EFFECT of TEST SPAN on the APPARENT MODULUS of ELASTICITY of RADIATA PINE TIMBER in SCANTLING SIZES

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FORESTRY COMMISSION OF N.S.W.
RESEARCH NOTE No. 39
Sydney, 1979

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The Forestry Commission of New South Wales holds patent rights for **MICROSTRESS** and **COMPUTERMATIC** Timber Stress Grading Machines which have been patented under the names of "Booth and Anton" in the following countries:

UNITED STATES	Patent No. 338851
AUSTRALIA	285255
NEW ZEALAND	140933
GREAT BRITAIN	11044486
SOUTH AFRICA	65 / 1266
CANADA	793545

National Library of Australia Card File
ISBN 0 7240 4755 7
ISSN 0085-3984

ABSTRACT

Strength (joist) and stiffness (plank) tests on radiata pine timber of various cross sections indicate that as the stiffness test span is reduced from 900 mm to 600 mm the average apparent modulus of elasticity decreases by 12%. The strength grade breakdown using the method described in the text resulted in 28% of the material graded as F8 and better when using the 900 mm span and 37% when using 600 mm.

The percentage difference in the two apparent ME values is shown to be an indicator of strength and when used in conjunction with the ME value it is suggested that it could provide a refinement to the present system of mechanical grading which relies on the ME value alone.

INTRODUCTION

Timber stress grading using automatic equipment is now an accepted practice in most of the developed countries (Refs. 1, 2, 3, 4, 5, 6, 8, 10, 11, 13, 14). The majority of grading machines in use at the present time measure timber stiffness and an estimate of the minimum probable strength of each piece is made by using the high correlation that exists between the timber stiffness and its strength. The Computermatic timber grader, developed by the Forestry Commission of New South Wales, is the most common machine in use and it measures the timber stiffness over a three point loading span of 914 mm.

Modulus of elasticity values for timber containing defects depend to a certain extent upon the span over which the measurements are taken and this is one of the reasons the term apparent modulus of elasticity (ME) is used. An interesting analysis of the effect of defects on stiffness can be found in Orosz (1969).

This project was designed to provide a deeper knowledge of the effect of span length on the stiffness. This information was also used to evaluate whether or not a span significantly smaller than 914 mm would provide a more efficient discrimination of stress grades in radiata pine. This work was carried out on a universal testing machine under laboratory conditions. Practical considerations may not allow the use of very small spans in a machine like the Computermatic because of deflection resolution problems associated with the machine design.

TIMBER SAMPLING

The timber used in the study was supplied to the Forestry Commission as quality control samples by machine grader operators in the following states:

N.S.W. and A.C.T.	— 15% of total number of samples
Victoria	— 45% of total number of samples
South Australia	— 6% of total number of samples
Tasmania	— 34% of total number of samples

The sampling method used is described in Australian Standard AS 1749-1978 "Rules for Mechanical Stress Grading of Timber" and is based on the selection of a sample from the weakest zone of each length of timber chosen for sampling.

Three hundred and thirty seven samples were used in the study. Five sizes were represented and their dimensions in mm are listed below:

35 x 70 — 12% of total number of samples

45 x 70 — 10% of total number of samples

35 x 90 — 47% of total number of samples

45 x 90 — 14% of total number of samples

35 x 120 — 17% of total number of samples

The mean moisture content (electric resistance moisture meter) of all the samples was 12% with a standard deviation of 2.2 There was no significant difference between the mean moisture content values of any of the sizes.

TEST METHOD

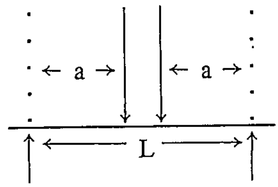
The spans chosen for this study were 600 mm and 900 mm, the latter being almost identical to the present span of 914 mm used in the Computermatic.

The apparent modulus of elasticity values were determined for each sample from deflection measurements taken at 6.5 MPa extreme fibre stress for all sizes over both spans. The samples were simply supported with the deflection measurements taken using a dial gauge accurate to 0.01 mm located at the centre of the span. Flat plates were used on the outer reaction points to prevent indentation of the timber. All samples were tested with the worst defect located at the middle of the span and with the load applied at the same point for each test span. No allowance was made in the calculations for deflection due to shear.

Samples were broken as joists in 4 point bending with the worst looking edge in tension. The spans used during the breaking tests for the various sizes are shown in Table 1.

