STRENGTH AND STIFFNESS OF AUSTRALIAN-GROWN STRESS-GRADED PINUS RADIATA WITH CROSS-SECTIONS OF 35 x 150 mm AND 35 x 200 mm

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ABSTRACT

Australian-grown **Pinus radiata** D. Don (radiata pine) timber, 35 × 150 mm and 35 × 200 mm in cross-section, was mechanically and visually graded, then subjected to mechanical testing to determine modulus of elasticity and modulus of rupture. Results were compared to previous ones for radiata pine 35 × 120 mm and 35 × 90 mm in cross-section, and to normally accepted in-grade strength and stiffness requirements.

Timber stiffness met the accepted requirements for all the visual and mechanical grades. Under the 1973 Australian visual grading rules the material had comparable strength ratings to that of mechanically graded timber. If, however, the current visual rules had been used the timber strength of the F8 and F7 grades would have been inadequate. A return to the 1973 rules appears warranted. For machine grading, the lower 2.5 percentile of modulus of rupture was, for most grades, slightly below the normally accepted limits and a minor change to the current grading programmes appears to be warranted for the larger cross-sections. Mean modulus of rupture, for all machine grades, was lower than found previously for radiata pine of smaller cross-sectional width.

INTRODUCTION

Little information is available on the stiffness and strength of Australian-grown radiata pine with cross-sections of 35 × 150 mm and 35 × 200 mm. Most of our knowledge of these properties is from quality-control testing and is limited to radiata pine less than 150 mm wide because of the relatively small volume produced in the larger sizes. (Quality-control samples are taken from graded stock by operators of stress-grading machines and then tested for stiffness and strength. The results are accumulated on behalf of the operators by the Forestry Commission of New South Wales.) The aim of the present study was to evaluate the stiffness and strength of visually and mechanically graded radiata pine of large cross-section for comparison with the more commonly produced sizes. Machine-grading programmes in current use (Forestry Commission of N.S.W. 1980) were designed using results from tests on cross-sections less than 150 mm in width and it was considered desirable to investigate the suitability of the programmes for the larger cross-sections as well as to gain some knowledge of the strength and stiffness of visually graded timber.

MATERIALS AND METHODS

The timber used in the study was the bulk of the scantling sawn to 35 × 150 mm (159 pieces) and 35 × 200 mm (197 pieces) during a grade-recovery study (Grant 1980). The sawing pattern aimed at the complete conversion of each log to 35-mm thickness scantling. Some 19-mm thick boards were recovered from the slabs. The trees from which the timber was sawn were from Uriarra Forest in the Australian Capital Territory; Cpt 79, 104, and 105 were 36–38 years old at sampling and had been thinned, trees from Cpt 139 were 30 years old and from an unthinned spacing trial. The timber was kiln dried using conventional commercial practice and then dressed to size. After some months each sample was weighed so that the air-dry density could be calculated. Random moisture-content checks were made on the timber with a resistance-type moisture meter during the weighing – average moisture content was approximately 12%.

Timber was mechanically graded using the existing commercial grading programmes (Forestry Commission of N.S.W. 1980). The modulus of elasticity ranges have been specified by the Forestry Commission of N.S.W. for the various stress grades, and a specially designed recording system (Grant 1977) was used during grading to determine the deflection and location of the lowest stiffness zone on each sample. This information, plus visual examination of each piece, enabled the lowest stiffness section to be identified and cut from the full length (4.95 m) for mechanical testing.

Visual grading was to AS1490-1973 (SAA 1973), not the amended version of 1977.

Modulus of elasticity was measured on the flat (ME_f) over a 914-mm span, with the load applied at the mid-point of the span and the deflection measured at the same point using a dial gauge placed under the sample. Each sample was positioned so that the lowest-stiffness/likely-weakest section was situated over the mid-point of the span. The load used for this test was equivalent to that applied during machine grading. This is the method of ME evaluation described in AS1749 (SAA 1978).

