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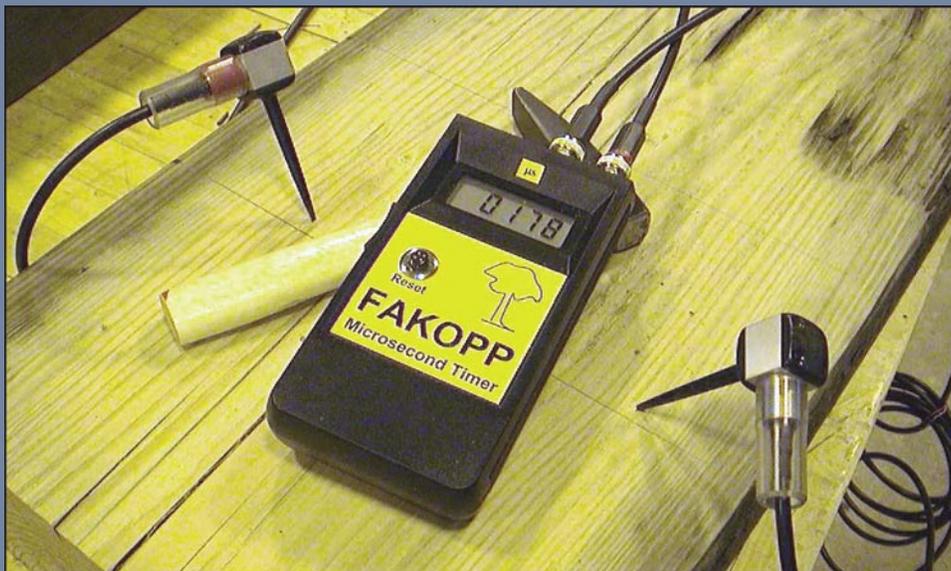
Federal
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Administration



Condition Assessment of Timber Bridges

2. Evaluation of Several Stress-Wave Tools

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Robert J. Ross



Abstract

This study was conducted to evaluate the accuracy and reliability of several stress-wave devices widely used for locating deteriorated areas in timber bridge members. Bridge components containing different levels of natural decay were tested using various devices. The specimens were then sawn (along their length) into slabs to expose their interior condition. The interior faces of these slabs were inspected visually and with a resistance micro-drill to confirm if deterioration was present. On the basis of these tests, we conclude that all four devices evaluated in this study can successfully be used to evaluate decay. There were, however, differences in the decay thresholds and user-friendliness among the devices.

Keywords: timber, bridge, inspection, stress wave, ultrasonic, nondestructive

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Condition Assessment of Timber Bridges

2. Evaluation of Several Stress-Wave Tools

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Introduction

Wood deterioration is one of the most common damage mechanisms in timber bridge structures and often inflicts damage internally. This may occur without visible signs appearing on the surface until a member's load-bearing capacity has been largely destroyed. Determining an appropriate load rating for an existing timber bridge and establishing rational rehabilitation, repair, or replacement decisions require an accurate assessment of the bridge's existing condition. Knowledge of the condition of the bridge can lead to savings in repair and replacement costs by minimizing labor and materials and extending its life.

In timber bridge structures, the degradation of a load-bearing (in-service) member may be caused by any one of several organisms that derive their nourishment or shelter from the wood substrate in which they live. For example, several types of fungi attack wood. The hyphae of these fungi secrete enzymes that depolymerize the chemical components of wood, thereby lowering the density, strength, and hardness of a member. This results in a significant reduction in load-carrying capacity, which in turn may result in the member's failure.

Recently, we prepared a comprehensive manual on the inspection of wood structural elements, *Wood and Timber Condition Assessment Manual* (Ross and others 2004). It was prepared at the request of the American Forest and Paper Association to assist field engineers and other inspection professionals. Published by the Forest Products Society, this manual includes chapters on visual inspection techniques, ultrasound- or stress-wave-based inspection tools, probing-type techniques, and post-fire inspection and assessment, plus a sample inspection report and summaries from several inspections. Detailed descriptions of the various available tools, guidelines on their use, and interpretation of data obtained from them are included.

As a consequence of our experience with various types of inspection methods and equipment (Ross and others 1999),

the Federal Highway Administration asked us to conduct a rigorous evaluation of the performance of several commercially available tools used to assess the condition of in-service wood. The results of that effort are summarized in a comprehensive report available through the University of Minnesota Duluth (Brashaw and others 2004). We prepared the following condensed report as a field guide for engineers from the information generated in the Brashaw and others (2004) study. This field guide focuses on our evaluation of several widely used stress-wave-based pieces of equipment.

Objective

The objective of this study was to evaluate the accuracy and reliability of several stress-wave devices for finding internal deterioration in timber bridge components. This was accomplished by testing several timber bridge components obtained from various in-service structures. Each device was also rated for ease of use as a bridge inspector's tool.

