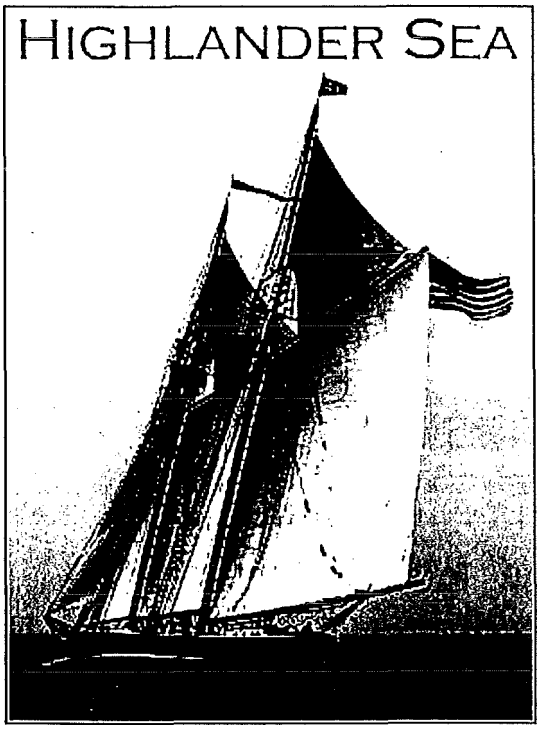
CONDITION ASSESSMENT OF THE MASTS OF HIGHLANDER SEA

By

Xiping Wang, Ph.D.
Natural Resources Research Institute
University of Minnesota Duluth

and

James P. Wacker, P.E.
USDA Forest Service, Forest Products Laboratory



November 2006
Project No. 187-2419
NRRI/TR-2006/24

Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Highway
Duluth, MN 55811

Prepared for:
Captain Micah David Faust-Allnutt
Highlander Sea, Inc./Acheson Ventures
2336 Military St.
Port Huron, MI 48060

Background

The Highlander is a 154 ft Grand Bank Topsail Schooner with a round wine glass bottom and full keel, overhanging transom design and Carvel wood planked construction. She was built in 1924 at the Yard of James and Tarr Shipwrights of Essex, Massachusetts. The vessel's design was created by Starling and Burgess. The Highlander sails with a fixed core complement of Master, Mate, Botswain and Cook and a sailing complement of cadets.

Dedicated to showcasing the marine lore of Port Huron, Michigan and the Great Lakes region, Acheson Ventures, LLC purchased Highlander Sea for her new role as Port Huron's flagship ambassador. Today, Highlander Sea offers opportunities for teamwork, character development, and community citizenship for the people of Port Huron, in particular its youth, through leadership and training. As Port Huron's flagship, the ship berths in Port Huron, sails the Great Lakes and Eastern Seaboard, and is available for public tours, educational programs, and special events.

Specifications of Highlander Sea:

Sparred length:	154 ft
LOA:	116 ft
LOD:	126 ft
LWL:	100 ft
Draft:	14 ft
Beam:	25.5 ft
Rig height:	131 ft
Freeboard:	3 ft 8 in.
Sail area:	9728 square feet
Tons:	140 GRT
Power:	Twin Detroit diesel, 250 hp each
Hull:	White oak

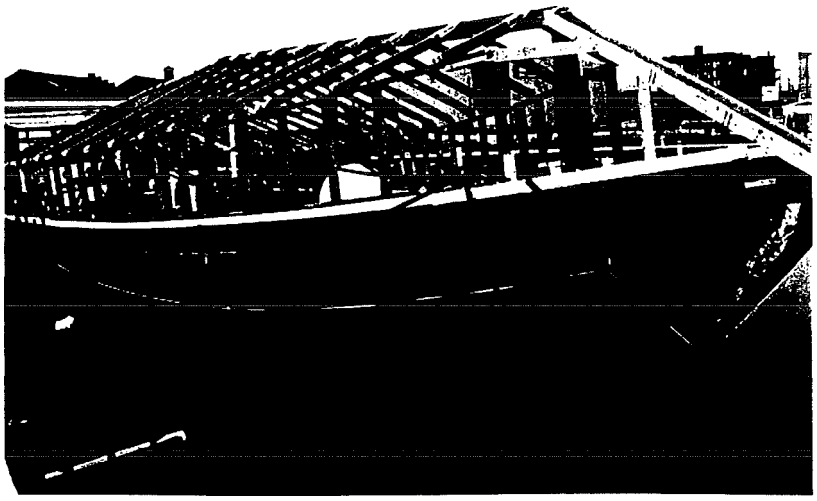


Figure 1. A recent photo of the Highlander Sea berthed at Port Huron, MI (In preparation for winter season. The masts were removed and staged in a warehouse).

Scope of Inspection

In response to the request from Mr. Micah David Faust-Allnutt, the Captain of the Highlander Sea (Highlander Sea Inc./Acheson Ventures), the Natural Resources Research Institute (NRRI) of University of Minnesota Duluth has signed a service agreement for conducting an on-site condition assessment of two lower masts of the Highlander Sea. The masts in use now have been in service since 1971, with a couple of overhauls performed in the 1990's. Currently, the masts are removed from the ship and staged in a warehouse for routine maintenance. This inspection was aimed to assess the physical condition of the main mast and fore mast of the Highlander Sea and evaluate their serviceability in terms of soundness and structural performance.

Inspection Team

Dr. Xiping Wang, Senior Research Associate of the Natural Resources Research Institute (NRRI), University of Minnesota Duluth and General Research Engineer at the USDA Forest Products Laboraotry, Madison, Wisconsin.

James P. Wacker, P.E., Research General Engineer of the USDA Forest Products Laboratory, Madison, Wisconsin.

Shanqing Liang, Visiting Graduate Student from the Chinese Academy of Forestry, Beijing, China, intern at the USDA Forest Products Laboratory.

Inspection Methodology

Inspection methods employed in this investigation included visual, stress wave scanning, and resistance micro-drilling techniques. Stress wave scanning and resistance micro-drilling are the state-of-the-art nondestructive testing techniques for assessing physical conditions of wood structures. These NDT techniques have been used by the team to conduct condition assessment in many historic structures, including wooden ships. The concepts of the techniques are briefly described here.

Stress Wave Scanning

Stress wave scanning (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 (Forest Products Laboratory 2000).

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.

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 1 to 3 mm, so that any weakening effect of the drill hole on the wood cross section is negligible.

Inspection Protocol
On-site inspection of the masts was conducted by the inspection team on November 8, 2006. The established protocol for this inspection was as follows:

1. Visually identify surface defects (checks, splits, decay) and mechanical damages of the masts;

2. Measure the size (width, depth, and length) of major checks using feeler gauges, rulers and resistance drill;

3. Evaluate soundness (internal conditions) of the masts through intensive stress wave scanning along the whole length;

4. Conduct resistance micro-drilling test using a Resistograph tool at critical areas identified by stress wave scanning.

A stress wave scanning diagram was created assigning identification numbers to each scanning point in the masts (Figure 2). Stress wave scanning was performed on the masts using a Fakopp Microsecond Timer, with an interval of 1 ft between two scanning points. At each scanning point, measurements were conducted in two directions, A-A: top-down (vertical); B-B: side-side (horizontal).

Stress wave transmission test requires access of two opposite sides of the mast for attaching sensor probes. Most parts of the main mast and fore mast were accessible during inspection. However, there were several locations in both masts where some attachments limited accessibility. Those locations were either not tested or tested in only one direction.

A Resistograph tool (IML-RESI F400) was used to conduct micro-drilling tests and obtain relative resistance profiles at some critical locations on the masts. The purpose of

conducting micro-drilling tests 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 some locations that can not be tested using stress wave techniques.

Test Results and Observations

The main mast and fore mast of the Highlander Sea are both Douglas-fir, according to the Captain of the Highlander Sea. The main mast is 94 ft in length with a maximum diameter of 19 ¾ inches. The fore mast is just under 80 ft with a maximum diameter of 18 ½ inches.

