by X. Wang, R.J. Ross, J.R. Erickson, and J.B. Ligon

NONDESTRUCTIVE EVALUATION OF TREES

The USDA Forest Service, Forest Products Laboratory (FPL) and Michigan Technological University have been developing nondestructive evaluation (NDE) techniques to identify degradation of wood in structures and the performance characteristics that remain in the structure. The research work has focused on using stress wave transmission NDE techniques for both laboratory and field investigations.

In previous publications,[1-3] we reported on experimental techniques that were developed to observe stress wave behavior in wood specimens. One technique utilized a mechanical impactor to induce a stress wave in wood specimens, Wave propagation in the specimens was observed by placing a piezo film sensor on the wood surface. Output of the sensor was recorded and displayed on a digital storage oscilloscope. Such a technique enabled us to examine fundamental relationships between wave propagation characteristics and the biological degradation of wood.

Based on the encouraging results from these efforts, we investigated the use of a stress wave transmission technique to evaluate the quality of wood in trees. This paper presents our experimental setup and typical experimental results obtained from using the technique in the field.

EXPERIMENTAL SETUP

The experimental setup consisted of two accelerometers, two spikes, a hand-held hammer, and a portable digital oscilloscope. A schematic diagram of key components of the experimental setup is shown in Figure 1; Fig. 2 shows NDE testing on trees in the field. Two spikes were imbedded into the tree trunk at about 45° to the tree surface, one spike at each end of the section to be assessed. The accelerometers were mounted on the spikes through two specially designed clamps. Figure 3 shows the upper accelerometer mounted on a tree trunk. A stress wave was introduced into the tree in the longitudinal direction by impacting the lower spike. The resulting signals were recorded on the oscilloscope. Figure 4 shows typical stress waveforms observed in trees. The stress wave transmission time could be determined by locating the two leading edges of these waveforms. Stress wave speed (SWS) was then calculated by dividing the test span *(L)* by the measured stress wave transmission time (At). A span of 4 ft (1.22 m) was found to produce good readings and rapid measurements; this span was therefore used for testing.

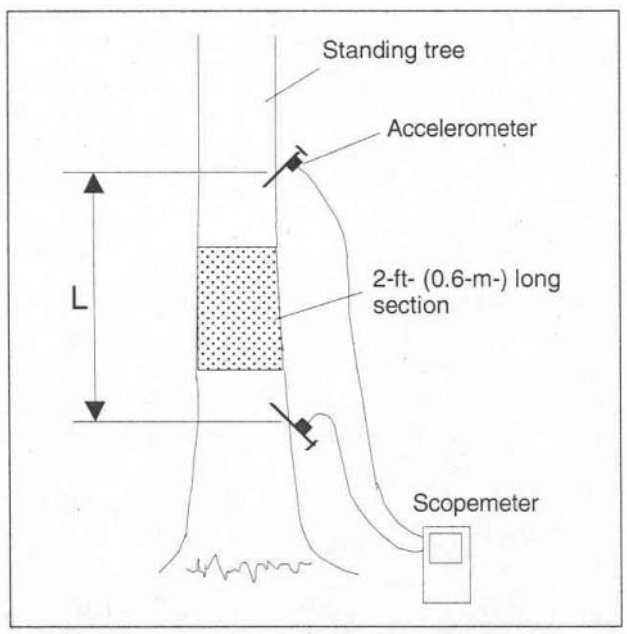

Fig. I: Schematic illustration of experimental setup utilized in field test

Field NDE tests were conducted on a sample of approximately 160 trees. Tree species included western hemlock and Sitka spruce. In the in situ stress wave measurements, the spikes used to mount the accelerometers were inserted into the trunk about 1 inch (25 mm) to go through the bark. This procedure was done to eliminate or minimize the effect of bark on stress wave measurements.[4] Because the spikes penetrated the wood less than 1 inch (25 mm) after entering the bark, they could be easily removed after each measurement and caused little or no damage to the growth of the test trees.

