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TIMBER STRESS GRADING: ANALYSIS OF EXISTING TIMBER STRENGTH GROUPING AND STRENGTH CLASSIFICATION SYSTEMS*

by

Timber Research and Development Association**

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INTRODUCTION

In an exercise to make recommendations for a strength grouping system acceptable for international adoption by UNIDO for work in developing countries, a review of existing major strength grouping and strength classification systems in the world was made. From this review, it appears that many countries have either adopted the Australian system of strength groupings or have used it as the basis for developing their own system.

Some of the well known grouping systems such as those used in North America were not discussed in this report as they were mainly concerned with a comparatively small number of softwood species.

Strength grouping

Due to the multiplicity of timber species involved in many countries, it has long been a problem to present structural timber data to the end-user in an appropriate fashion. A technique devised to minimise this problem is grouping. Where the structural species of timber used in a country are easily identifiable, and few in number, it may be appropriate that specific structural design properties be published for each of these species. However, in many countries, numerous species are used and it is not practicable to have long lists of design data. Rather it is preferable to group the timbers and to provide structural design properties for a limited number of strength groups. In general each strength group will cover a large number of species and commercial mixtures of species.

The use of a limited number of strength classifications is of considerable value to the designer as it enables him to specify timber by a strength group rather than by species. This makes it possible to have a wider choice of timbers to select from for any specific design. For the producer it assists in the utilisation of lesser-known species which may be sporadic and regionally limited in their occurrence.

Essentially, grouping for structural purposes means the creation of a preferably small set of hypothetical species so that any timber may be grouped within this set and considered as equivalent to one of the hypothetical species. It has been mentioned by Keating (1982) that it would appear many countries have either adopted the Australian system of strength grouping as 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 Guinea, Fiji, Samoa and Solomon Islands. Of course there are many other systems in use, but most of the well known ones, such as those used in North America, are in the main, concerned with a comparatively small number of softwood species.

Existing Strength Grouping Systems

In preparing this section a considerable amount of information was gathered from publications by W.G. Keating and R.H.Leicester, both from CSIRO Australia and references to their work are given at the end.

In Australia, strength grouping methods have been developed over a period of some 40 years and formalized through a set of building standards (Standards Association of Australia 1979a, 1979b, 1979c, 1980a, 1980b) Information on strength grouping in other countries is given in publications prepared for ISO (Larsen 1978), Africa (Okigbo, unpubl.; Campbell and Malde 1970; Comben 1971; Bolza and Keating 1972; Ward 1974), Malaya (Burgess 1956; Engku Abdul Rahman Bin Chik 1972), Singapore (Singapore Timber Standardisation Committee 1966), Philippines (Espiloy 1978), Indonensia (Suparman Karnasudirdga et al, 1978; Iding Kartasujana and Abdurahim Martawijaya, undated), Laos (Timber Research and Development Association 1976), Papua New Guinea (PNG Department of Forests 1972; Eddowes 1977; undated; Bolza 1975), Fiji (Anon. 1968, 1970), South-east Asia (Bolza and Keating 1981), South America (Berni et al, 1979) and the United Kingdom (Sunley 1979).

a) Australia

The original strength grouping system in Australia was proposed for four strength groups by Langlands and Thomas (1939) in their Handbook of Structural Timber Design. This system was revised and expanded by Pearson (1965) and Kloot (1973) due to the availability of new information and new species. Working back from a set of working stresses developed by Pearson which has now become the basis for a strength classification system, it was then possible to develop the appropriate strength groups. 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 reference 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 Organisation for Standardization (ISO) and the Food and Agriculture Organisation (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 per cent. The range of the values chosen was such that it covered all the species likely to be used structurally in Australia.

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 mechanical 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	181

* 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

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.

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 stress-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 2 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 pine for structural purposes.

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 et al, 1979) and 362 South-East Asian species (Keating and Bolza, 1982).

In classifying a species from Tables 2 and 3 it is often necessary to decide 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.

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 6 and 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.

TABLE 6

COMBINATIONS OF PRELIMINARY CLASSIFACTIONS 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
x	x	x + 1	x
x	x - 2	x - 1	x - 1
x	x + 2	x + 1	x + 1

(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 the 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.

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.