Modulus of elasticity was also evaluated when the samples were tested on edge (ME_e) during the modulus of rupture (MR) test. Modulus of rupture was determined in general accordance with the method described in AS1749 (SAA 1978), i.e., using four-point bending and with the sample loaded in such a way that its expected load-carrying capacity would be a minimum. The distances between the base supports and between the top loading points were 1860 mm and 460 mm respectively for the 35 × 150-mm size and 2470 mm and 570 mm for the 35 × 200-mm size. Forces were measured using load cells at the supports, and beam deflection was measured using a digital dial gauge positioned over the beam at the mid-point of the span. The force/displacement relationship was plotted using an XY recorder and the force and displacement readings were printed out at regular intervals during each test. ME_e was then determined using the slope between the two points from the printed data which corresponded to the extremes of the most linear portion of the plotted line. No allowance was made for shear deflections in the calculations of ME_e.

RESULTS AND DISCUSSION

Modulus of elasticity and modulus of rupture data were analysed firstly for each size group and then for the two groups pooled. Pooling of the data was considered justified because there was generally no statistically significant difference between the mean MR and mean ME values for either size group for any one grade.

Two methods were used for the estimation of the 2.5 percentiles – (i) the "Pearson" method as described by Johnson *et al.* (1963) using four parameters, and (ii) the "ordered array" method which follows closely the interpolation method of ASTM D2915-74 (ASTM 1974), Section 5.4.4, except that the 2.5 percentile was determined, not the fifth percentile. It is the opinion of the authors that the Pearson method is superior to the ordered array method in the determination of the 2.5 percentile because of its capacity to accommodate most, commonly encountered, frequency distributions and to "smooth out" the occasional unusual value when dealing with relatively small data sets. Neither method is, however, foolproof and consideration must be given to sample size and the influence of unusual values on the final result.

It should be noted that the lower percentile values have not been modified to provide a margin of safety against the variability associated with the estimate of those percentiles. For the sample sizes considered here the recommended reduction (R. H. Leicester unpubl. data) would vary from approximately 15% to 10% for sample sizes of 65 to 200 respectively. The reduced, or characteristic, value as it is sometimes called would lead to an estimate, with 80% confidence, of the true characteristic value. The kurtosis values were not modified by subtracting 3 from the calculated value, i.e., the kurtosis value for a normal distribution would be 3.

Modulus of Rupture

Results of the analysis of MR values for samples with various visual grades are given in Table 1 for the individual cross-sections and in Table 2 for the pooled data. Equivalent results for the theoretical machine grades are given in Tables 3 and 4. The theoretical machine grades are based on the ME_f ranges specified by commercial grading programmes (Forestry Commission of N.S.W. 1980).

TABLE 1—MR values (MPa) for samples with particular visual grades

Grade	N	Mean	s.d.	Skewness	Kurtosis
(a) Size group 35 × 150 mm					
F11	12	56.86	8.10	- 1.10	3.77
F8	37	42.64	13.22	0.31	2.39
F7	24	37.76	10.33	0.06	2.16
F5	29	27.56	6.89	0.61	2.59
F5HI	21	36.41	11.31	1.73	5.82
Reject	27	21.64	9.93	2.25	9.60
(b) Size group 35 × 200 mm					
F11	17	49.94	10.17	0.00	1.88
F8	48	39.66	11.48	0.09	2.95
F7	41	33.61	10.32	- 0.13	2.32
F5	44	28.66	10.33	0.45	3.00
F5HI	26	31.55	8.38	0.35	2.20
Reject	17	19.80	9.69	1.27	4.55

TABLE 2—MR values (MPa) for samples with particular visual grades (pooled data)

Grade	N	Mean	s.d.	Skewness	Kurtosis	Lower 2.5 percentile	
						Pearson	Ordered array
F11	29	52.80	9.84	-0.42	2.06	—	—
F8	85	40.96	12.28	0.25	2.76	18.9	18.1
F7	65	35.14	10.44	-0.06	2.38	15.1	14.5
F5	73	28.23	9.08	0.56	3.36	13.1	10.7
F5HI	47	33.72	9.99	1.40	6.07	21.0	17.3
Reject	44	20.93	9.77	1.89	7.95	—	—

