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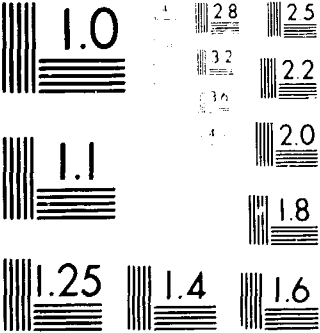

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11348

Dist.
LIMITED

ID/WG.359/2
22 April 1982

ENGLISH

United Nations Industrial Development Organization

Expert Group Meeting on Timber
Stress Grading and Strength Grouping,

Vienna, Austria, 14 - 17 December 1981

GENERAL REVIEW OF VISUAL STRESS GRADING SYSTEMS*

by

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V.82-24935

C O N T E N T S

FOREWORD.

This paper has been written upon a request by the United Nations Industrial Development Organization (UNIDO) as a background paper for the Meeting on Timber Stress Grading and Strength Grouping held in Vienna, Austria 14-17 December 1981. A draft paper was circulated among the attendants at the meeting in order to be discussed there and their opinions as well as that of the organiser of the meeting have been taken into account in order to prepare this final version. Indeed, a great deal of information was obtained from the participants at the meeting.

This final version tries to reflect the spirit of the meeting as best as possible and it is hoped that this goal was accomplished. Still, the opinions, appraisals and evaluations presented here are the sole responsibility of the author and it must not be inferred that they are necesarilly the same as those of the participants nor those of UNIDO.

1. INTRODUCTION.

This paper is intended for critically reviewing, discussing and appraising the different types of stress grading systems existing in the world, at least the most important ones. Only the visual stress grading systems will be reviewed here, as the mechanical grading systems will be discussed in another background paper. In order to have a better basis for comparison among the different systems, the grading rules have been divided into three major groups:

a). Rules belonging to developed or more technologically advanced countries.

b). Rules from developing or less technologically advanced countries

c). Rules drawn up by International or Regional Organizations

In each case, the most relevant grading rules are described and discussed in detail and then other rules are compared to them.

It must be pointed out that only rules for structural purposes have been considered here.

It must also be borne in mind throughout the reading of the paper the purpose of the meeting, as was stated by Mr. D.G.A. Butaev in his opening speech (9):

"We feel that the subject of timber stress grading and strength grouping is of fundamental importance in the process of rationalizing timber use in developing countries. It seems to us that it offers a key to increased used of lesser-know species for constructional uses domestically and eventually in major importing countries, and has not received enough attention at the international level despite some laudable progress regionally".

"Your (the participants') recommendations...may be for an international framework to be established and adopted by timber producing countries to serve their stress grading needs".

2. BRIEF DISCUSSION OF STRESS GRADING PRINCIPLES.

Because of its biological nature, which is influenced by many factors-genetical and environmental-timber comes in an extremely large variety of qualities from the structural stand point. Therefore, some sort of arrangement or classification must be done prior to its use, in order to make an efficient utilization of this valuable resource. It is obvious that not all the lumber can be used for the same purposes because not all of it has the same properties. There is high strength lumber-the top quality material, medium strength lumber, and low strength lumber-the weakest part of the population. Because of this, one must identify what characteristics are common to each one of these groups.

A grading rule is a set of definitions of lumber characteristics which describe in an orderly manner, the way in which a given piece of lumber from a certain species or group of species, will be designated and allocated to any of a number of groups or categories. Every one of these groups or classes is associated to a certain number of design properties-such as allowable stresses in bending, compression parallel to the grain, tension parallel to the grain, etc. In this context, all pieces of lumber pertaining to one of the groups are said to have the same design value, which is the minimum value of the property that the lumber/timber in that class or grade can safely withstand.

In the visual grading systems, the grading is performed by a human grader which identifies and appraises the defects and thence, their effect on lumber strength, according to a prespecified set of rules. Then he or she puts a marking on the piece of lumber which identifies the structural group to which it belongs, or else if it does not belong to any, meaning it is not useful for structural purposes.

This system of visually grading the lumber has certain drawbacks such as the subjectivity of the graders and some other grading systems have been developed lately to overcome these disadvantages, for example, the mechanical grading systems. Still, the visual grading system is the one which is the most widely used all over the world.

3. RATIONALE

As mentioned before, only the most important or widely used types of grading systems will be discussed in depth and then the others will be referred to as to how they differ from or they compare to the key ones.

Such aspects as the differences in the grading rules for the different species groups-hardwoods or softwoods-are discussed, as well as how the rules refer to related issues such as moisture content and lumber dimensions. The different methods for measurement of defects are presented and the associated stress grades or grade ratios are referred to. A critical appraisal of the rules is attempted and finally a comparison among them is made. The final recommendations are based on these appraisals and comparisons.

Some other important aspects such as the legal framework in which the grading rules are confined and their interaction with the strength grouping of species will be also discussed.

4. REGIONALIZATION

In the case of the developed countries, sixteen grading rules are studied. They are from the United States, the United Kingdom, Australia, Canada, South Africa, Germany, Sweden, Norway, Japan, Austria, Belgium, Finland, France, Holland, Denmark and New Zealand.

The most important rules are deemed to be those from United States, the United Kingdom and Australia.

For the developing countries rules from Mexico, Costa Rica, Malaysia, Philippines, Tanzania, Uganda, Kenya, India, Chile and Papua-New Guinea were chosen to be studied. Those from Mexico, Malaysia and the East African countries are discussed in detail.

And finally, three international or regional grading rules are examined. They are the ECE rules, the Andean Pact rules and the Scandinavian grading rules.

5. DESCRIPTION OF RULES

5.1 Developed countries

5.1.1 United States of America.

The current American softwood lumber standard is Product Standard PS 20-70 (61), a voluntary standard developed by the National Bureau of Standards in cooperation with producers, distributors and users. This standard came into effect in 1970. PS 20-70 establishes dimensional requirements for standard sizes, technical requirements for the product and methods of grading and marking these products. This standard incorporates several unique features including sizes related to moisture content resulting in the same end-use sizes for both green and dry lumber. Under this standard, a National Grading Rule was written that prescribed uniform grading features for the same dimension grades of all species (21).

For purposes of the National Grading Rule for Dimension Lumber, "dimension" is limited to surfaced softwood lumber of nominal thickness from 2 through 4 inches. The National Grading Rule for Dimension Lumber classifies dimension lumber into two width categories and five use categories. Dimension up to 4 inches wide is classified as "Structural Light Framing", "Light Framing" and "Studs". Dimension five inches and wider is classified as "Studs" and "Structural Joists and Planks". In addition, a single "Appearance Framing" grade of two inches and wider is designed for some special uses (63). The grades in these rules are referred to as size and use groups.

The major characteristics encountered in grading of softwood lumber are listed for each grade in the National Grading Rule for Dimension Lumber. This rule mentions knots, fissures (these include checks, shakes and splits) and slope of grain as being the chief characteristics whose size and position are limited. All grade descriptions set forth the limiting characteristics that may occur in lumber in each grade. Hence, the rules can be said to describe the poorest pieces allowed in a grade.

Knots, checks, shakes and slope of grain are measured in accordance with the provisions of ASTM D-245 "Methods for Establishing Structural Grades for Visually Graded Lumber" published by the American Society for Testing and Materials (3). The limitations on knot sizes and other characteristics governing strength listed for each grade must not be exceeded by the pieces included in the grade.

Two further types of construction lumber are not included in the National Grading Rule for Dimension lumber but they are nevertheless described in all United States Rules in accordance with the American Lumber Standard. They are the Beams and Stringers, 5 inches and thicker, 8 inches and wider in cross-section and the Posts and Timbers, 5 x 5 inches in cross-section and greater, approximately square.

The categories of Structural Light Framing and Structural Joists and Planks in the National Grading Rule each contain four grades, indicating a range of allowable characteristics and manufacturing imperfections affecting strength, stiffness and appearance. These grades are: Select Structural, No.1 Grade, No.2 Grade and No.3 Grade.

The Light Framing category contains three grades: Construction, Standard and Utility. Stud grade is a separate grade. Economy grades are also available in all three categories of Structural Light Framing, Light Framing and Structural Joists and Planks, but they are not intended for structural purposes. All these categories and grades are listed in Table 1. Grade names are generally uniform for dimension lumber in various softwoods, with a few exceptions such as the dense grades of several woods (like southern yellow pine and Douglas fir) and the special uses of western redcedar and redwood.

Knots in American rules are measured by the displacement method which means measuring the amount of clear wood displaced by a knot and considering it in relation to the amount it reduces the strength of the cross section of the piece under consideration. In all framing lumber 4" and less in thickness, the size of a knot, on a wide face is determined by its average dimension as in a line across the width of the piece. The size of knots on wide faces may be increased proportionately from the size permitted at the edge to the size permitted at the center line (Fig.1). Knots appearing on narrow faces are limited to the same displacement as knots specified at edges of wide faces (Fig.2). Knots in Beams and Stringers and Posts and Timbers are measured differently than knots in 4" and thinner material. Examples of these methods are shown in the drawings below (Figures 3.4 and 5).

The measurement of shakes, checks and splits in structural framing and beams and stringers is confined to the middle 1/2 of the height of the piece. Restrictions on checks apply for a distance from the ends equal to three times the width of the wide face. Shake is measured at the end between lines enclosing the shake and parallel to the wide face. Checks are measured as an average of the penetration perpendicular to the wide face. Splits are measured as the average penetration of a split from the end of the piece and parallel to the edges of the piece (Figures 6 to 9).

In lumber 2 inches nominal and thicker and 4 inches nominal and wider, slope of grain is measured over a sufficient length and area to be representative of the general slope of the fibers. Local deviations around knots and elsewhere are disregarded in the general slope measurement (Figure 10).

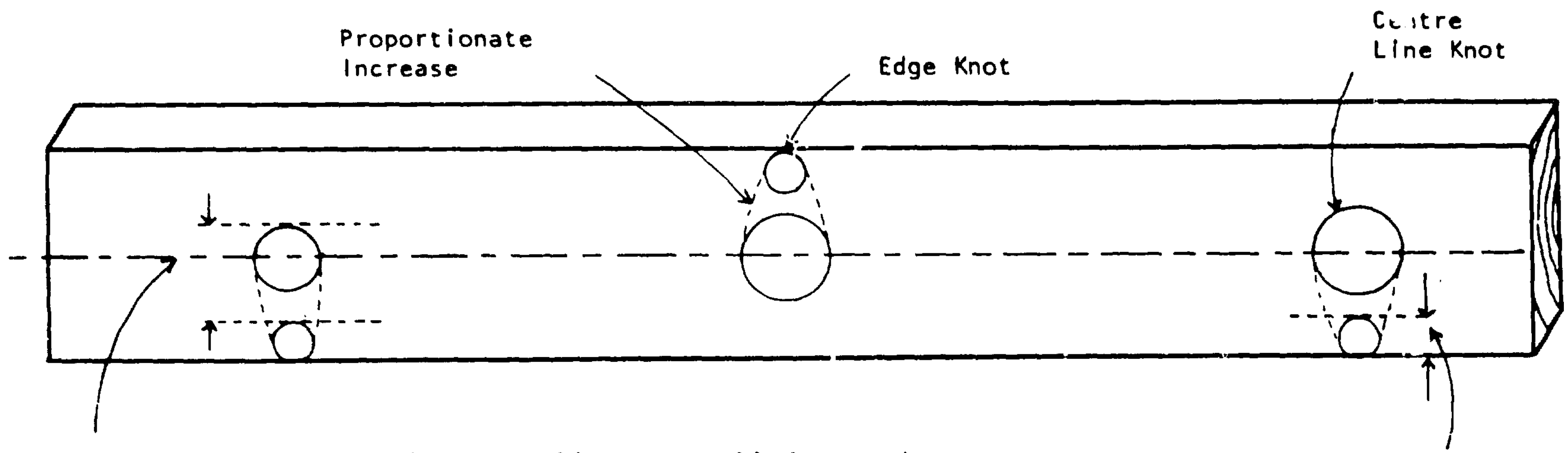


Figure 1. Measurement of knots in National grading rules (After NLGA grading rules (44)).

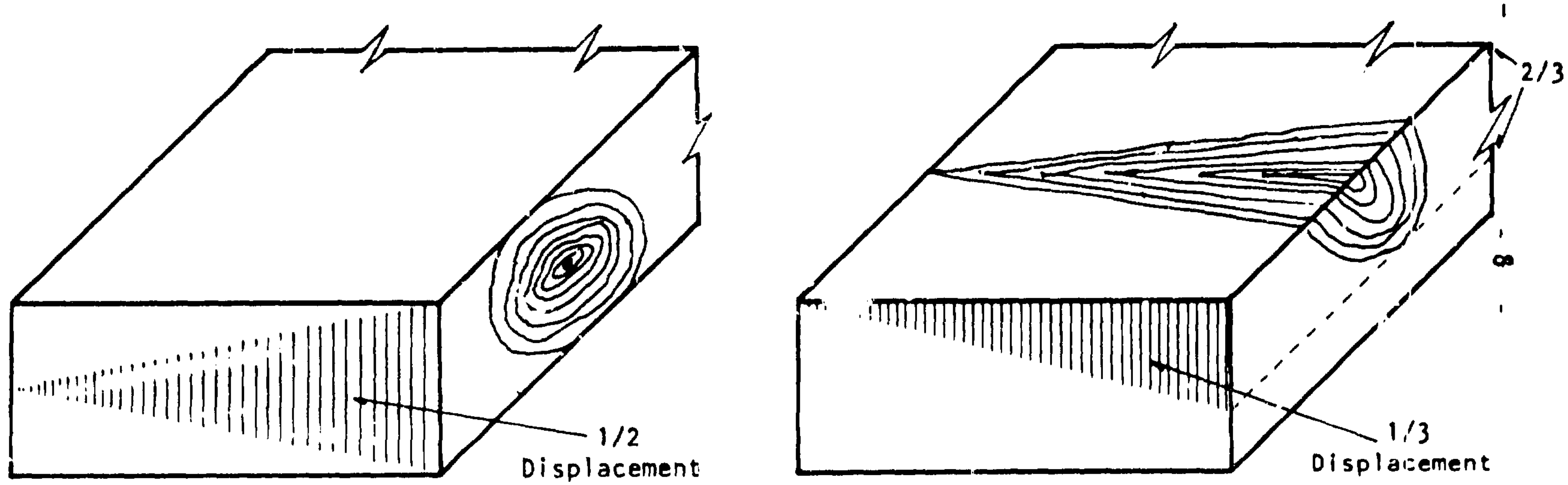


Figure 2. Measurement of narrow face and spike knots (After NLGA grading rules (44)).

