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Structural Engineering Properties of Cypress Pine

BY

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FORESTRY COMMISSION OF NEW SOUTH WALES

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ABSTRACT

This report gives the results of a comprehensive study of the in-grade properties of cypress pine. The tests were conducted on run-of-mill timber with visual reject grade material excluded from the analysis, that is, the population consisting of F4 and better visual grade was evaluated in accordance with AS 2858.

It was found that relative to the values given in the stress grade system of the Australian Standard AS 1720.1, this grade of cypress met or exceeded the stiffness, bending strength and tension strength requirements for F5.

It is suggested that the visual grading rules be changed to a one-grade system and that the resulting grade be called F5.

INTRODUCTION

1. Previous Studies

There has been extensive testing of cypress pine (*Callitris columellaris*) in scantling sizes over the past 20 years.

The earliest work (Forestry Commission New South Wales, 1972) was associated with the revision of the visual stress grading rules for cypress pine (SAA, 1974). The work showed that cypress did not fit well with the traditional visual stress grading system based on strength grouping using the results of small clear specimen testing. Despite the fact that the strength group of cypress was S5, SD6 (SAA, 1986a), the maximum visual stress grade that appeared justified as a result of the full size sample testing was about F5. Using the traditional methods for assigning visual stress grades (e.g. SAA, 1986b) the S5, SD6 ratings result in a top visual grade of F11 unseasoned and F14 seasoned. These grades are, of course, unattainable by cypress pine and the 1974 revision (SAA, 1974) reflected what was thought at the time to be the attainable stress grades, that is, F7, F5 and F4.

Follow up work associated with mechanical grading was commenced in the late 1970's. This lead to the discovery that the bending strength of cypress pine in scantling sizes had a tendency to decrease as the timber dries (Grant, 1979).

In order to quantify the decrease in bending strength on drying, the bending properties of seasoned and unseasoned cypress pine were studied by Cowley (1980). An overall reduction of 33% in bending strength was found at the 5 percentile level (Grant, 1983). Modulus of elasticity, however, was found to increase by an average of 15% as the timber dried.

The results of much of the above mentioned work were summarized by Grant (1983).

Extensive full size sample testing was also carried out during the development of proof grading in 1976 and 1977. These studies, conducted at Queensland Forest Service and C.S.I.R.O. Division of Building Research established "in-grade" properties for Queensland and New South Wales cypress pine based on a total sample of 658 sticks of visually graded "run-of-mill" timber in sizes from 75 x 38 to 150 x 50. The basic bending strength (R_{basic}) determined from these studies for F5 visually graded material ranged from 6.5 to 8.4 MPa (Mackenzie, 1977).

The tension properties of cypress scantling in both the seasoned and unseasoned condition were studied by Chapman (1983). The work indicated that tension strength was not adversely affected by seasoning and that there was an apparent increase in tension strength at the 5th percentile. The results, however, were based on a relatively small sample.

2. The Current Study

The earlier studies provided data suitable for the development of new visual grading, proof grading and mechanical grading systems but there was some question as to whether there was sufficient reliable information on all three important mechanical properties ie stiffness, bending strength and tension strength suitable for inclusion in revisions of AS1720.1 (SAA, 1988).

In 1985 the current project was commenced. Improved reliability of design values brought about as a result of this work was seen as an advantage for cypress producers who could then market their timber as being "in-grade tested" and thus take full advantage of the actual timber design properties. Cypress would also have a distinct advantage over most other species of timber, being one of the very few for which "in-grade" tests have been performed.

3. Format of Report

This follows the general format of C.S.I.R.O., Technical Report TR88/1 (Leicester *et al.*, 1988).

METHODS

1. *Sampling Method*

a) General. Cypress pine mills in both Queensland and New South Wales were sampled over a period of time in an attempt to provide as wide a sample of the parent population as possible. Cypress, being a native of the two States, is widely scattered over large areas of inland regions and it was expected that this method of sampling would provide a reasonably representative sample of the parent population in those two States.

b) Queensland. A total of 240 sticks of 75 x 50 mm and 125 x 38 mm were collected over a period of two months from 12 sawmills drawing timber from 15 forest resources in Queensland. 10 sticks in each cross-section were obtained from each of the 12 mills. The sticks were visually graded by the Timber Research & Development Advisory Council's quality control officer at the mills and each stick was individually marked and packs wrapped in plastic to maintain moisture content. All timber was sampled 'run of mill', that is, no grade pre-sorting took place. Stick lengths were from 3 m to 3.6 m.

c) New South Wales. An additional 96 sticks of the same cross-sections were obtained from two mills in New South Wales. This material was also 'run of mill' but was not visually graded. The timber in this sample was also wrapped in plastic before shipment to the laboratory.

