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Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
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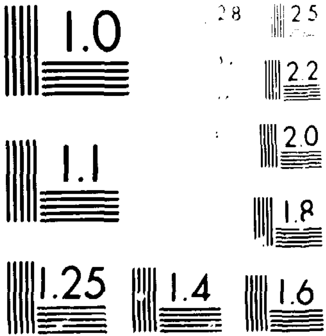
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THE PRINCIPLES INVOLVED IN STRESS GRADING, WITH SPECIAL REFERENCE TO ITS APPLICATION IN DEVELOPING COUNTRIES*

by

C. J. Mettem**

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** Head, Materials Section, Engineering Department, Timber Research and Development Association; Hughenden Valley, High Wycombe, Buckinghamshire, UK.

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PART 1

General considerations

INTRODUCTION

Stress grading is simply the sorting of timber into classes on the basis of its predicted strength. At the same time certain characteristics only indirectly related to strength, such as distortion, are taken into account. Non-structural defects such as stain and inactive borer holes are excluded from the assessment.

To the design engineer, stress grading is such patently good sense, so necessary in the efficient use of the resource, that it needs but little explanation. Its introduction in industrialised countries however, on a fully fledged, marked product, 'supplied-at-source' basis has been fraught with difficulties, and can hardly be said to be complete to this day. In considering the needs and application of stress grading specifically for timber construction development projects in the Third World, there are a number of special considerations. This, together with an accompanying paper (Mettem, 1981), approaches such problems in a spirit of humility, hoping at least to stimulate useful discussion and to further efforts in an international enterprise never previously undertaken with developing countries especially in sight.

REQUIREMENTS FOR STRUCTURAL TIMBER

Virtually any kind of wood can be used structurally if the size of the required member is designed to take account of the strength and stiffness of the timber. This applies equally to both softwoods and hardwoods, and to timbers of tropical or temperate origin. Factors likely to determine whether or not a timber will be available for structural uses are several, but the actual strength properties of the wood are not of great importance provided they are known. Important considerations include the following:

(1) The status of the timber or species group in the marketplace - if it has good utility or decorative properties, and can command a price for such reasons, it is less likely to be available structural dimensions. Similarly, certain timbers have a special reputation for durability and availability in large straight baulks for example, and although used structurally, cannot always be regarded as commonly available for general construction purposes.

(2) Peculiar disadvantages such as an exceptional tendency to distort, presence of toxicity or irritants in sap or dust etc. may occasionally rule out a few species for a particular structural end use.

(3) Resistance on the part of potential users - often on quite reasonable grounds - to the changes required in methods of design and manufacture needed to cope with newly available timbers or timber groups may inhibit their introduction until it is forced by scarcity.

(4) The availability or otherwise of data and recorded experience of previous uses of the timber. This of course includes strength properties, but it is TRADA's experience that it is very rare indeed to be unable to search out any records whatsoever of the physical and mechanical properties of a timber.

A market classification of hardwoods, mainly of tropical origin, from the viewpoint of a developed importing country (Ransom, 1981) has shown that general constructional species tend to fall into a 'High' (not 'Exceptionally high') density classification of 725 - 1000 kg/m^3 gross density. The visiting expert or local professional in a developing country however may find quite a different situation, due to local circumstances and differences between home and export markets.

Burgess (1971) for example explained how pieces of medium density hardwoods sawn to standard lengths of 16, 18, 20ft were regularly available in Malaya for low cost house construction at a time when only assorted widths and lengths of such timbers could be obtained in the United Kingdom. In work undertaken for a commercial sponsor on prefabricated buildings in West Africa, TRADA's engineers found themselves designing to use woods such as the decorative Khaya species of African Mahogany for wall frames and other parts, because these were available as reject and re-cut pieces from a large mill producing for export. In a project undertaken for UNIDO (TRADA, 1976) a manual was produced dealing with the grouping of timbers for a community building system for Laos. Part of the requirement of the contract was to build a prototype, and for this it was hoped to use treated timber of a local Dipterocarpus species quite similar to Keruing, already known to be suitable from experience elsewhere. The timber actually provided however, on the mistaken belief held locally that it would better suit the purpose owing to its high natural durability, was of extreme density and hardness, involving pre-drilling for nails, and several men to lift each component.

At the other extreme, circumstances exist in which it may be necessary to use softwoods of very low strength in the tropics. The first bridges built in Kenya to the design of UNIDO expert Mr.J.E. Collins (Parry, 1981) used modular wooden panels of East African Cypress Cupressus lusitanica, which could only reliably be ascribed to strength group S3 of the British timber code, a class of softwood rarely used in UK design. Similarly it is reported by Bryant (1978) that in South Africa there are abundant quantities of plantation pines yielding timber of low strength. This has led the National Timber Research Institute to expend considerable effort in developing stress grading techniques, both visual and mechanical, with the aim of providing large quantities of timber of low but reliable strength. It has been shown there that components such as light roof trusses for housing can be built with grades of wood having a design stress as low as 4.0 N/mm^2.

The ideal quality of wood for structural purposes, as well as for allied applications such as joinery, is of course timber which is as straight grained and free from knots as possible. In the case of softwoods, with a few exceptions normally commanding a high price for non-structural uses, it will be the exception rather than the rule to find such clear pieces. In tropical hardwoods from rainforest trees, such as the South East Asian dipterocarps and certain Amazonian and West African types, considerable proportions of the yield from the log may be entirely free from knots, but for structural purposes the straightness of grain must still be checked, whilst other features peculiar to such woods must be taken into account in grading rules.

For local use it is wrong to insist upon wood of ideal quality, or even of export quality. It is evident therefore that to provide the framework for an international stress grading system for developing countries, provision must be made for timbers of widely differing densities and mechanical properties, as well as ensuring that the rules encompass a gamut of varying growth characteristics.

THE DESIGNER'S NEEDS

The design engineer simply needs a set of stresses and moduli of elasticity for the timber under consideration. Additional data such as loads relating to fastener performance will also help. From these he will be able to make calculations and subsequent drawings. The stresses from which he starts off have various names. In Britain we call them 'grade stresses', and most frequently refer to the set relating to the dry exposure condition (18% moisture content). As already discussed, the grade stresses do not necessarily have to be high values, but should be reliable. This is a basic assumption in the derivation of stresses that will be discussed below. Initially however it is worth considering the response of the typical structural or consulting engineer familiar with design in steel or concrete; firstly when confronted with a timber design code, and secondly when facing the problem of locating a supply of structural timber.

There is a growing awareness amongst structural timber specialists concerned with the drafting of codes and standards that there is a grave danger of deterring the mainstream structural engineer from using timber altogether, because he is confronted with too many alternatives. Undue proliferation of grades must especially be avoided with wood, as we have the added complication of a natural product, with numerous botanical species to deal with. The actual concept of grade of a material he can cope with; we are familiar in everyday life with grades of commodities. The structural engineer, who in British codes finds for example Grade 43, Grade 50 or Grade 55 structural steel (BS 4360) or prescribed mixes and grades of concrete (BS 5328), will have no difficulty with the concept of grades for structural timber.