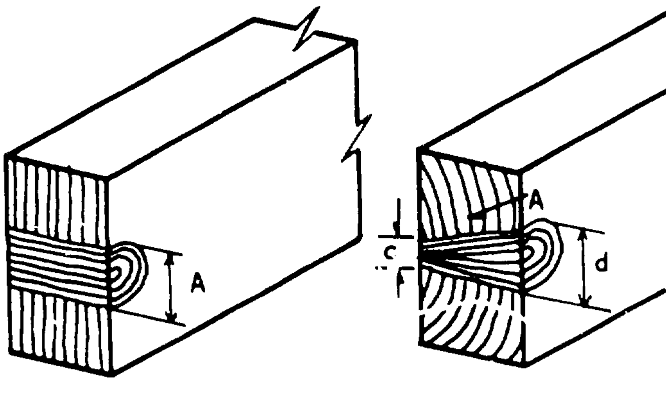
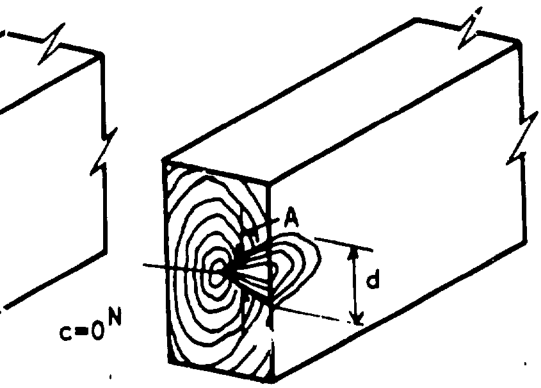


Figure 3. Measurement of wide face knots
grading rules (63)).



$$\frac{c+d}{2} = A$$

in 2" to 4" thick lumber (After WWPA

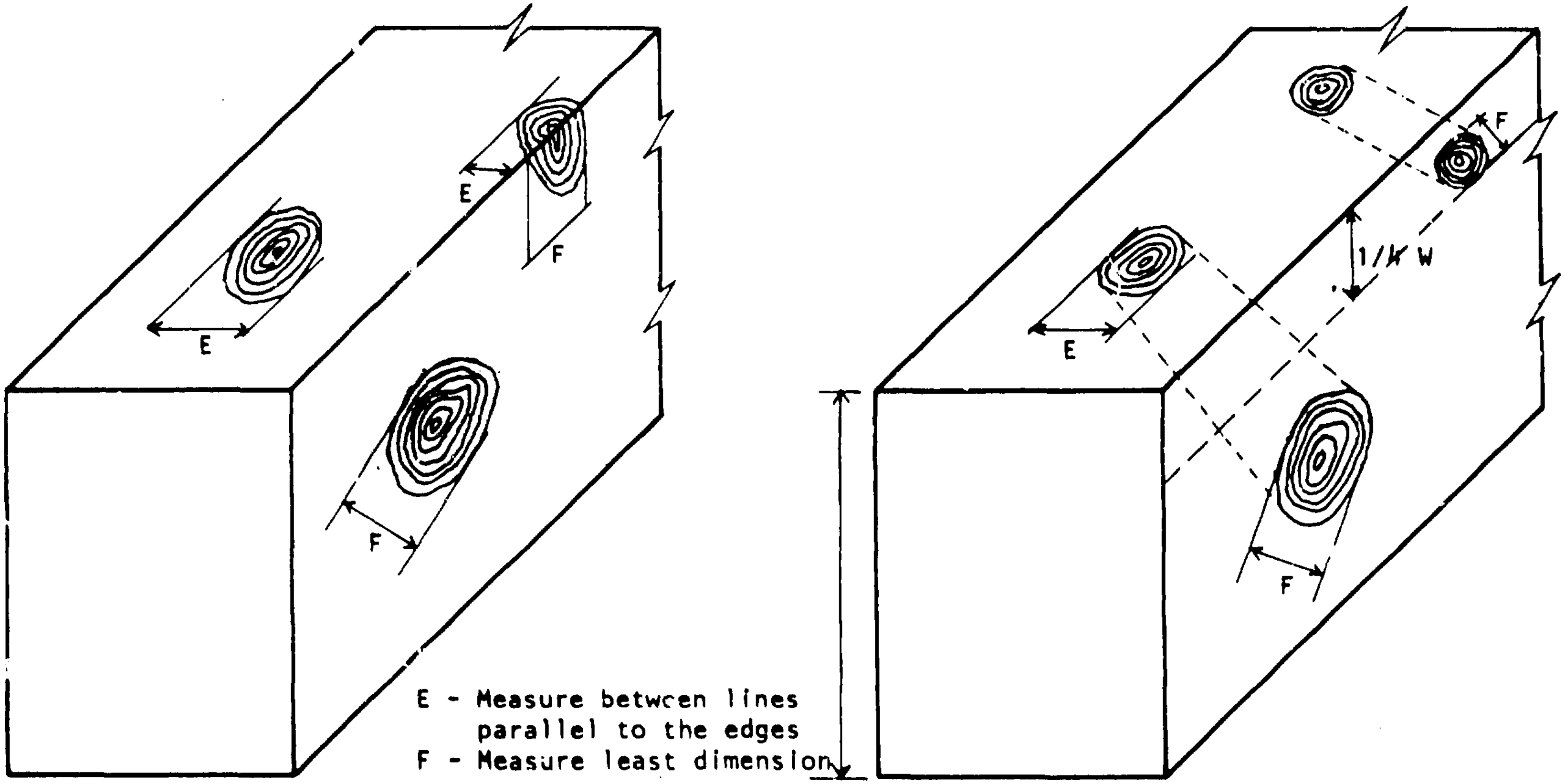
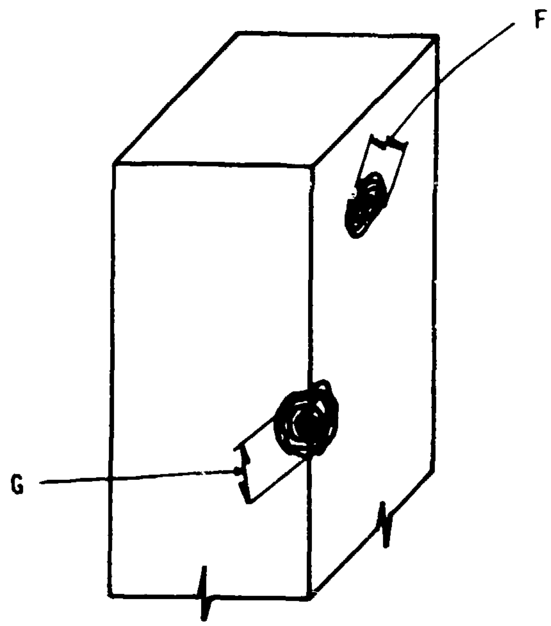


Figure 4. Measurement of knot in beam and stringer grades (After NLGA grading rules (44)).



F - Measure least dimension.

G - Measure along corner or measure size most nearly representing - diameter of branch causing the knot.

Figure 5.

Measurement of knots in Post and Timber grades (After NLGA grading rules (44)).

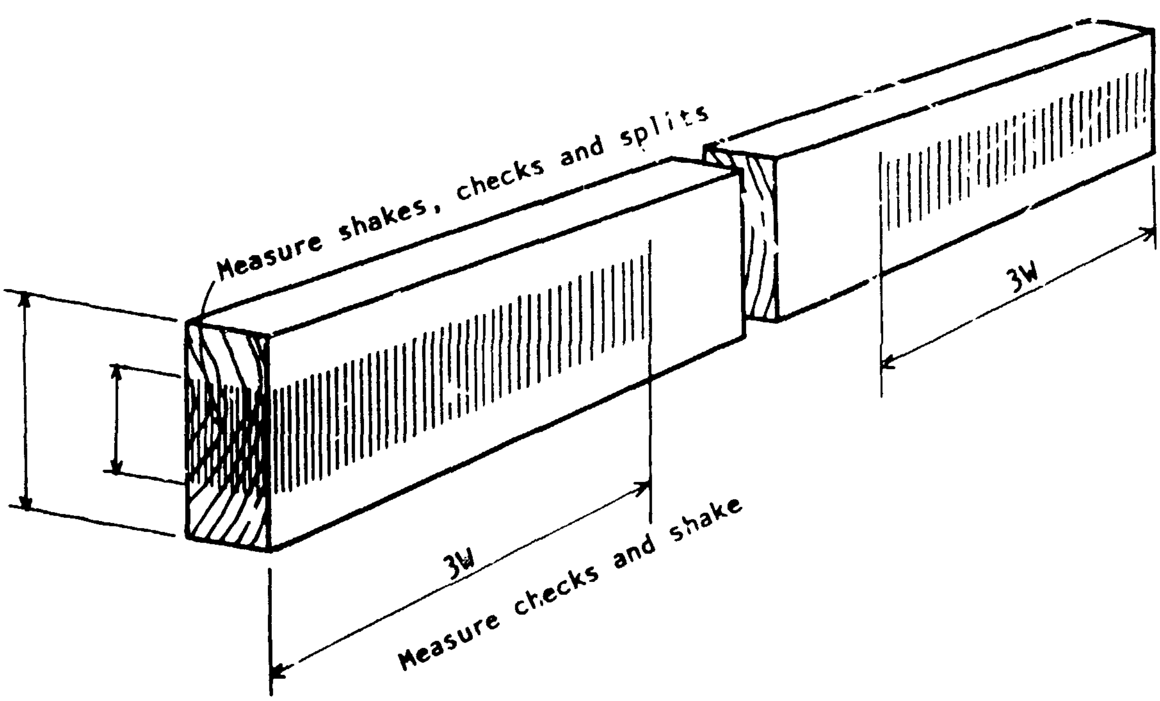


Figure 6. Area for measurement of shakes, checks and splits in National grading rules (After WWPA grading rules (63)).

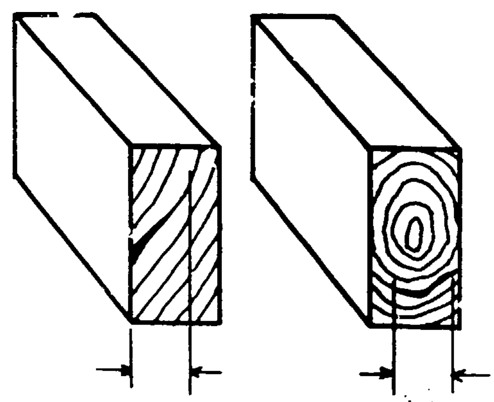


Figure 7. Measurement of shakes (After WWPA grading rules (63)).

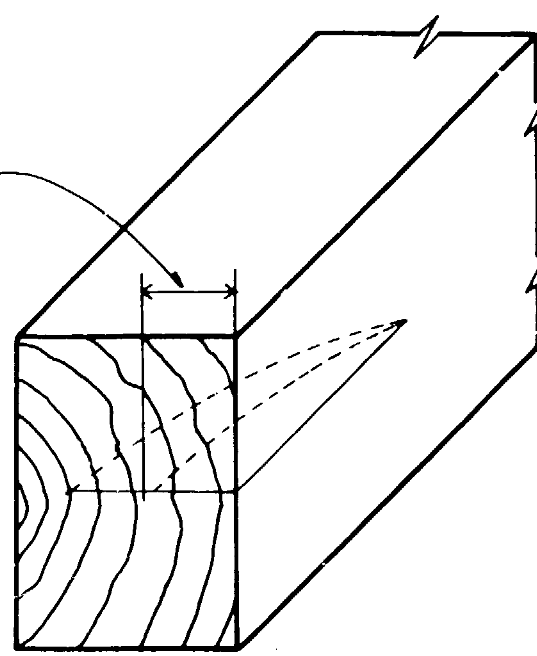


Figure 8. Measurement of checks (After NLGA grading rule (44)).

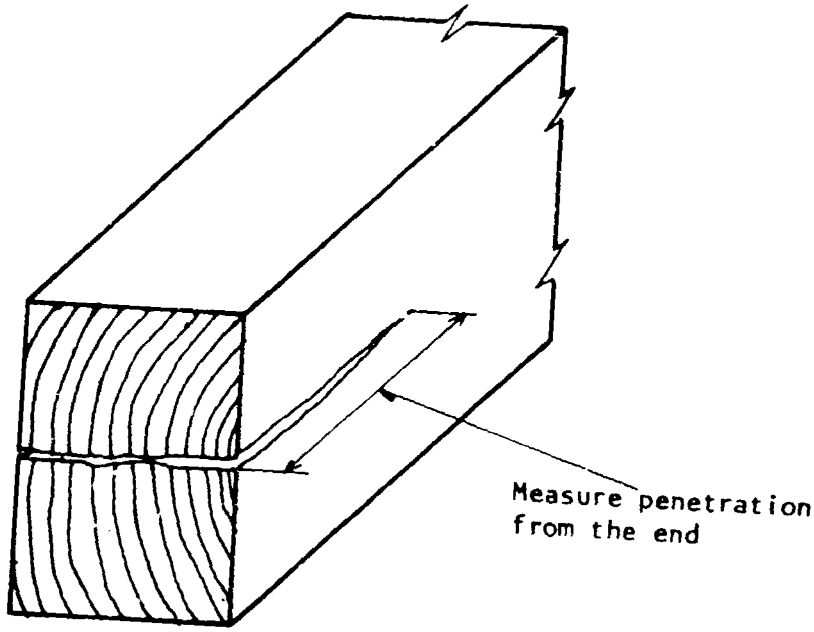


Figure 9. Measurement of splits (After NLGA grading rule (44)).