TABLE 1: Spans used for MR Tests

Sample width mm	L mm	a mm
70	1000	350
90	1300	500
120	1580	600



The methods of determination of ME and Modulus of Rupture (MR) follow very closely the methods described in Appendix A of AS.1749-1978 (1978) which follow the Wood Technology and Forest Research Division methods of test described in Anton (1967).

RESULTS

1. Effect of span on apparent Modulus of Elasticity

The ME decreased for all samples as the span was changed from 900 to 600 mm. The mean value of ME over 600 mm (ME_{600}) for the total population was 12% less than the corresponding value of ME over 900 mm (ME_{900}). Sample dimension did not have very much effect on this mean difference as can be seen from Table 2. This is probably because the ME is measured on the flat face and the thickness is almost constant for all sizes. The sample width does not have much effect on the ME determination.

TABLE 2: Comparison of the mean ME values for the two spans

Sample dimensions (mm x mm)	N	ME_{900}		ME_{600}		$\frac{ME_{900} - ME_{600}}{ME_{900}}$ %
		$\bar{x}$ (GPa)	S.D. (GPa)	$\bar{x}$ (GPa)	S.D. (GPa)	
35 x 70	39	8.78	2.94	7.78	2.82	11
45 x 70	35	8.28	2.61	7.27	2.45	12
35 x 90	160	8.22	2.43	7.22	2.24	12
45 x 90	47	8.41	2.21	7.32	2.01	13
35 x 120	56	7.92	2.20	6.89	2.05	13
Total population	337	8.26	2.45	7.25	2.28	12

2. Effect of span on the correlation between ME and MR

A linear regression analysis was carried out between MR and ME_{900} and between MR and ME_{600} results for the individual sizes and for the total population. The results from this analysis are shown in Table 3.

The regressions of MR on ME_{900} and MR on ME_{600} did not have significantly different slopes for any timber size class but they all had significantly different intercepts.

The regressions for MR on ME_{900} were not significantly different for any of the sizes. This was also true for the regressions of MR on ME_{600}. This indicates that the data can be pooled to obtain one equation for each span.

There was no significant difference in the correlation coefficients for each size class or the total population when the span was decreased from 900 to 600 mm. The correlation between ME_{600} and MR and ME_{900} and MR are high enough to permit either ME_{600} or ME_{900} to be used as an estimator of MR. All Correlation coefficients are significant at the 1% level.

TABLE 3: Comparison between the linear regression and correlation coefficients for the various sizes and over the two spans. (All correlations were significant at the 1% level).

Sample dimensions (mm x mm)	N	MR Vs ME_{900}			MR Vs ME_{600}		
		r	Slope	Constant	r	Slope	Constant
35 x 70	39	0.80	4.57	- 8.14	0.81	4.82	- 5.55
45 x 70	35	0.86	6.07	-17.96	0.87	6.47	-14.74
35 x 90	160	0.68	4.41	- 5.42	0.70	4.90	- 4.61
45 x 90	47	0.72	4.66	- 8.60	0.73	5.17	- 7.20
35 x 120	56	0.75	4.13	- 3.62	0.75	4.47	- 1.68
Total population	337	0.74	4.60	- 7.28	0.74	5.03	- 5.65

3. Minimum expected MR values of samples with ME values within a particular ME range

The MR values of samples which had ME values within particular ME ranges were analysed in order to find the mean and lower 2.5th percentile. The lower 2.5th percentile is used as the basis for the estimation of working stresses in bending for mechanically graded timber, (Anton 1977). The method used for the determination of the 2.5th percentile (or the 1/40 lowest probable value) was that of Johnson, Nixon and Amos (1963) called the Pearson method and is described in Appendix A.

The ranges chosen for ME are close to those used in Australian grading programs for softwood. Tables 4 and 5 show the relevant statistics of the various MR populations.

TABLE 4: Statistics of modulus of rupture values for samples with apparent modulus of elasticity measured over a 900 mm span within the stated ranges

ME_{900} range (GPa)	Modulus of rupture N	$\bar{x}$ MR mean (MPa)	S.D. (MPa)	$\sqrt{b_1}$	b_2	Pearson min. value ($MR_{1/40}$) (MPa)
4.5 - 6.0	51	20.09	6.87	-0.12	2.51	6.6
5.5 - 8.0	122	23.88	9.28	0.77	3.93	9.2
6.5 - 9.0	133	27.08	10.06	0.77	3.44	12.2
7.5 - 10.5	144	31.08	11.70	0.61	2.94	13.3
8.5 - 11.5	109	37.04	13.31	0.37	2.43	15.7
9.5 - 12.5	80	42.14	13.35	0.15	2.21	19.1
Total population	337	30.78	15.30	1.15	4.89	10.0

