NDE OF LOGS AND STANDING TREES USING NEW ACOUSTIC TOOLS
TECHNICAL APPLICATION AND RESULTS

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INTRODUCTION

New acoustic tools are increasingly being used for measurement of log and standing tree stiffness and related wood properties such as microfibril angle. The Director HM200 'resonance' tool has proven a very effective, robust and reliable tool for testing stiffness of felled stems or logs. More recently the release of the new Director ST300 'time of flight' tool has allowed efficient assessment of stiffness in standing trees in both research and commercial applications. Results exploit the strong relationship between acoustic speed in standing trees or green logs and stiffness in sawn timber and veneer end-products. The relationship between acoustic speed and other wood and fibre properties such as microfibril angle has also been confirmed, but have not yet been effectively exploited commercially.

Product markets readily segregate into applications where aesthetic appearance features, such as grain, color and knottiness, predominate in defining quality and applications where mechanical properties, such as stiffness and strength used by architects and engineers in designing structures, predominate in defining quality. In the US, about 52% of the solid-sawn lumber consumed is used in new residential and nonresidential construction and another 30% is used for repair and remodel of existing structures (Eastin 2004). Much of the veneer production is also used in products where stiffness and strength are critical quality characteristics. In Italy, perhaps more typical of Europe, in excess of 50% of solid-sawn lumber consumed is used in repair and remodel of existing structures.

Highest value applications have been found in log selection for laminated veneer lumber (LVL) veneer production, and the manufacture of machine stress rated (MSR) lumber. Grade recovery and financial return have been shown to be directly correlated with green log acoustic speed. With the development and rapid growth of new engineered wood products such as laminated veneer lumber (LVL), I-beams and I-joists, there has also been a parallel growth in non-destructive testing (NDT) for the stiffness and strength of lumber and veneer used as components of these products.

In addition, concerns with design values of structural lumber graded with visual methods is creating momentum for verification testing of visually graded structural materials. In New Zealand the use of acoustic testing on logs now underpins the implementation of a new 'verified visual' structural grading system being supported by the Timber Industry Federation to meet regulatory requirements and customer needs. The requirements of this new system mean that visual graded lumber has to meet a defined average stiffness, confirmed by static bending of samples drawn regularly from lumber production. Acoustic testing of logs, and sourcing of appropriate stiffness standing timber for purchase can ensure that target output stiffness is achieved.

Further, extensive testing with the HM200 has shown that there is far greater variation in stiffness within stands than between stands. Greatest benefit can be captured from log by log sorting, while low cost systems can be developed in most situations such as the use of average stiffness of logs from different stands to rank log supply (Carter et al 2004).

The new Director ST300 provides a means to efficiently assess stands for stiffness and related wood properties based on standing tree acoustic velocily measures, and can be easily integrated with pre-harvest and earlier stand assessments. This provides for effective valuation for forest sale, stumpage purchase, harvest planning, and ranking of progeny or clones in tree breeding programs.

BASICS OF NDT ASSESSMENT OF STIFFNESS

Stiffness of a piece of lumber, or a log, can be measured by placing it in a suitable static bending test apparatus, recording the deflection as load is applied, and calculating the modulus of elasticity (MOE or E), a measure of stiffness or resistance to deflection. Although this "static bending" MOE can be measured without testing the piece to failure, it is slow and involves expensive equipment that is not very portable. Consequently researchers have been exploring the use of the "dynamic" MOE, which is well correlated with the static MOE. Dynamic MOE is obtained by measuring the velocity of an acoustic wave through the material and is expressed by the following formula

$$E_d = \frac{\rho}{g} V^2$$

where

E_d	dynamic modulus of elasticity (lb/in^2 (Pa))
ρ	density of the material (lb/ft^3 (kg/m^3))
g	acceleration due to gravity (386 in/s^2 (9.8 m/s^2))
V	velocity of the wave through the material (ft/s (m/s))

Recognizing that g is a constant and applying any conversions between units, the constant k can be introduced and the equation becomes

$$E_d = k \rho V^2$$

In practice, the density of many materials is relatively constant hence the velocity of the acoustic wave can be used as a direct indicator of the dynamic MOE, a measure of the material's stiffness.

