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Stress Wave Techniques for Determining Quality of Dimensional Lumber From Switch Ties

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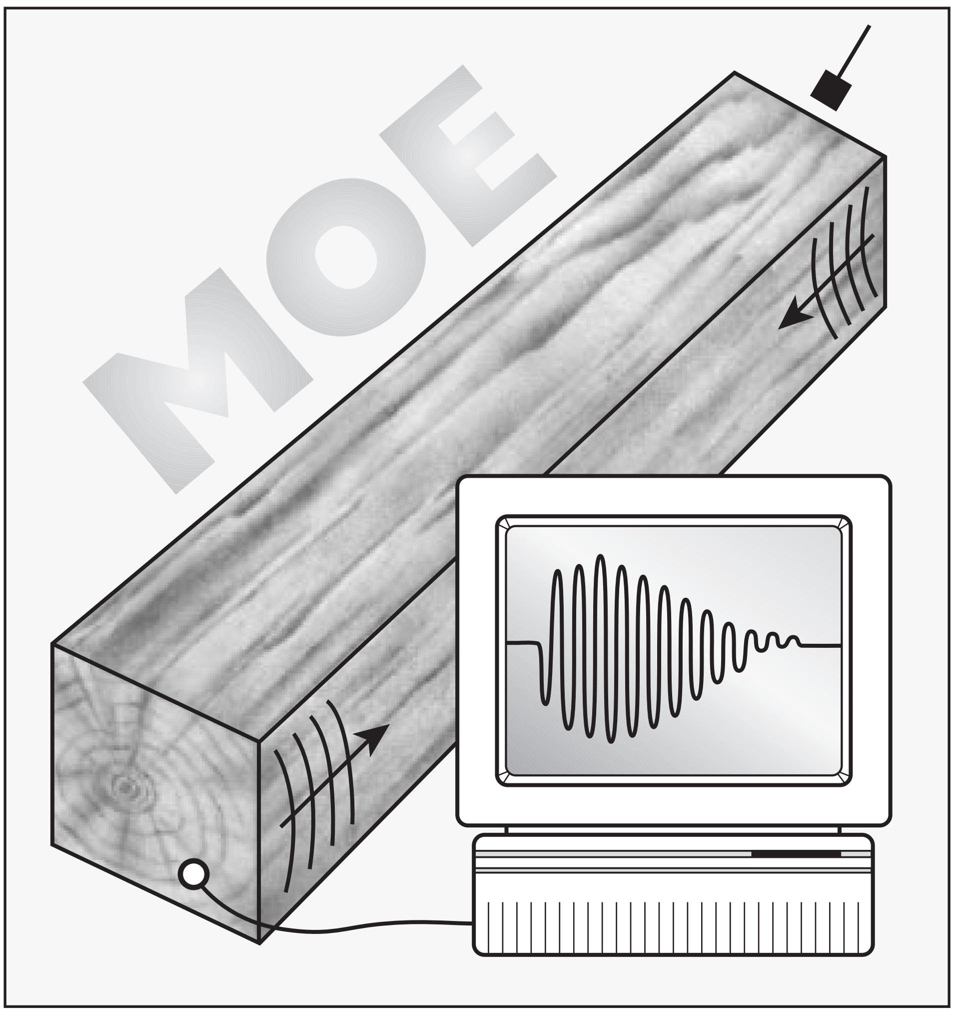

Abstract

Researchers at the Forest Products Laboratory, USDA Forest Service, have been studying nondestructive techniques for evaluating the strength of wood. This report describes the results of a pilot study on using these techniques to determine the quality of large dimensional lumber cut from switch ties. First, pulse echo and dynamic (transverse vibration) techniques were used to determine the modulus of elasticity (MOE) of 12 untreated red oak switch ties. The ties were then sawn into nominal 2 by 8 specimens, which were later resawn into nominal 2 by 4 specimens. Pulse echo and transverse vibration techniques were used to determine the MOE of the individual lumber members. Positive correlations were observed between the pulse echo MOE of a switch tie and the full-length parallel-to-grain pulse echo MOE and dynamic MOE of the lumber sawn from the tie. The accuracy of the prediction of lumber MOE decreased with a reduction in the size of the members: the greater the number of members cut from the tie, the less accurate the prediction. Strong relationships were seen between pulse echo and dynamic MOE of both green and dry lumber. The data also demonstrate that the speed of sound can be useful in predicting internal degradation of a tie and can be correlated to the specific gravity of the tie. The latter finding may be useful to hardwood crosstie producers who have expressed interest in a simple species-independent technique for nondestructive grading of ties on the basis of density.

Keywords: Red oak, NDE, transverse vibration MOE, pulse echo MOE, speed of sound, green, dry

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Introduction

The pilot study described in this report is part of a research program on nondestructive evaluation of wood at the Forest Products Laboratory (FPL), USDA Forest Service. Researchers have been using nondestructive stress-wave techniques to relate the quality of wood to structural performance.

Significant effort has been devoted to establishing fundamental relationships for the properties of several hardwood species using nondestructive evaluation (NDE) techniques (Green and others 1993). These efforts have shown that fundamental relationships that serve as the foundation for machine stress rating (MSR) of softwood structural lumber (Green and Kretschmann 1991) may well serve for machine grading of hardwood. The MSR system uses a combination of visual and NDE techniques to grade lumber. The success of applying MSR concepts to 2-in.- (51-mm-) thick hardwood lumber has prompted a desire to extend the concept to large timbers (Green and others 1994).

