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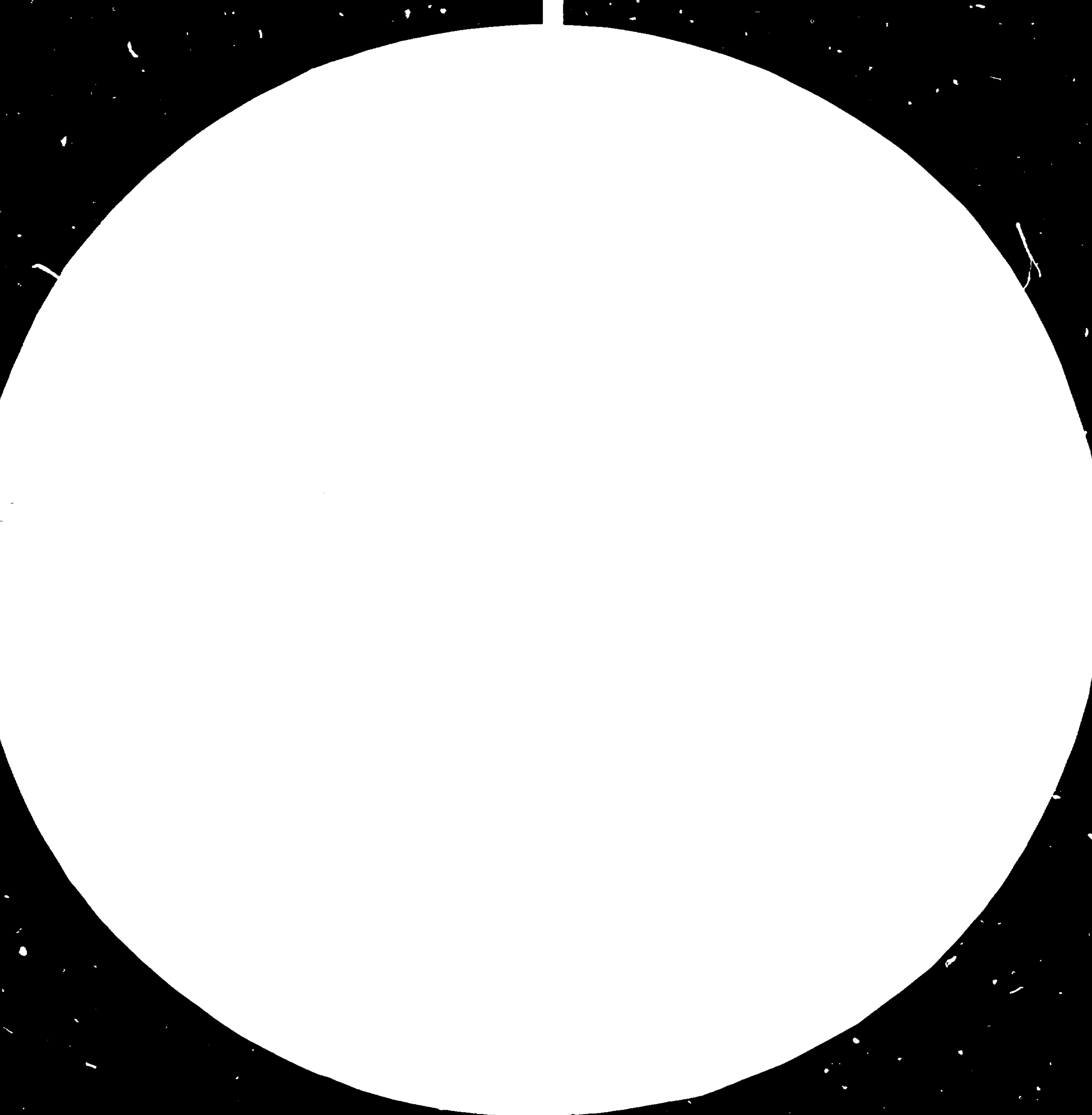

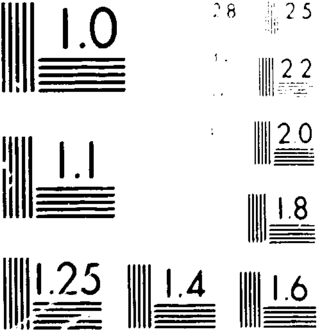
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Dist.
LIMITED
ID/WG.359/4
24 May 1982

ENGLISH

United Nations Industrial Development Organization

Expert Group Meeting on Timber
Stress Grading and Strength Grouping
Vienna, Austria - 14-17 December 1981

REVIEW OF TIMBER STRENGTH GROUPING SYSTEMS*

by

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1. Introduction

To the casual observer it must seem strange that in some countries, particularly those where forests are an obvious major natural resource, the structural use of timber lags well behind the level attained by other construction materials. There are probably many reasons based on economic, technical and even cultural aspects why this is the case. One reason surely must be the problem involved in presenting structural data to the end-user in an appropriate fashion whenever there is a multiplicity of species involved. A technique devised to minimize this problem is grouping.

To give just a few examples of the magnitude of the problem, Pong Sono (1974) has listed approximately 200 species of merchantable timber in Thailand, Espiloy (1978) notes that in the Philippines there are over 3000 timber species of which several hundred are probably potentially merchantable. In Australia, while there are about 80 species used extensively, more than 500 species have been classified for structural use (Standards Association of Australia, 1979a). Many of these species are sold in mixtures because of the practical difficulties associated with their identification and segregation, but strength grouping is able to cope with this requirement (Leicester and Keating, 1982).

2. Basis of Grouping

Essentially grouping for structural purposes means the creation of a preferably small set of hypothetical species so that any timber may be classified within this set and considered as equivalent to one of the hypothetical species.

From a survey of the literature it would appear that many countries have either adopted the Australian system of strength grouping described by

Pearson (1965) and Kloot (1973) or have used it as the basis for developing their own systems. Some of the countries are Kenya, Tanzania, Nigeria, Papua New Guidea, Fiji, Samoa and Solomon Islands. In addition, the United Nations Industrial Development Organization has used the technique in the development of the design of a low-cost modular prefabricated wooden bridge. Of course there are many other systems in use, but most of the well known ones such as those used in Northern America are, in the main, concerned with a comparatively small number of softwood species.