Unfortunately, the designer can happily complete his calculations and drawings without the remotest chance of the grade to which he is referring being available in practice. He must be encouraged to specify realistically. This can be done in at least two ways:

(1) Technical promotion in the form of booklets or leaflets may provide guidance to what is available and may exemplify good specifications. This is an important aspect of the work of organisations such as TRADA. Just three good examples are referenced (TRADA, 1980) (Building Research Establishment, 1979) (Timber Promotion Council, 1980) but there are many others.

(2) Those concerned with drafting new codes, standards, and international agreements must work towards simplification and inclusion only of relevant information leading to clarity of specification - important points to be borne in mind in this forum.

There are several types of situation relating to actual trade practice in structural timber which can confront the engineer working on overseas projects. Some of these are as follows:

(1) Over-developed

In codes and standards of such countries, many timbers are referred to, both as individual species, species combinations of various types, and in groups. Many grades exist, both structural and non-structural, current and obsolescent. The main problem is to identify what really is available and best suited to the need, at the right price. The situation is found in the UK, probably in the USA and Canada, and perhaps to a lesser extent in Australia. It is unlikely in developing countries.

(2) Self-contained

In certain countries, notably the Nordic region, relatively few varieties of timber are used structurally and a large proportion of these are produced at home. Codes and standards are written on this basis, which works well in the country concerned but does not translate easily to overseas practice.

(3) Current trading

In this situation, timber grown in the country concerned is used traditionally for construction, or has been used in the past and is now regarded as a poor man's material. Existing rules, written or unwritten, govern timber quality. Stress grading rules may exist, but more often than not are left on the design office shelf and are not so relevant to commercial use. Problems are to equate the technical need of the job concerned to available commercial supplies. For any form of industrialized construction, even at an intermediate technology level, it will normally be prudent to specify some form of written grade of timber, otherwise the Latin tag 'caveat emptor' will apply. Unfortunately, any such insistence upon a specified grade, of general or stress grading nature, will inevitably raise the price of the timber. A similar case existed in Britain up until about 8 or 10 years ago, and problems of this type exist in Malaysia and Mexico, to mention only countries of which the writer has experience.

(4) Carte blanche

Since woodworking occurs in nearly all societies to a greater or lesser extent, it will be unusual to find a country with absolutely no commercial understanding of timber quality. The situation may most nearly exist in rapidly developing desert countries, where the designer may have to rely upon expatriate rules for grading, and make special arrangements for supplies. Substantial quantities of ungraded timber are exported from Malaysia to Middle Eastern countries, whereas such exports to Western markets are banned.

DERIVATION OF STRESSES

1. Small clear approach

A detailed description of the traditional method of deriving grade stress values for timber from small clear test specimens is not appropriate here, and the procedure used in Britain has been well documented (Curry, 1967), (Sunley, 1968). Similar principles are followed in USA (American Society for Testing and Materials, D 2555, Annual), Australia (Pearson, Kloot and Boyd, 1962) and elsewhere. The alternative approach of testing selected samples of timber in the actual sizes and grades used in practice is preferable but costly, and cannot be achieved in the short term for all the timbers and groups used, even in industrialised countries, let alone elsewhere. The small clear approach has the advantage that it enables assessment to be made rapidly and at relatively low cost, and it allows greater flexibility in specifying stress grades and in changing levels in a developing situation.

Briefly, the standard procedure involves the selection of samples of a species; the determination of average ultimate strength values and their standard deviations; the calculation of lower probability levels (1st % ile in British codes until current revision which is changing to 5th % ile basis in line with other countries and other structural materials); the application of factors to allow for load duration, size effects and safety, and finally the modification of the resulting 'basic stresses' by different strength ratios to obtain stresses for the various grades. The strength ratios themselves were originally obtained by tests on full sized specimens of a limited range of North temperate zone softwoods; such information may for example be found in ASTM D245.

Figure 1 illustrates the allowance for variability in deriving the green basic compression parallel to grain stress for one of the species comprising the timber Keruing.

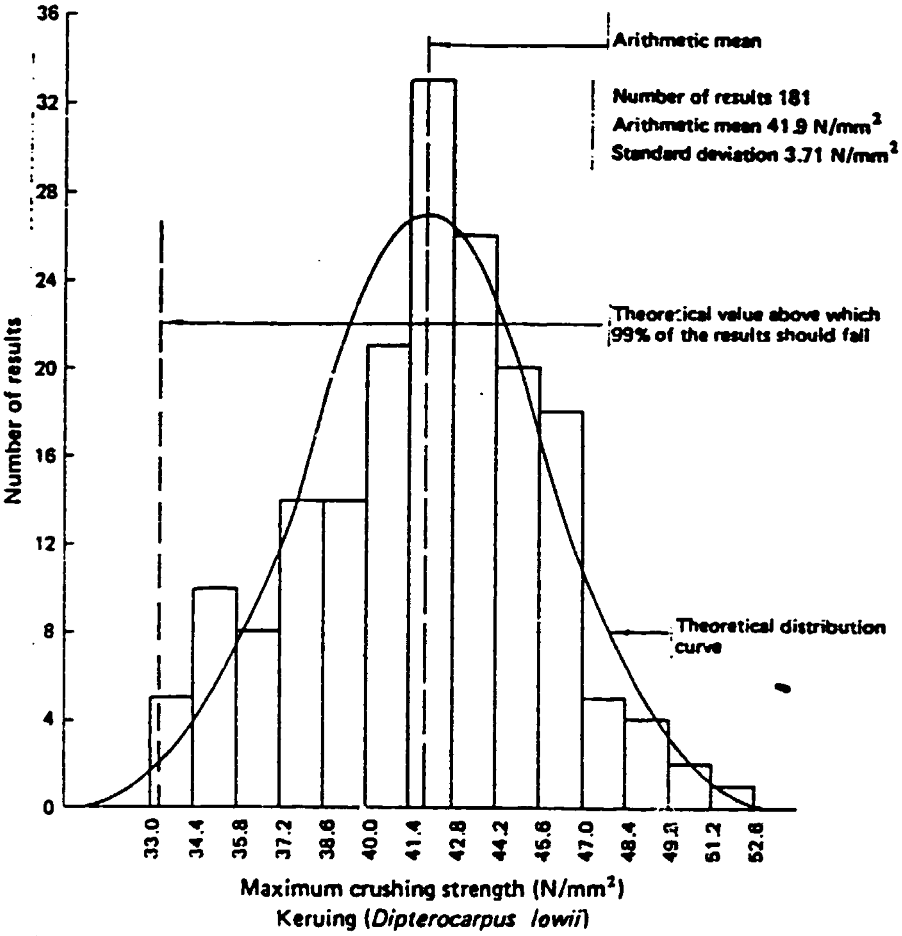


Figure 1 - Allowance for Variability, Green Stresses, Small Clear Specimens

2. Structural sized specimen approach

This is a more direct method for the derivation of stresses, based upon tests on samples of graded timber in full structural sizes. Such tests are not in fact new and reports can be found of such work nearly 50 years ago (Chaplin and Latham, 1935). The advantage of the more direct approach was noted by Curry (1967), and its adoption was only slowed by considerations of time and cost. British Standard 5820 entitled 'Methods of test for determination of certain physical and mechanical properties of timber in structural sizes' has recently been issued (1979) and a related international standard has been drafted (Joint Committee RILEM/CIB-3TT,1978). Large numbers of specimens of structural softwood have already been tested to such procedures. At a recent meeting (Tory, 1980) tests carried out at the Princes Risborough Laboratory of the UK Building Research Establishment were summarized. It was reported that about 6200 bending tests, 1100 tension tests and 1200 compression tests of structural sized members of the major imported and British grown softwoods have been completed. A current research programme at TRADA involves the testing of the tropical hardwoods Keruing and Kapur, using samples provided by the Malaysian Timber Industry Board. This is on a smaller scale, but when complete will provide results on about 800 bending specimens and 200 compression specimens, together with ancillary small clear tests.