TABLE 5: Statistics of modulus of rupture values for samples with apparent modulus of elasticity measured over a 600 mm span within the stated ranges

ME_{600} range (GPa)	Modulus of rupture N	$\bar{x}$ (MR mean) (MPa)	S.D. (MPa)	$\sqrt{b_1}$	b_2	Pearson min. value ($MR_{1/40}$) (MPa)
4.5 - 6.0	71	20.78	7.70	0.39	3.35	7.1
5.5 - 8.0	137	26.57	9.75	0.62	3.13	11.4
6.5 - 9.0	131	30.31	11.26	0.73	3.36	13.4
7.5 - 10.5	108	36.43	12.91	0.33	2.39	15.4
8.5 - 11.5	76	43.95	12.66	0.15	2.00	23.3
9.5 - 12.5	44	49.13	11.71	-0.16	2.32	26.2
Total population	337	30.78	15.30	1.15	4.89	10.0

Figure 1 shows plots of the regressions of MR mean on ME_{900} range and ME_{600} range and $MR_{1/40}$ on ME_{900} range and ME_{600} range. This data was extracted from tables 4 and 5. The regressions were performed on the minimum ME value for each ME range (n = 6 for each regression).

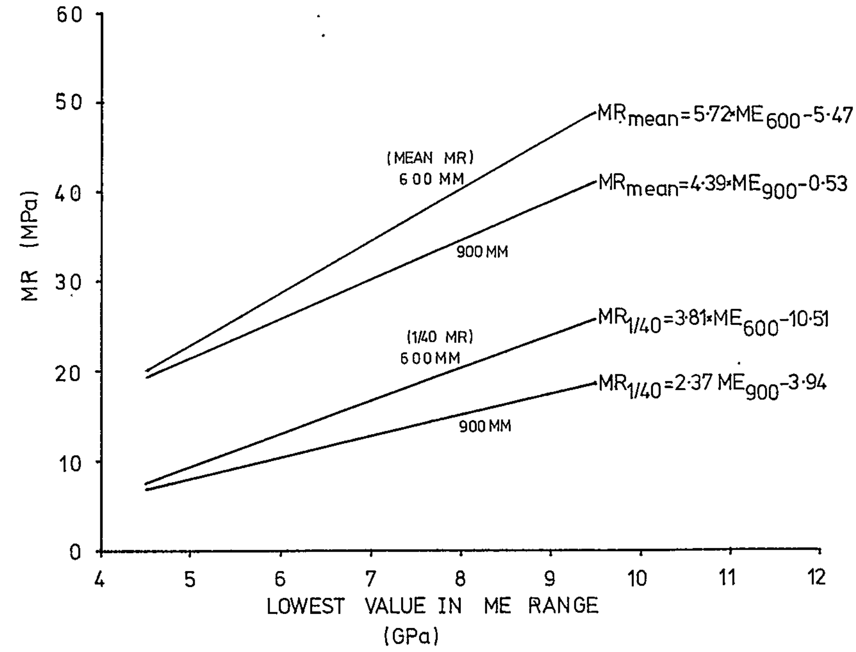


FIGURE 1. Regressions of the mean values of MR and the lower 2.5th percentile of MR on the minimum value of ME and each ME range for the 600 and 900 mm spans.

4. Approximate F grade distributions of samples measured over the two spans using a modified regression approach

The regression equations for the relationships depicted in Figure 1 are as follows:

$MR_{1/40} = 2.37 \times ME_{900} - 3.94 \ldots\ldots (1)\ r^2 = 0.99$

$MR_{1/40} = 3.81 \times ME_{600} - 10.51 \ldots\ldots (2)\ r^2 = 0.96$

$MR_{mean} = 4.39 \times ME_{900} - 0.53 \ldots\ldots (3)\ r^2 = 0.99$

$MR_{mean} = 5.72 \times ME_{600} - 5.47 \ldots\ldots (4)\ r^2 = 0.99$

The mean MR and the $MR_{1/40}$ values depend upon the width of the ME ranges used because as the ME range is increased and assuming the same minimum ME, then stronger material is included in the group thus raising the mean MR and $MR_{1/40}$ values. The extent of this effect has not been fully studied for radiata pine. However it is considered that the effect of small changes in range on the $MR_{1/40}$ values would be small and this effect has been ignored in the following analysis.