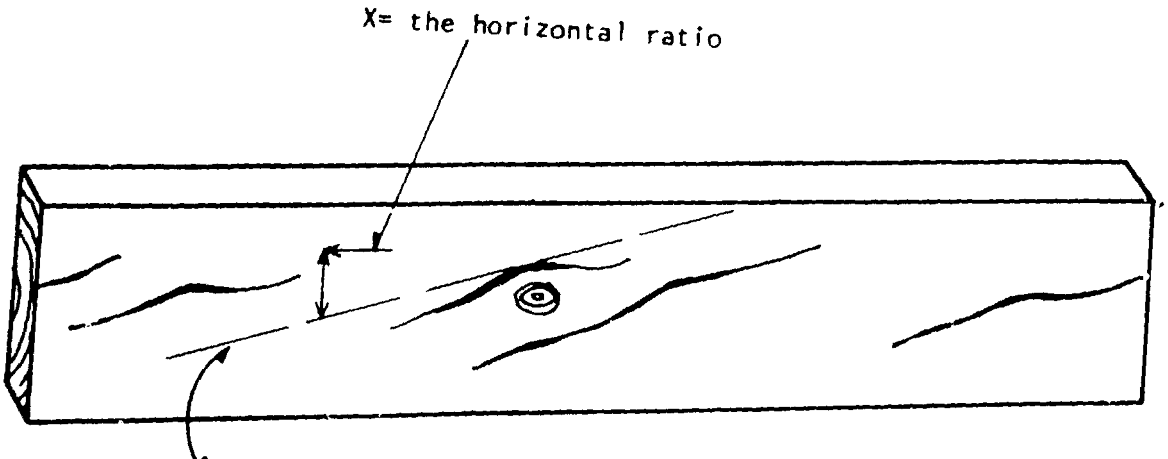


Figure 10. Measurement of slope grain (After WWPA grading rules (63)).

TABLE 1. GRADE CATEGORIES OF VISUALLY STRESS-GRADED LUMBER AVAILABLE COMMERCIALLY IN THE UNITED STATES.

CATEGORY	GRADE	THICKNESS	WIDTH
		In.	In
Structural Light Framing	Select Structural	2-4	2-4
	No. 1	2-4	2-4
	No. 2	2-4	2-4
	No. 3	2-4	2-4
Light Framing	Construction	2-4	2-4
	Standard	2-4	2-4
	Utility	2-4	2-4
Stud	Stud	2-4	2-5
Structural Joists and Planks	Select Structural	2-4	6 and wider
	No. 1	2-4	6 and wider
	No. 2	2-4	6 and wider
	No. 3	2-4	6 and wider
Beams and Stringers	Select Structural	5 and thicker	8 and thicker
	No. 1		
	Standard		
	Utility		
Posts and Timbers	Select. Structural	5x5 and greater approximately square	
	No. 1		
	Standard		
	Utility		

The various grades in National Grading Rules are based on the assumption that the joists, planks, beams and stringers are used in bending, while the posts and timbers are axially loaded as columns Stresses are given however, for all properties including both bending and compression for all groups of grades. The allowable unit stresses recommended for use in design for all normal construction are included in the "National Design Specification" published by National Forest Products Association (43).

Design values are computed in accordance with the requirements of 'Methods for Establishing clear Wood Strength Values. ASTM-2555 (1). The design values are based on computations which use the strength levels of clear green wood provided by the U.S. Forest Products Laboratory.

The values are computed from clear wood strength levels at which at least 95 percent of the clear wood is predicted to be stronger. Standard ASTM reductions are made from these clear wood values to account for safety and duration of load. For individual grades the resulting values are further reduced in accordance with the strength ratio concept, to reflect the predicted effect of knots or other differences from clear wood permitted by each grade classification. The term strength ratio as employed in ASTM standard represents the anticipated proportionate remaining strength after making allowance for the effect of maximum permitted knots, cross grain, and the like in a given grade, as compared to clear, straight-grained lumber. The bending strength ratios for dimension lumber given in National Grading Rules are shown in Table 2.

Design values for visually graded lumber are assigned to six basic properties of wood. These are fiber stress in bending (Fb), tension parallel to grain (Ft), horizontal shear (Fv), compression parallel to grain (Fc), compression perpendicular to grain (Fc⊥), and modulus of elasticity (E).

The effect of the moisture content on the st[illegible] lumber has been considered in calculating design values, [illegible] adjustment factors are given in National Design Specifications for cases where lumber is used at different moisture contents than which is stated in the Table. Design values are given for lumber surfaced dry or surfaced green, but used at 19% maximum moisture content.

The National Grading Rules as described above apply to all softwood lumber species manufactured in the United States. They may also be applied to hardwood species manufactured for applications where softwood species are ordinarily employed. Visual stress grading as permitted under PS 20-70 has been appied to aspen, red alder and cottonwood. Attempts are being made to extend this grading to yellow poplar (20).

TABLE 2. BENDING STRENGTH RATIOS FOR DIMENSION IN NATIONAL GRADING RULES.

2-4" thick, 2-4" wide
WIDE
STRUCTURAL LIGHT FRAMING

Bending Strength Radio	Grade Name
67%	Select Structural
55%	No.1
45%	No.2
26%	No.3

LIGHT FRAMING

34%	Construction
19%	Standard
9%	Utility

2-4" thick, 2-6" wide
STUDS

26%	Stud

2-4" thick 5" and wider
STRUCTURAL JOISTS AND PLANKS

65%	Select Structural
55%	No.1
45%	No.2
26%	No.3

2-4" thick, 2" and wider
APPEARANCE FRAMING

55%	Appearance

An evaluation of the stress values assigned in the current standard grading rules for the several visual grades as well as an evaluation of the grading rules themselves is deferred until section 6.

5.1.2. United Kingdom

The British structural grading system has undergone recently a period of major revision. The committee of the Code of Practice for the structural use of timber has recently decided to delete Appendix A and the numbered (75,65,50,40) and composite grades from CP 112: Part 2: 1971 (6) and to include (for British grades) only those given in BS 4978 (7), as is stated by Curry (13). Therefore, the old British grading system will not be included in this review and, the discussion will focus on the new standard BS 4978.

British Standard Specification BS 4978:1973 specifies the means of assessing the quality of timber for which more recent grade stresses have been added to CP 112 by means of amendments. For visual stress grading the principle of knot area ratio (KAR) has been adopted as a means of determining the maximum permissible knots for a given grade. The BS 4978 rules are internationally the only rules where this method is used exclusively, other than the ECE "Standard for stress grading of coniferous sawn timber" (60) the drafting of which was influenced strongly by the concepts introduced in BS 4978. Both BS 4978 and ECE rules are of a general purpose nature. Grading is carried out irrespective of the expected end use of the piece. They are therefore suitable for provision of supplies of stress graded material from the sawmill (40).

Two standard grades have been established for visually stress graded timber, namely, General Structural grade (GS), and a higher grade, Special Structural grade (SS). Since there can be small differences of opinion between experienced graders in the KAR method where projected patterns of knots have to be estimated, a small deviation in grading is permitted (not more than 5% of any given parcel should be found to be deficient).

The grader is left with the task of visualizing the projected pattern of the knot or group of knots considered as being in the weakest cross-sectional area. To understand what is meant by "the projected pattern of knots", it may help to imagine the selected cross-sectional area as if made of glass, with only the knots themselves made out of wood. The disposition of the wooden knots as viewed from one end of the glass "box" is the projected pattern (57). It is upon this projected pattern of the knot formations that the various grading assessments are made. This principle of knot area ratio (KAR) grading is illustrated in Figure 11.

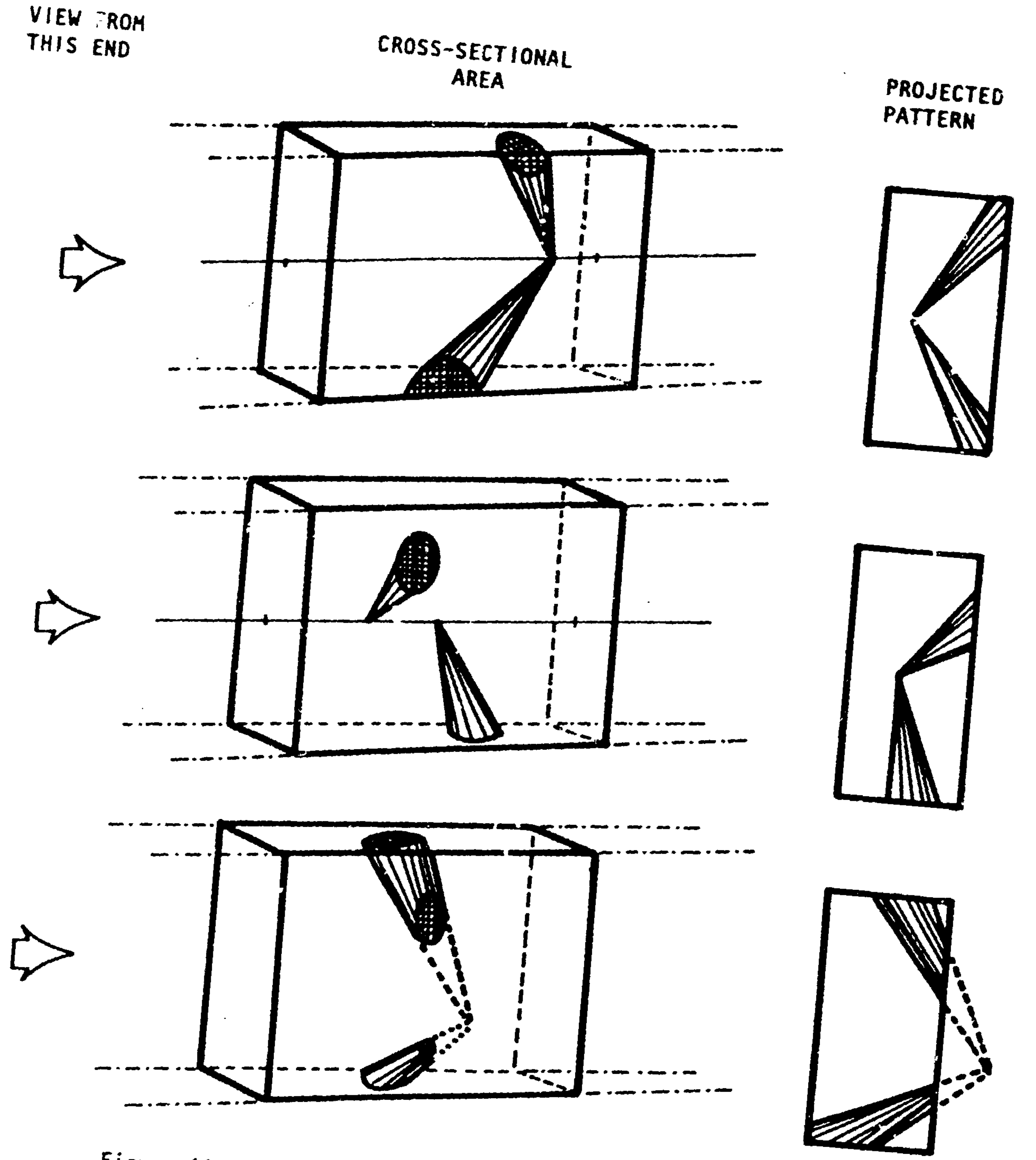


Figure 11. Knot area ratio (KAR) grading technique. Example of projected patterns of knots (After visual stress grading, TRADA (57).

Knots present in margin areas are dealt with more severely in the BS 4978 rules, because in bending applications they are the most critical ones. Therefore, in practice the grader is especially concerned with the two quarters of the width nearest each edge. These extreme quarters, referred to as "margin areas" are illustrated in Figure 12.

A very important aspect of the grading under these rules involves the definition of a "margin condition" In the context of these rules, a margin condition exists when more than 1/2 the area of either margin is occupied by the projected area of knots.

The way of grading with these British rules is best explained with the help of the diagrams shown in Figures 13 and 14 depicting the decision sequences when selecting for GS Grade and, the decision sequence when selecting for both SS and GS Grades simultaneously, respectively.

BS 4978 also includes the specifications for timber for laminating but they are not discussed here.

Obviously, besides the limitations for KAR for the different grades, the pieces of lumber must also fulfill the other requirements specified such as rate of growth, fissures, slope of grain and wane. Table 3 summarizes the grade limitations for KAR, fissures, and slope of grain for the BS 4978 visual grades.

In regard to the design values for visually graded lumber, "The Building Regulations 1976" (59) accepts all structural members in timber designed in accordance with CP 112. CP 112 covers the stresses and moduli of elasticity in two moisture conditions: green which refers to lumber with a moisture content exceeding 18 percent and dry, which refers to lumber with a moisture content not exceeding 18 percent. Dry stresses apply only to timbers less than 102 mm thick which have been dried to a moisture content of 18 percent or less before being subjected to service loads and which will mantain a mositure content of 18 percent or less throughout its service life (56).

The adjustment factors considered in the conversion of small, clear, straight-grain standard properties to defect-free lumber are somewhat different from the US system. Effect of shape and size of specimen are included in the general adjustment factor; seasoning adjustment does not follow a systematic procedure instead, it is treated individually by grade and species. The maximum air dry moisture content is 18 percent. The effect of variability in strength is expressed by the use of 1.0 percent low exclusion, strength value for the small, clear, straight-grained properties. The mean and low exclusion values are both reported for the modulus of elasticity.

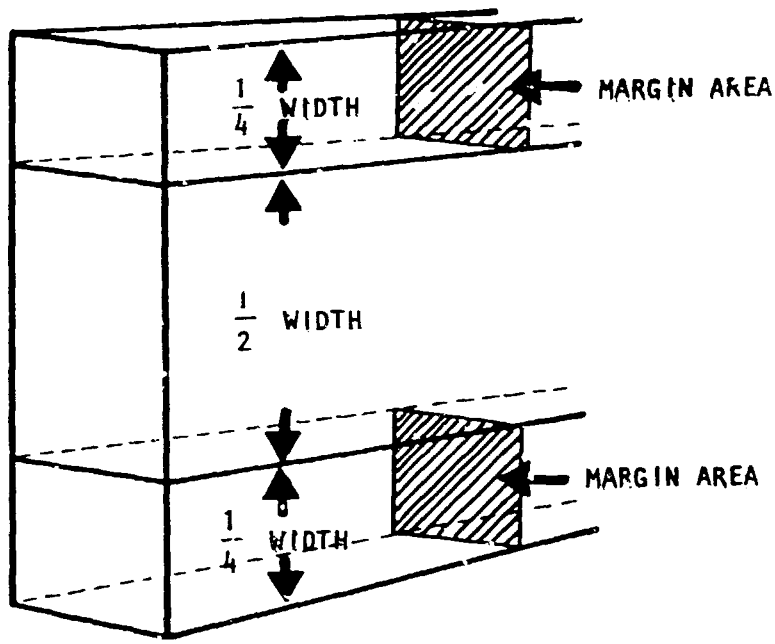


Figure 12. Margin areas as defined in BS 4978: 1973 (After visual stress grading, TRADA (57)).

