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The funds requested in this proposal were used to provide hands-on assistance with approximately twenty timber bridge inspections and demonstration use of University equipment. This included cooperative inspections with bridge inspectors and engineers in St. Louis County (Mn/DOT District 1), Aitkin County (Mn/DOT District 3), Wright County (Mn/DOT District 3), Ottertail County (Mn/DOT District 4), Mn/DOT District 1 and the Mn/DOT Office of Bridges (Mn/DOT Metro). A standard inspection procedure using visual, mechanical and nondestructive evaluation techniques was used to familiarize these professionals with timber bridge specific experience. NDE equipment that was used during inspections included the Fakopp Microsecond Timer, the Sylvatest Duo and the IML Resistance Drill. The use of these inspection techniques and equipment resulted in better inspections and more accurate assessments of timber bridge components.

An intensive one-day short course was created for future use as requested by Mn/DOT. It is a one-day course that provides in-depth practical training in timber bridge materials, preservative treatments, inspection techniques and assessment, demonstration and hand-on use of advanced inspection equipment, case studies and demonstration of advanced vibration techniques.

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Advanced Timber Bridge Inspection Techniques: Mn/DOT Implementation

Final Report

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Executive Summary

During the FY 2003 NATSRL project; Advanced Timber Bridge Inspection Techniques, a 2-hour timber bridge short course inspection was developed and customized for Minnesota County, State and Federal bridge inspectors introducing them to advanced techniques, assessment methods and equipment. This short course was presented as part of Mn/DOT's 2003 Annual Bridge Inspection Seminar at each of Mn/DOT's eight districts. Approximately 250+ state, county and city bridge inspectors and engineers were taught during this course and provided information on wood species and preservative treatments, inspection procedures and equipment for testing individual members and reports on techniques for testing entire bridges as a system. Demonstration activities included impact and ultrasound stress wave equipment, resistance drills, and probes on timber bridge components.

As the result of this short course, bridge inspectors and engineers requested further assistance to implement many of these inspection techniques and equipment. This assistance would include participation during bridge inspections, use of demonstration equipment and specific recommendations for equipment purchases. The funds requested in this proposal were used to provide hands-on assistance with approximately twenty timber bridge inspections and demonstration use of University equipment. This included cooperative inspections with bridge inspectors and engineers in St. Louis County (Mn/DOT District 1), Aitkin County (Mn/DOT District 3), Wright County (Mn/DOT District 3), Ottertail County (Mn/DOT District 4), Mn/DOT District 1 and the Mn/DOT Office of Bridges (Mn/DOT Metro). A standard inspection procedure using visual, mechanical and nondestructive evaluation techniques was used to familiarize these professionals with timber bridge specific experience. NDE equipment that was used during inspections included the Fakopp Microsecond Timer, the Sylvatest Duo and the IML Resistance Drill. The use of these inspection techniques and equipment resulted in better inspections and more accurate assessments of timber bridge components.

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Chapter 1
Introduction

The use of wood in timber bridges has many benefits including the fact that wood is a renewable and sustainable resource, that timber bridges are often more economical than steel and concrete bridges and that they can be installed easily in rural environments. There are currently over 41,000 bridges in service with a span of over 20 ft with an average age of 40 years old (FHWA). This represents 7 percent of the bridges reported in the National Bridge Inventory. Recent programs like the USDA Wood in Transportation Program have funded research to develop a new class of timber bridges and associated inspection techniques.

Wood is a natural occurring engineering material that is prone to deterioration caused by decay fungi and insect attack. For this reason, it is important to conduct frequent inspections of timber bridges with modern inspection equipment. As noted in the USDA Timber Bridge Manual, "Bridge members infected with decay fungi experience progressive strength loss as the fungi develop and degrade the wood structure. The degree of strength reduction depends on the area of the infection and the stage of decay development, whether advanced, intermediate, or incipient. In the advanced or intermediate stages, wood deterioration has progressed to the point where no strength remains in infected areas. At this stage, suitable detection methods can be used by the inspector to accurately define the affected areas with some degree of certainty. At the incipient or early stages of development, detection is much more difficult and the effect of strength loss varies among types of fungi." It is important to identify early stage decay to ensure the safety of the structure and allow for treatment in service.

Background discussions with Mn/DOT bridge inspection program managers and the St. Louis County bridge engineer revealed that current timber inspection procedures in Minnesota are limited to visual inspection of the wood components, sounding with a hammer and coring to confirm suspected damage areas. These techniques have proved adequate for advanced decay detection, but are not adequate when the damage is in the early stage or is located internally in the members.

A recent Federal Highway Administration publication, "Highway Bridge Inspection: State-of-the-Practice Survey (2001)," reported survey results from State division bridge engineers and bridge inspection managers. The primary inspection techniques reported for timber bridges showed that visual inspection and mechanical sounding were used by 75% of the reporting States as the primary inspection technique. Only 4% of the states used advanced inspection techniques and equipment such as stress wave analysis and resistance drilling. No States reported using any nondestructive evaluations for testing entire bridges as a system. The primary goal if funds were available was to add additional nondestructive evaluation equipment.

The Wood in Transportation program has provided condition assessments for many demonstration bridges that have been constructed since the early 1990's. The evaluation plan included monitoring of the moisture content, static load tests of the completed structure and visual inspection (Caccese and others 1991, 1993; Dagher and others 1991, Ritter and others 1991).

Stress wave analysis has been used to inspect wooden structures since 1972. This has included buildings, boats and bridges. An excellent review of timber inspection techniques and case studies has been prepared by the USDA Forest Products Laboratory (Ross 1994). A customized stress wave testing guide was prepared for inspection of timber bridges using stress wave timing (Ross et al 1999). This manual is currently being revised to include additional commercial equipment and defined inspection techniques.

Objectives:

The objective of this project was to provide assistance in completing timber bridge inspections using advanced timber bridge inspection techniques and equipment in cooperation with Minnesota Counties and the Minnesota Department of Transportation. This will build on information provided to inspectors and engineers during a two-hour session in the Mn/DOT 2003 Annual Bridge Seminar Series. Specifically, assistance and hand-on use of equipment was provided to include:

- Visual inspection techniques
- Sounding
- Probes
- Moisture meters
- Metriguard 239A Stress Wave Timber
- Fakopp Impact Wave Timer
- Sylvatest Duo
- IML Resistance Drill
- Load testing
- Advanced vibration testing

A secondary objective of this project was to provide a comprehensive one-day seminar for those inspectors and engineers with a large number of timber bridges in their district or county. A one-day short course would introduce bridge inspectors and engineers to the extensive research and development work completed through the USDA Wood In Transportation Program, provide background on wood species and preservative treatments, address inspection procedures and equipment for testing individual members and report on techniques for testing entire bridges as a system. Demonstration activities will include impact and ultrasound stress wave equipment, resistance drills, probes, and vibration of an existing timber bridge. A complete inspection and assessment manual will be developed for the participants. Implementation of these techniques will result in more accurate structural inspections leading to enhanced safety. It may also be possible to reduce the time associated with inspections on bridges that are in excellent condition.

