NONDESTRUCTIVE EVALUATION OF POTENTIAL QUALITY OF CREOSOTE-TREATED PILES REMOVED FROM SERVICE

XIPING WANG*
ROBERT J. ROSS*
JOHN R. ERICKSON*
JOHN W. FORSMAN
GARY D. MCGINNIS*
RODNEY C. DE GROOT*

ABSTRACT

Stress-wave-based nondestructive evaluation methods were used to evaluate the potential quality and modulus of elasticity (MOE) of wood from creosote-treated Douglas-fir and southern pine piles removed from service. Stress-wave measurements were conducted on each pile section. Stress-wave propagation speeds were obtained to estimate the MOE of the wood. Tests were then conducted on octagonal cants, boards, and small clear specimens obtained from piles and cants. Regression analyses gave a reasonably useful correlation between the stress-wave-based MOE of piles and cants and the corresponding flexural properties of boards and small clear specimens determined by transverse vibration and static bending techniques, respectively. The results show that wood from creosote-treated piles removed from service has the potential for use in exterior structural applications.

Preservative-treated wood products are important construction materials. Preservative-treated wood piles, after removal from service, constitute a major disposal problem for managers of waterfront facilities. For example, approximately 7,000 to 8,000 tons of mechanically or biologically deteriorated wood piles are currently removed from U.S. Naval facilities annually at a cost of at least $20 million per year (8). Although many of these piles are no longer useful because their outer layers are damaged, a considerable amount of the interior wood could be reused for other exterior applications. Options include fenceposts, retaining walls, landscaping timbers, unexposed sheathing, and other general structural applications. A key component in determining reusability is the nondestructive evaluation (NDE) of the structural quality of this wood.

Stress-wave-based NDE techniques developed over the past few decades have shown promise for predicting the mechanical properties of wood. A variety of wood-based materials, ranging from small clear specimens to wood-based composites, have been investigated. Recent research has focused on determining whether longitudinal stress-wave techniques could be used to determine the quality of logs. Several studies have shown a useful relationship (r^2 = 0.44 to 0.89) between the longitudinal stress-wave-based modulus of elasticity (MOE) of logs and the static MOE of lumber cut from the logs (2-7,9,10). However, studies have not addressed the use of NDE techniques to evaluate the potential quality of castoff preservative-treated wood pilings. The objective of this study was to investigate the use of longitudinal stress-wave NDE methods to assess the quality of wood in castoff creosote-treated wood piles.

The authors are, respectively, Postdoctoral Research Scientist, USDA Forest Serv., Forest Prod. Lab. (FPL), One Gifford Pinchot Dr., Madison, WI 53705-2398 and School of Forestry and Wood Prod., Michigan Technological Univ. (MTU), Houghton, MI 49931; Project Leader and Former Director (retired), FPL; Assistant Research Scientist, MTU; Associate Vice President for Graduate Studies, Illinois State Univ., Normal, IL 61790; and Research Plant Pathologist (retired), FPL. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Dept. of Agri. of any product or service. The authors would like to thank Dr. Douglas Gardner, Univ. of Maine, for his support in this work. This paper was received for publication in February 2000. Reprint No. 9092.
*Forest Products Society Member.

Forest Prod. J. 51(2):63-68.

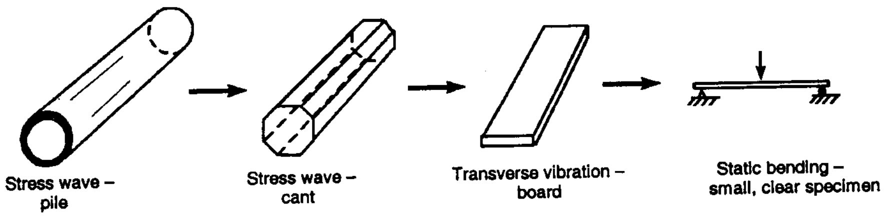

Figure 1. — Schematic of experimental procedure.