In the standard British test procedure, timber is dried or conditioned to a moisture content of 14 to 18 per cent, and tests are carried out under laboratory conditions. In all tests, the grade determining defect is located within the zone of maximum stress, and detailed records are retained of characteristics such as knots and slope of grain at the point of fracture. Thus a data bank is accumulated of immense value in considering possible effects of proposed changes in grading rules.

In Canada and the United States, similar standardised test procedures for full sizes exist (American Society for Testing and Materials, D198, Annual) but large in-grade testing programmes based on more rapid techniques have also been embarked upon. These include a programme based on the use of portable, hydraulic testing machines (Galligan, Green, Gromala and Haskell, 1980). Rapid proof loading test methods seeking to achieve about a

10 per cent breakage rate have also been conducted recently in Canada by Madsen. These are described in IUFRO proceedings but are not yet published.

This is not the place to discuss differences of opinion over testing philosophies in detail, but disadvantages of the North American approaches from a European viewpoint include the following two important aspects:

(1) At least until very recently, the programmes have been closely centred around existing ALS/CLS grades, apparently attempting to verify these rather than collecting basic data that would permit them to be revised. The lumber industries of Canada and USA are of such a scale and importance to the economy that radical changes in their grading rules are difficult to envisage. Recent analyses have certainly posed a number of questions about the rules however, for example in many instances little difference in estimated 5th %ile strength has been observed between No.1 and No.2 grades of several species combinations.

(2) The more rapid test methods have been developed to carry out 'crash programmes' of structural sized testing, covering nation-wide mill sampling, size and species combinations and so on. It has been argued that such procedures, accompanied by modern techniques of statistical analysis, can provide answers within the time scale required. It seems possible however that aspects such as random placement of defects, taking moisture content and temperature at test 'as they come', may coarsen the discrimination possible when the results are analysed, showing all timber to be more nearly alike than is truly the case. At the same time, the more fundamental data unrelated to present grades will be missing from the answers, making revision more difficult and entailing further work in the future.

For the analysis of structural sized test data it has become a widespread practice to estimate minimum values of ultimate strength using the Weibull distribution (Weibull, 1939) (Warren, 1972) (Pierce, 1976) (Bodig, 1977). The advantage may be explained in a practical way by reference to Figure 2 based on Bodig's report. One can see from this that the normal curve predicts negative values of bending strength at the low end of the distribution, clearly a non-existent situation. For those without high mathematical and statistical knowledge, the work of Weibull and those who have followed is not easily understood. However the avoidance of statistical concepts involving 'negative' strength can be found in plain writing in the original reference. There are actually a number of types of distribution based upon Weibull, furthermore, dependent upon the choice of parameters, it can be used to approximate other distributions.

The belief seems to be held by many that the Weibull distribution is especially germane to analysis of strength data for some fundamental physical or philosophical reason. Certainly, it was conceived to deal with problems in strength of materials. However the pragmatic benefit of the Weibull three-parameter distribution is that it is flexible, and capable of dealing with both skewness and kurtosis in the data, and it is better to regard it merely in this light.

The problems of deciding appropriate procedures to estimate minimum strength values, and to establish confidence limits for the ensuing estimates are complex. Suffice to record that at present the three-parameter Weibull distribution is favoured for full sized test pieces, whilst there seems no reason to doubt use of more traditional methods based on the normal distribution for small clear data.

The British Standard Code of Practice CP112: Part 2: 1971 is being revised and will be issued as BS 5268: Part 2. For this, sufficient information on the strength of timber used in Britain has been obtained from structural sized testing to warrant use of the method as a basis for the stresses to be published. By no means all timbers and properties have been covered however, and for this reason a dual approach has been taken. This is summarised briefly as follows (Curry and Fewell, 1981):

