frame 7 and 48. The keelsons beyond this portion were not tested due to lack of access or difficulty to access.

Figure 7 illustrated the distribution of stress wave transmission time (SWTT) (unit: μs/ft) along the length as well as the mapping of physical conditions of the rider keelson and main keelson. The physical conditions of each test location were rated into four categories by comparing the measured SWTT with the reference SWTT and color-coded as the following:

Solid:	< 300 μs/ft
Moderate decay:	300 - 600 μs/ft
Decay:	600 - 900 μs/ft
Severe decay:	> 900 μs/ft

The deterioration of the keelsons is concentrated between frame 25 and 42 and most severe decay occurred on the main keelson timber between frame 30 and 39. This is also confirmed by resistance micro-drilling tests (Appendix C1). It is likely that rainwater got into this area through the hatch over the years due to failed weather protection and water remained trapped. The water damage in untested portion of the main keelson between frame 30 and 39 and even beyond could also be significant. Deterioration could be further extended and advanced with the current outdated weather protection.

No significant deterioration was found between frame 7 and 25 according to stress wave scanning results. The tween deck, which extends from frame 11 to the forward end of the hatch at frame 26, has apparently protected the keelsons from direct exposure to rainwater dripping from above (through main decking). The Resistograph drill test revealed isolated internal rot (5 ½ - 9 ½ in.) at the location of frame 12. Similar condition at frame 11 was reported in a 1986's survey report (Tri-Coastal Marine, Inc. 1986).

6.1.2 Assistant Keelsons

Assistant keelsons are deteriorated variously in the hold area. Resistance micro-drilling on assistant keelsons at frame 8, 32, and 48 revealed both surface decay and internal decay as shown in Table 1 (Resistograph charts are shown in Appendix C3 – C5). An area of severe deterioration is seen between frames below the hatch.

We also observed that many surface areas of the assistant keelsons are saturated with rainwater, presumably dripping from the main deck, tween deck, or the main hatch. Moisture readings collected at many locations are well above the fiber saturation point (30%), indicating the potential of further deterioration (Moisture content data is shown in Appendix D).

Table 1. Deterioration in assistant keelsons revealed by Resistograph tests.

Frame No.	Starboard		Port	
	1st Assistant keelson	3rd Assistant keelson	1st Assistant keelson	3rd Assistant keelson
8	9 ½ - 11 in. decay	n/a	n/a	n/a
32	0 – 2 ½ in. engraver	9 ½ - 10 ½ in. decay	0 - 3 in. engraver 7 - 8 ½ in. decay	0 – 1 ½ in. decay
48	All solid	0 – 1 ½ in. decay	0 – 5 ½ in. decay	1 – 1 ½ in. decay 7 – 8 ½ in. decay

6.2 Keel

Stress wave scanning and mapping of the keel was done between frame 5 and 79. The scanning pattern is shown in Figure 3b. For the convenience of quickly establishing a scan pattern, we set frame 79 (where the iron tie plate ends) as the starting point and scanning was proceeded along two lines (A and B) from aft to fore. Stress wave transmission time data was collected between the keel blocks and at six feet intervals. Figure 8 shows the distribution of stress wave transmission time (unit: μs/ft) and the mapping of physical conditions of the keel.

Moderate deterioration was found at several areas of the keel as indicated in the mapping. Although no severe decay is present in the keel, the hogging in the mid section of the ship has caused significant mechanical damages (shear failure) to the keel as evidenced by the cracks or splits along the grain. This is also confirmed by previous report that the keel was broken when the ship was placed on the Barge 214 (Tri-Coastal Marine, Inc. 1986).