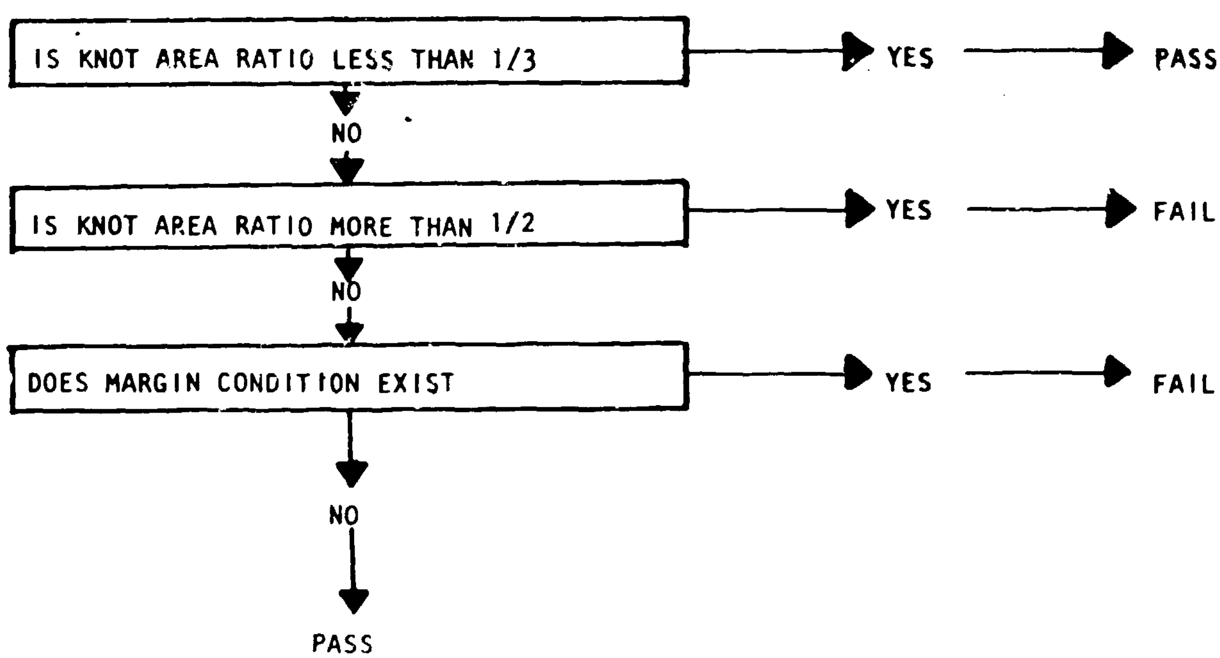


Figure 13. Decision sequence when selecting GS grade in BS 4978 (After BS 4978: 1973 (7)).

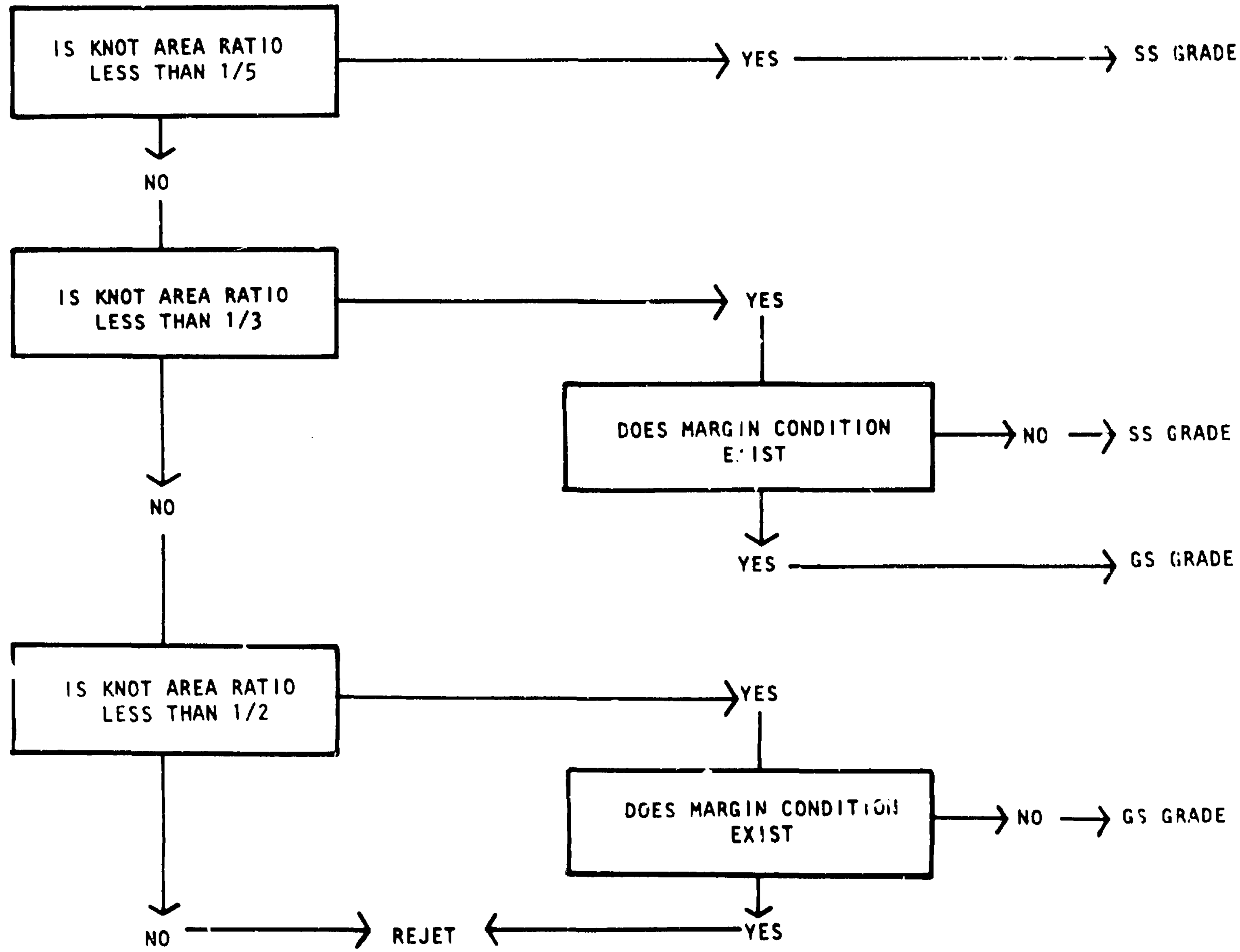


Figure 14. Decision sequence when selecting for SS and GS grades in BS 4978 (After BS 4978: 1973 (7)).

TABLE 3

GRADE LIMITATIONS FOR K A R , FISSURES & SLOPE OF GRAIN FOR BS 4978 VISUAL GRADES

Grade	Knot area ratio (K A R)		Fissures: Size	Fissures: Length	Slope of grain
SS	margin condition	1/5	less than or equal ¼ thickness	unlimited	1 in 10
	no margin condition	1/3	greater than ¼ but less than thickness.	to exceed neither 600 mm nor one quarter length.	
	square section	1/5	equal to thickness	not permitted other than at ends, where not to exceed width.	
GS	margin condition	1/3	less than or equal ¼ thickness	unlimited	1 in 6
	no margin condition	1/2	greater than ¼ but less than thickness	to exceed neither 900 mm nor one quarter length.	
	square section	1/3	equal to thickness	to exceed neither 600 mm nor 1.5 times width if at end.	

Design in hardwoods follows the same principles as for softwoods, introducing no extra difficulties and based on stresses taken from the code of practice, CP 112.

The following paragraphs are excerpts from Mettem's presentation in Vienna (40)

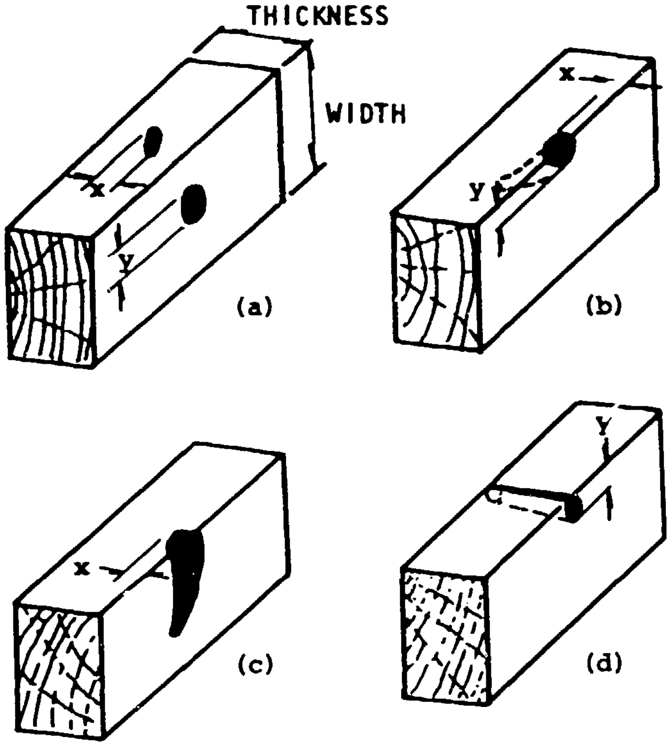
A new British standard, BS 5756: 1979 "Grading of Tropical hardwoods for structural purposes" (8) is the first British standard in grading dealing especially with tropical hardwoods. The standard lays down the grading rules for a single "Hardwood Structural" (HS) grade which is intended to be a good standard multi-purpose grade applying to all types of member for which structural design calculations are made in tropical hardwood timbers. A number of characteristics of tropical timber which may be considered defects from an appearance grading point of view, such as stain not associated with decay, and pinholes, can be accommodated in structural material with little or no loss in strength. Certain characteristics such as slope of grain, however, require careful limitation.

Dealing exclusively with tropical hardwoods, the standard is able to include some detail on characteristic which are of special significance to them. Conversely, the requirements governing characteristics of lesser occurrence in tropical hardwoods particularly knots, are in a simplified form that would not be possible with out innefficiency of use in softwoods.

Another aspect of simplification is that in common with the visual stress grades of BS 4978, the HS grade is applicable to all types of structural member, whether used in bending, compression or tension. It is thus applicable to the grading of supplies of stress graded tropical timber, when the exact nature of the end use is unknown.

Interlocked grain, caused by alternating layers of spiral growth in the tree, is a normal feature of certain tropical hardwoods and the grading rules warn that care should be taken to avoid confusing it with sloping grain.

Figure 15a) shows how simple knots are measured. When a knot emerges from within the cross section on to an arris, and neither of the exposed sections of the knot is definitely elongated (the arris knot of CP 112 "numbered" grades) then the knot is measured as shown in Figure 15b) A knot showing on both edge and face but cut so that one of its exposed sections is definitely elongated is measured as shown in Figures 15c) and 15d). Again it should be emphasized that knots are not a common feature in tropical hardwoods of the types normally



a) simple knots
b) arris knot
c) splay knot
d) edge knot

Figure 15. Measurement of knots according to BS 5756 (After Mettem (40)).

used structurally.

Brittleheart is the defective core of a log characterized by abnormal brittleness, which occurs in certain tropical hardwoods. There is not necesarily any difference in color between the brittleheart and the unaffected wood, and the limits of the defect are not sharply defined.

Brittleheart may be detected at the end of a piece by a pitted appearance of the wood. It is a defect which should be excluded from structural timber under all circumstances, and any timber in which its presence is suspected should be rejected.

Compression failures are fractures across the grain which may be found in tropical timber as it is converted and which are not due in any way to stresses applied to the piece through any use or misuse. The fibers are found to be broken transversely or crushed by compression. All pieces containing them shall be rejected.

Table 4 summarises the grade limitations for slope of grain, knots fissures and distortion for the BS 5756 HS grade.

Until here the description of BS 5756 is taken from the work of Mettem. Again, discussion of the rules is deferred until a later chapter.

5.1.3 Australia.

The structure of the Australian structural grading system is rather complex. The reason for this complexity is the large number of species which are utilized for structural purposes. In Australia about 80 species are used extensively and over 500 species have been classified for structural use (35).

Where such a number of species is utilized it is not feasible nor perhaps wise and necessary, for timber engineering standards to publish design information specific to each species. Rather it is preferable to group structural design properties into a limited number of strength classes. In general each strength class will cover a larger number of species and mixtures of species (35).

The visual grading system only forms a part of the strength classification scheme, as shown in Figure 16. The strength grouping concepts will not be dealt with in this paper as they are covered in another background paper by Keating (32) from which Figure 16 was taken. Only the derivation of working stresses and the visual grading rules will be analyzed here.

TABLE 4

GRADE LIMITATIONS FOR SLOPE OF GRAIN, KNOTS, FISSURES & DISTORTION
FOR BS 5756 HS GRADE

Characteristic	Qualifications	Limit
Slope of grain	normal sloping grain interlocked grain	1 in 11 1 in 4
Knots	limiting dimension lengthwise separation	¼ of thickness or width twice width
Fissures*	not more than 1/3 thickness	length unlimited
	greater than 1/3 thickness but less than thickness	length to exceed neither 1.5 times width nor 0.2 times length of piece
	equal to thickness	not permitted other than at ends, where length not to exceed width of piece
Distortion	spring (mandatory)	not to exceed 7 mm per 2 m
	bow	15 mm per 2 m
	cup	1 mm per 25 mm of width
	twist	1 mm per 25 mm of width in any 2 m length

* Bark pockets and included phloem subject to similar limitations.

Australian classification systems have evolved over a period of about 45 years. The current forms are given in the Australian standard 1720-1975, the SAA Timber Engineering Code (52).

The Standards Association has grouped Australian timber species into seven green strength groups, S1 to S7 and eight seasoned strength groups, SD1 to SD8 in decreasing order of strength.

