BENDING PROPERTIES OF STRUCTURAL TIMBER FROM A 28-YEAR-OLD STAND OF NEW ZEALAND PINUS RADIATA

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ABSTRACT

Seventy-eight upper logs taken from a 28-year-old stand of **Pinus radiata** D. Don in Kaingaroa State Forest, New Zealand, were sawn to maximise yields of 200 × 50-mm and 100 × 50-mm timber which was then dried, planed, visually and mechanically graded, and tested in bending.

The timber was not as strong or as stiff as timber from older trees. Although the basic working stress in bending was higher than the code value, the modulus of elasticity was lower but not to an extent that is likely to cause problems in practice. A simplified grading rule was proposed which yields material with a basic working stress 50% higher than No. 1 Framing grade. Relationships between log variables and the properties of timber from each log were derived, and it was shown that currently prescribed design moduli of elasticity for Engineering grade might be obtained only for timber from logs with a basic density in excess of 490 kg/m^3.

Keywords: in-grade testing; strength; stiffness; basic density; modulus of rupture; modulus of elasticity; branch index; structural timber.

INTRODUCTION

About 86% of New Zealand's 1 million ha of exotic forest is planted in *Pinus radiata* (N.Z. Forest Service 1984). This resource is changing rapidly (Whiteside 1984) as the stands planted in the 1920s and 1930s are depleted and timber is beginning to be cut from silviculturally managed stands planted since the late 1950s. Heavy thinning and pruning in some stands has provided large-diameter trees with significant amounts of clear timber in the butt logs. Other stands, whilst not grown specifically for clear timber, will also be less mature than the older crop. It is expected that much of the structural timber will come from these younger stands and the upper logs of the trees with clear butt logs. The rotation age at felling may be as low as 30 years.

The branch size and relative immaturity of these logs is likely to yield timber of lower density with some larger knots and wide growth rings (Bunn 1981; Cown & McConchie 1982). It is therefore important to quantify the effects of these variables on the properties of the timber.

A computer-based silvicultural stand model available in New Zealand can be used to predict the effects of silviculture on grade recovery (Whiteside 1982) but this model has not been developed to predict the strength and stiffness of sawn timber. The data base includes samples selected for extremes of branch size and density. To establish the effects on strength at the fifth percentile (which is used for deriving design stresses), a random selection of logs is required. Other studies on timber of specific grades have not included log quality measurements (Walford 1982). If relationships exist between timber strength properties and log and wood quality measurements these would:

(1) Assist in revising the strength values to be assigned to standard grades obtained from younger stands, or

(2) Aid in the formulation of revised grading rules to maintain current strength values, and

(3) Indicate what silviculture will produce better-quality structural material if this is seen as desirable.

The main object of the present study was to determine in-grade bending strength and stiffness of the sawn timber from the upper logs of pruned trees from a 28-year-old stand, and relate them to log quality measurements as well as timber grading parameters. The testing of timber in structural sizes is expensive and so, in obtaining data to achieve the objective, it was prudent to record data that will be useful for many purposes. This paper is confined to a comparison with timber from older trees, the effect of some timber variables on in-grade strength, and the effect of log variables on strength properties.

For an earlier report (Bier & Collins 1984), only the results of tests on 100 × 50-mm timber were available. For these the mechanical grading parameter, bending stiffness on the flat, was the best single indicator of mean strength and stiffness on the edge, but for visual grading, knot area ratio was the best single indicator of strength, and ring width the best single indicator of stiffness. However, the imposition of ring width limitations on visually graded timber was shown to have no significant effect on the fifth percentile strength and only a small effect on average stiffness. The derived allowable stresses of the visual timber grades exceeded current New Zealand design code values but the stiffness was about 10% below the current code values for Engineering grade and 3% for No. 1 Framing grade. This paper includes the results of tests on 200 × 50-mm material.

MATERIAL AND METHODS

Forty trees were selected from Cpt 1250 of Kaingaroa State Forest, yielding 78 upper logs of a range of diameters. The pruned butt logs were excluded from the study because these contained a large proportion of clearwood which is more likely to be used for higher value non-structural products.

All logs were measured in the forest according to established procedures (Whiteside 1982) to obtain end diameters, the largest branch size in each of the four quadrant prisms of the log (branch index), and sweep. A disc was cut from the upper end of each log to determine basic density.

Small-end diameters ranged from 250 mm to 550 mm. The total under-bark volume of logs was 56.5 m^3, yielding 31 m^3 of sawn timber in 50-mm thickness. The logs less than 350 mm small-end diameter were cut to maximise 100 × 50-mm framing timber and those greater than 350 mm were cut to maximise 200 × 50-mm framing timber (Fig. 1). Properties of the log sample are summarised in Table 1.