In the pilot study reported here, NDE techniques were used to evaluate the modulus of elasticity (MOE) of green and dry dimensional lumber obtained from green, untreated, red oak switch ties. The results of this study have ramifications for grading of lumber. The results also have ramifications for another facet of FPL research—estimating the yield of mechanically graded lumber using a combination of visual assessment of log characteristics and pulse echo stress wave measurement of log MOE. In previous work, this approach resulted in a better estimate of the yield of mechanically graded lumber than that obtained using only visual estimates of log quality (Green and others 1992). The results from the pilot study on switch ties will be used to predict possible outcomes from the study of logs.

Another aim of the pilot study was to study the feasibility of using pulse echo NDE to evaluate the density of switch ties. Ties are a major market for the northeastern hardwood industry, and density is known to be the critical factor in switch tie performance and durability. Currently, railroad switch ties are sold by specifying a particular species of known density that can be treated with preservatives. Oak is the most frequently used species and is consequently in high demand. To enable the use of species other than oak and to make better use of the mixed hardwood supply, hardwood tie producers have expressed interest in developing a simple and inexpensive species-independent technique for nondestructive grading of crosstie material on the basis of density. Pulse echo NDE promises to provide this information on density.

The results from the pilot study were also used to compare pulse echo and transverse vibration techniques for obtaining the MOE of a hardwood in green and dry conditions.

Objectives

The objectives of the pilot study on switch ties were as follows:

- To investigate the possibility of using speed of sound perpendicular to grain to detect internal degradation in large wood members
- To determine the feasibility of using pulse echo NDE techniques for predicting specific gravity of switch ties
- To compare pulse echo and dynamic (transverse vibration) methods of obtaining MOE in green and dry lumber
- To determine how pulse echo MOE of switch-tie material relates to MOE of dimensional lumber cut from the tie

Materials and Methods

Materials

Twelve untreated red oak (*Quercus rubra*) switch ties, 8 in. by 10 in. by 8.5 ft (203 mm by 254 mm by 2.59 m), were obtained from a mill in West Virginia. Each tie was measured for overall dimensions and weight. After NDE measurements were taken, each tie was cut into five nominal 2 by 8 specimens (total of 60 specimens) (Fig. 1). The specimens were tested by dynamic transverse vibration and pulse echo techniques. Each 2 by 8 specimen was then cut in half, producing ten 2 by 4 specimens per tie (Fig. 1) or a total of 120 specimens. [1]

NDE Measurements

Switch Ties

To obtain stress wave (pulse echo) measurement of MOE parallel to grain, piezoelectric film was attached with double-sided tape to one end of the tie and pulse energy was introduced to the specimen through a hammer impact on the opposite end. The rate of pulse echo transmission was recorded on an oscilloscope. The pulse echo MOE was calculated using the speed of the sound wave, c, and density ρ of the tie using the following equation (Ross and Pellerin 1991):

$$\text{pulse echo MOE} = c^2 \times \rho \tag{1}$$

The speed of sound waves perpendicular to grain was recorded to examine internal degradation of the wood. The transmitter and receiver were held in place with hand pressure, using glycerin as a coupling medium. Using a commercial pulsing and timing device, through-transmission speed of sound times were taken at 1-ft (0.3-m) intervals along the length of the ties (Fig. 2). Measurements were made at four positions at each interval. For the sound paths across both the 10- and 8-in. (254- and 203-mm) dimensions, sound waves were passed radially through the pith and 1 in. (25.4 mm) from the edge furthest from the pith.

Lumber

The MOE data for the 2 by 8 and 2 by 4 lumber specimens were obtained in two ways. As with the switch ties, a pulse echo MOE measurement was taken using piezoelectric film. In addition, a dynamic transverse vibration MOE measurement was acquired. The equipment and equations used for these measurements were previously described (Ross and others 1991). After the dynamic measurements were taken, a 1.5-ft (0.46-m) section of each 2 by 4 was removed for determining moisture content and specific gravity (Fig. 1). Moisture content

[1] Nominal 2 by 4 in. = standard 38 by 89 mm; nominal 2 by 8 in. = standard 38 by 184 mm.

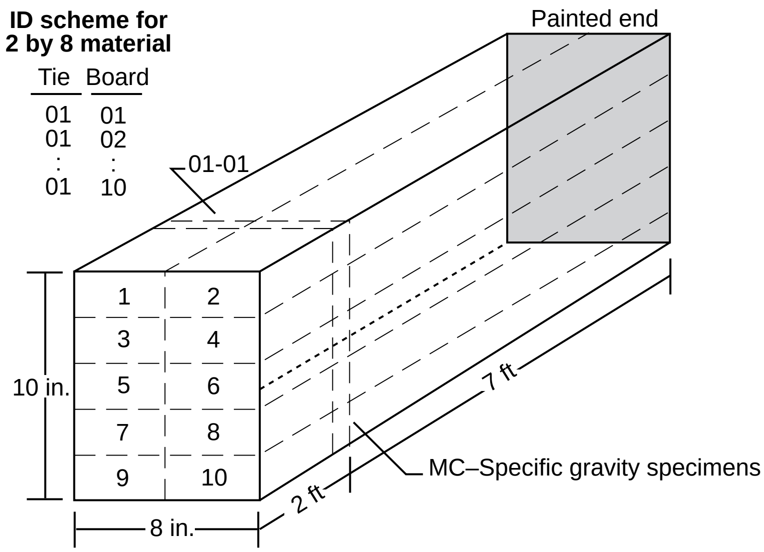

Figure 1—Cutting pattern for 8 by 10 ties.
1 in. = 25.4 mm; 1 ft = 0.3048 m.

