

NONDESTRUCTIVE EVALUATION OF WOOD USING ULTRASONIC DRY-  
COUPLED TRANSDUCERS

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INTRODUCTION

The nondestructive evaluation of wood is of considerable importance in several structural applications such as wooden bridge decks, wooden structural components, and wooden railway ties. This problem has attracted the attention of several researchers [1-19]. The specific topics that are being considered include: detection of natural defects like bacterial growth, knots, and splits; grading of wood; estimation of strength and stiffness characteristics; assessment of the effect of chemical treatment on strength; and, in-situ evaluation of degradation in wooden structural components and railway ties. Ultrasonic techniques have achieved a reasonable amount of success in the estimation of structural properties and defects [11, 16, 18]. Detection of natural defects such as knots, splits and decays provides valuable information which can be used for the grading of wood. The wave velocity measurements can also be used for the determination of structural properties (e.g., modulus of elasticity) of wood leading to grading, and to monitor the in-situ degradation of wooden structural members exposed to loads and environmental conditions.

In the past, application of ultrasonic techniques to wood under relatively dry condition (non-marine environment) posed a great difficulty due to problems with transducer coupling which led to loss of considerable energy at the transducer-wood interface. Recent advances in sensor technology have enabled the use of ultrasonic techniques to

dry wood without the use of any couplant. The modern data processing technology has also significantly broadened the scope and enhanced the sensitivity of ultrasonic techniques. The results presented in this paper demonstrate the use of dry-coupled transducers for the detection of defects in wood. Several samples of wood (both hardwood and softwood) were tested to assess the magnitude of velocity changes caused by cracks, knots, and rotten areas under different moisture content levels.

#### MEASUREMENT TECHNIQUE AND CHARACTERISTICS OF WOOD

The ultrasonic wave was generated using a high energy system (peak amplitude of 400 volts) manufactured by Nuson, Inc., PA. The signal (P-wave) was transmitted and received using 250 KHz dry coupled transducers (0.5" diameter) manufactured by Ultrason Laboratories, PA. These transducers usually did not require the use of any couplant, but in some cases (e.g., if the surface of wood is rough) use of Vaseline petroleum jelly as a couplant resulted in better signals. The through transmission technique (i.e, pitch-catch mode) was adopted to test samples of wood, as this method resulted in the most consistent wave velocity measurements. For the above transducers, it was found experimentally that ultrasonic waves could be propagated in wood through a distance of at the most 6 to 8 inches.

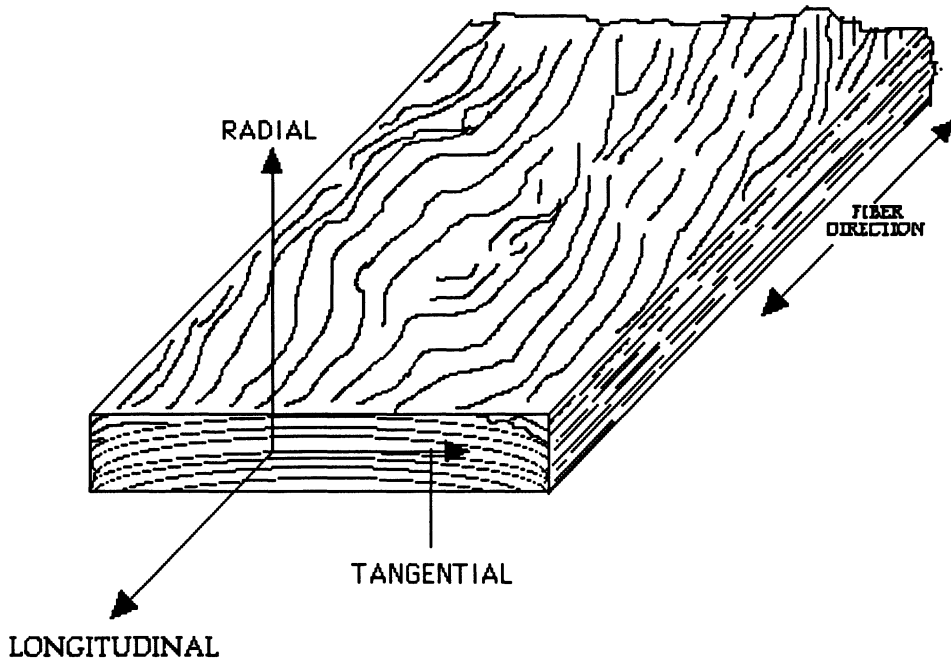


Fig. 1. Three perpendicular axes in wood.