3. Motivation for Grouping

The degree of motivation for adopting a classification system based on structural properties varies directly with the number of species that are required to be accommodated. Without grouping, the problems involved are most obvious when it comes to publishing design information. Even if the data on a large number of species from a particular country were available, it is often not feasible to publish the relevant design information in a readily accessible form. This is where the use of grouping techniques makes such data presentation much easier.

The area of building regulations is one where grouping introduces advantages that are of particular value (Leicester, 1981a). Besides the obvious simplification regulations written in terms of groups rather than individual species have tables of design properties incorporated within them that remain fixed. This means that no major change is involved should a new timber be introduced on to the market or an existing one be reassessed. In Australia the SAA Timber Framing Code AS 1684 (Standards Association of Australia, 1979b) through a limited set of tables manages to present spans and sizes of all the timber framing members required in domestic housing construction applicable to all grades for several hundred species or species mixtures in a most convenient format.

Even in the case where a single species dominates the timber construction scene, grouping in relation to building regulations is advantageous. The structural properties of populations of timber taken from the same species, particularly with plantation timbers, can vary from one forest location to the next and can also vary with forest age and silvicultural practices.

Transferring a species, or the production from one area, from one group to another is not nearly as complicated as promulgating a new or additional set of design stresses (Leicester, 1981a).

Internationally an agreed grouping technique could help timber utilization generally and have special relevance to the structural timber trade. The UNIDO Bridge Project mentioned previously is a good example of grouping applied to the world situation as the set of design standards based on eight strength classes is directly applicable for almost any timber in the world. It is not difficult to envisage how other examples of technology transfer in the form of timber design codes and manuals would be possible if an agreed or compatible grouping system for structural timber was in general use. The grouping technique has the following advantages:

1. Building regulations are concerned with only limited sets of design parameters;

2. Marketing of structural timber is easier as it is carried out in terms of structural properties rather than by nomination of the species and grading methods;

3. More flexibility is available to the supplier as the range of species is much wider;

4. The entry of new lesser-known species onto the market is facilitated;

5. Trade, both internal and international, in structural timber is simplified;

6. Technology transfer in the form of timber design codes and manuals, is easier;

7. It is much less expensive in time and material to place a species in a group than it is to develop individual working stresses; and

8. It is possible to group a species, albeit conservatively, based on density measurements alone.

4. Existing Strength Grouping Systems

It is proposed to discuss strength grouping systems in a few selected countries.

(a) Australia

Strength grouping in Australia has been in operation now for more than forty years. Langlands and Thomas (1939), in their Handbook of Structural Timber Design, proposed for Australian conditions four strength groups. A species was placed in a group according to its species mean values as determined from standard tests on small clear specimens. These strength groups were established when there was little information available about the properties of most Australian species and their successful use was possible only because the limits were not closely defined (Pearson 1965).

The impetus at that time to establish strength groups came, as it does now, from the need to cope with a large number of species, many of which are difficult to identify and many are also marketed as mixtures.

The original Australian strength grouping system was revised and expanded as has been explained by Pearson (1965) and Kloot (1973). Prior to the expansion of the strength groups, made necessary to cope with new information and new species, Pearson developed a set of working stresses that has now become the basis for a strength classification system.

Working back from the set of working stresses, it was then possible to develop the appropriate strength groups. This process is the reverse of the usual procedure for deriving working stresses for an individual species allowing for duration of load, accidental overloads and estimating the 1% probability point.

In the development of this set of stresses, Pearson reported that three decisions were required. Firstly, it was necessary to decide whether the stresses should be in arithmetic or geometric progression. Secondly, a compromise was required on the magnitude of the differences between successive stresses in order to achieve a satisfactory balance between simplicity associated with having only a few groups and the greater efficiency associated with numerous groups. Finally, the actual value of the stresses had to be decided.

Cooper (1953) had shown the merits of a geometric series for working stresses and such a choice had also been recommended by the International Organization for Standardization (ISO) and the Food and Agriculture Organization (FAO). Accordingly, such a choice was made using a preferred number series with adjacent terms chosen in the ratio of 1.25 to 1 for Modulus of Rupture. This was judged to be the appropriate compromise between simplicity and preciseness. Also, as appeared certain, the Australian visual grading rules then being developed would probably have differences between grades also of 25%. The range of the values chosen was such that it covered all the species likely to be used structurally in Australia.

Using the set of values decided upon as the basic working stresses in bending, the values of the other properties were determined from regression equations.

From this technique has developed Table 1, which is the basis of the current Australian strength classification system.

TABLE 1

DESIGN PROPERTIES FOR SAWN TIMBER, ROUND POLES AND PLYWOOD

Stress* grade	Basic bending strength (MPa)**	Basic tension strength (MPa)	Basic compression strength (MPa)	Modulus of elasticity (MPa)
F34	34.5	20.7	26.0	21 500
F27	27.5	16.5	20.5	18 500
F22	22.0	13.2	16.5	16 000
F17	17.0	10.2	13.0	14 000
F14	14.0	8.4	10.2	12 500
F11	11.0	6.6	8.4	10 500
F8	8.6	5.2	6.6	9 100
F7	6.9	4.1	5.2	7 900
F5	5.5	3.3	4.1	6 900
F4	4.3	2.6	3.3	6 100
F3	3.4	2.1	2.6	5 200
F2	2.8	1.7	2.1	4 500

* The insertion of the letter F before each value in the Table introduces the concept of stress grade. Stress grade is defined as the classification of a piece of timber for structural purposes by means of either visual or mechancial grading to indicate primarily the basic working stress in bending in megapascals for purposes of design and by implication the basic working stresses for other properties normally used in engineering design. For example, a piece of timber with a stress grade of F14 resulting from a certain combination of strength group and visual grade would have a basic working stress in bending of 14 megapascals.

** These values are the result of a soft metric conversion of a preferred series of values in imperial units viz. 5000, 4000, 3200, 2500, 2000, 1600, 1250, 1000, 800, 630, 500, 400 p.s.i., readily recognisable as the R10 series.

As described above, the species mean values for clear material for each strength group for the critical properties were developed for green and dry timber and are shown in Tables 2 and 3 respectively.

TABLE 2

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 3

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.