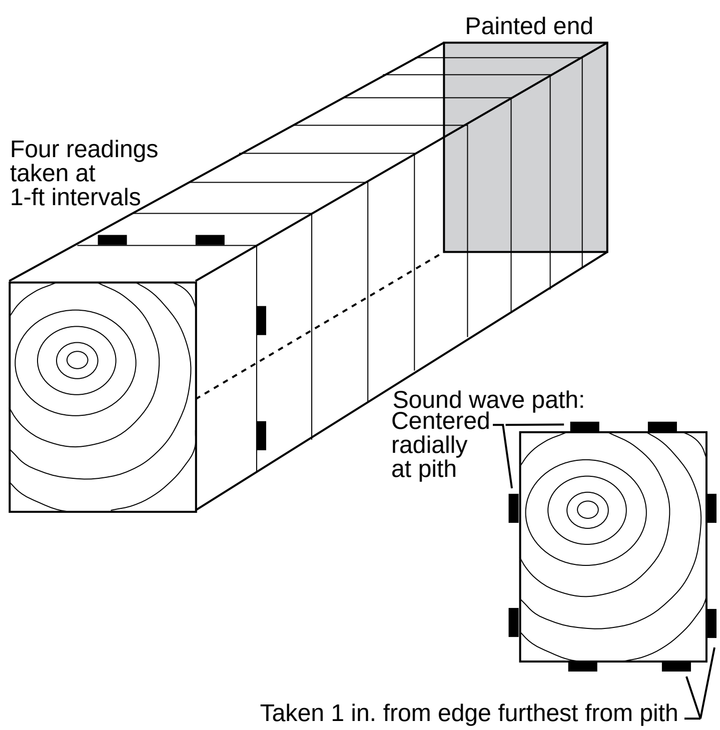

Figure 2—Through transmission of stress waves.

was obtained by comparing the green weight of a small sample taken from the 1.5-ft (0.46-m) section to its oven-dry weight.

The 2 by 4 specimens were stickered and placed in a conditioning chamber at 75°F (24°C) and 65 percent relative humidity and dried to approximately 12 percent moisture content. Moisture content was measured with an electrical resistance moisture meter.

Results and Discussion

The results of tests on individual ties and lumber members are summarized in Table 1. The table also shows average moisture content for the dried lumber from each tie.

Switch Ties

The pulse echo MOE for the twelve ties ranged from 1.54 to 2.28 × 10^6 lb/in^2 (10.6 to 15.7 GPa).

The data from the through-transmission NDE are reported in the Appendix. This table includes both the measured transit time and calculated velocity. In general, ties had stable through-transmission speeds in the range of 5,000 to 6,000 ft/s (1,524 to 1,829 m/s). This speed is in the expected range for oak (McDonald 1978). The 2 by 4 specimens cut from the ties were examined for degradation. Decay was visually apparent in 6 of the 12 ties (ties 1, 4, 5, 7, 9, and 12). Internal degradation as revealed by through-transmission speeds ranged from spotty pockets of decay in ties 1, 4, 5, and 12 to distinct zones of decay in ties 7 and 9. Internal decay as indicated by slow wave speed (Ross and others 1992) was detected in ties 5, 7, 9, and 12.

Table 1—Average moisture content, specific gravity, and modulus of elasticity of switch ties and lumber[a]

Tie				Lumber MOE (×10^6 lb/in^2)						Moisture content of dry 2 by 4 lumber (%)
				2 by 8		2 by 4 Green		2 by 4 Dry		
Moisture content (%)	Specific gravity	MOE (×10^6 lb/in^2)	Inverse speed (µs/ft)	PE	TV	PE	TV	PE	TV	
72	0.58	1.54	99.7	1.31	1.22	1.28	1.18	1.67	1.46	12
55	0.64	2.28	81.8	1.98	1.72	2.01	1.81	2.44	1.94	12
62	0.60	2.03	84.4	1.83	1.55	1.78	2.31	2.37	1.94	12
66	0.57	1.92	86.2	1.78	1.54	1.74	1.52	2.27	1.89	11
74	0.59	1.76	92.9	1.53	1.34	1.50	1.35	1.93	1.64	12
50	0.67	1.82	88.2	1.64	1.52	1.64	1.47	2.05	1.78	12
76	0.61	1.92	90.3	1.73	1.50	1.66	1.45	2.17	1.76	12
52	0.64	1.97	84.1	1.80	1.60	1.79	1.59	2.22	1.96	13
71	0.55	1.72	92.9	1.52	1.34	1.48	1.31	2.03	1.76	11
79	0.60	1.84	89.4	1.70	1.52	1.63	1.52	2.18	1.83	12
53	0.66	2.14	81.8	1.97	1.68	1.94	1.68	2.41	1.99	13
73	0.56	1.65	95.0	1.18	1.05	1.38	1.22	1.79	1.56	12

[a]PE is pulse echo; TV, transverse vibration. 1 in/lb^2 = 6.894 kPa; 1 ft = 0.3048 m.