2. *Test Procedures*

a) General. Upon receipt at the Forestry Commission of New South Wales, Wood Technology and Forest Research Division, Timber Engineering Laboratory the material was divided into two groups, of roughly equal sizes, on a random basis; one group for bending strength tests and the other for tension tests. All tests were carried out with the timber in the unseasoned condition.

b) Modulus of Elasticity Testing. Initially, all sticks were tested in three point bending, on edge, over a span of 2.74 m to determine overall modulus of elasticity (E). Sticks were positioned with equal overhang on both sides of the test span during this test with the tension edge randomly selected.

The long bed Shimadzu universal testing machine was used for the tests. Displacement was recorded with the aid of an electronic dial gauge positioned at mid-span. The measurement sequence was as follows: a small initial load was applied, the dial gauge zeroed, the final load applied, and the final deflection noted. The differential loads were 300 N and 900 N for the 75 mm and 125 mm widths respectively.

c) Modulus of Rupture Testing. The sticks assigned for bending strength tests were inspected and up to two short bending specimens were taken from each. These specimens were specially selected to contain, around their mid-point, the largest visually identifiable defects on the parent stick. The specimen lengths and the test spans used for modulus of rupture (R) tests were those specified in AS 1749 (SAA, 1978). The span to depth ratio was therefore approximately 14 to 1. Rate of loading was set to achieve failure after about three to five minutes. This, however, was not always achieved.

For each of the bending specimens R was determined with the subjectively worst strength reducing defect at mid-span and on the tension side. R for each of the parent sticks was taken as the smaller value if two test specimens were sourced from the stick.

d) Tension Strength Testing. Tension tests were conducted on the full length sticks. Some sticks slipped in the tension jaws during testing and these are included in the results as they invariably slipped at high loads. The slipping would only affect the upper portion of the data, tending to limit the maximum apparent tensile strength.

Rate of loading was set to achieve failure after about three to five minutes. This, however, was not always achieved.

e) Additional Measurements. Other data taken included moisture content and basic density. Moisture content was estimated from a small section taken from the specimen and oven dried. Basic density was also determined using this small section.

3. *Method of Analysis*

a) Description of the Population used for Analysis. The main results presented here are based on a population consisting of run of mill timber with the only sticks excluded being those falling below the F4 grade of AS 2858 (SAA, 1988). Theoretically this only applies to the Queensland sourced sticks as these were the only ones visually graded by a qualified timber inspector. All sticks from New South Wales were included in the analysis and therefore there is a possibility that some reject grade pieces may have been included. This may have the effect of reducing the strength results but would have had little influence on stiffness. This is discussed in more detail later.

The above approach was taken because of the small yields in the F4 and F7 grade groups (see below). Exclusion of the reject pieces is logical as this would be expected to eliminate the pieces with the largest defects and pieces not normally considered merchantable.

Overall visual grade yields for the Queensland data were F7-2%, F5-70%, F4-9% and reject-19%.

Supplementary results are also presented for the subpopulation consisting of the F5 visually graded material from Queensland.

b) Basis of Analysis. The analysis was performed using the methods presented in the draft Australian standard TM3/90-47 (SAA, 1990). The draft standard supplies a method for determining the following values:

For Limit States Codes:

Characteristic Strength (R_k) given by

$$R_k = [1-(2.7V_R \,/\sqrt{n})]\, R_{0.05} \qquad \text{......(Eq 1)}$$

where $R_{0.05}$ and V_R are the 5 percentile value and the coefficient of variation respectively and n is the sample size.

Normalized Characteristic Strength ($R_{k,norm}$) given by

$$R_{k,norm} = \frac{(1.35)}{\varnothing} \frac{R_k}{[1.3 + 0.7\, V_R]} \qquad \text{..... (Eq 2)}$$

where $\varnothing$ = material coefficient specified in the limit states code (assumed to be 0.85 in this analysis).

Characteristic Stiffness (E_k) given by

$$E_k = [1 - (2.7\, V_E \,/\sqrt{n})]\, E_{0.05} \qquad \text{.....(Eq 3)}$$

where $E_{0.05}$ and V_E are the 5 percentile value and the coefficient of variation and n is the sample size.