APPLICATION OF ACOUSTIC TECHNOLOGY

While adoption of acoustic technology for testing stiffness is underway within the industry. a number of questions remain requiring further quantification such as the effect of temperature on velocity measures; comparison of velocity and MOE values across species; the relationship between absolute tree and log measures; the conversion of velocity measures to MOE indices and end product values. Results from investigation of some these factors follow.

Temperature is known to affect MOE of lumber, with higher temperatures resulting in lower stiffness. Similarly higher temperatures also result in lower acoustic speed. A study of green sawn timber carried out by Xiping Wang showed acoustic speed variation with temperature as outlined in Figure 1.

When testing logs in summer, average temperature of the wood will be higher than in winter, yet average moisture content will likely be a little lower than in winter. As lower moisture content results in higher velocities, these factors tend to compensate for each other such that the acoustic velocity measured will differ little in a log of equivalent properties assessed in winter or summer (Carter et al 2004). In the case of standing tree assessment however, it becomes more important to account for the impact of changes in temperature on acoustic velocity, as there is unlikely to be any significant moisture content related compensating influence. Accordingly, based upon the results outlined in Figure 1 above, for comparison of standing tree acoustic velocities in different seasons, a compensation in the order of 20 m/sec per degree Celsius is suggested. In operational applications, because the magnitude of change in velocity is relatively small, it will likely be only the extremes of summer and winter average ambient temperature which need to be accounted for.

With the recent availability of the new Director ST300™ tool, a series of projects have been conducted to determine efficient sampling strategies within and between trees, and to confirm the relationship between standing tree acoustic velocities and velocities of logs derived from those trees.

A study was carried out on 50 standing radiata pine trees in Eyrewell Forest in Canterbury, New Zealand. Trees were assessed for acoustic speed with the new Director ST300™ tool on each of two sides of the butt log. Where there was any lean apparent in the sample trees, the first sample was taken on the upper side of the lean, avoiding any possible effect from the existence of compression wood, and the second sample was taken on the underside of the lean. The trees were then felled and bucked into standard length logs as for normal harvest operations. Felled logs were tested again with the Director ST300™ tool, as well as the Director HM200™ log testing tool. Correlations were derived between the standing tree measures of velocity and those of the resulting logs.

Correlations progressively improved with increasing numbers of hits recorded. The best prediction of log velocity was achieved by averaging all 27 hits/tree. In applications where it is most important that individual tree values are measured, a comprehensive sampling approach is suggested, while where a stand average value is required, an more appropriate strategy might be to sample as many trees as possible with available time and resources, as there is likely to be greater variability between trees than between samples on the same tree. A Douglas fir example in Washington State suggests that a sample size of 35-50 trees, each sampled with 3 hits at a single location, would be adequate to differentiate between similar stands (Carter et al 2004).

The relationship between the best estimate (average of all 27 measures) of standing tree velocity and resulting log velocity is outlined in Figure 3 below.

Similar trials have been carried out across a range of species and locations in New Zealand, Australia, and North America. Stand or plot average velocities from 22 such trials are outlined in Figure 4 below, highlighting the fundamental relationship between standing tree velocities and those measured on the resulting logs following felling. In most cases the correlation between standing tree velocities and log velocities increases as age and diameter decrease. Typically young trees being tested m a progeny trial aged around 10 years will show an R^2 close to 0.90 between standing tree and log velocities.

While confirming this relationship offers a high level of confidence that measured standing tree acoustic velocities may be used to derive equivalent log velocities and so enabling derivation of end product stiffness values, minor variations about this general relationship deserve further exploratory work. Consideration of average log green density and the effect this has on log acoustic velocity may offer some explanation for minor deviations of individual plot results from the general trend highlighted in Figure 4 above. Superficially at least for the plot results in Figure 4 above where green density data is available, the derivation of a density adjusted log velocity results in an improvement in the fit of the relationship between standing tree and resulting log acoustic velocities. Measured log velocity was adjusted to a standard (1000kg/m^3 velocity equivalent) using the following formula.

$$V_{adjusted} = V_{measured} \sqrt{(\rho_{green}/1,000)}$$

Such that;

ρ_{green} = average log green density (kg/m3)

In addition to the relationships explored above, there is also an opportunity to investigate relationships between acoustic velocity and other wood properties, such as dimensional stability, tendency for intra ring checking, decay and others.