TABLE 4

RELATIONSHIP BETWEEN STRENGTH GROUP, VISUAL GRADE AND STRESS GRADE FOR GREEN TIMBER

Visual grade*		Stress grade						
Nomenclature	% strength of clear material	S1	S2	S3	S4	S5	S6	S7
Structural grade No.1	75	F27	F22	F17	F14	F11	F8	F7
Structural grade No.2	60	F22	F17	F14	F11	F8	F7	F5
Structural grade No.3	48	F17	F14	F11	F8	F7	F5	F4
Structural grade No.4	38	F14	F11	F8	F7	F5	F4	F3

* Australian Standard AS 2082-1977, Visually stess-graded hardwood for structural purposes; and AS 1648-1974. Visually stress-graded cypress pine for structural purposes.

Note the interlocking effect (diagonal line) reducing a possible 28 stress grades to 10.

TABLE 5

RELATIONSHIP BETWEEN STRENGTH GROUP, VISUAL GRADE AND STRESS GRADE FOR SEASONED TIMBER

Visual grade*		Stress grade							
Nomenclature	% Strength of clear material	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8
Structural grade No.1	75		F34	F27	F22	F17	F14	F11	F8
Structural grade No.2	60	F34	F27	F22	F17	F14	F11	F8	F7
Structural grade No.3	48	F27	F22	F17	F14	F11	F8	F7	F5
Structural grade No.4	38	F22	F17	F14	F11	F8	F7	F5	F4

* Australian Standard AS 2082-1977, Visually stress-graded hardwood for structural purposes; AS 2099-1977, Visually stress-graded seasoned Australian grown softwood (conifers) for structural purposes (excluding radiata pine and cypress pine); AS 1490-1973, Visually stress-graded radiata pine for structural purposes; and AS 1648-1974, Visually stress-graded cypress pine for structural purposes.

By use of Tables 2 and 3, every species that had been or was capable of being properly sampled and tested by standard methods using small clear specimens may be strength grouped. Once strength grouped, commercial pieces of that species can, following visual grading, be allocated a stress grade by reference to Tables 4 and 5.

From Table 1 the appropriate design parameters may be determined.

Because of international agreement on the standard methods of test for small clear specimens, it is possible to utilise data from recognised laboratories anywhere in the world to place any species into a strength group. This has been done for 700 African (Bolza and Keating, 1972), 190 South American (Berni <u>et</u> <u>al</u>., 1979) and 362 South-East Asian species (Keating and Bolza, 1982).

One assessment that is often required in classifying a species from Tables 2 and 3 is what to do when the three properties do not all have the same classification. A conservative approach would be to assign the species to the lowest group indicated 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.

Table 6 summarises the procedure that is followed indicating that more emphasis is placed on modulus of rupture and modulus of elasticity than on compression strength.

TABLE 6

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—			
Modulus of rupture	**Modulus of elasticity**	**Maximum crushing strength**	**Assessed S or SD strength group**
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 $x - 1$.

This leaves those species for which the strength data available are from less than a valid sample, assessed as a minimum of five trees, or is just not available at all. A recent examination by Leicester and Keating (1981) of the relationship between density and modulus of rupture of seasoned timber for 30 species from each of four regions around the world is indicated in Figure 1.

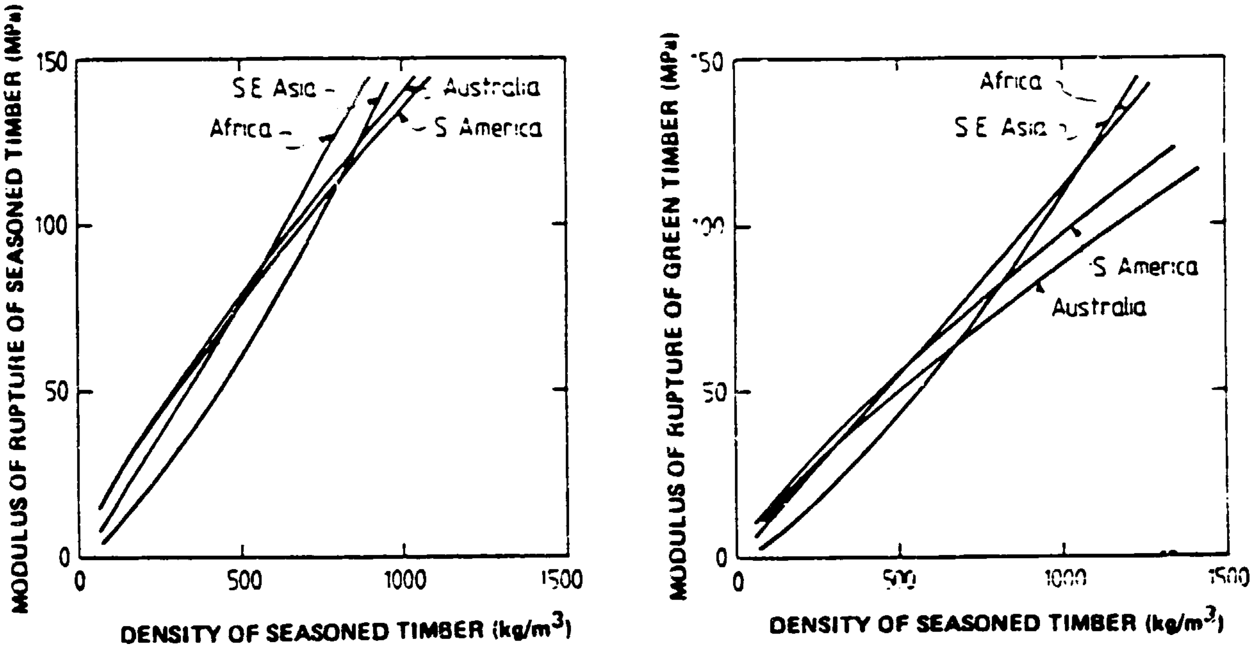

Figure 1. Regression lines for Modulus of rupture versus density of seasoned timber.

On the basis of this relationship, the following table was constructed to permit a classification to take place. This gives a rather conservative assessment, but at least it does allow those species with limited data to be entered into the system. In the Australian Standard MP 45-1979, Report on Strength Grouping of Timbers, species assessed in this fashion are listed with their strength groups in brackets to indicate the provisional nature of the assessment.

TABLE 7

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/m^3)	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/m^3)	1200	1080	960	840	730	620	520	420

To this point, discussion has been confined to the means of entering the strength classification system in Table 1 by way of strength grouping combined with visual grading. Direct entry into the system is also possible through machine stress grading and proof grading. Both these techniques are described in a later section.