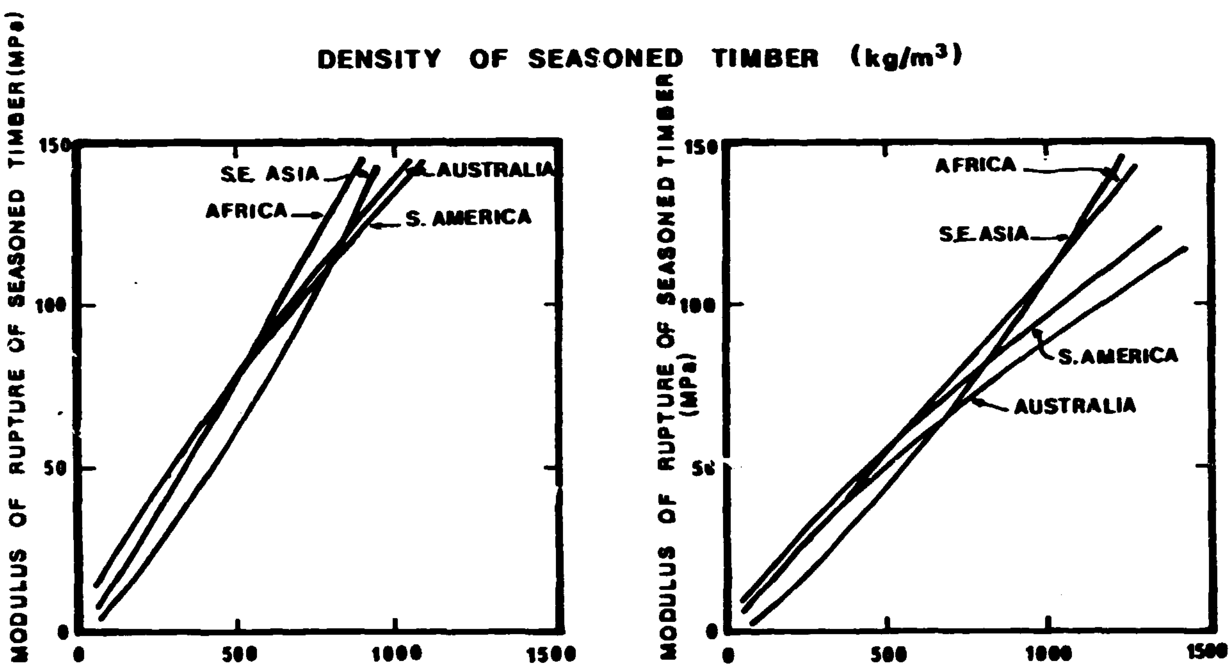

Figure 1: Regression lines for Modulus of rupture versus density of seasoned timber.

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 DESNITY 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/cbm)	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/cbm)	1200	1080	960	840	730	620	520	420

(b) United Kingdom

In the United Kingdom, a system of strength classes for solid timber has been provided for the first time in the British Standard BS 5268 "Code of Practice for the structural use of timber" Part 2 : 1984. The system classifies timbers and species combinations whose grade stresses are similar to one of nine strength classes. The strength classes, which are designated SC1 to SC9 (in ascending order of strength), enable designers to select a suitable class and to use its assigned stress values in structural calculations without making a final choice of timber, species combination or grade. For special cases where it is preferable, the code still gives strength properties for individual timbers and grades. Strength classes SC5 to SC9 form mainly the denser hardwoods and have stresses which progress in a geometrical series.

Grade stresses for the dry exposure condition, as defined in BS5268: Part 2 are tabulated for nine strength classes which is given in Table 8. When basing a design on strength classes, the material specification should indicate clearly the strength class required. Conditions arise where it may be advisable to limit choice of material through considerations other than strength. In SC5, both softwoods and hardwoods are combined.

Procedure adopted for softwoods

It was considered that establishing strength class boundaries on the basis of a mathematical progression, results in a system which is inefficient for many of the commonly used species/grades. Because of the wide variety of structural component types, sizes and spans it is also impractical to tie the class boundaries to increments of structural component design. The current (draft) BS5268 is to make the class boundary strength values match the major species/grades used in the UK. Whilst this ensures the most efficient use of these species/grades inevitably others are penalised. However, for those species which can be machine graded, machine settings can be produced which will enable a more efficient approach by grading directly to the strength class boundaries. The strength for species/grades are ranked on the basis of bending strength. Taking into account the strength values of the major species/grades used in the UK, bending stress values of 10.0, 7.5, 5.3, 4.1 and 2.8N/sq.mm. were given for classes SC5 to SC1 respectively. Class values for the other properties were taken from the lowest value for species/grades combinations with bending stress values equal to or greater than the bending value for that class. An exception to this was made where the lowest value of a particular property would have penalised the remaining species/grades in that class too severely. An example of this is the demotion of SS grade British grown spruce to the C2 class because of its low modulus of elasticity values. Species/grades were admitted to a strength class if their bending stress values were equal to or greater than the class value and their values for other properties exceeded 95 per cent of the class values.