Summary of Previous Work:

During a FY 2003 NATSRL project, a two-hour short course has been developed and presented to Mn/DOT through their 2003 Annual Bridge Inspection Seminar. This full day Mn/DOT seminar was presented by the Office of Bridges and Structures at all 8 of the Mn/DOT districts including Duluth, Bemidji, Brainerd, Detroit Lakes, Rochester, Mankato, Willmar, and Minneapolis/St.Paul Metro. This course provided an overview of timber bridge inspection techniques and assessment methods, inspection equipment review and demonstration and a discussion of advanced vibration testing of complete timber bridges. This short course was presented through slides, videos and equipment demonstration on timber bridge components.

Further, the project leader is completing two cooperative research projects with the USDA Forest Products Laboratory, Michigan Technological University and the US Federal Highway Administration to use and evaluate advanced nondestructive evaluation technologies to assess the quality and performance of timber members in bridges and to develop in-place assessment technologies for complete bridges.

In the first project, the objective is to evaluate the effectiveness of several nondestructive evaluation (NDE) technologies for locating decayed sections of bridge timbers. Commercial testing equipment including impact and ultrasound stress wave timers, resistance drills and moisture meters will be evaluated on a wide variety of timber members containing decay. Further, several in-service bridges will be inspected to evaluate the field effectiveness of currently available inspection procedures and equipment. A scientific publication and a guide for practicing inspection professionals will be prepared comparing the relative effectiveness of this equipment.

In the second project, the cooperative research effort has shown that forced and free vibration evaluation systems can yield accurate estimates of the stiffness of the bridge. This assessment system can be permanently installed on a bridge and would allow for rapid testing of the vibration performance, an indirect measure of the bridge stiffness. This information can be further used to assess whether a bridge has lost stiffness due to biodeterioration, loose connections or some other degradation factor.

Finally, the project leader, Brian Brashaw and primary cooperator, Robert Ross, are continuing education instructors for the American Society of Civil Engineers. They teach the wood structures section of a course titled, "Structural Condition Assessment of Existing Structures" This course provides structural engineers, architects and inspection professionals with background information on wood structures, simple and advanced inspection techniques and equipment and numerous case studies they have been involved in detailing nondestructive evaluation and assessment of wood structures including historic buildings, boats, timber bridges and other wood structures. They have taught this course to over 1,000 participants in 50 locations over the past five years.

Chapter 2
Results

Each of the two tasks that were proposed for this project will be summarized with results and discussion in the following section.

Task 1. Provide implementation assistance to Mn/DOT on the use of advanced timber bridge inspection techniques and equipment.

a) Develop a timber bridge inspection request form for distribution through the Mn/DOT Office of Bridges and Structures.

b) Schedule inspection assistance with requesting inspectors, ensuring that all Districts are presented. It is expected that assistance will be provided with approximately 20 bridges.

c) Complete inspections in cooperation with Mn/DOT across Minnesota.

Deliverables: Assistance with the completion of approximately 20 Mn/DOT timber bridge inspections.

Results and discussion:

Contacts were made with the Mn/DOT Office of Bridges and Structures alerting them to the inspection assistance available through this project. They made information available to each District; however only District 1 directly approached NRRI research staff for assistance. Alternately, a summary of the inspection assistance was made available to all of the inspectors and engineers that attended the Mn/DOT Office of Bridges' Annual Bridge Inspector Training Series in the Spring of 2003. We received requests from Aitkin County, Ottertail County, St. Louis County and Wright County to participate in bridge inspections and demonstrate advanced inspection techniques and equipment. Individual trips were scheduled with each County during 2004.

<u>Ottertail County</u>

In March 2004, Ottertail County closed bridge 56509 due to the failure of a timber pier cap as shown in Figure 1. The timber pile had broken through the pier cap as the result of extensive decay in the cap. The Ottertail Highway Department was extremely concerned that other bridges of similar design were also vulnerable. NRRI personnel were requested to assist in an inspection to address 10 other bridges of similar design. Bridges 7266, 56509, 56502,

Figure 1. Timber pier cap failure on bridge 56509 in Ottertail County, Minnesota.

56501, 56503, 7267, 56508, 56517, 56513, and 56514 were inspected using visual inspection techniques, moisture meters, and an IML resistance drill to determine the presence and extent of decay that was present in pier caps, pilings and abutments. It was determined that there was not any significant, immediately threatening decay present in these bridges. Several sections of early stage incipient decay were located and will be closely monitored during future inspections. The Ottertail County Highway Department will be actively requesting funds to purchase this modern equipment in future budget cycles for long term implementation.

Aitkin County

NRRI personnel spent two inspection days with an Aitkin County bridge inspector and evaluated 13 timber bridges. These inspections included rapid visual inspection, use of a moisture meter to assess the moisture content of individual timber components, use of a Fakopp Microsecond timer to locate decay sections and a resistance drill to confirm the extent of the decay. The Fakopp equipment was left with the inspector for his use on additional bridges. The inspector reported that this equipment was all easy to use and the results fairly easy to interpret. He has submitted a budget request to purchase a Fakopp test unit for use in future inspection projects. Figure 2 shows the Aitkin County inspector using a Fakopp stress wave timer to assess the quality of timber bridge pilings.

Figure 2. Aitkin County bridge inspector using a Fakopp stress wave timer to assess the structural condition of timber piles.

Wright County and Mn/DOT Metro Office of Bridges

NRRI assistance was requested to help evaluate the timber piles on Wright County Bridge #7098. There was some concern that the piles contained significant levels of decay, weakening the structure. A resistance drilling tool was used to evaluate all 24 timber piles. The moisture content of each pile was also determined. Training was provided to the County and State inspectors that participated and they completed the majority of the drilling evaluations. For further detail on this testing, please review Appendix A that shows a newsletter story that was prepared as part of a NATSRL newsletter in 2004. It was determined that the piles were in good condition, with some trouble areas. A decision was made to replace the bridge to increase the roadway width, but not due to decay or damage to the current structure. Figure 3 shows a Mn/DOT inspector using a resistance drill and Figure 4 shows the data generated by the resistance drill. When decay is present, the drilling amplitude ranges from 0-10%.

Figure 3. Mn/DOT engineer using a resistance drill to determine the structural condition of a Wright County bridge timber pile.