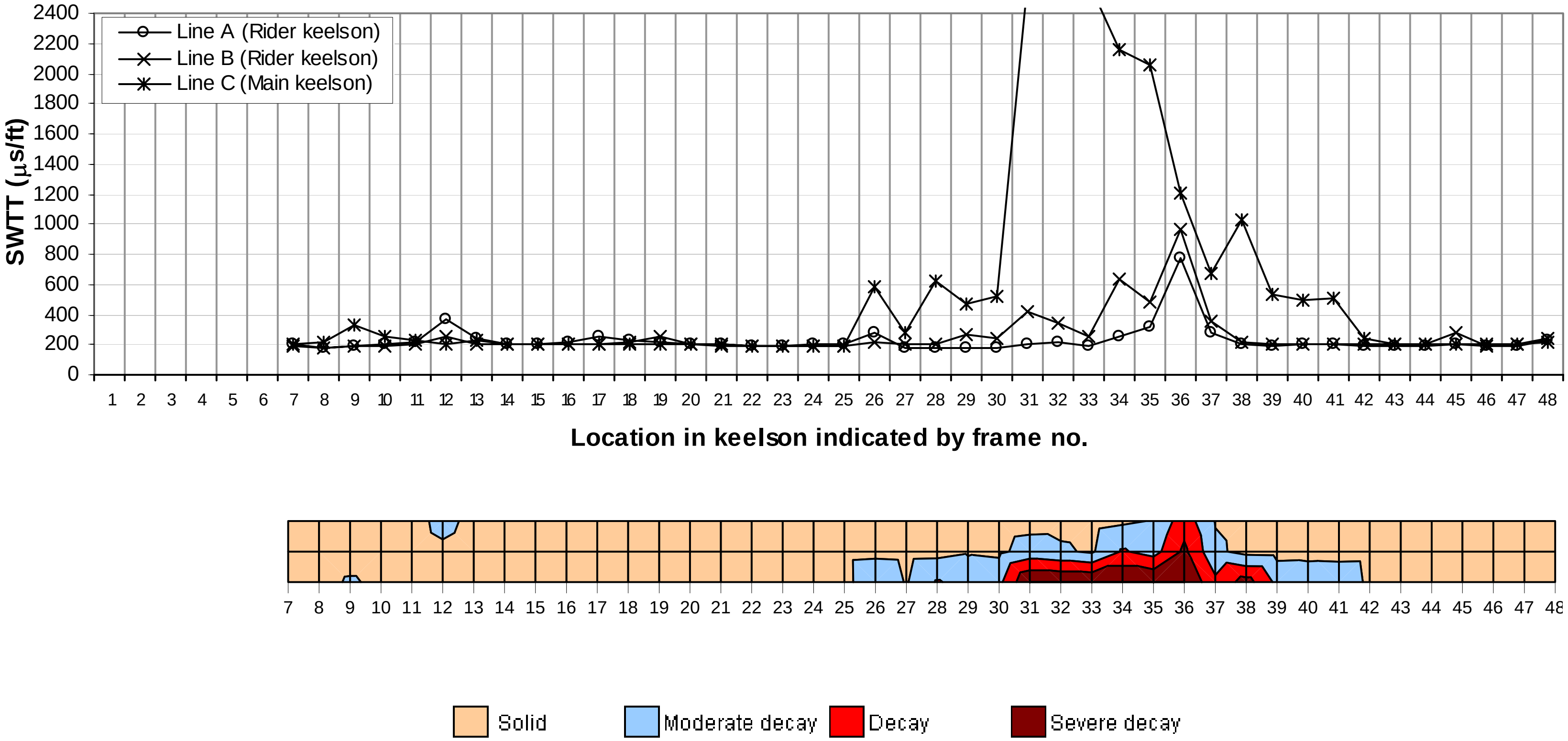


Figure 7. Distribution of stress wave transmission time (SWTT) and mapping of physical conditions of the keelsons.

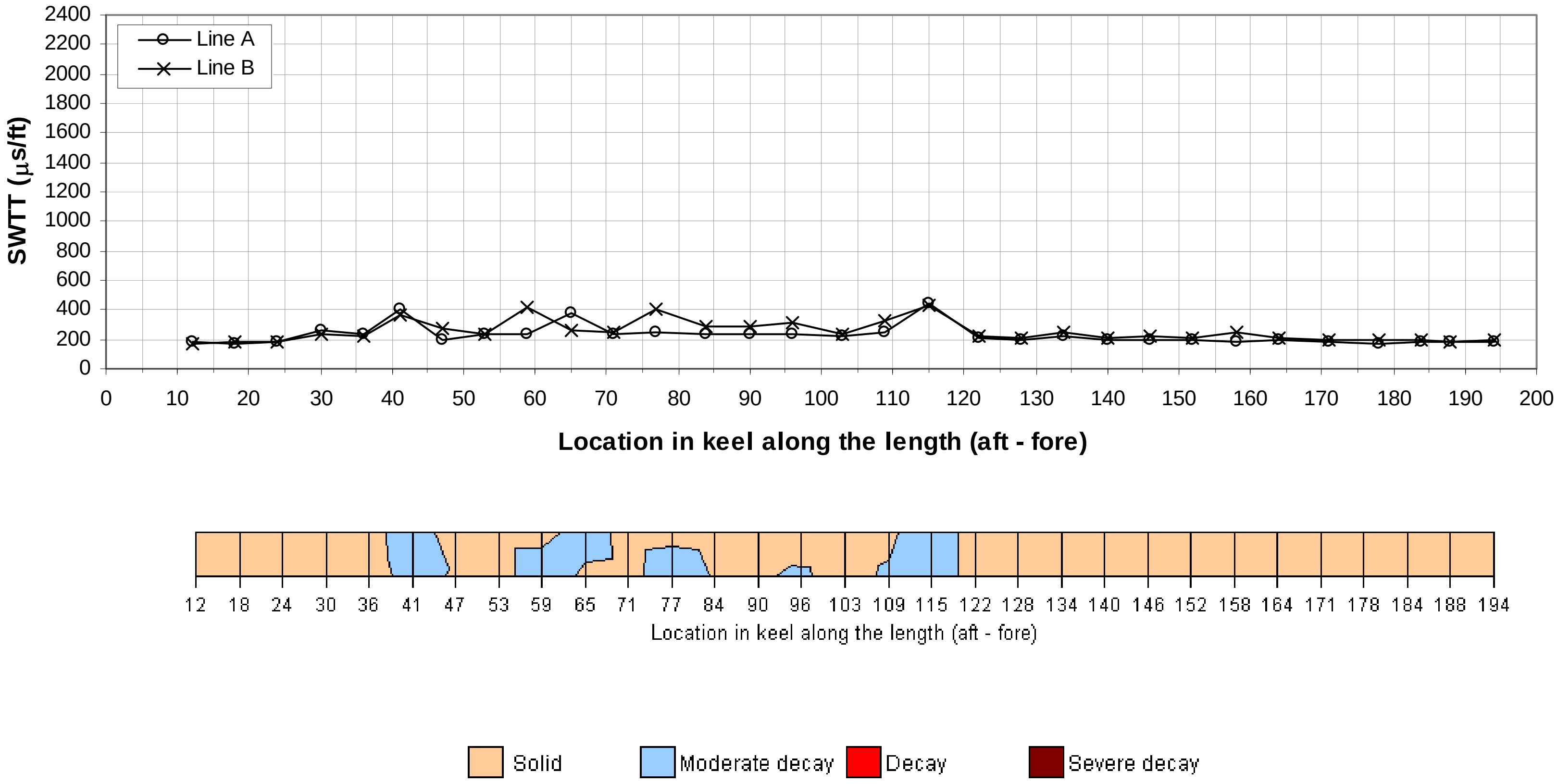


Figure 8. Distribution of stress wave transmission time (SWTT) and mapping of the physical conditions of the keel.