TABLE 3—MR values (MPa) for samples with various ME_f ranges

ME_f range (GPa)	Equiv. grade	N	Mean	s.d.	Skewness	Kurtosis
(a) Size group 35 × 150 mm						
>11.58	F11	29	52.56	11.17	-0.31	2.38
8.28 to 12.20	F8	101	35.42	12.18	0.76	3.36
5.52 to 8.59	F5	34	22.98	7.31	0.82	4.58
4.14 to 5.65	F4	2	—	—	—	—
= <4.21	Reject	0	—	—	—	—
7.73 to 9.27*	F7*	30	27.13	7.79	0.58	2.38
5.52 to 7.99*	F5*	23	22.80	8.20	0.87	4.30
(b) Size group 35 × 200 mm						
>11.58	F11	47	44.39	10.97	0.21	2.76
8.28 to 12.20	F8	126	34.78	11.16	0.19	2.21
5.52 to 8.59	F5	47	26.10	10.02	0.21	2.34
4.14 to 5.65	F4	2	—	—	—	—
= <4.21	Reject	4	—	—	—	—
7.73 to 9.27*	F7*	51	28.20	9.79	0.08	2.28
5.52 to 7.99*	F5*	27	22.51	8.24	0.17	2.58

* ME_f ranges as proposed by D. J. Grant (unpubl. data) for sizes up to 35 × 120 mm.

TABLE 4—MR values (MPa) for samples with particular ME_f ranges (GPa) (pooled data)

ME_f range	Equivalent grade	N	Mean	s.d.	Skewness	Kurtosis	Lower 2.5 percentile	
							Pearson	Ordered array
>11.58	F11	80	48.05	11.66	-0.05	2.35	25.9	25.7
8.28 to 12.20	F8	227	35.06	11.60	0.49	2.88	16.2	16.0
7.73 to 9.27	F7	81	27.81	9.07	0.23	2.37	12.2	11.6
5.52 to 8.59	F5	81	24.79	9.07	0.48	2.88	9.9	8.5
4.14 to 5.65	F4	4	—	—	—	—	—	—
= <4.22	Reject	4	—	—	—	—	—	—

The MR values for samples with ME_f within various 2-GPa ranges were analysed so they could be compared with a previous analysis of data from quality-control samples taken from machine-grading operations, with cross-section size of 35 × 120 and 35 × 90 (D. J. Grant unpubl. data). Results are given in Table 5.

TABLE 5—MR values (MPa) for samples with various ME_f (GPa) ranges for the pooled data, and for 35 × 120-mm and 35 × 90-mm cross-section size samples from a previous study*

ME_f range	35 × 150 mm & 35 × 200 mm cross-section				35 × 120 mm cross-section				35 × 90 mm cross-section			
	N	Mean	2.5 percentile		N	Mean	2.5 percentile		N	Mean	2.5 percentile	
			Pearson	Ordered array			Pearson	Ordered array			Pearson	Ordered array
4–6	5	—	—	—	145	19.31	7.0	7.0	846	21.57	7.7	7.4
5–7	24	—	—	—	160	21.53	8.8	7.1	860	24.27	8.9	9.1
6–8	49	22.74	8.5	8.0	176	25.50	11.7	11.5	800	26.96	10.7	10.4
7–9	84	26.97	12.5	11.5	180	27.84	13.7	12.4	772	30.83	13.9	13.5
8–10	122	30.17	14.2	13.7	141	32.44	15.0	14.3	683	35.74	15.4	15.1
9–11	128	33.72	15.4	15.6	107	38.77	16.4	17.8	529	40.88	16.4	16.8
10–12	113	37.88	19.0	17.5	89	46.33	18.7	19.5	408	46.07	20.3	19.7
11–13	89	43.87	22.8	21.4	63	50.94	22.2	20.3	289	51.49	25.8	26.3

* D. J. Grant unpubl. data of Forestry Commission of N.S.W.