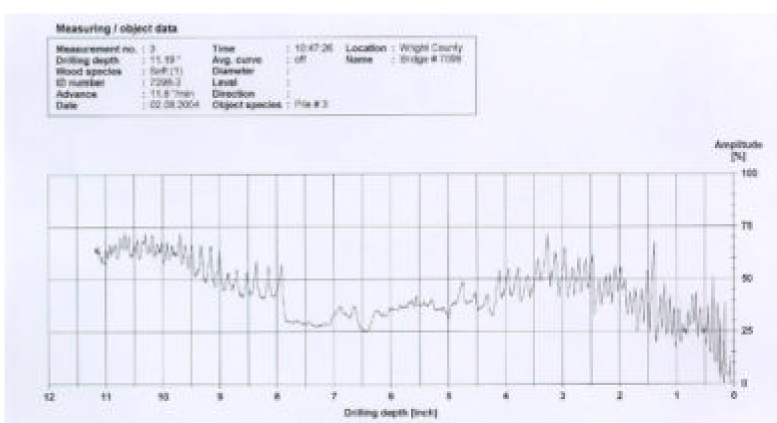

Figure 4. A resistance drilling chart that shows no presence of decay in a Wright county bridge piling.

Mn/DOT District 1

Assistance was requested by District One inspectors to evaluate the timber pilings on bridge 5919 using a resistance drill. The testing took about 6 hours and it was determined that the pilings were in excellent condition. A summary report for Mn/DOT is included in Appendix B. Figure 5 shows the numbered pilings for bridge 5919 and Figure 6 shows the inspector using a resistance drill to complete the inspection.

Figure 5. Mn/DOT District 1 bridge 5919 showing the 16 timber piles that were tested.

Figure 6. Mn/DOT inspector completing a resistance drill test on a timber piling on bridge 5919.

Task 2. Provide a comprehensive one day short course including the following potential topics:

- USDA Wood in Transportation Program.
- Timber bridge species and materials.
- Wood preservatives used for timber members.
- Visual inspection.
- Physical and mechanical property methods and equipment.
- Nondestructive evaluation technologies including stress wave testing.
- Drilling and coring methods and equipment.
- Timber bridge inspection case studies.
- Demonstration and hands-on testing of commercially available equipment.
- Advanced vibration testing of bridge systems with a demonstration on a timber bridge.

Deliverables: Compilation and completion of a one-day advanced timber bridge inspection program.

Results and discussion: The short course was prepared and is provided in Appendix C. It has not been requested at this time by Mn/DOT.

Chapter 3
Conclusions

Assistance and demonstration was provided to several Minnesota Counties and Mn/DOT District Offices with the use and implementation of advanced inspection techniques for assessing the condition of timber bridges in Minnesota. Their use of these techniques and inspection equipment resulted in more thorough inspections and provided inspectors and engineers an improved assessment of the bridge condition. If these techniques are more broadly used, they will result in improved maintenance of the structure, potentially extending the life of the structure. Further, the lack of confidence in completing timber bridge inspections has limited the use of timber as new or replacement bridges.

A one-day training program has also been prepared for use as a continuing education workshop and is available at the request of Minnesota counties and Mn/DOT Districts.

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Appendix A

NATSRL Newsletter Story Fall 2004

[For NATSRL Newsletter—October 2004

Testing for wood rot bridges agencies

Bridge #7098 over the Crow River is looking pretty good for a 50-year-old. But when it comes to rural wooden bridges, looks can be deceiving. Traffic over the Wright County bridge can be heavy and the 24 timber pilings that support the structure can start to decay from the inside, weakening the structure without notice.

Minnesota's back roads are peppered with some 4,000 timber bridges for vehicles, snowmobile trails and other recreational uses. Inspections of their structural integrity have relied mostly on visual assessments and sounding with hammers—examples of non-destructive tests. Another option has been to bore the wood to see if it was rotting from the inside—damaging what the highway departments are trying to protect.

Working with the Northland Advanced Transportation System Research Laboratory, wood products experts from UMD's Natural Resources Research Institute (NRRI) searched the international market for a better way to test wood for rot. Now, county and state highway departments have the latest technology available to test wooden bridges without cutting them. One of these new products is the Resistograph drill that produces graphical images that show the exact locations of soft spots in the wood, and whether they're caused by decay, natural defects or something else.

NATSRL/NRRI's researchers gave instruction courses on how to use the Resistograph drill to highway bridge inspectors across Minnesota, including on-site bridge inspections. Bridge #7098, and its 24 timber pilings, was scheduled for replacement and MN DOT Bridge Safety Engineer Jim Flannigan needed to confirm its condition to make a more informed decision and to communicate more responsibly with the Federal Highway Administration.

"Typically we test timber with a hammer and try to listen for that particular sound that rotted wood makes when it's tapped," Flannigan said. "We thought this bridge had a certain level of degradation, but NRRI's testing showed otherwise. Structurally it's pretty sound, though it still has to be examined for its functional abilities."

So far, NRRI researchers have worked with county and state inspectors around Minnesota in areas including Ottertail, Aitkin, Wright and St. Louis counties.

"This is an excellent example of government agencies working together," said Flannigan. "NRRI is able to share their knowledge and tools with other agencies creating a win-win-win situation for everyone. This technology is effective and efficient and it gets right down to the core of the wood. Literally."

NRRI's research team is available to help other counties and MnDOT districts perform testing with the new technologies. For more information about NRRI's wood rot testing capabilities, contact Brian Brashaw at 218-720-4248, or by email at bbrashaw@nrri.umn.edu.

Appendix B

Mn/DOT Bridge 5919 Summary Inspection Report

Summary Report for Mn/DOT Bridge 5919

Summary

Assistance in completing an inspection of 16 timber piles on Bridge 5919 was requested by Mn/DOT District One inspectors. They had completed traditional increment coring of these timbers and needed to confirm the presence or absence of decay in the pilings near the water line. A commercial resistance drilling unit was used through the centerline of the 14-16 in diameter pilings. The drilling resistance results showed that the pilings were in good condition where the drilling was completed. The majority of the pilings showed 98-100% of the piling cross-section was in good condition. In the worst piling, a 4 inch diameter circle of partially decayed wood was identified, but this only converted to a 13% loss in cross-sectional area.

Background

Structure:	Bridge 5919
Location:	McGregor, Minnesota
Special Consideration(s):	None
Estimated age:	30-50 years
Inspection date:	December 2004
Construction details:	Three span; heavy timber southern yellow pine pilings with steel girders and a bituminous wear surface

Bridge photo:

Objectives

The objectives of this assessment were:

1. to assess the condition of 16 timber pilings on bridge 5919 near the location of previously completed increment coring;

2. to transfer advanced timber bridge inspection techniques and equipment to Mn/DOT inspectors.

Materials and Method

Sixteen timber piles on bridge 5919 were inspected approximately 12-16 inches above the water line using a commercial available IML Resistance Drill as shown in Figure 1. The Resistograph Drill is based on a drilling resistance measuring method. A drilling needle with a diameter of 1.5 mm to 3.0 mm penetrates into the wooden structure with a uniform speed, and the drilling resistance was measured. The diameter of the pilings was 14-16 inches. The resistance drill measured the first 11.0 in. The remaining 3-5 inches was not assessed with the drill but was visually inspected. The core of the pilings is the most vulnerable to decay and it was evaluated with the drill. The data was recorded on a wax paper strip at a scale of 1:1 and captured electronically for download to a personal computer. The location of the drilling and number of the 16 pilings is noted on Figure 1.