Nominal Average Stiffness (E_{av}) being the minimum of two estimates:

$$E_{av,mean} = [1 - (0.7\, V_E \,/\sqrt{n})] E_{mean} \qquad \text{.....(Eq 4)}$$

$$\text{and } E_{av,char.} = 1.4\, E_k \qquad \text{.....(Eq 5)}$$

where E_{mean} is the average value of E.

For Working Stress Codes:

Basic Working Stress (R_{basic}) given by

$$R_{basic} = R_k \,/[\, 1.75\, (1.3 + 0.7\, V_R\,)\,] \qquad \text{.....(Eq 6)}$$

Specified stiffness is the nominal stiffness given by Eq 4 or Eq 5 as appropriate.

c) Adjustment Factors. Some of the test methods varied from standard and appropriate factors, if known, were used to adjust the data to standard conditions. No factors were used for the tension data. The factors are detailed below:

E Factors

The span effect factor for non-standard spans given in TM3/90-47 is as follows:

$$E_s = (\, E_o /1.04\,)\, [\, 1 + 14\, (\, h/1_o\,)^2\,] \qquad \text{.....(Eq 7)}$$

where E_s is the value for the standard span and E_o is the value measured on the non-standard span.

This equation gives a factor of 0.97 for the 75 mm wide sticks and 0.99 for the 125 mm sticks.

As the deflection tests were conducted in three point bending the factor specified in Table 2 of ASTM D 2915-74 (ASTM, 1981) was used to convert the E values to standard third point loading conditions. This factor was found to be 1.03 for 75 mm sticks and 1.01 for 125 mm sticks.

The two compensating factors when combined gave a value of 1 for both cross-sections.

R Factors

The defect location factor was assumed to be 1.2 as suggested in TM3/90-47 for F5 radiata pine. The frequency of large defects appears similar for both radiata pine and cypress pine and so this assumption is considered reasonable.

The span effect factor suggested in TM3/90-47 for MOR is as follows:

$$k_1 = (\, 1_o \,/\, 1_s\,)^{V_R} \qquad \text{.....(Eq 8)}$$

where 1_s = the standard span
1_o = the non-standard span.

For this work the equation results in values of 0.91 and 0.9 for the 75 mm and 125 mm widths respectively. It is considered, however, that it is inappropriate to apply these factors here as the specimens were biased so that the worst defects on the individual sticks were at the point of maximum bending moment. The use of the span effect factor is considered more appropriate to methods based on unbiased selection of specimens.

RESULTS - STRUCTURAL PROPERTIES

1. *Modulus of Elasticity*

Results for the main analysis are given in Table 1. Mean E for the bending and tension groups for the two individual cross-sections are almost identical. This is an expected result considering the two groups came from the same population.

The larger cross-section appears to have a generally slightly higher stiffness, as illustrated in the cumulative frequency plots shown in Figures 1 and 2, but this is of little consequence in a practical sense. Pooling of the data from the two cross-sections is therefore considered justified.

The overall mean Nominal Average Stiffness was 6.9 GPa which is identical to the value given in AS 1720.1 for the F5 stress grade.

2. *Modulus of Rupture*

Results of the main analysis are given in Table 2. The computed R values for the larger cross-section group are approximately 15% higher than those for the smaller cross-section group.

A plot of the cumulative frequency of modulus of rupture, (Fig. 3) shows the similarity of the data frequency for the two cross-sections and an apparent divergence below about the 10 percent level. This divergence is illustrated in Fig. 4 which shows a closeup of the lower tail of the distribution. The divergence is thought to be sample related and not a product of cross-section size effects. It was thought the effect may be a result of using ungraded pieces as part of the data set (see 2.3 above). A check, however, of the data set shows that the three lowest R values for the 75 x 50 size and the lowest R value for the 125 x 38 size were Queensland samples graded as F5 (see Fig. 4). Therefore, the ungraded samples did not appear to be reducing the strength statistics.

Table 1. Modulus of elasticity results after exclusion of rejects (GPa units).

