WOOD DENSITY AS AN INDICATOR OF THE BENDING PROPERTIES OF PINUS RADIATA POLES

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ABSTRACT

The outerwood density of 57 **Pinus radiata** D. Don poles from two stands (aged 15 and 25 years) in the central North Island was assessed gravimetrically using increment cores and indirectly using a Pilodyn Wood Tester, and the poles were tested to destruction by cantilever loading. Relationships between wood density of the outer 20% of the radius and the poles' strength and stiffness in bending were found to be highly statistically significant. From these relationships and regional data for wood density, the bending properties of poles have been predicted for a range of crop ages and growing sites, and these predictions compared to the values given in the Timber Design Code. In this study, pre-preservation steaming of **P. radiata** poles appeared to influence their bending properties more than anticipated.

The Pilodyn Wood Tester was shown to be potentially useful for segregating poles into strength classes.

INTRODUCTION

For some years past, stands of Corsican pine (*Pinus nigra* subsp. *laricio* (Poir.) Maire) have been a major source of preservative-treated softwood post and pole material in New Zealand, particularly for structural uses. The supply of this species is diminishing rapidly but there will soon be a substantial increase in the amount of *P. radiata* available throughout the country. Although not ideally suited for all roundwood uses, it seems inevitable that this species will become the main source of round produce in future.

Structural poles may be used in frameworks where they react in groups, effectively averaging out differences between individuals (load-sharing), but in many applications (e.g., transmission lines, orchard windbreaks) there is little or no load-sharing. In either situation it is obviously important to ensure that there is a probability of their strength exceeding the design requirements.

For practical reasons, early recommendations on *P. radiata* poles for engineering uses adopted an effective wood age of 15 growth rings at the small end as the criterion to ensure an outer envelope of relatively mature, dense wood in the critical (highly stressed) zone. Even so, separate stress ratings were assigned to four regions on the basis of wood density data available at the time (Hellawell 1965; Walford & Hellawell 1972).

Criteria for selection of load-bearing piles and poles are set out in NZS 3605 : 1977 (Standards Association of New Zealand 1977). Many of the clauses refer to visual requirements, i.e., straightness, taper, and nodal swelling. Provision for satisfactory mechanical properties is catered for by restricting the knots and spiral grain allowed and including a "maturity" factor (requiring a minimum of 11, 13, and 15 growth rings for minimum small-end diameter of 125, 150, and 175 mm respectively in poles exceeding 3 m in length). These growth criteria will become increasingly burdensome as supplies of roundwood from unthinned or slow-grown stands decrease. Current *P. radiata* silviculture aims to maximise early growth rates such that logs of suitable dimensions are produced with younger effective wood ages.

The stress rating of *P. radiata* poles in the recently finalised Code of Practice for Timber Design (NZS 3603 : 1981 – Standards Association of New Zealand 1981) is confined to a single value for New Zealand as a whole (based on the central North Island data) and consequently both reliability and efficiency will be adversely affected.

Whether future round produce comes from thinnings or from specially managed stands (Hellawell 1981), increasing experience in the use of *P. radiata* indicates a size-for-age problem that makes some alternative to ring counts as a quality criterion highly desirable. Clearly, there is a case for using wood density or some related property in this way.

Basic wood density varies radially within tree stems as a function of age and also varies between trees and between sites (Cown 1974). The density assessment of standing trees from core samples taken with an increment borer at breast height (1.4 m) gives accurate density information, but requires laboratory facilities for the detailed and time-consuming measurements (Smith 1954). However, by using this procedure FRI has produced information relating breast-height density to the density of various stem components (Cown & McConchie 1982). By collecting density samples from a minimum of 15 trees in each stratum (e.g., site, or age class) estimates can be made of the crop density characteristics. This background work has led to a suitable method for extensive, or intensive, field assessments.

Three broad site density classes have been recognised in *P. radiata* "old-crop" stands (*see also* Fig. 1): high density = Auckland region, coastal Rotorua, coastal Nelson; medium density = inland Rotorua, inland Nelson, coastal Wellington; low density = inland Wellington, Westland, Canterbury, Southland.

Recently, alternative means of estimating wood density of trees or logs have been examined (Cown 1978, 1982) and, of these, the Pilodyn Wood Tester appears to hold the most promise. In this method a spring-loaded pin is forced into the wood and the depth of penetration is significantly correlated with density.