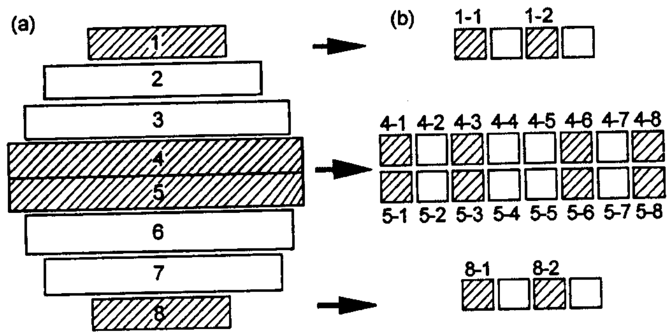

Figure 2.— Schematic of cutting pattern for boards and small clear specimens. Pattern indicates locations of clear specimens cut from boards: a.) boards sawn from octagonal cant; b.) small clear specimens cut from two side boards and two middle boards.

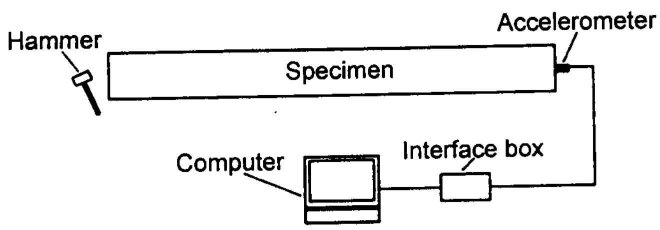

Figure 3. — Schematic of experimental set-up for stress-wave measurement.

MATERIALS AND METHODS

MATERIALS

Nine castoff creosote-treated wood piles (six Douglas-fir (*Pseudotsuga menziesii*) and three southern pine (*Pinus* spp.)) were obtained from U.S. Navy shore facilities. The first batch consisted of five Douglas-fir piles (designated DF1 to DF5) that were cut into approximately 6-foot- (1.8-m-) long sections on site and transported to the Institute of Wood Research at Michigan Technological University. The second batch contained one Douglas-fir (DF6) and three southern pine piles (SP1 to SP3) that were transported to the Institute as full-length piles and subsequently cut into 8.5-foot- (2.6-m-) long sections. A total of 57 sections were obtained from both batches of piles, 44 from Douglas-fir and 13 from southern pine.

These creosote-treated piles had been used as fenders in piers and wharves, and their outer portions had been severely damaged mechanically or biologically during service. The major visual defects were splits, decay, and marine borer damage. More splits and marine borer damage were found in Douglas-fir piles than in southern pine. Douglas-fir piles ranged from 30 to 62 feet (9.14 to 18.90 m) in length and 14 to 15.7 inches (356 to 399 mm) in butt diameter; the depth of creosote penetration (measured visually) ranged from 0.25 to 2 inches (6.4 to 51 mm). Southern pine piles ranged from 40 to 47 feet (12.2 to 14.3 m) in length and 14.5 to 15.8 inches (368 to 400 mm) in butt diameter; creosote penetrated the wood from a depth of 1.5 inches (38 mm) to near the pith.

EXPERIMENTAL PROCEDURE

A schematic of the experimental procedure is shown in **Figure 1.** Longitudinal stress-wave NDE methods were used to assess the piles and the large octagonal cants obtained from them. Transverse vibration and static bending tests were performed on boards and small clear specimens obtained from the cants, respectively.

To estimate the maximum yield of solid wood, we sampled 18 pile sections from 8 piles that had less creosote and cut the sections into octagonal cants, thereby removing most of the creosote-treated outer shell. The outer shell material was saved for a study on remediation and potential use of piles for composite board. Stress-wave measurements were conducted on each pile section and cant. Cants were then sawn into 4/4 (1-in., 25.4-mm) boards. Transverse vibration and static bending tests (destructive) were then performed on boards and small clear specimens cut from boards, respectively, to obtain an estimate of MOE to correlate with E-rating values obtained from piles and cants.