For softwoods, there are two visual grades, namely GS -General Structural and SS -Special Structural visually graded to BS4978: 1973 "Timber grades for structural use" and the grade ratios for these two grades are 0.35 and 0.50 of the bending stress respectively.

Procedure adopted for hardwoods

Procedure adopted for strength grouping of hardwoods in BS5268: 1984 is based on the Australian system.

It was noted that the relation between strength properties and dry nominal specific gravity of the species related to the BS5268 hardwoods was very similar to the relationships obtained by the Australians. Due to this close similarity the values given in SAA MP45 would be applicable to the types of tropical hardwood required for inclusion in BS5268. The derivation of basic and grade stresses for BS5268 has been described in detail by Mettem (1981, 1982). Since these stresses were derived using different factors and also due to different assumptions appearing in the code, it would not be appropriate to simply adopt the Australian basic working stresses for hardwood strength classes in the British code.

Preliminary classification values for seasoned (ie 12 percent m.c.) timber and corresponding values for unseasoned material (above saturation point - assumed as an average of 25 percent for timbers of this type) were adjusted for stresses to the dry moisture condition (18 percent). Table 9 shows the final strength classes and their corresponding strength values which after rounding off, appear in Table 8 (BS5268: 1984). The earlier table does not indicate values for tension and shear parallel to the grain. For tension a ratio of 0.6 of the grade stress in bending has been applied and this procedure has been carried through in the case of all the strength class tension stresses. For shear, an ad hoc ranking procedure was applied , listing the hardwoods in ascending order of individual HS grade shear stress (graded to BS5756: 1980) within the classes into which they fell because of other properties and choosing a convenient series in steps of 0.50 or 0.25N/sq.mm.

For tropical hardwoods visually graded to BS5756: 1980 "Specification for tropical hardwoods graded for structural use", there is only one structural grade which is HS (Hardwood Structural) with a grade ratio for bending of 0.67

TABLE 8: GRADE STRESSES AND MODULI OF ELASTICITY FOR STRENGTH CLASSES: FOR THE DRY EXPOSURE CONDITION

Strength class	Bending parallel to grain	Tension parallel to grain	Compression parallel to grain	Compression perpendicular to grain		Shear parallel to grain	Modulus of elasticity		Approximate density
	Grade Stresses						Mean	Minimum	
	(N/sq.mm)	(N/sq.mm)	(N/sq.mm)	(N/sq.mm)	(N/sq.mm)	(N/sq.mm)	(N/sq.mm)	(N/sq.mm)	(kg/cu.mm)
SC1	2.8	2.2	3.5	2.1	1.2	0.46	6800	4500	540
SC2	4.1	2.5	5.3	2.1	1.6	0.66	8000	5000	540
SC3	5.3	3.2	6.8	2.2	2.7	0.67	8800	5800	540
SC4	7.5	4.5	7.9	2.4	1.9	0.71	9900	6600	590
SC5	10.0	6.0	8.7	2.8	2.4	1.00	10700	7100	590/760
SC6	12.5	7.5	12.5	3.8	2.8	1.50	14100	11800	840
SC7	15.0	9.0	14.5	4.4	3.3	1.75	16200	13600	960
SC8	17.5	10.5	16.5	5.2	3.9	2.00	18700	15600	1000
SC9	20.5	12.3	19.5	6.1	4.6	2.25	21600	18000	1200

TABLE 9

UNROUNDED VALUES OF GRADE STRESSES8 AND MODULI OF ELASTICITY
FOR STRENGTH CLASSES FOR TROPICAL HARDWOODS TO HS GRADE OF BS5756

Strength class **	Strength group +	Bending parallel to grain	Compression parallel to grain	Modulus of elasticity: Mean	Modulus of elasticity: Minimum
SC5	S5	10.53	10.68	12308	10289
SC6	S4	12.62	12.48	14C98	11786
SC7	S3	14.81	14.28	16216	13556
SC8	S2	17.48	16.69	18666	15605
SC9	S1	20.52	19.58	21570	18032

* dry exposure condition
** BS5268: Part 2
\+ SAA MP45: 1979

(c) Philippines

The strength grouping system developed in the Philippines is very similar to that in Australia where the system 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 (Epsiloy, 1978). However, it was judged that there was no need to cover the same range as the Australian system, so only five groups have been chosen. The advantages of the grouping system according to Epsiloy are:

(1) Each member species within a class can substitute for the other, thus in a way overcome the problem of supply.