Figure 2. Mn/DOT inspector completing a resistance drill test on a timber piling on bridge 5919.

Figure 2. Bridge 5919 showing the 16 timber pilings inspected with a resistance drill 12-18 inches above the waterline.

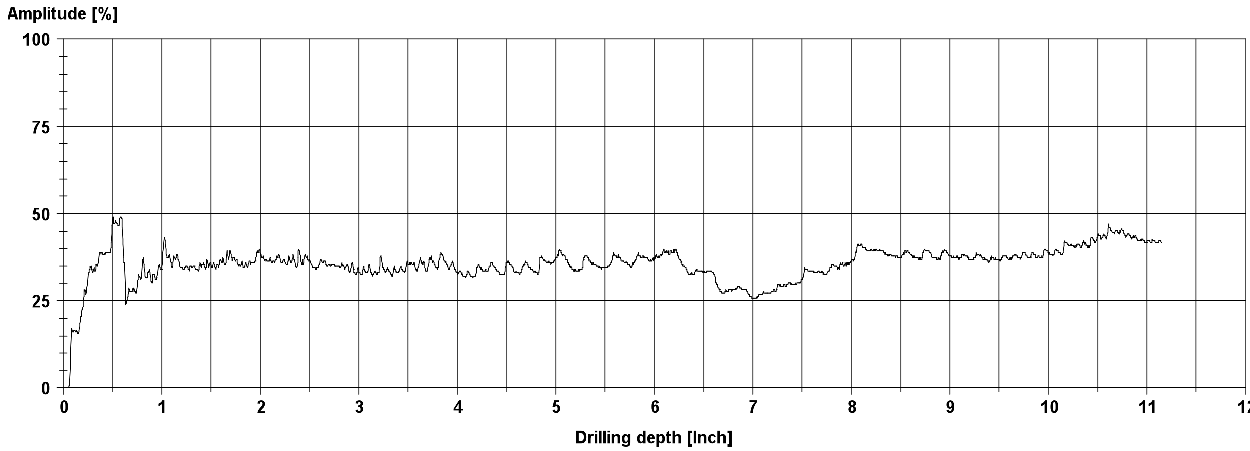
Results

Results obtained from the inspection are shown in Table 1. The unit was very accurate at determining the presence of decay at the drilling location. It measures the resistance on a 0-100% amplitude scale. Typical measures of resistance for sound softwoods are > 25%, 10-20% for moderate decay and 0-10% for advanced or severe decay.

Pilings 1-6, 8-15 all showed resistance readings > 25% across the width of the piling. This corresponds to 98-100% of the cross-section being in good condition. Piling 7 showed a 2 inch diameter decay pocket at the center of the piling. This corresponds to a 2% loss in cross-section. Piling 16 did show that the center 4 inches contained moderate decay. This corresponds to a decay section of about 13% of the cross-section of the piling. Both of these pilings should be monitored in the future to identify any changes in the piling's condition.

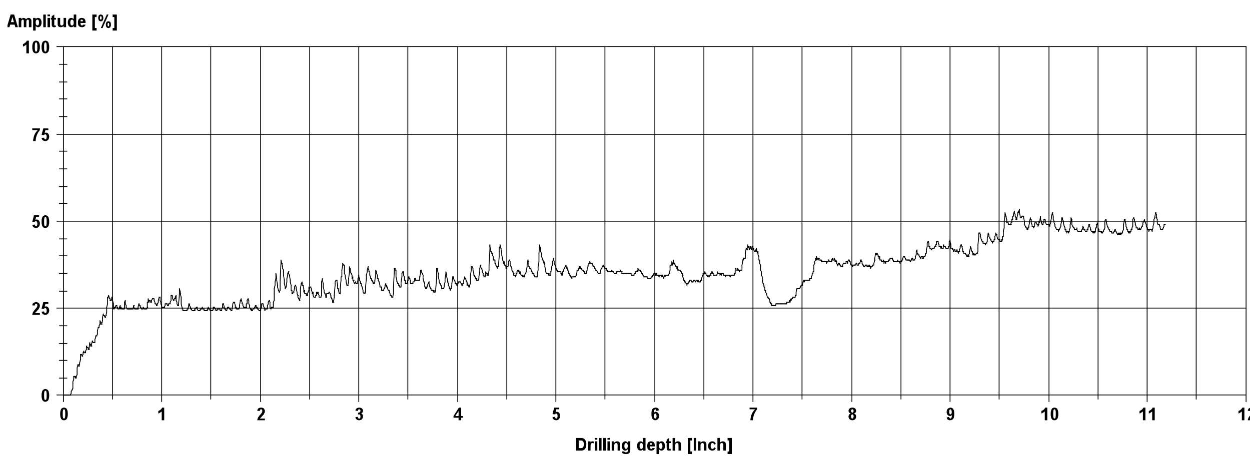
Table 1. Resistance drilling results from Bridge 5919 timber pilings.

