Chapter 3

Sorting Red Maple Logs for Structural Quality

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Nondestructive evaluation (NDE) of wood materials has a long history of application in the wood products industry. Visual grading of lumber is perhaps one of the earliest NDE forms. Visual assessment of a piece of lumber requires the grader to estimate a strength ratio on the basis of observed external defects (USDA 1999). The ratio is used to estimate the strength of lumber relative to a similar piece without defects. The estimation is based on standard lumber grading rules; however, it is entirely subjective and governed by the judgment of the grader. Furthermore, the value assigned to clear lumber of comparable size is only an estimated minimum based on tests of small, clear specimens (Bodig and Jayne 1982).

Machine stress rating (MSR), a nonvisual NDE technique, offers an opportunity to eliminate both of these limitations. As currently practiced in North America, MSR couples visual sorting criteria with nondestructive measurements of the stiffness of a piece of lumber to assign it to an established grade based on a pre-established strength–MOE (modulus of elasticity) relationship (Galligan et al. 1977). Annually, nearly 2.12 million m^3 (900 million board feet) of softwood lumber are graded in this manner (Ross et al. 1998). Similarly, laminated veneer lumber production facilities use stress wave NDE techniques to sort incoming veneer into strength categories, which are established through empirical relationships between stress wave velocity and strength (Sharp 1985).

Although research efforts have paved the way for the successful use of NDE with finished products, little effort has been expended on developing NDE techniques for use in grading or sorting logs for structural quality. Existing log grading procedures in the United States make only visual assessments of log quality (Green and Ross 1997). These procedures do not incorporate estimates of the MOE of the wood in logs. It is questionable whether the visual grading procedures currently used for logs adequately assess the potential quality of structural products manufactured from them, especially those for which MOE is of primary concern. In addition, the research that has been conducted on log NDE has focused on the use of relatively costly scanning techniques (Hailey and Morris 1987), which can have limited applications in the field. Techniques that have been investigated include x-ray and neutron radiography, computer tomography, as well as magnetic resonance (Benson-Cooper et al. 1982, Burgess 1985, Chang et al. 1987, Funt and Bryant 1987, Hailey and Morris 1987, Holoyen and Birkeland 1987, Taylor et al. 1983).

In recent years, some research has been conducted to investigate the feasibility of using longitudinal stress wave vibration techniques for evaluating log quality. Aratake et al. (1992) utilized longitudinal vibration characteristics to estimate the quality of lumber obtained from 59 Japanese cedar logs and observed a strong relationship between the natural frequency of logs and log MOE. Ross et al. (1997) examined the relationship between log measurements and the quality of lumber obtained from 95 balsam fir logs and 98 eastern spruce logs. They observed useful relationships and found that this relationship was exceptionally strong for eastern spruce logs. Green and Ross (1997) described the results from a series of studies using the same technique with Douglas-fir, western hemlock, and southern pine logs. Results were comparable with Ross et al. (1997).

Demonstration of Stress Wave NDE to Sort Red Maple Logs

To demonstrate the use of stress wave NDE to sort red maple logs, 95 red maple logs were evaluated at a sawmill. Longitudinal stress wave transmission time was determined for each log. The stress wave measuring system consisted of a specially equipped personal computer, a hand-held hammer, and an accelerometer fixed to one end of the log. A stress wave was induced in the log through a hammer impact on the opposite end, and the resulting stress wave was recorded in the computer. A detailed description of the instrumentation and analysis procedures used is given in Ross et al. (1994), and a discussion of the application to large wood specimens is included in Schad et al. (1995).

After longitudinal stress wave testing, each log was sawn into 6- by 8-inch (152- by 203-mm) cants. Each cant was then sawn into four pieces of 2- by 6-inch (5 1 - by 152-mm) lumber. Special care was taken to ensure that each individual lumber specimen could be traced to the cant and the log from which they were sawn. Stress wave transmission times in cants and lumber were then determined in green condition. Finally, the green lumber was placed in a dehumidification kiln and dried to approximately 12 percent moisture content. Stress wave transmission time, in the lumber specimen, was also obtained after drying. Flatwise MOE was then determined for each dry lumber specimen using a transverse vibration NDE technique (Ross et al. 1991).

Stress Wave Transmission Times in Logs, Cants, and Lumber

Stress wave transmission times have been recognized as good indicators of wood strength and stiffness (Rippy et al. 2000, Ross et al. 1999). Lower stress wave transmission times, which corresponds to higher stress wave speed (length/time), indicates higher strength and stiffness.

Table 3.1 summarizes the stress wave transmission times measured in red maple logs and corresponding cants and lumber produced from the logs. The stress wave transmission times of logs ranged from 254 to 355 µs/m with a mean of 289 µs/m, which was about 3 percent higher than that of cants and green lumber. The stress wave transmission times for lumber was the average value of all four pieces of lumber obtained from each cant. It was found that the stress wave transmission times of green lumber was very close to that of the cants. Statistical analysis indicated that there was no significant difference between stress wave transmission times of cants and stress wave transmission

Table 3.1. - Stress wave transmission times (SWT) of red maple logs and corresponding cants and lumber produced from logs.