TABLE 1—Mean statistics of the log samples* (standard deviations in parentheses)

Log properties	Diameter < 350 mm		Diameter > 350 mm		Second log	Third log	Fourth log	Fifth log
Small-end diameter (mm)	307	(28)	423	(53)	412	370	334	313
Taper (mm/m)	7.74	(2.90)	8.75	(4.03)	7.65	7.82	11.1	12.3
Branch index (cm)	4.3	(1.25)	5.6	(1.9)	5.0	5.0	5.8	6.3
Volume (m^3)	0.46	(0.07)	0.87	(0.21)	0.83	0.67	0.59	0.51
Internode lengths (m)	1.73	(1.32)	2.04	(1.13)	2.40	1.45	1.91	–
Number of logs	28		50		34	29	14	1

* Stand: altitude 180 m, latitude 38° 18′S, medium Site Density Class (Cown & McConchie 1982).

Silvicultural treatment:	Naturally regenerated on clearfelled forest	1955–56
	Pruned to 2.4 m, thinned to 900 stems/ha	1961–62
	Pruned to 6.1 m (445 stems/ha)	1964–65
	Thinned to 300 stems/ha	1969–70
	40 sample trees felled at age 28	1984

Log length 5.5 m

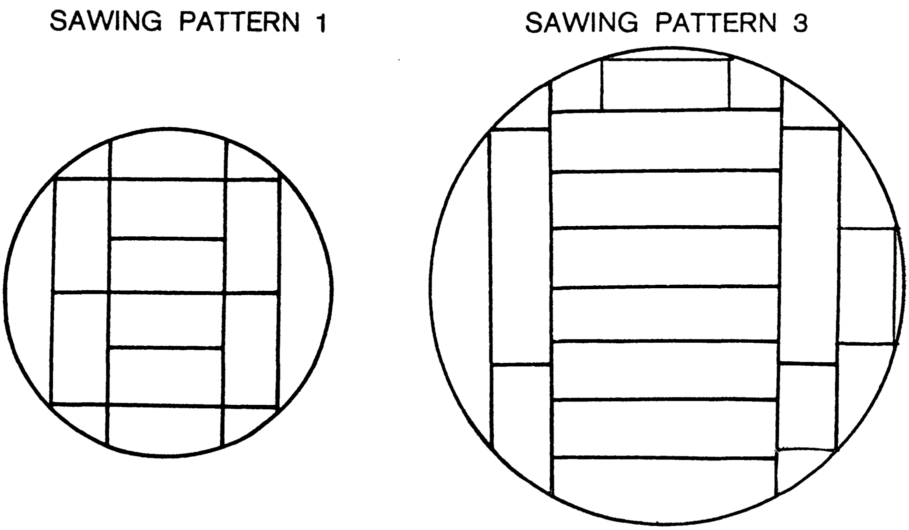

FIG. 1—Sawing patterns (after Whiteside 1982).

Processing

The timber was visually graded in the green condition to Box, No. 2, and No. 1 Framing grades according to the New Zealand standard grading rules (SANZ 1978) by a professional timber grader. After kiln drying to a target moisture content of 16% for the sample, the No. 1 Framing grade was regraded to extract Engineering grade material. This procedure follows normal commercial practices.

The timber was then machined to dry dressed sizes (90 × 45 mm and 180 × 45 mm) and mechanically graded with a Plessey Computermatic Mark IVA machine set to sort Australian stress grades (SAA 1978).

Test Material

There were 340 sticks of 100 × 50-mm and 389 sticks of 200 × 50-mm graded timber. Each of the 100 × 50-mm sticks was cut into as many pieces of 1.8-m length as possible – altogether 888 pieces. The 200 × 50-mm timber was not long enough to cut into discrete test pieces, but a test piece length of 3.3 m was marked from each end. When sufficient length remained undamaged after the first test on a stick, two tests were possible, so that a total of 562 "pieces" were tested. All pieces were regraded visually in the laboratory. Each piece therefore had a mechanical grade (from colour coding), a piece grade (laboratory), and a stick grade (commercial grade of the parent stick). Each piece was randomly marked with an X to denote the top edge. The orientation of the worst defect (whether in compression or tension) and its location (inside or outside load heads) were noted before testing.

Test Methods

Modulus of elasticity as plank

Each piece was tested on the flat over a span of 914 mm by applying a central preload of 222 N at the colour code indicating the lowest mechanical grade. A dial gauge at midspan was set to zero and a further 888-N load applied, with readings taken at 444 N and 888 N. The test was repeated if the second deflection was more than 0.1 mm different from twice the first reading.

The modulus of elasticity as a plank (EP) was computed from

$$EP = \frac{P\ 914^3}{4\ \delta\ b^3 d}$$

where δ was the midspan deflection (mm) for a 888-N load P, d was the width of the piece (mm), and b the thickness (mm).

Bending as a joist

A ramp third-point load was applied, with the X mark uppermost, over a span (L) of 1620 mm for the 100 × 50-mm and 3240 mm for the 200 × 50-mm timber (L/d of 18 : 1) to reach failure in about 3 minutes. The failure load was recorded. Deflection at midspan relative to reaction points was measured using an LVDT which was connected to an X–Y plotter to give a load deflection curve.