(b) United Kingdom

Details of the system currently under discussion in the United Kingdom to be the basis of the revision of the British Standard Code of Practice on the Structual Use of Timber CP112:1967, have been given by Mettem (1981). Briefly nine strength classes have been proposed, C1 to C9, as shown in Table 8.

TABLE 8
DRY GRADE STRESSES AND MODULI OF ELASTICITY
FOR STRENGTH CLASSES AS PROPOSED FOR
BS 5268 : PART 2 (MPa)

Strength Class	Bending	Tension	Compression parallel	E	
				Mean	Min.
C1	2.8	2.2	3.5	6 800	4 500
C2	4.1	3.2	5.3	8 000	5 000
C3	5.3	4.2	6.8	8 800	5 800
C4	7.5	5.1	7.9	9 900	6 600
C5	10.0	6.0	8.7	10 700	7 100
C6	12.5	7.5	13.6	12 100	9 200
C7	15.6	9.5	15.7	14 900	11 400
C8	19.5	12.0	18.2	17 900	13 800
C9	24.4	15.0	21.3	21 500	16 700

The derivation of these stresses and the allocation of the various grades of those softwood species in common use in the United Kingdom to the appropriate strength classes was based on a testing program using structural sized timber. The range of species tested in this fashion did not include all those in use but for those not yet tested recourse was made to the small-clear test data and a ratio applied based on the 5th percentile results obtained from the tests on structural sized timber.

For the softwoods visually graded to BS 4978:1973 'Timber grades for Structural Use', the two visual grades, GS General Structural and SS Special Structural, cater for most of the imported softwood species have been allocated to the C3 and C4 strength classes respectively. The grade ratios (i.e. the comparison with clear strength values) for these two grades are considered to be 0.35 and 0.50 respectively in bending (Mettem, 1981).

For tropical hardwoods that will also be included in BS 5268 only one grade, HS Hardwood Structural, is proposed with a grade ratio in bending of 0.67. As with the softwoods the basic stresses were based on a combination of test data from small clears and the 5th percentile values obtained from testing of structural sized timber.

(c) Philippines

In the Philippines a system has been developed that is very similar to the Australia strength grouping system in that it is based on the results of small clear tests and adopts a preferred number progression with an interval of 1.25 between the base numbers (Espiloy, 1977). However it was judged that there was no need to cover the same range so only five groups have been chosen. The advantages of the grouping system according to Espiloy, are:

(i) Each member species within a class can substitute for the other, thus in a way overcome 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 familiarize themselves with alternate 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 stresses are adequate to cover the proposed strength classes and grades of timber.

The limiting average values for classifying a species into one of the strength classes, C1 to C5, are given in Table 9.

A procedure has been developed to cover the case when the property values for a particular species do not all fall within the same strength class.

(d) South America

Five South American countries, Bolivia, Columbia, Ecuador, Peru and Venezuela under the auspices of the Andean Pact have in recent years undertaken a comprehensive testing program aimed at developing a set of grade rules and a strength grouping system applicable to the region. This was the subject of a detailed report by Centeno (1978). In this th advantages of a strength grouping system are stated as follows·

(i) it permits the introduction of a large number of new little-used species to the building industry;

(ii) it allows a more homogeneous, balanced and rational exploitation of the forest;

(iii) it allows the limitation or elimination of the vices implicit in the selective exploitation of a few precious species; and

(iv) it drastically simplifies the use and commercialization of wood as a construction material.

TABLE 9

MINIMUM STRENGTH-CLASS LIMITS FOR GROUPING PHILIPPINE TIMBER SPECIES

Property	Moisture condition	Class of timber				
		C1	C2	C3	C4	C5
Modulus of rupture in bending (kg/cm^2)*	Green	800	630	500	400	315
	12% MC	1250	1000	800	630	500
Modulus of elasticity in bending (1000 kg/cm^2)	Green	130	100	77 0	60 0	46 0
	12% MC	160	120	95 0	73 0	56 0
Compression parallel to grain (kg/cm^2)	Green	400	305	235	185	140
	12% MC	650	500	385	300	230
Compression perpendicular to grain (kg/cm^2)	Green	90 0	56 0	25 5	22 5	14 0
	12% MC	135	90 0	58 0	[illegible]	24 5
Shear parallel to grain (kg/cm^2)	Green	100	80	63 0	50 0	40 0
	12% MC	140	110	85 0	65 0	50 0
Specific gravity•	Green	0.670	0.545	0.450	0.365	0.300
	12% MC	0.710	0.580	0.475	0.385	0.315

• Based on weight when oven-dry and volume at test

* 1 kg/cm^2 = 0.098 MPa

As a result of the above study, these five countries have agreed on a single visual grading rule for structural hardwood and a strength grouping system comprising three strength groups. The working stresses derived for each strength group were arrived at after taking cognizance of both the results available from small clear testing of 72 species and the testing of approximately 1500 beams of structural size timber representing more than 30 species.

The proposed working stresses for the three strength groups are as given in Table 10. These values are derived by taking the lowest 5th percentile value for the group. The minimum Modulus of Rupture values are then divided by 2.1 to account for accidental overload and the effect of duration of load; a further reduction of 10 per cent is applied to account for a further size effect. The Modulus of Elasticity values are the averages taken directly from the tests without further modification.

TABLE 10

PROPOSED WORKING STRESSES (kg/cm²)* (Centeno, 1978)

Group	F_b Flexure	F_c Comp. Para.	F_t Tens. Para.	F_p Comp. Perp.	F_v Shear Beams	F_v Shear Joints	E Modulus of Elasticity $E_{0.5}$	E Modulus of Elasticity $E_{0.05}$
A	220	170	160	60	20	25	140	110
B	170	130	120	45	16	20	120	95
C	130	100	90	30	12	15	90	70

* 1 kg/cm² = 0.098 MPa

For a new species to be classified under the proposed system it is recommended that at least 60 beams be tested in third point bending and that the 5th percentile MOR values (modified as above) and the mean MOE values be used to determine the correct strength group by direct comparison with the Table. A species may be allowed in a particular group when these parameters are no more than 10% lower than the values indicated.

During the course of the testing program it was observed that basic density was a good indication of strength and as a consequence basic density is now proposed as a method of positioning a species in a group on a preliminary basis. The limits selected taking a conservative approach were as given in Table 11.