Figure 2a shows a typical sawing scheme used to obtain boards from the octagonal cants. This scheme took advantage of the shape of the cant to obtain the maximum yield of solid wood. The number of boards obtained from the cants varied according to the diameter of the pile sections. **Figure 2b** shows the scheme for cutting 1- by 1- by 16-inch (25.4- by 25.4- by 406-mm) small clear specimens from boards. Specimens were obtained from the two middle boards and the two outer boards. The shaded specimens in **Figure 2b** were used for static bending tests of wood strength and stiffness.

STRESS-WAVE MEASUREMENTS

Figure 3 is a schematic of the experimental set-up for stress-wave measurements. The pile sections and octagonal cants obtained from selected sections were laid on the ground and tested in the longitudinal direction. Longitudinal stress waves were generated by a hand-held hammer blow on one end of each specimen; the stress waves were propagated back and forth along the length of

TABLE 1. — *Physical characteristics of creosote-treated piles removed from service.*[a]

Species and pile ID	Pile length	No. of sections	Moisture content			Density	Creosote penetration	
			Average	Minimum	Maximum		Minimum	Maximum
	(ft.)		---------------- (%) ----------------			(pcf)	---------- (in.) ----------	
Douglas-fir								
DF1	57.4	10	14.8	11.0	17.8	35.21	0.25	2.00
DF2	62.2	11	12.7	9.9	15.2	37.39	0.25	2.00
DF3	40.5	7	13.2	10.7	15.2	32.01	0.25	2.00
DF4	38.1	7	34.1	25.6	56.9	37.02	0.25	1.00
DF5	29.1	6	42.1	28.1	62.5	53.10	1.00	7.00
DF6	36.0	4	59.3	45.5	85.1	51.30	1.50	4.00
Southern pine								
SP1	46.0	5	28.2	17.9	43.8	49.15	2.00	6.50
SP2	47.0	5	88.6	39.5	153.9	53.63	2.50	6.00
SP3	39.5	4	22.7	18.5	26.8	53.51	Full	Full

[a] 1 foot = 0.3048 m; 1 pcf = 16.01 kg/m^3; 1 inch = 25.4 mm,

the specimen. The stress-wave signals were detected by an accelerometer (Columbia model 3021) attached to the opposite end of the specimen. The waveform, monitored and recorded by a computer, consisted of a series of equally spaced pulses whose magnitude decreased exponentially with time. The stress-wave speed (SWS) was determined by coupling measurements of time between pulses (Δt) and specimen length (L):

$$SWS = 2L/\Delta t \quad [1]$$

Based on these measurements, the dynamic modulus of elasticity (MOE_d) of piles and cants was calculated using the one-dimensional wave equation:

$$MOE_d = (SWS)^2 \rho \quad [2]$$

where ρ = specimen density.

DENSITY DETERMINATION

Each pile section and cant was weighed after stress-wave measurement. For pile sections, the diameters of both the large and small ends were measured and the bulk volume of the pile section was calculated using the following equation:

$$V_{pile} = (\pi/12)\, L\, (D_1^2 + D_2^2 + D_1 D_2) \quad [3]$$

where V_{pile} = bulk volume of pile section; D_1 = diameter of large end of pile section; D_2 = diameter of small end of pile section; L = length of pile section,

For the octagonal cants, the circumference was measured at each end and the bulk volume was calculated as:

$$V_{octagon} = \frac{3\sqrt{3}}{2}\left(\frac{l}{6}\right)^2 L \quad [4]$$

where l = average circumference of cant; L = length of cant.

Density was determined using the bulk weight and bulk volume.

A disk cut from the middle section of each pile was used to investigate density distribution and determine pile moisture content (MC). Each disk was wrapped tightly in a plastic bag and taken to the laboratory at Michigan Technological University. Nine 1- by 1- by l-inch (25.4- by 25.4- by 25.4-mm) samples were immediately cut from each disk, four from the outer part, four from the middle, and one from the center. The MCs of samples were determined on the basis of the ovendrying method.