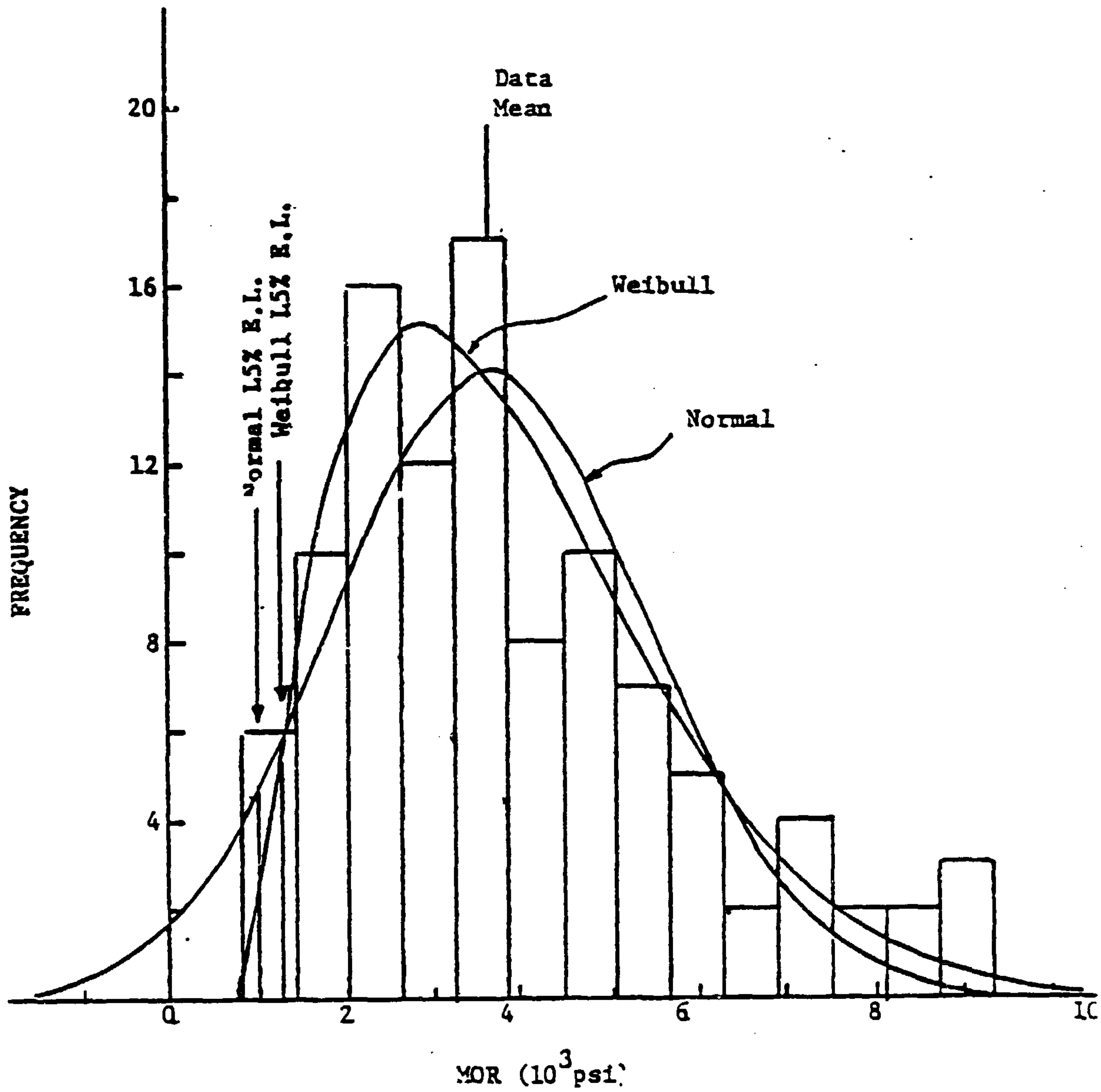


Figure 2. MOR Distribution of Douglas fir-Larch 2 x 8 No. 3 grade joist as approximated by Normal and Weibull curves.

(1) Estimated 5th % ile minima were calculated using the three-parameter Weibull distribution for the standard structural (SS) grade of BS 4978 and for the principal structural softwoods.

(2) These stresses were expressed as ratios of the corresponding mean small clear stress for each of the species concerned.

(3) Characteristic values of bending strength and modulus of elasticity for the SS grade of other softwoods for which no structural sized data were available were obtained by use of the ratios obtained from step (2).

(4) Values for tension, compression and other grades were obtained by use of relativity factors obtained from tests on a smaller scale.

Values for hardwoods are to be based on small clear testing for the current revision (Mettem, 1981) but it is expected that a similar approach to the above will be adopted once the results of structural sized testing become available.

Summarising this section dealing with derivation of stresses, it is hoped that it has shown that both small clear and full sized testing methods are still needed. Extremist attitudes should be avoided, particularly when dealing with the difficult situations encountered whilst aiding developing countries. The merits of including in research programmes sufficient ancillary testing of the more traditional type, to enable both approaches to be married, should be borne in mind. Over recent years one of the main weaknesses which has given rise to disillusionment with the small clear, strength ratio approach seems to have been at first blind faith, and subsequently bitter disappointment, in the information on grade ratios given in ASTM D245.

PART 2

Visual grading

SYSTEMS OF VISUAL GRADING

Amongst the various types of visual grading rule encountered in different parts of the world it is possible to identify some in which the grades defined are multi-purpose grades. These are applicable to all structural timbers whether used as bending members or in end-uses involving compression or tension. Other visual grading rules distinguish between members used as joists, planks and beams and those used as struts, columns or ties. Some rules of this type also classify stress grades by size. Consequently the grades of such rules will be referred to as 'size and use group' grades.

A very brief description of stress grading would probably mention knots, fissures (these include checks, shakes and splits) and slope of grain as being the chief characteristics whose size and position should be limited. Whilst it is equally important that all of these features should be controlled, together with others enlarged upon in specific rules, it is the various treatments of the measurements of knots that permit a further subdivision to be made of types of visual stress grading rule. Less variation is possible in dealing with aspects such as slope of grain. Because it is in softwoods amongst the commonly used structural timbers that knots feature so largely, it is in grading rules for these that differences chiefly occur. Many grading rules rely for knot measurements essentially upon a determination of the diameter of the knots, with additional explanations provided to cater for knots of non-cylindrical form. There is another type of rule however that limits the ratio of the sum of projected cross-sectional areas of all knots at a cross section to the cross-sectional area of the piece. These are known as knot area ratio rules, abbreviated K A R.

Visual stress grading rules based upon size and use groups

Examples of visual stress grading rules of this type include those given in Appendix A of British Standard Code Of Practice CP112: Part 2: 1971 and the National Grading Rule (Canada) for dimension lumber included in the 1978 National Lumber Grades Authority 'Standard Grading Rules for Canadian Lumber'. The CP112 Appendix A rules are often referred to as the 'numbered grades' because the stresses assigned to the timber associated with them are designated by number which relate to the strength ratio. Thus there are four stress grades specified as having strength ratios of 75, 65, 50 and 40 per cent. Provision is also made for timber used in load sharing systems for a Composite Grade where not more than 25 per cent of the pieces are 40 grade, the remainder being of 50 grade and better. The stress values appropriate to Composite Grade are taken as 20 per cent higher than those for the 40 grade.

The NLGA stress grades (and there are very similar rules in the USA) are classified by size and use into five major groups:

- i Light Framing
- ii Structural Light Framing
- iii Joists And Planks
- iv Beams And Stringers
- v Posts And Timbers

Each group has three or more grades. The various grades are based on the assumption that the joists, planks, beams and stringers are used in bending, whilst 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. Maximum economy will occur if a grade related to the appropriate use is selected in design. However a degree of inefficiency will occur if for example a grade intended for use as a post is selected when a bending member is being designed.

In practice this distinction is more relevant to the grades related to the larger sizes of timber. In the beam and stringer grades complications that permitted knot sizes are allowed to increase towards the ends of members are introduced. (This modification also occurs in the rules for beams in the British 'numbered' grades). The first three of the five major groups mentioned as covered by the National Grading Rule for dimension lumber account for the major quantities of timber produced for use outside North America.

TABLE 1 summarises the primary intended uses of the NLGA grades, their designations, and intended strength ratios in bending.

TABLE 1
PRIMARY PURPOSE, DESIGNATIONS & STRENGTH RATIOS OF NLGA 'DIMENSION' GRADES

Grade name	Primary purpose	Grade designations	Bending Strength ratio %
		DIMENSION UP TO 4 in. WIDE	
Structural Light Framing	Engineered applications where higher bending strength ratios are needed.	Select structural	67
		No.1	55
		No.2	45
		No.3	26
Light Framing	To provide dimension of good appearance at lower design levels	Construction	34
		Standard	19
		Utility	9
		Economy	-
Studs	Studs	Stud	26
		DIMENSION 6 in. AND WIDER	
Structural Joists And Planks	Engineering applications for timber 6 inches and wider	Select Structural	65
		No.1	55
		No.2	45
		No.3	26

The CP112 'numbered' grades, whose principal measurement methods are illustrated in Figures 3 to 7 inclusive, fall under the general category of grades based upon use, since they require the grader to distinguish between members used in bending, tension members and those in compression.

