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THE COMMONWEALTH OF DOMINICA

Technical report: Strength grouping of timbers*

Prepared for the Commonwealth of Dominica
by the United Nations Industrial Development Organization

Based on the work of C. R. Francis,
Timber Engineer

* This document has been reproduced without formal editing.

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Acknowledgement

This report quotes from and reproduces sections of various Australian Standards, listed in detail in references. The kind permission of the Standards Association of Australia in allowing this is gratefully acknowledged. Such quotations are indicated in the text by the standard number in brackets thus (AS 2082).

Thanks are also due to my friend Dr. R. H. Leicester CSIRO Melbourne for his critical review of this report.

Scope and Contents

A guide is presented to the application and use of strength grouping of timber, using and including reference to Australian practice and standards. It is expected to be useful in promoting timber construction and in harmonizing international cooperative efforts in this sector.

STRENGTH GROUPING AND STRESS GRADING OF TIMBERS

Introduction

The United Nations Industrial Development Organisation (UNIDO) is actively promoting the use of timber, a wide-spread resource in many developing countries, as a construction material. It is doing this in three main ways - by setting up timber utilisation projects, by arranging courses to teach timber engineering and by the active promotion of the UNIDO prefabricated timber bridge system.

This bridge system was designed for world wide use and to solve the problem of making it universally applicable, the designers adopted the Australian strength grouping system and carried out the design according to AS 1720 the SAA Timber Engineering Code. The manual for the bridge contains a list of timbers classified into their strength groups, and appropriate grading rules. Since the introduction of the bridge to various developing countries, and particularly with the experience of three successful timber engineering training courses it has become apparent that a wider and more detailed explanation of the strength grouping system and how to put it into practice is required than what is contained in the UNIDO bridge manual. This information is available but is dispersed through several Australian Standards and technical papers. This report endeavours to gather this material together into a concise and practical form.

Strength Grouping - The Concept

"There are no obvious limitations to the acceptability of any timber population for structural utilisation provided its structural properties can be defined with sufficient reliability". (Leicester 1981)(2) The key word in this statement is "sufficient".

The classical approach to this problem of definition has been to test the mechanical properties of very large numbers of small clear specimens of each species so that the lower bound of each property is defined with a high level of precision and confidence. The stresses so defined are then adjusted by factors to cover the weakening effects of defects, long term loading etc. and working stresses for various grades are assigned accordingly. An alternative more recent approach gaining very wide acceptance is the testing of full size structural timbers in the actual grades supplied, and determining with similar high precision, the lower bound properties. this involves a large amount of laboratory time and effort. This approach works well in countries with few dominant species, e.g. western Canada or New Zealand. However, many countries, particularly tropical ones, have vast numbers of species. For example Australia lists 630 trade names (AS MP45), there are 200 species in Thailand, 2000 in the Philippines. The effort involved using the classical approach to evaluate all these is too enormous to contemplate.

"Strength Grouping" approaches the problem from the other end. A set of basic working stresses is arbitrarily determined, then the timber properties required to produce timber with not less than these stresses are also determined. Because of the discrete steps between design stresses and lowering of statistical precision (but not of confidence level) much less laboratory work is required to classify a species or group of species, assign working stresses and permit a species to be used in designed or codified structures.

The Australian system used fibre stress in bending as its primary classification. Twelve values of this stress and other association stresses have been selected. Table 1 reproduced from AS 1720 shows them:

Table 1

BASIC WORKING STRESSES AND STIFFNESS (MPa) FOR STRUCTURAL TIMBER

Stress grade	Basic Stress				Short duration modulus of elasticity* E	Short duration modulus of rigidity G
	Bending F'_b	Tension parallel to grain F'_t	Shear in beams F'_s	Compression parallel to grain F'_c		
F34	34.5	20.7	2.45	26.0	21500	1430
F27	27.5	16.5	2.05	20.7	18500	1230
F22	22.0	13.2	1.70	16.5	16000	1070
F17	17.0	10.2	1.45	13.2	14000	930
F14	14.0	8.4	1.25	10.2	12500	800
F11	11.0	6.6	1.05	8.4	10500	700
F8	8.6	5.2	0.85	6.6	9100	610
F7	6.9	4.1	0.70	5.2	7900	530
F5	5.5	3.3	0.60	4.1	6900	460
F4	4.3	2.6	0.50	3.[illegible]	6100	410
F3	3.4	2.[illegible]	0.45	2.6	5200	350
F2	2.8	1.7	0.35	2.1	4500	300

*The modulus of elasticity includes an allowance for shear deformation

It will be seen that this table covers the whole spectrum of timber strengths and stiffness found anywhere in the world.

The "F34", F27" etc are "Stress Grades". These grades are determined from a combination of the intrinsic strength properties of the wood - the "Strength Group" as determined by testing small clear samples, and the quality of the individual pieces concerned, that is the size of knots, slope of grain etc. as determined by suitable grading rules for "Structural Grades". Thus any particular Stress Grade may be formed by several combinations of Strength Group and Structural Grade - strong wood in a low quality grade, weak wood in a high quality grade or intermediate values of both.

In practice four structural grades are given in the relevent grading rules (AS 2082 for hardwoods, AS 1490 for radiata pine etc.). These describe grades with 75%, 60%, 48% and 38% of clear wood strength, or strength ratio.

It will be observed that the Fb values in Table 1 are in geometric progression with a common ratio of about 1.25, similarly the strength ratios for the grades have the same common ratio. They can thus be combined in a concise form as shown in Table 2.

Table 2

RELATIONSHIP BETWEEN STRENGTH GROUPS AND STRESS GRADES FOR UNSEASONED TIMBER

Strength group	Stress grade 75 % No 1 Structural	60 % No 2 Structural	48 % No 3 Structural	38 % No 4 Structural
S1	F27*	F22	F17	F14
S2	F22	F17	F14	F11
S3	F17	F14	F11	F 8
S4	F14	F11	F 8	F 7
S5	F11	F 8	F 7	F 5
S6	F 8	F 7	F 5	F 4

Reproduced from AS 2082

It is well known that most mechanical properties of timber particularly those of interest to structural engineers, increase as the wood gets dryer. To allow for this, two determinations of strength group for each species or species group are made. Seasoned timber which remains below 15% moisture content may have a higher stress grade assigned to it than green timber of the same structural grade. These are shown in Table 3. The seasoned or dry condition is distinguished by the use of "SD", opposed to "S" for the green conditon.