There are two types of grades, the stress grade and the visual grade. The stress grade as defined in Australian timber standard is a grading index of the ability of a piece of timber to perform satisfactorily in a structural capacity in a building (33). More precisely, it would be 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 for purposes of design and, by implication, the basic working stress for other properties normally used in engineering or building design". The stress grade is designated in a form such as "F14", which indicates that for such a grade of material the basic working stress in bending is approximately "14 magapascals (MPa)".

There are 12 stress grades from F2 to F34. These stress grades were established by using a preferred number series with adjacent terms chosen in the ratio of 1.25 to 1. The range of the values chosen was such that it covered all the species likely to be used structurally in Australia (32). The visual grade consists of four grades for every species. The Australian visual grading rules developed also have differences between grades of 25%.

A particular species is placed in one of the S or SD groups based on the results of a series of standard mechanical tests using small clear specimens. As the specimens involved are free of any defect, provision must then be made for commercial material. The visual grading rules provide limits on the size and number of defects permitted so that the four grades used are claimed to be at least 75%, 60%,48% and 38% of the clear strength values. When the appropriate reduction factors are applied, a basic working stress for the particular piece based on a combination of strength group and grade is developed. Tables 5 and 6 show the relationship between strength group, visual grade and stress grade for green timber and seasoned timber respectively (31).

As an example of the Australian visual grading system the grading rules for hardwood are shown next.

Knots are measured by the surface method (53). Knots are classified as round, oval and spike or arris.

TABLE 5

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

Visual grade		Strength group						
Nomenclature	Per cent strength of clear material	S1	S2	S3	S4	S5	S6	S7
		Stress grade						
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

TABLE 6

RELATIONSHIP BETWEEN STRENGTH GROUP, VISUAL GRADE AND STRESS GRADE FOR SEASONED TIMBER IN AUSTRALIAN SYSTEM.

Visual grade		Strength group							
Nomenclature	Per cent strength of clear material	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8
		Stress grade							
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

For round or oval knots and knot holes, the size shall be the width as measured between lines enclosing the knot or hole and parallel to the arrises of the piece. (Figure 17).

For arris knots the size shall be the dimension of the knot which forms the lesser proportions of the surface on which it occurs as measured between lines touching the boundaries of the knot on both surfaces and parallel to the arris that intersects the knot (Figure 17).

In these rules, internal checks shall be measured as their projection on the width of the piece (Figure 18).

Sloping grain shall be measured over a distance sufficient to determine the general slope but not less than three time the width of the piece. Localized variations around knots shall be disregarded. (Figure 19).

The moisture content of the timber sold as "seasoned" shall not be less than 10 percent nor more than 15 percent, according to these rules.

In Table 7 are shown the permissible imperfections for the four structural hardwood grades. The less important features are not included in the Table.

In the Australian system the procedure of converting the standard small clear properties to defect-free lumber properties is also different somewhat from either the US or the British systems. The factors of size and/or depth are not yet accounted for in the Australian system, and the seasoning adjustment factor is for a maximum moisture content of 15 percent. Like the British system, the Australian system adopted the 1.0 percent low exclusion limit for strength properties and the average value for elastic property.

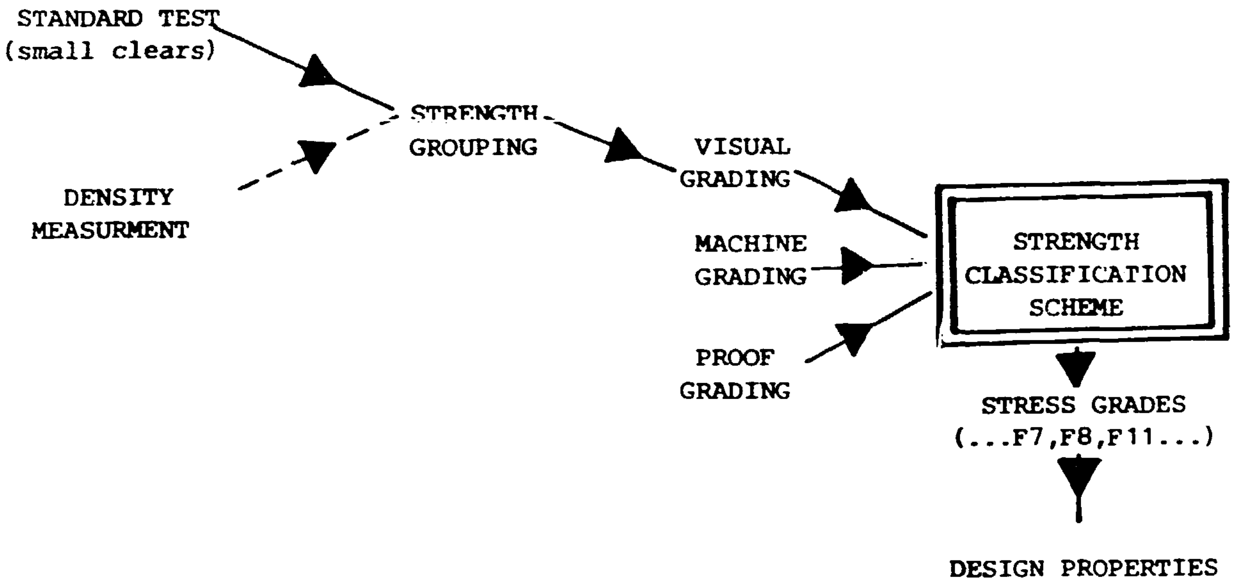


Figure 16. Strength Classification scheme for Australian timber (After Keating (32)).

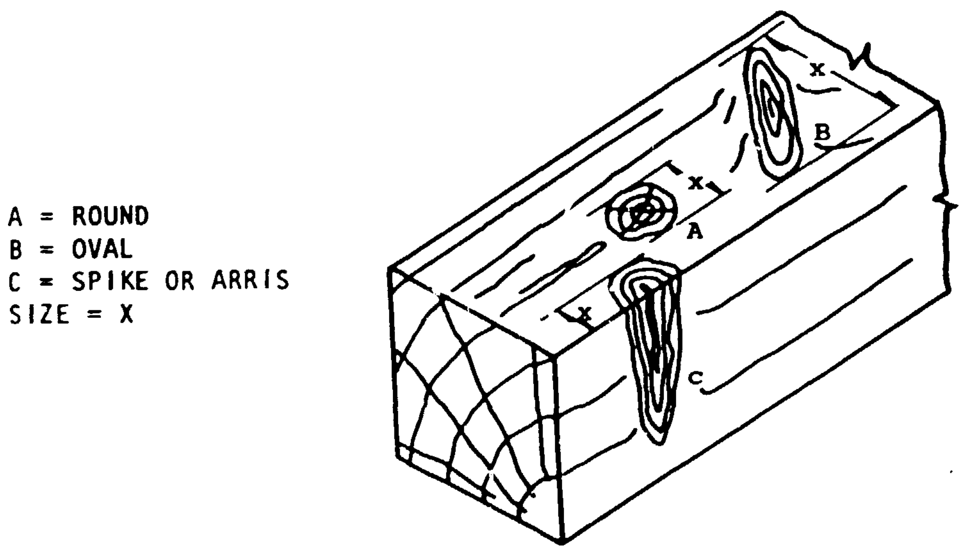
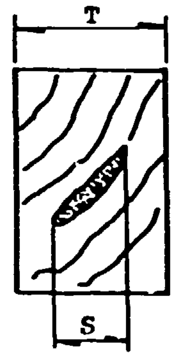


Figure 17. Measurement of knots in visual grading rules for Australian hardwoods (After visually stress graded hardwood (53)).



Size of internal check = S

Figure 18. Measurements of Internal Checks with Australian grading rules (After visually Stress-Graded Hardwood (53)).

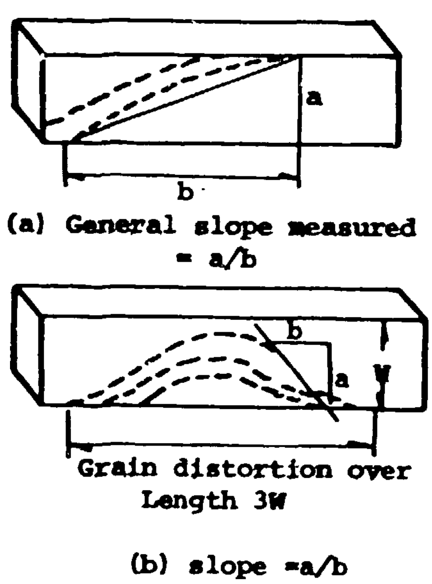


Figure 19. Measurement of Slope of grain in Australian grading rules (After visually Stress-Graded Hardwood (53)).

TABLE 7. GRADE DESCRIPTIONS IN AUSTRALIAN SYSTEM FOR HARDWOODS

STRUCTURAL GRADE No.1.

General.- Each piece of timber of structural grade No.1 shall be free from compression failures and other fractures, termite galleries, end splits and included bark intersecting an end.

Major Permisible Imperfections.

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

(b) Checks.
   (i) Surface checks-
      A. on surfaces up to and including 75 mm wide-individually not exceeding 2 mm wide

      B on surfaces exceeding 75 mm wide-individually not exceeding 3 mm wide

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

(c) Sloping grain
   (i) All species except jarrah-not exceeding 1 in 15

   (ii) Jarrah-not exceeding 1 in 12

STRUCTURAL GRADE No.2

General.- Each piece of timber of structural grade No.2 shall be free from compression failures and other fractures.

Major Permissible Imperfections.

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

(b) Checks
  (i) Surface checks-unlimited

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

(c) Sloping grain
  (i) All species except jarrah-not exceeding 1 in 10

  (ii) Jarrah-not exceeding 1 in 8

(d) End splits-equal in aggregate to the face width or 100 mm whichever is the lesser

STRUCTURAL GRADE No.3

General.- Each piece of timber of structural grade No.3 shall be free from compression failures and other fractures.

Major Permissible Imperfections.

(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) Checks
  (i) Surface checks-unlimited

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

(c) Sloping grain
  (i) All species except jarrah-not exceeding 1 in 8.

  (ii) Jarrah-not exceeding 1 in 6

(d) End splits-aggregate length at each end not exceeding 1.5 times the face width or 150 mm, whichever is the lesser.

STRUCTURAL GRADE No.4

General.-Each piece of structural grade No.4 shall be free from compression failures and other fractures.

Major Permissible Imperfections

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

(b) Checks

(i) Surface checks-unlimited

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

(c) Sloping grain (all species including jarrah)-not exceeding 1 in 6

(d) End splits-aggregate length at each end not exceeding 1.5 times the face width or [illegible] mm, which ever is the lesser.

5.1.4. Canada.

Softwood lumber in Canada is manufactured in accordance with CSA Standard 0141 (11). This is a voluntary, non-mandatory standard until it is adopted as a bylaw or requirement by a municipality or some other body. CSA 0141 provides a common basis for the classification, measurement, grading, grade marking, and standard sizes of softwood lumber. It also gives commercial or common names to lumber of various species, abbreviations used in the trade, and definitions of term used to describe lumber (22).

The grading rules for lumber manufactured in accordance with CSA standard 0141 are written by the National Lumber Grades Authority (NLGA) as the "NLGA Standard Grading Rules for Canadian lumber" (7). These NLGA rules for dimension lumber are identical to the National Grading Rules used throughout the United States, therefore, they have been already shown. The method of derivation of working stresses is also the same as that used in the United States, based on ASTM methods.

5.1.5 South Africa.

Structural visually graded timber is covered by S.A.B.S. 563-1971 (50) which defines three grades, viz, V4,V6 and V8. The general requirements of the specification for structural timbers limit knot sizes to a relatively low proportion of face width. But, it is claimed (15), with South African-grown, relatively immature timber, it is almost, impossible to integrate visually the effect of variations in density with the extent of defects. Due to this peculiarity, it is essential in South Africa that wood to be used in engineered structures must be carefully sorted for density (which is closely correlated with strength) irrespective of species. The only difference between V4 and V6 grades is related to density.

Knots are measured to the nearest 1mm on the relevant faces of the worst 150 mm length of the piece. The basic rule for measurement is as follows:

When round, oval and splay sound tight knots are measured, measure the distance the knot extends across the width of the face of the piece and take this as the size of the knot.

In the case of checks, measure the sum of the lengths of checks to the nearest 10 mm and their width to the nearest 0.1. mm. When adjacent checks are separate by more than 5 mm of sound wood, regard them as separate checks. As for slope of grain, measure to the nearest 1 mm the general slope of grain over a length (along the piece) of 210 mm. Finally, measure the length of splits to the nearest 10 mm.

To arrive at permissible stress values, grade stresses must first be obtained. Grade stresses are derived from the strength at failure of full size test specimens. The criterion for ultimate strength of timber members is failure in compression, tension, bending, or shear. After the necessary number of tests have been conducted in the manner required the strengths obtained are converted to a value corresponding to a lower level of probability of failure called the characteristic value, which corresponds to the 5% lower exclusion limit. The grade stress is equal to the 5% lower exclusion limit divided by a factor of 2.22.

The factor takes into account the duration of the load and effects such as accidental overloading errors in design assumptions and workmanship.

The factor is assumed to be constant for all strength properties such as compression, tension, bending and shear. (51).

It is important to note that for the case of bending, tension and shear no adjustment factor for moisture content is applied and Grade Stresses for South African Pines are given irrespective of the mositure content of the member.

5.1.6. Germany.

There are three grades in German rules specified in standard DIN 4074 and they are Gute Klass I, GKII and GKIII (49). GKII corresponds mainly to SS, and GKIII to GS in the British system. There is no comparable grade in the British rules for GKI. No more information is available to the author on German visual.grading rules.

5.1.7 Sweden.

The grading of timber in Sweden is made according to the "Instructions for sorting and grading of T-timber" issued by the T-timber association and authorized by plankvert. There is an additional grading rule, the "O-virke rule" where a stress grade called "O-virke" is defined as sawn or planed structural timber of fifth quality or better as per "sorting of sawn timber of fir and spruce" issued by the Association of Swedish Sawmillmen in 1965.

The Swedish system is based on a measurement of visible knots (Figure 20). These Swedish rules are also known as Scandinavian rules and are widely used throughout the Scandinavian countries. The grading of timber with these rules is carried out according to the ratio of knot diameter to edge and face dimensions respectively.