Pile Number: 1



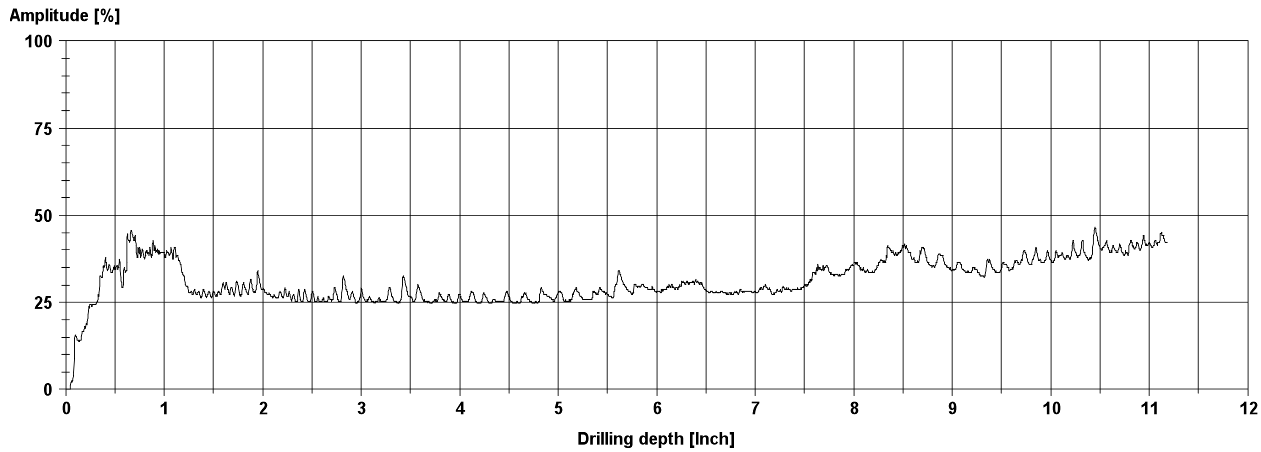
Comments: Good condition

Pile Number: 2



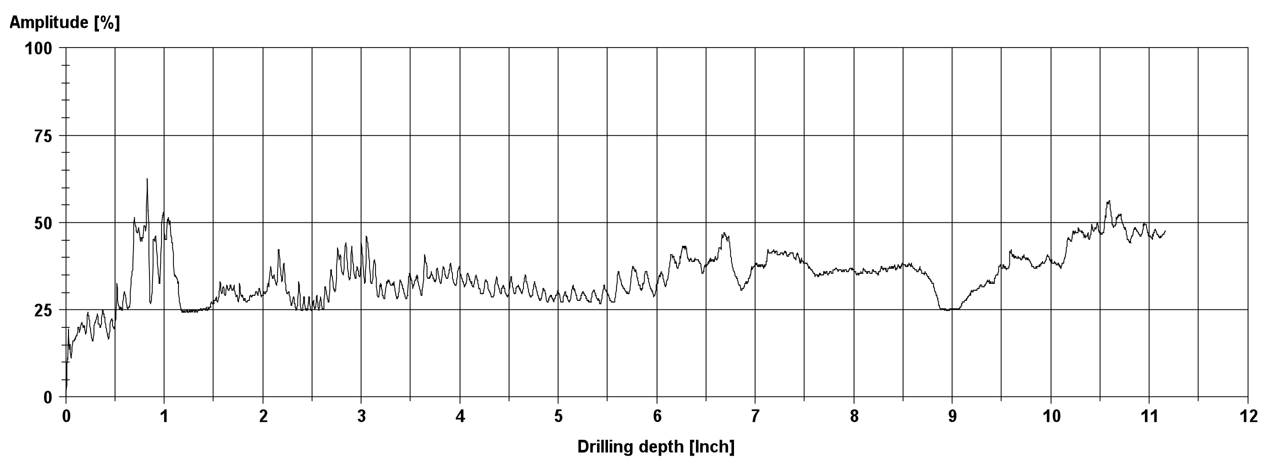
Comments: Good condition

Pile Number: 3



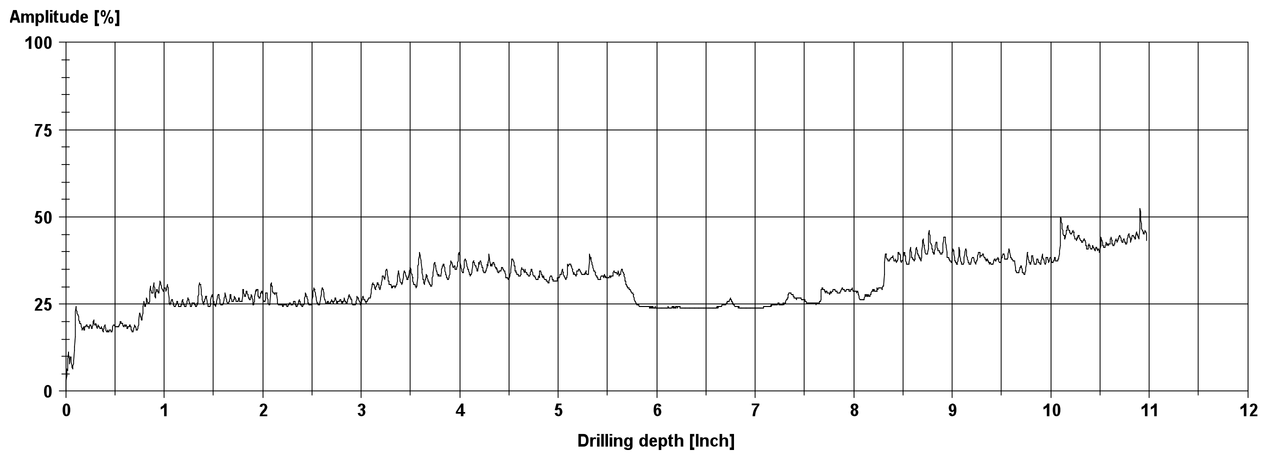
Comments: Good condition

Pile Number: 4



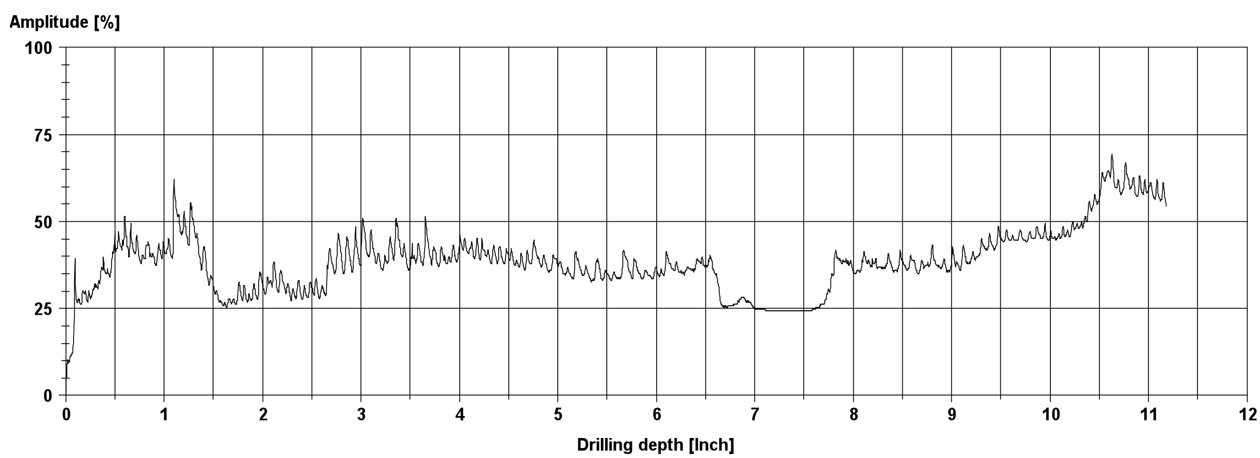
Comments: Good condition

Pile Number: 5



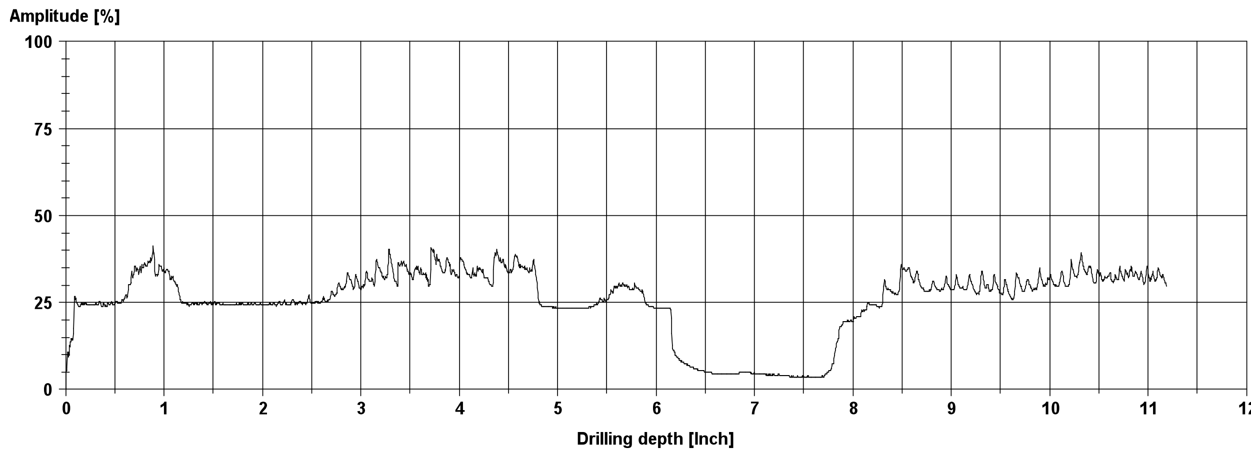
