TECHNICAL NOTE: VELOCITY OF ULTRASONIC WAVES IN LIVE TREES AND IN FRESHLY-FELLED LOGS

*Raquel Gonçalves**†
Associate Professor and Coordinator

Cinthya Bertoldo Pedroso
Master Student

Marcus Vinicius Massak
Master Student

Fernando Batista
Master Student

Chiara Barros Secco
Master Student
Laboratory of Nondestructive Testing (LabEND)
University of Campinas–UNICAMP
Av. Candido Rondon 501, 13083-875 Campinas SP

(Received February 2011)

Abstract. The objective of this study was to evaluate variations between the velocity of ultrasonic wave propagation in trees and in freshly felled logs as well as to investigate the correlation between those speeds and corrections that would improve this correlation. The study was conducted using 210 exotic trees growing in Brazil, including the species *Eucalyptus grandis*, *Pinus elliottii*, *Toona ciliata,* and *Eucalyptus* resulting from cloning. Although the velocity of ultrasonic wave propagation in a tree (V_t) is not equal to that in a freshly felled log (V_l), the two values are correlated such that V_l can be obtained from V_t. The regression indicated a nonlinear equation for determining the log velocity from the tree velocity.

Keywords: Forest sector, acoustic evaluation, selection of trees.

INTRODUCTION

One might expect that the longitudinal wave propagation velocity would be the same in a tree and in a freshly felled log. However, in the case of a standing tree, where there is no access to the ends for placing transducers, the wave is induced from the trunk's surface, generating a nonuniaxial state. Moreover, the distance between the transducers is usually shorter than in the case of log transmission, as methods must be adopted such that the screening is feasible in the field. These conditions, in the case of trees, induce disturbances in wave propagation that affect the wave velocity in such a way that the final generated wave is a mixture of several types of waves. The wave propagation mechanism for standing trees is not yet totally understood (Wang et al 2007a). Additionally, because of the transducers' positions on the field testing on standing trees, where both are aligned in a vertical line on one side of the tree trunk, the wave propagates in the external growth rings, which in the case of more mature trees correspond to mature wood zone, whereas in a log, the path will be within a combination of the young and adult wood. Thus, the velocity measured in standing trees can be affected by several parameters and

* Corresponding author: raquel@agr.unicamp.br
† SWST member

in different ways, making its value different from that obtained for a log.

The objective of this study was to evaluate variations between the velocity of ultrasonic wave propagation in trees and in freshly felled logs as well as to investigate the correlation between those speeds and corrections that would improve this correlation.

METHODOLOGY

This study was conducted using 210 trees, including the species *Eucalyptus grandis*, *Pinus elliottii*, *Toona ciliata,* and *Eucalyptus* resulting from cloning. Table 1 shows information about the age, diameter at breast height (DBH), and origins of these trees.

The tests were conducted in trees using ultrasound equipment (USLab, AGRICEF, Brazil) and 45-kHz exponential transducers. The transducers were placed at 45° and 0.50 m apart. Eight measurements were taken at four sides of the log to cover the perimeter. On each side, measurements were taken by placing the transducers either at breast height and 0.50 m below it or at breast height and 0.50 m above it. From the eight measurements taken, we obtained average values for each tree. All tested trees were felled, and logs were taken from them with lengths ranging from 1.8 to 3.5 m. The tests were conducted by placing the transducers at both ends and at five different points so as to obtain an average value. The measurement points were located at the center, top, and bottom and the right and left sides of the log.

RESULTS AND DISCUSSION

Table 2 shows the average values, the variability, and the ratio (k) for the obtained velocities in trees and in freshly felled logs for each individual tree and for each species. The variability of velocities for *Pinus elliottii* was greater because the trees for this species were between 8 and 23 yr old. A smaller variability was obtained for the *Eucalyptus* clones and for the *Toona ciliata*, which were 6 and 4 yr old, respectively.

The velocities obtained for the trees in this study (V_t) are, in general, higher than the log velocity (V_l) as previously reported by Wang et al (2007a, 2007b) and Moore and Lyon (2008). Table 2 also shows the values of ratio (k) between V_t and V_l. Wang et al (2007a) obtained a k value of 1.20 when considering all of the species studied, and for separate species, the k values ranged from 1.07 to 1.36. In the case of this research, the average k obtained when considering all of the species measured was 1.11, lower than that obtained by the previously mentioned author. Considering the age, the V_t values were lower than V_l for the Pinus trees at 8, 9, and 13 yr of age (average $k = 0.65$), were practically the same at 15 yr of age (average $k = 0.97$), and were higher at the ages of 22 ($k = 1.19$) and 23 yr ($k = 1.36$). Wang et al (2007a) obtained an increase in k with increasing tree age, but the values were always higher than 1.0. Moore and Lyon (2008) obtained a $k = 1.23$ for an 83-yr-old *Picea sitchensis*.

For linear models between log speed and tree speed, the correlation coefficients (R) varied from 0.54 to 0.91 for the separate species, and

Table 1. Dimension, origin, and age characteristics of the studied trees.

				DBH (mm)				
Species	Origin	Age	Number	Minimum	Maximum	Average	s	CV (%)
Eucalyptus clones	Agudos São Paulo	6	143	118	178	141	15	10.7
Eucalyptus grandis	Lençóis Paulista São Paulo	34	5	380	800	538	166	30.9
Pinus elliottii	Caçador Paraná	8-23	12	184	427	261	61.8	23.7
Toona ciliata	Pariquera-Açu São Paulo	4	50	111	223	159	26.8	16.9
All species	—		210	111	800	176	70.3	40.0

DBH, diameter at breast height; CV, coefficient of variation.