Sample Group*	No.	Measured parameters			Computed E values			Nominal Average Stiffness
		Mean	$E_{0.05}$	V_E	E_k	$E_{av,mean}$	$E_{av,char.}$	(E_{av})
B 125 x 38	60	7.4	5.1	0.21	4.7	7.3	6.6	6.6
T 125 x 38	65	7.3	5.4	0.18	5.1	7.2	7.1	7.1
pooled	125	7.4	5.3	0.19	5.1	7.3	7.1	7.1
B 75 x 50	60	7.1	4.9	0.17	4.6	6.9	6.4	6.4
T 75 x 50	73	6.9	4.8	0.18	4.6	6.8	6.4	6.4
pooled	133	7.0	4.9	0.17	4.7	6.9	6.5	6.5
All samples	258	7.2	5.1	0.19	4.9	7.1	6.9	6.9

* B - bending group
T - tension group

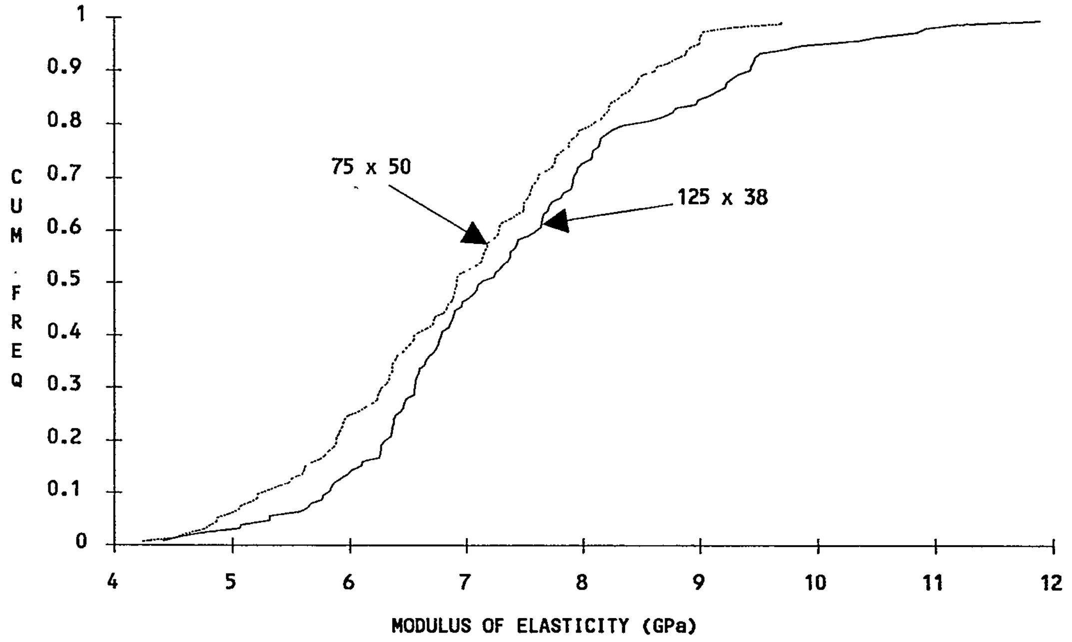

Figure 1. Measured modulus of elasticity for the two cross-sections (all data excluding rejects).

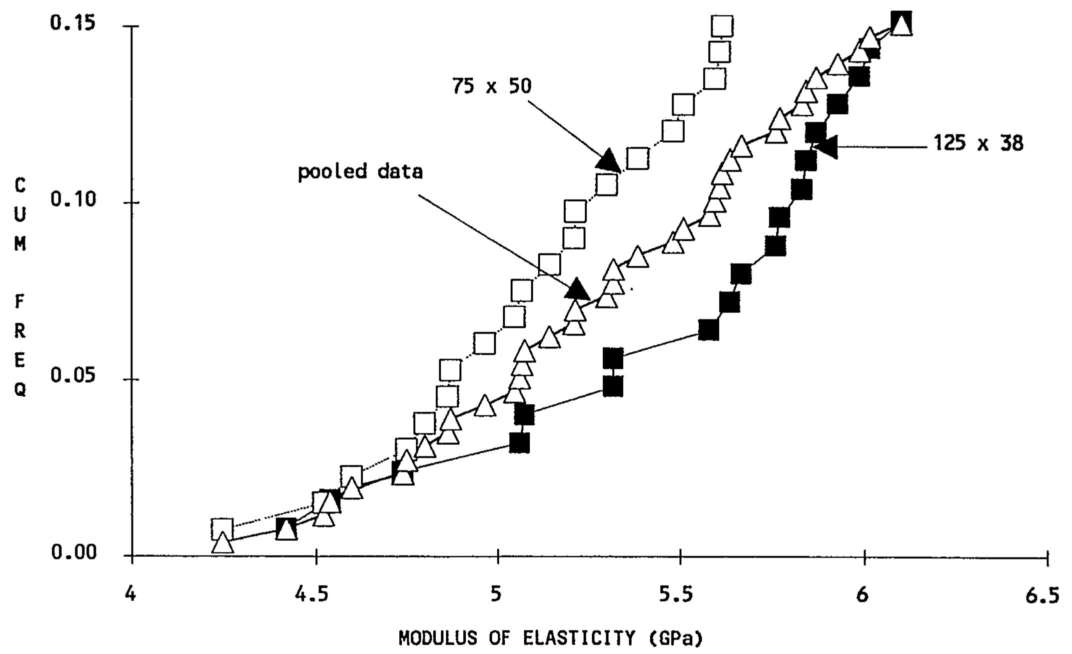

Figure 2. Lower tail of the measured modulus of elasticity for the two cross-sections (all data excluding rejects).