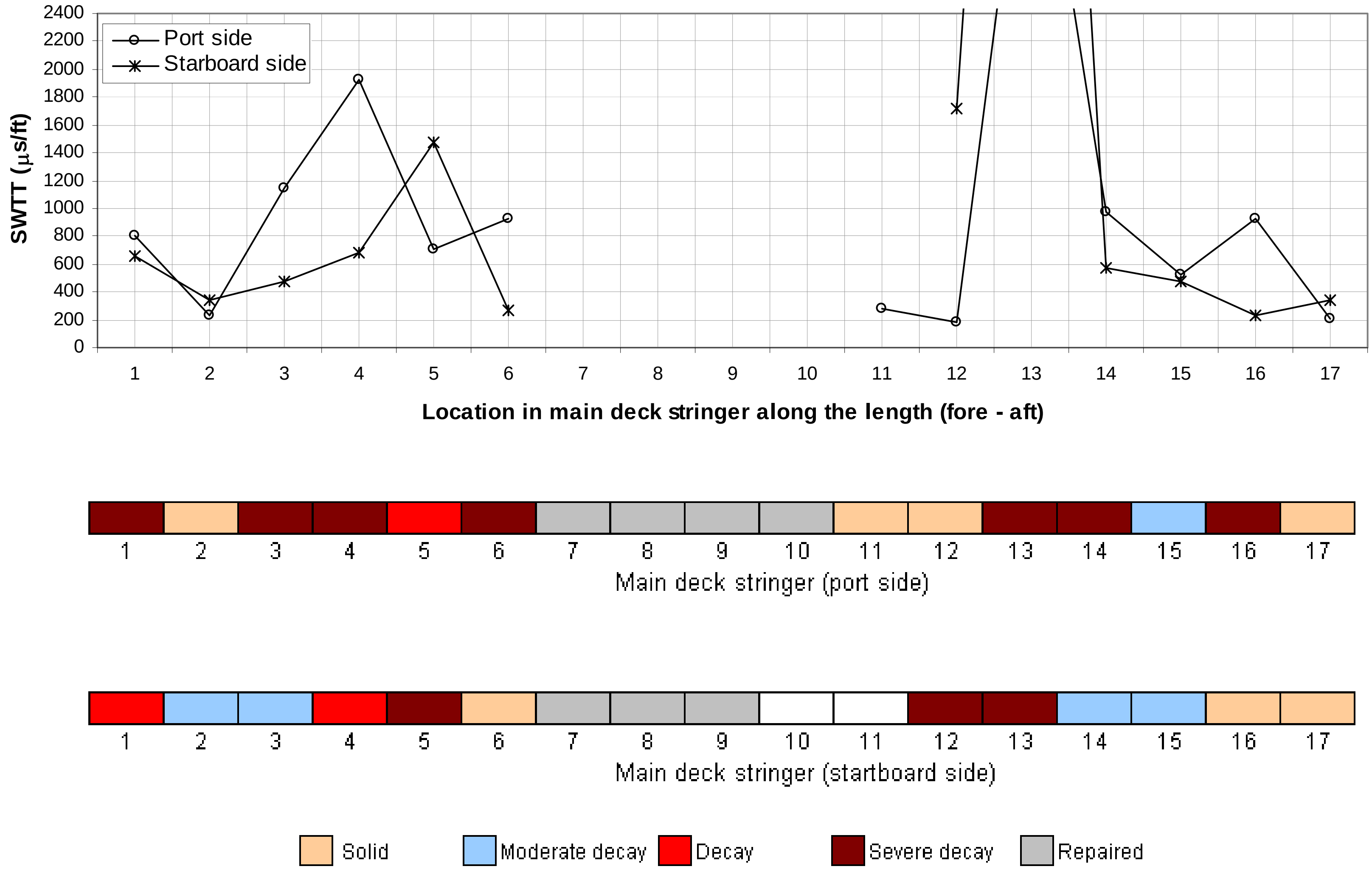


Figure 9. Stress wave transmission time (SWTT) and physical conditions of the main deck stringers.

6.3 Main Deck Stringers

The main deck stringers have lost most integrity due to severe deterioration. Visual signs of rot, splits, and checks are present in most portions of these members. To quantify the levels of deterioration, stress wave scanning was carried out on two side stringers with a less extensive interval (5 ft) and along the centerline of the member.

Figure 9 shows the distribution of stress wave transmission time (unit: μs/ft) along the length as well as the mapping of physical conditions of the main deck stringers.

6.4 Main Framing Timbers

The main framing timbers of the WAPAMA were evaluated through micro-drilling tests at three main cross-sections of the main hull assembly: 1) section at frame 8; 2) section at frame 32; and 3) section at frame 48 (Figure 1). Frame 8 is located in fore section of the cargo hold area near the vessel's bow. Frame 32 is located mid-ship area underneath the main cargo hatch. Frame 48 is located in aft portion of the cargo hold area approximately 3 ft forward of the engine room.

6.4.1 Cross-Section at Hull Frame 8

A total of seven micro-drilling resistance measurements were collected from the hull assembly at frame 8 (Figure 4). Safety concerns limited our access to the smaller area underneath the tween deck, therefore no data was collected from tween deck beams. From the interior of the vessel, five micro-drilling locations penetrated downward through ceiling planks and a portion of the hull frame. One additional micro-drilling location penetrated into the first assistant keelson (starboard). From the exterior of the vessel, one micro drilling location on the starboard side penetrated upward through strake planks and a portion of the hull frame. The thickness of the interior ceiling and/or exterior strake planking varied and resulted in differing penetration levels into the main frame members.

A schematic summary of micro-drilling resistance data collected at hull frame 8 is provided in Figure 10 (micro-drilling plots for hull frame 8 are provided in Appendix C3). Severe decay was detected at two out of seven (29%) drilling locations at this section. Most of the ceiling planks and the first assistance keelson (starboard) are in good condition, with decay present only in the ceiling plank at drill location no. 2. Moderate decay was detected in the inside upper portions of the hull frame drill locations, with severe decay present at drill location no. 2. There were visual indicators of water seepage through overhead tween and main decks that probably caused this deterioration since the WAPAMA was lifted onto barge 214.