Materials

The primary materials used for this project were bridge timbers containing different levels of natural decay. These timbers were obtained from several sources and had been removed from service for various reasons. Timber bridge girders, pilings, decking material, and railing components were obtained from the USDA Forest Service, Chequamegon–Nicolet National Forest. The materials had been remaining after construction of new bridges or had been removed from service for replacement. In addition, timber bridge girders, decking, and railing components were obtained from the Oliver Bridge, a combination motor-vehicle and railroad-timber-and-steel bridge located between Duluth, Minnesota, and Superior, Wisconsin. This bridge was being rebuilt by the owner, the Duluth and Missabe National Railroad. Additional materials were obtained from Michigan Technological University, Duluth Timber Recycling Company (Duluth, Minnesota) and Minnesota Power (Duluth, Minnesota).

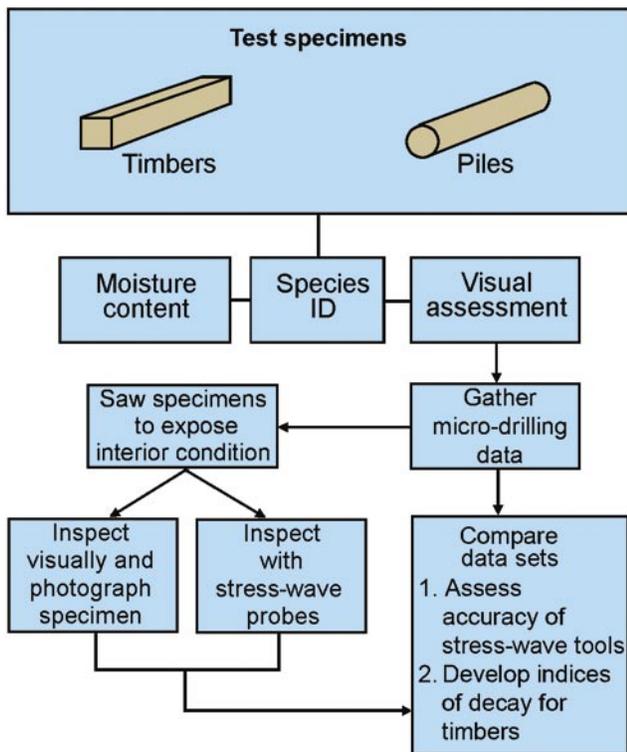


Figure 1—Stages of this study.

A total of 46 timber specimens were evaluated with the various stress-wave devices. Thirty-six of the timber specimens were sawn timbers and 10 were round timber piles. The sawn timbers varied in size from 3 by 12 in. (76 by 305 mm) to 20 by 20 in. (508 by 508 mm) and were up to 99 in. (251 cm) long. The round timber piles were 9 to 18.75 in. (229 to 476 mm) in diameter and up to 143 in. (363 cm) long. Thirty-eight (~83%) of the timber specimens were Douglas-fir species. Other timber specimens included western redcedar (4), southern yellow pine (2), and northern white pine (3). Nearly two-thirds of the Douglas-fir specimens were creosote treated.

Methods

This study was accomplished in several different stages (Fig. 1). Several types of data were collected on the timber specimens in their original (unsawn) condition. First, the timber specimens were tested to determine moisture content and wood species. Second, the bridge timbers were visually inspected to locate deteriorated areas. Then stress-wave measurements were collected at several locations on each specimen. Last, micro-drilling resistance measurements were collected from each of the timber bridge specimens. Micro-drilling resistance results from this study are published in a companion report (Brashaw and others 2005).

After the timber specimens were sawn along their length into slabs that exposed their interior condition, additional data were collected. The sawn components obtained from



Figure 2—Metriguard 239A Stress-Wave Timer.

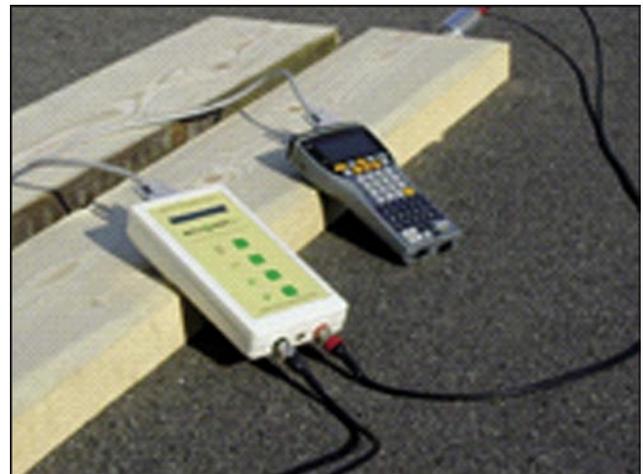


Figure 3—Sylvatest Duo.

the specimens were inspected visually to assess the extent and locations of the decay or other degradation. We also documented the sawn components with photographs.

Data from each timber bridge specimen were analyzed to determine the effectiveness of various stress-wave equipment for locating degraded or decayed material. Graphs of the data were prepared and used to develop indices of decay. These two data sets were then compared to determine the effectiveness of the various stress-wave equipment in detecting deterioration. Each specimen's resistance chart was captured electronically by the equipment and was accompanied by a photograph of the specimen after being cut apart. These photographs revealed the representative quality of the specimen regarding its level of decay.

Stress-Wave Equipment Tested

Several types of commercially available stress-wave equipment were used to assess decay in the timber bridge



Figure 4—Fakopp Microsecond Timer.