Wood is an inhomogeneous, anisotropic, highly porous and attenuative material with a number of naturally occurring defects (e.g., knots). The wave velocities in wood vary significantly along the three perpendicular axes, which are, longitudinal, tangential and radial as shown in Fig. 1 [11]. The highest velocity is observed along the longitudinal direction (i.e., parallel to the grains). The velocity along the tangential direction (i.e., tangential to the growth rings in wood) and the radial direction (i.e., normal to the growth rings in wood) is about 30 to 45% of the velocity in the longitudinal direction. For example, measurements on a typical clear grained (i.e., defect free) sample of oak (specific gravity = 0.69, average moisture content = 5.8%) resulted in a velocity of 4900 m/sec, 2222 m/sec and 1702 m/sec along the longitudinal, radial and tangential directions, respectively. Similarly, the velocity in a clear grained sample of southern pine (specific gravity = 0.48, average moisture content = 5.8%) was found to be 4300 m/sec, 1350 m/sec and 1300 m/sec along the longitudinal, radial and tangential directions, respectively.

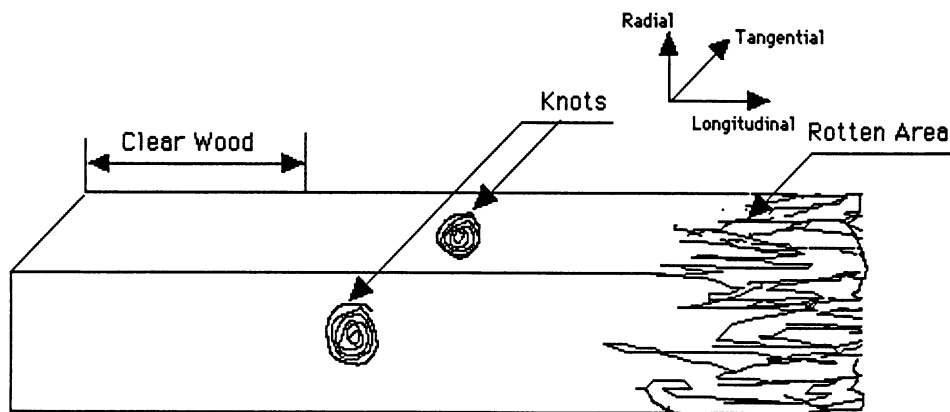


Fig. 2. Clear, knots and rotten areas in wood.

#### EFFECT OF MOISTURE CONTENT AND DEFECTS ON WAVE VELOCITIES

This section presents the results of the study conducted to determine the ultrasonic wave velocities in clear and defective areas (with knots, cracks and rotten zones) of wood under varying moisture conditions. Twelve samples of oak (hardwood) and seven samples of pine (softwood) were used for this purpose. Long samples of wood had to be cut into smaller pieces for accurate readings and ease in measurement.

The samples of wood after being cut into the required sizes were soaked in water for about 3 to 4 days, and then allowed to dry slowly under room temperature. Measurements were made in fully as well as partially saturated and dry conditions. A number of readings were taken for the moisture content using a moisture meter and averaged to obtain reliable percentage of moisture content of wood. It was observed that the wave velocity increased by about 10% for both oak and pine with an increase in moisture content from about 6% (relatively dry) to about 30% (fully saturated).

The defect-detection example presented herein is that of a 1.23 meter long sample of yellow pine from an 18 year old bridge which was used to determine the magnitude of velocity differentials between clear and defective areas. This sample of wood had some areas which were clear and straight grained while other areas had defects like knots and rotten zones as shown in Fig. 2. A number of velocity measurements were made on the sample in the radial and tangential direction for different moisture contents, and the results are shown in Figs. 3 and 4. The velocity along the longitudinal direction could not be measured because the sample was long resulting in a high attenuation. Figs. 3 and 4 show that the velocities in both the radial and tangential directions increase with the increase in moisture content for clear as well as defective areas. Usually, the areas with knots are expected to have velocities which are higher than the velocities through clear areas. Areas with defects and rotten zones are expected to exhibit lower velocities.