(2) 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 alternative species by specifying that any timber within a given class may be used instead of specifying the timbers by name.

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

(4) 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 10. The figures quoted are the minimum values of strength class limits for the different properties. These have been derived from the regression equations relating modulus of rupture (MOR) with major strength properties; and from various relationships, sets of strength values of MOR in the preferred number series were assigned to obtain the strength limits of other properties. The results were then rounded off to fit in the suitable series.

TABLE 10: 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/sq.cm)†	Green 12% MC	800 1250	630 1000	500 800	400 630	315 500
Modulus of elasticity in bending (1000 kg/sq.cm)	Green 12% MC	130 160	100 120	77 95	60 73	46 56
Compression parallel to grain (kg/sq.cm)	Green 12% MC	400 450	305 500	235 385	185 300	140 230
Compression perpendicular to grain (kg/sq.cm)	Green 12% MC	900 1135	560 900	255 580	225 375	140 245
Shear parallel to grain (kg/sq.cm)	Green 12% MC	100 140	80 110	63 85	50 65	40 50
Specific gravity‡	Green 12% MC	0.670 0.710	0.545 0.560	0.450 0.475	0.365 0.385	0.300 0.315

† 1kg/sq.cm = 0.098 MPa
‡ Based on weight when oven-dry and volume at test

(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 programme 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 (1973). In this the 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;

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

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 11. 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 11

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

Group	F. Flexure	Fc Comp. Para.	Ft Tens. Para.	Fp Comp. Perp.	Fv Shear Beams	Fv Shear Joints	E Modulus of Elasticity Eo.5	E Modulus of Elasticity Eo.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/cbm = 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 programme 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 12.

TABLE 12
LIMITS FOR BASIC DENSITY (gm/cbm)
FOR EACH STRENGTH GROUP

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

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 applications in housing such as sheathing and joinery.

As a consequence to the acceptance of the above system, a Timber Construction 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 incentives for the Andean Pact countries to develop a stress grading and grouping syste, 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 programme (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 programme.

The proposed grading rules have been framed so that, on average, mill output would be 30 per cent in 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 fulfill 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 13.

TABLE 13

TENTATIVE DESIGN VALUES FOR MEXICAN PINE (kg/cbm) *

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

* 1 kg/cbm = 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.

(f) Malaysia

In Malaysia it is usual to market timber in parcels of mixed species of similar properties under one trade name. These species are often indistinguishable from one another.

At present the system of strength grouping adopted in Malaysia is to place structural timbers into four strength groups denoted by A, B, C and D in order of decreasing compressive strength (Burgess, 1956). In deciding the position of the timber in the group, bending strength had also been considered. When these strength groups were established little information was available on the properties of some Malysian timbers and the working stresses were based on the weakest species in a particular group.

The placing of the species in the group is determined by their green and dry basic stresses. By necessity the minimum basic and grade stresses for the weakest species will determine the basic and grade stresses for the group. Tables 14 and 15 give the green and dry basic and grade stresses for the strength groups respectively. The timber is graded according to the "Malayan Grading Rules for Sawn Hardwood Timber".

TABLE 14

GREEN STRESSES AND MODULI OF ELASTICITY FOR MALAYSIAN STRENGTH GROUPS
(Stresses and moduli expressed in lbf/in sq.)

Strength Group	Grade	Bending and tension parallel to grain	Compression parallel to grain	Compression perpendicular to grain	Shear parallel to grain	Modulus of elasticity: Mean	Modulus of elasticity: Minimum
A	Basic	3 000	2 500	250	400	2 000 000	1 250 000
	Select	2 400	2 000	210	280		
	Standard	1 850	1 550	200	220		
	Common	1 500	1 250	180	180		
B	Basic	2 500	2 000	150	300	1 600 000	900 000
	Select	2 000	1 600	120	210		
	Standard	1 500	1 250	120	160		
	Common	1 250	1 000	110	130		
C	Basic	1 800	1 400	100	200	1 300 000	750 000
	Select	1 400	1 100	85	140		
	Standard	1 100	850	80	110		
	Common	900	700	75	90		
D	Basic	1 100	950	60	200	830 000	420 000
	Select	850	750	50	140		
	Standard	650	550	45	110		
	Common	550	470	40	90		

TABLE 15

DRY STRESSES AND MODULI OF ELASTICITY FOR MALAYSIAN STRENGTH GROUPS
(Stresses and moduli expressed in lbf/in sq.)