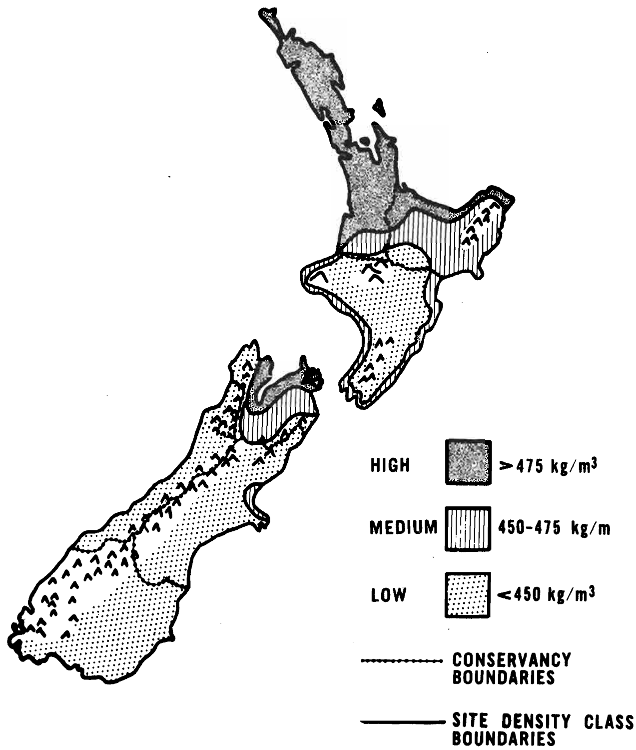

FIG. 1—Radiata pine outerwood density.

In the current study Pilodyn readings were taken on groups of green *P. radiata* poles and compared with their outerwood density. The poles were then loaded to determine their strength and stiffness in bending. The aim was to confirm the influence of outerwood density on these properties and to determine if a Pilodyn can provide a satisfactory measure for the stress rating of round produce. The study included an evaluation of the effects of steam conditioning on the bending properties of some of the poles because this pre-treatment is an important alternative to air drying in the preparation of round produce of pine species for preservative treatment by pressure methods. The trials were instituted to extend the limited knowledge (Hellawell 1965) of the mechanical properties of pole material from central North Island crops.

MATERIALS AND METHODS

At the N.Z. Forest Products Ltd site at Kinleith a cantilever test rig was built in which poles were tested to destruction. The poles were positioned vertically with the base end securely fixed; loads were applied horizontally near the top, and measured with the aid of a transducer load cell. Deflections were measured by fixing a horizontal scale to the top end of each pole and recording its displacement against a fixed point on the support structure at given load increments. The method of loading was similar to that used by Hellawell in earlier pole testing (Hellawell 1965), but the method of measuring deflections differed. It is believed that this did not affect the accuracy of results.

Test material included:

(1) Thirteen poles from 25-year-old thinnings (6 m × 142–204 mm small-end diameter), steamed and vacuum/pressure-treated with a multisalt preservative (Sample 1). These were from a relatively slow-grown stand, and conformed to NZS 3605 : 1977 in respect of knots, taper, and maturity requirements.

(2) Twenty-four poles, mostly from 15-year-old thinnings (6 m × 170–210 mm diameter), 12 tested after steaming (Sample 2) and 12 unsteamed (Sample 3). Four poles had ring counts of 18 or more. The rest were from a fast-grown stand of which only two poles conformed to the taper requirements of NZS 3605 : 1977. Two poles from each sample had excessive knots.

(3) Twenty poles from 15-year-old thinnings, 10 poles tested after steaming (Sample 4) and 10 unsteamed (Sample 5). Diameters were similar to Samples 2 and 3 above. Two of Sample 5 had excessive knots in the critical region, and two of Sample 4 had excessive spiral growth.

(4) Two poles (third or fourth logs, 9.0 m × 250–340 mm diameter) from a 35-year-old clearfelled stand, steamed and vacuum/pressure-treated with a multisalt preservative (Sample 6).

A summary of pole characteristics is given in Table 1.