Table 3

SD6

(AS 2082)

For example Australian brown alder is classified as S5. SD6. A piece of 60% grade of this species would qualify as F8 if green, F11 if seasoned to less than 15% moisture content.

This increase in stress grade is not uniform for all species. Another Australian species, candlebark is also S5, but is SD 5, which would made a dry piece of 60% grade qualify as F 14.

Strength Grouping Methods

Two procedures for strength grouping are allowed by Australian authorities. These are positive strength grouping and provisional strength grouping, depending on the amount and type of information available. A provisional strength grouping is necessarily conservative and is subject to revision in the light of further data. Provisional grouping is distinguished by enclosing the group in brackets, thus (S6) (SD7).

The following section is reproduced from AS MP 45 "Report on Strength Grouping of Timbers".

SECTION 1. SCOPE AND GENERAL

1.1 SCOPE. This document is intended to provide a uniform basis for the classification of timber species into strength groups. By such classification a particular species may be used for structural purposes under the provisions of AS 1720, SAA Timber Engineering Code, AS 1684, SAA Timber Framing Code, Building Regulations and any other documents related to these codes.

Section 3 sets out the strength grouping of most timbers used in Australia.

1.2 DEFINITIONS. For the purpose of this document the following definitions apply:

Species mean—the mean of the tree mean values of a given property.

Strength group—the group to which a timber or a group of timbers is assigned (seven groups in descending order S1 to S7 for unseasoned timber, eight groups SD1 to SD8 for seasoned timber) on the basis of the mechanical properties and/or density determinations of defect free material of the species.

Depending on the nature and amount of data on which the classification is made, the strength grouping may be termed 'positive' or 'provisional' in accordance with the following definitions:

(a) *Positive strength group*—the group to which a timber is assigned based on mechanical test data for five or more correctly sampled trees (see Appendix A and Appendix B).

(b) *Provisional strength group*—the group to which a timber is assigned based on density and/or limited mechanical test data. The provisional nature of the assessment is indicated by the use of brackets in Tables 3.1 and 3.2.

SECTION 2. PROCEDURES FOR THE STRENGTH GROUPING OF A SPECIES

2.1 GENERAL. As defined under 'strength groups' in Clause 1.2 above, a species may be given either a positive or a provisional strength grouping depending on the amount and reliability of the information available for the species. Provisional classifications are conservative and desirably so, because of the use of predictive relationships in making the assessment. Either classification may be changed in the light of additional information but both are currently valid.

The information necessary for applying the procedures of this Section is as follows:

(a) *For positive strength grouping.* The species mean values of modulus of rupture, modulus of elasticity and maximum compression strength parallel to the grain are required.

Each of these species mean values is to be obtained from the results of standard tests on small clear specimens sampled from not fewer than five properly selected trees of the species (see Appendix A).

Species mean values obtained from tests on unseasoned material will allow the species to be strength grouped for use in this condition. Species mean values obtained by adjusting to 12 percent moisture content (see Appendix C) the results obtained from tests on kiln-dried or air-dried material will allow the species to be strength grouped for use in the seasoned condition.

NOTE: Although not usually required for the purposes of applying the procedures described below, it is often useful that the standard deviation of individual results be available for the abovementioned properties, particularly for modulus of rupture.

(b) *For provisional strength grouping.* Species mean values for the properties mentioned in (a) above obtained from tests on material from not fewer than three trees and/or the species mean value for air dry density obtained from standard measurements on specimens sampled from not fewer than five selected trees of the species are required.

(c) *Species having wide variability in wood properties.* For some species having a wider than usual variability in wood properties, larger than normal sampling may be required to take this variability into account.

2.2 PROCEDURE FOR POSITIVE STRENGTH GROUPING.

2.2.1 Preliminary Classification Based on Individual Critical Properties. Modulus of rupture, modulus of elasticity and compression strength parallel to the grain of a species are first classified separately, by comparing the species means of these properties with the minimum values listed for each strength group in Tables 2.1 and 2.2.*

As strength grouping is primarily to give an indication of bending strength, shear values are not considered since they are not closely related with modulus of rupture. The value of a property measured in the seasoned state is adjusted to the reference moisture content of 12 percent (see Appendix C) before it is compared with the tabulated values of SD1 to SD8 in Table 2.2.

2.2.2 Positive Strength Classification Based on the Combination of Properties. Should all three properties in the unseasoned state have the same classification derived in accordance with Clause 2.2.1, the species is assigned to that S-group. Analogously, should all three properties in the dry state command

*Extracted from an article by N.H. Kloot in *CSIRO Forest Products Newsletter* No 394, 1973.

TABLE 2.1

PRELIMINARY CLASSIFICATION VALUES FOR UNSEASONED* TIMBER

Property	Minimum species mean						
	S1	S2	S3	S4	S5	S6	S7
Modulus of rupture (MPa)	103	86	73	62	52	43	36
Modulus of elasticity (MPa)	16300	14200	12400	10700	9100	7900	6900
Maximum crushing strength (MPa)	52	43	36	31	26	22	18

*As measured or estimated at a moisture content above fibre saturation point.

TABLE 2.2

PRELIMINARY CLASSIFICATION VALUES FOR SEASONED* TIMBER

Property	Minimum species mean							
	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8
Modulus of rupture (MPa)	150	130	110	94	78	65	55	45
Modulus of elasticity (MPa)	21500	18500	16000	14000	12500	10500	9100	7900
Maximum crushing strength (MPa)	80	70	61	54	47	41	36	30

*As measured or adjusted to a moisture content of 12 percent.

the same group, the species is assigned to that SD-group. When the three properties listed in Clause 2.2.1 do not all have the same classification a conservative approach would be to assign the species to the lowest group obtained from the individual properties. This must apply for many combinations but there are several for which raising the overall species strength group one step above the lowest assessment is deemed justified.

The assignment of a species to a strength group above the lowest group obtained from individual properties places more emphasis on the modulus of rupture and the modulus of elasticity than on compression strength. The procedure applied is detailed hereunder and summarized in Table 2.3, and x may be any of the numbers 1 to 8 in S1 to S7, or SD1 to SD8. In all other cases, the lowest of the three separate assessments is assigned as the species grouping.

(a) If the lowest group is that obtained from the modulus of rupture, then the overall species strength group may be raised one step above that minimum group only if the modulus of elasticity is in a group at least two steps, and the compression strength in a group at least one step, above that minimum.

(b) If the lowest group is that of the modulus of elasticity, then the overall species strength group may be raised one step above that minimum only if the modulus of rupture is in a group at least two steps, and the compression strength in a group at least one step, above that minimum.