In Australia radiata pine is normally graded into F11, F8, F5 and F4 mechanical grades. To calculate the required near minimum values of MR (i.e. the lower 2.5th percentile or $MR_{1/40}$) we normally use a factor of 2.2 for F11, F8 and F5 and 2.0 for F4. The lower factor is used for the F4 grade because this grade is not used in critical applications. The $MR_{1/40}$ values for the various grades are shown in table 6.

TABLE 6: Basic working stress in bending and $MR_{1/40}$ values for the various stress grades

Metric stress grade designation	Basic working stress in bending (MPa)	$MR_{1/40}$ (MPa)
F11	11.0	24.2
F8	8.6	18.9
F5	5.5	12.1
F4	4.3	8.6

If the minimum probable values shown in table 6 are introduced into equations 1 and 2 then the ME values which would give the required stress grades can be found for each span. These values are shown in table 7.

TABLE 7: Minimum ME values required for particular mechanical grades as determined from equations 3 and 4

Approximate F grading	ME_{900} value from eq 3 (GPa)	ME_{600} value from eq 4 (GPa)
F11	11.9	9.2
F8	9.7	7.8
F5	6.8	6.0
F4	5.3	5.1

The ME_{900} value for F11 is well outside the data limits and therefore all the F11 material was included in the F8 grade.

The number of samples in each of the theoretical grades according to their ME values was then calculated and the results are shown in table 8.

TABLE 8: Number of samples in each of the theoretical grades for each span

Approximate F grade	No. of samples in F grade over given span			
	900 mm		600 mm	
	No. in grade	% in grade	No. in grade	% in grade
F8+	96	28	123	37
F5	147	44	108	32
F4	56	17	45	13
reject.	38	11	61	18

This indicates that there could be some advantage in using the smaller span to discriminate the higher grades. However it appears that there would be an increase in the number of pieces rejected from F4.

If the regression line 3 is extrapolated to accommodate the F11 grade then the breakup of the samples in the F8 grade would be as follows:

600 mm span - F11 - 19% of total, F8 - 18% of total

900 mm span - F11 - 8% of total, F8 - 20% of total

These results are not conclusive but they do indicate that a better F grade discrimination can be achieved when timber is tested over shorter spans especially in the higher grades where local stiffness around defects is much lower than the surrounding clear section. This discrimination would also be better as the section size decreases.

5. The relationship between Modulus of Rupture and the percentage decrease in apparent Modulus of Elasticity when the test span is shortened from 900 mm to 600 mm

The percentage decrease in ME when the span is shortened from 900 mm to 600 mm (ME_{dec}) was calculated for each sample and a linear regression of MR on ME_{dec} for each sample size was carried out. The results are shown in Table 9. Figure 2 is a plot of the regression lines listed in Table 9.

TABLE 9: Regression of MR on ME_{dec} for the various sizes and for the total population

Sample dimensions (mm x mm)	N	Correlation coefficient r	Regression slope	Regression constant
35 x 70	39	-0.49*	-1.46	49.94
45 x 70	35	-0.35	-1.92	56.53
35 x 90	160	-0.28*	-1.09	44.38
45 x 90	47	-0.23	-0.73	40.18
35 x 120	56	-0.16	-0.53	35.98
All data	337	-0.30*	-1.10	44.64

*Significant at the 1% level

These results indicate that if the ME is measured over 600 and 900 mm spans then the percentage difference in ME could be used to separate to some degree the samples with higher MR from the samples with lower MR. Fig. 3 is a plot of the MR and ME_{dec} values for the 35 x 70 samples as well as the regression line given in table 9.

A multiple regression analysis was carried out for MR on ME & (ME_{900} - ME_{600}) and for MR on ME & ME_{dec} for both spans. This showed that there was no significant improvement in correlation coefficient when the additional factors were introduced. Despite this result the means and extreme values of M of R were calculated for groups of samples with ME_{900} values within particular ranges and with ME_{dec} values within the following ranges - 1% to 9.9%, 10% and higher, 1% to 13.99%, 14% and higher. It was thought that by calculating the mean MR's and the lower 2.5th percentiles for each group a trend toward higher strength for groups with lower ME_{dec} values would be evident.

As expected the subgroups with the lower ME_{dec} ranges had higher mean MR values than the subgroups with higher ME_{dec} ranges. The lower 2.5th percentile for each subgroup with more than 100 samples was calculated using the Pearson method. These results are presented in tables 10 and 11.