The difference in R values between the two cross-sections is approximately half a grade but this is considered of little significance because of the relatively small sample sizes involved. The pooled results are therefore considered as providing reasonable estimates of the R values for cypress pine.

The pooled Rbasic result of 8.4 MPa is close to the value given in AS 1720.1 for the F8 stress grade (8.6 MPa).

3. Tension Strength

Results of the analysis are given in Table 3. The two cross-sections show almost identical measured and computed parameters.

A cumulative frequency plot of tension strength, (Fig. 5) indicates that the 75 x 50 cross-section has a higher general tension strength for percentiles above about 10%. However, the lower percentiles are very similar for the two cross-sections (Fig. 6) and therefore pooling of the results is warranted for the determination of R values.

The pooled Rbasic result of 3.5 MPa is almost equal to the value specified in AS 1720.1 for tension parallel to the grain for the F5 stress grade (3.3 MPa).

An interesting observation was made after an inspection of the tension strength data. This showed that all the tension strength values below about 10 MPa (ie the 5% level) were samples from New South Wales. This is illustrated in Fig. 6. The reasons for this have not yet been determined.

4. Queensland F5 Visually Graded Subpopulation

Results are shown in Appendix A. Sampling effects appear to be the main reason for differences between results for the F5 and main populations. The smaller sample sizes in the F5 group also had the effect of reducing the computed values (see the equations in Section 4.2). Overall, however, the results are regarded as similar for the two groups and it is recommended that the results for the total population be used for determination of design values for cypress pine.

Table 2. Modulus of Rupture results after exclusion of rejects (MPa units).

Sample Group	No.	Measured parameters			Computed R values		
		R_{mean}	$R_{0.05}$	V_R	R_k	$R_{k,norm}$	R_{basic}
125 x 38	61	34.3	20.2	0.28	21.8	23.2	8.4
75 x 50	68	34.3	17.4	0.28	19.0	20.2	7.3
pooled	129	34.3	19.5	0.28	21.8	23.2	8.4

Note: Computed values have been adjusted by a factor of 1.2 (see Page 3)

Table 3. Maximum Tensile Strength results after exclusion of rejects (MPa units).

Sample Group	No.	Measured parameters			Computed R values		
		R_{mean}	$R_{0.05}$	V_R	R_k	$R_{k,norm}$	R_{basic}
125 x 38	68	16.2	9.2	0.26	8.4	9.0	3.2
75 x 50	77	18.3	9.9	0.28	9.0	9.6	3.4
pooled	145	17.3	9.7	0.28	9.1	9.7	3.5