The visual grading statistics (Table 2) produced the working stress ratios (WSR) (Table 6) when the 2.5 percentiles estimated from Pearson curves were used; WSR = 2.5 percentile divided by the basic working stress in bending as specified in the Standards Association of Australia Timber Engineering Code (SAA 1975).

TABLE 6—Working stress ratios for visually (V) and mechanically (M) graded timber; visual grading was conducted using AS1490-1973 (SAA 1973)

Grade	N	2.5 percentile (MPa)	Basic working stress (MPa)	Working stress ratio
V F11	29	*	11.0	-
V F8	85	18.9	8.6	2.2
V F7	65	15.1	6.9	2.2
V F5	73	13.1	5.5	2.4
V F5HI	47	21.0	5.5	3.8
M F11	80	25.9	11.0	2.4
M F8	227	16.2	8.6	1.9
M F7	81	12.2	6.9	1.8
M F5	81	9.9	5.5	1.8
M F4	4	*	4.3	-

* Sample size too small

The higher strength of the F5HI (heart-in) visual grade than the F5 visual grade (Table 2) is probably because of the presence of smaller knots in the heart-in material. This has been observed in laboratory work for many years and was mentioned previously by Anton (1979).

The machine-grading statistics (Table 4) produced the WSR given in Table 6 when the 2.5 percentiles estimated from Pearson curves were used. The WSR normally applied in Australia is 2.22 to account for a long-term loading factor of 9/16 and an uncertainty factor of 4/5. Visual grading produced WSR equal to or greater than 2.2 for all grades but it should be noted that the visual grading rules applied were the original ones included in AS1490 (SAA 1973). In a report on a re-evaluation of the mechanical properties of Australian-grown radiata pine (Ditchburne *et al.* 1975) it was concluded that radiata pine should be reclassified into strength group SD6 (it was in a lower group, SD7).

> "As a result of reclassifying seasoned radiata pine into strength group SD6, the 75% (select engineering), 60% (standard engineering), 48% (select building) and 38% (standard building) grades as presently defined in AS1490 would become F14, F11, F8 and F7 stress grades respectively and attract the basic working stresses for these grades as given in AS1720."

As a result of this work AS1490 was changed so that F5 became F7, F7 became F8, and a new F5 was introduced. Neither F14 nor F11 were included in the new version – possibly because of the limited demand for those grades.

The calculated working stress ratios using the revised grading rules and including the F11 grade for the material in this study are given in Table 7. These WSR would accommodate the long-term loading factor but not the 4/5 uncertainty factor. A reversion to the 1973 grading rules appears warranted for the cross-sections covered in this work.

TABLE 7—Working stress ratios for timber visually graded using the revised grading rules

Grade	N	2.5 percentile (MPa)	Basic working stress (MPa)	Working stress ratio
F11	85	18.9	11.0	1.7
F8	65	15.1	8.6	1.8
F7	73	13.1	6.9	1.9

Machine grading produced WSR below 2.22 for the F8, F7, and F5 grades. Generally the WSR was 1.8 to 1.9, a ratio which would accommodate the long-term loading factor but not the uncertainty factor.

In an extensive analysis of data accumulated during the testing of a large number of quality-control samples of various cross-sections taken from machine-grading operations in Australia, WSR around 2.0 were found to be fairly common – except for the 35 × 70-mm size which had generally lower WSR, and for the 45 × 90-mm which had higher WSR (D. J. Grant unpubl. data). This work led to the revision of machine-grading programmes (Forestry Commission of N.S.W. 1980). When the 2.5 percentiles from the present study are compared to those of the earlier one for the 35 × 120-mm and 35 × 90-mm sizes they appear to be slightly lower for all groups (Table 5).

It was suggested by Anton (1981) that, for machine grading, working stress ratios of 2.0 be used for F11, F8, and F7 grades and a factor of 1.8 be used for F5 and F4. The results from this study indicate that a modification is necessary to the current programme used to machine-grade widths above 120 mm.