TRANSVERSE VIBRATION AND STATIC BENDING TESTS

The transverse vibration technique was used to estimate the MOE of boards obtained from octagonal cants, using a Metriguard Model 340 E-computer. The test board was supported at one end by a knife-edge support and at the opposite end by a load-cell transducer. The dimensions of the boards were physically measured, and weight and natural frequency were automatically determined by the load-cell transducer, which was interfaced with the computer. Board MOE was determined by the following equation:

$$MOE_v = f_r^2 WL^3/2.46Ig \quad [5]$$

where MOE_v = MOE determined by transverse vibration; f_r = natural frequency (Hz); W = weight of board (lb. (kg.g)); L = span of board between supports (in. (m)); I = moment of inertia (in^4 (m^4)); g = gravitational constant (386 in./$sec.^2$ (9.8 m/s^2)).

Static bending tests were performed on a limited number of 1- by 1- by 16-inch (25.4- by 25.4- by 406-mm) clear wood specimens obtained from octagonal cants using a SATEC Universal Testing Machine. These tests were conducted according to ASTM D 143 Standards (1). The average value from all 12 specimens for each pile was assumed to be the average property of the solid wood in the piles.

RESULTS AND DISCUSSION

PHYSICAL PROPERTIES OF PILES

Table 1 summarizes the physical characteristics of creosote-treated piles used in this study. Average MC of Douglas-fir piles ranged from 12.7 to 59.3 percent and that of southern pine from 22.7 to 88.6 percent. Average MCs of Douglas-fir piles DF1, DF2, and DF3 and that of southern pine pile SP3 were below the fiber saturation point (about 30%); for DF4, DF5, DF6, SP1, and SP2, MC values were close to or exceeded the fiber saturation point. The great difference in MC from pile to pile may imply different service conditions or service histories. According to the information provided by the U.S. Navy, DF4, DF5, DF6, SP1, and SP2 were older than DF1, DF2, DF3, and SP3. The older piles had higher MCs than the newer piles and also exhibited more MC changes in the radial direction than did the newer piles. Further investigation indicated that the MC was lower in the outer layer of the pile than in the middle layer or center. This may have been

TABLE 2. — MOE of piles, cants, boards, and small clear specimens obtained from piles [a]

Species and pile ID	MOE_d of piles and cants		MOE_v of boards			MOE_s of small clear specimens		
	Pile	Cant	Average	Minimum	Maximum	Average	Minimum	Maximum
	($\times 10^6$psi)							
Douglas-fir								
DF1	2.12	1.98	1.40	0.96	2.05	1.37	1.11	1.72
DF2	2.32	2.26	1.89	1.51	2.42	1.62	1.25	2.00
DF3	1.55	1.44	1.16	0.89	1.32	1.19	1.04	1.41
DF4	1.88	1.8	1.55	1.23	1.93	1.41	1.18	1.88
DF5	1.69	1.59	1.36	1.23	1.53	1.24	1.07	1.37
DF6	2.05	1.88	1.55	1.34	1.92	1.32	0.94	1.48
Southern pine								
SP1	1.85	1.71	1.52	1.34	1.94	1.31	1.03	1.74
SP2	1.17	1.63	1.33	1.17	1.55	1.28	0.83	1.37
SP3	1.39	--	--	--	--	--	--	--

[a] 1 psi = 6.894 kPa.

TABLE 3. — Linear regression analyses for correlation between MOE_d of piles and cants and properties of boards and small clear specimens cut from piles. [a]

Properties of boards and small clear specimens	MOE_d of piles and cants	Linear regression model $Y = a + bX$			
Y	*X*	*a*	*b*	*r*	Syx
Average board MOE,	Piles	0.3443	0.5889	0.85	0.123
Average board MOE,	Cants	0.1408	0.7403	0.91	0.101
Bark-side board MOE,	Piles	0.0677	0.8752	0.90	0.144
Bark-side board MOE,	Cants	-0.1447	1.0514	0.91	0.137
MOE, of small clear wood	Piles	0.7114	0.3355	0.76	0.103
MOE, of small clear wood	Cants	0.5064	0.4669	0.85	0.084
MOR of small clear wood	Piles	510.2	4133.9	0.69	1538.9
MOR of small clear wood	Cants	-757	5059	0.68	1566.0

[a] Small clear specimens were tested in static bending according to ASTM D 143 standards (I). MOE_d = stress-wave-based dynamic modulus of elasticity; MOE_v = modulus of elasticity determined by transverse vibration; MOE_s = static modulus of elasticity; MOR = modulus of rupture: *r* = correlation coefficient; Syx = standard error of estimate.

caused by natural drying after the piles were removed from the water.