TABLE 1—Summary of test material

Treatment	Steamed			Unsteamed	
Sample No.:	1	2	4	3	5
Stand age (yr):	25	15	15	15*	15
No. of poles	13	12	10	12	10
Effective wood age (rings at base)	23	12	13	15	13
Average small-end diameter (mm)	176	193	198	185	195
Taper (mm/m)	5.7	5.4	7.1	6.8	6.6
Knots in the critical region†					
Range in largest diameters (mm)	0–36	0–40	0–50	0–50	0–55
Sum of diameters (mm)	0–155	0–210	0–164	0–270	0–150

* Samples contained four stems from older trees.
† Data supplied by C. R. Hellawell, Forest Research Institute.

All samples were derived from central North Island crops and were hydraulically debarked at Kinleith to minimise physical damage (Walford 1982). Steaming was carried out generally in accordance with New Zealand Timber Preservation Authority

Specifications Amendment No. 4 (1980), with the time determined by the largest pole in the charge. This is a normal precaution adopted in commercial practice.

Wood discs were collected from both ends of each pole for ring counts and wood density assessment. The outer 20% of the radius is the critical zone for pole strength, so basic density was measured on that portion of the discs, and individual pole averages were derived from the results. Pilodyn penetration readings were obtained from the groundline position (1.5 m) of the freshly debarked poles (two tests per pole).

In addition, corresponding data were available from beam tests of 15 poles (2.4 m × 180–230 mm diameter) from a 40-year-old stand in Woodhill Forest (Walford, in press). These had also been carefully peeled to avoid damaging or removing nodal swellings.

Modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated using effective values of pole circumference (Hellawell 1965).

By combining strength/density relationships from these tests with the wood density information collected during a nationwide wood properties survey (Cown & McConchie 1982) estimates of the bending properties of poles from other localities were made.

RESULTS AND DISCUSSION

Wood Density and Pole Mechanical Properties

From analyses of the results (Tables 2–3) it was clear that wood density of the outer zone of the poles (and effective wood age, based on a ring count at the large end) were closely related to both strength and stiffness. The regressions shown in Figs 2 and 3 for unsteamed poles demonstrate that the derived relationships hold for a range of ages (15–40 years), crop types (unthinned old crop, new crop thinnings), and wood densities (350–600 kg/m^3). It is also noteworthy that the strength regression is very similar to that given by Hellawell (1965).

TABLE 2—Summary of test results

Treatment:	Steamed			Unsteamed	
Sample No.:	1	2	4	3	5
Stand age (yr):	25	15	15	15	15
Wood density of outer zone (kg/m^3)	473	409	421	440	421
Pilodyn (mm penetration)	11.1	12.0	11.1	11.2	11.3
Modulus of elasticity (GPa)	8.6	6.2	5.8	8.5	7.1
Modulus of rupture (MPa)	40.6	32.0	29.0	44.6	42.8

Regression equations derived from the Kinleith tests are given in Table 4. Outer zone basic density accounted for 70% of the variation in bending properties of unsteamed poles and 60% in steamed poles.

TABLE 3—Correlation coefficients

		Steamed				Unsteamed		
Sample No.:		1	2	4	2 + 4	3	5	3 + 5
Stand age (yr):		25	15	15	15	15	15	15
MOE	v. density	0.83**	0.59*	0.84**	0.70**	0.90**	0.90**	0.89**
	v. Pilodyn	–0.60*	–0.46NS	–0.82**	–0.67**	–0.64*	–0.87**	–0.69**
	v. effective wood age†	0.83**	0.73**	0.83**	0.74**	0.88*	0.82**	0.85**
MOR	v. density	0.76**	0.84**	0.78**	0.67**	0.87**	0.90**	0.88**
	v. Pilodyn	–0.76**	–0.85**	–0.64*	–0.53**	–0.69**	–0.96**	–0.79**
	v. effective wood age	0.69*	0.59*	0.67*	0.56**	0.92**	0.79**	0.85**
Density	v. Pilodyn	–0.82**	–0.74**	–0.91**	–0.86**	–0.83**	–0.95**	–0.87**

† Number of growth rings at the large end
MOE Modulus of elasticity
MOR Modulus of rupture