The distributions of stress wave transmission time (unit: μs/ft) along the length of the masts are shown in Figure 3 and 4. Figure 5 is a mapping of the physical conditions of the masts interpreted from the test results and observations. *Appendix A* documents problem areas of both main mast and fore mast. The resistance profiles of some critical locations in the masts are shown in *Appendix B*.

Main Mast

Stress wave scanning results of the main mast revealed areas of moderate deterioration in the lower portion (0 – 2', 11 – 15') and the upper portion (83' – 90') of the mast. Severe decay pockets were found between 75' and 77', which is around the metal mast band as shown in *Appendix A – Photo 4*. This finding has been confirmed by resistance micro-drilling results as shown in *Appendix B*. Moisture measurements at this location indicated a high moisture condition (30 to 50% MC), which is continuously promoting further development of internal decay.

Several locations of the main mast were not tested (or only partially tested) due to lack of accessibility. These areas include 16' – 17' (rope attached), 63' – 64' (copper flashing), 72' – 74' (copper flashing), and 77' – 82' (upper-mast anchors). One can not assume decay is absent in those areas. Especially in the area of 72' – 74', where incipient to moderate decay might have been developed since it is near the severe decay zone and it has high moisture contents (42, 37, and 33% at 1, 2, and 3 inches in depth).

Fore Mast

Stress wave scanning results of the fore mast revealed areas of moderate deterioration in the upper portion (between 70' – 80') of the mast. Remaining areas seemed to remain intact, with no significant decayed regions.

Extensive deep checks, ranging from ¼" to ½" wide and up to 7" deep, were observed between 15' and 39' from the butt of the fore mast (*Appendix A – Photo 7-9*). Table 1 lists the deep checking measurements and their respective locations along the fore mast. The presence of these large checks in the fore mast increases the likelihood of structural failure and presents an immediate safety concern.

For checking to significantly affect the structural integrity of a bending member, their depth must generally penetrate more than 20 percent of the cross-sectional diameter

(AITC 2004). For the fore mast of the Highlander Sea, a large number of deep checks (up to 7 inches deep) reduced the mast's cross-section by approximately 36 percent. Since these deep checks exceed the 20 percent rule and located within a high-stress region in the fore mast, significant strength reductions are warranted in torsion and bending capacities.

Table 1. Measurements of major deep checks on the fore mast.

Distance from butt end (ft)	Measurements of major checks	Observations
0 – 6	¼" – ½" wide, up to 6" deep	Appendix A, Photo 6
15 – 19	¼" wide, 5 – 7" deep	
18 – 25	Long deep crack, ½" wide, up to 7" deep	Appendix A, Photo 7, 9
24 – 27	¼" – ½" wide, 5" deep	
25 – 30	½" wide, 7" deep	
31 – 39	¼" wide, 2" – 6" deep	Appendix A, Photo 8

Conclusions and Recommendations

Stress wave scanning and resistance micro-drilling revealed severe decay pockets between 75' and 77' in the main mast (*Appendix A – Photo 4*). The exact size and shape of the internal decay can not be determined with limited tests, but the resistance profile showed decay up to 5 in. deep. The current high moisture condition at this area continues to promote further development of internal decay. The location and magnitude of this decay constitutes an immediate concern to the performance and safety of the main mast.

Extensive deep checks are present in the fore mast between 15' and 39' from the butt of the mast. The size of the checks ranges from ¼" to ½" wide and up to 7" deep (*Appendix B – Photo 7 - 9*). The depth of the checks exceeds 20 percent of the cross-sectional diameter, which could cause significant strength reductions in terms of torsion and bending capacities.

Based on the findings from this investigation (Figure 5), and the fact that the masts have undergone some significant rehabilitations in the 1990's, we recommend that both main mast and fore mast of the Highlander Sea be removed from service and replaced with new masts.

References

AITC. 2004. Technical Note 18 – Evaluation of checking in glued laminated timbers. Centennial, CO: American Institute of Timber Construction. 12 p.

Forest Products Laboratory. 2000. Stress wave timing nondestructive evaluation tools for inspecting historic structures - A guide for use and interpretation. Gen. Tech. Rep. FPL-GTR-119. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 15p.

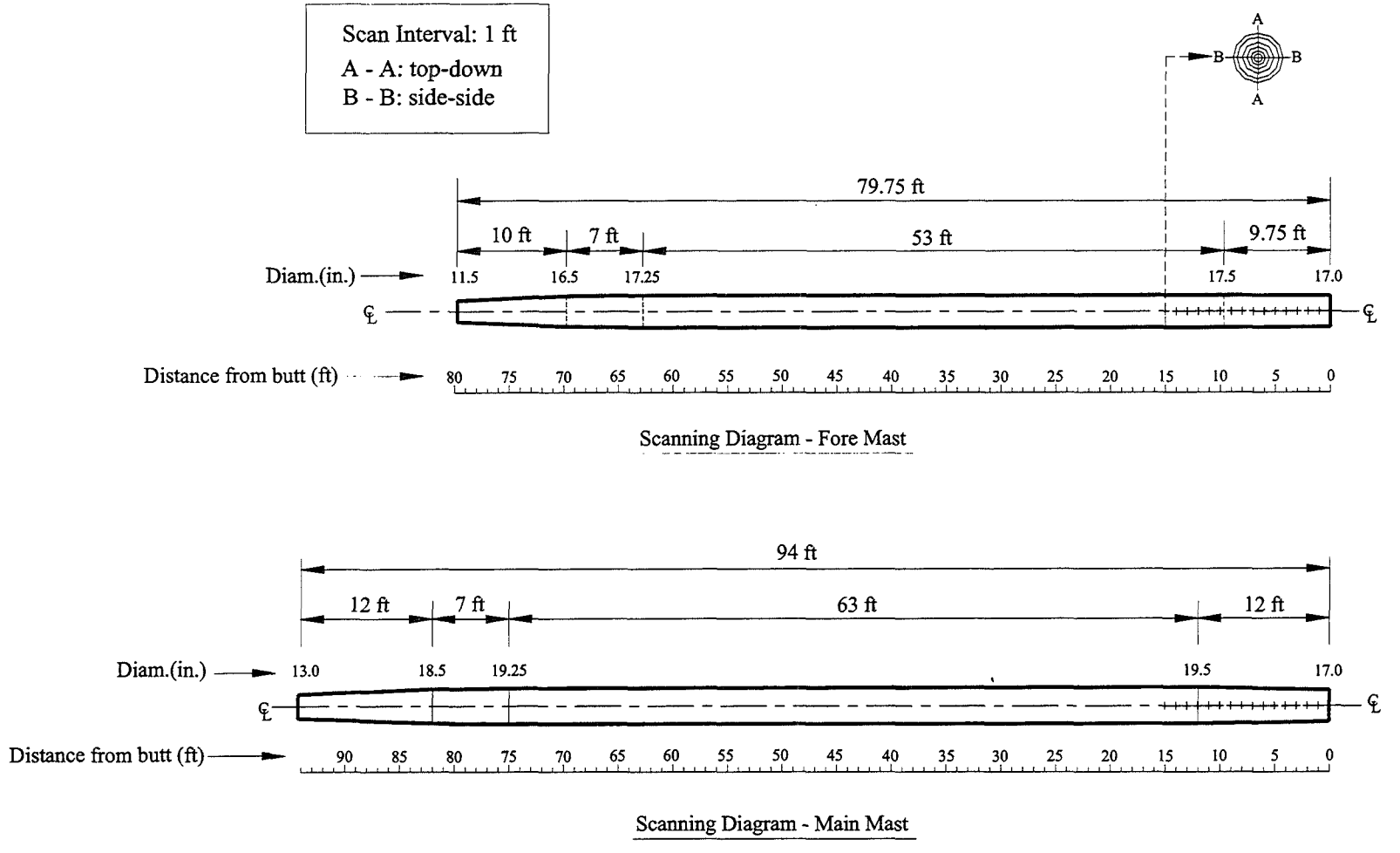


Figure 2. Diagram of stress wave scanning on the masts.