Figure 5—IML Electronic Hammer.

specimens (Figs. 2–5). In general, each piece of equipment induced a mechanical stress wave into a timber specimen by a hammer or other means, which was detected with accelerometers at two points along the propagation path. The timer started when the wave front arrived at the first accelerometer. The timer stopped when the wave front arrived at the second accelerometer and displayed the propagation time between accelerometers in microseconds. Additional information on equipment manufacturer, method of operation, key considerations, specifications, and testing procedures is provided in the Appendix.

Data Collection with Stress-Wave Equipment

The timber specimens were of various cross sections and lengths; nonetheless, similar data collection procedures were used for all timber specimens. Figure 6 illustrates the standard data collection grid where measurements were obtained. Depending on the size of a specimen, we measured stress-wave transmission times along its length with up to three lines (A, B, and C) on the side surfaces, with A, the upper line; B, the middle line; and C, the lower line.

Some of the specimens had only one or two measurement lines. The measurement points in the longitudinal direction started at 3 in. (76 mm) from the end with varying intervals from 3 in. (76 mm) for the first, to 6 in. (152 mm) for the second, and then remained constant at 12 in. (305 mm) along the remainder of the timber specimen. Each specimen’s data were graphed along the length of each measurement line.

Each member was inspected with the following stress-wave timing equipment:

- Metriguard 239A (Metriguard, Inc.; Pullman, Washington, USA)
- Sylvatest Duo (Concept Bois Structure; Les Ecorces, France)
- Fakopp Microsecond Timer (Fakopp Enterprise; Agfalva, Hungary)
- IML Electronic Hammer (IML Inc., Kennesaw, Georgia, USA)

Each piece of equipment was used in accordance with the instructions provided in the user’s manual. All operators became familiar with the manufacturer’s instructions and recommendations. During testing, each piece of equipment was evaluated to determine the accuracy and reliability of the unit in determining the extent of decay and ease of use.

Metriguard 239A

Because we used a direct-contact measurement technique with the Metriguard 239A, results can be variable if the surface of the wood member is damaged. It is possible to mount the start and stop accelerometers to lag bolts for increased consistency, although that was not done during this study.

Sylvatest Duo

We used two techniques with the Sylvatest Duo during the inspection of timber bridge components: for the first set

Measurement line	Measurement locations from end of specimen (in.)					
	3	6	12	24	36	48
A →	+	+	+	+	+	+
B →	+	+	+	+	+	+
C →	+	+	+	+	+	+

Figure 6—Typical stress-wave testing locations used for each timber bridge specimen.



Figure 7—Portable band saw cutting timbers lengthwise along measurement lines.

of measurements, we placed the probes in direct contact with the member, and for the second set, we drilled a small contact hole and placed the probes into the hole. Both techniques were effective in locating severe decay in wood members, but the direct-contact technique resulted in more variability in measurements, especially for those members with no or low levels of decay. We recommend that only experienced operators use the probes through direct contact when the shell condition of the member is good. If the shell is damaged, we recommend placing the probes in predrilled-contact holes. The Sylvatest Duo also determines the peak energy received during testing. This information should only be used if the data are collected using the predrilled-contact holes method.

Fakopp Microsecond Timer

This unit has its transducers mounted directly to metal spikes, which provide intimate contact points when hand pressed into the timber test specimens.

IML Electronic Hammer

Several timbers were scanned using the IML Electronic Hammer, which was effective in identifying decay in the timber specimens evaluated during the project. We discontinued using this equipment after three timbers, however, because of the time-consuming process required to obtain measurements. Further information on the IML Electronic Hammer is in the Appendix.

Following stress-wave testing, each timber was cut into slices using a portable band saw (Fig. 7). Each timber specimen was cut along the measurement lines A, B, and C along the length of the piece. Each section was then laid out so that the interior faces of each measurement line were revealed and could be documented through digital pictures. Figure 8 demonstrates how the sawn samples were typically laid out for visual assessment and documentation. The top board corresponds with data collected along measurement line A. The bottom board corresponds with data collected along measurement line B.

Results and Discussion

Each specimen's stress-wave transmission time data are compared with photographs of the specimen after being cut apart. Results for all 46 specimens tested with the various stress-wave timing equipment are reported in Brashaw and others (2004). Results from three representative specimens, each having different stages of deterioration, are described as follows.

Figure 9 illustrates results obtained from a specimen with areas of severe, moderate, and no (sound wood) deterioration. All stress-wave transmission times were within the severe deterioration zone for a majority of the points along line C. Stress-wave transmission times along line B were mostly in the moderate decay zone by Sylvatest, whereas Metriguard and Fakopp detected severe deterioration at many test locations. Transmission times along line A