SUMMARY AND CONCLUSIONS

The effect of temperature on acoustic velocity is relatively small on a daily or weekly basis, but should be accounted for when comparing standing tree values measured in different seasons. There is a compensating factor in moisture content which means that log measures are less likely to be significantly affected even by seasonal temperature variation.

Sampling strategy for acoustic velocity using the new standing tree tools needs to account for the precision desired in individual tree and stand average measures. For tree breeding applications or situations where limited sized samples are available and individual tree measures are most critical, a more intensive within-tree sampling strategy should he adopted. Whereas for determining stand average measures for harvest planning or stumpage purchase, a single set of samples/tree and perhaps 50 trees/stand or more would be preferred.

The interpretation of stand average velocity measures and conversion to equivalent log velocities can he carried out using the general relationship confirmed across a wide range of species, ages and location. The incorporation of a green density adjustment to log measures brings improved predictability of log measures from standing tree velocity measures.

Although a number of research questions remain, acoustic speed as an NDE measure of wood quality can now he effectively integrated into tree breeding, forest valuation, management, log supply and processing decision-making allowing both industry and researchers to capture the benefit of NDE in their programs.

While nondestructive testing of logs for stiffness with the Director HM200TM offers a new reliable and flexible approach for sorting and matching logs to manufacturer and customer demands for stiffness and strength of products they contain. It also provides an additional means by which landowners and loggers can grade and market logs.

The nondestructive testing concept has been extended to standing trees with Director ST-300TM which also provides an indicator of stiffness. This provides a new means for assessing mature stands for marketing, for harvest planning and scheduling, assisting in planning silvicultural operations in immature stands, and in tree breeding operations.

LITERATURE

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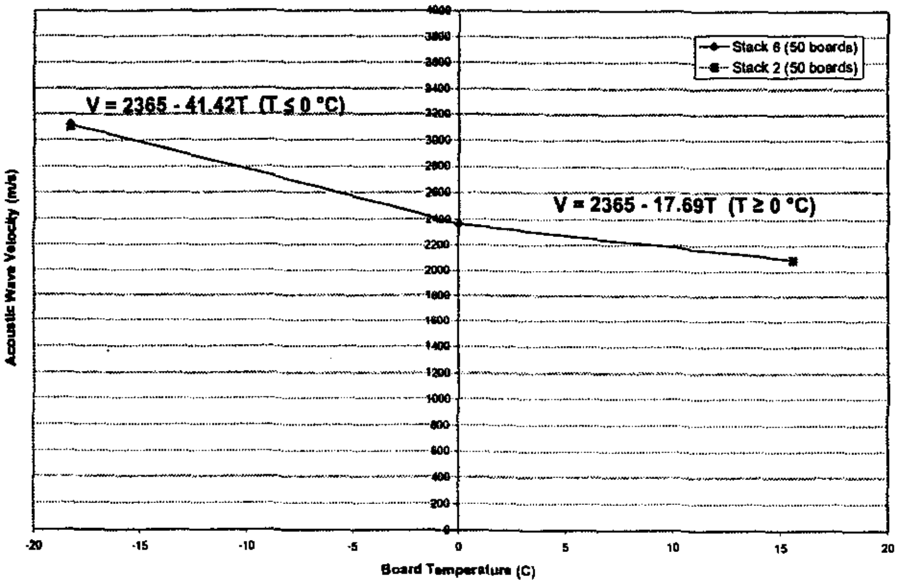

Figure 1. The effect oftemperahue on acoustic velocity in green lumber

Location/s on tree	Hits/tree	R^2
Upper side (A - first set)	3	0.44
Upper side (A - second set)	3	0.48
Upper side (A - third set)	3	0.43
Upper side (A - 3 sets combined)	9	0.50
Lower side (B - 3 sets combined)	9	0.45
Random side (C - 3 sets combined)	9	0.60
Combined samples A+B	18	0.61
Combined samples A+C	18	0.62
Combined samples A+B+C	21	0.67

Figure 2. Correlations between standing tree velocities and resulting log velocities