	SWT (µs/m)			
Material	Mean	Standard deviation	Minimum	Maximum
Log	289	20.1	254	355
Cant	281	19.9	247	342
Green lumber	279	19.8	238	347
Dry lumber	230	15.1	199	270

times of green lumber. However, due to the loss of moisture content, the stress wave transmission times measured on dry lumber decreased about 18 to 20 percent compared with that measured in green lumber, cants, and logs.

Stress Wave Time Relationships

Regression analyses were conducted to examine the relationships between stress wave transmission times of logs and stress wave transmission times of corresponding cants and lumber obtained from them. Specifically, stress wave transmission times were compared for logs and cants, cants and lumber, and logs and lumber. **Figure 3.1** shows the relationship between stress wave transmission times of logs and of cants. The relationships between stress wave transmission times of logs and lumber and stress wave transmission times of cants and lumber are shown in **Figures 3.2 and 3.3,** respectively.

Results obtained from regression analyses are summarized in **Table 3.2.** The results indicated that strong relationships existed between stress wave transmission times of logs, cants, and green lumber (r = 0.75 to 0.92). A good relationship was also found between stress wave transmission times of logs and cants and stress wave transmission times of dry lumber. As expected, the correlation coefficient was not very high for dry lumber and logs (r = 0.68). This could be caused by several factors that were involved in the conversion from logs to dry lumber, such as loss of moisture, removal of outer materials, and drying defects. These relationships, however, are strong enough to indicate that it should be possible to use stress wave transmission times to sort red maple logs for the production of structural products.

Table 3.2.– Regression analysis of stress wave transmission times (SWT) for red maple logs and corresponding cants and lumber produced from the logs.

		Linear regression model	Correlation coefficient	Standard error of estimate
y	x	$y=a+bx$	r	Syx
SWT of cant	SWT of log	$y = 40.4 + 0.8316x$	0.82	10.93
SWT of green lumber	SWT of log	$y = 60.5 + 0.7560x$	0.75	12.81
SWT of green lumber	SWT of cant	$y = 21.1 + 0.9187x$	0.92	7.63
SWT of dry lumber	SWT of log	$y = 82.3 + 0.51\ 07x$	0.68	11.17
SWT of dry lumber	SWT of cant	$y = 58.7 + 0.6096x$	0.80	9.06

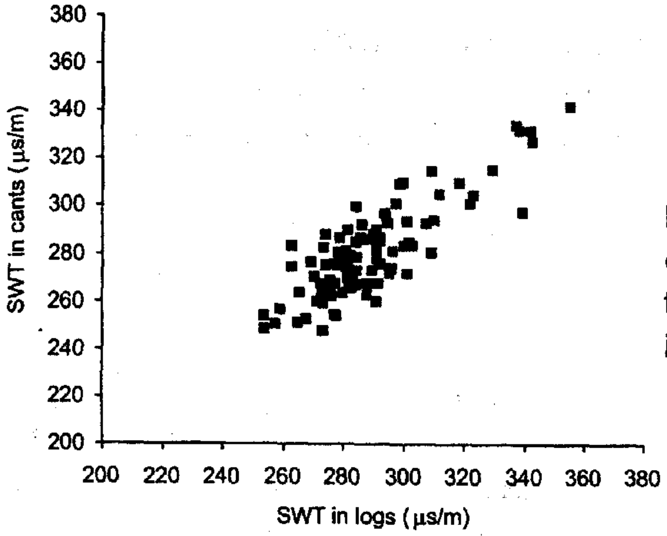

Figure 3.1. – Relationship of stress wave transmission time (SWT) in logs and SWT in cants.

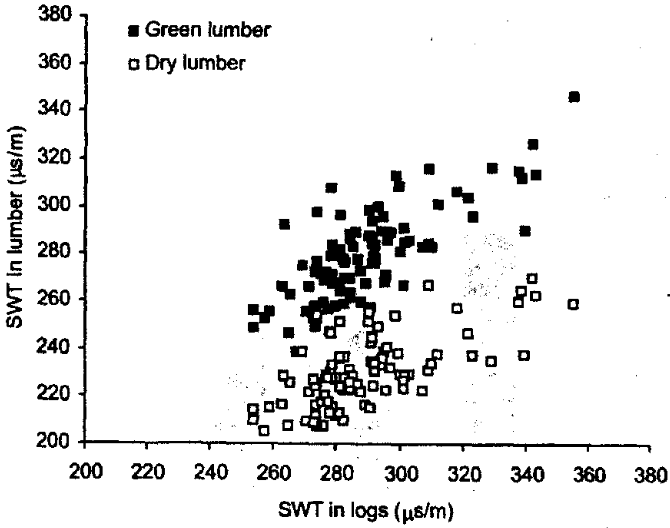

Figure 3.2. – Relationship of stress wave transmission time (SWT) in logs and SWT in lumber.

