

Inferences From Growing Trees Backwards

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ABSTRACT

The objective of this paper is to illustrate how longitudinal stress wave techniques can be useful in tracking the future quality of a growing tree. Monitoring the quality of selected trees in a plantation forest could provide early input to decisions on the effectiveness of management practices, or future utilization options, for trees in a plantation. There will likely be utilization options that will include the production of structural products that use modulus of elasticity (MOE) as part of the grading criteria. Examples include machine stress rated (MSR), solid-sawn lumber and veneer for laminated veneer lumber (LVL). Existing U.S. log and tree grading procedures only make visual assessments of log and tree quality. These procedures do not incorporate estimates of log or tree MOE. Research has shown good correlation between log and lumber MOE. In the pilot study reported herein, monitoring the properties of a growing tree was simulated by periodically measuring the MOE of a log as annual rings are peeled from the log. Such reverse monitoring allowed us to assess the potential of this approach without having to take measurements every year for 15 to 30 years, as the tree adds successive growth increments. Results from a southern pine log indicate that tree MOE and stress wave speed show a more regular pattern with age than does specific gravity. Results from a yellow-poplar log were not as definitive.

BACKGROUND

The increased demand for forest products, coupled with restrictions on harvesting timber from U.S. Federal lands, magnifies the importance of wood production on managed plantations. Genetically selected trees, managed under intensive silvicultural regimens and harvested in short rotation cycles, increase the importance of monitoring tree quality to provide continuing input into management decisions. For structural products produced from softwood species, it is well known that the amount of juvenile wood can have

a major impact on the mechanical properties of products (Koch 1972). The modulus of elasticity (MOE) of structural lumber containing 100% juvenile wood can decrease from 50% to 60% compared with lumber containing no juvenile wood (Fig. 1) (Kretschmann and Bendtsen 1992). In addition, although structural composite products, such as laminated lumber veneer (LVL), may incorporate a certain percentage of juvenile wood in their composition and still maintain acceptable properties, manufacturing costs will increase as a result of a higher level of breakage during processing (Kretschmann et al. 1993). Other properties, such as ultimate tensile stress parallel to the grain (Kretschmann and Bendtsen 1992) and horizontal shear and compression perpendicular to the grain (Kretschmann 1997), have been shown to decrease significantly with increasing juvenile wood content. Thus, monitoring tree quality for improvement in

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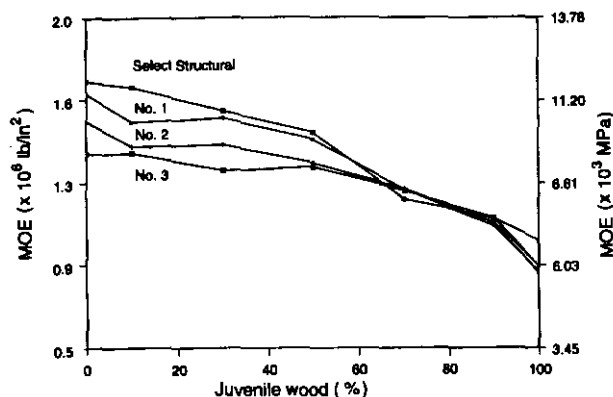


FIGURE 1. MOE as a function of the percentage of juvenile wood for four grades of southern pine 2 by 4 lumber (Kretschmann and Bendtsen 1992).

product performance could have real benefits for products like mechanically stress rated (MSR) lumber, which uses MOE as part of the grade sorting procedure.