TABLE 11
LIMITS FOR BASIC DENSITY (gm/cm^3)
FOR EACH STRENGTH GROUP

Group	Basic Density*
A	0.76 and above
B	0.60 - 0.75
C	0.44 - 0.59

* Basic density is the denisty of timber calculated from the green (or fully saturated) volume and the mass when oven dry.

An interesting approach taken in the development 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 aplications in housing such as sheathing and joinery.

As a consequence of the acceptance of the above system, a Timber Constuction Manual has been produced and industry has expanded as is evidenced by the establishment of nine factories producing prefabricated houses in the five countries concerned and the construction of a wood/cement panel plant in Ecuador. It is noteworthy that the various governments support the rules and are incorporating them into the relevant building codes.

The incentive for the Andean Pact countries to develop a stress grading and grouping system was the assistance it would provide in overcoming the serious housing shortages, the need to utilize a valuable resource and the need to create employment.

(e) Mexico

In Mexico (Davalos, 1981) development of a simplified set of grading rules is close to being finalised. The 50 pinus species in use throughout the country have for convenience been treated as a single species group. A large in-grade testing program (5000 full-sized pieces) is in progress to determine the appropriate working stresses for the two grades of structural timber considered necessary. Up until now, North American grading rules have been used but their validity has been queried prompting the above testing progam.

The proposed grading rules have been framed so that, on average, mill output would be 30 per cent of the top grade, 40 per cent into the second grade with the remainder going into non-structural applications. If this break-down can be reflected throughout the country there would be sufficient production to fulfil the needs of the local market.

The tentative design values based on the tests to date for the two suggested grades of pine are given in Table 12.

TABLE 12

TENTATIVE DESIGN VALUES FOR MEXICAN PINE (kg/cm^2)*

Grade	Bending		Mean M of E x 10^3
	Single Members	Load sharing Members	
A	140	160	115
B	80	90	90

* 1 kg/cm^2 = 0.098 MPa

Investigations are also under way in an attempt to obviate the need for visual grading. A TRU-grader has been purchased from South Africa and is currently being evaluated in the field.

Also being examined is the indication that for Mexican conditions the within mill variation is larger than the regional variation. If this is the case, sampling will be much simpler than previously thought and considerably less expensive. This could be of interest to the countries with a widespread pine resource.

In Mexico it is felt amongst research workers that the lack of a suitable timber grading system is the main reason why industrialised housing using timber framing has not become established. It is felt that timber frame construction could help considerably to lower housing costs below those incurred with traditional masonry materials and so make home ownership accessible to a larger proportion of the population.

(f) Other Countries

There are several other countries, particularly those with a hardwood resource, that have strength grouping systems similar to or based on the Australian system. In Canada and the United States grouping techniques are used for the comparatively small number of species used structurally, but the degree of refinement attempted appears to have little relevance to the problems of developing countries. However, in the broader sense, much of the research work emanating from both Canada and USA has important implications for other countries but with the proviso that naturally most of the work is on softwood species. Of particular interest are the developments arising as a result of in-grade testing research programs and the detailed studies being undertaken to determine the duration-of-load effect.

(g) Summary

While the strength grouping/stress grading systems described so far vary somewhat in the way they have been developed and are being utilized they still have much in common. Firstly, they all use a small number of groups to cater for a comparatively large number of individual species, secondly they each aim to estimate the influence of defects on strength and stiffness, and thirdly they are all based on visual grading. Their commonality becomes more obvious when working stresses are developed for some well known species using the different systems. Having regard to the lack of accuracy inherent in the concept as a whole the end-results are very similar.

It is when attempts are made to bestow on any of the systems a degree of precision that is really not there, nor warranted, that apparent discrepancies arise.

5. Extension of the Grouping Technique

(a) Joints

It has been found that grouping is also a very useful technique in developing the basic loads applicable to metal fasteners (Mack, 1978). When revised, the Australian Timber Engineering Code will be using the following classification system based on basic and air-dry density as shown in Table 13.

TABLE 13

PROPOSED MINIMUM DENSITY FOR JOINT STRENGTH GROUPS

	Green timber		Seasoned timber
Group	Basic density (kg/m³)	Group	Air-dry density^A (kg/m³)
J1	750	JD1	940
J2	600	JD2	750
J3	475	JD3	600
J4	380	JD4	475

^A Density at 12% moisture content after reconditioning.

An example of its application to nailed joints is given in Table 14.

TABLE 14

PROPOSED MINIMUM PROPERTIES OF NAILED JOINTS

LOADS ARE FOR 2.8 mm DIAMETER NAILS IN SINGLE SHEAR

	Green timber				Seasoned timber^A		
Group	Minimum value			Group	Minimum value		
	Maximum load (N/nail)	Load at 0.4 mm displacement (N/nail)	Stiffness modulus		Maximum load (N/nail)	Load at 0.4 mm displacement (N/nail)	Stiffness modulus
J1	2170	685	1220	JD1	1920	925	1420
J2	1710	505	895	JD2	1490	700	1110
J3	1330	365	650	JD3	1170	530	875
J4	1050	270	480	JD4	905	395	680

^A Approximately 12% moisture content.

(b) Poles

From Tables 4 and 5 it can be seen that if the product under consideration had only one visual grade and one moisture condition, then a much simplified new table would be possible. This is the case with poles if they are graded to the Australian Standard.

On the basis of a large pole testing program carried out by the Commonwealth Scientific and Industrial Research Organization (Boyd, 1962) poles from mature trees are considered to be in a single grade, the next above the 75% grade. As poles are normally regarded as unseasoned, then Table 4 leads to Table 15.

TABLE 15

CORRESPONDENCE BETWEEN STRENGTH GROUP AND STRESS GRADE FOR ROUNDED TIMBERS GRADED TO AS 2209-1979

Strength group	Stress grade
S1	F34
S2	F27
S3	F22
S4	F17
S5	F14
S6	F11
S7	F8

NOTE: The equivalence expressed is based on the assumption that poles or logs are from mature trees.

(c) Plywood

A similar development is possible with plywood. In the Australian Standard 2269-1979 for structural plywood (Standards Association of Australia, 1979c) visual grading rules for plywood veneer are specified so that their strength is roughly 60 per cent of the clear wood strength when the maximum permissible defects occur. With this prerequisite satisfied, the stess grade for a plywood may be derived from any one of the following three parameters:

(i) the strength group of the timber veneer;
(ii) the density of veneers; or
(iii) The stiffness of the plywood sheets.