Table 2. Average velocities on trees (V_t) and logs (V_l) and ratio (k) between V_t and V_l

Species	Tree velocity (ms^{-1})				Log velocity (ms^{-1})				k
	Minimum	Maximum	Average	CV (%)	Minimum	Maximum	Average	CV (%)	
Eucalyptus clones	4097	4777	4449	4.2	3429	4305	3872	5.9	1.15
Eucalyptus grandis	4549	5037	4832	4.2	3548	4486	4189	9.2	1.15
Pinus elliottii	990	3756	1999	53.4	1434	3053	2123	21.4	0.90
Toona ciliata	3871	4789	4347	5.4	3413	4357	3910	5.8	1.11
All species	990	5037	4257	15.1	1434	4486	3800	12.6	1.11

CV, coefficient of variation.

for all of the species as a group, it was 0.93. Except for the *Pinus elliotii*, the variability of velocities within each species was small (Table 2), which explains the best correlation coefficient obtained for *Pinus elliottii* trees (0.91) and for the group of all species. Wang et al (2007a) obtained, for all of the species combined, a value of $R = 0.92$, and it was indicated in their study that the most appropriate correlation is that of the combined species as the model involves a higher variability in that case. Moore and Lyon (2008) obtained a correlation with $R = 0.69$ using a single species (*Picea sitchensis*).

Wang et al (2007a) indicated that there may be a correlation between k and the diameter of the trees; however, for the five species analyzed, the authors found a correlation for only two of these. In this study, we only obtained a significant statistical correlation between k and the diameter for the *Pinus elliottii* trees ($R = 0.71$). For the *Eucalyptus* clones and the *Toona ciliata*, the variations in diameter were very small, thus not allowing for an appropriate evaluation of such a correlation. For the *Eucalyptus grandis*, an increasing trend of k was observed with increasing diameter, but the correlation was not significant. Moore and Lyon (2008) indicated a weak and negative correlation between velocity and log diameter.

Wang et al (2007a) tested a nonlinear multiple regression model for the correlation between tree velocity (V_t) and log velocity (V_l). This model involves the DBH and the distance between the transducers (L), which, according to the authors, was set to 1.2 m. The application of this model had little effect on the determination coefficient (R^2), which was already expected because the DBH did not affect the results for most of the species studied. For the same reason, in this research, this model was not appropriate for correlating V_t and V_l, because it did not allow for an improvement in the correlation coefficients. For a nonlinear model, the best results for the species as a group were obtained using Eq 1 with $R = 0.96$.

$$V_1 = \frac{1}{(0.0022 - 0.00023 \ln(V_t))} \qquad (1)$$

By adopting Eq 1 as a velocity correction ($V_{adjusted}$), for the combined species, we observed that the maximum deviation between the expected value for the log velocity and the real value was 17%, which an average k value of 1.05. Figure 1 shows the difference between the ideal condition ($V_t = V_l$) if the adjustment were perfect (dotted line) and the real condition obtained using the adjustment with Eq 1 (continuous line) with the actual measurements. Our results indicate that the adjusted velocity explains 92.5% of the variability of the log velocity; therefore, 7.5% of

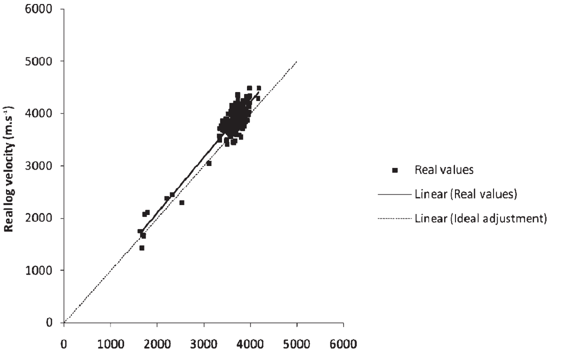

Figure 1. Relationship between the adjusted velocities obtained through nonlinear regression and the log velocity for all of the species as a group.

the variability is caused by a number of factors such as small moisture differences between the tree and the freshly felled log and measurement errors. However, it is evident that the fundamental cause for the differences originates from the difference between wave propagation mechanisms. In the case of the logs, the wave propagation occurs in a longitudinal direction with a planar shape. In the case of tree measurements, the propagation occurs in an indirect way, and due to the small wavelength employed, the log is wide enough to absorb and dissipate the energy in a three-dimensional manner, causing the wave to expand as dilatational waves (Wang et al 2007a).

CONCLUSIONS

The velocity of ultrasonic wave propagation in a tree (V_t) is not quantitatively equal to that in a freshly felled log (V_l), but the two values are correlated such that it is possible to obtain V_l from V_t. The regression indicated a nonlinear equation for determining the log velocity from the tree velocity. With the use of this equation, an average value of 1.05 was obtained for the ratio between tree velocity and log velocity, indicating very similar values.

REFERENCES

Moore J, Lyon A (2008) Effects of rotation length on the grade recovery and wood properties of Sitka spruce (*Picea sitchensis*) structural timber grown in Great Britain. Report of the Centre for Timber Engineering, Napier University, Edinburgh, UK.

Wang X, Carter P, Ross RJ, Brashaw BK (2007a) Acoustic assessment of wood quality of raw forest materials—A path to increased profitability. Forest Prod J 57(5):6-14.

Wang X, Ross RJ, Carter P, Harvey CH (2007b) Acoustic evaluation of wood quality in standing trees. Part I. Acoustic wave behavior. Wood Sci Technol 39(1):28-38.