Traditionally, density has been considered the single best indicator of wood quality (Panshin and de Zeeuw 1980). However, some researchers suggest that sorting trees on the basis of tree MOE is a better approach if structural lumber is the intended product (Tsehay et al. 1995, Nanami et al. 1992). Several studies have shown a good relationship between log MOE and the MOE of lumber cut from the log (Green and Ross 1997). For example, Arima et al. (1990) found a coefficient of determination (R^2) of 0.83 between log MOE and the average MOE of the lumber cut from Sugi logs using longitudinal stress wave techniques to obtain the MOE of the log. Using similar techniques, Aratake et al. (1992) reported R^2 values between log and lumber MOE ranging from 0.83 for green lumber cut from Sugi logs to 0.71 for dry lumber compared with the MOE of the green logs. Sandoz and Lorin (1994) reported R^2 values of 0.44 between log MOE and lumber MOR for European spruce. Green and Ross (1997) reported R^2 values between log MOE and the average MOE of lumber cut from that log that are very good for some species (Table 1). Research is also in progress at the USDA Forest Service, Forest Products Laboratory, to evaluate the relationship between log MOE and the MOE of veneer cut from a log. Establishment of this relationship could help select logs to be peeled into veneer for the production of LVL. From this briefly summarized information, it would appear that relating log MOE to lumber MOE holds great promise for improving the ability to select mature trees with superior potential for the production of structural products. Could similar techniques be used to monitor

TABLE 1. Summary of log-lumber correlations between log MOE and the MOE of lumber cut from individual logs (Green and Ross 1997).

Species	Number of logs	Coefficient of determination, R^2	
		Individual boards	Average of all boards from a log
Western spruce	98	0.50	0.82
Balsam fir	95	0.17	0.33
Southern pine	98	0.31	0.63
Douglas-fir	100	0.30	0.50
Douglas-fir plus western hemlock	200	0.54	0.74

potential quality of a growing tree? In addition, can we get some indication of this potential without having to monitor a number of growing trees for several years before we can even decide if the approach is useful? This paper discusses the results of a pilot study that evaluated the use of stress wave techniques for monitoring tree quality.

EXPERIMENTAL PROCEDURES

Two 2.44-m (8-ft) logs of southern pine (*Pinus* spp.) and yellow-poplar (*Liriodendron tulipifera* L.) were cut at, or near, the stump. These logs were de-limbed, measured, and kept green. The small end diameters were approximately 305 mm (12 in.) and the large end diameters were 330 to 356 mm (13 to 14 in.). A disk from the small end of each log was removed to obtain moisture content and specific gravity information by annual increment of growth. Where growth rate was slow, several annual increments were grouped. For each increment, or grouping of increments, from the bark to the pith, a small cube was cut. The oven-dry moisture content was determined by ASTM D4442 procedures and specific gravity based on oven-dry weight and density by Method A of ASTM D2395 (ASTM 1996).

Each log was mounted in a large lathe with a tail stock that was offset to allow uniform removal of annual growth increments (or multiples thereof) parallel to the bark. Annual rings were marked on the log end before cutting. Initially, and between each removal,

stress wave measurements were obtained and recorded from the remaining portion of the log. Care was taken to record the number of annual rings removed. Although eccentricity of the growth rings led to some overlapping of annual increments, a close approximation of the tree at a particular age was maintained.

Stress measurements were taken by mounting the receiving accelerometer on the small end of the log, removing the log from the lathe, and propagating sound in the log by striking the large end of the log with a hammer. A Dolche computer was used to record the received sound wave as it bounced back and fourth between the two ends of the log. The stress wave speed (V) at which the wave traveled through the log was determined from the time between stress wave peaks and the length of the logs. The MOE of each log was determined by the following:

$$\text{MOE of log} = K \times D/V^2 \quad (1)$$

where

D is the log density in lb/ft^3 , V is stress wave speed, in microseconds per ft, and K is a conversion factor, 215,730,000.

RESULTS AND DISCUSSION

The average specific gravity of the southern pine log was 0.468, based on oven-dry weight and green volume. On an oven-dry basis, this would be 0.54, about the same value of 0.55 given for the average for the species grouping (AF&PA 1991). The variation in specific gravity value along a radial line from the bark to the pith is shown in Figure 2. We were able to remove annual increments to within about eight rings of the pith. The irregular pattern of specific gravity with age is similar to that found in other studies (Koch 1972). The specific gravity is often lower adjacent to the bark because cell wall thickening may not be complete (Koch 1972). The decline at about 14 rings removed is due to an increase in growth rate. The reason for the increased growth rate is not known. This is information that could be obtained from an increment core on the tree prior to harvest or by taking increment cores periodically as the tree grows. Stress wave speed, per unit length of log, decreased from the pith of the tree toward the bark in a more regular pattern than did specific gravity (Fig. 3). The MOE generally increased from year 12 to when the tree was cut at year 40 (Fig. 4).