6.4.2 Cross-Section at Hull Frame 32

A total of forty micro-drilling resistance measurements were collected from the hull assembly at frame 32 (Figure 5). Eighteen micro-drilling locations were from the interior portion of the hull assembly and penetrated into clamps, ceiling planks, and assistant keelson members. Fourteen micro-drilling locations were from topside of the main deck and penetrated into bulwarks, waterways, decking, stringers, and assistance stringers.

Eight micro-drilling locations were from the outer hull portions that were accessible from the barge deck.

A schematic summary of micro-drilling resistance data collected at hull frame 32 is provided in Figure 11 (micro-drilling plots for full frame 32 are provided in Appendix C4). Severe decay was detected at fifteen (38%) of all 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). The deterioration of the lower hull members and keelsons was mostly moderate. Deterioration ranging from decay to severe decay was detected at nearly all drilling locations drilled downward from topside main deck. The outer waterways 19 and 30 and portside main deck planks (21 and 22) showed signs of moderate decay. Deterioration ranging from decay to severe decay was detected in clamps 1, 2, and 17, ceiling planks 5, 12, and 14, the 3rd assistant keelson portside 11), and the inside upper portion of the hull frame 1, 3, 5, 14, and 17. Drillings upward into the outer hull detected mostly sound wood with only moderate decay present in the outer lower hull frame B.

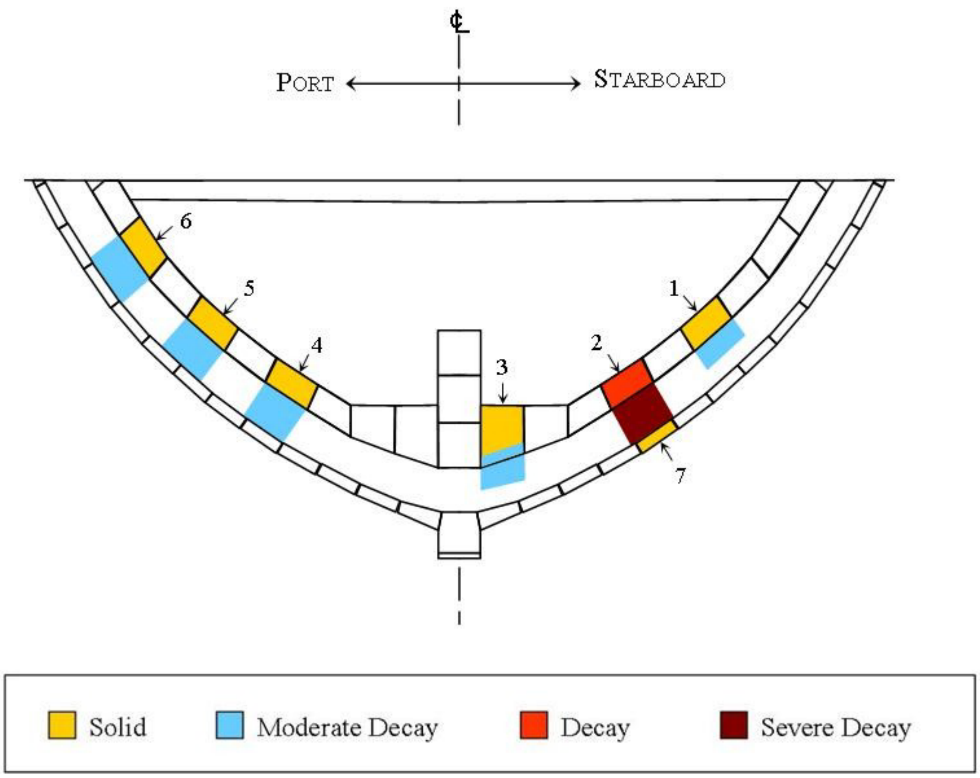


Figure 10. Mapping of physical conditions of the cross-section at frame 8 (Resistograph interpretation).

6.4.3 Cross-Section at Hull Frame 48

A total of forty micro-drilling resistance measurements were collected from the hull assembly at frame 48 (Figure 6). Eighteen micro-drilling locations were from the interior portion of the hull assembly and penetrated into clamps, ceiling planks, and assistant