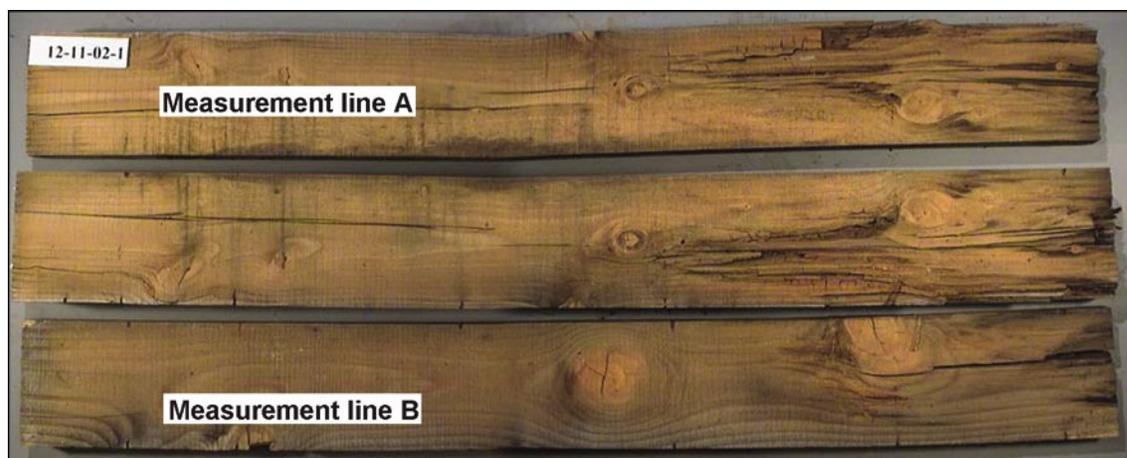


Figure 8—Typical layout of sawn timber specimens for photograph documentation.

Table 1—Comparison ratings for stress-wave equipment^a evaluated

	Metriguard 239A	Sylvatest Duo ^b	Fakopp
Accuracy	Good	Good	Good
Reliability	Good	Good	Good
Variability	Medium	Low	Low
Ease of use	Better	Good	Best
Size	Large	Small	Small
Display	Easy to see	Difficult to see	Easy to see
Key consideration	Accelerometers must be orientated properly	Probes are placed in pre-drilled contact holes	Spike-mounted transducers provide good contact

^aIML Electronic Hammer not included; see additional comments in Appendix.

^bBased upon placing probes in small contact holes, direct-contact method not recommended.

Table 2—Stress-wave transmission times perpendicular to the grain for various levels of degradation using the Metriguard 239A

Species	Stress-wave transmission time (µs/ft) ^a			
	Sound wood	Moderate decay	Severe decay	Splits
Douglas-fir	130–400	400–600	600+	400–700
Western redcedar	200–500	600–800	800+	600–1100
Southern yellow pine	250–400	NR	NR	NR
White pine	280–400	NR	700+	NR

^aNR, no results to report. Because of limited numbers of southern yellow and white pine samples, not all decay levels were present to report.

revealed mostly sound wood or slightly moderate decay except for the stress-wave transmission time at 96 in. (244 cm), which was within the severe decay zone by all stress-wave devices. Figure 10 illustrates results obtained from a specimen that showed mostly sound wood with a pocket of moderate–severe deterioration at approximately 60 in. (241 mm) from the specimen end after being cut open. Nearly all measured stress-wave transmission times were within the sound to slightly moderate decay zones. However, the stress-wave transmission time measured at 60 in. (241 mm) was in the severe to slightly moderate decay zone for the Sylvatest device, whereas it was in the severe decay zone for the Metriguard and Fakopp devices. Figure 11 illustrates results obtained from a specimen that showed sound wood, with no deterioration after being cut open. All stress-wave transmission times for Lines A, B, and C were within the sound wood zone using all stress-wave devices. However, stress-wave transmission times measured with the Metriguard device along Line A were slightly higher and were in the proximity of the moderate decay threshold level.

Results on comparative performance characteristics such as accuracy, reliability, and ease of use in detecting

internal decay in the bridge timber specimens are summarized in Table 1. Our operators learned how to use each piece of equipment tested in less than one day. The operator’s manual and manufacturer’s website provide good information on use of the equipment and interpretation of the testing results. Regardless of the unit used, the user must be careful to differentiate the presence of decay from internal splits, cracks, or ring shake in the timbers. We recommend that an increment corer or resistance drill be used to confirm the exact levels and locations of decay.

Summary results from all timber bridge specimens tested are also provided for each stress-wave unit by wood species and deterioration level. The stress-wave (perpendicular to grain) transmission times recorded with the Metriguard 239A are listed in Table 2. The stress-wave (perpendicular to grain) transmission times along with peak energy values recorded with the Sylvatest Duo are listed in Table 3. The stress-wave (perpendicular to grain) transmission times recorded with the Fakopp Microsecond Timer are listed in Table 4.