Mean values given in Table 5 are generally lower for the wider cross-section group than for the 35 × 120-mm and 35 × 90-mm groups, especially as ME_f increases. This, however, is not necessarily owing to depth alone but could possibly be caused by differences between the two groups in density and the type and size of defects. The effect of depth of beam on strength is discussed below.

Modulus of Elasticity

The ME_e values of samples with the various visual and mechanical grades were analysed and the results are given in Tables 8 to 10. Also included in Tables 9 and 10 are the modulus of elasticity design values from the Australian Timber Engineering Design Code (SAA 1975).

The average ME_e for all visual and mechanical grades in this study exceeded the design values, especially considering that "in service" loading conditions would generally be uniformly distributed and over a wider span than the test span used here. The difference between the upper values of the ME_f ranges for the two F5 grades shown in Table 10 is due to the fact that the next highest grade in the YELLOW programme is

TABLE 8—ME_e values (GPa) for samples with particular visual grades

Grade	N	Mean	s.d.	Skewness	Kurtosis
(a) Cross-section 35 × 150 mm					
F11	12	13.29	1.58	- 1.11	3.38
F8	37	11.86	1.89	0.15	2.17
F7	24	11.34	1.47	- 0.41	3.36
F5	29	9.77	1.45	- 0.51	4.11
F5HI	21	10.63	1.51	0.90	3.40
Reject	27	8.93	2.07	0.79	3.98
(b) Cross-section 35 × 200 mm					
F11	17	13.35	1.56	0.03	2.47
F8	48	12.04	1.47	0.04	3.22
F7	41	11.15	1.43	- 0.61	3.04
F5	44	10.17	1.72	- 0.58	4.18
F5HI	26	10.00	1.48	0.11	2.84
Reject	17	9.06	1.54	0.60	2.29

TABLE 9—ME_e (GPa) for samples with various visual grades (pooled data)

Grade	AS1720 design value	N	Mean	s.d.	Skewness	Kurtosis	Min.	Max.
F11	10.50	29	13.32	1.54	- 0.44	2.89	9.78	16.47
F8	9.10	85	11.96	1.66	0.07	2.65	8.30	16.08
F7	7.90	65	11.22	1.44	- 0.53	3.19	7.07	14.30
F5	6.90	73	10.01	1.62	- 0.49	4.15	5.18	13.44
F5HI	6.90	47	10.28	1.51	0.45	3.40	7.29	14.40
Reject	–	44	8.98	1.87	0.74	3.93	5.14	14.80

TABLE 10—ME_e (GPa) for samples within various ME_f ranges (pooled data)

ME_f range	Equiv. grade	AS1720 design value	N	Mean	s.d.	Skewness	Kurtosis	Min.	Max.
>11.58	F11*	10.50	76	13.26	1.11	0.11	2.97	10.47	16.08
8.28 to 12.20	F8*	9.10	227	11.01	1.42	- 0.10	3.34	5.67	15.04
5.52 to 8.59	F5*	6.90	81	8.85	1.35	- 0.51	3.05	5.14	11.47
4.14 to 5.65	F4*	6.10	4	–	–	–	–	–	–
= <4.22	Reject	–	4	–	–	–	–	–	–
7.73 to 9.27	F7†	7.90	81	9.55	1.07	- 0.53	4.23	5.67	11.95
5.52 to 7.99	F5†	6.90	50	8.50	1.36	- 0.24	2.88	5.14	11.30

* ME_f ranges specified in a grading programme called YELLOW (Forestry Commission of N.S.W. 1980)

† ME_f ranges specified in a grading programme called YELLOW F7 (Forestry Commission of N.S.W. 1980)

F8 and the next highest grade in the YELLOW F7 programme is F7. The stiffness of visually stress-graded timber is highly dependent on wood density and, because of the high variability of density in radiata pine wood due to geographical location, tree age, and position in tree, the air-dry density of the samples in each visual grade were analysed so that results could be compared with previous data on radiata pine scantling.