Density is an important component in the determination of stress-wave-based MOE_d. Bulk density values ranged from 32.0 to 53.1 pcf (0.51 to 0.85 g/cm^3) for Douglas-fir piles and from 49.2 to 53.6 pcf (0.79 to 0.83 g/cm^3) for southern pine piles. Density of small samples ranged from 29.2 to 52.0 pcf (0.47 to 0.83 g/cm^3) for Douglas-fir and 49.7 to 58.8 pcf (0.80 to 0.94 g/cm^3) for southem pine. These results indicate that the bulk values were in agreement with average density values of small samples cut from the piles.

EFFECTS OF CREOSOTE AND DEFECTS ON STRESS-WAVE PROPAGATION

After the piles were cut into cants, wood density decreased considerably: by 6.2 to 26.1 percent for Douglas-fir (DF) piles and 18.6 for southern pine pile SP1. Stress-wave speed measured in Douglas-fir cants increased 2 to 19.1 percent and about 12 percent in southern pine cants compared to stress-wave speed measured in piles. This supports the hypothesis that creosote attenuates stress-wave propagation in wood. The attenuation effect was dependent on the depth of creosote penetration in the piles. In Douglas-fir piles where penetration depth was only 1 to 4 inches (25.4 to 102 mm) (all piles except DF5), stress-wave speed was 2 to 5 percent lower than that measured in corresponding cants. By contrast, in DF5 and all southern pine piles, in which creosote penetration was much deeper (6 to 7 in. (152 to 178 mm)), stress-wave speed was about 11 to 16 percent lower than that measured in corresponding cants. In addition, defects such as splits (across the wave propagation line), decay, and marine borer damage weakened stress-wave propagation in piles.

MOE AND MOR OF PILES

Table 2 shows the MOE of piles, cants, boards, and small clear specimens obtained from piles. The maximum MOE values shown in **Table 2** were obtained from the boards and small clear specimens cut near the outer surface of the piles. Note that the MOE_d values of piles and cants tended to be higher than the average MOE of boards and small clear specimens but close to the MOE of the boards and the small clear specimens cut near the outer surface of the piles. The same phenomenon was observed in further investigations on the variation of SWS and MOE in the middle boards cut from piles (11,12). This may imply that the stress waves tend to lead on the bark-side as they travel through piles or octagonal cants.

The results show that castoff creosote-treated piles still contain wood of good quality. The MOE, of boards obtained from these piles ranged from 0.89 to 2.42 × 10^6 psi (6.2 to 16.7 GPa) for Douglas-fir and 1.17 to 1.94 × 10^6 psi (8.1 to 13.4 GPa) for southern pine. Static bending tests conducted on small clear specimens supported these results. The static MOE (MOE,) values for small clear specimens ranged from 0.94 to 2.00 × 10^6 psi (6.5 to 13.8 GPa) for Douglas-fir and 0.83 to 1.74 × 10^6 psi (5.7 to 12.0 GPa) for southern pine. The values for modulus of rupture (MOR) ranged from 5.41 to 14.6 × 10^3 psi (37.3 to 100.8 MPa) for Douglas-fir piles and from 4.3 to 9.5 × 10^3 psi (29.6 to 65.5 MPa) for southern pine piles.Therefore, it should be possible to remove some of the damaged outer shell of piles and reuse the center core for other exterior applications.

RELATIONSHIP OF STRESS-WAVE PROPERTIES TO FLEXURAL PROPERTIES

Results obtained from various regression analyses are summarized in **Table 3.** The correlation coefficients (*r*) obtained from these analyses indicate reasonably useful relationships between stress-wave properties of piles and cants and corresponding flexural properties of boards and small clear specimens.