The relationship between wave speed and specific gravity for each tie is shown in Figure 3. The inverse of wave speed was negatively correlated to specific gravity ($r^2 = 0.44$). This relationship suggests the possibility of using pulse echo wave speed as a method for sorting ties on the basis of specific gravity.

2 by 8 Lumber

The relationship between pulse echo and transverse vibration MOE for green 2 by 8 specimens is shown in Figure 4. The regression equation fit to this information is given in Table 2. The high coefficient of determination (0.79) suggests a strong correlation between pulse echo and transverse vibration MOE.

The MOE of each 2 by 8 was directly related to the pulse echo MOE of the tie. Therefore, a nested regression was used to determine within-tie error estimates (Table 3) (Burdick and Graybill 1992). The relationship of pulse echo MOE of ties to pulse echo and transverse vibration MOE of 2 by 8 material is shown in Figure 5. On average, pulse echo and transverse vibration MOE values of 2 by 8 specimens were respectively 10 and 20 percent lower than pulse echo MOE values of ties (Table 1).

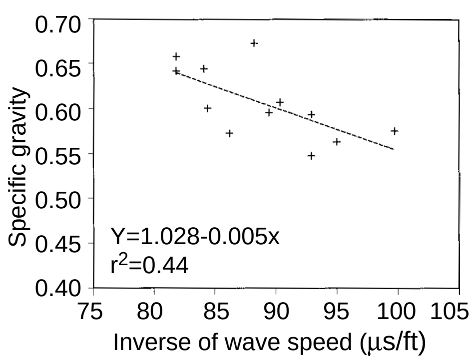

Figure 3—Relationship between inverse of pulse echo wave speed and average specific gravity of ties.

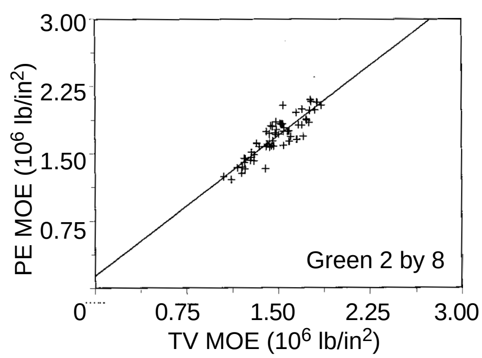

Figure 4—Relationship between transverse vibration (TV) and pulse echo (PE) MOE for green 2 by 8 material. 1 lb/in^2 = 6.894 kPa.

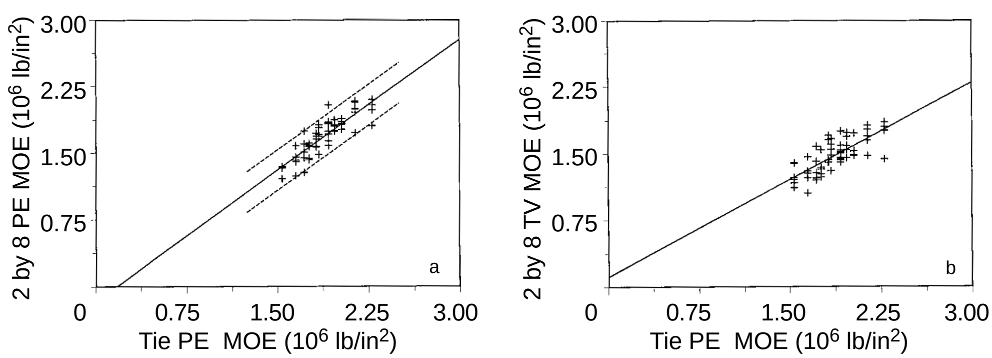

Figure 5—Relationship of pulse echo MOE of ties to (a) pulse echo MOE and (b) transverse vibration MOE of 2 by 8 material.

2 by 4 Lumber

Green Material

The relationship between transverse vibration and pulse echo MOE for green 2 by 4 material was strong, with a coefficient of determination of 0.83 (Fig. 6). The regression equation fit to this information is given in Table 2.

The nested regression method was applied to the data to determine the within-tie error. The relationship of pulse echo MOE of ties to pulse echo and transverse vibration MOE of green 2 by 4 material is shown in Figure 7. Like the MOE of the green 2 by 8 lumber, the MOE of the green 2 by 4 lumber was strongly correlated to the MOE of the ties. Likewise, pulse echo and transverse vibration MOE of the green 2 by 4 material was respectively 10 and 20 percent lower than the pulse echo MOE of the ties.