The 'numbered' grades have never been used to provide large quantities of stress graded timber as a commerical raw material. Their not being general purpose rules has tended to discourage their use for such purposes, irrespective of any economic or trade practice considerations. They have

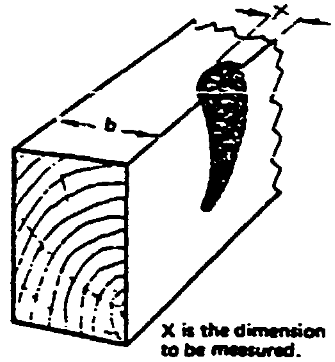


Figure 3 - Splay Knot

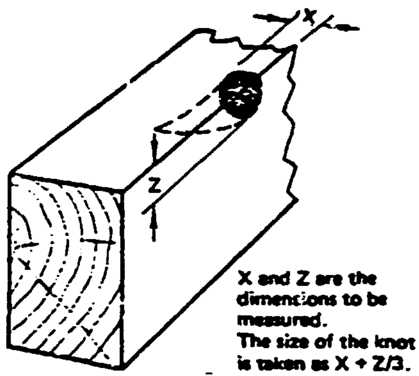


Figure 4 - Arris Knot

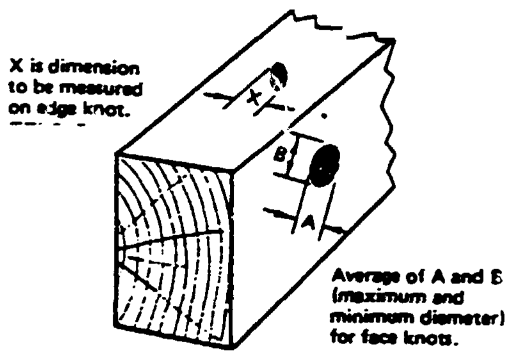


Figure 5 - Edge and Face Knots

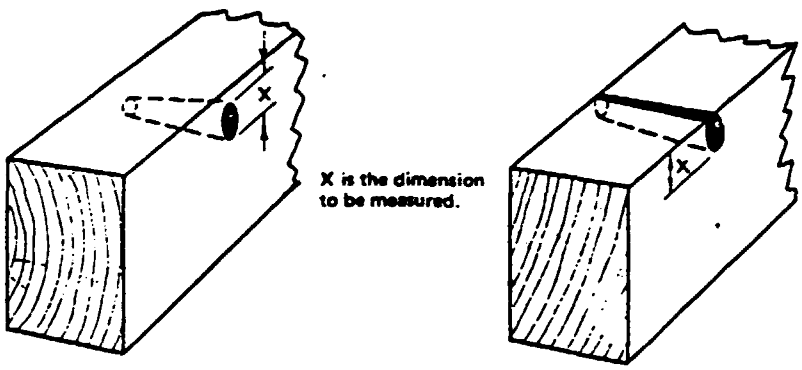


Figure 6 - Margin Knots

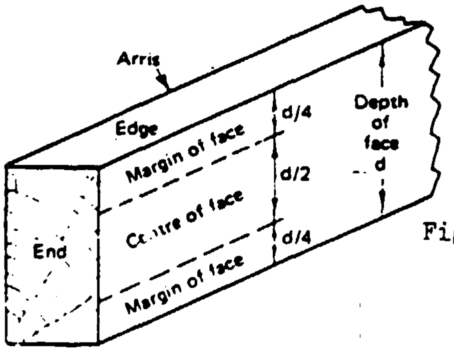


Figure 7 - Edge, Face and Arris Knots

an advantage however in that the grade of a piece is precisely definable from measurements of the characteristics that appear on its surface, and grading may be carried out at any time, even when pieces have been built into components or installed in a building. The complications of increased knot sizes towards the ends of simple bending members, and distinctions in the rules between different types of member can also present more apparent than actual difficulties. It is possible for these rules to be simplified and in such a form they may provide valuable guidance on structural timber quality. In British Standard Code Of Practice CP112: Part 3: 1973 'Trussed Rafters For Roofs Of Dwellings' for example, simplifications to the numbered grade rules include a recommendation to grade both rafters and ceiling ties of trussed rafters as beams. The relaxation of knot diameters towards ends does not apply, since the rafters and ceiling ties of trusses are not in simple bending on a single span. Consequently these rules reduce to a quite simple and practicable form for such components.

Examples of knot size grading limits for two grades and three widths of surface for the numerical grading rules are given in TABLE 2. Corresponding limitations of other defects are summarised in TABLE 3. The 50 grade is regarded as a fairly good quality grade of structural softwood which would be used for members such as those in trussed rafters, and better quality timber framing members such as joists and studs. 75 grade material would only be obtained by a high degree of selection in visual grading.

TABLE 2

MAXIMUM PERMISSIBLE SIZE FOR KNOTS IN THREE WIDTHS OF SURFACE IN 50 AND 75 GRADE TIMBER

Width of surface	Beams						Knots on any surface of compression member		Knots on any surface of tension member	
	Edge, arris and splay knots		Margin knots		Face knots, in centre half of depth					
	75 Grade	50 Grade	75 Grade	50 Grade	75 Grade	50 Grade	75 Grade	50 Grade	75 Grade	50 Grade
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
50	13	25	5	14	13	23	13	23	5	14
100	25	50	13	29	25	45	25	45	13	29
200	44	87	28	59	50	85	50	85	28	59

TABLE 3

GRADING LIMITS FOR FEATURES OTHER THAN KNOTS IN 50 AND 75 GRADE

	50 Grade	75 Grade
Wane	0.2 times width of surface	0.1 times width of surface
Slope of grain	1 in 8	1 in 14
Rate of growth	4 rings per 25 mm	8 rings per 25 mm
Fissures*	0.5 times thickness	0.3 times thickness
Sap stain	Not a defect	
Wormholes	Scattered pin holes and small occasional wormholes permitted. Active infestation rejected.	
Other defects	Fungal decay, brittleheart and other abnormal defects affecting strength excluded	

* Outside the middle half of the depth of the end cross section, and at a distance from the end equal to three times the depth of the piece, and on compression members, the depth of fissures may be 1½ times normal.

General purpose and knot area ratio (KAR) rules

British Standard specification BS 4978: 1973 deals with the assessment of grades for which more recent grade stresses have been added to CP112 by means of amendments. Provision is made for both visual and machine stress grading. For visual stress grading the principle of knot area ratio (KAR) has been adopted to determine the maximum permissible knots for a given grade. Although this is applied to a minor extent in the NLGA National Grading Rule for Dimension Lumber, 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', 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.

Two standard grades have been established for visually 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.

It was envisaged that with these rules a far greater proportion of stress grading should be carried out at the sawmilling stage. Provision is made in the standard for grading in Britain or in the country of origin of the timber. It is a requirement that the grade should be marked on every piece of timber, together with other identifying information. This is in line with North American grading practice following the NLGA rules.