Modulus of elasticity as a joist (EJ) was determined from

$$EJ = \frac{23}{108} \frac{W}{\Delta} \frac{L^3}{b\ d^3}$$

where W/Δ was the slope of the load deflection curve up to the elastic limit.

Modulus of rupture (RJ) was computed from

$$RJ = \frac{W_{max}\ L}{b\ d^2}$$

After testing, a block was cut from near the fracture zone to determine moisture content, ring width (RW) (mm), distance from pith (CUT) (mm) to the nearest face, and nominal density (DN) (oven-dry weight/volume at test) (kg/m^3).

A diagram of the projected area of knots in the failure zone was drawn for each piece (*see* Fig. 2). From these diagrams, the knot area ratio (KAR) was calculated as

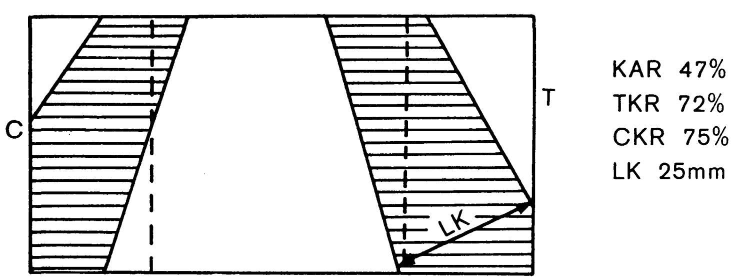

FIG. 2—Sample knot diagram. KAR = knot area ratio; TKR = tension margin knot area ratio; CKR = compression margin knot area ratio; LK = largest knot.

the area of the knots divided by the area of the cross-section and the margin knot area ratios (tension [TKR] and compression [CKR]) calculated as the area of the knots in the margin divided by the area of each margin (1/4 of the total area). The width of the largest knot (LK) in the section was also measured.

RESULTS AND DISCUSSION

Recovery and Grade

Total log volume was 56.5 m^3 and the recovery of 100 × 50-mm and 200 × 50-mm timber was respectively 15% and 37% of this total. About 8% of the volume was cut as 25-mm boards and 75 × 50-mm pieces.

The laboratory grade yields for the 5.4-m sticks are given in Table 2. The laboratory grade of the stick was governed by the laboratory grade of the worst piece in each stick. Lower-grade sticks contained individual pieces of higher grade. From the laboratory grades of each 1.8-m piece of 100 × 50 mm there were 60% No. 1 Framing and better pieces and 24% No. 2 Framing.

Laboratory mechanical grade was determined from the EP of the worst piece for the limits given in Table 3. The commercial grades recorded will be used for a future examination of grading efficiency and its effect on strength.

TABLE 2—Grade yields as percentage of structural material (excluding boards and 75 × 50-mm material)

	100 × 50 mm	200 × 50 mm
Visual grade		
Engineering	4	12
No. 1 Framing	32	12
No. 2 Framing	26	25
Box	38	51
Mechanical grade		
F11	4	–
F8	12	7
F5	36	38
F4	18	39
Reject	30	16

TABLE 3—Limits on EP (GPa) for mechanical grades

Grade	100 × 50 mm	200 × 50 mm
F11	8.83–	11.03–
F8	7.36–9.30	8.02–11.77
F5	5.52–7.68	5.52– 8.41
F4	4.91–5.70	4.20– 5.69
Reject	0.00–5.05	0.00– 4.31

Strength Properties

The statistics of the tests on all pieces are given in Table 4.

Although the ring width of the larger size is about 20% greater than the 100 × 50-mm ring width, the densities are similar. The 200 × 50-mm was milled from the larger logs and therefore has larger ring widths and larger knots. In the larger members there is a greater amount of material containing imperfections subjected to maximum stress in the bending tests. Consequently the lower strength and stiffness of the 200 × 50-mm timber is consistent with a volume or size effect that has long been recognised in design codes.

Comparisons with older material: In a previous study, timber from older trees from the same forest was tested at the grade-determining defect with the worst edge in tension (G. B. Walford unpubl. data). Direct comparison between this older material (estimated 40- to 50-year-old trees) and the current study requires the selection of those pieces in the data tested with worst edge in tension and between load heads. This was done to derive the values in Table 5.

There was a decrease in density and an increase in ring width in the timber from the younger trees. For the 100 × 50-mm timber the stiffness and strength of Engineering (the highest) and No. 2 Framing (the lowest) grades were less for the timber from young trees, but the No. 1 Framing grade was little affected. For the 200 × 50-mm there was a small (less than 8%) reduction in strength, but no change in stiffness.

There was a substantial size effect in both grades for both old and new material in both strength and stiffness: EJ was between 14% and 6% lower for the 200 × 50-mm and the fifth percentile RJ was between 12% and 36% lower.