After field tests, 56 trees were felled. A 2-ft- (0.61-m-) long section in the test span was cut from each felled tree and shipped to the laboratory. The sections were still in a green state upon arrival. To obtain the density of wood, each section was weighed using a scale. The bulk density was then determined based on the bulk weight and bulk volume of the section. This density and the stress wave speed obtained from the standing trees were used to determine the dynamic modulus of elasticity (MOE,) of wood in standing trees.

Eight 1- by 1- by 16-inch (25- by 25- by 406-mm) small, clear wood specimens were then cut from each section for further evaluation of stress wave properties. A previously reported technique[1] was used to obtain the stress wave properties. The green density of small, clear wood specimens was also

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Fig. 2: In-situ NDE testing of standing trees

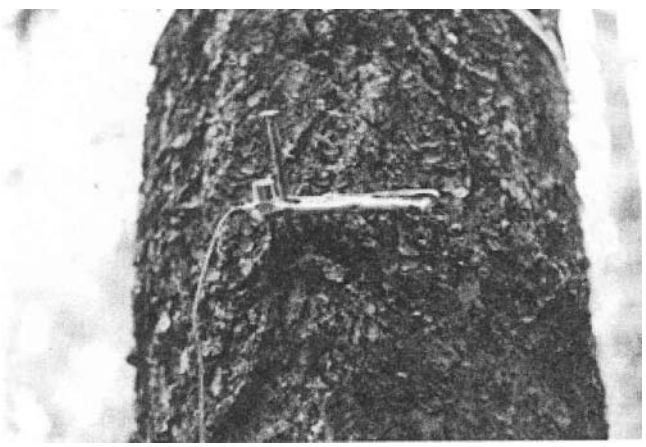

Fig. 3: Upper accelerometer mounted on tree trunk by spike driven into wood

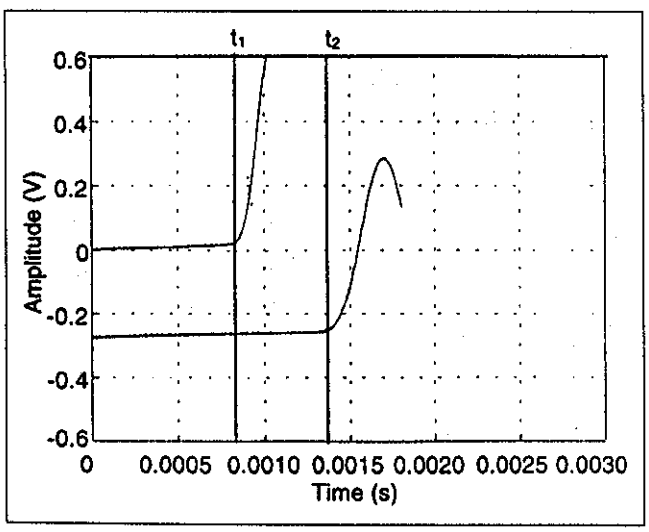

Fig. 4 Typical stress waveforms observed in trees

determined and used for stress wave E-rating of small, clear wood.

RESULTS

Figure 5 shows the relationship of stress wave speed measured in standing trees to stress wave speed measured in the small, clear wood specimens cut from the trees. The stress wave speeds of the specimens are average values obtained from eight samples of each tree. There is a strong relationship between stress wave speeds of trees and specimens. The correlation coefficient (R = 0.83) was highly significant at the 0.01 confidence level. The average stress wave speed measured in trees using this technique was 11,066 ft /
s (3,373 m/s), which is very close to the average stress wave speed of 10,800 ft/s (3,292 m/s) measured in small, clear specimens.

The dynamic modulus of elasticity (MOE_d) values of trees and small, clear wood specimens were evaluated based on the stress wave equation $MOE_d = SWS^2\rho$. The relationship between MOE_d of trees and that of wood specimens is shown in Figure 6. The MOE_d values of trees are the average values obtained from eight samples of each tree. Statistical analysis revealed a good relationship between MOE_d of trees and that of wood specimens. The MOE_d of trees determined in the field ranged from 1.00 to 2.02 million lb/in^2 (6.89 to 13.9 MPa) for western hemlock and 1.01 to 1.97 million lb/in^2 (6.96 to 13.57 MPa) for Sitka spruce. For both species, the average MOE, for trees was found in good agreement with that obtained for small, clear wood specimens.