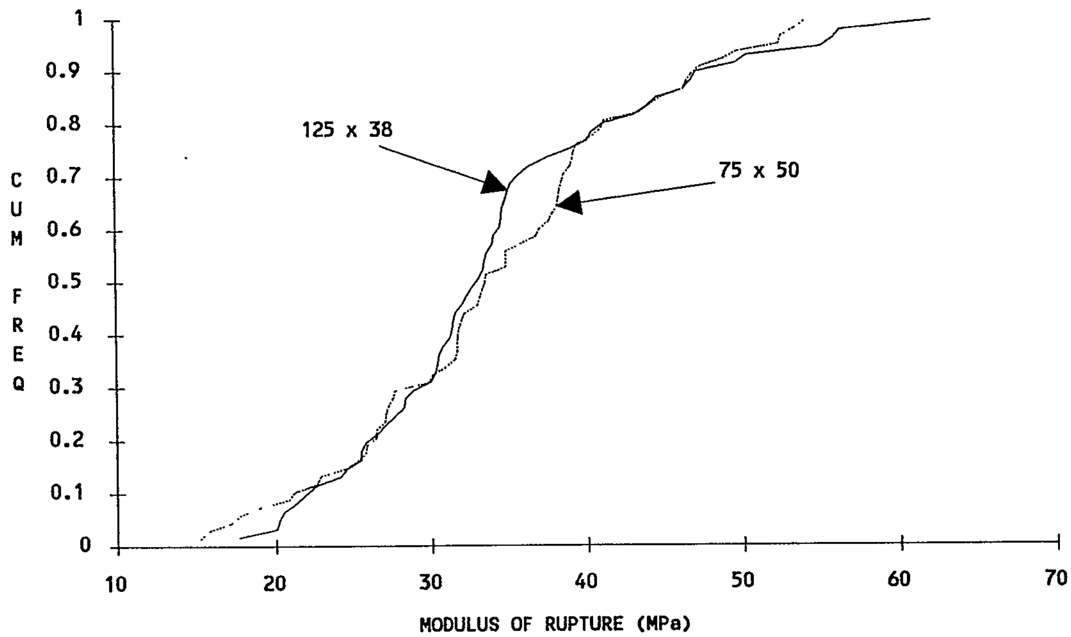

Figure 3. Measured bending strength for the two cross-section sizes (excluding reject samples).

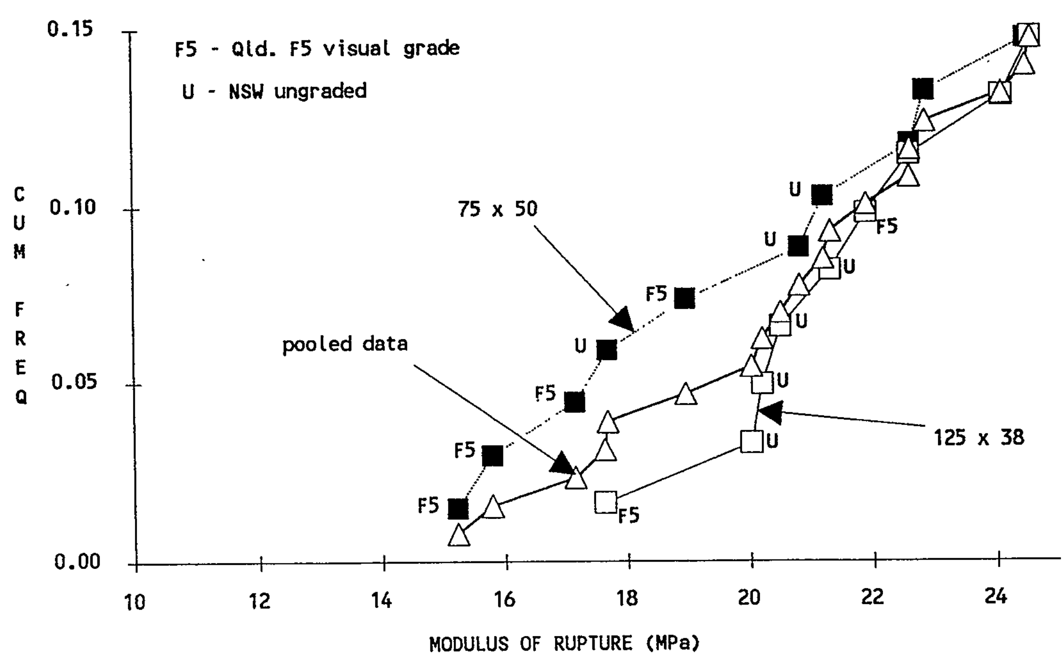

Figure 4. Lower tail of measured bending strength for the two cross-section sizes (excluding reject samples).

Nominal average stiffness in the F5 sample is about 15% below the total population value. This is mainly due to the lower estimate of the 5th percentile (4.8 against 5.1).

The lower, computed R values for bending strength in the F5 subpopulation are the direct result of the four lowest strength samples being present in this group (see Section 5.2).

The higher, computed R values for tension strength in the F5 population are the direct result of none of the samples having tension strength values below 10 MPa (see Section 5.3).

RESULTS - DENSITY AND MOISTURE CONTENT

Results are given in Table 4. Basic density had a mean value for the total population of about 600 kg/m^3. There was no significant difference in mean density between the two States or between the two cross-sections.

Moisture content had an overall mean value of 27%. There was no significant difference in MC between States and between cross-sections except for the tension samples in the smaller cross-section where the samples for both States appeared to have a slightly lower mean MC.

Perhaps these samples dried out a little before testing occurred on this group. This may also explain the generally higher tension values for the 75 x 50 cross-section.