Comparison with code values: The derived grade stresses are compared in Table 6 with the stresses in the current New Zealand design code (SANZ 1981). The grade stress in bending (F_b') is calculated as 0.45 times the fifth percentile to allow for load duration and safety (Bier 1984). The fifth percentile MOR has been calculated by the method described in ASTM D2915 where the individual values are ranked in ascending order, and assigning them rank values $Ri = i/(n + 1)$ where $i = 1, 2, 3 \ldots$ etc., for the first, second, third, etc., ranked values, and $n =$ the total number. The fifth percentile corresponds to $Ri = 0.05$. The modulus of elasticity (E) is the mean value. The values in Table 5 and Table 6 represent the most pessimistic view of the strength of the framing timber since they exclude pieces tested with worst edge in compression and pieces which failed outside load heads.

There is some strength loss in the higher grade pieces due to lower maturity, but the derived basic working stresses were higher than the design values for the 100 × 50-mm material though lower for the 200 × 50-mm. A 10% lower mean modulus of elasticity of Engineering grade for the young timber is unlikely to cause problems in practice. Larger reductions mean that current code strength values may be too high for both old and new 200 × 50-mm material; however, the effects of random edge testing must be taken into account. Even a 10% increase would elevate the

TABLE 4—Statistics for two sizes of **Pinus radiata** tested in bending

Variable	Symbol	100 × 50 mm			200 × 50 mm		
		Mean value	Standard deviation	Number of pieces	Mean value	Standard deviation	Number of pieces
Nominal density (kg/m^3)	DN	387	41.3	884	386	32.3	556
Ring width (mm)	RW	10.3	2.98	884	12.5	3.57	556
Moisture content (%)	MC	16.8	2.54	884	15.5	1.86	555
Knot area ratio (%)	KAR	28	19	882	32	15	552
Tension margin knot area ratio (%)	TKR	25	31	882	41	31	552
Compression margin knot area ratio (%)	CKR	32	34	882	31	31	552
Largest knot (mm)	LK	23	15	882	38	17	552
Modulus of elasticity as a plank (GPa)	EP	6.78	1.87	883	5.82	1.54	561
Modulus of elasticity as a joist (GPa)	EJ	7.58	2.00	887	6.92	1.82	560
Modulus of rupture as a joist (MPa)	RJ	33.2	13.63	888	24.1	10.96	562

TABLE 5—Comparison of strength data for old and new growth **Pinus radiata** framing grades from Kaingaroa tested with the worst edge in tension (for explanation of abbreviations **see** Table 4)

	No. 2 Framing		No. 1 Framing		Engineering	
	Old	New	Old	New	Old	New
(a) **100 × 50-mm size**						
No. of tests	60	71	85	150	71	52
Mean m.c. (%)	14.9	16.0	15.4	17.1	15.9	17.9
Mean DN (kg/m³)	414	370	426	387	448	408
Mean KAR (%)	43	35	29	23	11	12
Mean TKR (%)	68	52	61	41	23	19
Mean RW (mm)	7.73	11.0	7.21	10.3	6.25	9.2
Mean EP (GPa)	6.67	5.75	7.56	7.20	10.0	8.79
Mean EJ (GPa)	7.64	6.44	7.86	7.77	10.4	9.28
coeff. of var. (%)	27	26	27	22	19	17
Mean RJ (MPa)	23.2	23.3	30.1	31.1	49.2	41.7
coeff.of var. (%)	44	45	39	37	28	26
5% excl. lim. (MPa)	10.8	8.27	15.1	15.3	26.8	23.2
(b) **200 × 50-mm size**						
No.of tests	60	54	113	34	175	51
Mean m.c. (%)	14.8	15.4	15.0	15.8	14.8	16.4
Mean DN (kg/m³)	427	380	421	394	440	401
Mean KAR (%)	40	31	35	18	23	20
Mean TKR (%)	56	54	57	49	33	38
Mean RW (mm)	8.30	12.2	7.33	11.7	6.15	10.5
Mean EP (GPa)	6.72	5.64	6.95	6.43	7.54	7.50
Mean EJ (GPa)	6.74	6.60	7.41	7.19	8.92	8.80
coeff. of var. (%)	25	22	22	17	22	16
Mean RJ (MPa)	21.1	19.5	24.1	23.1	35.8	33.2
coeff. of var. (%)	43	47	40	34	35	37
5% excl. lim. (MPa)	9.47	9.23	12.3	11.4	17.3	16.3

Sources: Old growth — G. B. Walford (unpubl. data)
New growth — this study
100 × 50-mm — Bier & Collins (1984)

N.B.: Old material DN, KAR, TKR, and RW figures include about 10% pieces tested with worst edge in compression.

basic working stresses in Table 6 for both old and new material to well above existing code values for the 100 × 50-mm material. The actual amount of this increase is grade dependent and is between 9% and 32%. This will be demonstrated in a future report.