Comments: Good condition, some exterior shell softening in the first 1 in.

Pile Number: 6



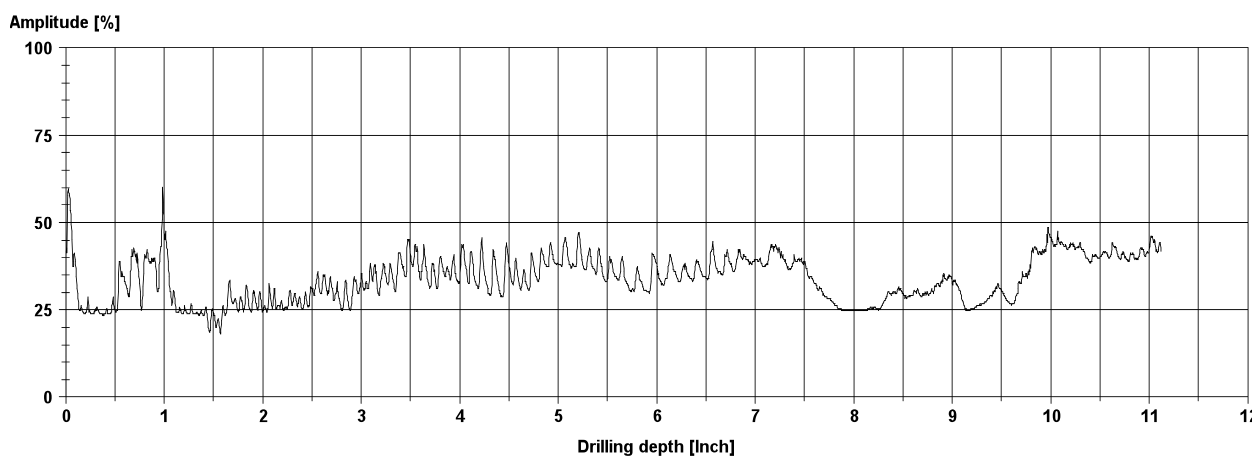
Comments: Good condition. The low point between 7 and 8 is the pith center of the piling.

Pile Number: 7



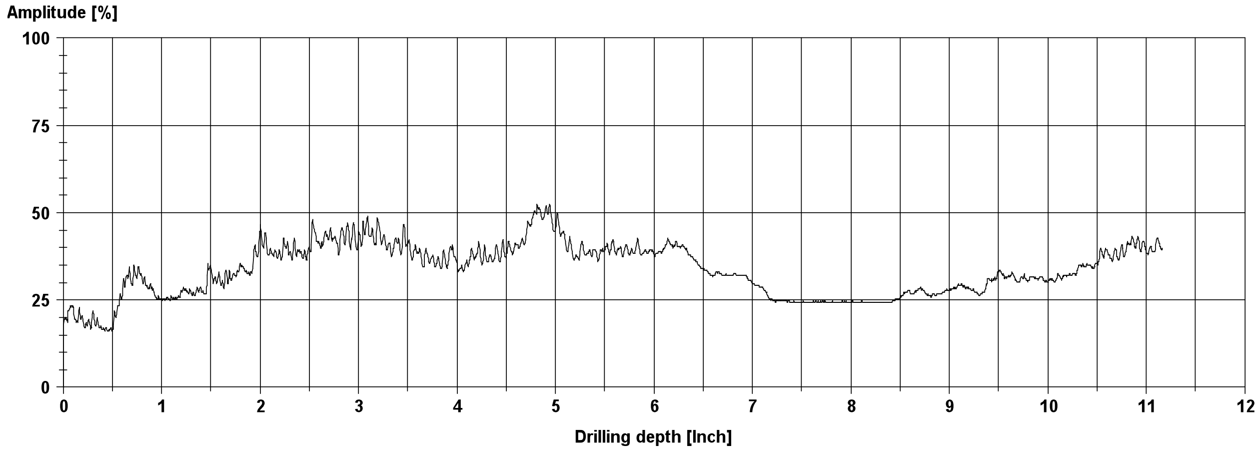
Comments: Decayed section near the center of the pile. 98% of the cross-section remains.