(c) If the lowest group is that obtained from the compression strength then the overall species strength group may be raised one step above the minimum only if both the modulus of rupture and the modulus of elasticity are in a group at least one step above that minimum.

2.3 PROCEDURE FOR PROVISIONAL STRENGTH GROUPING.

2.3.1 General. When the available data for either unseasoned or seasoned strength values are from fewer than five trees the procedure adopted is as follows, using Table 2.4 where appropriate; while a large range of combinations is possible the following are likely to be the most common:

(a) *Only either unseasoned strength values or seasoned strength values from five or more trees available.*

(i) Evaluate on the basis of the condition for which the data are available, i.e. allocate the green or seasoned strength grouping as appropriate.

(ii) Evaluate the other condition on the basis of air-dry density from Table 2.4 and allocate a provisional rating.

(b) *Air-dry density values only from five or more trees available.* Determine provisional strength group from Table 2.4. Figures to be placed in brackets.

2.3.2 Acceptable Difference between Unseasoned and Seasoned Strength Groups. For any one species the provisional strength grouping for unseasoned and seasoned material should not vary by more than one strength group. Any adjustment required must be on the conservative side; e.g. for a species initially classified as say (S5), (SD3), its final assessment would be (S5), (SD4).

TABLE 2.3

COMBINATIONS OF PRELIMINARY CLASSIFICATIONS THAT PERMIT THE OVERALL STRENGTH GROUP ASSESSMENT TO BE ONE STEP ABOVE THE LOWEST IN THE COMBINATION

Preliminary classification based on—			Assessed S or SD strength group
Modulus of rupture	Modulus of elasticity	Maximum crushing strength	
x	x	$x + 1$	x
x	$x - 2$	$x - 1$	$x - 1$
x	$x + 2$	$x + 1$	$x + 1$

NOTE: Strength group $x - 1$ is stronger than strength group x; e.g. if strength group S4 is denoted by x then strength group S3 is denoted by $x - 1$

TABLE 2.4

MINIMUM AIR-DRY DENSITY VALUES FROM 5 OR MORE TREES FOR ASSIGNING SPECIES TO STRENGTH GROUPS IN THE ABSENCE OF ADEQUATE STRENGTH DATA

(a) Unseasoned Material

Strength Group	S1	S2	S3	S4	S5	S6	S7
Air-dry density at 12 percent moisture content (kg/m³)	1180	1030	900	800	700	600	500

(b) Seasoned Material

Strength Group	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8
Air-dry density at 12 percent moisture content (kg/m³)	1200	1080	960	840	730	620	520	420

APPENDIX A

SAMPLING

Valid sampling is achieved when the distribution of values in the sample represents the distribution of values in the population, and when the sample is free of bias. Failure to adopt a proper sampling procedure will prevent valid estimates of sampling errors from being calculated, and consequently the accuracy of the calculated means and other statistics will be doubtful.

Regions, localities within regions, and stands should be sampled so as to ensure that the number of trees sampled at each level is as closely proportional as practicable to its component of the estimated standing volume of a species throughout its range.

A detailed discussion of sampling and its technical background is given in CSIRO Forest Products Technical Note No 5, Sampling of Timber for Evaluation of Species Properties.

APPENDIX B

STANDARD MECHANICAL TESTS

The methods used in Australia for the testing of small clear specimens of timber to determine mechanical strength properties are described by Mack (1979)*.

Two sizes of specimens, referred to as the 50 mm and the 20 mm standards, are described for many of the tests. While the former is the preferred size, international standards based on the 20 mm standard have been written. This size is used in Australia when insufficient material is available for the larger size.

In the absence of an Australian standard, BS 373:1957, Methods of Testing Small Clear Specimens of Timber, and ASTM D143-52, Standard Methods for Testing Small Clear Specimens of Timber, have been used with some modifications.

APPENDIX C

ADJUSTMENT OF TEST DATA TO 12 percent MOISTURE CONTENT

The paper by Mack referred to in Appendix B fully describes the method used to correct individual test results from seasoned material to 12 percent moisture content. This applies only to standard mechanical test data.

Average corrections per 1 percent moisture content difference from 12 percent are as follows:

Static bending:	modulus of rupture, 4 percent stress at limit of proportionality, 4 percent modulus of elasticity, 1.5 percent
Compression parallel to the grain:	maximum crushing strength, 5 percent stress at limit of proportionality, 5 percent; modulus of elasticity, 1.5 percent.

Corrections are additive if the moisture content at test is above 12 percent and subtractive if below.

*Mack, J.J (1979) Australian Methods for Mechanically Testing Small Clear Specimens of Timber. CSIRO Division of Building Research, Technical Paper (Second Ser.) No 31.

It has been shown how the four structural grades interlock with the strength groups to yield the system of stress grades, and that these four structural grades have strength ratios of 75%, 60%, 48% and 38%.

Suitable grades are described in Australian Standards:

- AS 2082-1979: Visually Stress Graded Hardwood for Structural Purposes.
- AS 2099-1977: Visually Stress Graded Australian Grown Softwood (Conifers) for Structural Purposes (excluding Radiata pine and Cypress Pine).
- AS 1490-1973: Visually Stress Graded Radiata Pine for Structural Purposes.

Summaries of these standards are given in Tables 4, 5 and 6. Note that these are summaries only and do not contain all the data of the above standards and timber graded to them cannot be strictly described as complying with an Australian standard. The terms used are illustrated in Figures 1, 2 and 3. Tables of permissible spring and twist are given in Table 7.

A very large number of grading rules exist around the world. These rules may be for export timber or for domestic consumption. In the case of reasonably widespread use of a particular rule, it is recommended that it should be compared with the rules in Tables 4, 5 and 6 and if possible used with minor modifications to produce stress-graded timber. In this way, there is a minimum of disruption to an existing trade practice and timber design codes for both timber engineering and timber framing based on Australian strength-grouped timber may be used with confidence.