TABLE 6—New Zealand design code grade stresses compared with derived values

	No. 1 Framing		Engineering	
	E (GPa)	F'_b (MPa)	E (GPa)	F'_b (MPa)
100 × 50-mm size				
Code value	8.0	6.0	10.5	9.4
Old material	7.9	6.8	10.4	12.1
New material	7.8	6.9	9.3	10.4
200 × 50-mm size				
Code value	8.0	6.0	10.0	8.3
Old material	7.4	5.5	8.9	7.8
New material	7.2	5.1	8.8	7.3

Relationships between sawn timber variables: The simple regression equations for both sizes are shown in Table 7 in order of decreasing coefficients of determination (r^2). All were significant at the 1% level.

The elastic moduli EJ and EP provide the most significant contribution to strength prediction but these must be determined by test or machine. Knot area ratio (KAR) and tension margin knot area ratio (TKR) provide the best correlation for the visually determined characteristics (Table 7).

TABLE 7—Simple regression equations for two sizes of timber

100 × 50 mm Equation (881 specimens)	r^2	200 × 50 mm Equation (542 specimens)	r^2
Strength (RJ)			
-4.60 + 4.98 EJ	0.53	-5.86 + 4.31 EJ	0.51
-2.51 + 5.27 EP	0.52	-0.50 + 4.24 EP	0.36
45.4 + 0.444 KAR	0.38	32.8 + 0.210 TKR	0.36
41.0 — 0.244 TKR	0.36	35.9 + 0.366 KAR	0.25
45.7 — 0.550 LK	0.35	37.8 — 1.10 RW	0.13
47.8 — 1.42 RW	0.09	19.4 + 0.070 CUT	0.10
-4.86 + 0.098 DN	0.09	-14.5 + 0.100 DN	0.09
28.6 + 0.069 CUT	0.05	31.5 — 0.193 LK	0.09
Stiffness (EJ)			
1.56 + 0.89 EP	0.69	1.72 + 0.90 EP	0.59
11.2 — 0.352 RW	0.27	10.9 — 0.317 RW	0.39
-1.89 + 0.025 DN	0.26	-5.04 + 0.031 DN	0.30
8.87 — 0.046 KAR	0.20	5.72 + 0.018 CUT	0.22
6.47 + 0.017 CUT	0.14	8.56 — 0.050 KAR	0.17
8.70 — 0.050 LK	0.13	7.56 — 0.15 TKR	0.06
8.16 — 0.018 TKR	0.09	7.53 — 0.015 LK	0.02
DN = 467 — 7.70 RW	0.31	DN = 432 — 3.73 RW	0.17
DN = 355 + 0.482 CUT	0.27	DN = 367 + 0.279 CUT	0.17
RW = 13.1 — 0.041 CUT	0.38	RW = 14.9 — 0.037 CUT	0.24

Stepwise regressions of RJ and EJ on all variables are shown for the 200 × 50-mm timber in Tables 8 and 9. The regressions for 100 × 50-mm timber were given by Bier & Collins (1984). For mechanically graded timber, EJ or EP is the independent variable. Including visual parameters gives a significant improvement in the relationship for RJ (Table 8a) but no marked improvement for EJ (Table 8b). This agrees with the conclusions of Walford (1981) for timber from older trees.

The effect of KAR and largest knot (LK) is more marked in the 100 × 50-mm size (Table 7). Knots of a given size occupy a greater proportion of smaller cross-sections.The grain deviation around these knots anywhere in the cross-section extends further into the margin than in larger sizes. In the larger size, the knots must actually be in the margin to have a marked effect, and TKR is the best indicator of strength, with largest knot being the least significant variable.

The elastic modulus is determined from strains below the proportional limit. It is therefore not as dependent on limiting properties such as minimum strength in the tension margin but, rather, is dependent on wood properties which affect both tension and compression margins equally. There is a greater dependence on ring width, density, and over-all knot area ratio.

TABLE 8a—Stepwise linear regression analysis of RJ on seven variables (including EP); n = 542

Constants	Coefficients			Correlation
(MPa)	EP (GPa)	TKR (%)	RW (%)	(r^2)
-0.50	4.24			0.36
10.83	3.54	-0.176		0.600
15.72	3.23	-0.178	-0.24	0.604

No significant contribution from KAR, DN, LK, CUT.

TABLE 8b—Stepwise linear regression analysis of EJ on seven variables (including EP); n = 542

Constants	Coefficients				Correlation
(GPa)	EP (GPa)	RW (mm)	DN (kg/m³)	TKR (%)	(r^2)
1.72	0.900				0.59
4.53	0.718	-0.140			0.64
0.09	0.644	-0.115	0.0118		0.67
0.60	0.601	-0.121	0.0122	-0.008	0.69

No significant contribution from KAR, LK, CUT.