The strong correlation between MOE_d of pile sections and MOE_d of cants **(Fig. 4)** reveals that the stress-wave properties of castoff piles can reflect the MOE of solid wood within the piles; even though creosote and pile defects affected stress-wave propagation and measurements as mentioned previously. **Figure 5** shows the relationship between average MOE, of boards and MGE_d of piles, and **Figure 6** shows the relationship between average MOE_v of boards and MGE_d of cants. Good correlation (r = 0.85 to 0.91) was found between stress-wave-predicted MOE_d and board MOE. Note that pile MOE_d had a better correlation with the MOE of bark-side boards than with the average MOE of boards. Regression analyses gave reasonably useful relationships between MOE_d of piles and cants and MOE, and MOR of small clear specimens **(Table 3).**

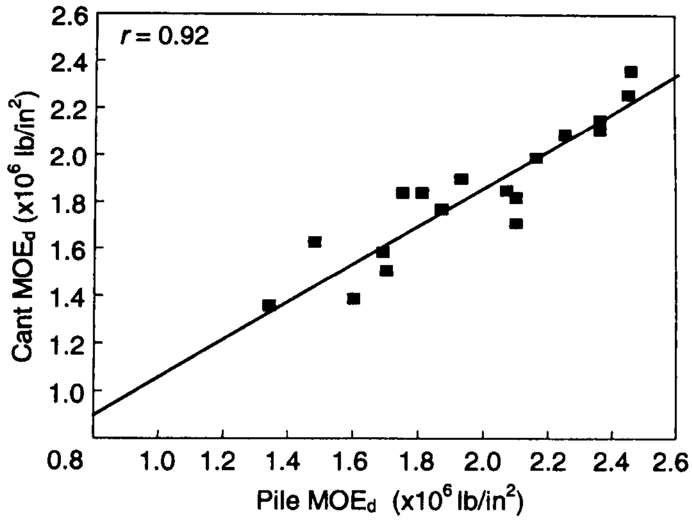

Figure 4. — Relationship of MOE_d of piles to MOE_d of cants.

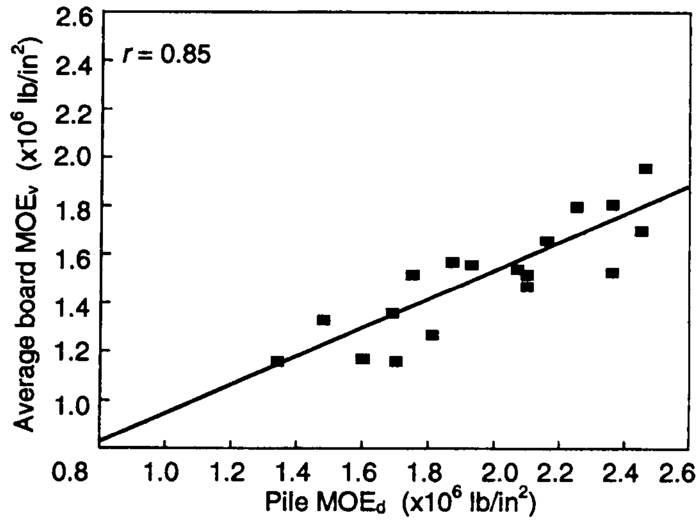

Figure 5. — Relationship of average MOE_v of boards to MOE_d of piles.

CONCLUSIONS

The results of this study indicate that longitudinal stress-wave nondestructive evaluation (NDE) methods can be used to assess the potential quality of wood in creosote-treated piles removed from service. Although creosote and surface defects affected stress-wave propagation in castoff piles, there was a reasonably useful correlation between stress-wave-based MOE of piles and corresponding flexural properties of boards and small clear specimens obtained from the piles. The results also indicated that castoff piles retain wood of good quality. Therefore, timber and lumber from these piles have the potential for use in exterior structural applications.