* significant at $p = 0.05$
** significant at $p = 0.01$
NS not significant

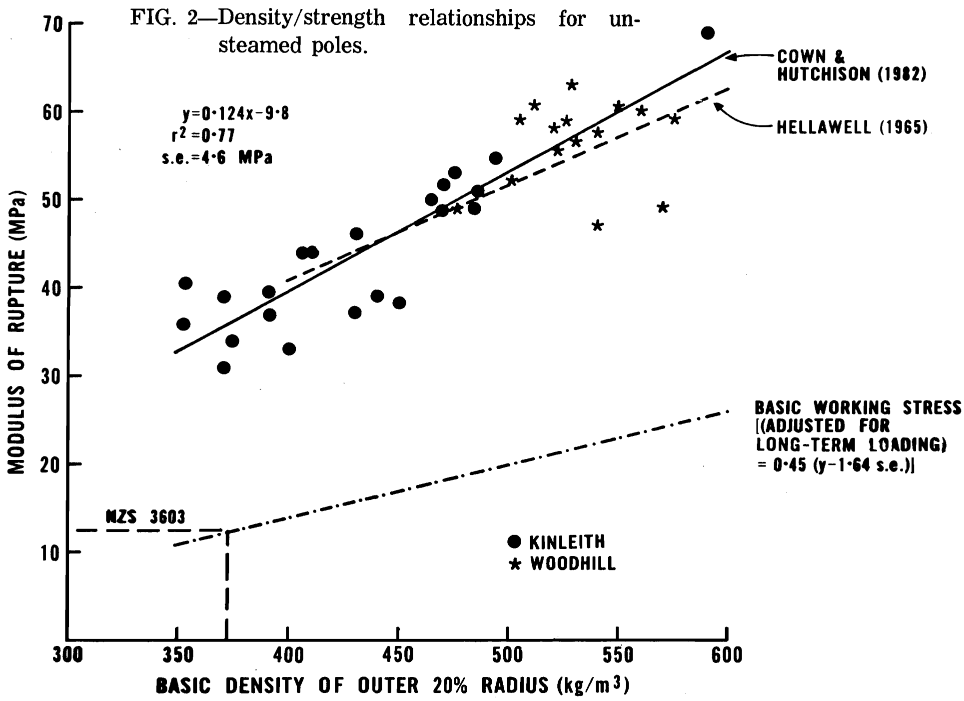

FIG. 2—Density/strength relationships for unsteamed poles.

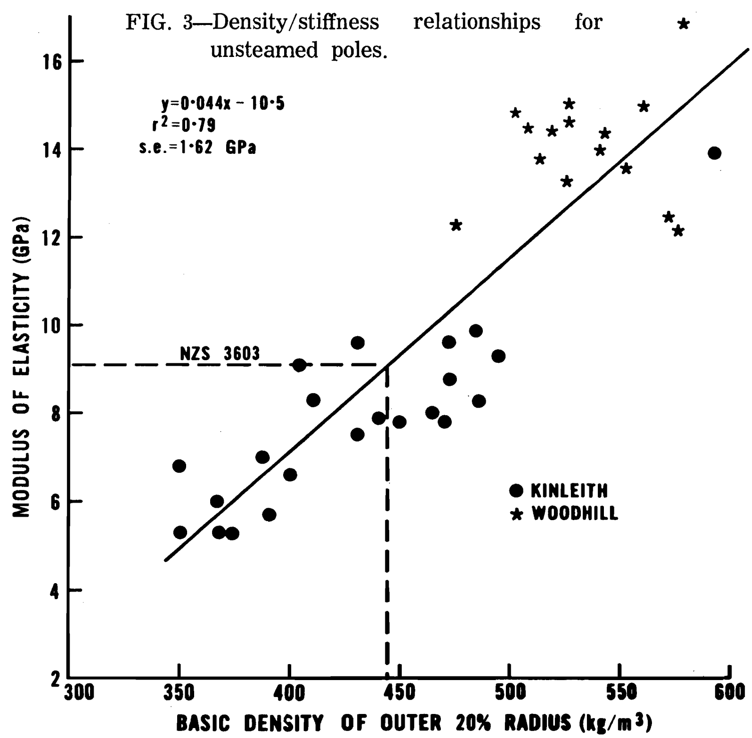

FIG. 3—Density/stiffness relationships for unsteamed poles.

Regional Wood Density Variation

The average radial density pattern for each site density class (Cown & McConchie 1982) was used to derive outerwood densities of poles of effective wood age (ring count) between 10 and 30 years, and strength and stiffness values predicted using the regressions in Table 4 to obtain the results given in Table 5. Strength and stiffness are expressed in terms of basic working stresses for comparison with NZS 3603 : 1981. The trends are clearcut and indicate that produce from the high density class will attain given strength and stiffness properties at a much earlier age than materials from other sites. In terms of the code values, properties are more likely to be limiting in younger age classes and the lower site density classes.