TABLE 9a—Stepwise linear regression analysis of RJ on six variables (excluding EP); n = 542

Constants (MPa)	Coefficients TKR (%)	RW (%)	KAR (mm)	DN (kg/m³)	LK (mm)	CUT (mm)	Correlation (r^2)
32.82	-0.210						0.36
45.38	-0.205	-1.02					0.47
47.25	-0.172	-0.903	-0.147				0.50
25.01	-0.273	-0.718	-0.140	+0.051			0.52
23.72	-0.173	-0.753	-0.090	+0.058	-0.063		0.52
23.12	-0.170	-0.642	-0.056	0.052	-0.103	0.027	0.53

TABLE 9b—Stepwise linear regression analysis of EJ on six variables (excluding EP); n = 542

Constants (GPa)	Coefficients RW (mm)	DN (kg/m³)	KAR (%)	TKR (%)	CUT (mm)	LK (mm)	Correlation (r^2)
10.90	-0.317						0.38
2.40	-0.244	+0.020					0.48
3.54	-0.218	+0.019	-0.033				0.55
3.61	-0.222	+0.019	-0.026	-0.007			0.57
3.64	-0.202	+0.017	-0.025	-0.007	0.004		0.57
3.31	-0.200	+0.018	-0.012	-0.007	0.006	-0.017	0.58

Grading rule for a high strength grade: For a section with a margin of a proportion β of the depth, it can be shown that the ratio of the moment resisted by the margin (M_m) to the total moment (M_t) is

$$\text{Ratio} \frac{M_m}{M_t} = 6\,\beta\,(1 - 2\,\beta + \frac{4}{3}\,\beta^2\ . \qquad (1)$$

When β is 0.5, the compression and tension margins occupy the full section and the ratio is 1. For margins occupying 25% of the cross-section as in this study, the ratio is 0.88. Tension perpendicular to the grain is wood's weakest property. This stress mode is introduced into structural timber when grain deviates around the knots. Knots or grain deviations occupying the tension margin are therefore expected to have great effect on the strength, whereas defects in the central portion can affect only 12% of the strength of the beam.

It follows that a high strength grade could be obtained by limiting defects in the tension margin. From the observed effects of KAR and TKR (above), such limits would have a greater influence on strength than on stiffness.

Pieces with tension margin knot ratios limited to 50%, 25%, 20%, and 0% (clear margins) were extracted from the No. 1 Framing grade timber (Table 10). The recovery figures are only indicative since they are for grades determined by knot area ratio at the breakpoint. Other defects away from the breakpoint may have exceeded these values. The fifth percentiles in this table were calculated with 75% confidence using a three-parameter Weibull distribution (Pierce 1976).

TABLE 10—Results of selecting from No. 1 Framing grade pieces of a grade of timber with tension margin knot ratios limited

	Limit on margin knot area ratio			
	50%	25%	20%	Clear margin
100 × 50-mm size				
Recovery (% No. 1F)	72	46	40	22
Strength (MPa) (No. 1F = 19.2)				
Timber remaining	16.1	16.8	17.1	18.1
Selected grade	20.9	24.4	25.7	27.3
Elastic modulus (GPa) (No. 1F = 8.17)				
Timber remaining	7.71	7.78	7.78	7.92
Selected grade	8.35	8.62	8.74	9.06
200 × 50-mm size				
Recovery (% No. 1F)	71	39	33	17
Strength (MPa) (No. 1F =13.3)				
Timber remaining	10.3	11.8	12.0	12.7
Selected grade	14.7	17.6	19.0	18.8
Elastic modulus (GPa) (No. 1F = 7.72)				
Timber remaining	7.95	7.70	7.55	7.67
Selected grade	7.63	7.76	8.07	7.97

The selected samples showed substantial increases in fifth percentile strength but only nominal changes in modulus of elasticity. Though clear margins provide maximum increases for the selected grade and minimum decreases for the remaining timber, the 20% ratio is very effective, and has twice the potential recovery of the clear margin grade. It is unlikely that quantities of a clear margin grade exist in timber from upper logs and the 20% (TKR) gives better than 50% improvement in basic working stress over the remaining grade. The 25% (TKR) is also adequate, but a 50% (TKR) does not provide enough margin between stresses for the two grades.

The effects of these rules and their influence on true recovery should be evaluated on timber from other sources, but a significant simplification of the existing grading rules for Engineering grade seems possible, with an attendant improvement in basic working stress.

Effect of log variables on strength properties: Linear regression of the strength and stiffness of individual pieces on the log variables branch index (BI) (cm) and internode length (m) yielded no relationship. By determining the average EJ, EP, RJ, and minimum RJ (MINRJ) for the pieces in each log it was possible to obtain the relationships in Table 11. Stepwise regression of all these average properties on all log variables (BI) (cm), internode index (m), number of internodes, and basic density (BD) (kg/m^3 of the log) reduced to the simple regressions in Table 11 or the equations with two independent variables in Table 12. The internode variables did not enter into any of the relationships.