Pile Number: 8



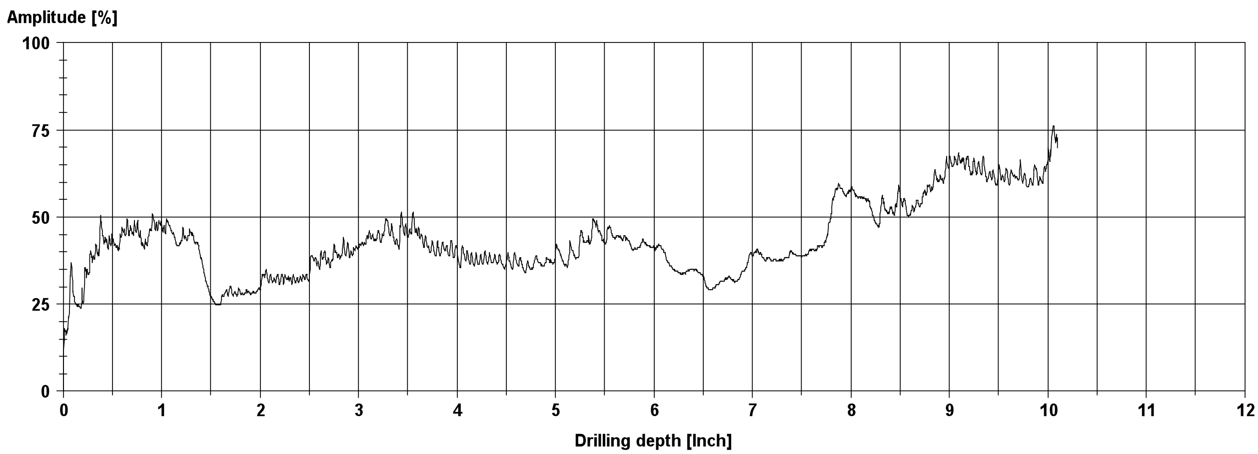
Comments: Good condition

Pile Number: 9



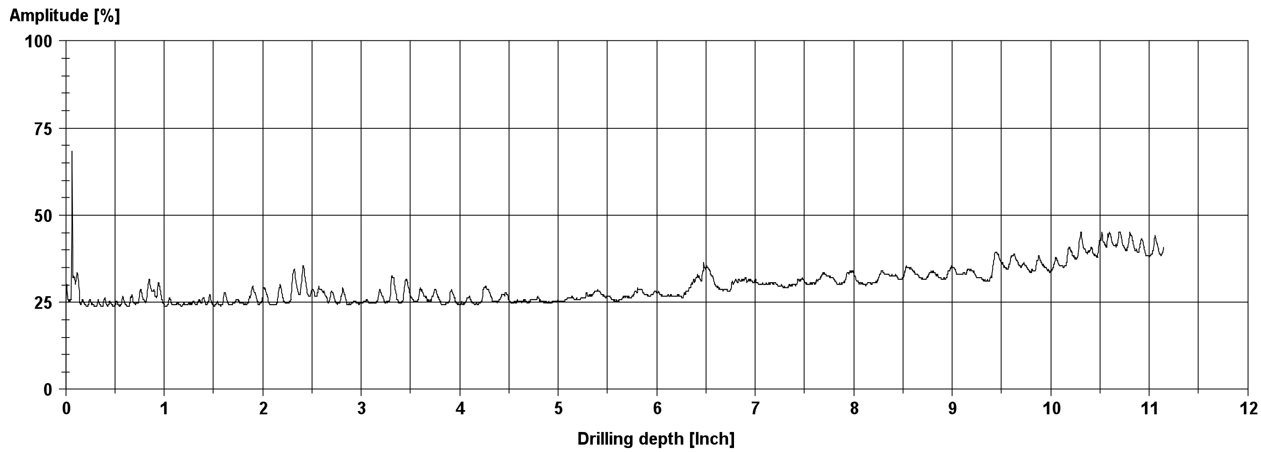
Comments: Good condition

Pile Number: 10



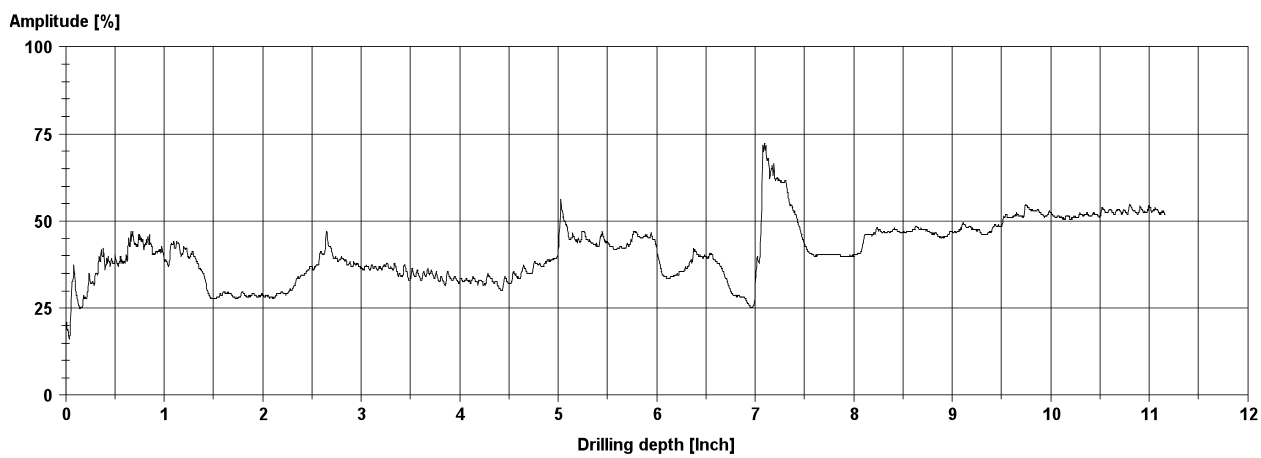
Comments: Good condition

Pile Number: 11



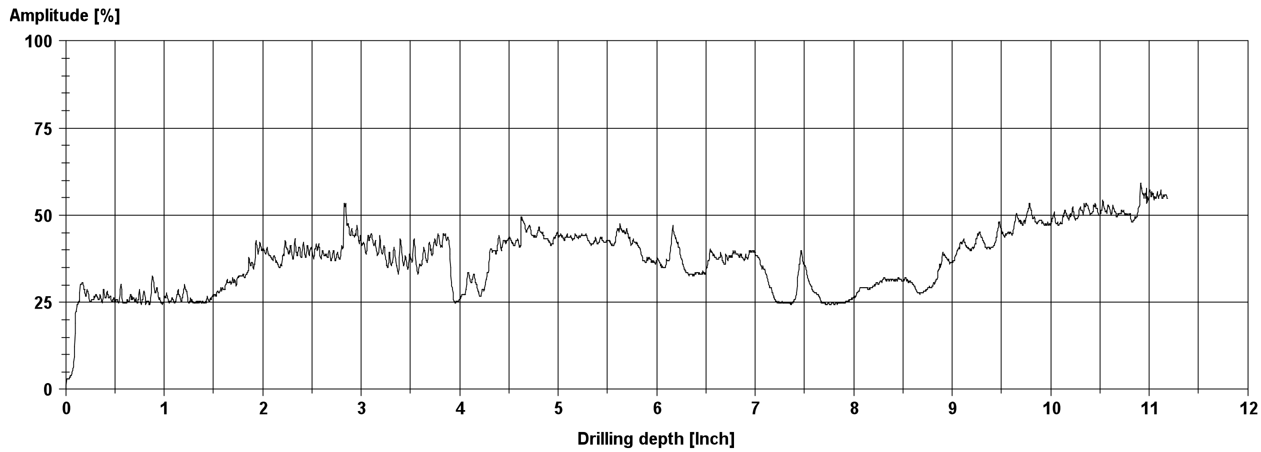
Comments: Good condition

Pile Number: 12



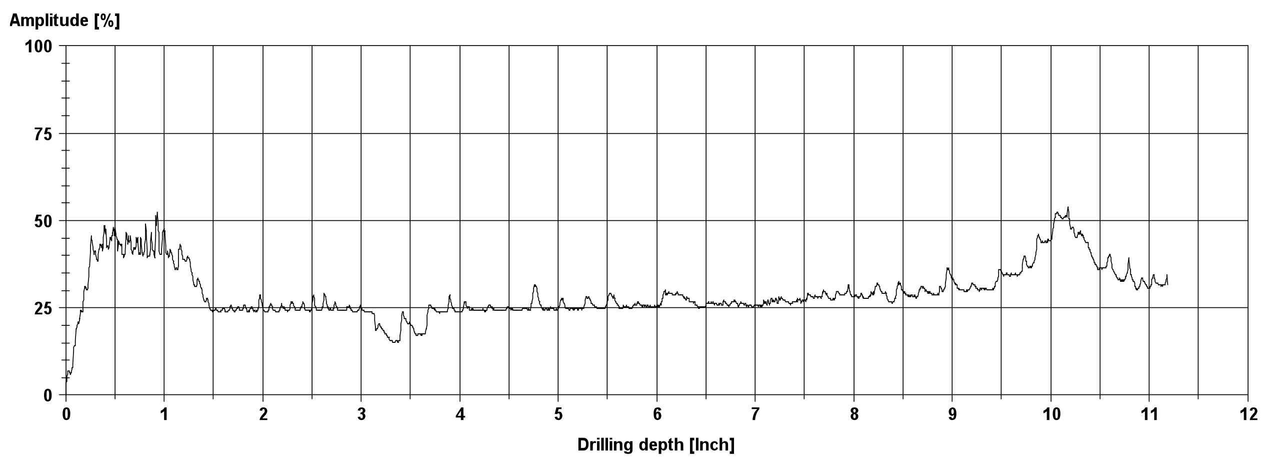
Comments: Good condition. The drill hit a bolt at 7 inches.

Pile Number: 13

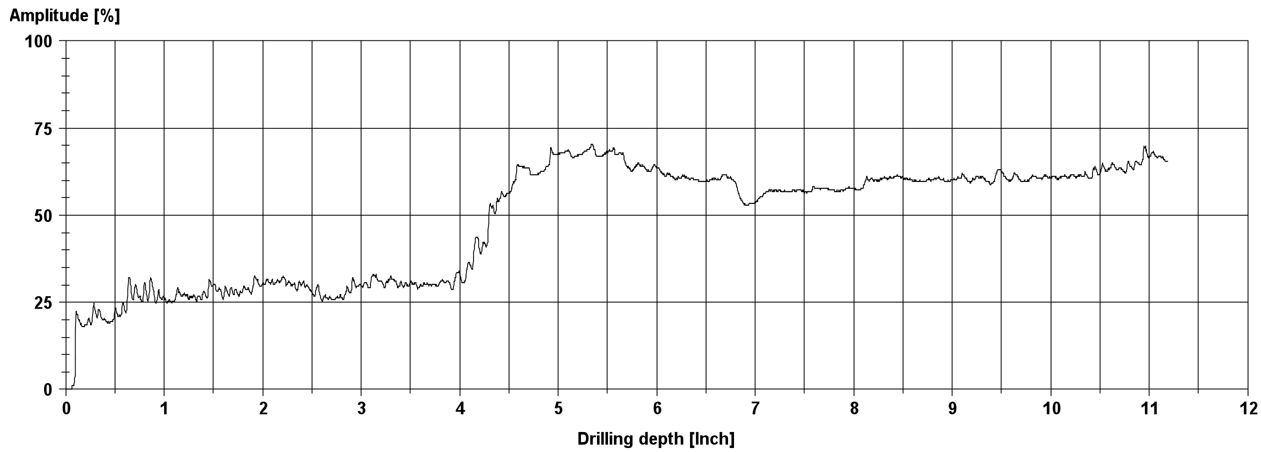


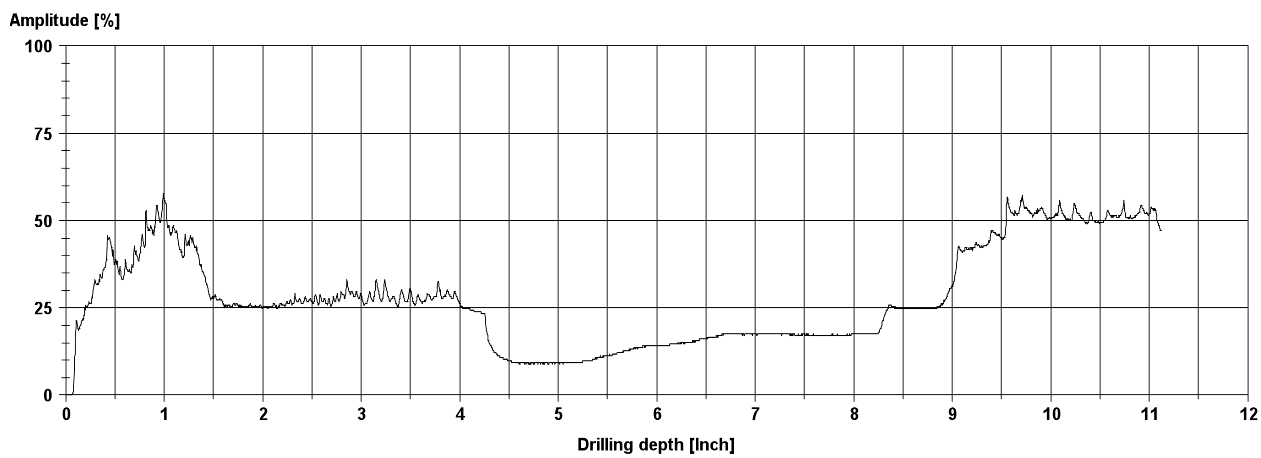
Comments: Good condition. A crack was present in the piling at 4 inches.

Pile Number: 14



Comments: Good condition

Pile Number: 15

Comments: The outer shell was slightly lower density than the remainder of the piling.

Pile Number: 16

Comments: A moderate decay section exists between 4 and 9 inches of the drilling path. There is 87% of cross-section remaining.

Conclusions and Recommendations

Sixteen 14-16-inch timber pilings on bridge 5919 were nondestructively evaluated using resistance drilling techniques. The testing showed that the pilings were in good condition at the location they were evaluated. Pilings 7 and 16 shows some internal decay and should be monitored in the future. Future testing should be more intensive and include the use of stress wave scanning of the entire above water section of the pilings.

Appendix C

Advanced Timber Bridge Inspection Short Course

[Appendix C text or tables here. Page number C-1 and so on.]

[When adding appendixes, pay attention to the page numbering. It is recommended that you create a new section for the appendix title page (with no page number) and create another section for the appendix content (numbered with the letter of the appendix and the page number).

To create a new section:
Go to the menu bar, choose Insert, Break, and then under Section Break Types, choose Odd Page.

To change page numbering:
Go to the menu bar; choose View, Header and Footer. It always opens to the page header. Refer to Word Help for detailed directions. Search for “Footers,” then choose, “insert footers,” and then click on, Create a different header or footer for part of the document.]

From Word Help:

1. On the **View** menu, click **Header and Footer**.
2. On the **Header and Footer** toolbar, click **Same as Previous** [an icon that looks like two pages with a little dotted arrow] to break the connection between the header and footer in the current section and the previous section.
3. Change the existing header or footer, or create a new one for this section.