The grader is required to visualise the projected pattern of the knot or group of knots under consideration. This may be explained by imagining the selected cross section to be made of glass, with only the knots being made of wood. The disposition of the wooden knots as viewed from one end of the glass piece is the projected pattern. This principle of knot area ratio (KAR) grading is illustrated in Figure 8. The method is taught, and applied in laboratory test work, by obtaining plots of knots at selected cross-sections under examination. These are taken by measuring between axial lines the widths of knots emerging on each surface and plotting the

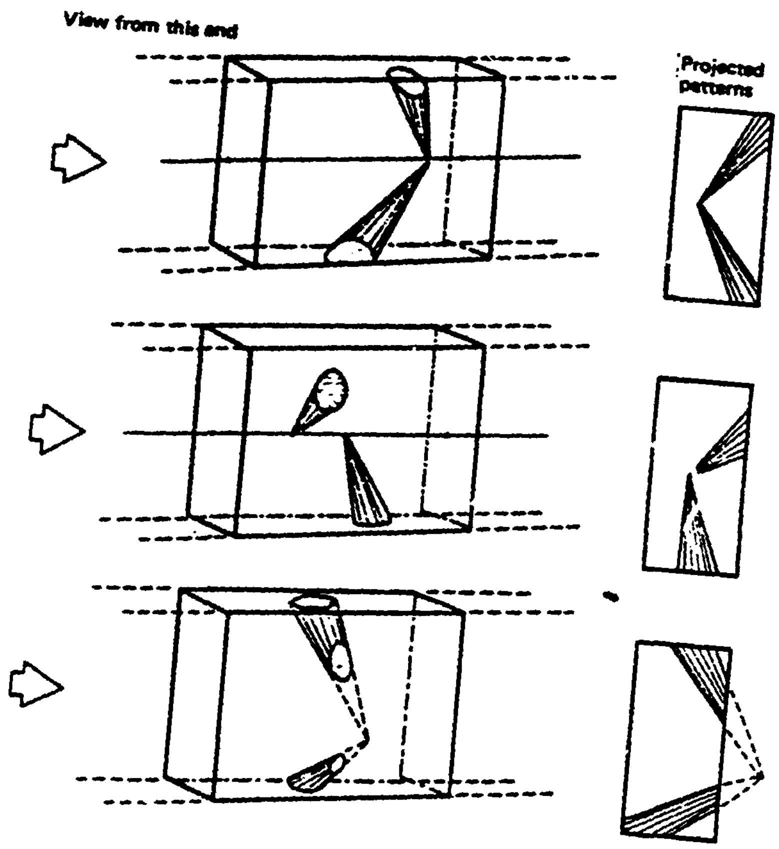


Figure 8 - Projection of Knots to Estimate Knot Area Ratio

results upon a scale representation of the cross section, assuming the knots to emerge as cones from the pith, as illustrated in Figure 9. In commercial grading, skill and experience gained by the application of such techniques during training are applied by the visual grader to make a KAR assessment without physical measurements.

Knots occupying positions in margin areas are dealt with more severely in the BS 4978 rules, in view of their potential detriment to the strength of flexural members. Figure 10 illustrates what is meant by these margin areas, whilst Figure 11 shows how an assessment is made of whether or not there is said to be a margin condition.

TABLE 4 summarises the grade limitations for KAR, fissures, and slope of grain for the BS 4978 visual grades, whilst TABLE 5 gives the grade limitations for wane.

Rules for tropical rainforest timbers

British Standard specification BS 5656: 1979 'Grading of tropical hardwoods for structural purposes' is the first British Standard on grading dealing especially with tropical hardwoods. Both the CP112 'numbered' grades and the BS 4978 grades nominally covered tropical hardwoods, but experience has shown that neither was entirely suitable for grading some tropical hardwoods. When changes in standards were drafted to render the 'numbered' grades obsolete, advantage was taken of the need for a new way to cover tropical hardwoods by writing a standard dealing exclusively with this type of timber.

The standard specifies a single visual stress grade, namely Hardwood Structural grade (HS) 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. These were distinctions that had to be made in the foreword to rules to emphasise the different requirements of stress grading, compared with visual quality rules, such as those given in the General Market Specification rules of the Malayan Grading Rules (MGR).

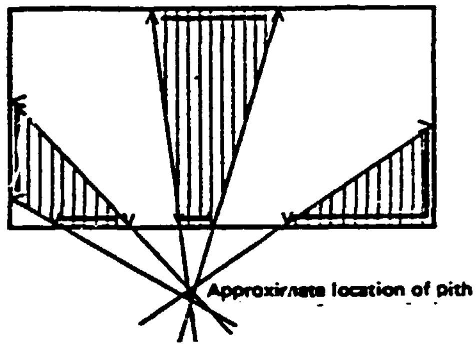


Figure 9 - Knot Plot

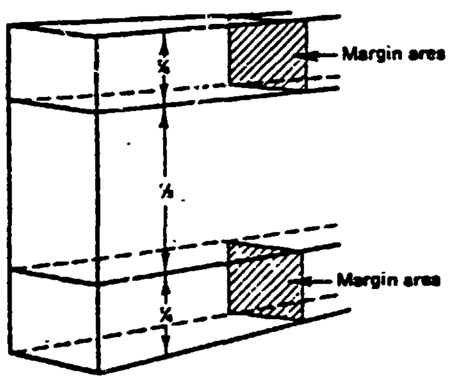
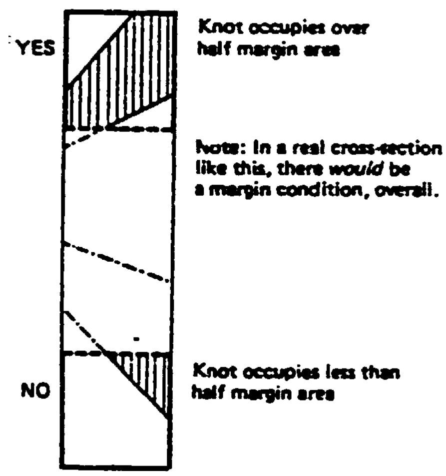


Figure 10 - Margin Areas



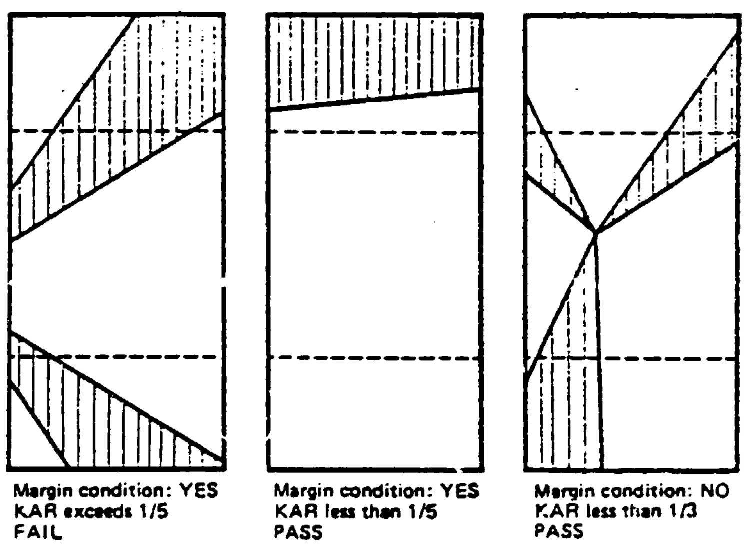


Figure 11 - Margin Conditions

TABLE 4

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 ½ thickness	unlimited	1 in 10
	no margin condition	1/3	greater than ½ 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 ½ thickness	unlimited	1 in 6
	no margin condition	1/2	greater than ½ 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.	