TABLE 11—Results of an analysis of air-dry density (kg/m^3) for samples with various visual grades (pooled data) for the current project and for previous work on radiata pine scantling of smaller cross-section sourced from most Australian States

Grade	Current project			Previous project		
	N	Mean	s.d.	N	Mean	s.d.
F11	29	542	49.9	*		
F8	87	522	40.5	*		
F7	62	519	37.1	278	515	60.9
F5	73	504	36.3	105	511	56.6
F5HI	49	495	35.9	162	444	48.8

* These two grades were not separated in the earlier work

There was no significant difference in mean density for either the F7 or F5 grades but there was a significant difference in mean density for the F5HI grade, with the timber in the current study having the higher density (Table 11). This difference may be due to the larger cross-sections used in this study, as these cross-sections would probably contain more of the older, more dense wood than would the smaller cross-sections of the previous study.

These results indicate that the average density of the timber sampled in this study was reasonably representative of average timber density in Australia generally.

Discussion

The effect of beam depth on the bending strength of timber has been studied by research workers for many years. Most work, however, has involved the testing of clear timber or timber with small defects. Little has been done on the effect of beam depth on strength for timber with the relatively large defects which are often present in timber from fast-grown trees.

Bohannan (1966) presented an analysis based on the Weibull (1939) "weakest link theory", and also a relationship between "strength ratio" and beam depth developed by Dawley & Youngquist in 1947 (published by Freas & Selbo 1954) using beams with depths up to 400 mm. This relationship predicts that there would be a 5% and 10% reduction in bending strength for 150-mm and 200-mm-deep beams, respectively, from the strength of a 100-mm-deep beam.

Curry & Tory (1976) stated that "tests have shown that the MR of graded timber (as opposed to clear timber) also exhibits a reduction when plotted against increased section depth". They also gave the formula for the reduction factor used in the British Standard Code of Practice (B.S.A. 1971). This they stated "is recommended for application to depths exceeding 300 mm (but) it has been shown to apply equally to shallower sections (Curry & Covington 1969)". This formula gives reductions of 6% and 10%

for 150-mm and 200-mm-deep beams, respectively, from the strength of a 100-mm-deep beam. Fewell & Curry (1983) summarised an examination of the effect of beam depth on the bending strength of timber using data from structural size tests carried out in the United Kingdom and Canada. The preferred depth effect equation presented in that paper gave reductions of 15% and 24% for 150-mm and 200-mm-deep beams, respectively, from the strength of a 100-mm-deep beam. The Australian Timber Engineering Design Code (SAA 1975) applies a reduction factor for beams of depth greater than 300 mm.

In an unpublished report, G. B. Walford observed that "basic working stresses for radiata pine in bending are from 14% to 34% less in 50 × 200-mm size than in the 50 × 100-mm size". D. J. Grant (unpubl. data), however, found that 45 × 90-mm cross-section radiata pine showed a higher strength for particular stiffness ranges than did any other cross-section up to 35 × 120 mm which was the widest size tested.

CONCLUSIONS

There is a small difference between working stress ratios for machine-graded radiata pine in the 35 × 150-mm and 35 × 200-mm sizes and for those achieved by machine grading the 35 × 120-mm size. If the current machine-grading programmes were used for the grading of the larger sizes, then WSR slightly below those currently achieved for the smaller sizes would be expected. A minor change to the current grading programmes appears to be warranted for widths of 150 mm and 200 mm.

The 35 × 150-mm and 35 × 200-mm material had a lower mean modulus of rupture than the 35 × 120-mm size, especially in the higher machine grades, and this could be a result of the 5–10% decrease expected because of the size effect.

Visual grading under laboratory conditions to the old AS1490-1973 rules achieved working stress ratios comparable to, and if anything higher than, those achieved by machine grading. Ratios significantly less than these, however, would be produced if the material had been graded to the current AS1490 rules. A reversion to the 1973 rules is therefore warranted.

Mean modulus of elasticity on edge for the various mechanical and visual grades exceeded the design values given in the Timber Engineering Design Code (SAA 1975).

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