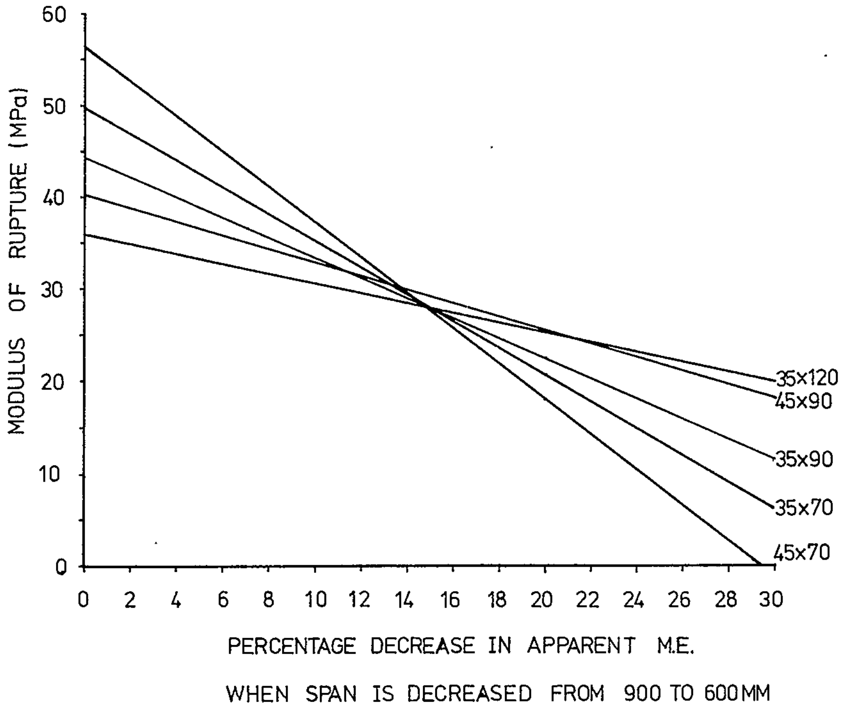


FIGURE 2: Regression of Modulus of Rupture on the percentage decrease in apparent Modulus of Elasticity when the span is shortened from 900 mm to 600 mm for various cross sections.

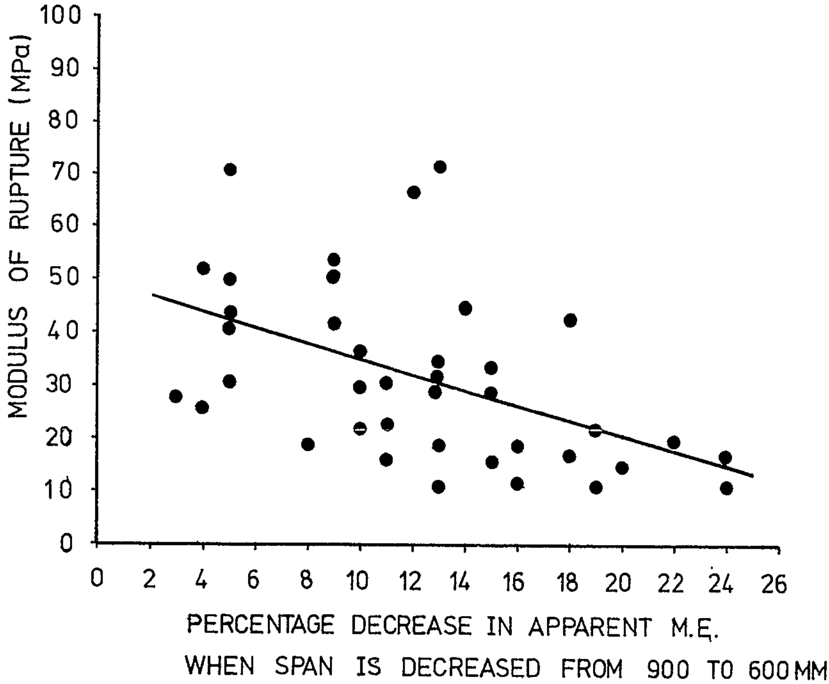


FIGURE 3: Relationship between Modulus of Rupture and the percentage decrease in apparent Modulus of Elasticity when the span is decreased from 900 mm to 600 mm for the 35 mm x 70 mm samples.

Other unpublished work by the author shows that there is a highly significant correlation between the mean modulus of rupture and the Pearson 2.5th percentile for most sample sizes. Therefore any difference in mean MR between two populations infers a difference in the Pearson estimate.