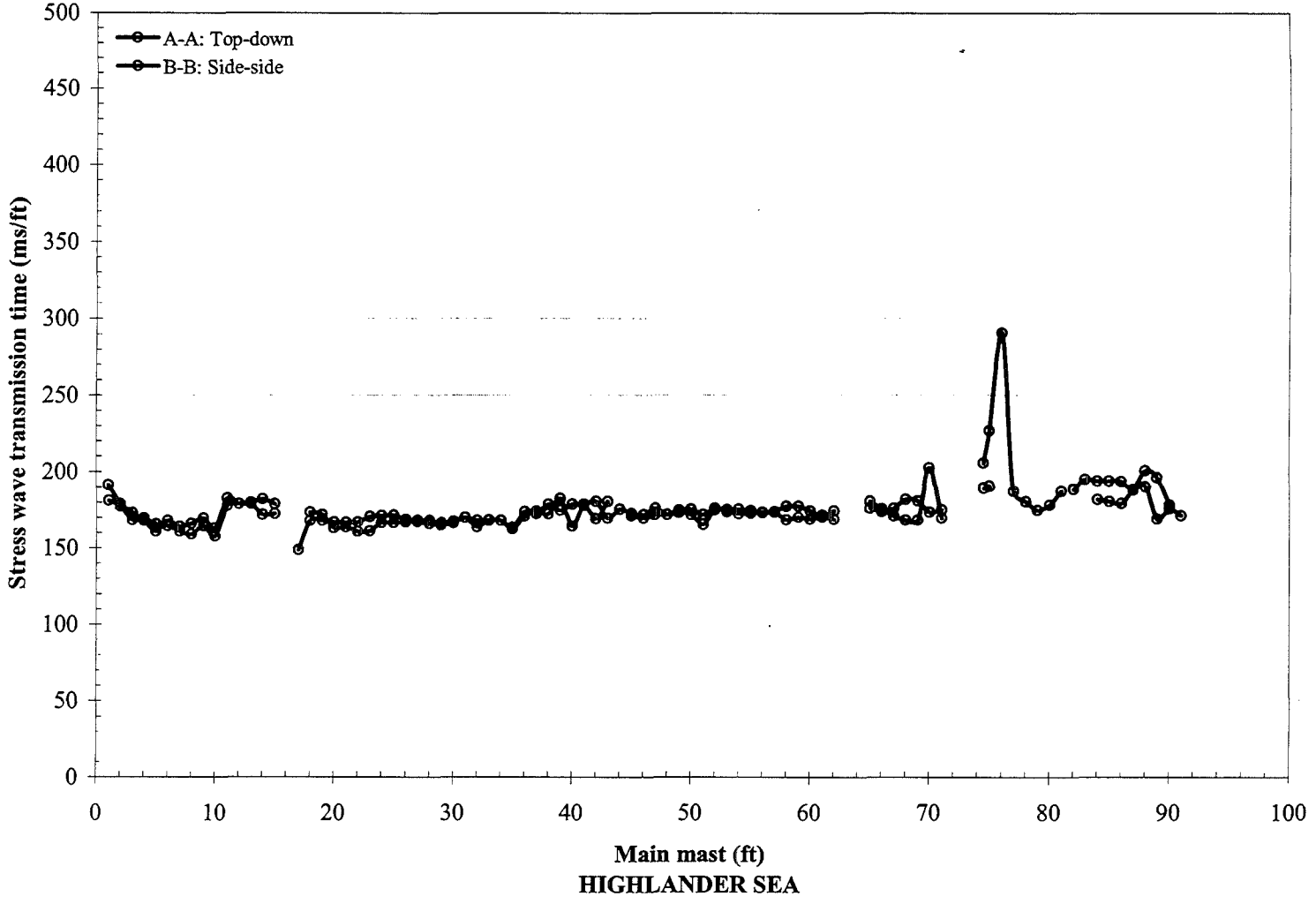


Figure 3. Distribution of stress wave transmission time of main mast.

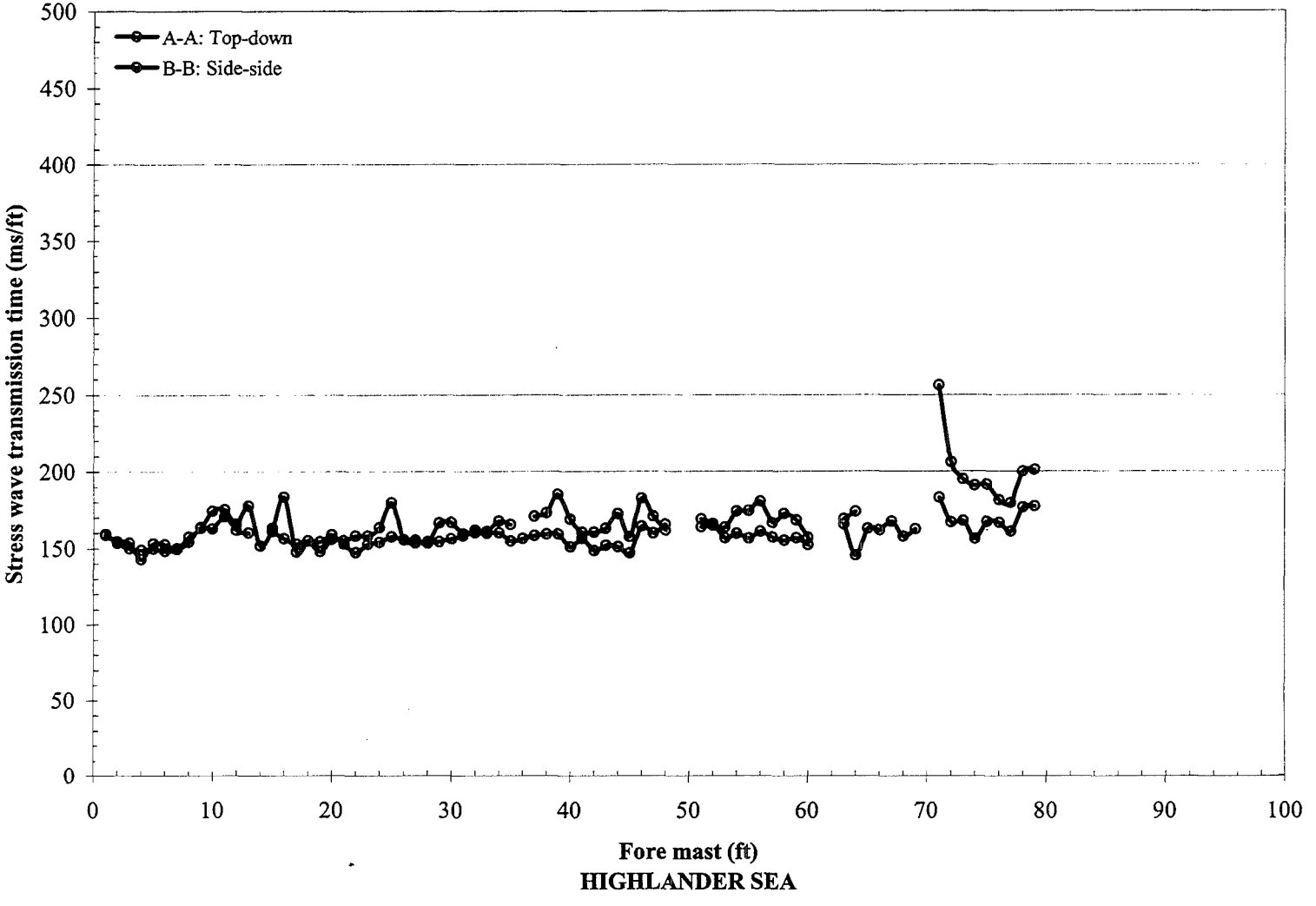


Figure 4. Distribution of stress wave transmission time of fore mast.