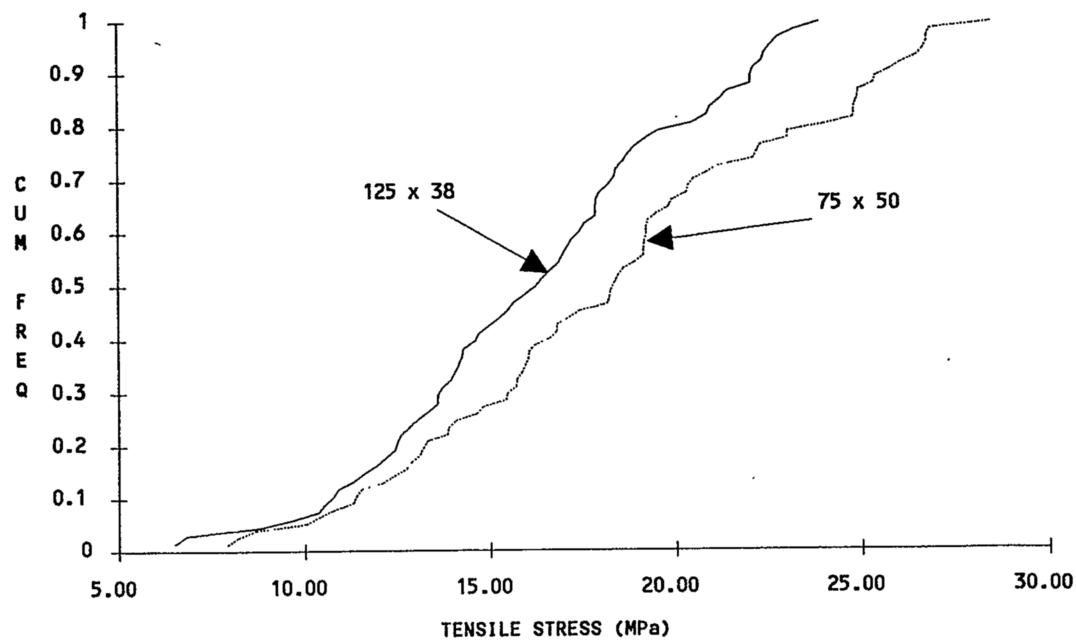

Figure 5. Measured tension strength for the two cross-section sizes (excluding reject data).