5.1.8. Norway.

The grading rule applicable in Norway for visually grading timber is the Norwegian Standard "Quality Specifications for Sawn Timber and

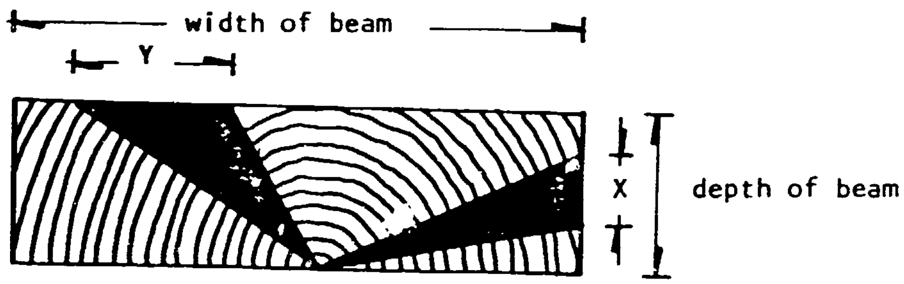


Figure 20. Method of Knot measurement in Scandinavian grading rules: measurement of the dimension of visible Knots (X and Y) (After Hoffmeyer, 1981 - (23)).

Precision Timber" NS 3080 (44), issued in 1972.

Timber graded according to this standard should be designated by stating the key letter for sawn or precision timber, thickness x width (in mm) x length (in meter) and the grade, eventually with the addition of the wood species. The Norwegian standard defines four grades: Timber quality E, S, C and Sx. Knots are measured by the surface method The grade letters stand for Extra grade (E), standard grade (S), other grade (C) and the supplementary grade (Sx). only the Extra grade and the standard grades are structural.

The knot sizes in this standard are limited as a proportion of the width of the face or the thickness of the edge. The limiting values for knots, slope of grain, shakes and checks are given in Table 8.

5.1.9. Japan.

A new Japanese Agriculture and Forestry Standard for dimension lumber has recently been drafted. This JAS is very similar to the grading rules of NLGA in North America except for a few points (42) and therefore, not discussed here

5.1.10 Austria

For this country, only one stress grade is mentioned in the literature available at the moment and it is the B 4100, whose associated properties are slightly smaller than those of German Gute Klass I.

5.1.11 Belgium.

Also a single stress grade has been identified by the author, and it is called STS 31. Its associated properties are virtually the same as those of German Gute Klass II.

5.1.12 Finland.

In Finland the applicable grading rules are the Scandinavian T-virke rules already mentioned for Sweden.

TABLE 8. QUALITY SPECIFICATIONS FOR SAWN TIMBER AND PRECISION TIMBER IN NORWEGIAN STANDARD NS 3080

Structural timber

	Extra grade (Grade E)	Standard grade (Grade S)
Knot[1]	On edge: 1/2 of the thickness On face: 1/4 of the width, though max. 35 mm	On edge: 2/3 of thickness, though max. 70 mm for square On face: 1/3 of width, though max. 70 mm
Knot cluster[1]	1/4 of width (max. 35 mm) + 1/2 of thickness	1/3 of width (max. 70 mm) + 2/3 of thickness (max. 70 mm)
Slope of grain	Up to 1:10 permitted	Up to 1:7 permitted
Ring shake	Not permitted	Ought not to appear
Hair surface check	Not permitted	Small checks permitted, also across the arris, but not down to the pith side
Check	A few shorter checks of depth up to 1/4 of the thickness is permitted, except on the edges	Permitted in the full length with depth up to 1/2 of thickness. For square, checks up to 3/4 of the side are permitted. Opposite checks are added together
Width of annual ring	Max. 5 mm	Unlimited
Hard decay Compression wood	Permitted to a limited extent	
Rot Defects due to insects	Not permitted	

1) The specifications apply to dimensions of thickness equal to or greater than 36 mm. For smaller thicknesses the specifications for knots are given in the respective products standards.

5.1.13 France

In France there are three grades of timber visually stress graded. They are called I, CI and II. They are specified in French Standard NF B 52-001 and in the standard CTB-CI. The I grade and the CI grade closely correspond to German GKI and II. The French rules are based on the measurement of the visible knots on the surface and the limits are given as proportions of the width of the piece.

5.1.14 Holland

Two visual stress grades for Dutch timber are mentioned in the literature: Standard Grade and Construction Grade. They are similar to the German classes KGII and III respectively.

5.1.15 Denmark.

In Denmark the same grading rules as in Sweden are used, since a great deal of the lumber used there is imported from the latter country.

5.1.16 New Zealand

In New Zealand about 90% of the timbers used for the structural framing of houses in green radiata pine (62) are graded visually as either No.1 or No.2 framing grade according to the National Grading Rules (54). These grades were not formulated as stress grades to which design values should be assigned but rather as utility grades for non-engineered uses. However, it has become necessary of late to assign stresses to these grades. The reference values characterising the visually graded timber were taken to be the five percentile modulus of rupture (MOR) and the mean modulus of elasticity (MCE), and they were derived from data on small clear specimens (62). The methods of deriving visual stress grades and assigning working stress values to these grades are very similar to those employed in most developed countries (65).

5.2. Developing Countries

5.2.1. México

The official regulations governing the building of timber structures in Mexico are those included in the Federal District Building Code (18). This Code makes reference as far as the grading of lumber is concerned to the C18-1946 standard (41) issued by the Federal Bureau of Standards from Mexico, as well as to an alternative method described in the body of the building code.

The grading of lumber according to C18-1946 Standard is based mostly on appearance purposes and therefore the visual grades mentioned therein are not strictly stress grades as defined in this paper, but nevertheless they are assigned design values for the different properties. Five grades are specified in the Mexican standard: A grade or "Select" B grade or "First", C grade or "Second"; D grade or "Third" and E grade or "Reject" lumber.

Pieces included in grade A must not have knots of any kind nor traces of them; this is, virtually clear material. The knots alowed in grade B are only small "Needle Head" knots. In grade "C" knots are allowed up to a certain size according to the size of the cross-sectional area. The same size of knots is allowed in grade D but other imperfections are allowed to a greater degree. Then, reject lumber will be that which presents larger, imperfections or defects than those allowed for grade D or "Third".

As an alternative to these appearance grading rules another set of grading rules was developed. They are based on the same principles as the old "numbered" British grades defining grades with strength ratios of 75,65,50 and 40 percent (46).

Still, these grading rules are not deemed completely suitable and a new visual grading rule has been developed which simplifies the grading process and assigns more realistic values to the different grades. These new grading rules are based upon a rather extensive and comprehensive study underway in Mexico by testing full size specimens in bending (17). The proposed grading rules which are not in effect at the moment make use of the concept of the projection of the knots on the cross-sectional area in a similar way to the British rules but on a rather simplified manner.

Only three grades are proposed in the new grading rules and they are the "A" grade or high strength and stiffness lumber, the "B" grade or medium strength lumber and the "R" grade or rejects which are not suitable for structural purposes. These grading rules are explained with the help of Figure 21. Of course, some other criteria such as slope of grain, decay, insect attack are included in the grading rules.

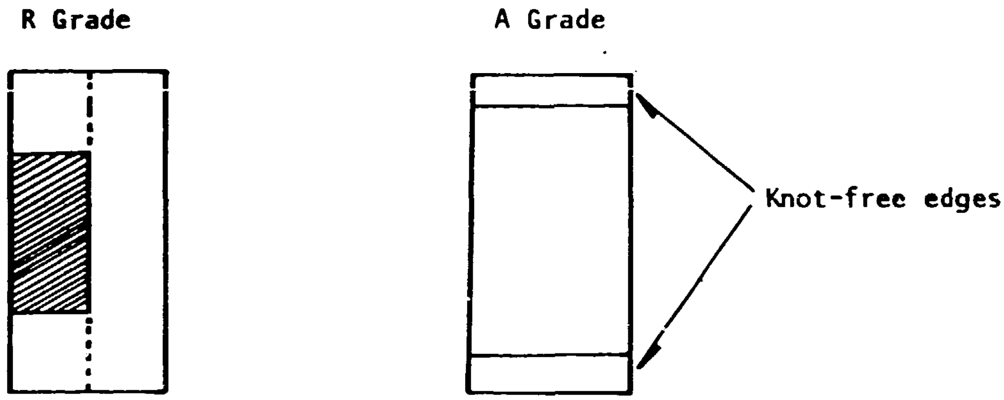


Figure 21a. Rules for 2" x 4" lumber.

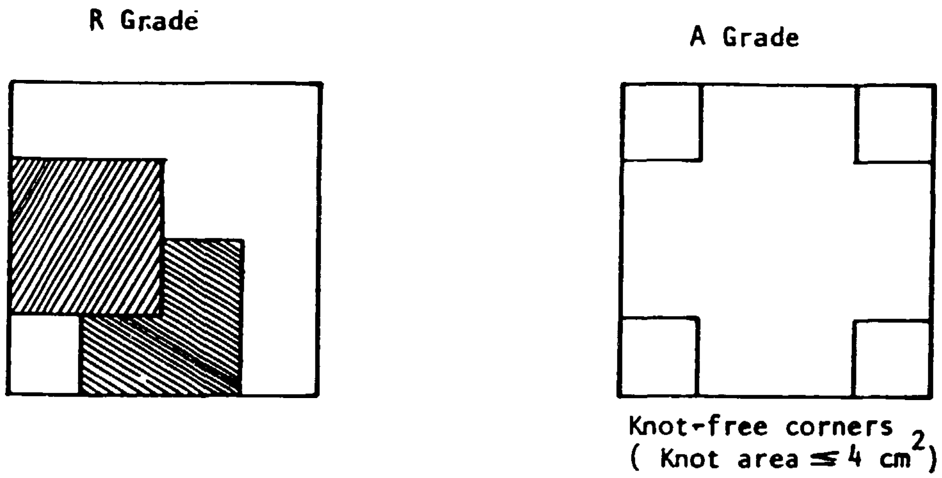


Figure 21b. Rules for 4" x 4" lumber

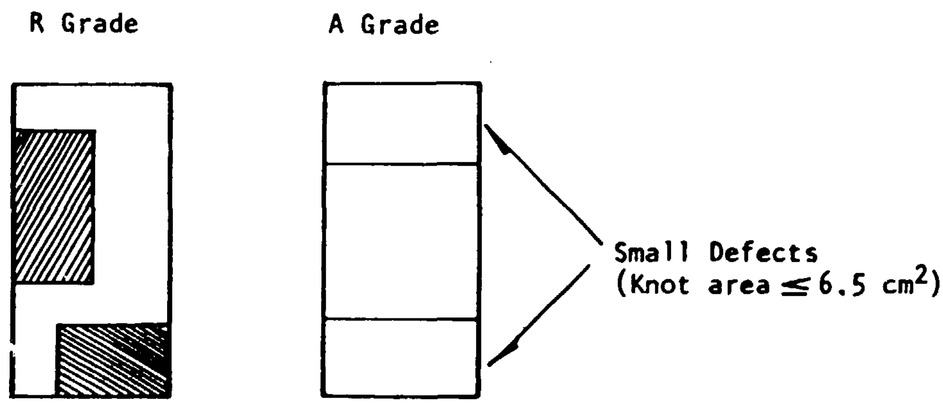


Figure 21c. Rules for 4" x 8" lumber

5.2.2. Costa Rica.

The newest grading rules proposed in Costa Rica are based on ASTM concepts in a manner very similar to the North American grading system only with three structural grades instead of four (58). The rules were written to grade lumber dressed or undressed of five hardwood species from the tropical rain forest.

Design properties associated with the grades are for seasoned lumber up to a maximum moisture content of 18%. The ASTM methodology has already been presented and is not discussed any further here.

5.2.3. Malaysia.

The Malayan Grading Rules define three structural grades: Select, Standard and Common with strength ratios of 0.80, 0.63 and 0.50 respectively. The grades are multi-purposes grades, i,e. applicable to all structural timbers whether used as bending members, or in end-wise compression.

For normal purposes, the standard structural grade should be specified. The select grade is intended for special purposes and the common grade is intended for wooden members used in the less important parts of building frames (55).

The methods of measuring defects have been simplified. The most important simplification occurs in the rules limiting the sizes of knots and specifying the method of measuring them. Severe limitations on curvature are to be expected in a multipurpose grade because the stress-graded timbers must be suitable for use as compression members even if in a particular case they are intended for use as beams.

The rules have been compounded largely from the recommendations of authorities in a number of different countries notably the U.S.A. and Australia. In Table 9 are given the grading requirements for multipurpose stress grades of Malayan timbers.

The small clear wood properties are obtained by using ASTM D 143-52 (3).

TABLE 9. GRADING REQUIREMENTS FOR MULTI-PURPOSE STRESS GRADES IN MALAYAN GRADING RULES (SECTION J).

Kind of Defect	I. Select Structural Grade	II.
(1) Sloping grain	1 in 16	
(2) Knots		
(a) Sound	One-eighth dimension of face, to max. of 1 $\frac{1}{2}$ in dia. 1 per 3 ft. in length.	
(b) Unsound or Hollow (knot holes)	None	
(3) Decay (Rot)	None	
(4) End splits and included phloem intersecting ends	None	
(5) Compression failures	None	
(6) Brittle heart	None	

Standard Structural Grade	III. Common Building Grade
1 in 10.7	1 in 8
One-quarter dimension of face to max. of 3 in dia. 1 per 3 ft in length	One-third dimension of face to max. of 4 in dia. 1 per 3 ft in length.
One-sixth dimension of face, to max.of 2 in dia. 1 per 8 ft in length	One-quarter dimension of face, to max. of 3 in dia. 1 per 8 ft in length
None, except in an unsound knot	None, except in an unsound knot.
Longest split or strand of phloem, 3 in at each end,	Longest split or strand of phloem, 6 in at each end
None	None
None	One-quarter of cross-section at ends

5.2.4. Philippines

There are two existing rules used in the Philippines in the classification of lumber: the "Grading Rules Governing the Inspection and Measurement of Philippine Lumber" and the "National Hardwood Lumber Association (NHLA) grading rules". The latter set of rules for grading is often used on lumber for export while the former, which was promulgated for local use, is seldom or never used in the country (19).