Summary and Conclusions

The purpose of this study was to evaluate the effectiveness of several pieces of commercial testing equipment for locating damaged or decayed timber bridge members. Further, we evaluated the equipment for ease of use and effectiveness in analyzing and interpreting the test data. This was completed for both individual timber members in a laboratory setting and on several field bridges. The following conclusions were evident from the testing, analysis, and data interpretation of the project:

- Stress-wave timing technologies can be used successfully to detect the presence and level of internal decay for timber bridge components.
- Stress-wave timing measurements perpendicular to the grain provide an excellent tool to assess the extent of internal decay in timber bridge components. All the equipment evaluated in this study can be used

Table 3—Stress-wave transmission times perpendicular to the grain and peak energy received for various levels of degradation using the Sylvatest Duo

Condition	Species	Stress-wave transmission time ^a (μs/ft)				Peak energy (mV) received ^{b,c}			
		Sound wood	Moderate decay	Severe decay	Splits	Sound wood	Moderate decay	Severe decay	Splits
Undrilled	Douglas-fir	160–600	400–600	700+	300–600	—	—	—	—
	Western redcedar	300–400	400–700	700+	300–700	—	—	—	—
	Southern yellow pine	400–600	NR	NR	NR	—	—	—	—
	White pine	200–400	NR	700+	NR	—	—	—	—
Drilled	Douglas-fir	130–250	300–450	600+	300–500	50–200	10–50	0–10	0–15
	Western redcedar	210–320	450–650	600–900	300–600	50–200	10–50	0–10	0–15
	Southern yellow pine	200–350	NR	NR	NR	50–200	NR	NR	NR
	White pine	180–360	NR	650+	NR	50–200	NR	0–10	NR

^aNR, n□ report.

^bPeak energy values are reported on an actual width basis, not on a per foot basis. Large cross-section members may have low energy received values.

^cThis technique is not recommended in the undrilled condition.

Table 4—Stress-wave transmission times perpendicular to the grain for various levels of degradation using the Fakopp Microsecond Timer

Species	Stress-wave transmission time (μs/ft) ^a			
	Sound wood	Moderate decay	Severe decay	Splits
Douglas-fir	130–260	300–400	500+	300–700
Western redcedar	160–300	300–400	500+	300–500
Southern yellow pine	220–250	NR	NR	NR
White pine	230–325	NR	500+	NR

^aNR, no results to report. Because of limited numbers of southern yellow and white pine samples, not all decay levels were present to report.

successfully to evaluate decay. There were, however, differences in the level of variability and the decay thresholds for this equipment. Primary differences among the equipment were the level of contact between the accelerometers and the wood component and the start and stop timer thresholds used by the manufacturer. Specifically, when used in an undrilled condition, the Sylvatest Duo showed more variability, resulting in less certainty for the inspector. This was also true for the Metriguard 239A because it uses a direct impact system. The Sylvatest Duo in the drilled condition and the Fakopp Microsecond Timer showed the least variability, and were the most effective at clearly differentiating decay from sound wood.

- All stress-wave timing equipment evaluated during the project was portable and relatively easy to use. Refer to Table 1 for comparison ratings.

Any nondestructive testing tool or device must be used as part of a comprehensive condition assessment that incorporates an in-depth visual inspection, knowledge of prior use of the structure, and a working knowledge of fundamental engineering properties of structural wood products. When used with visual and probing techniques, this technique provides a very accurate description of the internal condition of bridge timbers.

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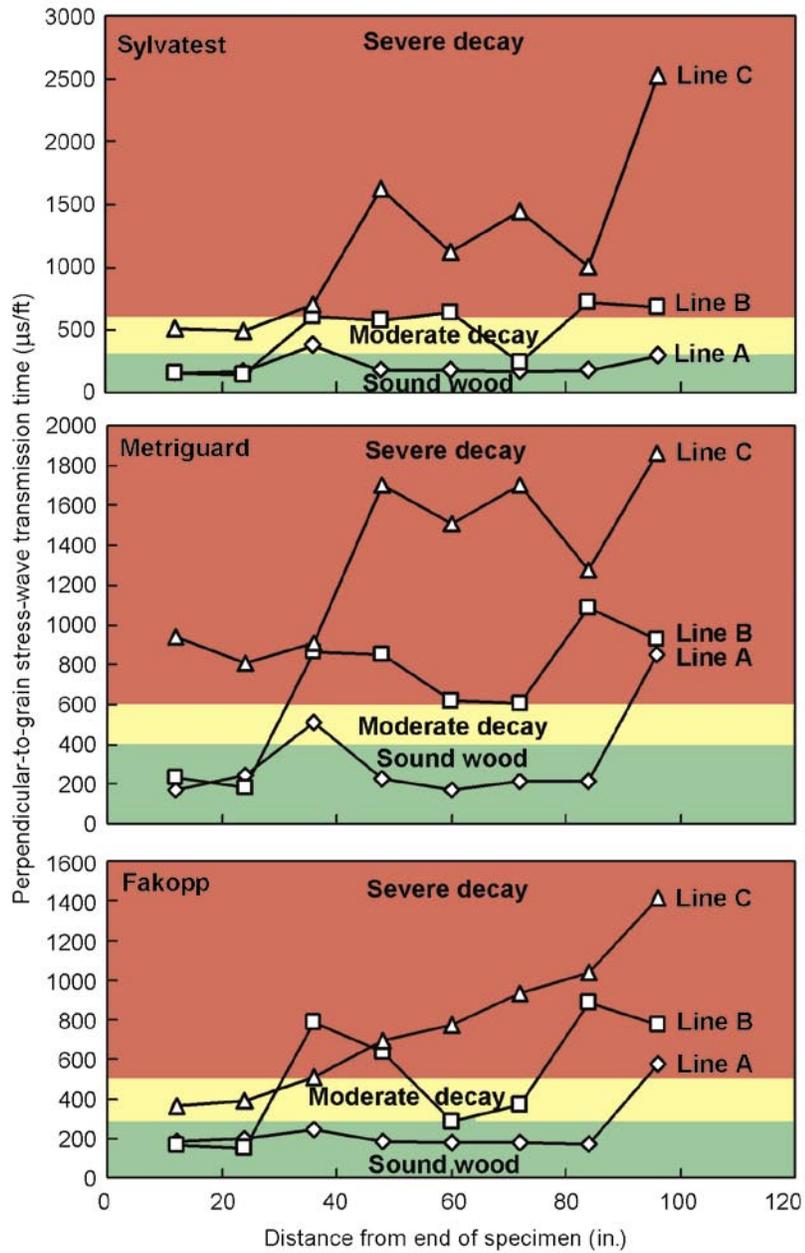
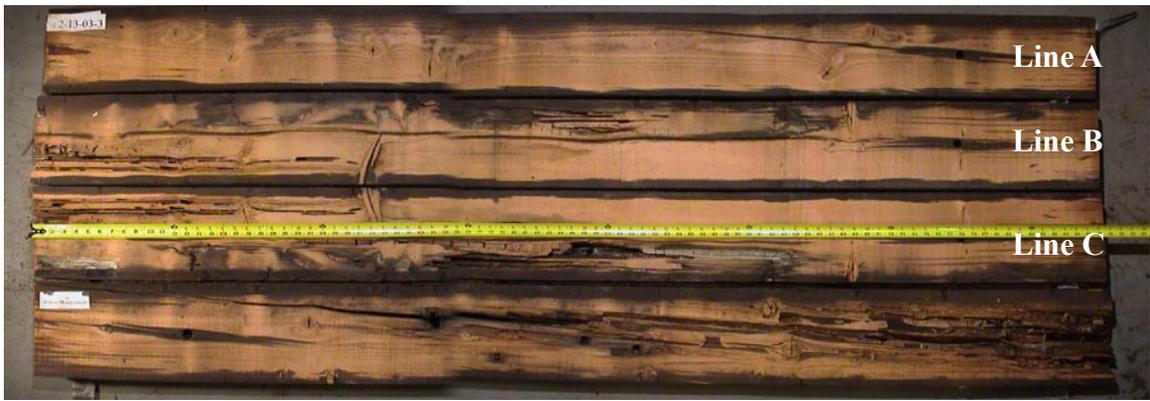