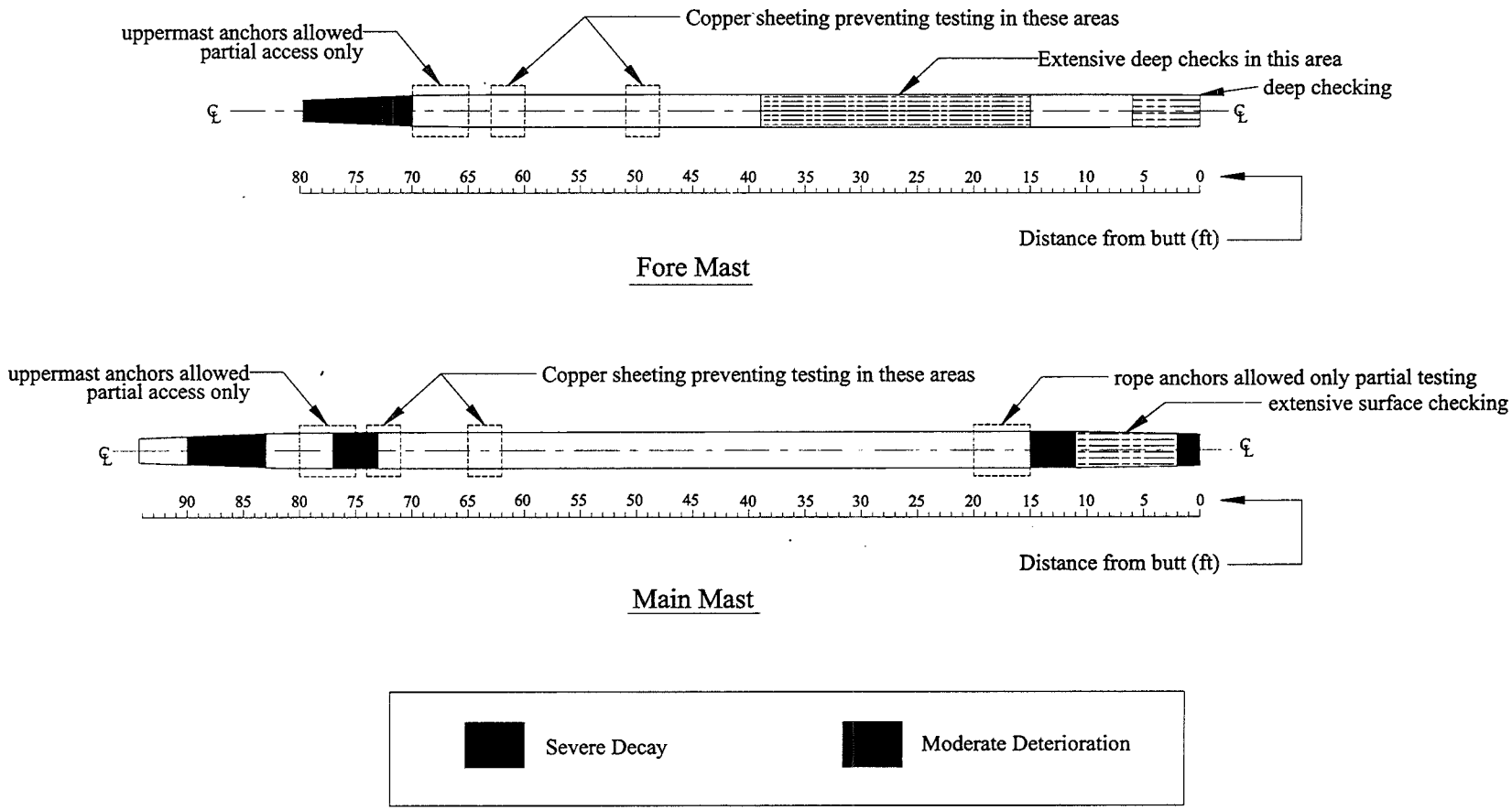


Figure 5. Mapping of the physical conditions of main mast and fore mast of the Highlander Sea.

Appendix A – Photo Documentation of the Masts of Highlander Sea

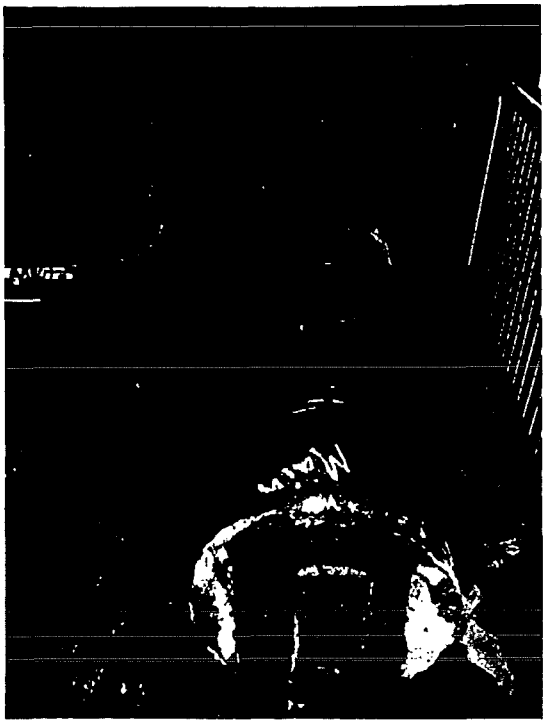


Photo 1. Lower portion of main mast.

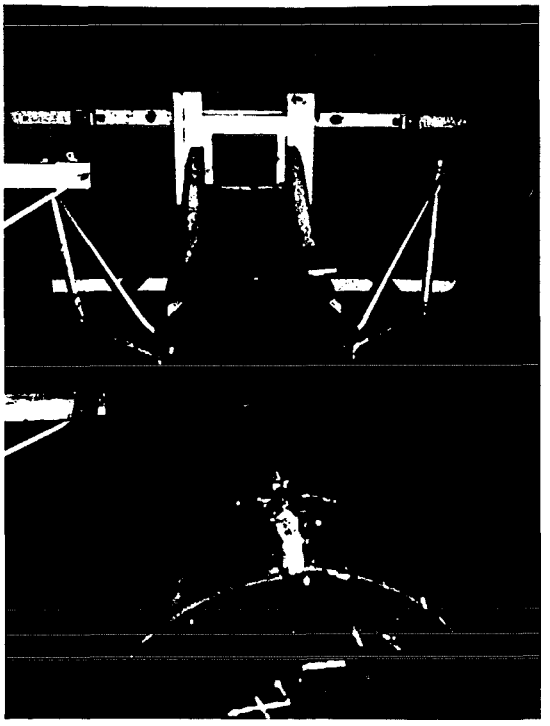


Photo 2. Upper portion of main mast.

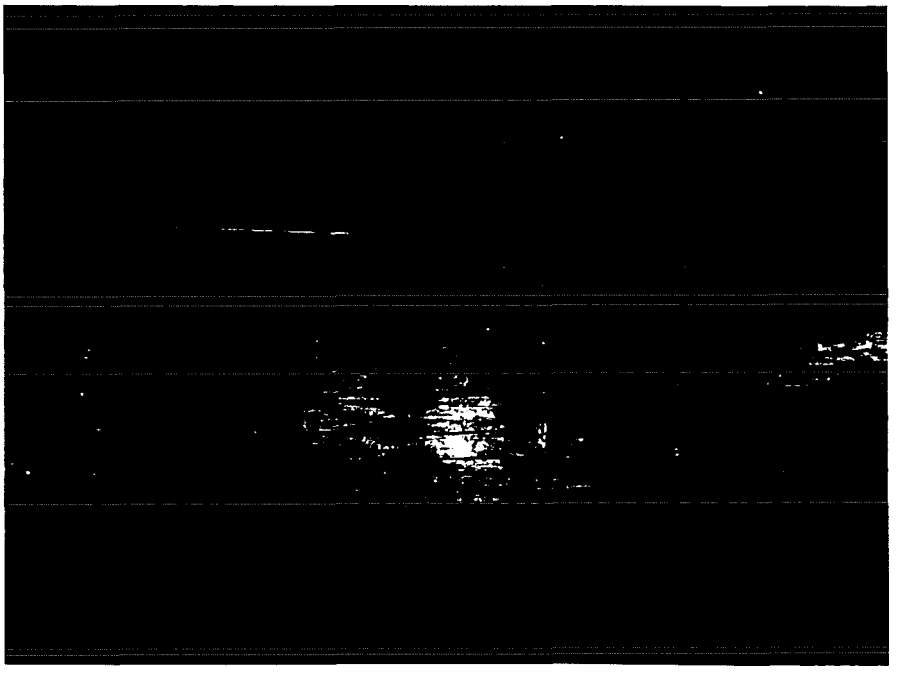


Photo 3. Extensive surface checking on the lower portion of main mast.