Table 9 shows the relationship between these parameters and the plywood stress grade. In this table, the modulus of elasticity refers to the value of stiffness of solid wood parallel to the grain that must be used in computing the stiffness of the plywood sheet.

TABLE 16
GRADING PARAMETERS FOR PLYWOOD STRESS GRADE

Plywood stress Grade	Grading parameters*		
	Timber strength group	Modulus of elasticity of plywood sheet (MPa)	Minimum air-dry density (kg/m^3)
F34	SD1	21 500	1 200
F27	SD2	18 500	1 080
F22	SD3	16 000	960
F17	SD4	14 000	840
F14	SD5	12 200	730
F11	SD6	10 500	620
F8	SD7	9 100	520
F7	SD8	7 900	420

* Only <u>one</u> of the three grading parameters need be used

(d) Non-Structural Properties

There are several properties that may be classed as non-structural, e.g. durability and shrinkage, but are still of critical importance to the engineer. Suggested methods for classifying these have been made by Keating (1981).

6. Trends and Developments

(a) In-grade Testing

For many years the major forest products research laboratories have been interested in the testing of stuctural-sized timber as a means of developing new grading rules, (Kloot and Schuster, 1972), and verifying existing ones. Australian work on jarrah (Eucalyptus marginata) (Kloot and Schuster, 1958) had the effect of altering the grading rules for that species as it determined that the effect of sloping grain was not as severe as had been assumed.

There are other documented examples of early work in this sphere, but at present there is renewed interest as work by Madsen (1978) in Canada has highlighted the fact that the performance of structural timber containing natural defects may not be the same as might be expected from small clear specimen results. The effect of moisture content and duration of load, for example, at the 5-percentile level of strength of structural sized pieces for the species tested was quite different from that on small clear specimens. As it is the weakest pieces in the population that determine the design properties for the grade, this aspect warrants examination.

In-grade testing can be expensive and time-consuming (Leicester, 1981b) which tends to limit its usefulness to the more plentiful species. At the same time the value of data collected from tests on small clear specimens must not be discounted completely. Such information will still be required and may well be able to be combined with that obtained from structural-sized pieces. Also work has indicated that for some species an in-grade testing program did not suggest a change in basic working stresses over those derived from small clear specimens (Walford, 1979). Hardwood species have not yet been studied to the same degree as softwoods.

(b) Grading Techniques

(i) Visual grading*

Visual grading is the oldest form of grading. Because of its simplicity it is likely to remain, on a world-wide basis, the predominate technique for many years to come. However, on the basis of work described previously, it is probable that the alloted grade stresses in the existing rules may undergo some change.

In the United Kingdom and some European countries the knot area ratio (KAR) method of assessing the influence of knots has been introduced (TRADA, 1974). In this method, the grader needs to visualise the pattern formed by the knots within a piece of timber. Once grasped the method is reported to be simpier and quicker than other methods.

(ii) Mechanical stress grading

Mechanical stress grading based on the regression between stiffness and strength is being widely used in many of the developed countries particularly in Europe with considerable success. In Australia the Computermatic and its predecessors have been operating commercially now since 1965 and currently radiata pine producers have the potential of grading 80% of the total scantling production of that species in the country (Anton, 1981). In conjunction with the quality control program associated with the Computermatic machine, more than 30 000 in-grade tests of scantling size pieces have been made.

Other machines of similar performance to the Computermatic are coming onto the market, but the costs of all these machines necessitate a restriction on their use to mills with very high throughputs.

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* Visual grading in this context is based on the principles laid down in ASTM D 245 (American Society for Testing and Materials, 1981) and the references listed therein.

Interest has been shown in 'spot testing' machines that are low cost/low throughput machines capable of grading for particular end-uses. They use a strength/stiffness correlation as with the more sophisticated machines, but the timber is stationary at the time of testing (CSIRO, 1968). A commerical version of this machine, the TRU Timber Grader, is available in South Africa (Bryant, 1978)*.

(iii) Proof grading

Proof grading is a much more recent development and it is one that has considerable potential (Leicester, 1979). Its main advantages are its improved reliability when compared to visual grading and its relative cheapness in comparison to the conventional machine stress graders.

The procedure is illustrated in Figure 2 as described by Leicester (1981). Every stick of timber in a population to be graded is passed through a proof testing machine. As it does so a heavy bending load is applied continuously to the timber so that the edge judged to be the weakest is placed in tension. If it emerges without failure or serious signs of distress the stick of timber is deemed to be acceptable for the stress grade application to the applied proof load.

In a typical grading operation the proof load is chosen so that about 1-3% of the timber fails and is rejected.

In the use of proof loading for stress grading, the criterion for the acceptance of each piece is that it demonstrates the capacity to carry a specified proof load. Thus every piece that is accepted has a guaranteed minimum strength. By contrast, other methods rely on the correlation between strength and some other property of the timber (Kloot and Leicester, 1977).

The main disadvantage with the method is that it is primarily a single grade method necessitating some presorting.

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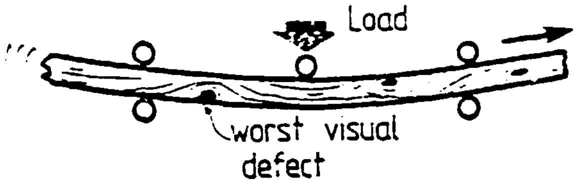
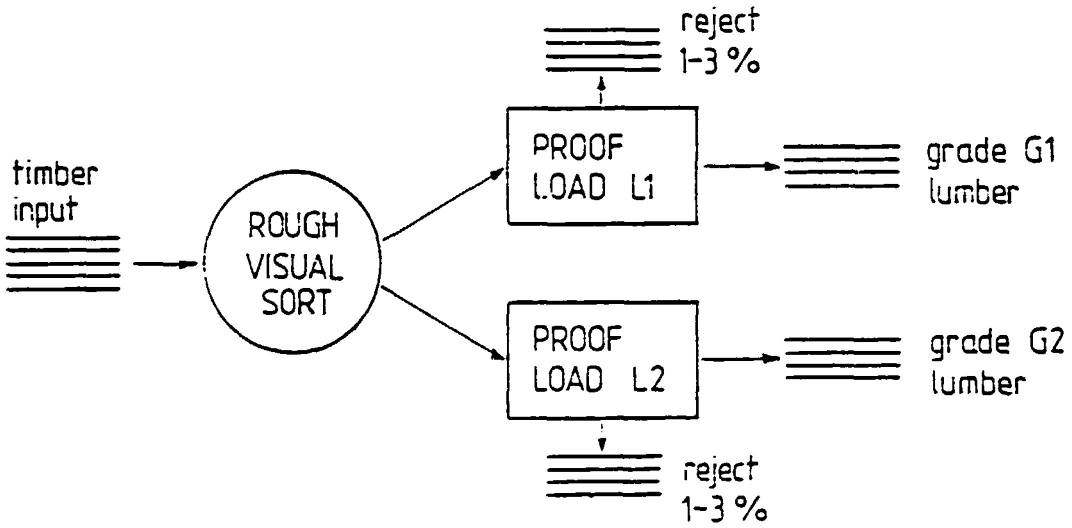
* See also UNIDO Document ID/WG359/3 for a discussion of machine stress grading developments and equipment.