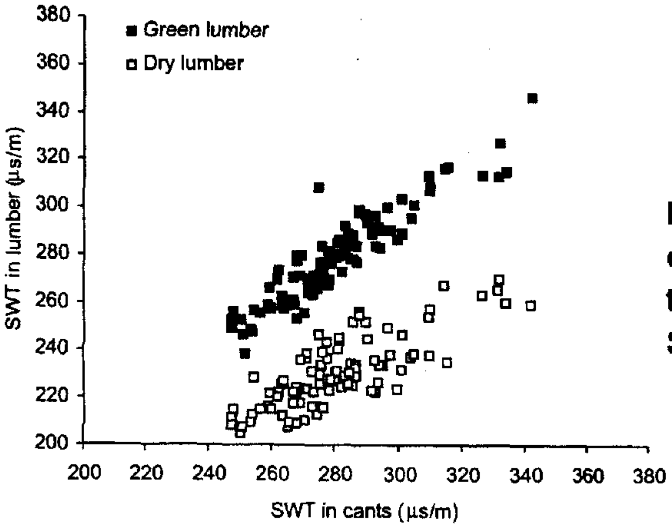

Figure 3.3. – Relationship of stress wave transmission time (SWT) in cants and SWT in lumber.

Log Stress Wave Grades and Lumber Yield

Based on the results obtained from stress wave measurements, the red maple logs were sorted into four grades (G l, G2, G3, and G4) as follows:

G1 < 272 µs/m

G2 = 272 to 298 µs/m

G3 = 298 to 328 µs/m

G4 > 328 µs/m

The majority (78%) of the logs fell into the G1 and G2 grades. Only 15 percent of logs were in G3 grade, and 7 percent of logs were in G4 grade. Figure 3.4 shows the average lumber MOE for different log stress wave grades. The lumber produced from G1 logs had the highest average MOE of 12.82 GPa, followed by the lumber produced from G2 logs, which had an average MOE of 12.34 GPa, and the lumber from G3 logs with an average MOE of 11.03 GPa. The lumber from G4 logs had the lowest average MOE of 9.86 GPa.

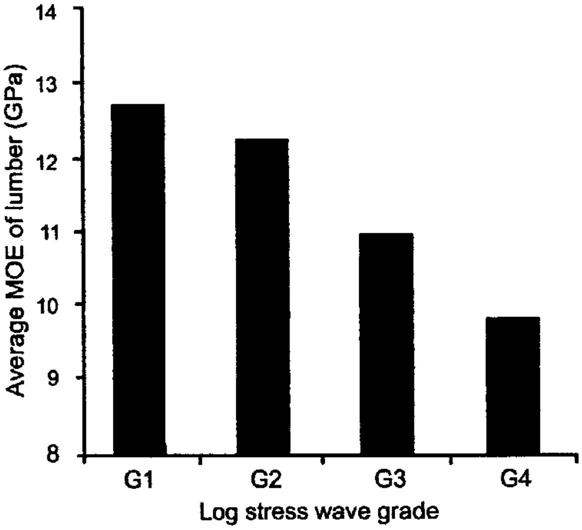

Figure 3.4. – Average lumber modulus of elasticity (MOE) for different log stress wave grades.

The relationship between log stress wave grades and lumber quality can be further illustrated by comparing log grades to lumber grades and lumber yields. The lumber produced from logs was therefore broken down into four grades (gl, g2, g3, and g4) based on lumber MOE determined from transverse vibration tests:

gl > 13.79 GPa

g2 = 11.10 to 13.79 GPa

g3 = 8.27 to 11.02 GPa

g4 < 8.27 GPa

Table 3.3 shows lumber yields for four different log stress wave grades. The yield values for each log grade were the percentages of the total lumber produced from the logs which were categorized as that stress wave grade. Table 3.3 shows that 71 percent of lumber from G4 grade logs (stress wave transmission time > 328 µs/m) were classified as g3 and g4 grades; no g1 lumber was produced in this log grade. In logs graded G3 (298 < stress wave transmission time < 328 µs/m), 87 percent of lumber produced were g2 and g3 grades, 7 and 6 percent of lumber were classified as g1 and g4, respectively. In G2 (272 < stress wave transmission time < 298 µs/m) and G1 (stress wave transmission time < 272 µs/m) grades of logs, the percentages of high-grade lumber (g1 and g2) were 73 and 86 percent, respectively. Clearly, log stress wave grades have a positive relationship with the grades of lumber produced from the logs. Logs that have a high stress wave grade contain high-grade lumber. If, in this case, a log cut-off value of 298 µs/m was used, a 76 percent yield of g1 and g2 lumber from logs with a stress wave transmission time ≤ 298 µs/m can be expected, while the logs with a stress wave transmission time > 298 µs/m can only yield 39 percent g1 and g2 lumber. This indicated that a significant improvement in the mechanical performance of red maple could be achieved with a simple sort-model to segregate high- and low-quality stress wave-rated logs.

Table 3.3. – Lumber yields of stress wave graded red maple logs.

Log grade	No. of logs	Average MOE of lumber (GPa)	Lumber yield in each lumber grade (%)			
			g1	g2	g3	g4
G1	17	12.82	30	56	14	0
G2	56	12.34	23	50	23	5
G3	15	11.03	7	36	51	6
G4	7	9.86	0	29	54	17

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