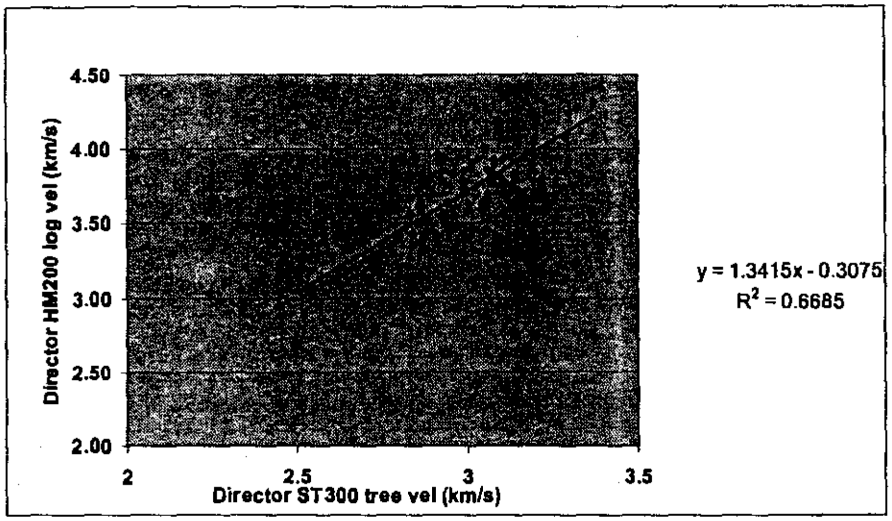

Figure 3. Relationship between individual standing trees and resulting log velocities

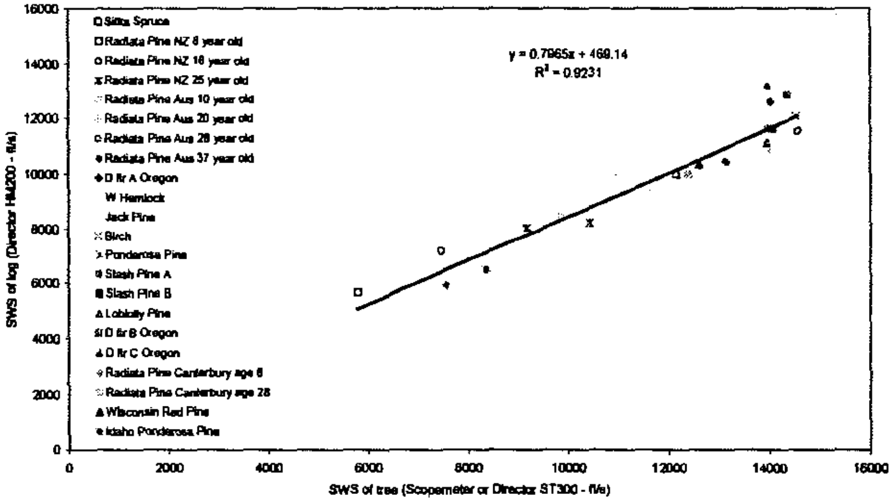

Figure 4. Relationship between plot average standing tree and average resulting log velocities

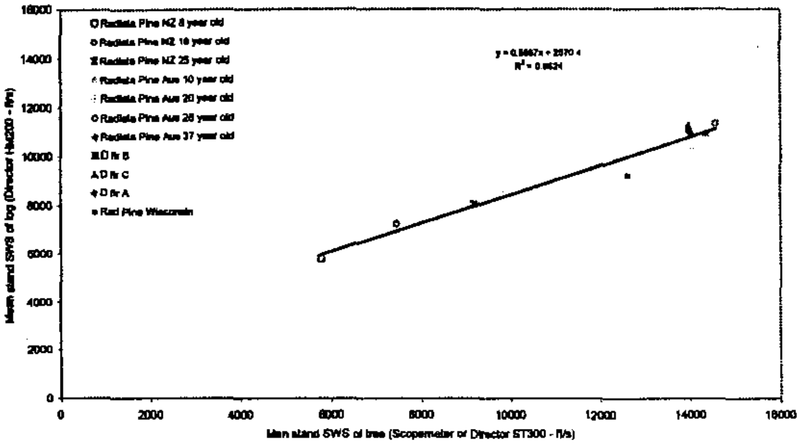

Figure 5. Density adjusted log velocity relative to average standing tree velocity

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