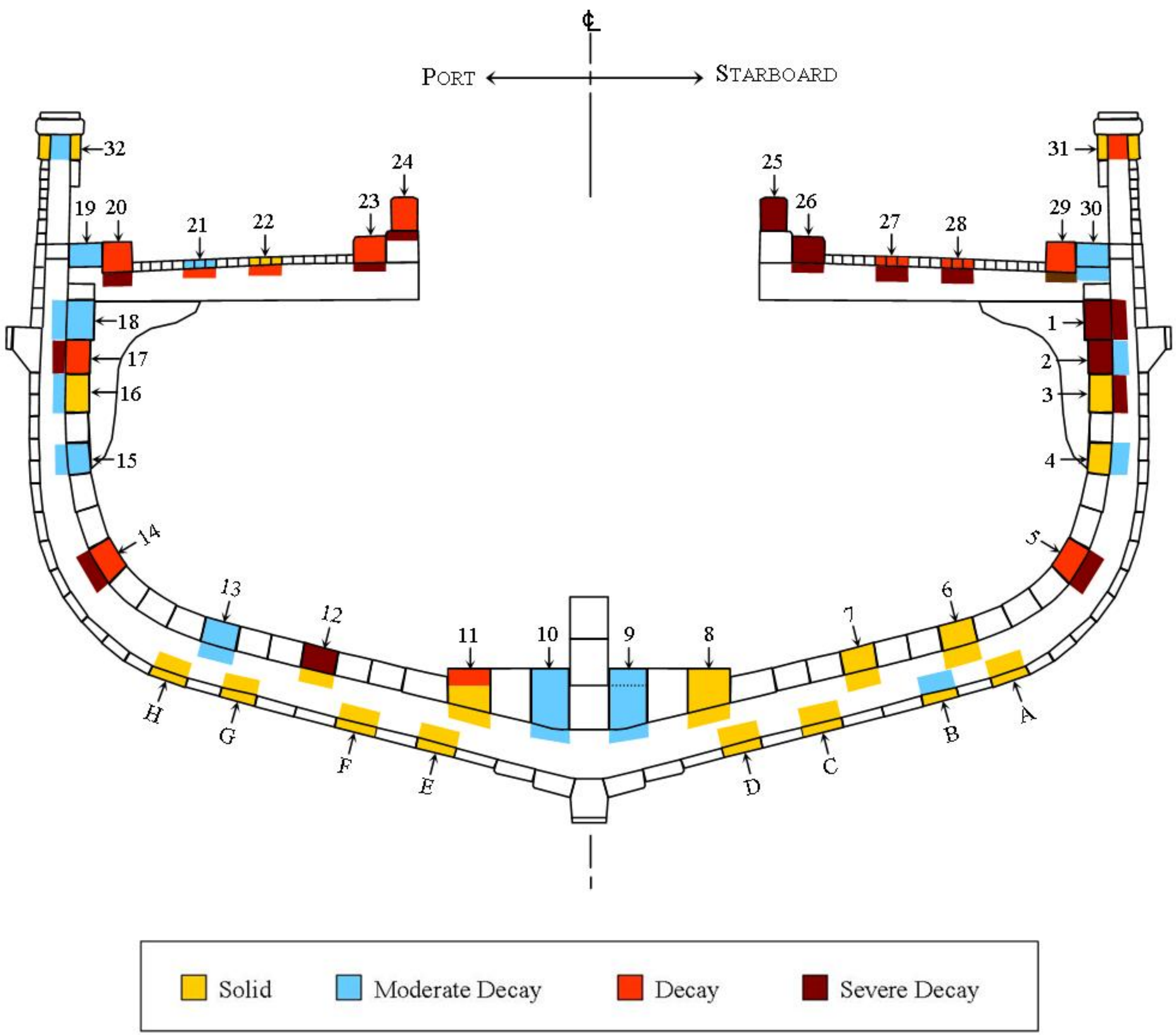


Figure 11. Mapping of physical conditions of the cross-section at frame 32 (Resistograph interpretation).

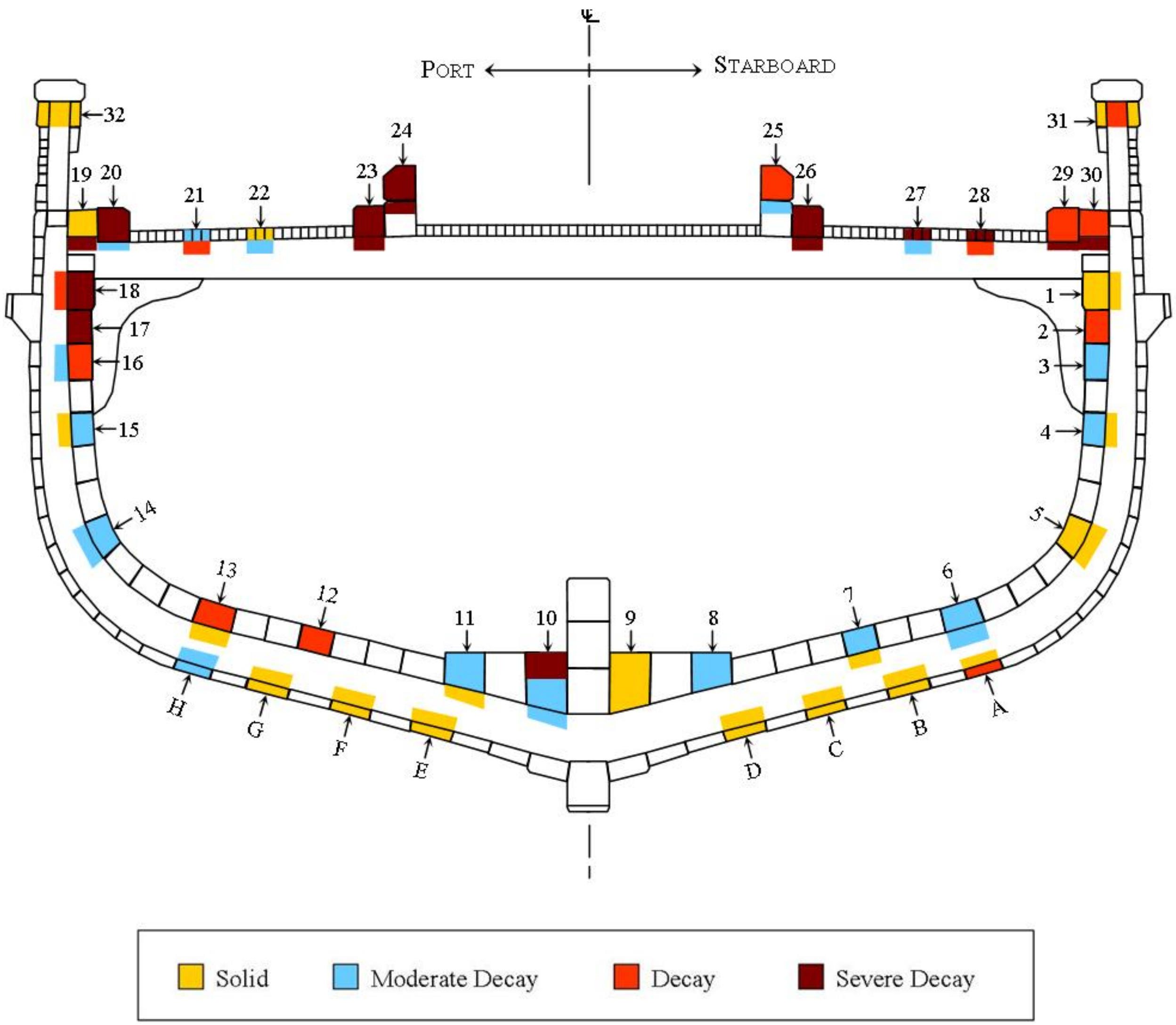


Figure 12. Mapping of physical conditions of the cross-section at frame 48 (Resistograph interpretation).

keelson members. Fourteen micro-drilling locations were from topside of the main deck and penetrated into bulwarks, waterways, decking, stringers, and assistance stringers. Eight micro-drilling locations were from the outer hull portions that were accessible from the barge deck.