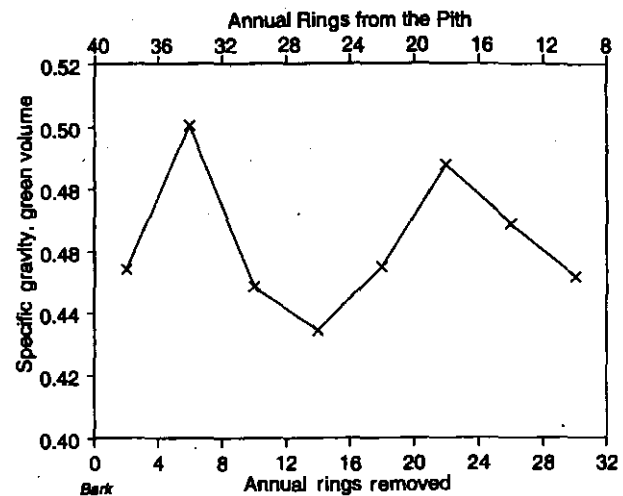


FIGURE 2. Specific gravity variation in southern pine log as a function of position in the log.

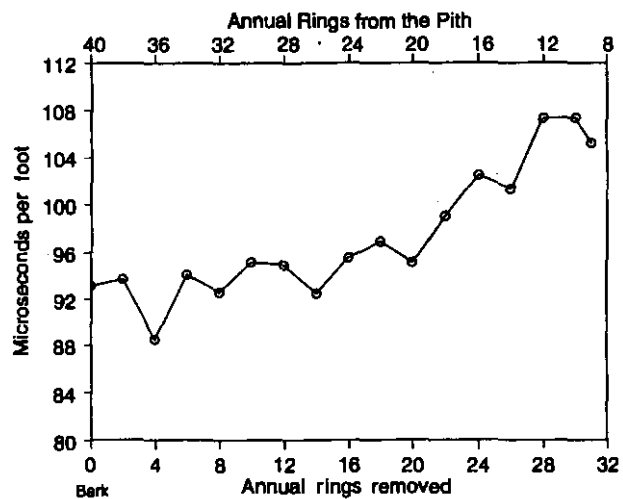


FIGURE 3. Change in stress wave speed as successive annual growth increments are removed from a southern pine log.

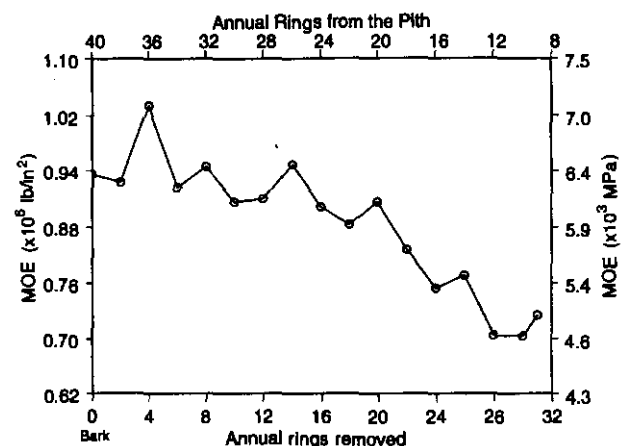


FIGURE 4. Change in MOE as successive annual growth increments are removed from a southern pine log.

The average specific gravity of the yellow-poplar log was 0.35 on an oven-dry weight–green-volume basis and 0.39 based on oven-dry weight and volume. The specific gravity based on oven-dry weight and volume is less than the species average of 0.43 (AF&PA 1991). The variation in specific gravity across the stem is shown in Figure 5. This is a typical pattern for yellow-poplar (Koch 1985). Stress wave speed shows no distinct trend with annual growth increment (Fig. 6) and is not changed by converting the speed to MOE (Fig. 7). Thus, it is not clear from this one log if stress wave techniques offer an advantage over density measurements for yellow-poplar.