TABLE 4

HARDWOOD STRUCTURAL GRADES

Permissible Imperfections	Ref	Structural No 1	Structural No 2	Structural No 3	Structural No 4
Knots(sound or unsound oval and arris) measurement not exceeding A of the width of the surface on which they occur (see Fig1)	A	one-seventh	one-quarter	one-third	three-eighths
Borer holes not associated with decay. Up to 3mm dia- not exceeding B in any 100m x 100mm or equivalent area.	B	12	20	Unlimited	Unlimited
Over 3mm diameter or where the distance between holes is less than twice their diameter as for knots.					
Tight gum veins - not exceeding C in aggregate	C	length of piece	Unlimited	Unlimited	Unlimited
No individual vein exceeding D of the length of the piece. Not extending from one surface of the piece to another.	D	one-half	-	-	-
Loose gum veins and shakes - not exceeding 3mm wide Aggregate length not exceeding E of the length of the piece. Not extending from one surface of the piece to another	E	one-tenth	one-ninth	one-quarter	one-third
Gum, latex or resin pockets and overgrowth of injury-					
Length- individually not exceeding three times the width of the surface on which it occurs or 300mm whichever is the lesser					
Width, if on one surface only, individually not exceeding F of the width of the surface or	F	one-quarter	one-third	one-half	one-half
G whichever is the lesser	G	12mm	20mm	25mm	30mm
If extending from one surface to another individually not exceeding H of the width of	H	one-eighth	one-quarter	one-third	one-third
the surface on which it occurs or J, whichever is the lesser, where it intersects an end it shall be considered as an end split (see below)	J	6mm	12mm	20mm	25mm

TABLE 4 (contd)

HARDWOOD STRUCTURAL GRADES

Permissible Imperfections	Ref	Structural No 1 75%	Strucutral No 2 60%	Structural No 3 48%	Strucutral No 4 38%
Bow Spring and Twist - Not exceeding the values given in Tables 7 and 8					
Cupping - not exceeding 1mm per 50mm of width.					
Checks. Surface checks-on surfaces up to 75mm wide-individually not exceeding K wide - on surfaces exceeding 75mm wide, individually not exceeding	K	2mm	Unlimited	Unlimited	Unlimited
L wide	L	3mm	Unlimited	Unlimited	Unlimited
Internal checks Projected length S (see Fig.1) not exceeding M of the thickness of the piece.	M	one-quarter	one-third	one-half	two-thirds
Sloping grain (see Fig.1) Not exceeding 1 in N	N	15	10	8	6
Primary rot and termite galleries		On the surface only and alight			Not greater than allowance for wane and want
Wane want and sapwood susceptible to Lyctid attack					
Not exceeding in aggregate or individually P of the cross sectional area	P	one-tenth	one-fifth	one-quarter	one-quarter
Not exceeding one-third of the thickness					
Heart and heart shakes Where the smaller dimension is less than 175mm - not permitted. Where the smaller dimension is 175 mm or more provided that they are in the middle third of the cross section of the piece					
Included bark - intersecting an end. Individual strands not more than Q long	Q	Not permitted	75mm	150mm	200mm
Not intersecting an end but within 600mm of an end, individual strands not exceeding R long	R	Not permitted	150mm	300mm	400mm

TABLE 4 (contd)

Permissible Imperfections	Ref	Structural No 1 75%	Structural No 2 60%	Structural No 3 48%	Structural No 4 38%
Included bark - Not intersecting an end and not within 600mm of an end but within the middle half of the depth - individual strands not exceeding S long and not less than 300mm apart.	S	15	300mm	600mm	800mm
Not intersecting an end and not within 600mm of an end but outside the middle half of the depth - individual strands not exceeding T long and not less than 300mm apart.	T	300mm	600mm	Unlimited if tight	Unlimited if tight
End splits equal in aggregate to U times the face width or V, whichever is the lesser.	U	Not permitted	1	1.5	1.5
	V		100mm	150mm	150mm

TABLE 5

SOFTWOOD STRUCTURAL GRADES

Permissible Imperfections	Ref	Structural No 1-75%	Structural No 2-60%	Structural No 3-48%	Structural No 4-38%
Knots, sound or unsound, round oval or spike, intergrown or partially intergrown, single or in clusters -					
Face knots - width not exceeding A of the width of the face and appearing wholly without the central B of	A	one quarter (25%)	one-third (33%)	two-fifths (40%)	half (50%)
the width of the face	B	half (50%)	five eighths (62%)	three quarters (75%)	three quarters (75%)
Margin knots - Width not exceeding C of the width of the face	C	one-seventh (14%)	one quarter (25%)	three tenths (30%)	three eighths (37%)
Through knots - as for face or margin knots as appropriate					
Edge knots - not exceeding D of the thickness of the piece	D	one-quarter (25%)	two-fifths (40%)	one half (50%)	three fifths (60%)
Knots in groups					
On the face - aggregate width not exceeding E of the width	E	one-quarter (25%)	one-third (33%)	two-fifths (40%)	half (50%)
of the face and no single knot in the group exceeding F of the width of the face	F	one-tenth (10%)	one-sixth (17%)	one-fifth (20%)	one-quarter (25%)
On the edge - width not exceeding G of the thickness of the piece	G	one-quarter (25%)	two-fifths (40%)	half (50%)	three fifths (60%)
Borer holes					
Up to 3mm wide not exceeding H in any 100mm x 100mm or equivalent area	H	12	20	Unlimited, provided that the distance between the holes is at least twice their width	
Over 3mm wide - or where the distance between the holes is less than twice their width		As for knots above	As for knots above	As for knots above	3mm to 6mm wide not more than 6 in any 1m of length
Rosin pockets bark pockets and overgrowths of injury - Not exceeding 10mm wide x 150mm long or equivalent area					
Bow Spring and Twist - not exceeding the values given in Tables					
Surface checks - individually not exceeding J wide or K long	J,K	1mm 450mm	1mm 450mm	1mm 600mm	2mm 600mm
L Sloping Grain - not exceeding 1 in L	L	15	10	8	6
L Insect Galleries - not more than M wide x N long and not more than one-quarter of the width of the piece	M,N	Not permitted	Not permitted	Not permitted	6mm 230mm
Wane and Want - not exceeding P of the width	P	one-sixth (17%)	one-quarter (25%)	one-quarter (25%)	one-quarter (25%)
Pith - In pieces 200mm and wider and only in the middle Q of the piece	Q	third (33%)	third (33%)	third (33%)	third (33%)
Stain		Unlimited	Unlimited	Unlimited	Unlimited

Note This is a very general table and for many species e.g. Douglas fir Radiata pine etc., specific structural grading rules have been developed and proved by extensive laboratory testing. Such rules take account of characteristics peculiar to the species concerned. Provided that such rules are associated with design stresses which in turn can be associated with the design stresses given in Table 1, they should be used in preference to the rules shown in this Table.