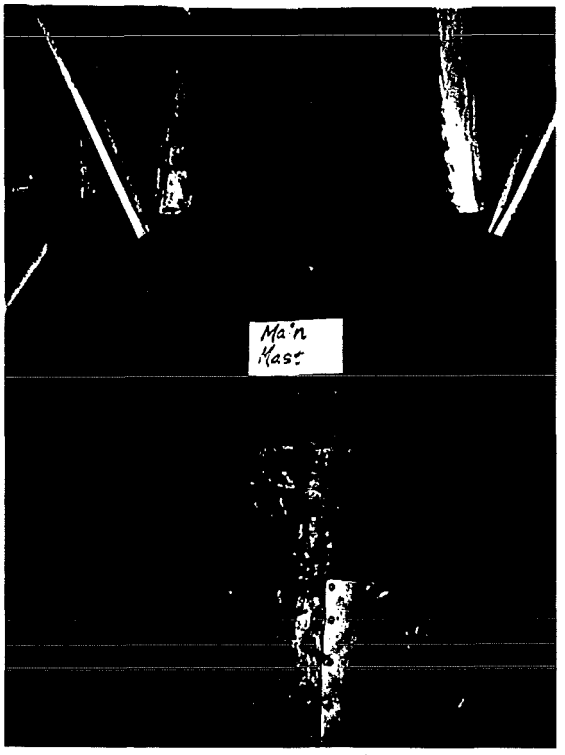


Photo 4. Severe decay pockets found between 75' and 77' at main mast.

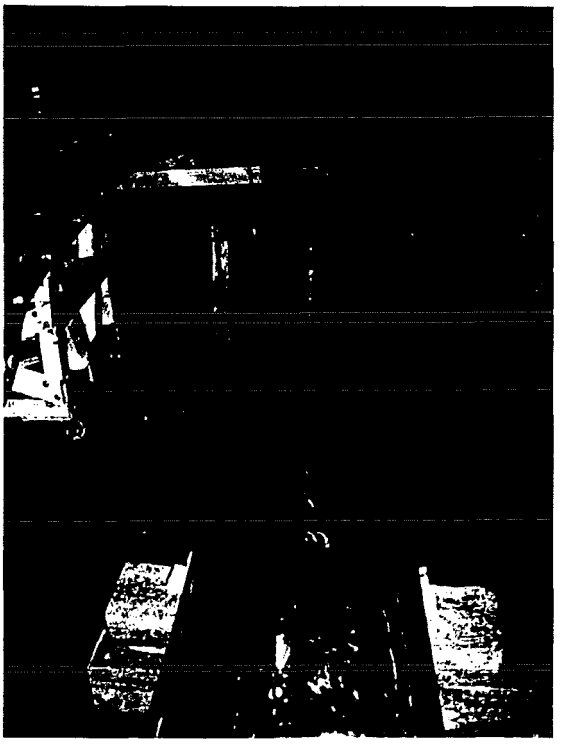


Photo 5. Fore mast of the Highlander Sea.

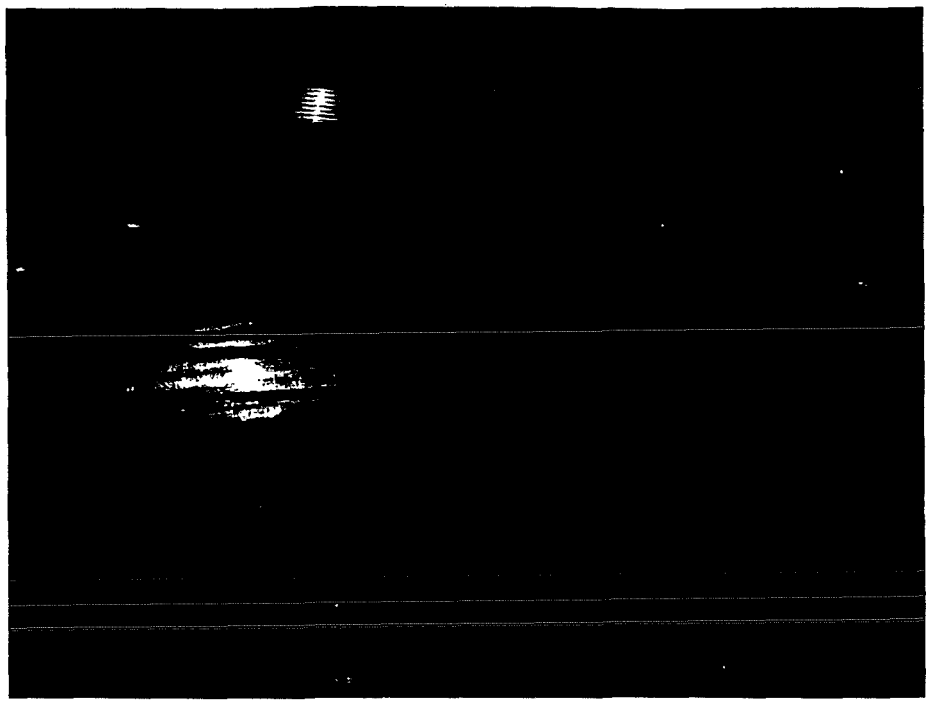


Photo 6. Deep checking at the lower portion of fore mast.

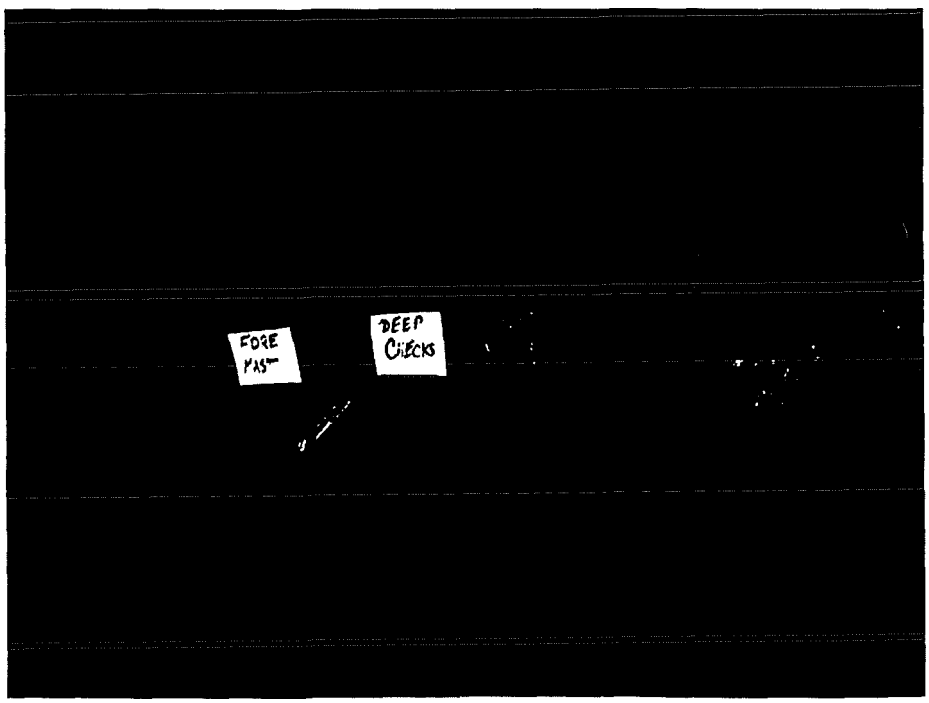


Photo 7. Deep checking on fore mast (19' – 23').