Strength Group	Grade	Bending and tension parallel to grain	Compression parallel to grain	Compression perpendicular to grain	Shear parallel to grain	Modulus of Elasticity	
						Mean	Minimum
A	Basic	3 660	3 230	280	470	2 140 00	1 400 000
	Select	2 960	2 550	230	330		
	Standard	2 300	2 000	220	260		
	Common	1 800	1 600	210	210		
B	Basic	2 880	2 330	180	310	1 700 000	950 000
	Select	2 300	1 850	150	270		
	Standard	1 800	1 450	140	170		
	Common	1 400	1 150	130	130		
C	Basic	2 100	1 600	110	210	1 350 000	800 000
	Select	1 650	1 250	90	150		
	Standard	1 300	1 000	80	110		
	Common	1 050	800	80	90		
D	Basic	1 400	1 200	90	200	950 000	450 000
	Select	1 100	950	75	140		
	Standard	800	750	70	110		
	Common	700	600	65	90		

(g) International Standards Organisation

Working group (WGI)of the International Standards Organisation Technical Committee (ISO TC/165) has produced a draft on Structural Grouping of Timber. This will incorporate the strength classifications given in the Timber Design Code which has been produced by CIB Working Group (W18) on timber structures.

Basis for grouping

The following are the two factors that will be used for grouping of timber with respect to its structural properties.

(i) Grouping based on the density of dry clear wood

(ii) Grouping based on the structural properties of stress graded timber elements containing natural defects

ISO system adopted in the Working Group (WGI 1983) is stated in terms of characteristic values that can (if desired) be measured directly by simple laboratory tests. Consequently this type of system has the potential to remain invariant and the characteristic values chosen for the above document are five percentile values.

Structural configurations have been deferred for each characteristic value because of the variability introduced by the occurrences of natural defects.

Table 16 shows the minimum acceptable characteristic values of uensity for timber classified according to the density. For design purposes 5-percentiles related to density classes are given in Table 17.

The target 5-percentile values of the structural properties of solid timber classified acco-ding to grade are given in the Table 18. If the measured property prof:les do not line up exactly with the values shown in Table 18, then the classification rules given in Table 4 should be applied.

TABLE 16

DENSITY CLASSIFICTION FOR TIMBER

density class	minimum characteristic value of density (kg/cbm)
D 800	780
D 600	630
D 500	500
D 400	400
D 300	300

For design purposes, 5-percentiles related to density classes are given in Table 2.

TABLE 17

CHARACTERISTIC VALUES RELATED TO DENSITY CLASS

density class	5-percentiles, MPa					
	green timber			dry timber (characteristic values)		
	ft,90	fc,90	fv,j	ft,90	fc,90	fv,j
D800	1.10	6.8	10.0	0.65	10.1	15.0
D600	0.85	4.5	7.0	0.50	6.8	10.0
D500	0.65	3.0	4.5	0.40	4.5	7.0
D300	0.40	1.3	2.0	0.25	2.0	3.0

NOTATION

D800, ..., D300	- density classes
Eo	- Modulus of elasticity chracteristic value
fm	- bending strength paralle to the grain, characteristic value
fc,o	- compression strength parallel to ghe grain, characteristic value
fc,90	- compression strength perpendicular to the grain, characteristic value
ft,o	- tension strength parallel to the grain, characteristic value
ft,90	- tension strength perpendicular to the grain, characteristic value
fv	- shear strength in beams, characteristic value
fvj	- local shear strength for design of joint details, characteristic value
T75, ..., T5	- grade classes for solid timber and poles.