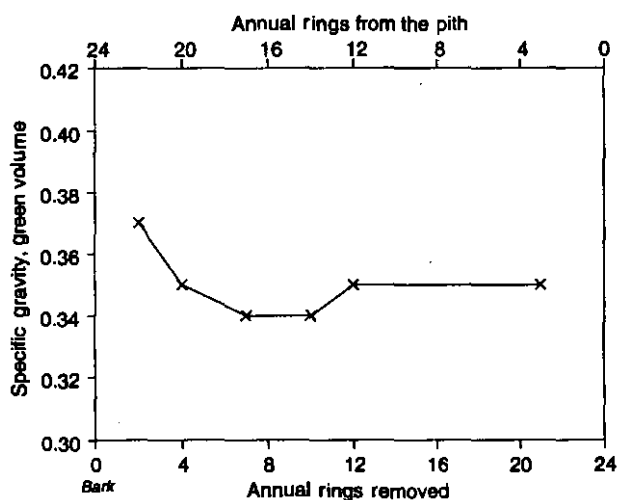


FIGURE 5. Specific gravity variation in yellow-poplar log as a function of position in the log.

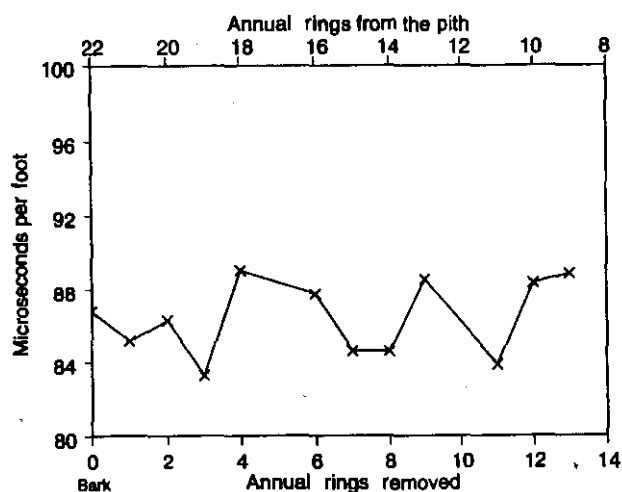


FIGURE 6. Change in stress wave speed as successive annual growth increments are removed from a yellow-poplar log.

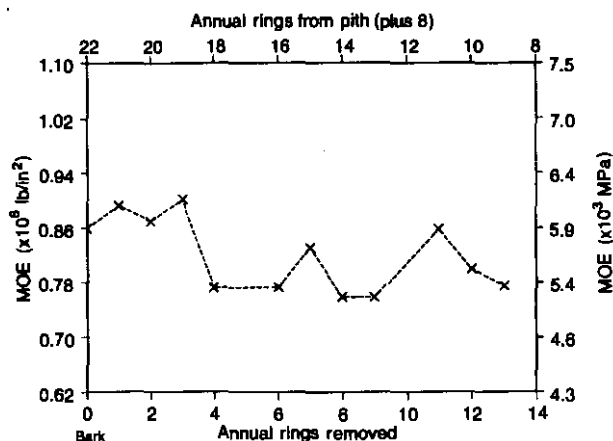


FIGURE 7. Change in MOE as successive annual growth increments are removed from a yellow-poplar log.