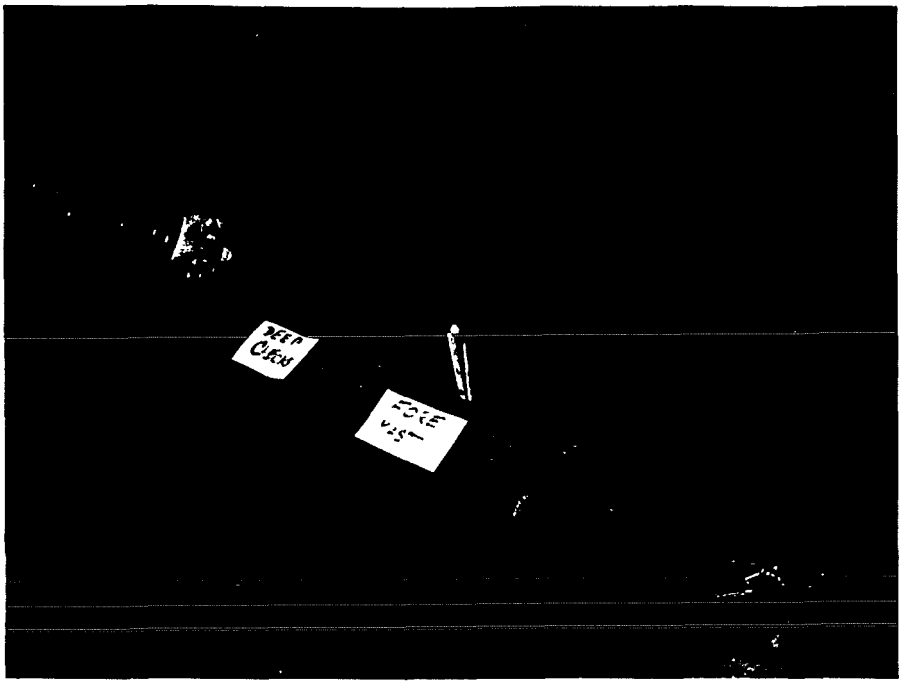


Photo 8. Deep checking on fore mast (32' – 35').

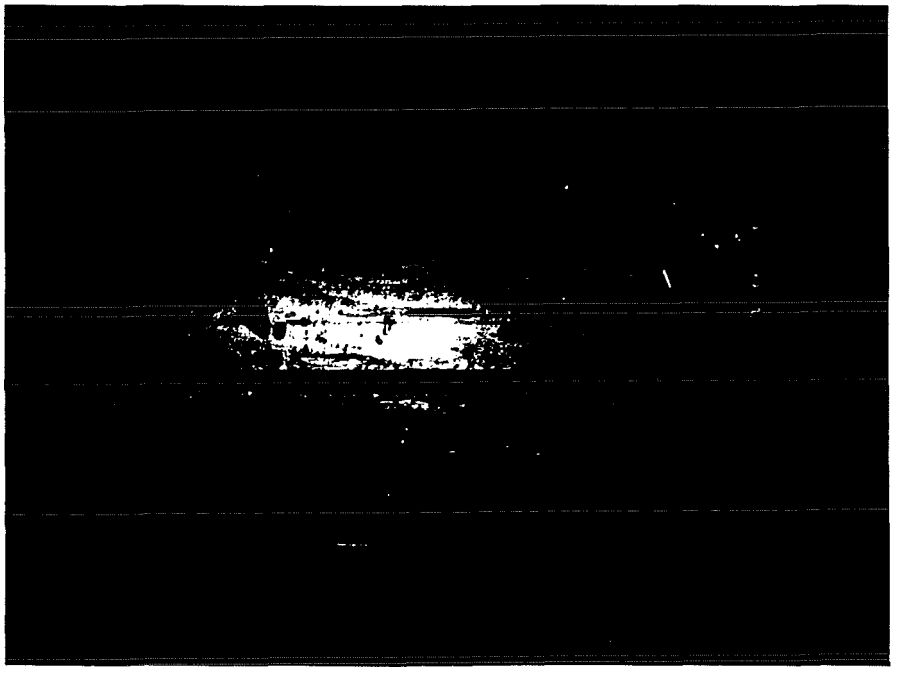


Photo 9. Close look of large deep check (1/2" wide and up to 7" deep)

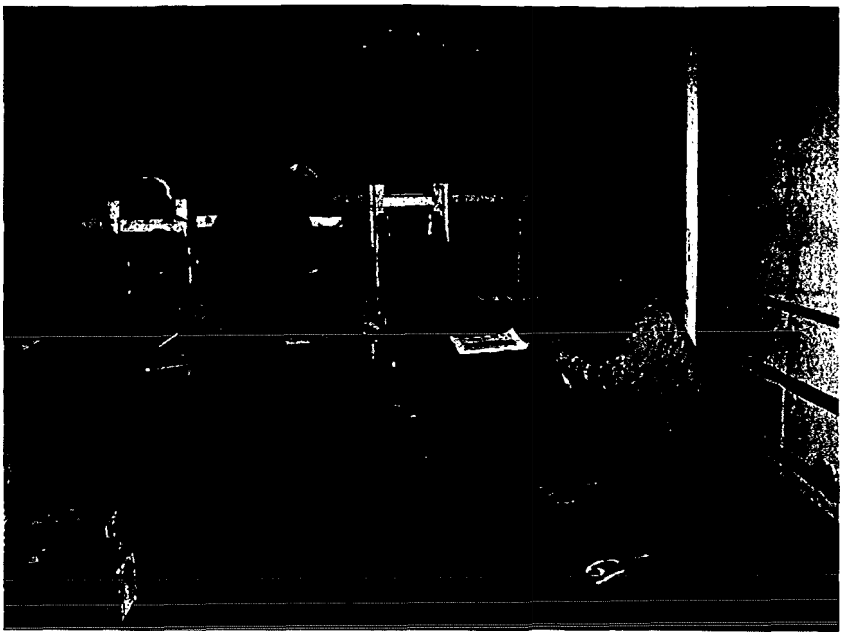


Photo 10. Stress wave scanning test.