TABLE 11—Simple regression equations of strength properties for each log for two sawing patterns

Saw pattern 1 100 × 50 mm (28 logs) Equation	r^2	Saw pattern 3 200 × 50 mm (50 logs) Equation	r^2
RJ = 35.4 — 0.87BI	0.04†	RJ = 30.2 — 1.08BI	0.14
RJ = -6.05 + 0.097BD	0.24	RJ = 20.8 + 0.114BD	0.24
MINRJ = 23.9 — 2.24BI	0.27	MINRJ = 17.6 — 1.10BI	0.21
MINRJ = -16.0 + 0.078BD	0.15	MINRJ = 17.3 + 0.074BD	0.14
EJ = 8.00 — 0.178BI	0.08†	EJ = 8.29 — 0.234BI	0.18
EJ = 0.857 + 0.0164BD	0.30	EJ = -3.66 + 0.027BD	0.37
EP = 7.33 — 0.217BI	0.13	EP = 7.03 — 0.216BI	0.24
EP = 0.02 + 0.0165BD	0.36	EP = -0.84 + 0.017BD	0.23

† All except those marked are significant at the 1% level.

TABLE 12—Stepwise linear regressions of strength properties for each log on all log variables

Equation	r^2	t value for slopes
100 × 50-mm size		
MINRJ = -2.1 — 2.05BI + 0.065BD	0.37	-3.0, 2.06
200 × 50-mm size		
RJ = 10.9 + 0.103BD — 0.89BI	0.33	3.7, -2.6
EJ = -1.72 + 0.025BD — 0.19BI	0.48	5.3, -3.2
MINRJ = 7.19 — 0.98BI + 0.062BD	0.30	-3.3, 2.6
EP = 1.11 — 0.189BI + 0.0148BD	0.40	-3.8, 3.6

Branch index has a greater influence on the properties of the larger size. The larger size has a greater chance of being cut from the branches which determine the index since for a given log it forms a greater part of the volume.

Average properties are more highly correlated with BD than with BI, but the minimum RJ is more dependent on the branch index. Figure 3 shows the relationships for EJ on BD and Fig. 4 shows the relationship MINRJ on BI for both sizes. The

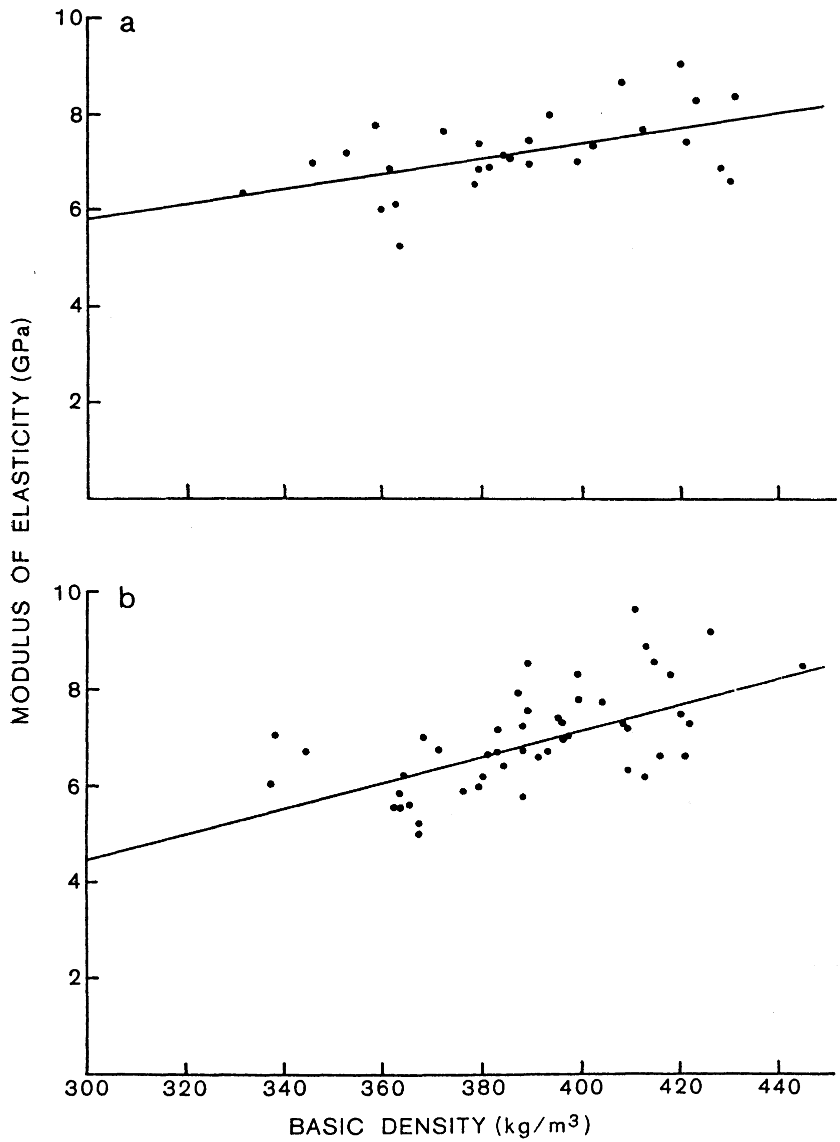

FIG. 3—Mean modulus of elasticity as a joist (EJ) v. basic density of log (BD) for (a) 100 × 50-mm and (b) 200 × 50-mm material.