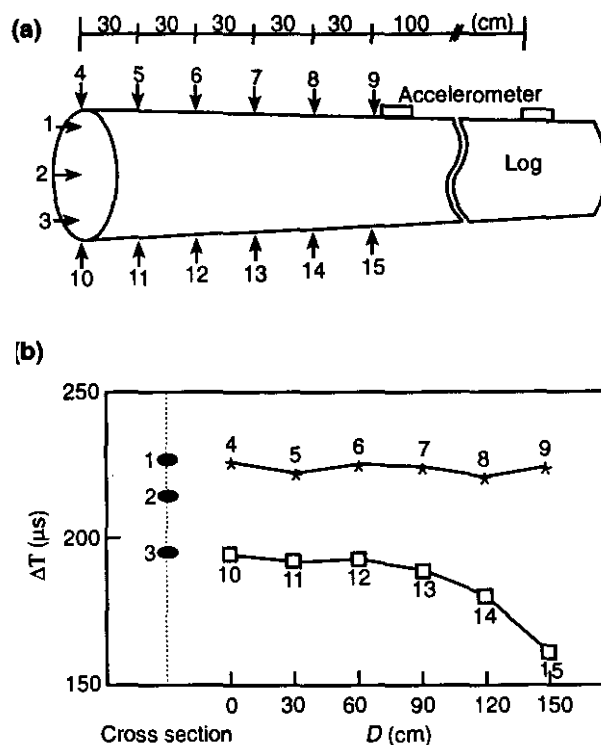


FIGURE 8. Effect of varying striking position on stress wave speed (Nanami et al. 1992): (a) striking location (b) comparison of stress wave speeds for fixed accelerometer spacing.

Application of this technique to a standing tree could not be applied exactly as indicated here. For one thing, accelerometers would have to be attached to the side of the tree. Nanami et al. (1995) has shown that better definition of transit time signals can be obtained by driving spikes into the tree: one spike for introduction of the impact wave and one spike for the receiving accelerometer. Their studies show that a stress

wave signal generated on the side of a log (such as positions 4–9 in Fig. 8a) tend to travel straight down the log (upper curve in Fig. 8b). Thus, with a species like southern pine, in which the outer growth increment may not be fully developed, it would be critical to make sure that the spikes are driven sufficiently into the tree to prevent getting readings only from the first growth increment. Another alternative would be to strike the tree on one side and receive the signal on the other. Nanami et al. (1995) showed that empirical relationships can be used to get good approximations of stress wave times. However, additional experiments are needed to fully understand the interpretation of such signals.

CONCLUSIONS

From the results of this pilot study to evaluate the use of stress wave techniques to monitor the quality of growing trees, we conclude the following:

- A more consistent relationship was found between stress wave speed and annual growth increment than between density and annual growth increment for a southern pine log.
- The relationship between stress wave speed and annual growth increment with a yellow-poplar log was no more consistent than that between density and annual growth increment.
- This study demonstrates the potential for monitoring the quality, and estimating the future quality, of growing trees through the use of a stress wave technique. The technique would appear to be especially advantageous for southern pine intended for the production of structural products.
- Additional research is needed to quantify interpretations of stress wave signals from growing trees. However, such research is not viewed as a major obstacle to the implementation of this technique.