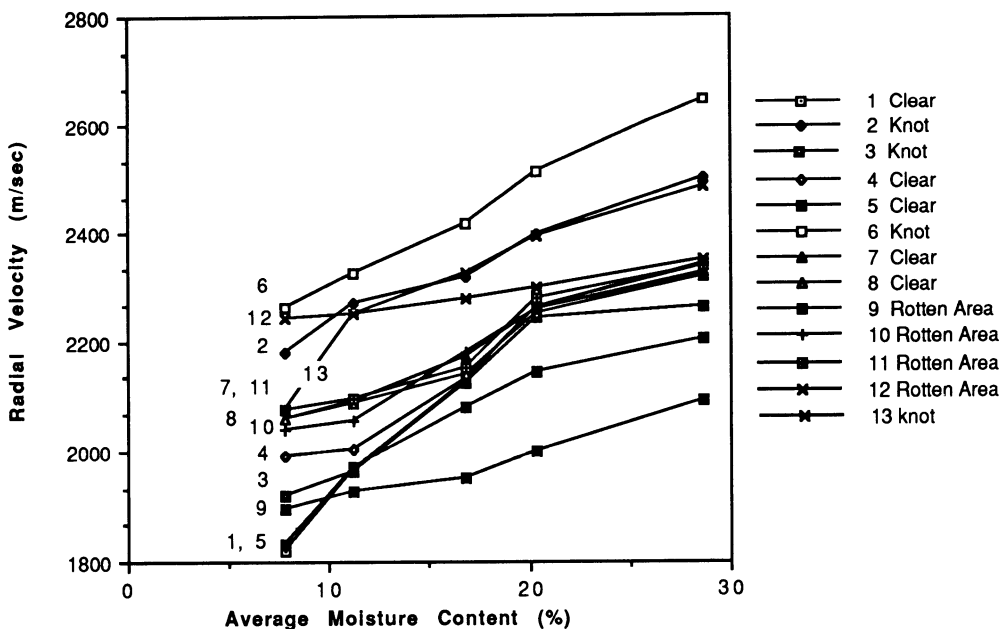


Fig. 3. Radial velocity versus average moisture content at different locations in a Yellow Pine sample.

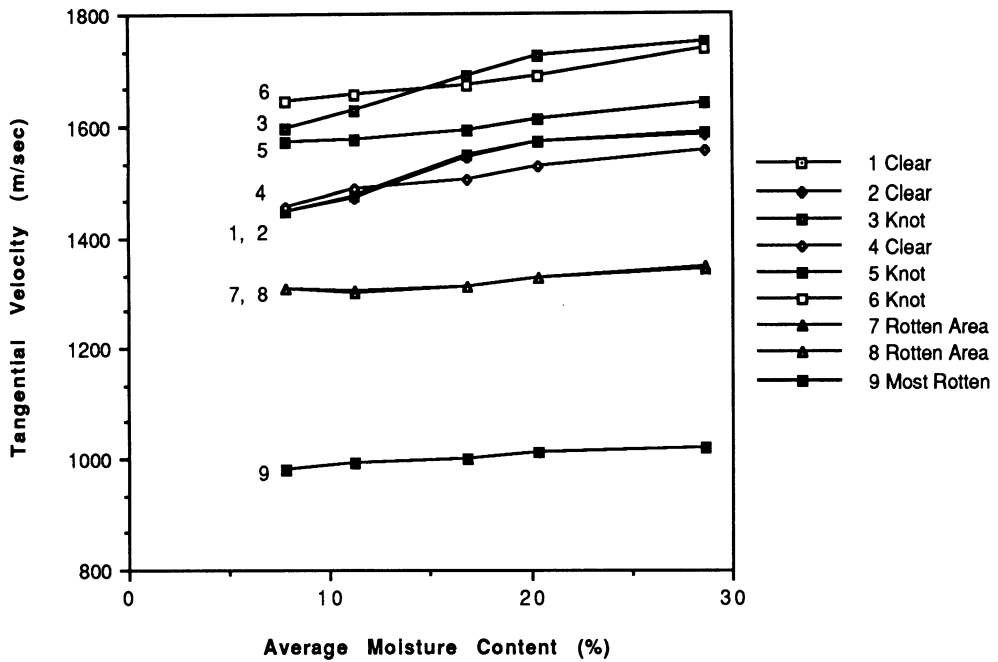


Fig. 4. Tangential velocity versus average moisture content at different locations in a Yellow Pine sample.