Table 2—Relationships between pulse echo MOE, transverse vibration MOE, and specific gravity[a,b]

Y		X	A	B	r^2
Specific gravity		Tie PE MOE	0.387	0.116	0.38[c]
		2 by 8 PE MOE	0.431	0.104	0.28[c]
		2 by 4 PE MOE	0.447	0.096	0.26[c]
2 by 8 green	PE MOE	2 by 8 green TV MOE	0.133	1.044	0.79
	PE MOE	Tie PE MOE	0.167	0.983	0.76[c]
	TV MOE	Tie PE MOE	0.114	0.728	0.57[c]
2 by 4 green	PE MOE	2 by 4 green TV MOE	0.259	0.946	0.83
	PE MOE	Tie PE MOE	0.297	1.036	0.70[c]
	TV MOE	Tie PE MOE	0.166	0.870	0.53[c]
2 by 4 dry	PE MOE	2 by 4 dry TV MOE	0.126	1.110	0.78
	PE MOE	Tie PE MOE	0.036	1.110	0.59[c]
	TV MOE	Tie PE MOE	0.270	0.814	0.50[c]
2 by 4 dry	PE MOE	2 by 4 green PE MOE	0.380	1.056	0.82
	TV MOE	2 by 4 green TV MOE	0.623	0.804	0.69
2 by 8 avg green	PE MOE	Tie PE MOE	–0.166	0.982	0.96[c]
	TV MOE	Tie PE MOE	0.119	0.726	0.91[c]
2 by 4 avg green	PE MOE	Tie PE MOE	–0.297	1.036	0.97[c]
	TV MOE	Tie PE MOE	–0.166	0.870	0.94[c]
2 by 4 avg dry	PE MOE	Tie PE MOE	0.024	1.116	0.90[c]
	TV MOE	Tie PE MOE	0.283	0.807	0.87[c]

[a]Values for Y = A + B(X).
[b]PE is pulse echo; TV, transverse vibration.
[c]This value is not a true representation of r^2 because the observations were not independent.

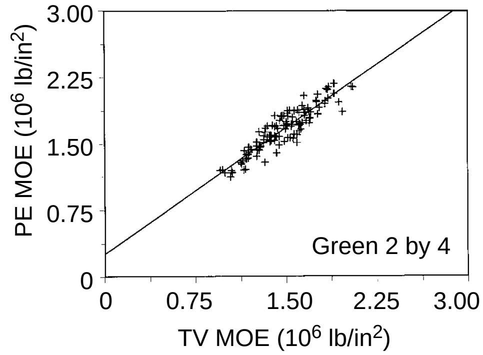

Figure 6—Relationship between transverse vibration and pulse echo MOE for green 2 by 4 material

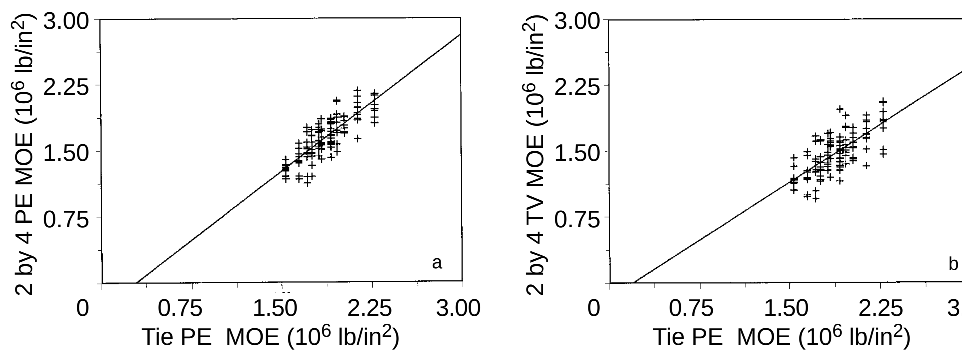

Figure 7—Relationship of pulse echo MOE of ties to (a) pulse echo MOE and (b) transverse vibration MOE of green 2 by 4 material.

Dry Material

The results showed a strong correlation between pulse echo and transverse vibration MOE for dry (12 percent moisture content) 2 by 4 material (r^2 = 0.83) (Fig. 8). The regression equation fit to this information is given in Table 2.

The relationship of pulse echo MOE of ties to pulse echo and transverse vibration MOE of dry 2 by 4 material is shown in Figure 9. The “Bootstrap” correlation coefficient suggests that both pulse echo and transverse vibration MOE had a strong relationship to the MOE of the original ties.

Comparison of Green and Dry Material

Figure 10 shows the relationship between MOE of green and dry 2 by 4 material by pulse echo and transverse vibration techniques. All pieces displayed an increase in pulse echo MOE with drying. The average ratio of dry to green MOE was 1.28. Almost all pieces displayed an increase in transverse vibration MOE with drying. The average ratio of dry to green transverse vibration MOE was 1.23.

Within-Tie Variability

As shown by the regression equations of the average pulse echo and transverse vibration MOE of the lumber specimens (Table 2), the pulse echo MOE of the ties gave a good indication of the MOE of the lumber produced from the ties. However, making use of the MOE data requires a clear understanding of potential within-tie variability.