TABLE 6

RADIATA PINE STRUCTURAL GRADES

Permissible Imperfections	Ref	F8 (60%) grade	F7 (48%) grade	F5 (38%) grade
Knots - round oval or spike, sound or unsound, intergrown or partially intergrown, single or in clusters -				
Face knots not exceeding A of the width of the face, if	A	two-fifths (40%)	one-half (50%)	three-fifths (60%)
appearing wholly within the central B of the width of the face.	B	three-quarters (75%)	three-quarters (75%)	four-fifths (80%)
Margin knots - not exceeding C of the width of the face	C	three-tenths (30%)	three-eighths (37%)	seven-sixteenths (44%)
Through knots - to be measured as face or margin knots as appropriate				
Edge knots - not exceeding D of the thickness of the piece	D	one-half (50%)	three-fifths (60%)	two-thirds (67%)
Knots in groups - on the face, not exceeding E of the width of the face when measured as a group and provided no	E	two-fifths (40%)	one-half (50%)	three-fifths (60%)
single knot in the group exceeds F of the face	F	one-fifth (20%)	one-quarter (25%)	three-tenths (30%)
On the edge - not exceeding G of the thickness of the piece	G	one-half (50%)	three-fifths (60%)	two-thirds (67%)
Arris knots - cross-sectional area not exceeding H of the cross-sectional area of the piece	H	three-tenths (30%)	three-eighths (37%)	seven-sixteenths (34%)
Holes - to be measured as knots				
Sloping grain - not exceeding 1 in J	J	8	6	5
Seasoning checks - individually not exceeding 600mm long				
Wane and or want - not exceeding one-quarter of the width of the face or edge being considered				
Resin pockets and bark pockets - not exceeding 12mm wide by 150mm long or an equivalent area				
Stain.				
Bow, Spring and Twist - as allowed in Tables 7 and 8				
Pith - only in pieces not less than 240mm wide and only if occurring within the middle third of the width of the piece.				

Note: This table summarises the grade requirements of AS 1490-1973. This standard applies only to Radiata pine, other pine species in Australia being graded to AS 2099. However, New Zealand, a major Radiata pine producer uses a single set of very similar grading rules for Corsican (P.nigra) loblolly (P.taeda) lodgepole (P.contorta) long-leaf (P.palustris) pines as well as for Radiata pine. See also the comments concerning Mexico on page 33.

ILLUSTRATIONS OF IMPERFECTIONS

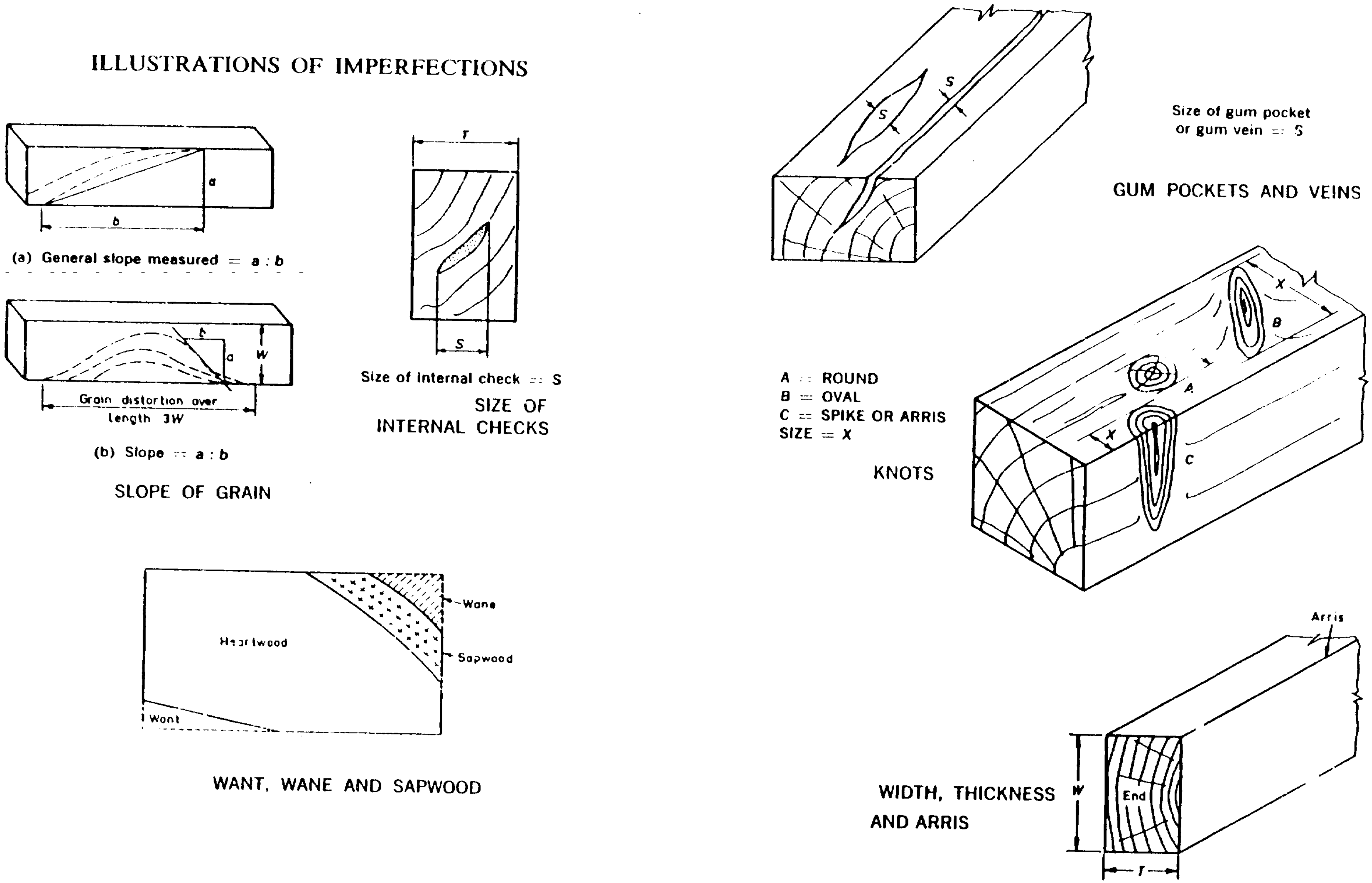
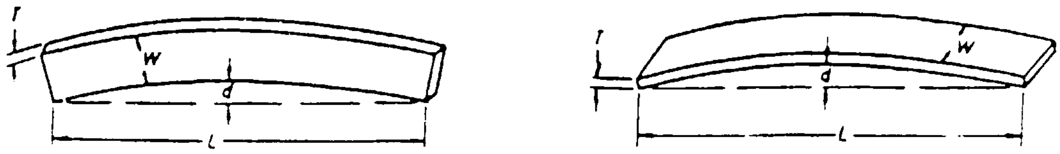