Although no clear distinction between the radial velocities in clear and defective areas was found (Fig. 3), a very clear distinction between the tangential velocities in the clear and defective areas was observed (Fig. 4). The highest velocity curves in Fig. 4 represent the area with knots, the intermediate curves represent clear areas, and the lowest ones represent rotten areas. This kind of pattern is not observed in case of the radial velocity shown in Fig. 3 because of the orientation of the knots and defects in this sample of wood. Other samples of wood may have defects oriented in some other direction may exhibit a different velocity pattern. The results presented above indicate that some of the defects are more easily detectable with velocity measurements in one direction, whereas others might show up in measurement along a different grain direction, depending upon the orientation of these defects within the wood. This conclusion was also supported by measurements conducted on five other samples of wood with simulated cracks and holes.

#### CONCLUSION

The ultrasonic technique has been found to be a viable means of locating defects such as cracks, knots and rotten areas in wooden structural members under fairly dry as well as moist conditions. It has been found that the defects lead

to significant changes in ultrasonic wave velocities. This study has shown that measurements can be made using dry-coupled transducers. Therefore, it is now feasible to use ultrasonic technique for rapid in-situ evaluation of wooden bridge decks.

#### REFERENCES

1. K.D. Anderson, R.C. DeGroot, and M. Patton-Mallory, in *Proceedings of the 6th Nondestructive Testing of Wood Symposium*, Washington State University, p. 167 (1988).
2. R.W. Anthony, and B. Jozsef, in *Proceedings of Nondestructive Evaluation of Civil Structures and Materials*, University of Colorado, Boulder, Colorado, p. 257 (1990).
3. V. Bucur, *Ultrasonics*, 269 (1985).
4. K.A. McDonald, R.G. Cox, and E.H. Bulgrin, USDA Forest Service, FPL 120, Madison, WI (1969).
5. M.A. Dean, J.H. Kaiserlik, *Forest Prods. J.* 34, 5156 (1983).
6. R.F. Pellerin, R.C. DeGroot, and G.R. Esenther, in *Proceeding of the 5th Nondestructive Testing of Wood Symposium*, Washington State University, p. 29 (1990).
7. R.H. Falk, M. Patton-Mallory, and K.A. McDonald, in *Proceedings of Conference*, p. 137 (1988).
8. R.H. Falk., R.J. Ross, in *Proceedings of the 1st Material Engineering Congress*, Vol. 1, p. 324 (1990).
9. J. Kaiserlik, USDA Forest Service, FPL 19, Madison, WI (1978).
10. R.H. McCuen, M.S. Aggour, B.M. Ayyub, *J Struc. Eng.* 114, 2652 (1988).
11. K.A. McDonald, USDA Forest Service, FPL 311, Madison, WI (1978).
12. R.J. Ross, R.F. Pellerin, *Forest Products J.* 41, 6 (1989).
13. R.J. Ross, R.F. Pellerin, USDA Forest Service, FPL-GTR-70, Madison, WI (1991).
14. R.H. Ross, E.A. Geske, G.H. Larson, and J.F. Murphy, USDA Forest Service, FPL-RP-502, Madison, WI (1991).
15. R.J. Ross, J.C. Ward, and A. TenWolde, USDA Forest Service, FPL-RP-512, Madison, WI (1992).
16. C.E. Solomon and U.B. Halabe, Technical Report, Constructed Facilities Center, West Virginia University, Morgantown, WV (1992).
17. Timber Truss Bridge Maintenance Handbook, Department of Main Roads, New South Wales (1987).
18. Y. Tomikawa, Y. Iwase, K. Arita, K., H. Yamada, *Ultrasonics* 16, 4 (1978).
19. Working Group Reports, in *Conference on Nondestructive Evaluation of Civil Structures and Materials*, University of Colorado, Boulder, Colorado (1991).