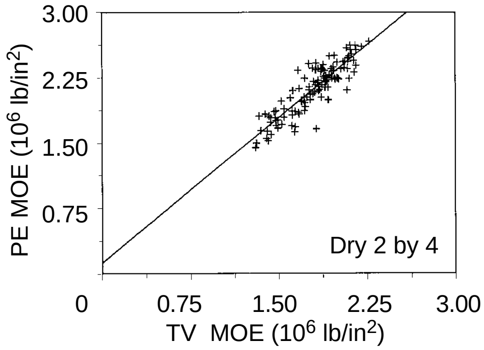

Figure 8—Relationship between pulse echo and transverse vibration MOE for dry 2 by 4 material.

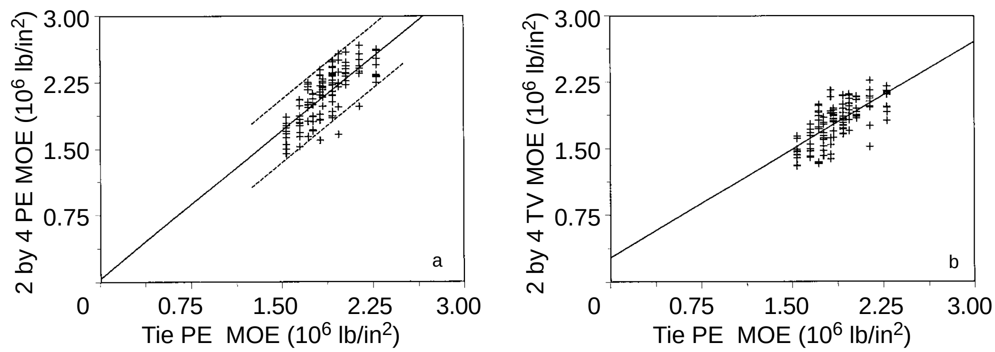

Figure 9—Relationship of pulse echo MOE of ties to (a) pulse echo MOE and (b) transverse vibration MOE of dry 2 by 4 material.

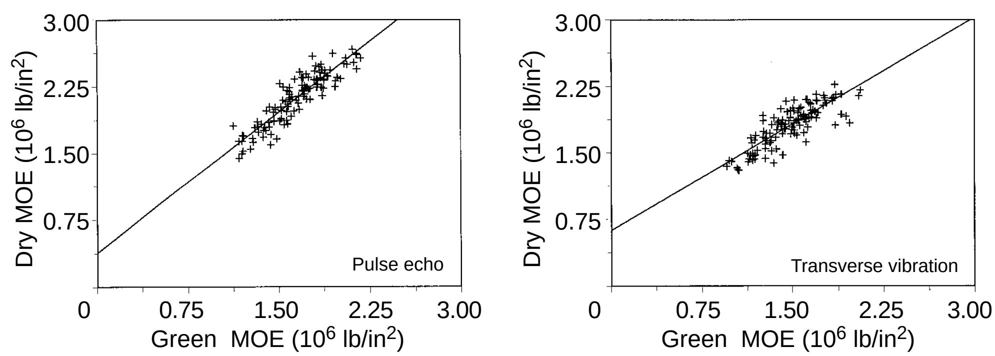

Figure 10—Relationship between MOE of dry and green 2 by 4 material by pulse echo and transverse vibration techniques.

Although a small sample size was used in this study, the data provide valuable indications of within-tie variability. A pooled estimate of within-tie variability for specific gravity and MOE of both 2 by 4 and 2 by 8 specimens is given in Table 3. The average pulse echo MOE of green 2 by 8 material, with two standard error boundary levels, is plotted against the pulse echo MOE of ties in Figure 11. A similar figure (Fig. 12) shows the average pulse echo MOE of ties and MOE of green and dry 2 by 4 material. Plots of transverse vibration MOE for 2 by 8 and 2 by 4 specimens would be similar. The spread about the regression line increased with increasing sample size; that is, the greater the number of members cut from the tie, the less accurate the prediction. The analysis of these data indicates that using pulse echo MOE of ties could lead to an error of $\pm 114 \times 10^3$ lb/in^2 ($\pm$786 MPa) for 2 by 8 MOE, $\pm 139 \times 10^3$ lb/in^2 ($\pm$958 MPa) for green 2 by 4 lumber MOE, and $\pm 179 \times 10^3$ lb/in^2 ($\pm$1,234 MPa) for dry 2 by 4 lumber MOE.

Table 3—Within-tie error estimates[a]

Lumber type	Property[b]	Total SS	n	Within-tie error estimate
2 by 8 green	PE MOE	6.28E11	60	114,000
	TV MOE	8.09E11	60	130,000
2 by 4 green	PE MOE	2.09E12	120	139,000
	TV MOE	3.00E12	120	167,000
	Specific gravity	0.08433	120	0.0280
2 by 4 dry	PE MOE	3.45E12	120	179,000
	TV MOE	2.71E12	120	158,000

[a]Error estimate was calculated as total SS/(n – 12).
SS is sum of squares.
[b]PE is pulse echo; TV, transverse vibration.

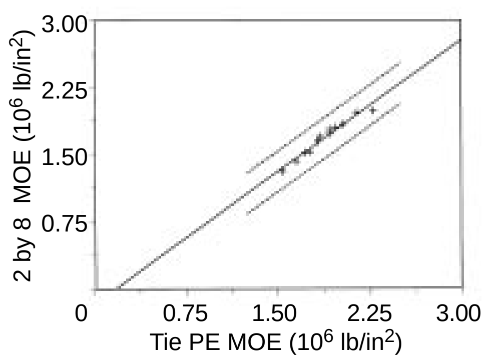

Figure 11—Relationship between pulse echo MOE of ties and green 2 by 8 material.