Figure 9—Comparison of stress-wave transmission plots and interior photographs of Douglas-fir specimen 2-13-03-3 reveals areas of moderate and severe deterioration and sound wood.

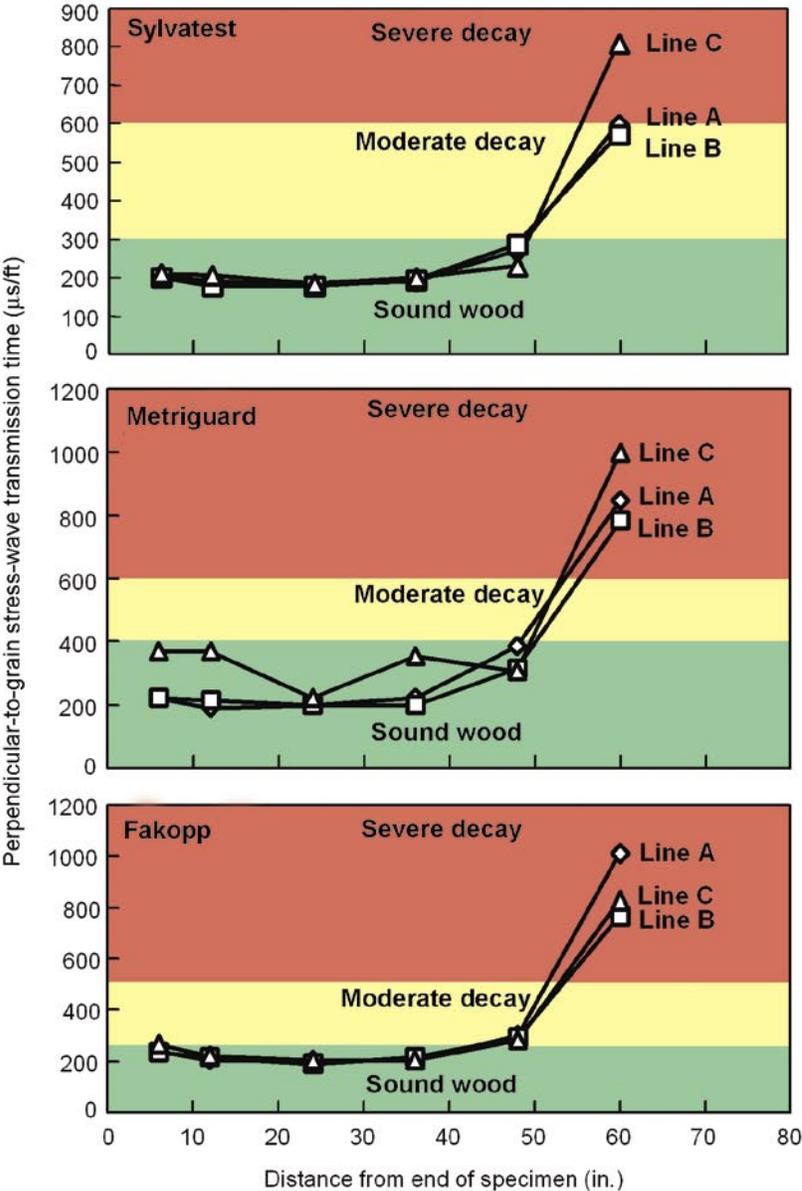


Figure 10—Comparison of stress-wave transmission plots and interior photographs of Douglas-fir specimen 2-11-03-5 reveals mostly sound wood with a pocket of moderate–severe deterioration at approximately 60 in. (241 mm) from specimen end.

