Acoustic velocity as a means to detect damage in 4-inch-diameter pine poles stressed in bending beyond their proportional limit

Robert Slay*
Rubin Shmulsky*
R. Dan Seale*

Abstract

Four-inch-diameter partially air-dried ungraded loblolly pine dowels were alternately tested for acoustic velocity and flexurally loaded to increasing load levels to the point of failure. It was anticipated that as the wood was loaded over and above the proportional limit, the permanent damage could be detected via acoustic velocity measurement. Acoustic velocity was shown to decrease following flexural loading to more than 80 percent of ultimate load.

High wind events such as those associated with large-scale storms are highly destructive to forest trees. The obvious effect of the high wind is broken timber. When acted upon expeditiously, this damaged timber may often be salvaged via logging. Standing timber is typically left to mature, especially if it is not obviously damaged. Standing timber may appear sound but contain unseen structural damage, in which case it may be more prudent to remove this wood than to let it continue to grow. The research conducted herein focused on nondestructive identification of damage in wood that has occurred via bending load in excess of the proportional limit, yet below breaking strength. In theory, at increasing load levels above the proportional limit, some damage occurs in the wood despite the fact that no obvious visible damage may be seen. Desired is a method to detect hidden structural damage in wood that otherwise appears sound. It was anticipated that internal damage and microcracking in overstressed wood would create discontinuities within each member, in which case acoustic velocity would potentially be able to detect damaged wood.

Procedure

Fifty-three 4-inch-diameter loblolly pine dowels were tested in bending. Eight-foot-long dowels were procured from a regional post manufacturer. Dowels were partially air dried and were not graded. Moisture content (MC) was not controlled. Each specimen was center-point loaded at 1 inch per minute across a 72-inch span (18/1 span to depth ratio). Anticipated average breaking stress was approximately 8.0 kpsi. Based on that value, a protocol was devised to measure acoustic velocity, load each dowel to a specific level, unload, remeasure acoustic velocity, then repeat the process with a higher load level. Acoustic velocity was measured with a Director-2000 (Fiber-gen) handheld device. For measurement, the device was pressed against the butt of each post, the butt of the post was tapped with a hammer, and the acoustic velocity was calculated and displayed by the device. A basic plot of this saw-tooth-like loading scheme is shown in **Figure 1**. This scheme was followed until each dowel fully failed. The acoustic velocity behavior was then compared to load level. Investigators were most interested in the acoustic velocity response within wood that had been loaded into the range over and above the proportional limit. Both stress and strain were recorded by the universal testing machine. Following testing, five samples were taken from the lot for MC analysis.

Results

Summary statistics for elasticity and breaking stress are given in **Table 1**. A correlation between ultimate stress (MOR) and elasticity as measured during the initial loading cycle, is given in **Figure 2**. For analysis of acoustic velocity,

The authors are, respectively, Graduate Research Assistant, Associate Professor, and Professor, Forest Products Dept., Mississippi State Univ., Mississippi (rslay@cfr.msstate.edu, rshmulsky@cfr.msstate.edu, dseale@cfr.msstate.edu). FWRC manuscript # FP399. This paper was received for publication in December 2006. Article No. 10280.
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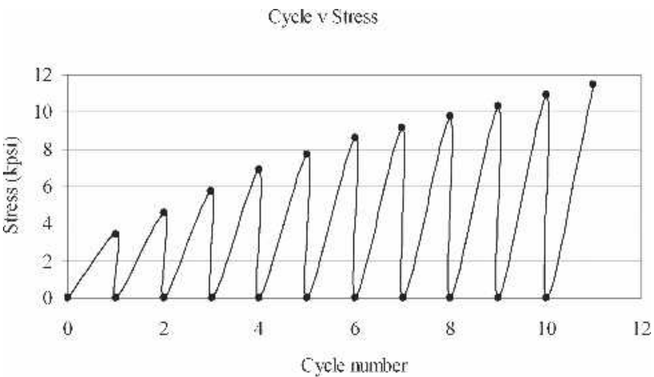

Figure 1. — Illustration of approximate loading scheme. After each load cycle, acoustic velocity was measured.

Table 1. — Summary statistics for dowel strength and stiffness.

	MOR	MOE
	(psi)	(Mpsi)
Mean	7220	0.99
Median	7330	0.99
SD	2260	0.26
COV	31%	26%
Minimum	3090	0.52
Maximum	12300	1.76
Number	54	54

the average of the velocities measured after loading to 80 percent or less of ultimate failure stress was compared to the average of the velocities measured after loading to greater than 80 percent of ultimate stress. Because each dowel broke at a different stress level, the greatest level of stress that was less than or equal to 80 percent of ultimate load varied; it averaged 75 percent and ranged from 61 percent to 80 percent. A summary of acoustic velocities is provided as **Table 2**. A paired t-test was used to compare the two acoustic velocity categories: the average of those measured at or below 80 percent of ultimate load vs. the average of those measured at greater than 80 percent of ultimate load. The paired t-test showed that the before and after readings were statistically different, *p*-value: 0.006. Because some of the test specimens broke before a sufficient number of readings (at least two) was taken, the number of test specimens contained in the analysis was reduced to 43. The sample of five MC sections showed average and standard deviation (SD) values of 13.6 and 0.50 percent,

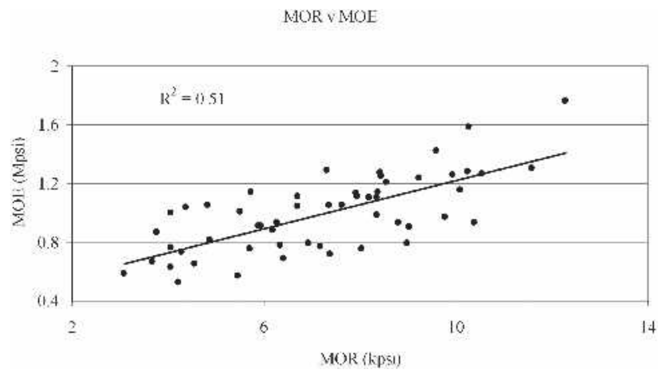

Figure 2. — Measured relationship between breaking stress and initial elasticity.

Table 2. — Summary statistics for acoustic velocity, as feet per second. The mean difference between the two categories was 485 and was statistically significant: p*-value = 0.006.*

	Average acoustic velocity after loading to 80 percent or less than ultimate breaking stress	Average acoustic velocity after loading to more than 80 percent of ultimate breaking stress
Mean	12,300	11,800
Median	12,400	11,900
SD	2,290	2,120
COV	19%	18%
Minimum	6,860	6,580
Maximum	16,400	16,000
Number	43	43

respectively.

Conclusions

Following increasing levels of bending load, beyond the proportional limit, the acoustic velocity decreased. This difference was statistically significant. From a practical perspective, the absolute level of difference was small. This level of difference, however, was not unexpected because the loading was not sustained for an extended period, and therefore creep should have been minimal. This finding suggests that this technique could be further developed and refined and perhaps used in conjunction with other techniques to identify mechanical damage in trees or logs that is not otherwise apparent via visual inspection. To become commercially viable, a substantial amount of technical refinement would likely be necessary.