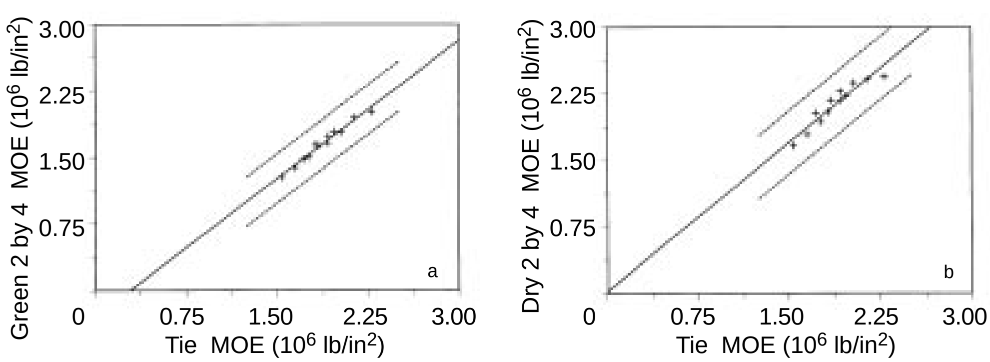

Figure 12—Relationship between pulse echo MOE of ties and pulse echo MOE of (a) green and (b) dry 2 by 4 material.

Conclusions

The conclusions from this pilot study are as follows:

- Through-transmission stress wave speed appears to be a promising method for detecting internal degradation, such as decay, of large members.
- The correlation between tie pulse echo MOE and specific gravity may allow for rough assessment of the quality of the material for railroad ties.
- Pulse echo and transverse vibration MOE are strongly correlated for green and dry red oak lumber.
- The MOE of dimensional lumber cut from a tie can be predicted from the pulse echo MOE of the tie. The accuracy of the prediction decreases with a reduction in the size of the members cut from the tie—that is, the greater the number of members cut from the tie, the less accurate the prediction.

This pilot study provided valuable experience in applying stress wave techniques to large wood members. The results suggest that pulse echo MOE for a tie will provide insight to the strength of the lumber produced from the tie. More data are needed on the relationship of the properties of smaller members to the properties of the material from which they are cut.

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Appendix

Data from through-transmission NDE of ties

		Stress wave travel time (µs)				Stress wave velocity (ft/s)			
	Interval[a]	Narrow face		Wide face		Narrow face		Wide face	
Tie	(ft)	Pith	Edge	Pith	Edge	Pith	Edge	Pith	Edge
1	1	119	127	159	154	5,821	5,454	5,372	5,547
	2	117	123	157	154	5,921	5,632	5,441	5,547
	3	116	123	156	152	5,972	5,632	5,475	5,620
	4	119	119	150	153	5,821	5,821	5,694	5,583
	5	120	121	151	153	5,773	5,725	5,657	5,583
	6	120	126	149	152	5,773	5,498	5,733	5,620
	7	109	126	156	154	6,355	5,498	5,475	5,547
	8	124	132	154	157	5,586	5,248	5,547	5,441
	Avg	118	125	154	154	5,878	5,563	5,549	5,561
2	1	112	123	146	156	6,138	5,589	5,886	5,509
	2	117	122	146	156	5,876	5,635	5,886	5,509
	3	117	120	147	157	5,876	5,729	5,846	5,474
	4	109	122	145	144	6,307	5,635	5,927	5,968
	5	119	119	148	152	5,777	5,777	5,807	5,654
	6	119	116	143	148	5,777	5,927	6,010	5,807
	7	116	113	144	144	5,927	6,084	5,968	5,968
	8	117	110	140	140	5,876	6,250	6,138	6,138
	Avg	116	118	145	150	5,944	5,828	5,933	5,753
3	1	114	122	136	140	6,122	5,721	6,089	5,915
	2	112	122	134	138	6,231	5,721	6,180	6,001
	3	113	119	131	134	6,176	5,865	6,322	6,180
	4	118	121	136	147	5,915	5,768	6,089	5,634
	5	116	120	134	149	6,017	5,816	6,180	5,558
	6	117	121	139	152	5,965	5,768	5,958	5,448
	7	109	119	137	146	6,403	5,865	6,045	5,672
	8	117	121	139	144	5,965	5,768	5,958	5,751
	Avg	115	121	136	144	6,099	5,786	6,103	5,770
4	1	116	128	144	142	6,034	5,469	5,859	5,942
	2	119	125	149	144	5,882	5,600	5,663	5,859
	3	121	124	147	149	5,785	5,645	5,740	5,663
	4	118	120	148	141	5,932	5,833	5,701	5,984
	5	121	124	146	149	5,785	5,645	5,779	5,663
	7	120	122	146	147	5,833	5,738	5,779	5,740
	8	122	122	144	148	5,738	5,738	5,859	5,701
	Avg	119	124	148	146	5,872	5,670	5,715	5,782
5	1	109	109	140	143	6,307	6,307	6,138	6,010
	2	105	99	148	142	6,548	6,944	5,807	6,052
	3	111	107	143	128	6,194	6,425	6,010	6,714
	4	121	111	184	145	5,682	6,194	4,671	5,927
	5	116	109	141	148	5,927	6,307	6,095	5,807
	6	105	107	128	135	6,548	6,425	6,714	6,366
	7	112	111	143	142	6,138	6,194	6,010	6,052
	8	112	108	139	138	6,138	6,366	6,183	6,227
	Avg	111	108	146	140	6,185	6,395	5,953	6,144
6	1	109	119	136	143	6,307	5,777	5,993	5,699
	2	112	116	131	142	6,138	5,927	6,221	5,739
	3	111	123	135	149	6,194	5,589	6,037	5,470
	4	113	121	130	149	6,084	5,682	6,269	5,470
	5	105	113	128	149	6,548	6,084	6,367	5,470
	6	105	123	138	141	6,548	5,589	5,906	5,780
	7	107	123	136	143	6,425	5,589	5,993	5,699
	8	110	106	130	146	6,250	6,486	6,269	5,582
	Avg	109	118	133	145	6,312	5,841	6,132	5,614