The current practice in the structural design of timber structures utilizes allowable working stresses established by the Philippine Lumber Producers Association in 1961. These stresses were derived from data from limited tests conducted by the Bureau of Forestry and the Bureau of Science. Based on these tests, they introduced a grouping system, comprising three structural grades with strength ratios of 0.80, 0.67, and 0.56 respectively, chosen from a preferred number series. They further present a set of defect limitations which emphasizes knots and it seems to be inspired by the US methodology (56).

Surjokusomo (56) citing other sources, mentions that the Forest Products Research and Industries Development Commission (FORPRIDECOM) at Laguna intended to begin a completely new process of deriving working stresses based on internationally accepted procedures and contemporary data concerning the strength properties of Philippine timbers. It was said there that in 1976 the Philippine Standards Association, and the FORPRIDECOM were working closely to formulate standard grading rules for lumber based on surface quality. Up until then, the small clear wood properties of Philippine timbers were obtained by mechanical testing using ASTM standard procedures.

5.2.5. Tanzania, Uganda and Kenya.

Grading rules are commonly shared by these three East African countries. Timber quality may be specified either at purchase from a mill or after inclusion in a building. "The Export of Timber Rules" for East Africa are concerned with the purchasing of timber and are not satisfactory as a specification for timber in a building. However, performance specifications have been drawn up to provide a timber quality that would be acceptable to architects and engineers after inclusion in the building fabric (10).

The performance specifications for structural work are aimed at provided members suitable for beams, trusses, columns, studding, suspended flooring and other members as specified by the designers carrying a significant load. Two grades are included in this specification. The PS grade is almost identical with second strength grade of the Export of Timber Rules except that defects on exposed surfaces have been reduced. There is also an amendment to the limits on splitting. This timber will have a strength equal to 50% of clear grade, i.e. 50% grade. Higher grades of structural material may be obtained by altering the PS specification to the maximum defects permitted for First Strength Grade (Export of Timber Rules). The maximum size of split should be not more than 1/4 of face. This will give a 75% grade timber.

The performance specifications for timber for use in building refer to all conifer (softwood) and broad leaved (hardwood) species and apply to timber sections incorporated in the building after they have had sufficient time to season. All timber used as structural members in East Africa shall conform to the specifications listed on Table 10.

Three Grading Rules have been issued in East Africa:

Tanzania: "The Export of Grading Rules"

Uganda : "The Timber (Export and Grading) Rules 1967" (Statutory Instrument 1967 No.86).

Kenya : "The Export of Timber Rules (1964)" L.N. 358, 1964

Grading rules are given for Hardwoods and Softwood species and while the intention is that these rules would be mandatory for exported timber they may also be used for timber in the local market and reference to these may be included in specifications.

The softwood grading rules are given in Table 11 for strength grades. This timber is graded on the worst face.

The grading rules make no mention of the moisture content at which grading should be carried out. Specifications should either state that grading is to be carried out on timber after it has been seasoned or provide a performance specification to cover this point.

Strength grade one is approximately 75% of the strength of clear timber, strength grade two, 50%. Strength grade 3 has no limitation on slope of grain and should be used for structural purposes with caution. Fourth grade material is of virtually no value for most construction purposes.

TABLE 10.

PERFORMANCE SPECIFICATION TABLE OF MAXIMUM PERMITTED DEFECTS FOR STRUCTURAL GRADE IN EAST AFRICAN RULES.

DEFECT	GRADE PS (structural)
Knots - Unsound	NES *
- Maximum size	75 mm
- Edge	Edge/2
- Margin	width/4
- Centre	width/3
- Splay	width/4
- Cluster (total)	width/3
Slope of Grain	1/3
Fissures	width/2 NES
Wane, Untreated Sapwood	Edge/8 width/12, Length/4, NES
Resin and Bark pockets	5 mm wide, 5% length, NES
Borer holes in treated timber	3 mm dia. 2 per metre length,NES
Softheart, pith	NIL
Bluestain	NES
Curvature	1/300
Departure from plane	5 mm

* NES.- NIL ON EXPOSED SURFACES

TABLE 11. EAST AFRICAN STRENGTH GRADING RULES

WHEN USED FOR STRUCTURAL MEMBERS THE LENGTHS OF SPLITS AND CHECKS SHOULD BE RESTRICTED TO:

FIRST STRENGTH GRADE - ¼ OF THE WIDTH OF FACE
SECOND STRENGTH GRADE - ½ OF THE WIDTH OF FACE

Defect and Characteristic	Maximum permissibles size of defect or characteristic per grade			
	First	Second	Third	Fourth
Knots	Sound knots only	Sound knots only	Unsound knots included	Unsound knots included
Edge	¼ thickness	½ thickness	3/4 thickness	Unrestricted
Margin	1/8 width	¼ width	1/3 width	Unrestricted
Centre	1/6 width	1/3 width	½ width	Unrestricted
Splay	¼ width	1/3 width	½ width	Unrestricted
Cluster (in Total)	¼ width	1/3 width	½ width	Unrestricted
Rot		Not allowed except in Unsound Knots		
Wane	-	-	-	-
Edge	Not allowed	1/8 thickness	¼ thickness	½ thickness
Face	Not allowed	1/12 width	1/6 width	1/3 width
Length	Not allowed	¼ length	1/3 length	Unspecified
Slope of Grain	1:14	1:8	Unrestricted	Unrestricted
Resin Pockets and Bark Pockets	Not allowed	Not more than 6 mm. wide Not more than 40 mm. in length per metre length of piece	Not more than 6 mm. wide Not more than 80 mm. in length per metre length of piece	Unrestricted
Checks and Splits	Total length not exceeding 150 mm.	Total length not exceeding 225 mm.	Total length not exceeding 300 mm.	Unrestricted

Hardwood grading rules are primarily intended for export and joinery, though some consideration has been given to strength considerations in the grading of scantlings. There are three grades: First or Prime; Second or Select; Third or standard. The application of these varies with the timber dimension and there are different rules for Boards, Strips, Scantlings and Shorts.

A major defect in the rules is that grading is done in the "Shipping-dry" condition which is not clearly defined but is usually about 25% moisture content on the surface. Specifications should either state that timber is to be graded after seasoning or provide a performance specification.

These grading rules are not very satisfactory for construction purposes. For structural members, specifications can call for all members to be graded as scantlings regardless of cross section and in this case first grade material may be considered as having 75% of the strength of clear timber and third grade 60%. Alternatively, specifications may call for all constructional timber (including hardwoods) to be graded under the softwood rules for strength (10).

5.2.6. India

In India, both hardwoods and softwoods are considered suitable for structural purposes. There are several grading rules in India. They are explained here very briefly.

In Indian standard IS: 1629-1960 rules for grading of cut sizes of timber (26), three structural grades are established: selected grade with strength ratio of 0.875, grade 1 with strength ratio of 0.75 and grade 2 with strength ratio of 0.625 (28)

The limitations for defects and magnitude of strength reduction due to defects are stated in the already mentioned Indian standards IS:1629-1960 rules for grading of cut sizes of timber (26) and restated in IS 3629-1966 specification, for structural timber in building (27).

The service moisture conditions, as stated in IS:3629:1966, are divided into three use categories: inside location where timber is used continuously dry and protected from weather, outside location where timber is subjected to occasional wetting and drying, and wet location where timber is subjected to almost continuously damp or wet conditions or in contact with earth or water. The standard provides allowable stresses for each condition.

The adjustment factors are handled in a little different way here than in the British or Australian systems, even though the basic philosophy of the generation of stresses of all three follows the US system (56).

Surjokusomo (56) again, citing other sources, mentions the system of conversion of the small clear properties to the allowable properties. Five factors are involved in the conversion: variability, long time loading, accidental loading, grade and location of use. The product of these five factors is called the "factor of safety". The mechanical tests for Indian timbers are conducted according to Indian standards which are very similar to US standards.

5.2.7 Chile.

In 1971 a set of grading rules was proposed in Chile to be used for structural purposes. The grading system proposed took as a base the standard American procedures including the determination of the mechanical properties of timber using the small clear specimen approach and also the measurement of the defects and the determination of strength ratios (47).

Three stress grades were defined:

Stress Grade 1 : Strength ratio 65% (structural)

Stress Grade 2 : Strength ratio 50% (select construction).

Stress Grade 3 : Strength ratio 40% (standard construction)

Since the US system has already been presented in detail, no further concepts are introduced here.

5.2.8 Papua - New Guinea.

This is one more country of which the literature was studied, and where no formal set of grading rules for timber exists. In the absence of these grading rules, so far, the set of rules applicable to building grades of Australian timber is applied after the timber is seasoned, and all designs are based in these values (23).

5.3. International or Regional Grading Rules

5.3.1 ECE Rules[1/]

In September 1974 and ad hoc meeting of experts on grading rules for coniferous sawnwood took place in Geneva, Switzerland. Sixteen ECE countries and two international organizations were represented.

The meeting agreed at that moment that it should approve an agreement which should serve as a platform for all international action in the field of grading of structural coniferous sawnwood, The meeting stressed the urgency of reaching agreement on a basic document even if this were to be modified later.

For the purposes of evaluating in depth the grading rule now considered it is deemed appropriate to include here the main points discussed at that meeting. This information is taken from reference (16).

The meeting discussed the principal factors to be taken into account when deciding on grading rules for coniferous sawnwood and noted especially the following:

a) Great importance was attached to the question of yields and reject rates which may determine the economic feasibility of a grading system. Many delegates felt that reject rates of 20% were excessively high.

b) The practicability of a grading system was also considered to be very important. The grader should be able to make accurate decisions at a speed which would enable a reasonably fast throughput. In this connexion it was pointed out that the definition of two separate margin conditions would complicate the grading decisions.

c) Furthermore, it was considered desirable that there should be an even distribution between the grades and especially that sufficient wood should fall into the lower grade, which would be in greater demand, at least initially, for price reasons.

1/ Economic Commission for Europe. The revised ECE Recommended Standard for Stress Grading and Finger Jointing of Coniferous Sawnwood is expected to be approved at the meeting of the Ad Hoc Group of Experts on Stress Grading and Finger Jointing scheduled for Geneva, 14 to 16 April 1982 (see also Document TIM/WP.3/AC.3/10 of the ECE Timber Committee).

The meeting discussed at length the question of the relationship between a grading system defined by the limitation of strength reducing charactetistics and the design stresses which would be allotted to the grades. It stressed the vital importance of this question.

On the basis of these considerations and after lengthy discussion of the draft proposal, the meeting finally aproved it but however stressed again the provisional nature of the agreement.

The meeting considered that at that point in time much research work remained to be done, notably on:

a) The design stresses to be allotted to the grades

b) The effect of the width of annual rings on strength

c) The effect of wane on strength

d) The yield and reject rate of the new grades.

It was decided that when definitive agreement had been reached, on the main features of the grading system, the document should be passed to ISO, which would prepare the final version and ultimately issue it as an International Standard.

The draft proposal agreed upon, to which reference has been made throughout this section of the paper, is the 1975 version of the ECE Grading Rules for Coniferous saftwoods (60). It was mentioned earlier in the paper that these grading rules were strongly influenced by the British Grading Rules BS 4978.

They are very similar in fact and among other things in common they both define two stress grades and are based on the knot area ratio (KAR) concept.

Subsequently, the ECE stress grading rules have been constantly revised and in the 1977 version density limits were included. In the 1981, as well as in the 1977 version, a third grade was included which was a higher grade than the first two included in the 1975 version, In the latest version, the density limits have been omitted, but in an attempt to keep the higher grade the knot limits have been further tightened (25).

Another major point has been the proposed adoption of the design values determined by CIB (14). In Table 12 are included the major stress grading criteria of the ECE visual grading rules. Thorough discussion of these important rules is deferred to a later chapter.

5.3.2. Andean Pact.

A joint research programa being carried out by the 5 member countries of the Andean Group (Bolivia, Colombia, Ecuador, Perú and Venezuela) has studied physical and mechanical properties of more than a hundred tropical hardwoods from the Amazon and Orinoco basin. Based on this and other studies, a grading rule, definition of strength groups and design working stresses and moduli have been proposed. For each strength group a set of design stresses and moduli were established based on both small clear specimen tests and actual size flexure specimens. A factor of safety, a size effect factor and a duration of load factor, were also applied to the basic stresses of each species to obtain design values for each group. All values are for green lumber (48).

In Table 13 the Visual Grading Rule for Tropical Structural Lumber from the Andean countries is presented. According to this only one grade is defined, that is, application of the rule would result in a piece of lumber being classified as structural or not. Approximately 40 to 45% of sawn wood as presently produced in a lumber yard would classify or be graded as structural (12).

5.3.3. Scandinavian Grading Rules.

The grading rules which are in effect in the Scandinavian countries have already been presented while commenting about the rules in Sweden. Because of this, they are not explained here again and they are only mentioned in this part for the sake of completeness in the presentation, as they are considered regional.

Table 12. Major Criteria of the ECE Recommended Standard for Stress-Grading of Coniferous Sawnwood

Visual Criteria		ECE Grading Rules				
		S10	S8		S6	
			either	or	either	or
Knots	1981	MKAR ≤ 1/5 MKAR ≤ 1/5	MKAR ≤ 1/2 TKAR ≤ 1/3	MKAR > 1/2 TKAR ≤ 1/5	MKAR ≤ 1/2 TKAR - 1/2	MKAR ≥ 1/2 TKAR - 1/3
	1977	MKAR ≤ 1/4 TKAR ≤ 1/4	MKAR ≤ 1/2 TKAR ≤ 1/4		TKAR ≤ 1/2	TKAR ≤ 1/3
Slope of grain		1:10			1:6	
Rate of growth Annual ring width limits		not more than 6 mm			not more than 10 mm	

MKAR Marginal Knot Area Ratio
TKAR Total Knot Area Ratio

TABLE 13. DEFECTS PERMITTED IN STRUCTURAL GRADED MATERIAL IN ANDEAN PACT GRADING RULES

DEFECT	TOLERANCE
SCALE (Shake)	On one face only, no more than 3 mm of separation and no more than 1/4 the length of the piece or 50 cm, whichever is less.
SEASONING CHECKS	Moderately, no more than approximately 2 mm in depth.
COMPRESSION FAILURES	Not permitted
SOUND HEART	Permitted
HEART with signs of decay or with splits.	Not permitted.
SOUND, INTERGROWN KNOTS	Permitted in the middle half of the width of the face with diameter of no more than 1/4 the width of the face or 4 cm, whichever is less; and with separation of at least 50 cm between knots. Sound knots of less than 1 cm in diameter are allowed on the faces with separation of 30 cm or more. In beams, knots are not permitted within 2 cm of the edges.
LOOSE, HOLLOW OR DECAYED KNOTS	Same as in sound knots except for appearance requirements.
SLOPPING GRAIN	One in eighth or less (1/8)
CROSSED GRAIN (interwoven)	When pronounced discontinuities of the grain are created on the edges of the middle one third of the piece, the angle of inclination of the face grain must be 1/8 or less. In any other case crossed grain is permitted.