TABLE 4—Regressions relating pole stiffness and strength to wood density at the large end (Kinleith results only)

Dependent variable	Pole* condition	Regression coefficient	Constant	Standard error of regression	Coefficient of determination (r^2)
Modulus of elasticity (GPa)	Unsteamed	0.029	–5.06	1.1	0.69
	Steamed	0.027	–5.41	1.1	0.61
Modulus of rupture (MPa)	Unsteamed	0.131	–15.10	4.9	0.71
	Steamed	0.106	–13.58	4.4	0.59

* Unsteamed — Samples 3 and 5 (22 poles)
Steamed — Samples 1, 2, and 4 (37 poles)

Influence of Steaming on Bending Properties

The effects of steaming determined in these trials were greater than those allowed for in the New Zealand design code, i.e., reductions of 15% *v.* 5% for MOE, and 25% *v.* 15% for average MOR, assessed at equivalent wood density. In fact, the values predicted in Table 5 suggest that there will be little chance of steamed poles conforming with code stiffness requirements, particularly material from young stands on low-density sites.

The tests and predictions were carried out on hydraulically debarked poles hence no account has been taken of the further losses in bending properties attributed to shaving (Walford & Hellawell 1972). This is expected to be additive, but requires further research in respect of radiata pine.

Interaction Between Wood Density and Pole Size Requirements

Deficiencies in properties of poles can be allowed for by adjusting the physical dimensions of the material. A theoretical exercise using NZS 3603 : 1981 values for the required stiffness and strength of steamed poles, and a range of outerwood densities indicates that substantial savings in pole volume, and hence cost, can be achieved through the use of high-density material (Table 6). Conversely, the data show the increase in pole size necessary to compensate for inherently poor physical properties.

Logs from any site can be considered for poles providing the density/size relationship meets user requirements.

TABLE 5—Predicted pole characteristics by site density class and effective wood age

Property	Site density class	Effective wood age (yr) 10	15	20	25	30
Estimated mean basic density of outer 20% radius (kg/m³)	high	390	445	480	495	505
	medium	360	400	430	455	465
	low	350	385	410	425	435
	Unsteamed (NZS 3603 : 1981 – 12.4 MPa)*					
Modulus of rupture – basic working stress (MPa)	high	12.6	15.8	17.9	18.7	19.4
	medium	10.8	13.2	14.9	16.4	17.0
	low	10.2	12.3	13.7	14.6	15.2
	Steamed (NZS 3603 : 1981 – 10.5 MPa)					
	high	9.3	11.9	13.5	14.3	14.7
	medium	7.8	9.7	11.1	12.3	12.8
	low	7.3	9.0	10.2	10.9	11.4
	Unsteamed (NZS 3603 : 1981 – 9.1 GPa)					
Modulus of elasticity – average value (GPa)	high	6.3	7.8	8.9	9.3	9.6
	medium	5.4	6.5	7.4	8.1	8.4
	low	5.1	6.1	6.8	7.3	7.5
	Steamed (NZS 3603 : 1981 – 8.6 GPa)					
	high	5.1	6.6	7.5	7.9	8.3
	medium	4.3	5.4	6.2	6.9	7.1
	low	4.0	5.0	5.7	6.1	6.3

* Basic working stresses and modulus of elasticity given in the Code of Practice for Timber Design

Non-destructive Wood Density Sampling

Within even-aged stands considerable variations in pole density can be found.

All poles destructively tested at Kinleith were assessed by Pilodyn while in the fresh green condition and results of correlation analyses are given in Table 3.

The Pilodyn/density relationship (Fig. 4) was shown to be consistently highly significant both within batches ($r = -0.74$ to -0.95) and over-all ($r = -0.80$). However, the range in standard errors (16–33 kg/m³) means that individual stems can only be segregated into broad density classes (e.g., high, medium, low) rather than precisely defined. This level of association is similar to that widely accepted in machine stress-grading operations (Walford 1981).