(i) loading method



(ii) procedure

Fig.2 Concepts of Proof Grading (after Leicester)

Although not yet extensively used in Australia, proof grading has certainly moved out of the research laboratory. Results of commercial experience and the development of a proof grading machine have now been reported by MacKenzie et al. (1981).

The first machine to be installed in Australia started operation in Queensland in 1969 and has been in continuous operation since that time (Straker, 1977). In 1976 a prototype machine suitable for more general commercial production was developed and commissioned by the Queensland Timber Research and Advisory Council. Following a series of mill studies involving 2500 pieces of scantling combined with an intensive research program undertaken by CSIRO Division of Building Research, appropriate load factors were developed for cypress pine (Callitris sp.) and two medium density hardwoods. (The bending stress applied to the timber during proof grading is equivalent to the basic working stress for a particular grade multiplied by the appropriate load factor).

In the commercial operation the improvement in recovery over that previously obtained from visual grading has been most marked and there is increased confidence in the reliability of the grading operation.

Whenever proof grading is mentioned the question is raised concerning the incidence of undetected damage. Laboratory and mill studies have shown that this appears to be extremely low and is well below the 5 per cent of low strength pieces currently permitted for other grading systems (MacKenzie et al., 1981; Leicester et al., 1981).

A commerical proof grading machine is now available and is capable without modification of testing timber of cross-sections up to 150 mm x 50 mm up to a stress grade of F17. The current cost with calibration equipment is approximately Aus $10,000. The machine can be used 'in-line' with a planer or 'hand fed' independently at feed rates to suit.

(iv) Density Measurement

Density has always been regarded as an important indication of most structural and other properties of timber. As mentioned previously, it is one method of strength grouping under the Australian system and it is also used for allocating joint groups. For these reasons any technique that reports to be able to rapidly assess density under field conditions attracts interest.

One such instrument is the 'Pilodyn' (Hoffmeyer, 1978). This instrument measures the resistance to penetration of a spring loaded pin in up to 70 mm of the outer wood of the tree. An extensive survey made by Smith et al. (1981) for three softwood species over a wide geographical range of Queensland has shown it is potentially a most useful instrument.

Of course there are many other methods of determining density, ranging from carefully controlled laboratory techniques to observation of the depth to which a specimen will sink when immersed in a beaker of water (Kauman and Kloot, 1968). However adequate sampling is necessary before a species or species group assessment can be made.

(c) International Standards

There is considerable activity at the moment at the international level in the development of a structural timber design code. The International Standardization Organisation, for Technical Committee 165, Timber Structures, ISO/TC165, and Conseil International du Batiment, Working Comission 18, Timber Structures, CIB-W18, are working towards the same end. Central to their aims is a grouping system stated in terms of the 5-percentile characteristic values. Thirteen stress grades are proposed with each grade having a corresponding set of design values. The range of stress grades proposed is such that it should cover all the world timbers. Species density is suggested as the basis for grouping when the design parameters concerned are related to clear wood strength and not to the magnitude of natural defects. This is the case with compression perpendicular to the grain and shear at joint details.

A constant geometric ratio has been used as the step between grades for the follwing reasons:

(i) the grouping system remains open ended and if required, may be extended either way; and

(ii) because the geometric ratio is constant the system does not show a special bias towards any particular group.

As stated by Leicester (1981a) the advantage of using the characteristic values rather than a developed set of design stresses is that they are based on the minimum of processing of measured properties and therefore may be expected to undergo minimum changes as new developments in technology occur. In the older established systems design stresses depend not only on short-term laboratory measurement but also on other parameters such as safety factors, duration-of-load effects and size effect. These parameters are not accurately defined at present and so might be expected to change. Furthermore there may be good reasons why some of these parameters should differ from one country to another.

These proposals are still at the draft stage and may yet be changed. Should they be adopted it will be some time before the concept would be applicable to countries or regions that are attempting to cope with production runs that involve hundreds of species.

7. Recommendations

The best way to have timber accepted as a legitimate construction material is to ensure its incorporation into the national building code. As mentioned previously a grouping system combined with a form of grading control is most useful for this purpose. In this way the regulatory authority can be satisfied that due regard has been given to the critical aspects of safety and performance and that some group or organisation is prepared to accept responsibility for the guaranteed quality of the production.

In the long term interests of timber utilization it is important that some type of grouping scheme is introduced whenever there is a problem of multiple species. In regions or countries where this occurs and there is no existing scheme then it is important to prepare one even through it may initially be ultra-conservative.

Acting on this assumption, the following course of action is suggested:

(i) Determine the air-dry density values of specimens cut from at least five trees of each species having due regard for proper sampling techniques.

(ii) Determine the strength group of the species sampled on the basis of air dry density. See Appendix.

(iii) Prepare a visual grading rule for a single grade with the limits chosen so that the average mill in the region will be capable of producing a reasonable percentage of its cut into graded structural material. See Appendix.

(iv) Arrange for a testing program of small clear specimens based on standard methods to be introduced. It is preferable that such testing should be made within the country concerned but if facilities are not likely to be available for some time, consideration could be given to sending material to an appropriate laboratory in another country.

(v) With these results, refine the original strength grouping.

(vi) Introduce an in-grade testing program to either verify or alter accordingly the limits chosen in (v) above.