Fig. 1: Illustrations of imperfections



Spring = *d* (see Table 7 for values of *d*)

SPRING

Bow = *d* (see Table 7 for values of *d*)

BOW

Fig 2 Spring and Bow

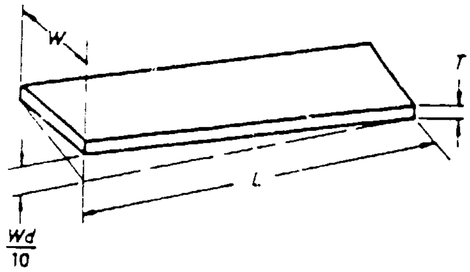
TABLE 7

MAXIMUM PERMISSIBLE SPRING OR BOW

Length *L* m	Maximum permissible spring or bow *d*, mm — Width *W* (for spring) or thickness *T* (for bow), mm												
	38	50	75	100	125	150	175	200	225	250	275	300	350
1·8	10	10	7	5	4	3	3	3	2	2	1	2	1
2·4	20	15	12	9	7	6	5	4	4	4	3	3	3
3·0	35	25	19	14	11	9	8	7	6	6	5	5	4
3·6	50	35	25	20	16	13	12	10	9	8	7	7	6
4·2	6[illegible]	45	25	28	22	18	16	14	12	11	10	9	8
4·8	70	50	30	30	29	24	21	18	16	14	13	12	10
5·4	75	55	40	40	36	30	26	23	20	18	17	15	13
6·0	80	60	45	45	45	37	30	28	25	22	20	19	16
6·6	85	65	50	45	45	45	39	34	30	27	25	23	19
7·2	90	70	55	50	50	50	46	40	36	32	29	27	23
7·8	100	75	60	50	50	50	50	45	40	38	34	32	27
8·4	105	80	65	55	55	55	55	55	50	44	40	37	31
9·0	110	85	70	60	60	60	60	60	55	50	46	42	36

NOTE The limitations on distortion have been governed by considerations of production and utilization within the constraints of the principles of structural adequacy as set down in Appendix G of AS 1720

(AS 2082)



Maximum permissible twist $= \frac{W \times d}{10}$ (see Table 8 for values of d)

Fig. 3 TWIST

TABLE 8
MAXIMUM EQUIVALENT TWIST

Length L	Maximum equivalent twist, d mm/10 mm width of piece					
	Thickness T, mm					
m	38	50	75	100	125	150
1·8	1·6	1·2	0·8	0·6	0·5	0·4
2·4	2·1	1·6	1·1	0·8	0·6	0·5
3·0	2·6	2·0	1·3	1·0	0·8	0·7
3·6	3·1	2·4	1·6	1·2	1·0	0·8
4·2	3·6	2·8	1·8	1·4	1·1	0·9
4·8	4·2	3·2	2·1	1·6	1·3	1·1
5·4	4·7	3·6	2·4	1·8	1·4	1·2
6·0	5·3	4·0	2·7	2·0	1·6	1·3
6·6	5·8	4·4	2·9	2·2	1·8	1·5
7·2	6·3	4·8	3·2	2·4	1·9	1·6
7·8	6·8	5·2	3·5	2·6	2·1	1·7

NOTE: The limitations on distortion have been governed by considerations of production and utilization within the constraints of the principles of structural adequacy as set down in Appendix G of AS 1720.

Provisional Strength Grouping

Two approaches to strength grouping are acceptable. Preferably, mechanical properties are determined. This required the services of a mechanical testing laboratory and skilled technicians. Recommendations on the establishment of such a laboratory are beyond the scope of this report.

The alternative provisional method is to infer a strength group from density measurements.
The density is measured as:

$$\frac{\text{weight at 12\% m.c.} \quad (Kg)}{\text{Volume at 12\% m.c.} \quad (m^3)}$$

Volumetric shrinkage of wood is about ½% per 1% change in moisture content (m.c.). Consequently errors can arise if the volume is measured at m.c's differing greatly from 12% Fortunately shrinkage is fairly linear with moisture content.

It is recommended that volume measurements should be taken on pieces of machined board about 2.5 x 15 x 30 cm as shown in Figure 4. These should be machined accurately and cross cut square with a fine tooth saw.

Measurements should be taken with vernier calipers if possible. These pieces are then kiln dried, re-measured and finally oven dried.

A worked example will demonstrate the procedure. Note that several measurements have been taken. The positions should be marked so that remeasurements are taken at the same points. Measuring points should be about on-quarter of the way along the length or width to avoid excessive shrinkage at the ends as shown in Fig. 4.

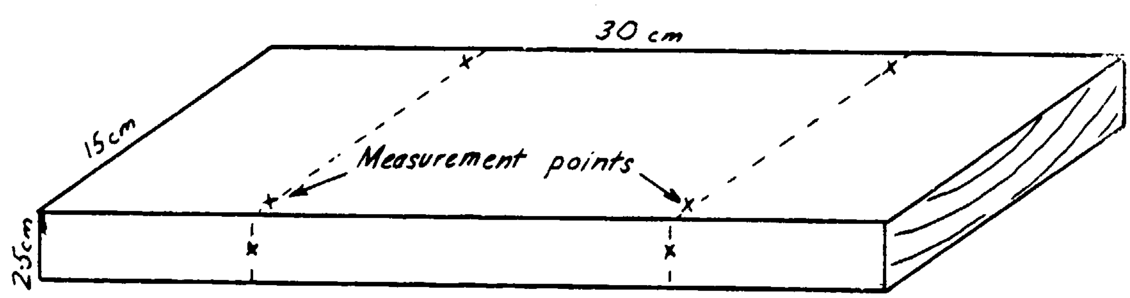


FIG. 4 DENSITY SPECIMEN

Sample Calculations

Species .... Sample No. ....