TABLE 5

GRADE LIMITATIONS FOR WANE FOR BS 4978 VISUAL GRADES

Grade		Wane
SS	general	not to exceed $\frac{1}{4}$ of dimension of surface
GS	general	not to exceed $\frac{1}{3}$ of dimension of surface
	not nearer than 300 mm from either side	up to $\frac{1}{2}$ dimension of surface within a single continuous length not exceeding 300 mm

Dealing exclusively with tropical hardwoods, the standard is able to include some detail on characteristics 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 without inefficiency 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. The standard includes provision for timber graded abroad, particularly material graded to the standard structural grade defined in Section J, Stress Grading, of the MGR, to which grade the HS grade has deliberately been kept a close parallel. This may be of benefit, since graded and marked timber to Forest Department standards is available from Malaysia, and prospects of encouraging the supply of material stress graded at source from this particular origin are real.

The standard requires that timber graded to its requirements shall also comply with BS 5450 which deals with hardwood dimensions. In common with BS 4978 and the ECE standard rules for stress grading coniferous sawn timber, BS 5756 recognises that deviation in grading should reasonably be allowed for. It states that a parcel of visually graded timber shall be deemed to satisfy the grade specified if on reinspection at least 90% of a representative sample is within the permissible limits. The defects in any piece in the remaining 10% may not exceed the specified limits by more than 15%.

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. To the extent that it is a normal feature in a tropical timber occurring even in the 2 in. small clear specimens tested to obtain defect-free ultimate strengths, it can be regarded as having been allowed for without the grader's concern. However the rules warn that in doubtful cases, where in the grader's judgement interlocked grain occurs to an undesirable extent in relation to the cross-sectional dimension of the piece, bearing in mind the normal slope of grain limitation, then the piece shall be rejected. Research has shown that interlocked grain with a local slope of 1 in 4 is approximately equivalent in its strength reducing effects to normal sloping grain of 1 in 11, which is the HS grade limitation. Consequently both limitations are applied to the grade.

When the sawn size is small in relation to the width of the interlocked growth layers then, depending on the method of sawing of the piece (quartered or flat sawn), the effect of interlocked grain can be as if there were normally sloping grain over the whole transverse dimension of the surface. In this case the slope should not be allowed to be worse than 1 in 11.

Figure 12a) shows how simple knots are measured. When a knot emerges from within the cross section onto an arris, and neither of the exposed sections of the knot is definitely elongated (the arris knot of the CP112 'numbered' grades) then the knot is measured as shown in Figure 12b). Taken in conjunction with the grade limitation applied, this is a simple and cautious way of dealing with this particularly deleterious type of knot. 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 Figure 12c) and 12d).

Again it should be emphasised that knots are not a common feature in tropical hardwoods of the types normally used structurally. When they do occur they will frequently be more nearly in the form of cylinders or oval prisms within the piece than in the form of cones as in softwoods sawn from small trees. Not only the size of the log, but also the fact that the heart is excluded from the sawn material in the topical hardwood is the reason for [illegible]

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

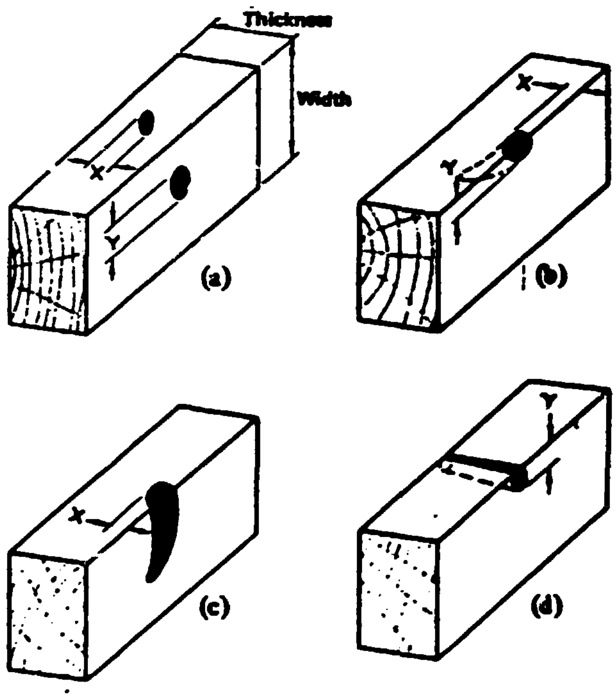


Figure 12 - Knot Measurement

Brittleheart may be detected at the ends of a piece by a pitted appearance of the wood. Detection of brittleheart on a face is more difficult but it is frequently associated with compression creases. Abnormally low density is also common in the material containing brittleheart. 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 fibres are found to be broken transversely or crushed by compression. Various causes are suggested, such as felling across obstructions, and failure inside the growing tree brought about by causes such as high winds and growth stresses. All pieces containing them shall be rejected.

TABLE 6 summarises the grade limitations for slope of grain, fissures and distortion for the BS 5756 HS grade, whilst TABLE 7 gives the limitations for insect holes, wane, resin pockets and other features.

Grade ratios

When grade stresses are derived by structural sized testing, as opposed to the application of a strength ratio to basic stresses from small clear specimens, it is nevertheless still possible to define a strength ratio. Indeed this must be done, since basic stresses are required for certain structural design purposes, including glued laminated construction. The calculation is therefore simply made in reverse, and having assigned grade stresses from structural sized tests, there are compared with the basic stress for the same timber calculated from small clear tests, to deduce strength ratios.

Grade ratios for the BS 4978 grades, GS and SS, which are in effect almost exclusively grades for structural softwood timbers, are given in TABLE 8. The ratios for the single HS grade, defined in BS 5756 for tropical hardwoods, are given in TABLE 9.

TABLE 5

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 ½ thickness	length unlimited
	greater than ½ 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.

TABLE 7

GRADE LIMITATIONS FOR INSECT HOLES, WANE, RESIN POCKETS AND OTHER FEATURES FOR BS 5756 HS GRADE

Characteristic	Qualifications	Limit
Insect holes	pinholes	not more than 32 in a portion of surface represented by a square of 100 mm sides.
	shotholes & grubholes	not more than 4 in square of 300 mm sides.
	holes exceeding 6.0 mm	
Wane		not exceeding one quarter of transverse dimensions of surface.
Resin pockets	not greater than 3 mm width	unlimited in lengths not in excess of 1.5 times width.
	greater than 3 mm not greater than 10 mm width.	once in any 600 mm length of piece, length of pocket not in excess of ½ width.
	larger than above	not permitted.
Others	permitted	stain free from decay.
	excluded	fungal decay other than in unsound knots; brittleheart; compression failures; tension wood and other abnormal defects.

TABLE 8

GRADE RATIOS FOR BS 4978 GRADES GS AND SS (SOFTWOODS)

Property	Grade	
	GS	SS
Bending	0.35	0.50
Tension	0.24	0.35
Compression parallel to grain	0.44	0.63
Compression perpendicular to grain	0.68	0.76
Shear parallel to grain	0.54	0.54
Mean modulus of elasticity	0.90	1.00

TABLE 9

GRADE RATIOS FOR BS 5756 GRADE HS (TROPICAL HARDWOODS)

Property	Grade ratio for HS
Bending	0.67
Tension	0.60*
Compression parallel to grain	0.875
Compression perpendicular to grain	0.75
Shear parallel to grain	0.67
Modulus of elasticity	0.95

* 0.60×grade bending stress

PART 3

Machine stress grading

STRENGTH-STIFFNESS PRINCIPLE

The principle of machine stress grading has been well described by Curry and Tory (1976) and Curry and Fewell (1980) and the following is based largely on these references.