TABLE 6—Influence of wood density on the volume of steamed poles required to meet code-assigned stiffness and strength values

Outerwood density (kg/m³)	MOE (GPa)	Pole volume required* (% of code)	Basic working stress (MPa)	Pole volume required† (% of code)
360	4.31	141	8.80	122
400	5.39	126	9.71	105
440	6.47	115	11.62	93
480	7.55	107	13.53	84
520	8.63	100	15.44	77
Code values	8.60	100	10.50	100

$$* \text{ Relative volume required} = 100 \times \left[\frac{\text{MOE code}}{\text{MOE actual}}\right]^{2/4}$$

$$\dagger \text{ Relative volume required} = 100 \times \left[\frac{\text{BWS code}}{\text{BWS actual}}\right]^{2/3}$$

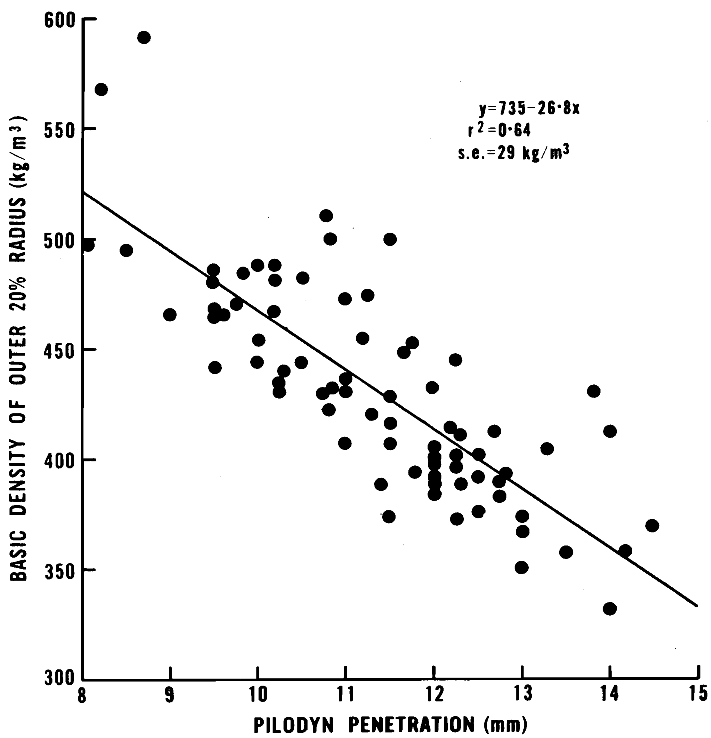

FIG. 4—Relationship between Pilodyn penetration and density for 76 poles from Kinleith.

Correlations between Pilodyn readings and strength and stiffness were highly significant within batches of both unsteamed and steamed poles, and in fact the instrument was successful in discriminating between poles of different mechanical properties (Figs 5 and 6). For instance, it indicated that the two large poles (Sample 6) had a relatively low density. Testing only for stiffness showed both these poles had very low values of MOE (5.9 and 7.2 GPa).