1. Air Dry

	Width mm	Thickness mm	Length mm	Weight
	146.32	22.68	295.70	671.80 gm
	146.48	22.60	296.10	
Average	146.40	22.72	295.90	
		22.64		
		22.66		

Volume = 981.63 cm3

2. Kiln Dried

	Width mm	Thickness mm	Length mm	Weight
	141.80	22.01	295.60	620.10 gm
	141.68	21.99	295.90	
	141.74	21.86	295.75	
		21.90		
		21.94		

Volume = 919.72 cm3

3. Oven Dried

Weight
567.90 gm

4. Calculations

AD wt	671.80 gm
OD wt	567.90 gm
Water	103.90 gm

m.c. = (103.90/567.90) x 100 = 18.30%

KD wt	620.10 gm
OD wt	567.90 gm
Water	52.20 gm

m.c. = (52.20/567.90) x 100 = 9.20%

Weight at 12% m.c. = 567.90 x (112/100) gm

= 636.00 gm

AD Volume	981.63 cm^3
KD volume	919.72 cm^3
Difference	61.91 cm^3

Difference in m.c. 18.3% - 9.2% = 9.1%

Volume change per 1% m.c.	= 61.91/9. 10 = 6.80 cm^3
Volume change for (12-9.1	= 2.90 x 6.80 cm^3
	= 19.73 cm^3
Volume at 12% m.c.	= 919.72 + 19.73 cm^3
	= 939.45 cm^3
Density at 12% m.c.	= (636.00/939.45) x 1000 Kg/m3
	= 677.00 Kg/m3

Provisional strength group (S6,) (SD6).

In the absence of proper facilities, a kiln may be improvised from a small room or a large cupboard containing an electric fan heater. Be careful not to let the temperature rise above 55 degrees cent. Too high a temperature may result in driving off extractives, thus giving an excessively low weight, but temperature lower than 100 degrees cent. will not drive off all the moisture. Oven drying should continue for several days and be checked every 8 hours to ensure that constant weight has been reached.

Equipment costs would be about:

15 cm vernier callipers	$50
30 cm steel rule with hook	$15
Balance 2000 gm x 0.1 gm	$125
Thermometer 0.2000	$15

It may be possible to borrow these from a high school or polytechnic.

Note that data from at least five separate trees is required. This may be arranged by taking one freshly cut board per day over a period of a week. Preferably as wide a geographical range as possible should be covered and a sampling from different mills should be made if possible.

Joints

In the same way as timbers may be grouped for their overall performance as structural elements (beams, columns, ties etc.) so they may also be grouped for their holding power for fasteners. Grouping for joint strength is done on a different basis from strength grouping.

Two papers by J.J. Mack (Mack 1978, Mack 1978b) (4.5) describe the background to the joint grouping as presented in AS 1720 Section 4, and also a proposed revision. The present situation in AS 1720 is shown in Table 9.

Joint Group	Basic density Kg/m3	Allowable load for 2.8 mm dia. nail
J1	700	360
J2	650 - 700	320
J3	500 - 650	265
J4	500	190

Table 9 - Joint Groups - AS 1720 - 1975

Mack does not make it clear exactly wi the boundaries lie, i.e. 649 or 650. He then recommends a rather more rational grouping shown in Table 10 which is now (March 1985) under discussion for adoption as a revision to AS 1720. Nail loads for this grouping are shown in Tables 11 and 12 for green and seasoned timber respectively.

Table 10 Proposed Revision to AS 1720

Classification of Timbers for Use in Joint Design

Group	Basic Density	Group	Air-dry Density
J1	750	JD1	940
J2	600	JD2	750
J3	475	JD3	600
J4	380	JD4	475
J5	310	JD5	380
J6	250	JD6	310

Note how densities and the allowable loads for the typical nail lock in as for stress grades. Loads for other nail sizes are proportional to the 1.75 power of their diameters.

Since the system summarised in Tables 10 and 11 is as yet (March 1965) only proposed, it is recommended that those wishing to institute this system of design should group their timbers for joint strength in accordance with Table 9, but also be prepared to regroup in accordance with Table 10 when AS 1760 Section 4 is revised. This will ensure that existing detailed designs may be used without revision.

TABLE 11 (a)
BASIC LATERAL LOADS FOR ONE NAIL IN SINGLE SHEAR
IN SIDE GRAIN OF UNSEASONED TIMBER

Species group	Basic lateral load per nail (N)						
	Nail diameter (mm)						
	2.5	2.8	3.15	3.75	4.5	5.0	5.6
J1	330	400	490	665	915	1100	1340
J2	260	315	385	525	720	870	1060
J3	185	225	275	375	515	620	755
J4	130	160	195	265	365	440	540
J5	100	120	150	200	275	330	400
J6	75	90	110	150	210	250	300

TABLE 11 (b)
BASIC LATERAL LOAD FOR ONE STEEL NAIL IN SINGLE
SHEAR IN SIDE GRAIN OF SEASONED TIMBER

Species group	Basic lateral load per nail (N)						
	Nail diameter (mm)						
	2.5	2.8	3.15	3.75	4.5	5.0	5.6
JD1	435	530	650	885	1210	1460	1780
JD2	330	400	490	665	915	1100	1340
JD3	260	315	385	525	720	870	1060
JD4	185	225	275	375	515	620	755
JD5	150	185	230	310	425	510	620
JD6	115	140	170	235	320	385	470

Table 11 Proposed Revision to AS 1720

Strength Grouping and Design Codes

Apart from the advantages described above, strength grouping allows the effective seperatiuon of materials specification from building codes. Leicester 1961 (2) illustrates this separation in Fig 5.

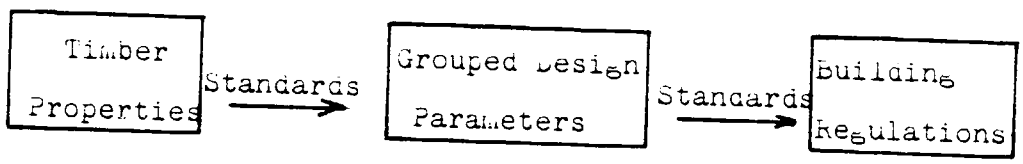


Figure 5 - Separation of material properties from building codes

There are many obsolescent building codes which contain requirements for species long since cut out, or for cities whose inspectors have no authority to permit the use of newly imported species or the produce of recently matured plantations.

In the process of introducing or vitalising timber construction it is almost inevitable that mistakes or omissions will be made. This is certainly likely to happen if building codes contain data for individual species, and building codes are notoriously difficult to update. Separation in the fashion indicated in Fig 5, separates new knowledge or newly available materials from the building code and gives a much better chance of up to date data being included in current construction.

Other Considerations

Strength alone is not the only property to be considered when a species of wood is evaluated for its suitability for structural purposes. Important considerations are:

Identification: Will the species specified actually be supplied and is it readily recognisable in situ?

Ease of Drying: Does the species dry quickly with little or no splitting or warping?

Natural durability, or alternatively

Ease of preservative treatment.

Ease of working.