This method could possibly be applied in the machine grading field with the knowledge of the ME over two spans providing a better estimate of grade than by just using a single span. This could result in a more efficient grading system and warrants further study using various test spans and timber sizes. The advantage in knowing the ME over two spans will be of greater significance for the higher grades and most probably the smaller cross sections. Table 11 shows that as the ME decreases then the effect of ME_{dec} becomes less significant as an estimator of MR.

TABLE 10: Means and Pearson 1/40 values of MR for all the samples for various ME_{dec} ranges

ME_{dec} range %	N	Mean MR (MPa)	Min. MR (Pearson) (MPa)
All Samples	337	30.78	10.0
1 - 9.99	73	38.5	-
10 - max	264	28.6	10.6
1 - 11.99	133	35.1	10.2
12 - max	204	27.9	9.9
1 - 13.99	201	33.0	11.7
14 - max	136	27.5	9.4

Another application for this technique is in the laboratory where timber strength could be estimated more accurately than by simply using a single span ME value.

There is a limit on the minimum span that is feasible for a Computermatic machine because of resolution problems associated with the small deflections involved when using the shorter spans.

A Computermatic machine with a span significantly less than 914 mm would not be able to discriminate as many grades as the existing machine. There is the possibility however that another machine with a short span using analog transducers and a modified outrigger system could be designed that would permit a grade discrimination equivalent to that of the present system. The shortest span feasible is probably around 600 - 700 mm.

TABLE 11: Mean values of MR for various ME_{900} ranges and for the various ME_{dec} ranges within each ME_{900} range

ME_{900} range (GPa)	ME_{dec} range (%)	N	Mean MR (MPa)
11.0 - max	1 - 9.99	18	59.3
"	10 - max	25	50.5
"	1 - 13.99	36	55.5
"	14 - max	7	47.9
8.5 - 11.0	1 - 9.99	25	40.4
"	10 - max	72	33.7
"	1 - 13.99	65	36.4
"	14 - max	32	33.4
5.5 - 8.5	1 - 9.99	21	27.0
"	10 - max	131	24.5
"	1 - 13.99	78	23.7
"	14 - max	74	26.0
4.2 - 5.5	1 - 9.99	6	19.2
"	10 - max	32	18.7
"	1 - 13.99	19	19.9
"	14 - max	19	17.6

CONCLUSION

1. The apparent modulus of elasticity when measured on the flat at the most defective sections of radiata pine scantling decreases an average of 12% when the test span is reduced from 900 to 600 mm. This average decrease appears to be independent of timber dimension for the sizes tested.

2. The correlation coefficient between ME and MR did not change as the span was varied from 900 to 600 mm. Even so the grade breakdown using the modified regression approach described in the text resulted in 28% of the material graded as F8 and better when using the 900 mm span and 37% when using 600 mm. There were however 18% below F4 when the 600 mm span was used but only 11% when 900 mm was used. Practical considerations could preclude the use of small spans in timber grading machines because of the limited grade discriminating power of machines with smaller spans.

3. If the stiffness of radiata pine containing defects is measured over two (or possibly more) spans the percentage difference in the ME values could be used as an indicator of strength. This percentage change when used in conjunction with the ME value could possibly be a refinement to the present system of mechanical grading which relies on the ME value alone. It could also be used as a laboratory method for estimating the relative strength of timber samples of similar ME.

ACKNOWLEDGEMENTS

The author would like to thank Dr. R. Curtin for his valuable criticism of the paper and to Mr. P. Lind for his assistance with some of the statistical work.

APPENDIX A

Discussion of Pearson method for determining the lower percentiles

This method bypasses the problem of determining the full frequency distributions. With the aid of tables it is possible to estimate the percentiles of the distribution in question by calculating estimates of the mean ($\bar{x}$), standard deviation (S), standard skewness ($\sqrt{b_1}$) and standard kurtosis (b_2)

where $\sqrt{b_1} = m_3/(m_2)^{3/2}$

$$b_2 = m_4/(m_2)^2$$

and

$$m_2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}$$

$$m_3 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^3}{n}$$

$$m_4 = \frac{\sum_{i=1}^{n} (x - \bar{x})^4}{n}$$

Hahn and Shapiro (3) provide an excellent discussion of the above formulas and of the Pearson method.

Tables of percentage points are given in Reference (2).

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National Library of Australia Card File
ISBN 0 7240 4755 7
ISSN 0085-3984

D. WEST, NEW SOUTH WALES GOVERNMENT PRINTER, 1979