A schematic summary of micro-drilling resistance data collected at hull frame 48 is provided in Figure 12 (micro-drilling plots for hull frame 48 are provided in Appendix C5). Severe decay was detected at twelve (30%) of all drilling locations with most of these areas located in the members at the main deck level (waterways, stringers, main deck planks, and main deck beams) or near the main deck level (clamps). The deterioration of the lower hull members and keelsons was mostly moderate. Deterioration ranging from decay to severe decay was detected at nearly all drilling locations drilled downward from topside main deck, except main deck plank 22. Deterioration ranging from decay to severe decay was also detected in clamps 2, 16, 17, and 18, the 1st assistant keelson portside (10), ceiling planks 12 and 13, and the inside upper portion of the hull frame 18. Drillings upward into the outer hull detected mostly sound wood with deterioration noted only in outer hull plank A and in outer hull plank/hull frame H.

6.5 Main Deck Beams

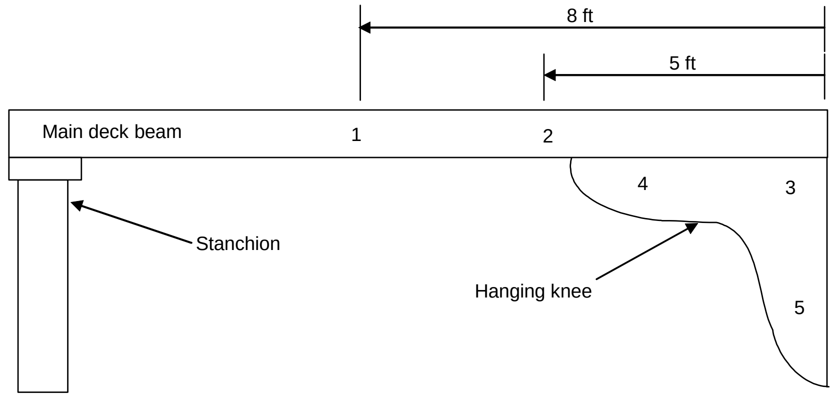
Stress wave transmission data was collected from the main deck beams at two areas on the ship's portside (Figure 13). Five test locations were located in the main deck beams above the tween deck including some at the hanging knees (Figure 13a). Five test locations were also located in the rear cargo hold between the main hatch and the cabin deck (Figure 13b). A summary of the condition of the main deck beams is provided in Table 2 and Figure 14.

6.5.1 Beams above Tween Deck

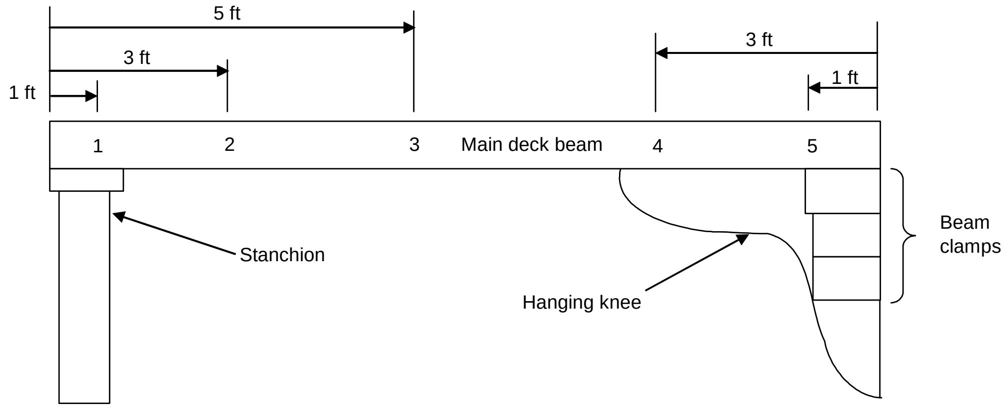
Stress wave transmission data confirmed that the main deck beams above the tween deck are in an advanced state of deterioration. Decay and severe decay were detected at all beams as indicated by the stress wave transmission times in Table 2. Beams located at or near hull frames 13, 15, 20, 22, 24, and 26 have almost lost their entire strength and are considered having zero load capacity. In addition, severe deterioration was found in the hanging knees at frames 15 and 26, which raise serious concerns on the rest of the hanging knees that have not been tested.

6.5.2 Beams at Rear Cargo Hold

The condition of the main deck beams at rear cargo hold varied. Decay to severe decay is present at the beam ends over the stanchion for most beams. The exception is the deck beam located near hull frame 44 which is sound. At the beam ends near the outer hull frame, only the beam at hull frame 40 shows decay, the beams near frames 38 and 46 shows moderate decay and the beams near 42, 44, and 48 are generally sound. The condition of the main deck beams away from their supports is mostly sound with moderate deterioration detected at some beams. The main deck beam in the best condition is at hull frame 44. Severe deterioration was present only at the end support (over the stanchion) at hull frame 42.



(a) Main deck beams and hanging knees above tween deck



(b) Main deck beams at rear cargo hold

Figure 13. Stress wave testing locations for portside main deck beams.