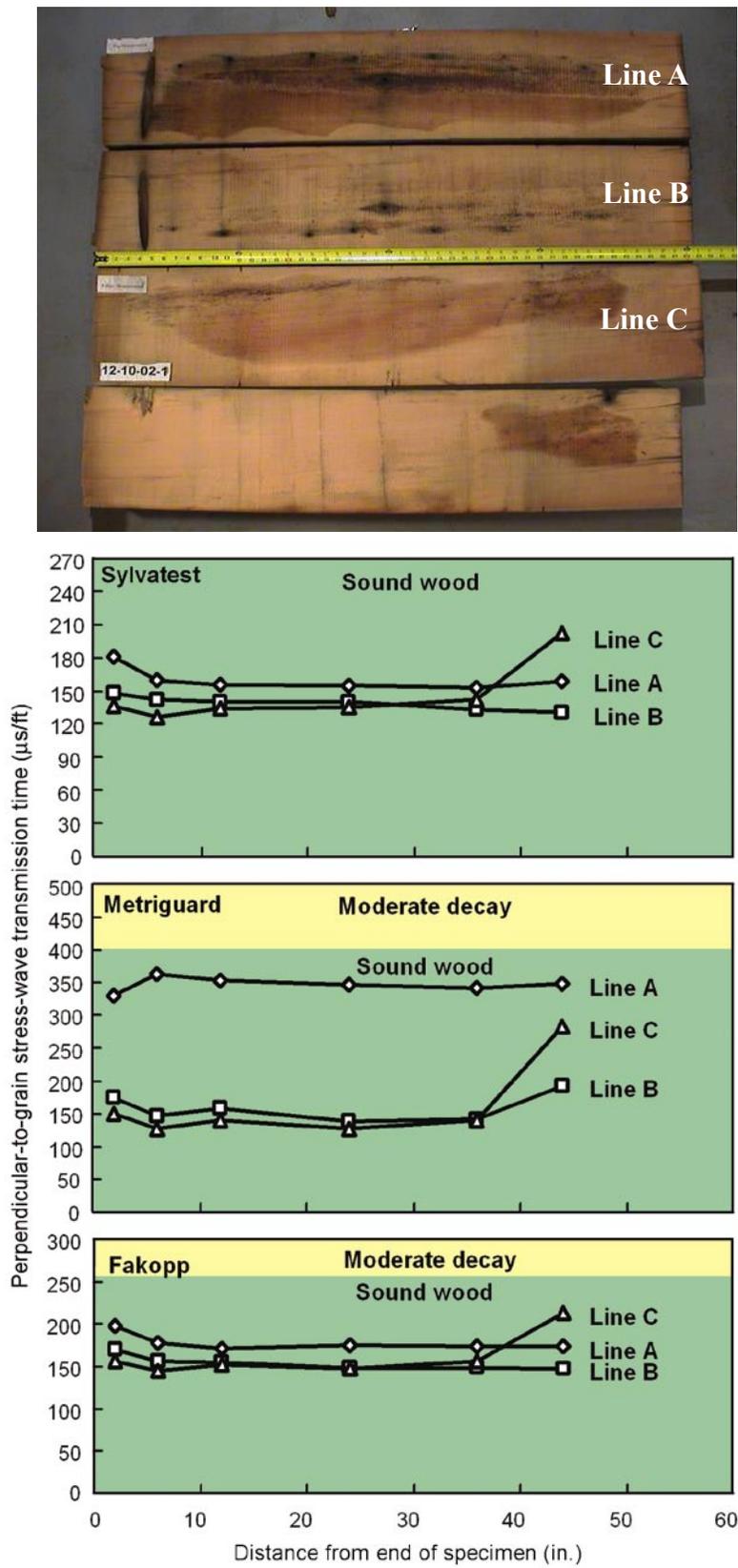


Figure 11—Comparison of stress-wave transmission plots and interior photographs of Douglas-fir specimen 12-10-02-1, reveals sound wood throughout with no deterioration.

Appendix—Additional Equipment Information

Metriguard Model 239A Stress-Wave Timer

Manufacturer

Metriguard, Inc.

Method of Operation

A mechanical stress wave is induced in a member by a hammer or other means and is detected with accelerometers at two points along the propagation path. The timer starts when the wave front arrives at the first accelerometer. The timer stops when the wave front arrives at the second accelerometer and displays the propagation time between accelerometers in microseconds.

Consideration

It is imperative that the accelerometers are oriented properly when using this equipment.