TABLE 18

CHARACTERISTIC VALUES RELATED TO GRADE CLASS, FOR SOLID TIMBER

grade class	5-percentiles (MPa)				
	fm	ft,0	f,,0	fv	Eo
T75	75.0	54.0	52.0	5.2	12,200
T60	60.0	44.0	43.0	4.6	10,600
T48	48.0	34.0	36.0	4.0	9,300
T38	38.0	26.0	30.0	3.5	8,100
T30	30.0	20.0	25.0	3.5	7,000
T24	24.0	15.5	21.0	2.6	6,100
T19	19.0	11.8	17.5	2.3	5,300
T15	15.0	9.1	14.5	2.0	4,600
T12	12.0	7.0	12.0	1.7	4,000
T10	9.5	5.4	10.0	1.5	3,500
T8	7.5	4.1	8.4	1.3	3,000
T6	6.0	3.2	7.0	1.1	2,600
T5	5.0	2.5	5.8	1.0	2,300

EO,mean = 1.4 EO

Gmean = 0.095 Eo

TABLE 19

CLASSIFICATION RULES FOR GRADE CLASSES

Preliminary grade classification for each design parameter				resultant assigned grade class for the timber
fm	ft,0	fc,0	Eo,mean	
T	T	T	T	T
T	T	T-1	T+1	T
T+1	T	T-1	T-1	T

T+1 denotes one grade class higher than T

Classification into grade classes

In the application of Table 19 to classify stress graded solid timber the structural properties of the timber may be determined directly by the methods described in the ISO draft standard ISO/TC16S N688 "Timber Structures: Solid Timber in Structural Sizes: Determination of some Physical and Mechanical Properties"; or the properties may be assessed through indirect methods based on correlations with other structural characteristics. In all cases, the properties to be used for classification purposes are assessed with at least 75 per cent confidence.

Other countries

There are several other countries, such as Papua New Guinea, Solomon Islands, Fiji, etc., that have strength grouping systems similar to or based on the Australian system. In Tanzania, a strength grouping system with seven groups (A to G) has been in existence since 1970. (Cambell & Malde, 1970). Timber Research and Development Association (TRADA), UK in connection with a wood working project sponsored by UNIDO in 1976 drew up a strength grouping system with 3 groups for Laos timbers and a set of stress grading rules having only one grade equivalent 63 percent of the basic bending stress (air dry).

In other developed countries such as Canada, USA, etc. grouping techniques are used for a small number of species and they are mainly for softwoods.

RECOMMENDATIONS

In considering a fundamental system for bringing timbers into strength groups on the basis of their small clear properties, the Australian system detailed in SAA MP 45 is well documented and established, has been applied to a large range of timbers from many parts including less developed countries, and is fully appropriate to UNIDO's requirements. It is therefore the obvious choice.

Stresses published in design codes to form the basis of permissible values for design differ from the properties associated with small clear strength groups. Most industrialized timber-using countries and quite a number of less-developed countries have national stress grading rules. Sets of simplified model rules for tropical hardwoods and for conifers have also been proposed within the scope of this project. Such rules should form the basis of future UNIDO field projects, and also possibly further developments in the form of guidance documents.

The terms used for the 'safe working stress' values published in codes differ, unfortunately, according to the country considered. Those to be mentioned in this section dealing with recommendations are the 'grade stresses' as defined in BS 5268, Part 2, 1984 and the 'stress grades' given in AS 172, SAA Timber Engineering Code. It is recommended that design in accordance with either of these codes, or their successors in the light of revisions, should be encouraged when experts and consulting organisations are engaged by UNIDO in future timber projects.

Occasions may arise when special local considerations suggest the use of other design recommendations. These might for example be those given in the Junta del Acuerdo de Cartagena (Andean Pact) timber design manual or the US National Design Specification for Wood Construction. Both of these examples are thoroughly applicable to the types of timber enginering design that might be considered in UNIDO projects. Unfortunately however the basis of the classifications and species combinations which they contain are so different from the systems discussed under British and Australian standards that they must remain separate options rather than documents whose good features can be isolated and brought into special use in UNIDO projects. They are either used in their entirety or not at all. Nor can it be recommended at this stage that international developments such as the timber design code which has been produced by the CIB Working Group W18, or the ISO TC/165 draft recommendations on strength grouping are sufficiently mature or prescriptive documents to enable them to be used in in projects in less developed countries where only scant information on the performance of the materials available may be to hand.

The recommendation to use either the British or the Australian code may seem insuffficiently decisive, but this is not in fact the case, since as explained elsewhere, if the basic strength group of a timber is known according to the methodology of SAA MP 45, then either strength class stresses according to BS 5268, or 'grade stresses' according to AS 1720 can be determined. This will be particularly easy if the recommended UNIDO simplified grading rules are adopted in work for the organisation, in which case the procedures explained elsewhere in the papers relating to this project will be followed. If it is a matter of indifference whether the Australian or the British code be adopted for a particular project, then it is recommended the latter be chosen, since the system is simpler, relating only to five strength groups, and having only nine classes, rather than seven groups and twelve stress grades in the Australian case.

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