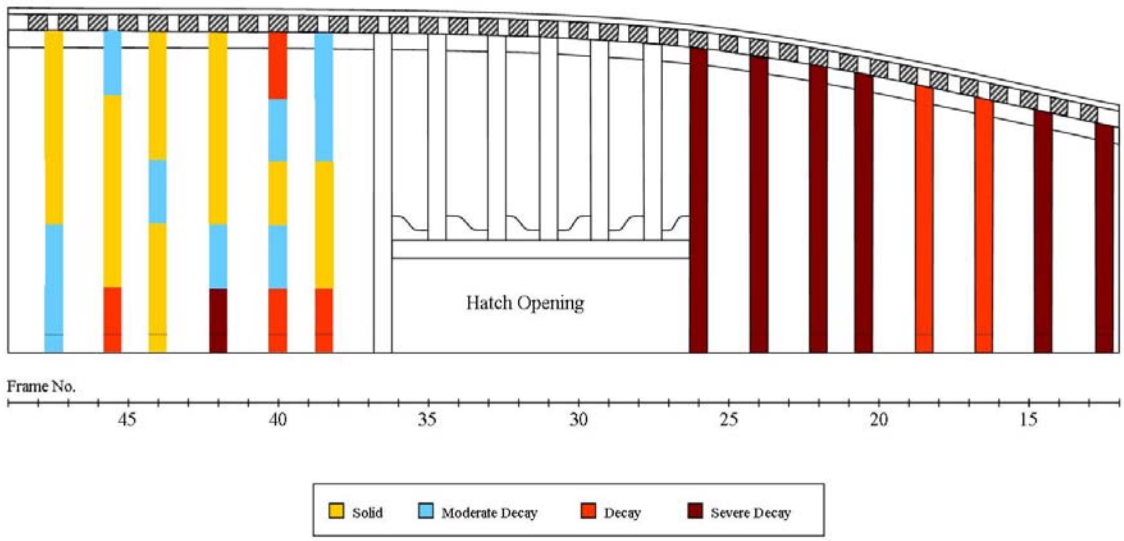


Figure 14. Mapping of physical conditions of portside main deck beams (Plan view).

Table 2. Stress wave transmission time (SWTT) and physical conditions of the portside main deck beams and hanging knees.

Portside beam location	Ref. frame no.	Relative Deterioration Level and SWTT (μs/ft)				
		Main deck beams		Hanging knees		
		1	2	3	4	5
Above tween deck	26	Severe 1051	Moderate 397	Severe 4948	Severe 2966	Severe 3050
	24	Decay 700	Severe 828	--	--	--
	22	Severe 3087	Severe 4374	--	--	--
	20.5	Severe 1551	Severe 3126	--	--	--
	18.5	Decay 759	Moderate 568	--	--	--
	16.5	Moderate 555	Decay 742	Decay 621	Severe 933	Severe 999
	14.5	Severe 4783	Severe 4997	--	--	--
	12.5	Severe 4966	Severe 5379	--	--	--
		Main deck beams				
		1	2	3	4	5
Rear cargo hold	38.5	Decay 736	Sound 221	Sound 225	Moderate 575	Moderate 378
	40	Decay 678	Moderate 442	Sound 206	Moderate 474	Decay 698
	42	Severe 969	Moderate 329	Sound 187	Sound 230	Sound 190
	44	Sound 177	Sound 207	Moderate 427	Sound 282	Sound 209
	45.5	Decay 628	Sound 254	Sound 222	Sound 249	Moderate 486
	47.5	Moderate 429	Moderate 529	Sound 204	Sound 296	Sound 292

6.6 Vertical Supporting Columns

The physical conditions of six pillars and twenty hold stanchions were evaluated with stress wave transmission technique. The pillars were located in the aft part of the ship with their length spanning the hold to the boat deck. The hold stanchions are located in the hold of the ship and support the main deck beams. Member testing was took place in two directions – the fore-to-aft direction, where the test faces were to the forward and aft of the ship, and port-to-starboard, where the test faces were to the port and starboard directions of the ship, respectively.

6.6.1 Pillars

The pillars were tested at three levels of the ship: engine/boiler room (lower level), main deck (middle level), and cabin deck (upper level). The lower level of the ship allowed access to fore-to-aft and port-to-starboard faces on all six pillars (A-F, Figure 15), whereas the main deck only allowed access to four pillars, those in the forward part of the cabin deck house (A-D), and in the fore-to-aft direction. The pillars accessible on the upper level (cabin deck house) were the two in the foremost part of the engine room (A and B), and they were only accessible in the port-to-starboard direction. Table 3 summarizes the physical conditions of the pillars evaluated by stress wave tests (the stress wave transmission data of the pillars is shown in Appendix B7).

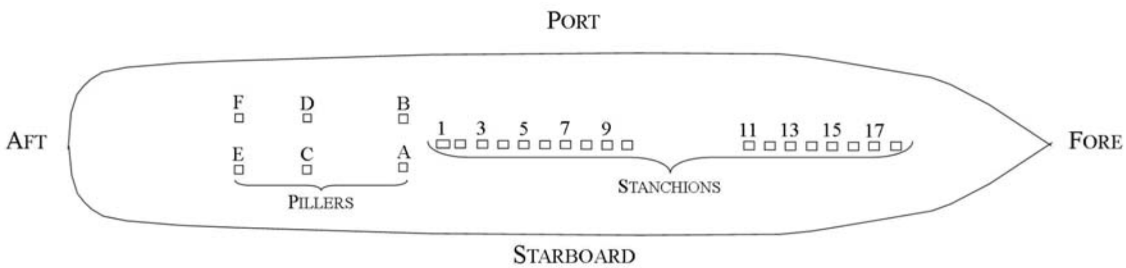


Figure 15. Location of pillars and stanchions on the ship (Plan view).

Table 3. Physical conditions of the pillars evaluated by stress wave tests.

Pillar	Deck Level		
	Lower	Middle	Upper
A	Moderate	Decay	Solid
B	Moderate	Decay	Solid
C	Decay	Moderate	Not accessible
D	Moderate	Solid	Not accessible
E	Solid	Not accessible	Not accessible
F	Solid	Not accessible	Not accessible

Deterioration is present in most pillars, but varies at different levels (lower, middle, and upper). Pillars A and B show moderate deterioration in the lower level, decay in the middle level, and are sound in the upper level. Pillars C and D have areas of moderate deterioration and decay in the lower and/or middle level, while pillars E, and F are found in sound condition in the lower level. Since the pillars E and F could only be accessed and tested at one level of the ship, the testing results are not conclusive for the entire members.