These encouraging results led us to conclude that this field NDE testing technique could provide relatively accurate and reliable stress wave information on wood and therefore could enable the prediction of wood properties in standing trees. Further investigation revealed a clear correlation between edynamic modulus of elasticity of trees and static modulus of elasticity of small, clear wood specimens obtained from the trees?

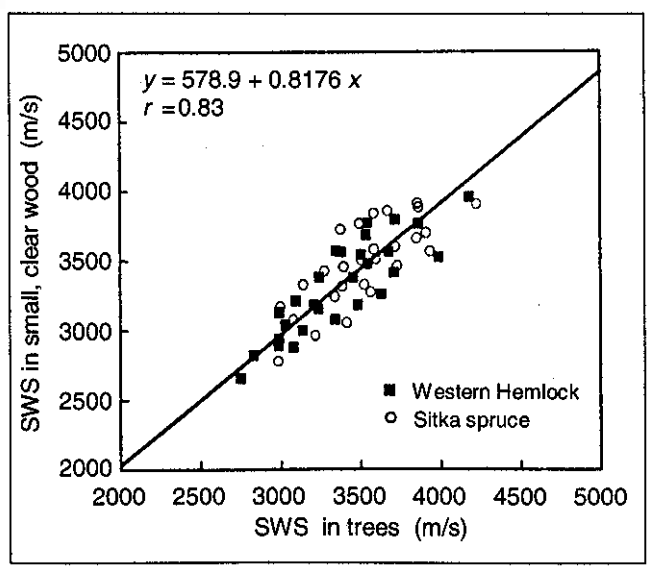

Fig. 5: Relationship of stress wave speed (SWS) measured in standing trees to SWS measured in small, clear wood specimens from trees. I ft = 0.3048 m

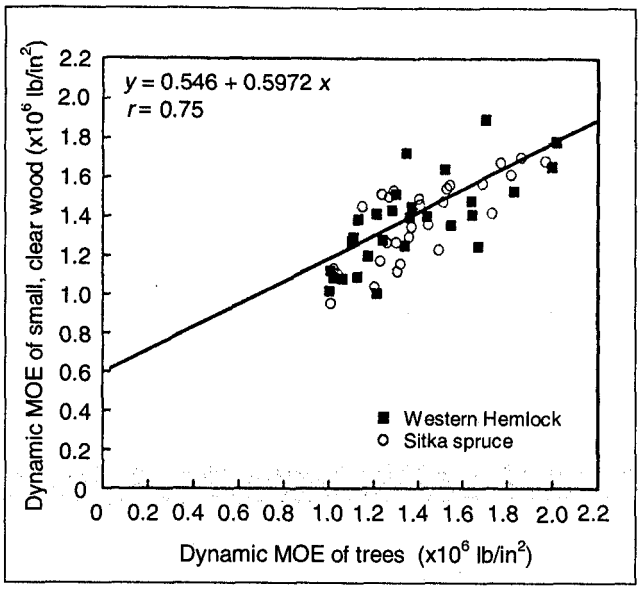

Fig.6: Relationship of dynamic modulus of elasticity (MOE_d) of trees to MOE_d of small, clear wood specimens obtained from trees. 1 lb/in² = 6.89 kPa

SUMMARY

We developed an experimental technique to evaluate wood properties in standing trees. The technique utilizes two accelerometers coupled to a digital oscilloscope. With this technique, we were able to obtain relatively accurate and reliable stress wave information that could be utilized to predict the mechanical properties of wood from trees. We believe that this technique provides a good in-situ estimate of wood quality and strength. The results indicate that this method may be used in the future to determine how forests could be managed to meet desired wood and fiber qualities.

References

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