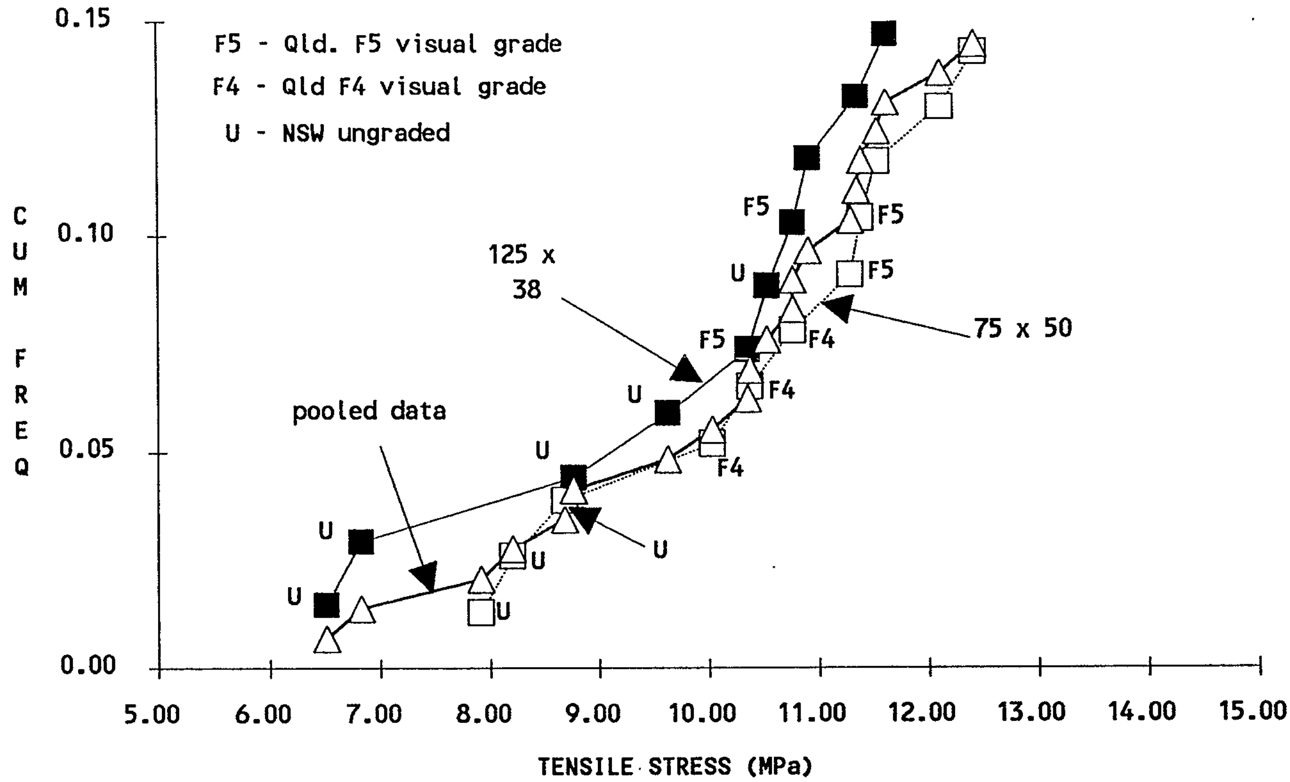

Figure 6. Lower tail of measured tension strength for the two cross-section sizes (excluding reject data).

Table 4. Moisture content and basic density of the total population including rejects.

Sample Group		No.	Density (kg/m^3)		Moisture Content (%)	
			Mean	C.V. %	Mean	C.V. %
Bending NSW	75x50	24	598	8	27	14
Tension NSW	75x50	24	622	10	22	9
Bending Qld	75x50	55	599	8	26	17
Tension Qld	75x50	57	600	8	23	18
Bending NSW	125x38	24	605	9	29	8
Tension NSW	125x38	23	594	6	27	8
Bending Qld	125x38	50	604	6	29	19
Tension Qld	125x38	50	590	5	26	17
Bending All		153	601	7	28	17
Tension All		154	599	8	25	17

CONCLUSIONS

The final design values for the three properties evaluated indicate that 'run-of-mill' cypress, ie cypress pine graded to AS 2858 (SAA, 1986b) F4 and better grade are equal to or better than the values specified for the F5 grade in AS 1720.1 (SAA, 1988).

This result would also apply to F5 and better grade as the exclusion of F4 stress graded material would be expected to increase the strength properties. The result raises the possibility of sorting cypress pine into just one visual grade with design values for E, R_{basic} and T_{basic} equivalent to F5 stress grade. The grading rules therefore could be modified to include one grade with defect limits equivalent to the current F4 values in AS 2858 (SAA, 1986b).

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APPENDIX 1. Results for the Queensland F5 population.

Modulus of Elasticity results for the Qld. F5 samples only (GPa units).

Sample Group*	No.	Measured parameters			Computed E values			Nominal Average Stiffness
		Mean	$E_{0.05}$	V_E	E_k	$E_{av,mean}$	$E_{av,char.}$	(E_{av})
B 125 x 38	29	7.4	4.7	0.22	4.2	7.2	5.9	5.9
T 125 x 38	35	7.7	5.7	0.18	5.2	7.6	7.3	7.3
B pooled	64	7.6	5.4	0.20	5.1	7.4	7.1	7.1
B 75 x 50	32	6.9	4.6	0.19	4.2	6.7	5.9	5.9
T 75 x 50	39	6.8	4.6	0.20	4.2	6.6	5.9	5.9
T pooled	71	6.8	4.7	0.19	4.4	6.7	6.2	6.2
All samples	135	7.2	4.8	0.20	4.6	7.1	6.5	6.5

* B - bending group
T - tension group

Modulus of Rupture results for the Qld F5 samples only (MPa units).

Sample Group	No.	Measured parameters			Computed R values		
		R_{mean}	$R_{0.05}$	V_R	R_k	$R_{k,norm}$	R_{basic}
125 x 38	30	33.9	20.0	0.30	20.4	21.5	7.7
75 x 50	40	35.3	15.9	0.27	16.8	17.9	6.4
pooled	70	34.6	17.4	0.28	19.0	20.2	7.2

Note. Computed values have been adjusted by a factor of 1.2 (see Page 3)

Maximum Tensile Strength results for the Qld. F5 samples only (MPa units).

Sample Group	No.	Measured parameters			Computed R values		
		R_{mean}	$R_{0.05}$	V_R	R_k	$R_{k,norm}$	R_{basic}
125 x 38	36	17.6	10.7	0.21	9.7	10.7	3.8
75 x 50	41	18.5	11.4	0.23	10.3	11.2	4.0
pooled	77	18.1	11.4	0.22	10.6	11.6	4.2