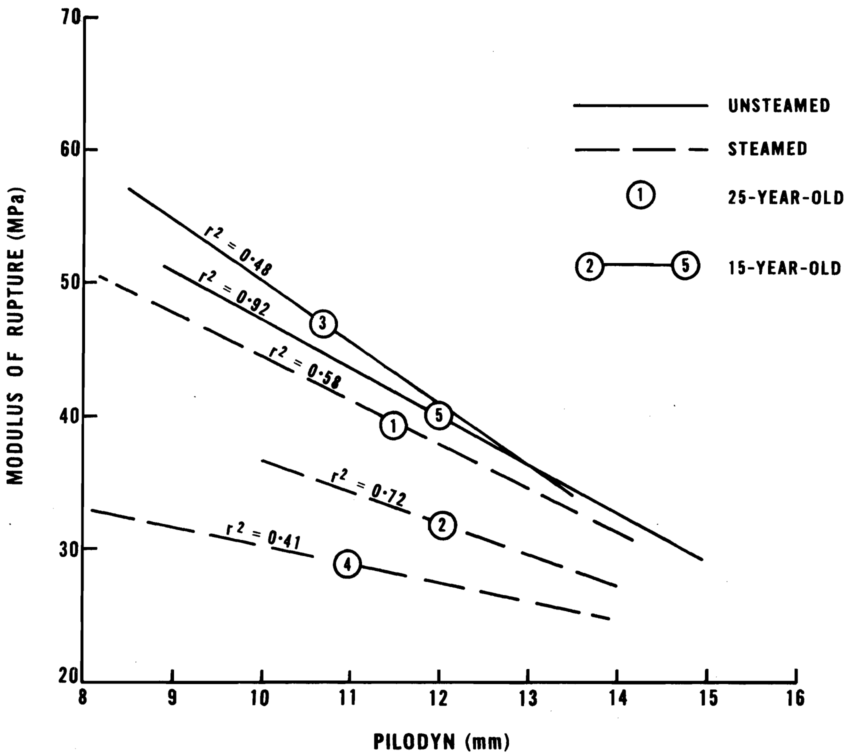

FIG. 5—Relationship between Pilodyn penetration and modulus of rupture in steamed and unsteamed poles.

CONCLUSIONS

Pole tests have confirmed that basic wood density of the outer growth sheath is closely related to the mechanical properties over a wide range of raw material types. Since wood density variations have been well documented in *P. radiata,* predictions of pole properties can be made using site density class and effective wood age. Such estimates show that significant differences in strength and stiffness can be anticipated and that in certain situations deficiencies in these properties may limit the suitability of *P. radiata* poles in respect of present design data (NZS 3603 : 1981).

Steaming appears to reduce the mechanical properties of *P. radiata* poles more than previously anticipated. Use of the code values for strength and stiffness of steamed poles may therefore over-state their capacity for load carrying. Further work needs to

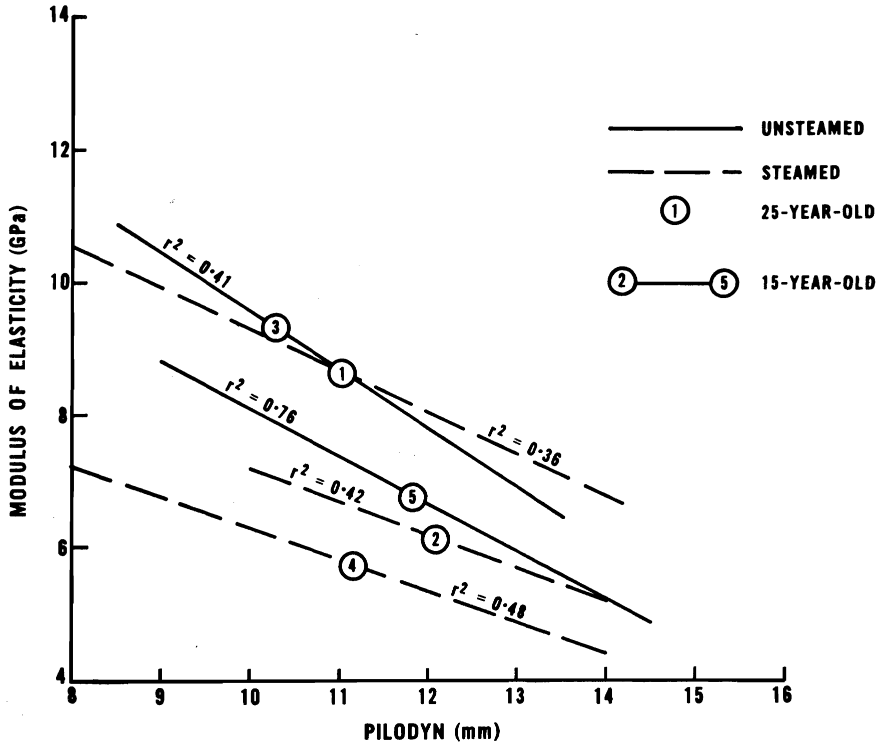

FIG. 6—Relationship between Pilodyn penetration and modulus of elasticity in steamed and unsteamed poles.

be done to substantiate the current code values with regard to pole material presently available.

The results fully vindicate the suggestion of Hellawell (1982) and others that there is a case for establishing pole stands of cuttings from high density ortets in appropriate areas (e.g., sites with inherently low wood density). In this way supplies of uniformly high-quality poles can be strategically located around the country.

Large variations in pole characteristics due to environmental, age, genetic, and treatment effects highlight the need for a rapid non-destructive means of screening produce for mechanical properties. This can be done either on a broad basis prior to felling, by estimating density of the outer wood at breast height, or on individual poles in the mill. Test results indicate that the Pilodyn Wood Tester could have an application in either use, and may help overcome the restrictive maturity factor in the current national standard.

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