6. CRITICAL APPRAISAL OF THE RULES AND OF THE METHODS OF DERIVING ALLOWABLE STRESSES.

The aim of any grading rule which is intended for structural purposes is to be able to predict beforehand what the strength and stiffness of the piece of lumber being graded will be. If the grading rule is efficient- and so are the graders-it will permit to fully exploit the potential of the lumber when it is used in a structure.

In order to evaluate the existing grading rules it will be described first what is an ideal grading rule* in the author's concept and then the different grading rules will be compared to this ideal rule and therefore it will be easier to point out their deficiencies. The grader using the hypothetical ideal grading rule would conceivably be able to determine exactly what would be the effect of every growth characteristic of defect on the strength and stiffness of lumber He would also be capable of quickly measuring with enough precision the magnitude of the defects.

The characteristics of this ideal grading rule are the following:

1) The effect of the main defects and growth characteristics on lumber strength and stiffness should be very well reflected in the grading rules. This can only be accomplished (when it has not been done so in the past) by means of a through testing program with well defined goals and objectives and a sound methodology. The tests should reflect as best as possible the real work conditions of the lumber.

2) The method of measurement of defects must be simple but at the same time accurate. If the magnitude cf the defects can not be measured quickly, simply and precisely, then their effects on strength and stiffness can not be predicted accurately.

3) The yields of the different grades should ideally match the market demands.

4) The grading rule ought to be species-independent, preferably.

A grading rule of these characteristics should not establish more than two or three structural grades. It is very important that all the factors which affect lumber mechanical properties are explicity and correctly written down in the building codes as well as the method of application of these factors.

As we shall see now, the majority of the grading rules now in effect do not completely comply with the hypothetical requirements of the ideal rule and therefore most of them should not be considered as suitable to be applied in developing countries where new grading rules are needed.

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* At least, from the point of view of developing countries.

We start the discussion with the US grading rule. The ASTM methodologies of deriving allowable stresses and establishing stress grades for lumber are perhaps the most influential set of rules in the world. They have served as a model for many of the countries all over the world. They can not be blamed for being unsafe nor useless. They can however, be considered deficient in many respects. First of all, the strength ratio concept, used as a predictor of lumber strength has been found to be poorly correlated with this property (5,42). The moisture content effect on strength has also been found to be different from what is stated in ASTM procedures (29,38). A size effect has also been identified and it has been made clear that it is not correctly considered in the derivation of permissible stresses (36). And finally, the duration of load effect as it is considered by ASTM has been shown to be wrong for commercial lumber (30).

The grading rules themselves are overly complex and they fail to distinctly discriminate among some of the grades they establish (17,37). The permissible stresses given in NDS* are species dependent and again, tests have proven that no significant difference exists at the 5th percentile level of strength among a good number of conifers (37).

For all those reasons, the US rules are deemed unsuitable to be adopted by developing countries. Furthermore, they are mostly concerned with softwoods and it is evident that the growth characteristics governing strength in hardwoods, especially those from the tropical areas, are different than the ones that control strength of conifers.

The British grading rules while being better than the American rules are still not completely suitable because of their complexity. The knot area ratio concept is not very easy to understand and to apply by non-skilfull graders. One must remind oneself that in many developing countries there are not very many highly trained graders.

Some of the drawbacks mentioned in the case of the US rules are also present in British standards, such as the moisture content effect, the duration of load effect and so on.

Perhaps the same could be said of the Australian grading rules and permissible stresses. What is critical in all these cases is that they use small clear specimens to determine the strength of wood and then, they apply correction factors to consider the strength-reducing defects. The results of structural size tests can be compared with the strength predictions based on the small clear specimen approach, and comparisons in the case of dimension lumber and solid

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*National Design Specification (43)

sawn timber have shown that large differences exist between the two approaches. (4).

As a rule we could consider that many of the grading rules associated with design values based on the small clear specimen approach are not completely suitable. In those developed countries like Canada, United States and Australia, large testing programs are underway to evaluate the mechanical properties of lumber with full-size testing, and the "in grade" concept has been gaining acceptance more and more. Still, no serious attempt has been made in these countries to change their old visual grading rules for more efficient ones. They have concentrated instead in the development of proof-grading procedures and mechanical stress grading.

The ECE rules which are very similar to the British rules are very efficient in their ability to segregate the lumber according to strength (17). Again their complexity must be recalled. The 1981 proposal is even more complicated because it adds a new grade making the graders's task more difficult. And. furthermore, it has been found that the new high grade does not meet the strength requirements set up by CIB (25).

Different approaches have been attempted trying to improve the grading ability of visual grading rules, particularly ECE grading rules. They include mainly, the use of the "Pilodyn" instrument, or the additional measurements of ring widths, (25,39). These attempts have been made mostly in connection with the higher grade in ECE rules considering the fact that it is a grade where few and small knots are allowed and their behavior tends to resemble that of the small clear specimens where density is of paramount importance in the explanation of strength. Density does not matter very much when dealing with knotty timber, but is surely does with high quality material.

Because no practical way of measuring density of individual pieces at the sawmill site was devised, in the 1981 version of ECE rules, density limits were dropped. But the tightening of knots for the higher grade was unable to pick out the differences in strength among the pieces of lumber.

It was shown by both T.L. Madsen (39) and Hoffmeyer (25) that the use of the "Pilodyn" could improve the performance of ECE rules while used in addition to visual grading. Interestingly enough, it would even simplify the grading process somehow (from the grader's stand-point) because, the grader would only have to grade the lumber as "S8 and better" forgetting about S10 grade (25). Then, the "Pilodyn" could be used to identify the high quality lumber.

A word of caution is in order here. The use of "Pilodyn" proved succesful only at laboratory controlled conditions, since the instrument is very sensitive to moisture content differences. Still, its use, or some other practical means of determining density for high quality material seems promising and its potential should be further explored.

In T.L. Madsen's study (39), the Scandinavian T-virke grading rules proved superior to the ECE rules (1977 version) and the same is reported by Hoffmeyer (24). They both used Norway Spruce as their testing material. One way of measuring the efficiency of a grading system is by the ability of the grading criteria to separate the timber into groups of significantly different 5-percentile values.

The ECE 1981 rules result in a difference between the characteristic bending strength values for the lowest grade (S6) and the highest grade (S10) of the order of 8 MPa. The corresponding difference for the ECE 1977 rules is of the order of 4.5 MPa. The difference between the high and low grade for the T-virke system is of the order of 11.5 MPa, the highest of the three, thus resulting in a better separation (24).

In order to include also the yield in the comparison, the efficiency of the grading rules is assessed by the mean loading capacity (MLC). This value is calculated as the weighted mean of the characteristic values for the grades, with weights according to the number of pieces in the grade. Again, for bending at least, the T-virke rules are superior to the ECE 1981 and 1977 rules as reported by T.L. Madsen and Hoffmeyer (24,39).

Neither of the Nordic T-virke rules nor the ECE rules are very simple since they involve some kind of computations and rather complex grading criteria.

In the author's opininion, some sort of grading rules similar to the BS 4978 or the 1975 version of the ECE rules could be adequate for most developing countries (where there were conifers) if they could be simplified somehow. The newly proposed Mexican grading rules which are discussed later seem to fit the bill rather well. They are not based on complex criteria as the British and ECE rules, but in a lot more simpler measurements. The author does not have experience with Scandinavian rules and does not have a basis to recommend them for implementation in developing countries since he does not know of a straight forward way to simplify them. Still he does not rule them out completely. A South African study reported next tends to agree that the grading concept employed in the Nordic Rules is very capable of differentiating visual stress grades.

The South African building code is one of the most advanced in the world as of today, Nevertheless, the South African grading rules themselves are not strictly accurate nor reliable. In a recent critical review, some factors, notably density, in the present SA grading system are found to be less effective (34). It is indicated there, that the grading predictors used are not efficient in separating the two lower grades (V4 and V6) into two distinct populations. The higher grade is, nevertheless, well differentiated from the other. Among the conclusions of that study the following stands out: It appears that the only strong predictor capable of differentiating visual stress grades in normally knotty timber is the knot circumference ratio.

The results of Knuffel's study while apparently being in contradiction with Madsen's and Hoffmeyer results, really are not. The explanation of density not being an accurate predictor of strength is that in SA rules density is used to segregate lumber of the lower grades (between V4 and V6) where it does not reflect the behavior of lumber, rather than using it as a criterion to segregate high quality material.

What is advanced in the South African Building Code (51) is the way the moisture effect is considered and, the concept of grade stress. No moisture effects on strength of lumber are considered for bending tension and horizontal shear and therefore no moisture content factor is incorporated. In the case of compression, however the moisture effect is taken into account. These considerations are in line with, the newest information available, particularly the work of B. Madsen and co-workers (38). To the author's knowledge there is no other building code in the world where the moisture content effect on strength has been considered in such a way.

The South African building code defines a grade stress as the stress that is assigned to a timber member or product to quantify its strength, and it notes that the grade stress is derived from the strength at failure of full size test specimens.

It has been left to the last the discussion on the new proposed Mexican grading system. All the considerations mentioned above about the derivation of permissible stresses, the simplicity of the rules the determination of the effect of the growth characteristics on strength, and so on, were pondered in the planning process of a study for the derivation of allowable stresses for Mexican pine lumber and the development of a new grading rule. A testing program has been going on since three years now and rather interesting findings have been obtained.

The paramount feature of this grading system still being evaluated is its simplicity. The grader has to determine first, following quite simple rules, if a piece of lumber should be rejected. If it is not, he has to look at it and say if it belongs to the higher grade.If it does not then, necessarily, belongs to the medium grade. Rules of this sort can be taught in a mather of hours, instead of weeks. Obviously, it takes a good number of hours of practice to master the grading concept but its foundation is strikingly simple.

The derivation of design stress is based on structural size tests and therefore all the inherent effect of the defects is implicitly taken into account. A provisional set of design values has been proposed and they are being verified on a country-wide basis. The results of this research program should be available by the end of 1982.

The grading rules for pines we are developing in Mexico are the closest thing to the ideal conditions described earlier that we know of.

Nevertheless, no inferences must be made in any way that they are totally suitable for any country which has to develop softwood grading rules. They fit in very well to the Mexican conditions and it is not known if they will fit some other conditions.

A better feeling of these grading rules can be obtained by comparing them to ECE rules, for example.

The allowable stresses for the higher grade in ECE rules are lower than in Mexican rules. This is because Mexican rules are more strict than ECE rules when dealing with edge-knots. No edge-knots are allowed in Mexican rules for the higher grade, at least for the 2 x 4s. (40 x 90 mm). For other sizes small edge knots are allowed (less than 1/2 of the margin area) but the characteristic values are lower. The characteristic stresses for the low grade are also higher in Mexican rules.

Mexican rules do not provide for an intermediate grade while ECE does. For Mexico this is not deemed a disadvantage anyway.

One apparent advantage of ECE rules is that they define the same grading rule for all sizes while in the Mexican case the grading rules differ a little (but not much) among some of the sizes (in the Mexican case, a grading rule is proposed for 2 x 4, another for 4 x 4, still other for 4 x 8, which are the same as for 2 x 4s but with an additional requirement, and then a single rule for 2 x 6, 2 x 8, 2 x 10, 2 x 12 very similar, while less strict, than the grading rule for 2 x 4). In the Mexican case it was emphasized the yields rather than the uniqueness of the grading rules. If the same grading rules were used for all sizes, different grade-yields would be obtained for different sizes. For 2 x 4, 4 x 4 and 4 x 8, yields of 30,40 and 30 percent are aimed at, for A grade, B grade and reject respectively. For 2 x 6, 2 x 8 2 x 10 and 2 x 12 yields of 45,35 and 20 percent are aimed at. This was deemed necessary to fit the market conditions. But since the grading rules are not very different from one another, and they are simple enough, and based on the same principle of the projected knot area (as a percentage of the cross-sectional.area) this difference in grading rules for different sizes does not pose a too serious problem.

In the case of tropical hardwoods, perhaps the most suitable grading rules would be the Andean Pact countries' rules. Their main disadvantage is the high rejection rate implied in the rules. If it could be narrowed and one more grade added they would almost be completely suitable to be applied in most developing countries.

It is in these cases, where a great many species are employed for structural purposes that the strength grouping concept coupled with the grading rules provide a unified frame in the structural utilization of timber. The Australian experience in this matter is worthy of consideration while implementing grading rules in developing countries A suitable grading rule and sound strength species-grouping could be a quite valuable asset for those countries.

7. CONCLUSIONS AND RECOMMENDATIONS

The majority of the grading rules in effect at the present time in the world present serious disadvantages and have been under severe scrutiny of late. Therefore, they are not deemed as completely suitable to be implemented in countries where no grading rules exist.

The British and the ECE rules are perhaps among the most desirable for conifers, although they present the disadvantage of being somehow complex. It is the author's opinion that simpler rules should be preferable considering the conditions prevailing in many developing countries.

In the author's opinion, the proposed grading rules for Mexico are the closest thing to the optimum condition in the case of softwoods. They deal directly with the effect of the defects and not indirectly through strength ratio concepts. The design stresses allocated to the grades take into consideration the most recent developments in Timber Engineering as it is done in a similar manner in the South African building code. These new Mexican rules could possibly serve as a basis for the implementation of simple and efficient grading rules for conifers in developing countries.

All these rules could benefit from the use of additonal simple density related measurements to fully exploit the potential of the top quality material for whose case the visual rules are unable to distinctly separate from the rest.

For the hardwoods especially from tropical regions, the Andean Pact rules seem to be an appropiate model, although some major modifications would be needed with regard to the yields and the addition of another grade. The concept of species grouping is of particular significance in this case, and the wealth of Australian experience should be fully considered.

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