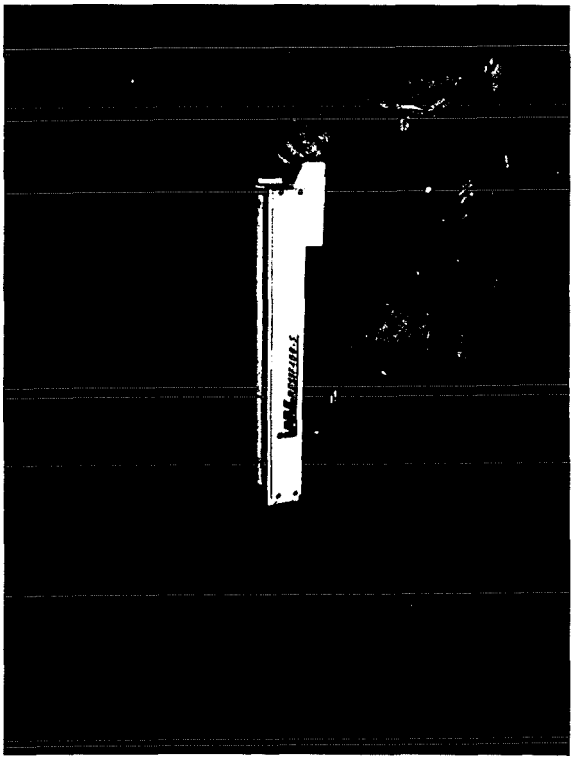
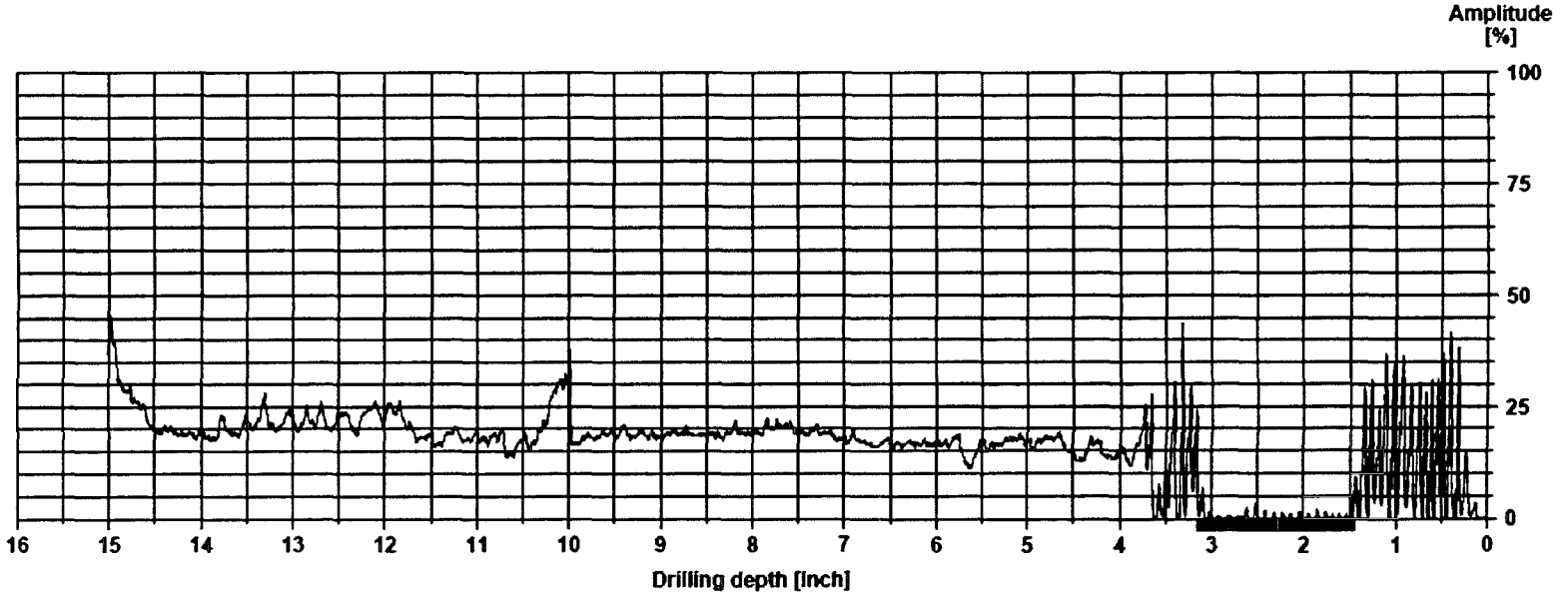


Photo 11. Resistance micro-drilling test.

Appendix B – Resistance Profiles of Critical Locations in the Masts of Highlander Sea

Measuring / object data

Measurement no.	: 7	**Time**	: 21:21:16	**Location**	: 75 ft + 2 in.
Drilling depth	: 15,02 "	**Avg. curve**	: off	**Name**	: Main Mast
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: —
ID number	: 06	**Level**	:	**Min. width / height**	: —
Advance	: 23,6 "/min	**Direction**	: Top-down	**Start of detecting**	: —
Date	: 08.11.2006	**Object species**	: Douglas-fir	**Detect last cavity**	: —



Assessment

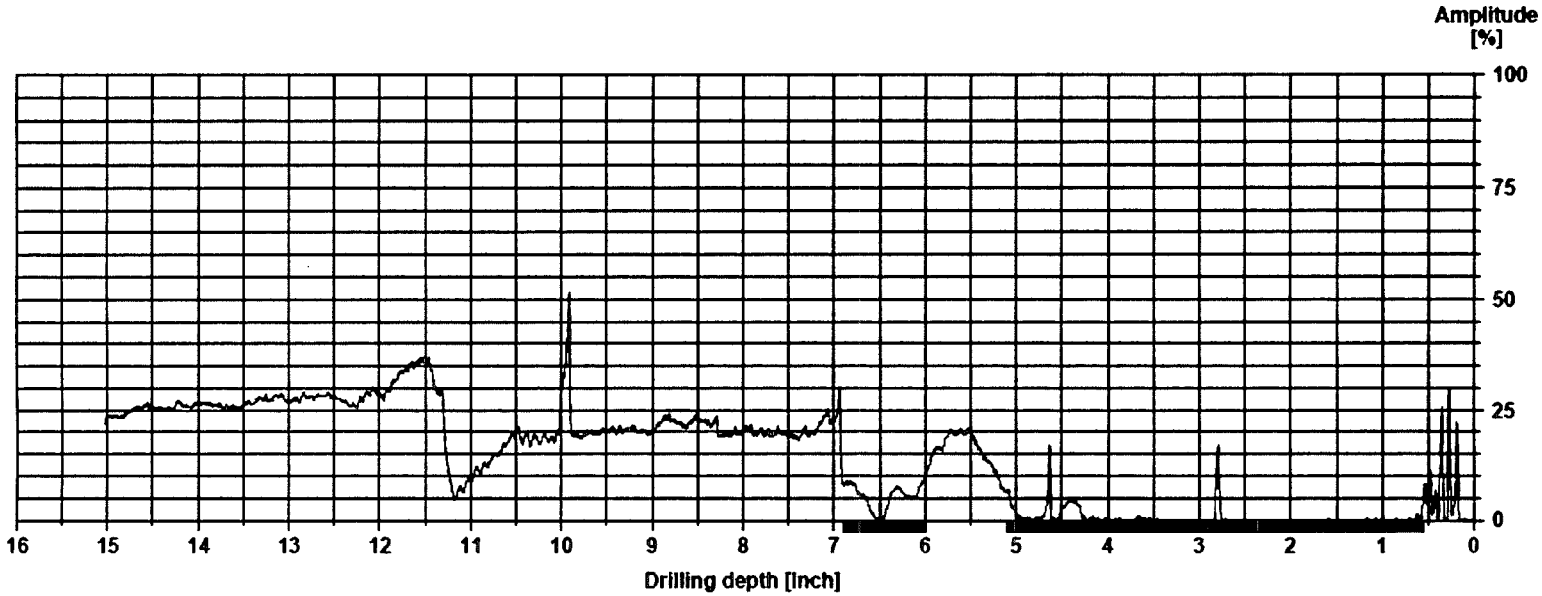
From	1,45 "	to	3,15 "	:	Severe decay
From	0,00 "	to	0,00 "	:	
From	0,00 "	to	0,00 "	:	
From	0,00 "	to	0,00 "	:	
From	0,00 "	to	0,00 "	:	
From	0,00 "	to	0,00 "	:	

Comment

HIGNLANDER SEA
Main Mast
@75 ft +2 in.
Top-down

Measuring / object data

Measurement no.	: 10	**Time**	: 21:30:59	**Location**	: 76 ft
Drilling depth	: 15,03 "	**Avg. curve**	: off	**Name**	: Main Mast
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 08	**Level**	:	**Min. width / height**	: ---
Advance	: 24,1 "/min	**Direction**	: Top-down	**Start of detecting**	: ---
Date	: 08.11.2006	**Object species**	: Douglas-fir	**Detect last cavity**	: ---