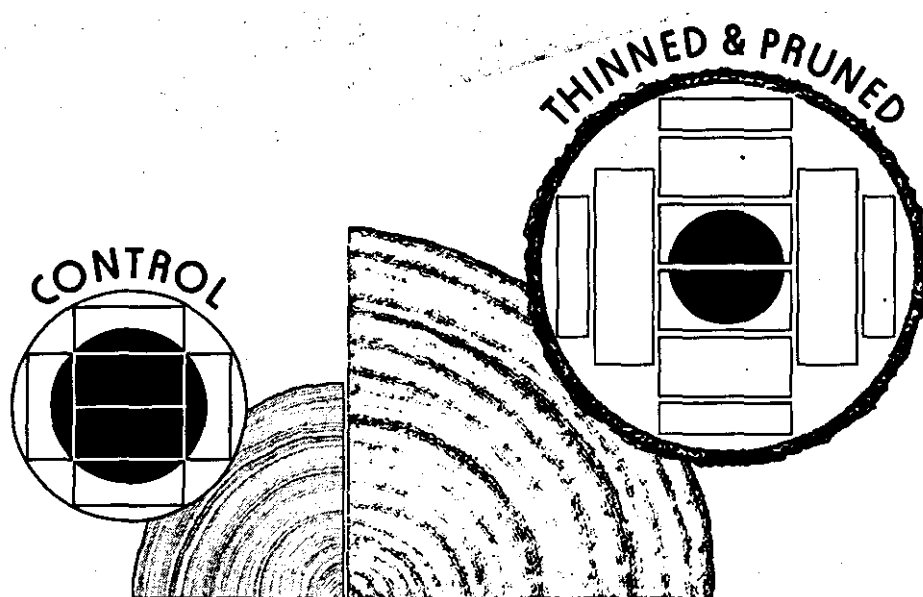
REFERENCES

- AF&PA. 1991: National Design Specification for Wood Construction. Revised. American Forest and Paper Association, Washington, DC.
- ASTM. 1996: Annual Book of Standards, Volume 04.10. Wood. American Society for Testing and Materials, West Conshohocken, PA.
- D2395. Standard test methods for specific gravity of wood and wood-based materials. p. 348–355
- D4442. Standard test methods for direct moisture content measurement of wood and wood-based materials. p. 485–489.
- Armtek, S.; Arima, T.; Sakoda, T.; Nakamura, Y. 1992: Estimation of modulus of rupture (MOR) and modulus of elasticity (MOE) of lumber using higher natural frequency of log in pile of logs. Possible application for Sugi scaffolding board. *Mokuzai Gakkaishi*. 38(11): 995–1011.
- Arima, T.; Maruyama, N.; Maruyama, S.; Hayamura, S. 1990 Natural frequency of log and lumber hit with hammer and applications for production processing. In: *Proceedings, 1990 International Timber Engineering Conference*; 1990 Oct. 23–25; Tokyo, Japan. Science University of Tokyo: 527–533.
- Green, D.W.; Ross, R.J. 1997: Linking log quality with product performance. In: *Proceedings; Forest Products for Sustainable Forestry, IUFRO Division 5 Conference*; 1997 July 7–12, 1997; Pullman, WA.
- Koch, P. 1972: Utilization of the Southern Pines. *Ag. Handb.* 420. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. Stock 0100–1483, Superintendent of Documents, Washington, DC.
- Koch, P. 1985: Utilization of hardwoods growing on Southern Pine sites. *Ag. Handh.* 605. U.S. Department of Agriculture, Forest Service. Southern Forest Experiment Station. Library of Congress 83-600592, Superintendent of Documents, Washington, DC.
- Kretschmann, D.E.; Bendtsen, B.A. 1992: Ultimate tensile stress of modulus of elasticity of fast-grown plantation loblolly pine lumber. *Wood and Fiber Science* 24(2): 189–203.
- Kretschmann, D.E.; Moody, R.C.; Pellerin, R.F.; Bendtsen, B.A. [and others] 1993: Effect of various proportions of juvenile wood on laminated veneer lumber. *FPL–RP–521*. US. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.
- Kretschmann, D.E. 1997: Effect of juvenile wood on shear parallel and compression perpendicular-to-grain strength for loblolly pine. In: *Proceedings, Timber Management Toward Wood Quality and End-Product Value. CTIA/IUFRO International Wood Quality Workshop*. Montreal, PQ, August 18–22, 1997.

- Nanami, N; Nakamura, N.; Arima, T.; Okuma, M.
1992: Measuring the properties of standing trees with stress waves, I and II. *Journal of Japan Wood Research Society* 38(8):7 39–752.
- Panshin. A.J.; deZeeuw. C. 1980 *Textbook of Wood Technology*. McGraw–Hill Company, New York, NY.
- Sandoz, J.L.; Lorin, P. 1994: Standing tree quality assessments using ultrasound. In: *Proceedings, First European symposium on nondestructive evaluation of wood*, 1994 Sept. 21–23; University of Sopron, Sopron, Hungary. Vol. 2, p. 493–502.
- Tsehay, A.; Buchannan, A.; Walker, J. 1995: A comparison of density and stiffness for prediction wood quality (or density: the lazy man's guide to wood quality). *Journal of the Institute of Wood Science* 13(6): 539–543.



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