(vii) Consider the purchase or construction of a proof grading machine.

(viii) Instigate a grader training scheme.

APPENDIX

SUGGESTED LIMITS FOR A STRENGTH CLASSIFICATION SCHEME

A. VISUAL GRADING RULES* FOR A 48 PER CENT GRADE

(If this grade is unsuitable or more grades are required, it is suggested that the choice be made from the ...38, 48, 60,... series).

1. STRUCTURAL HARDWOOD

1.1 General. Each piece of timber of structural hardwood shall be free from compression failures and other fractures.

Each piece shall be sawn with adjacent surfaces square to each other and within the tolerances specified. The ends shall be neatly trimmed.

1.2 Permissible Imperfections. The following imperfections shall be permitted subject to the limitations herein:

(a) Knots (sound or unsound, round, oval and arris): measurement not exceeding one-third of the width of the surface on which they occur.

(b) Borer holes not associated with decay:

- (i) up to 3 mm diameter - unlimited provided that the distance between the holes is at least twice this diameter;
- (ii) over 3 mm diameter or where the distance between holes is less than twice their diameter - as for knots (see (a) above).

(c) Tight gum veins: unlimited.

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* These suggested limits have been extracted from Australian Standard 2082-1979 for hardwoods and Australian Standard 2099-1977 for softwoods.

(d) Loose gum veins and shakes:

(i) not exceeding 3 mm wide;

(ii) aggregate length not exceeding one-quarter of the length of the piece;

(iii) where they intersect an end and extend from surface to surface they shall be considered as end splits (see (o) below);

(iv) not extending from one surface of the piece to another.

(e) Gum pockets, latex pockets, resin pockets, and overgrowths of injury:

(i) length - individually not exceeding three times the width of the surface on which it occurs or 300 mm, whichever is the lesser;

(ii) width -
A. If occurring on one surface only - individually not exceeding one-half of the width of the surface on which is occurs or 25 mm, whichever is the lesser;
B. If extending from one surface to another - individually not exceeding one-third of the width of the surface on which it occurs or 25 mm, whichever is the lesser; where the imperfection intersects an end it shall be considered as an end split (see (o) below).

(f) Bow, spring and twist: not exceeding the values given in Appendix...

(g) Cupping: not exceeding 1 mm per 50 mm of width.

(h) Checks:

(i) Surface checks - unlimited

(ii) Internal checks - projected length S not exceeding one-half of the thickness of the piece.

(j) Sloping grain: not exceeding 1 in 8.

(k) Primary rot and termite galleries: on the surface only and slight.

(l) Wane, want and sapwood susceptible to Lyctid attack (see Section B):

(i) not exceeding in aggregate one-quarter of the cross-sectional area;

(ii) not exceeding one-third of the thickness of the piece, except that for one-third of the length of the piece sapwood only may extend to the full thickness of the piece.

(m) Heart and heart shakes:

(i) where the smaller dimension is less than 175 mm - not permitted;

(ii) where the smaller dimension is 175 mm or more - provided that they are within the middle third of the cross-section of the piece.

(n) Included bark:

(i) intersecting an end - individual strands not exceeding 150 mm long;

(ii) not intersecting an end - individual strands not exceeding 300 mm long.

(o) End splits: aggregate lengtn at each end not exceeding 1.5 times the face width or 150 mm, whichever is the lesser.

2. STRUCTURAL SOFTWOOD

2.1 General. Each piece of timber of structural softwood shall be free from decay, compression failures and other fractures, insect galleries, shakes and splits.

No piece shall be of exceptionally low density.

Each piece shall be sawn with adjacent surfaces square to each other and within the tolerances specified. The ends shall be neatly trimmed.

2.2 Permissible Imperfections. The following imperfections shall be permitted subject to the limitations herein:

(a) Sound knots (round, oval or spike; intergrown or partially intergrown; single or in clusters):

(i) face knots - width not exceeding two-fifths of the width of the face, and appearing wholly within the central three-quarter of the width of the face;

(ii) margin knots - width not exceeding three-tenths of the width of the face;

(iii) through knots - as for face knots or margin knots, as appropriate (see (i) and (ii) below);

(iv) edge knots - width not exceeding half of the thickness of the piece.

(b) Knots in groups:

(i) on the face - aggregate width not exceeding two-fifths of the width of the face, and no single knot in the group exceeding one-fifth of the face;

(ii) on the edge - width not exceeding half of the thickness of the piece.

(c) Arris knots: as for margin knots (see (a)(ii) above).

(d) Unsound and defective knots, knot holes and cone holes: as for sound knots (see (a) above).

(e) Borer holes:

(i) up to 3 mm wide - unlimited provided that the distance between the holes is at least twice their width;

(ii) over 3 mm wide or where the distance between holes is less than twice their width - as for knots (see (a) and (b) above).

(f) Resin pockets, bark pockets and overgrowths of injury: not exceeding 10 mm wide by 150 mm long or equivalent area.

(g) Bow, spring and twist: not exceeding the values given.

(h) Surface checks: individually not exceeding 1 mm wide or 600 mm long.

(j) Sloping grain: not exceeding 1 in 8.

(k) Wane or want: not exceeding one-quarter of the sum of width and thickness and not exceeding one-quarter of the thickness of the piece.

(l) Pith: in pieces 200 mm and wider only and within the middle third of the width of the piece.

(m) Stain: unlimited.

B. SUGGESTED DENSITY LIMITS, STRENGTH GROUPS AND STRESS GRADES

Moisture Condition at time of use	Air Dry Density kg/cm³	Suggested Strength Groups	Stress* Grade
Green	905 +	A	F11
	705 - 900	B	F7
	500 - 700	C	F4
Dry	840 +	AD	F14
	620 - 835	BD	F8
	420 - 615	CD	F5

* see Tables 1-5.

C. DESIGN PROPERTIES FOR THE SUGGESTED STRESS GRADES

(Extract from Table 1)

Stress* grade	Basic bending strength (MPa)	Basic tension strength (MPa)	Basic compression strength (MPa)	Modulus of elasticity (MPa)
F14	14.0	8.4	10.2	12 500
F11	11.0	6.6	8.4	10 500
F8	8.6	5.2	6.6	9 100
F7	6.9	4.1	5.2	7 900
F5	5.5	3.3	4.1	6 900
F4	4.3	2.6	3.3	6 100

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