Assessment

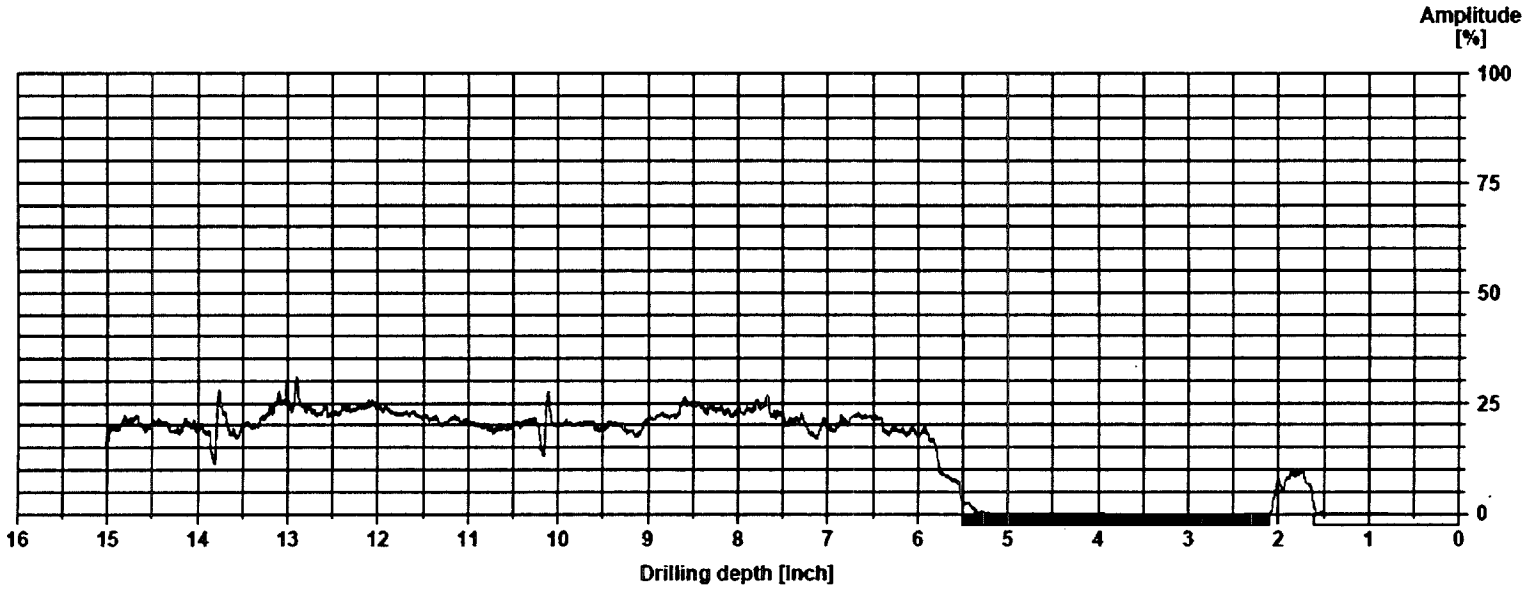
- From 0,55 " to 5,10 " : Severe decay
- From 6,00 " to 6,90 " : Moderate decay
- From 0,00 " to 0,00 " :
- From 0,00 " to 0,00 " :
- From 0,00 " to 0,00 " :
- From 0,00 " to 0,00 " :

Comment

HIGHLANDER SEA
Main Mast
@76 ft Top-down

Measuring / object data

Measurement no.	: 13	**Time**	: 21:48:49	**Location**	: Steel Collar +76 ft
Drilling depth	: 15,03 "	**Avg. curve**	: off	**Name**	:
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 11	**Level**	:	**Min. width / height**	: ---
Advance	: 24,1 "/min	**Direction**	: Angle	**Start of detecting**	: ---
Date	: 08.11.2006	**Object species**	: Douglas-fir	**Detect last cavity**	: ---



Assessment

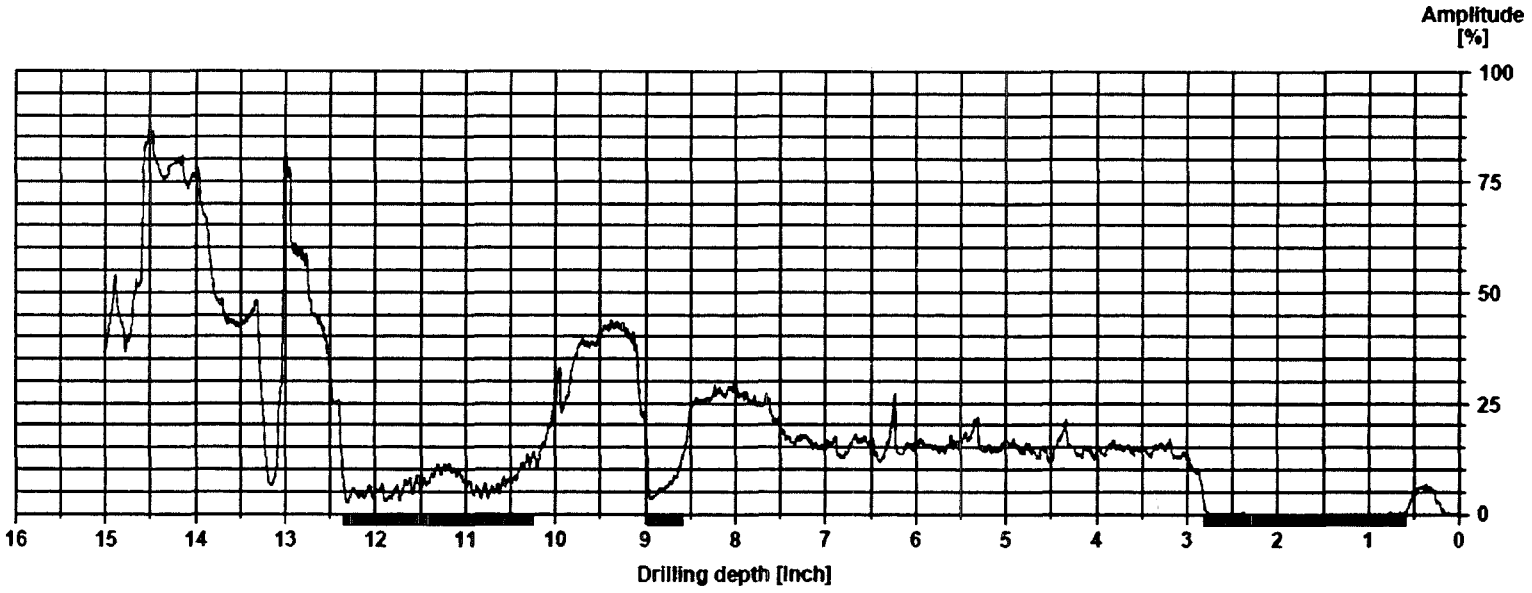
From	0,00 "	to	1,60 "	: Gap
From	2,10 "	to	5,50 "	: Severe decay
From	0,00 "	to	0,00 "	:
From	0,00 "	to	0,00 "	:
From	0,00 "	to	0,00 "	:
From	0,00 "	to	0,00 "	:

Comment

HIGHLANDER SEA
Main Mast
@Steel Collar (+76 ft)

Measuring / object data

Measurement no.	: 14	**Time**	: 21:59:44	**Location**	: 76.5 ft.
Drilling depth	: 15,02 "	**Avg. curve**	: off	**Name**	: Main Mast
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: —
ID number	: 12	**Level**	:	**Min. width / height**	: —
Advance	: 24,1 "/min	**Direction**	: Top-down	**Start of detecting**	: —
Date	: 08.11.2006	**Object species**	: Douglas-fir	**Detect last cavity**	: —



Assessment

From	0,60 "	to	2,80 "	: Severe decay
From	10,25 "	to	12,35 "	: Moderate decay
From	8,60 "	to	8,98 "	: Moderate decay
From	0,00 "	to	0,00 "	:
From	0,00 "	to	0,00 "	:
From	0,00 "	to	0,00 "	:

Comment

HIGHLANDER SEA
Main Mast
@76.5 ft.