Data from through-transmission NDE of ties—con.

Tie	Interval[a] (ft)	Stress wave travel time (µs)				Stress wave velocity (ft/s)			
		Narrow face		Wide face		Narrow face		Wide face	
		Pith	Edge	Pith	Edge	Pith	Edge	Pith	Edge
7	1	114	113	201	148	6,122	6,176	4,250	5,771
	2	119	119	151	149	5,865	5,865	5,657	5,733
	3	118	123	149	142	5,915	5,674	5,733	6,015
	4	117	123	151	147	5,965	5,674	5,657	5,811
	5	123	124	152	149	5,674	5,628	5,620	5,733
	6	121	124	152	152	5,768	5,628	5,620	5,620
	7	114	118	148	152	6,122	5,915	5,771	5,620
	8	118	120	146	153	5,915	5,816	5,850	5,583
	Avg	118	121	156	149	5,918	5,797	5,520	5,736
8	1	108	123	135	146	6,318	5,547	6,250	5,779
	2	109	107	134	140	6,260	6,377	6,297	6,027
	3	111	112	133	148	6,147	6,092	6,344	5,701
	4	109	120	134	143	6,260	5,686	6,297	5,900
	5	110	124	137	148	6,203	5,502	6,159	5,701
	6	101	121	126	143	6,755	5,639	6,696	5,900
	7	107	124	132	147	6,377	5,502	6,392	5,740
	8	108	123	132	146	6,318	5,547	6,392	5,779
	Avg	108	119	133	145	6,329	5,736	6,353	5,816
9	1	140	128	167	154	5,060	5,534	5,052	5,479
	2	141	131	167	153	5,024	5,407	5,052	5,515
	3	132	128	160	154	5,366	5,534	5,273	5,479
	4	132	124	151	154	5,366	5,712	5,588	5,479
	5	124	127	157	156	5,712	5,577	5,374	5,409
	6	237	131	226	166	2,989	5,407	3,733	5,083
	7	281	130	—[b]	154	2,521	5,449	—[b]	5,479
	8	336	316	400	156	2,108	2,242	2,109	5,409
	Avg	190	152	179	156	4,268	5,108	4,023	5,416
10	1	108	108	132	135	6,269	6,269	6,313	6,173
	2	107	111	135	140	6,328	6,100	6,173	5,952
	3	111	114	136	138	6,100	5,939	6,127	6,039
	4	115	118	143	148	5,888	5,738	5,828	5,631
	5	112	116	144	147	6,045	5,837	5,787	5,669
	6	113	120	144	142	5,992	5,642	5,787	5,869
	7	113	121	147	149	5,992	5,596	5,669	5,593
	8	109	117	141	150	6,212	5,787	5,910	5,556
	Avg	111	116	140	144	6,103	5,864	5,949	5,810
11	1	116	124	136	145	5,837	5,460	6,204	5,819
	2	112	123	138	146	6,045	5,505	6,114	5,779
	3	113	125	132	144	5,992	5,417	6,392	5,859
	4	107	121	132	140	6,328	5,596	6,392	6,027
	5	116	124	139	148	5,837	5,460	6,070	5,701
	6	106	119	136	136	6,388	5,690	6,204	6,204
	7	115	125	135	144	5,888	5,417	6,250	5,859
	8	109	121	132	141	6,212	5,596	6,392	5,984
	Avg	112	123	135	143	6,066	5,518	6,252	5,904
12	1	123	125	160	157	5,759	5,667	5,404	5,507
	2	123	129	158	145	5,759	5,491	5,472	5,963
	3	126	129	164	157	5,622	5,491	5,272	5,507
	4	122	129	155	152	5,806	5,491	5,578	5,688
	5	123	132	212	158	5,759	5,366	4,078	5,472
	6	120	128	170	157	5,903	5,534	5,086	5,507
	7	119	130	173	156	5,952	5,449	4,998	5,542
	8	116	129	170	154	6,106	5,491	5,086	5,614
	Avg	122	129	170	155	5,833	5,497	5,122	5,600

[a]Readings taken at 1-ft intervals. 1 ft = 0.3048 m. [b]No signal.