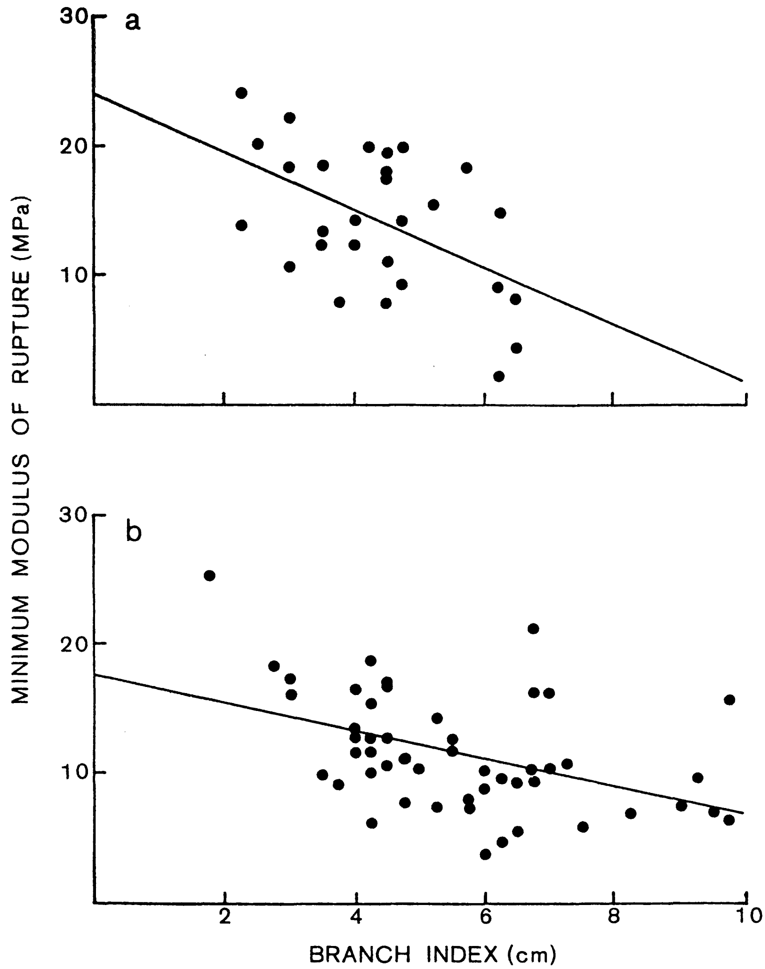

FIG. 4—Minimum modulus of rupture (MINRJ) v. branch index (BI) for (a) 100 × 50-mm and (b) 200 × 50-mm material.

logs with the lowest branch index have the highest minimum strength properties. High-quality structural material is therefore best cut from these logs. The best prediction of minimum strength is obtained with both branch index and basic density.

To achieve desirable strength or stiffness levels in structural timber, it is feasible to select logs with a small branch index from a low-density site to obtain material of the required properties. For example, from Table 12:

$$EJ = -1.72 + 0.025BD - 0.19BI \quad (2)$$

For No. 1 Framing grade and Engineering grade, the current code moduli of elasticity in-grade are 8.0 and 10.0 respectively (Table 6).

Cown & McConchie (1982) showed average sawlog densities for 25-year-old trees to be 460 kg/m,^{3} 415 kg/m^3, and 390 kg/m^3 in the high-, medium-, and low-density classes. Substituting these values into Equation (2) it is calculated that a high-density site requires logs of a branch index of 9.4 or less, medium site of 3.45 or less, and a low-density site requires clear logs to obtain the desired code moduli No. 1 Framing grade.

For Engineering grade, none of the site classes will yield an average EJ of the desired level; only logs with a basic density in excess of 490 kg/m^3 will yield such timber, assuming the regression can be extrapolated. This is mirrored in Table 6 which shows that EJ values for Engineering grade are below the code requirements for both old and new material.

The relationships above provide the tools with which to evaluate the effect of log basic density and branch index on the design stresses of sawn timber. Further work is required to fully assess effects at the fifth percentile level, since the branch index has a greater effect on minimum strength than on mean strengths.

CONCLUSIONS

The strength of No. 1 Framing grade timber from 28-year-old trees was similar to that of timber from 40- to 50-year-old trees. There was a minimal reduction in the strength of Engineering grade in the young material.

Basic working stresses (for bending strength) derived for timber tested with the worst defect in tension were above code values for 100 × 50-mm material and below for 200 × 50-mm material. A simple grading rule was derived which yields material with a basic working stress 50% higher than No. 1 Framing grade timber.

The moduli of elasticity of both old and new material were about 10% below code values.

Relationships between strength properties and log variables have been established. Currently prescribed moduli of elasticity for Engineering grade timber cannot be obtained from average sawlogs of any age in even the high-density class.

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