Specifications

Power requirements: 9-V battery

Resolution: $\pm 1 \mu\text{s}$

Dimensions: 7 by 9 by 9 in. (18 by 23 by 23 cm)

Weight: 12 lb (5.4 kg) (including hammer and accelerometers)

Test Procedure Summary

1. Connect lead from impact-end accelerometer to start terminal.
2. Connect lead from receive-end accelerometer to stop terminal.
3. Turn switch on.
4. Switch gain to a level close to but above the ambient noise level. For each channel, rotate the gain selector switch until the display trigger indicator dot for that channel does not come on from ambient noise. Gain settings used in this testing were 1 for start and 20 for stop.
5. Place the start and stop accelerometers in positions that are a straight line across the specimen. Impact the sample and record the time of propagation for the stress wave between the two accelerometers. The impact was repeated three times to obtain an average reading for that location.
6. Repeat process at intervals along the specimen.

Sylvatest Duo

Manufacturer

Concept Bois Structure

Method of Operation

The Sylvatest unit uses an ultrasonic pulse generator to impart a stress wave into a member. Two transducers are placed a fixed distance apart on a member. A transmitting transducer imparts a wave into the member, and a receiving transmitter is triggered upon sensing of the wave. The time it takes the wave to pass between the two transducers is then coupled with various additional information, such as wood species, path length, and geometry (round or square section), to compute modulus of elasticity. A second set of pulses is evaluated to determine the maximum energy of the received wave.

Consideration

Use of pre-drilled contact holes is recommended for improved accuracy and reliability.

Specifications

Power requirements: 9-V battery

Resolution: $\pm 1 \mu\text{s}$, ± 1 millivolt (mV)

Dimension: 1.5 by 4 by 8 in. (38 by 102 by 203 mm)

Weight: 1.2 lb (0.5 kg) (instrument only), 3 lb (1.4 kg) (instrument with carrying bag and accessories)

Test Procedure Summary

1. Connect probes to the main unit. This unit can be coupled to the surfaces of the material being tested through direct pressure or by drilling a 0.19-in.- (5-mm-) diameter hole to a depth of 0.39 in. (1 cm) deep on each side of the wood you want to measure. The operator may use a conic-shape drill or awl for accuracy. Regardless of whether a hole is drilled, a good contact point is necessary for accurate measurements. We recommend that a drilled hole is used when the peak energy readings are of interest.
2. Push the on key. Press any key to enter menu mode.
3. Select a mode by pressing + or – keys. Change values or execute action by pressing ok.
4. During two series of faint clicks or pings, the transmission time and peak energy value will be displayed.
5. Continue sampling along entire timber and record data.

Fakopp Microsecond Timer

Manufacturer

Fakopp Enterprise

Method of Operation

A mechanical stress wave is induced in a member by a hammer or other means into an accelerometer-instrumented sharp probe that is inserted into the member. A similar probe is inserted on the opposite side of the member. The timer starts when the wave front arrives at the first accelerometer. The timer stops when the wave front arrives at the second accelerometer and displays the propagation time between accelerometers in microseconds.

Specifications

Power requirements: Four AA batteries

Resolution: $\pm 1 \mu\text{s}$

Dimension: 1.8 by 3.2 by 5.9 in. (45 by 82 by 150 mm)

Weight: 0.8 lb (347 g)

Data output: RS-232 port

Test Procedure Summary

1. Connect the transducers to the timer box.
2. Switch on the timer at the side of the unit.
3. Press the reset button prior to repeating impact.
4. To use the auto reset feature, turn on the timer while holding the reset button down. This will result in continuously updated readings after each impact.
5. The transducers are identical. Make sure that the one you are going to “hit” is connected to the “start” connection.
6. Hit the start transducer with the hammer, making sure the direction of the hit is parallel to the direction of the nail.
7. Never use a hammer heavier than 7 oz (200 g).
8. Continue measurements along specimen.

IML Electronic Hammer

Manufacturer

Instrument Mechanic Labor (IML), Inc.

Method of Operation

A mechanical stress wave is induced in a member by striking an instrumented hammer into a lag bolt that is inserted into the member. A similar lag bolt is inserted on the opposite side of the member. The timer starts when the lag bolt is impacted. The timer stops when the wave front arrives at the second accelerometer and displays the propagation time between accelerometers in microseconds.

Specifications

Power requirements: 9-V battery

Resolution: $\pm 1 \mu\text{s}$

Dimension: 2 by 4 by 8 in. (5.1 by 10.2 by 20.3 cm)

Weight: 1.6 lb (0.7 kg)

Test Procedure Summary

1. Drill two starter holes in the side of the member being tested.
2. Insert the lag bolts into the starter hole until they are about $\frac{1}{2}$ in. (12.7 mm) deep.
3. Attach the transducers to each of the lag bolts.
4. Switch on the unit.
5. Take measurements.

General Comments

- The transducers are mounted on lag bolts, which results in intimate contact with the member.
- The display window is easy to see.
- The unit is small and portable.
- The testing process is very slow. Lag bolts must be inserted into the specimen, and then transducers must be attached to the lag bolts. It took almost five times longer to use this equipment than the other stress-wave timers evaluated.