6.6.2 Hold Stanchions

The hold stanchions were first visually assessed for deterioration, then a subset of the members was spot-checked with stress wave transmission testing. The hold stanchions tested were numbers 1-3, 5, 7-10, 13-15, 17, and 20 (Figure 15). Hold stanchions 1, 2, and 3 were found to have moderate decay, with stress wave transmission times ranging from 326 to 584 μs/ft. The remaining hold stanchions were found to be solid with stress wave transmission times ranging from 179 to 200 μs/ft.

6.7 Pointers

The pointers tested were the second pointers in the front of the ship accessible by the tween deck in the hold. There is one pointer on each side of the boat and they were labeled as the port and starboard pointers. The pointers were spot-checked with stress waves at 4-ft. intervals beginning at the foremost part of the member. Results show that the pointers are generally in a sound condition. The aftmost 4 feet on the portside pointer and the aftmost 8 feet on the starboard pointer had a large crack that resulted in moderate levels of deterioration, but the remaining length of each member was solid. Stress wave transmission times ranged from 190 to 287 μs/ft in solid areas and from 460 to 518 μs/ft in moderately decayed areas.

7. Summary

A general condition assessment of the historic steam-schooner, WAPAMA, was conducted during a four-day period in January 2006. 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, and 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 resistance micro-drilling were the primary methods used in this investigation, coupled with visual inspection and moisture content determination.

7.1 Condition of Structural Components

7.1.1 Keelsons

The rider keelson and main keelson (top-tier) were evaluated between frame 7 through 48 with stress wave scanning and resistance micro-drilling. Advanced deterioration of the keelsons was concentrated under the main hatch area. The rider keelson was deteriorated between frame 30 through 39, and the main keelson (top tier) was deteriorated between frame 25 through 42. No significant deterioration was detected in the keelsons under the tween deck between frame 7 and 25. Assistant keelsons were evaluated with resistance micro-drilling (topside downward) at frames 8, 32, and 48. Resistance plots indicated only isolated pockets of moderate decay.

7.1.2 Main Deck Stringers
The main deck stringers were spot-checked with stress-wave timing and resistance micro-drilling. Severe deterioration was confirmed in both side stringers and assistant stringers. Overall, the main deck stringers have lost nearly all structural integrity.

7.1.3 Waterways and Bulwarks
Waterways and bulwarks were evaluated at several locations with resistance micro-drilling at the main deck. Most severe deterioration was present in the waterways, while many of the bulwarks had moderate to severe decay.

7.1.4 Keel
The keel was evaluated at 6 ft intervals (between the keel blocks) with stress-wave timing and spot-checked with resistance micro-drilling. Moderate deterioration was present at several locations in aft half of the keel. Visual signs of large splits and cracks may indicate that the keel was broken while being lifted onto barge 214.

7.1.5 Hull Assembly
The hull assembly was evaluated at frames 8, 32, and 48 using resistance micro-drilling techniques. The condition of the hull assembly at frame 8 is generally good, with moderate decay present in the ceiling and framing timbers. Severe deterioration was confirmed at one location near the assistant keelson with both inboard and outboard drilling data. The condition of the lower hull assemblies at frame 32 and 48 is good with minor pockets of decay present at a few locations. All clamps and upper framing timbers at frames 32 and 48 have moderate to severe decay present.

7.1.6 Main Deck Beams
The main deck beams at the portside of the vessel were spot-checked with stress wave timing. Severe deterioration was found present in nearly all main deck beams above the tween deck. Test results indicate that these beams have lost entire structural integrity and have potential to collapse in the near future, which poses a significant safety hazard. The main deck beams at the rear cargo hold area are mostly sound, with moderate to severe decay found at the end support areas.

7.2 Condition of the Vessel by Areas

7.2.1 Area Under Cabin Decks
Findings for the aft portion of the vessel beneath the cabin decks were largely based on visual assessment. These areas appeared to be generally in good condition as they were similarly reported in the 1986 condition assessment (Tri-Coastal Marine, Inc. 1986).

7.2.2 Main Cargo Hold to Tween Deck

Findings for the midship portion of the vessel extending from the cabin deck to forward hatch side were largely based upon NDE techniques. Significant areas of decay were noted in the following longitudinal structural components: the portion of the rider and main keelson under the main hatch, main deck stringers, and waterways. Significant areas of decay were noted in the following transverse structural components: clamps and framing timbers near waterways, main deck beams, and main deck planking. The lower hull assembly at frames 32 and 48 showed isolated pockets of significant decay.

7.2.3. Tween Deck Forward

Findings for the forward portion of the vessel from the main hatch forward were largely based upon NDE techniques. Significant areas of decay were noted in main deck stringers, waterways, bulwarks, and main deck beams. The main deck beams located over the tween deck are in bad condition with severe internal decay. The lower hull assembly at frame 8 showed an isolated pocket of severe decay.

8. Recommendations

The following recommendations are provided based upon our findings from this on-site investigation:

Repair or replacement of the temporary roof shelter over the main deck is recommended. The current weather protection over the main deck is clearly ineffective in preventing rainwater as evidenced by water seepage from the underside vents in the outer hull. Moisture is saturating several key structural components on the main deck and in the cargo hold. An effective roof will prevent further decay until restoration work is initiated.

Should the decision be made to disassemble the WAPAMA, more intensive NDE scanning and analysis of key structural components is recommended during the restoration process. This will provide more accurate assessment of the extent of internal deterioration and can help in making decisions to retain key components or to salvage portions of key components for non-structural members elsewhere in the restored vessel.

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Appendix A. Photographs of the WAPAMA.

Appendix B. Stress Wave Data Summary.

Appendix C. Resistance Micro-Drilling Plots.

Appendix D. Moisture Content Data Summary.

Appendix E. Stress Wave Timing Nondestructive Evaluation Tools for Inspecting Historic Structures – A Guide for Use and Interpretation.