It is important that weak or non-durable timbers are not mixed in with the selected species. In many countries control of logging operations is lax or non-existant and timber may be marketed merely as "red" or "white", "hard" or "soft". This situation is obviously unsatisfactory, if end use demands on strength and durability are high. It may be necessary to include supervision of logging and sawmilling operations to ensure that the species specified is actually supplied. Identification of sawn timber is much more difficult than identification of trees and timber becomes more and more anonymous as it passes through the various processing stages.

It may be necessary to paint the butts of trees when they are felled, and also paint each sawn log as it is bucked from the stem. In this case, use a type of paint not locally available to foil unscrupulous operators from later foisting off unsuitable but similar coloured wood.

Drying is an important consideration in structural timber. Timber coming into a fabricating plant should ideally be dry, flat, straight and free of major checks and splits.

Some species are extremely difficult to dry without degrade, or dry very slowly. Other considerations being equal, it may be preferable to choose a weaker species with more favourable drying characteristics than a stronger one which does not dry satisfactorily.

Degrade during drying can be controlled by good practice. This is a major subject by itself and is not covered further here. Some references on good practice are given in the bibliography.

Durability is an important consideration in exterior structures. Information on natural durability of woods is available from as variety of sources, some of which are listed in the bibliography. It should be remembered that durability is an interaction between the environment and the wood, and less naturally durable species may give long service in dry cool climates. Sap wood of nearly all species is non-durable and should therefore be excluded from structural timber which is not to be preservative treated.

In assessing the required durability, a "Climatic Index" has been proposed by Sheffer (6) to indicate the relative hazard of decay in above-ground structures due to moisture and warm temperature.

It has the form:

$$I = 1/17 \sum_{Jan}^{Dec} ((T-2)(D-3))$$

where T = mean monthly temperature, centigrade
D = number of days in the month when rainfall equals or exceeds 0.25 mm.

Values of I less than 35 indicate low decay hazard, up to 65, an intermediate decay hazard and greater than 65 a high decay hazard. Assuming that the meteorological data for a site are available, an estimate of any necessary measures against decay may be made. This may include specifications of specially durable timber or varying intensities of preservative treatment. Preservative treatment is an alternative to the use of durable timbers. Well preserved timber will frequently outlast untreated durable timber in the same environment. If nondurable timber is to be used in a high decay hazard area, then preservation becomes essential, and ease of treatment becomes an overriding consideration. Preservation can also provide protection against insect attack which in some cases may be more of a hazard than decay.

In general, strong timbers are dense and difficult to treat by pressure methods. Non-pressure treatments rarely give protection against decay. Again this is a major subject and will not be discussed further here. Information on the treatability of various species is contained in several of the references given in the bibliography.

Strong dense timbers are more difficult to work than soft weaker timbers. It is impossible to drive nails into many desne species without resort to preboring. Also many timbers contain siliceous deposits or, like coconut, have a fibrous structure which quickly blunts steel tools. These timbers may be readily worked with tungsten carbide tipped tools, but these are about 3 or 4 times as expensive as steel tools and require precision diamond wheel grinders for sharpening. Information on the abrasive properties of woods is found in the same references as for durability and ease of preservation.

General Discussion

There are many arguments in favour and many against the concept of strength grouping. This report details the Australian system for two reasons:

1. The UNIDO prefabricated bridge has been designed using the concept. If a country (or organisation) wishes to use the designs, it will have to strength-group and structurally grade its timber in accordance with this system.
2. Following on and based around the concept are the comprehensive Australian Timber Design and Timber Framing codes. Adoption of the system will then immediately open the way for designers in developing countries to build in timber as soon as a minimum of testing, or even literature research, has been carried out using these Australian documents.

Consideration 1. above was the main incentive for the preparation of this report. However, international enthusiasm is such that Leicester (1981) reports that strength grouping to the Australian system has been carried out on 700 African species (SAA 1979) and 190 South American species (Berni et al 1979).

The Australian concept is not the only one possible. Many people consider the number of grades and the complexity of the Australian codes are excessive. To quote Leicester (1981).

"In setting up grouping systems, the primary factor to bear in mind is that grouping is a technique to provide a compromise between simplicity (achieved by reducing the number of groups) and utilization efficiency (achieved by increasing the number of groups in an attempt to match all grades of the major species). In deciding the optimum compromise an important factor to bear in mind is that the minimum step between each group should be related to the accuracy with which strengths can be assessed. Too fine a step size will lead to additional complexities which are not compensated by any real increase in the efficiency of utilization. On the other hand, too large a step size will lead to a noticeable selling price differential between each strength; this in turn will lead to undue pressure on timber producers to market their timber as being of a strength class higher than is correct, with resulting chaos in the areas of both marketing and building regulations."

Keating (1982)(1) describes alternative grouping systems in use or proposed in several countries. The United Kingdom is discussing the introduction of nine strength classes with two softwood grades of SR 35% and 50% and one hardwood grade of 67%.

The Philippines has developed a system close to the Australian one in that it uses a preferred number series with an interval of 1.25 but it has been limited to only five strength groups. The advantages of this system are given as:

(i) Each member species within a class can substitute for the other; thus in a way overcoming the problem of supply.

(ii) The traditional bias against the lesser-known species is easily overcome when these are grouped together with the more common species. Hence, this system will help engineers and architects familiarise themselves with alternative species by specifying that any timber within a given class may be used instead of specifying the timbers by name.

(iii) It will overcome the problem that is usually encountered in identifying sawn timber of similar physical and strength characteristics.

(iv) Grouping will simplify design and specification procedure and thus facilitate the formulation of a comprehensive building code for structures using solid wood. The grouping scheme will form a rational series that will fit closely with timber grades. With this system, only a few sets of working stressses are adequate to cover the proposed strength classes and grades of timber".

(Espiloy 1977 in Keating op. cit.)

In South America, Bolivia, Colombia, Ecuador, Peru and Venezuela have combined to produce a strength grouping system comprising three strength groups and one 40% hardwood grade. An interesting approach taken in the developoment of the single visual grading rule was that the limits set on size and location of defects should permit an average mill to produce 50-60% of acceptable structural material. The remainder of the mill output would normally be suitable for non-structural applications in housing such as sheathing and joinery.

In Mexico, an apparently even more drastic grouping has been made of the country's 50 pinus species into a single strength group. Two structural grades have been designated which would approximate F14 and F8. The cut of an average mill would be 30% top grade, 40% second grade and 30% non structural. There is an indication which would appear to justify this simplicity that within mill variation is larger than the regional variation.

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