LITERATURE CITED

1. American Society for Testing and Materials. 1988. Standard methods for testing small clear specimens of timber. ASTM-D 143. ASTM, West Conshohocken, Pa.
2. Aratake, S. and T. Arima. 1994. Estimation of modulus of rupture and modulus of elasticity of lumber using higher natural frequency of log in pile of logs. Part II. Possibility of application for sugi square lumber with pith. Mokuzai Gakkaishi 40(9):1003-1007:
3. ____________________, T. Sakoda, and Y. Nakamura. 1992. Estimation of modulus of rupture and modulus of elasticity of lumber using higher natural frequency of log in pile of logs. Possibility of application for sugi scaffolding board. Mokuzai Gakkaishi 38(11):995-1001.
4. Arima, T., N. Maruymura, S. Maruyama, and S. Hayamura. 1990. Natural frequency of log and lumber hit with hammer and ap-

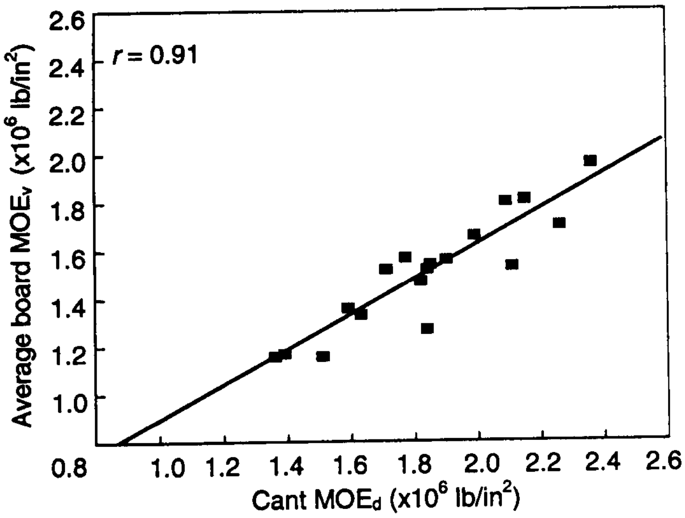

Figure 6. — Relationship of average MOE_v of boards to MOE_d of cants.

plications for production processing. *In:* Proc. 1990 Inter. Timber Engineering Conf., Oct. 23-25, Tokyo, Japan. Sci. Univ. of Tokyo. pp. 527-533.

5. Iijima, Y., A. Koizumi, Y. Okazaki, T. Sasaki, and H. Nakatani. 1997. Strength properties of sugi (*Cryptomeria japonica*) grown in Akita Prefecture. Part III. Some relationships between logs and sawn lumber. Mokuzai Gakkaishi 43(2):159-164.

6. Koizumi, A., Y. Iijima, T. Sasaki, and Y. Okazaki. 1997. Strength properties of sugi (*Cryptomeriajaponica*) grown in Akita Prefecture. Part II. Mechanical properties of lumber. Mokuzai Gakkaishi 43(2):210-214.

7. __________, __________, __________,Y. Kawai, Y. Okazaki, and H. Nakatani. 1997. Strength properties of sugi (*Cryptomeria japonica*) grown in Akita Prefecture. Part I. Young's moduli of logs. Mokuzai Gakkaishi 43(1):46-51.

8. Pendleton, D.E. and T. Hoffard. 1998. Management of treated wood removed from waterfront services: options for Navy activities. Special Rept. Naval Facilities Engineering Serv. Center, Port Hueneme, Calif. 13 pp.

9. Ross, R.J., K.A. McDonald, D.W. Green, and K.C. Schad. 1997. Relationship between log and lumber modulus of elasticity. Forest Prod. J. 47(2):89-92.

10. Sandoz, J.L. and P. Lorin. 1994. Standing tree quality assessments using ultrasound. *In:* Proc. First European Symp. on Nondestructive Evaluation of Wood. September 21-23, Univ. of Sopron, Sopron, Hungary. Vol. 2. pp. 493-502.

11. Wang, X. 1999. Stress-wave-based nondestructive evaluation methods for wood quality of standing trees. Ph.D. diss., Michigan Technological Univ., Houghton, Mich.

12. __________, R.J. Ross, J.R Erickson, J.W. Forsman, G.D. McGinnis, and R.C. De Groot. 2000. Nondestructive methods of evaluating quality of wood in preservative-treated piles. Res. Note FPL-RN-0274. USDA Forest Serv., Forest Prod. Lab., Madison, Wis. 9 pp.