Machine stress grading became possible when it was realised that reasonably close relations exist between the bending, compression and tension strength of timber and its short span modulus of elasticity (Sunley and Curry, 1962) (Curry and Fewell, 1977). Thus if a machine could be developed to measure modulus of elasticity satisfactorily, and information was available to enable its operation to be controlled and regulated, it could be used to grade pieces of timber having strength properties above any specified minimum value. There are many ways of measuring modulus of elasticity and the method used will affect the grading operation.

When research on machine stress grading was started in Britain, before commercial machines were available, it was recognised that machines could be producing using various indicating properties, and that the relations between strength and these properties could well be affected differently by section size, operating speeds and other factors. It would also be necessary to produce control information, ie grade limits for each type of machine for a range of grades, sections and species. To obtain this information directly for each type of machine, and for each indicating property, would require an enormous amount of laboratory test work with many hundreds of pieces of timber being tested to destruction. So from the outset attention was given to developing a general approach to machine stress grading which would minimise the test work and allow maximum use to be made of all accumulated data. A single basic property was therefore introduced which could be measured non-destructively and which was independent of commercial grading machines as such. Preliminary investigations showed that an appropriate property would be short span modulus of elasticity measured under laboratory conditions with the timber loaded in edge-wise bending, free from shear and under constant moment over a gauge length of 910 mm (3 feet). Details of this test are given in BS 5820:1979. The modulus obtained from this test is identified as E(true) and Figure 13 gives an indication of how closely bending strength is related to this property for one sample of Canadian hem-fir.

Knowledge of the basic property E (true) can be applied to all types of machine simply by establishing from non-destructive tests the relations between E(true) and the machine's particular indicating property, Figure 14. In this way the need to test many samples of timber to destruction for each type of machine is avoided, and this advantage outweighs the disadvantage of having a multi-stage approach to the determination of grade limits.

The current generation of grading machines all use essentially the same principle in that the piece of timber being graded is deflected as a beam and the magnitude of a force or deflection, associated with a constant imposed deflection or force, is the indicating property used to provide a measure of modulus of elasticity. Other principles of operation, using different indicating properties may be introduced in the future.

DEVELOPMENT OF REGRESSION METHODS IN THE UK

To establish relationships between modulus of elasticity and target values of bending stress, in order to derive settings for particular machine grades, the procedure originally adopted in Britain was to use a straight line regression analysis, Figure 15. A lower exclusion straight line associated with a particular probability value was calculated and its slope was reduced by a factor to give a grade stress line. The factor was considered to include allowances for the effect of duration of load and to incorporate a safety factor. The grade stress line was then used to obtain the value of the minimum modulus of elasticity corresponding to any required grade stress and from this the control setting for a machine was determined using the multi-stage relationship described above.

The assumption of a linear lower exclusion line had the attraction of simplicity but it raised a number of difficulties, particularly when there were relatively high intercept constants in the equations, since these could infer a nonsensical situation of zero strength or stiffness. Also with this approach no account was taken of the influence of the range of

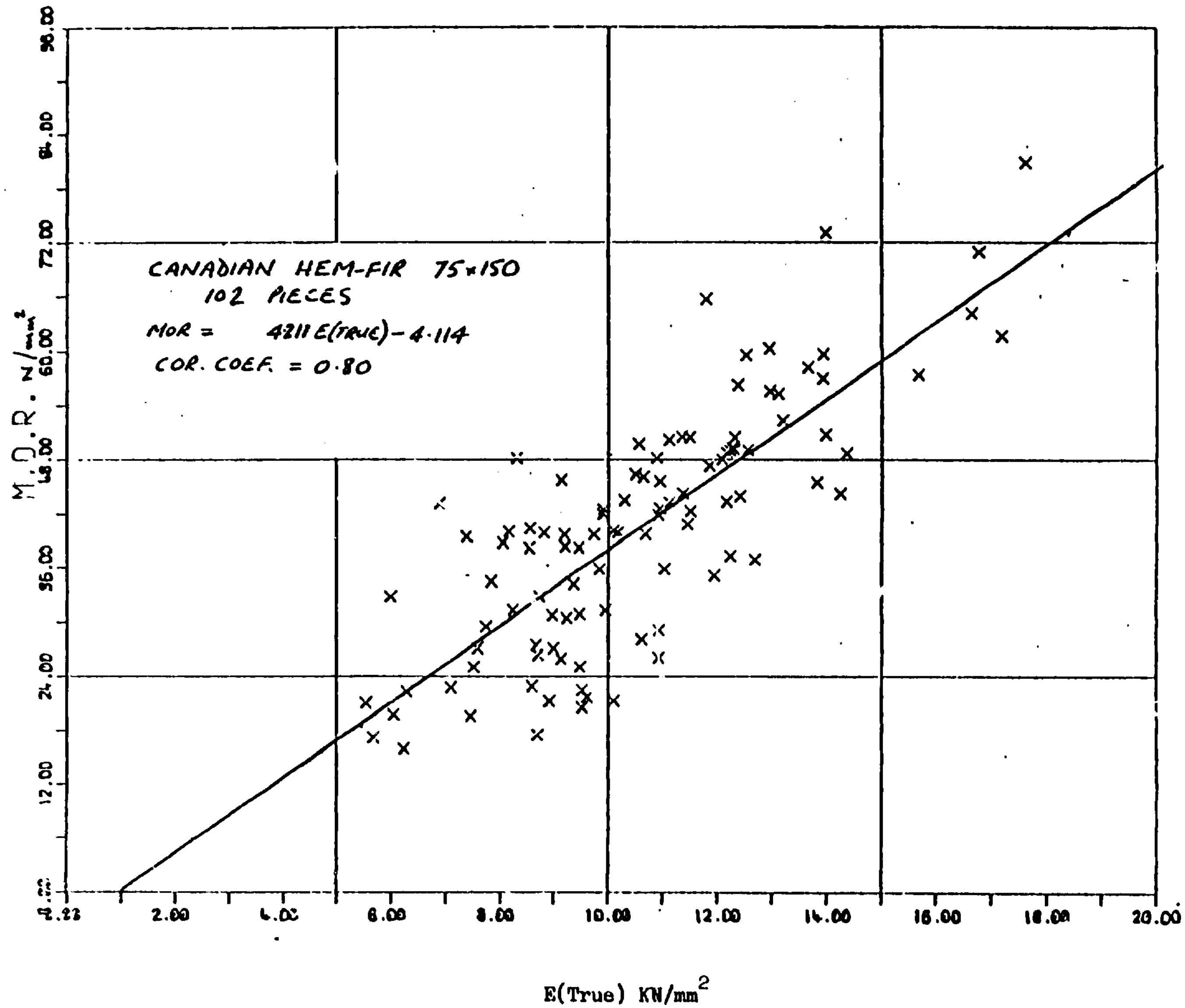


FIGURE 13: The Relation Between Bending Strength and E(True) for one Sample of HEM-FIR.

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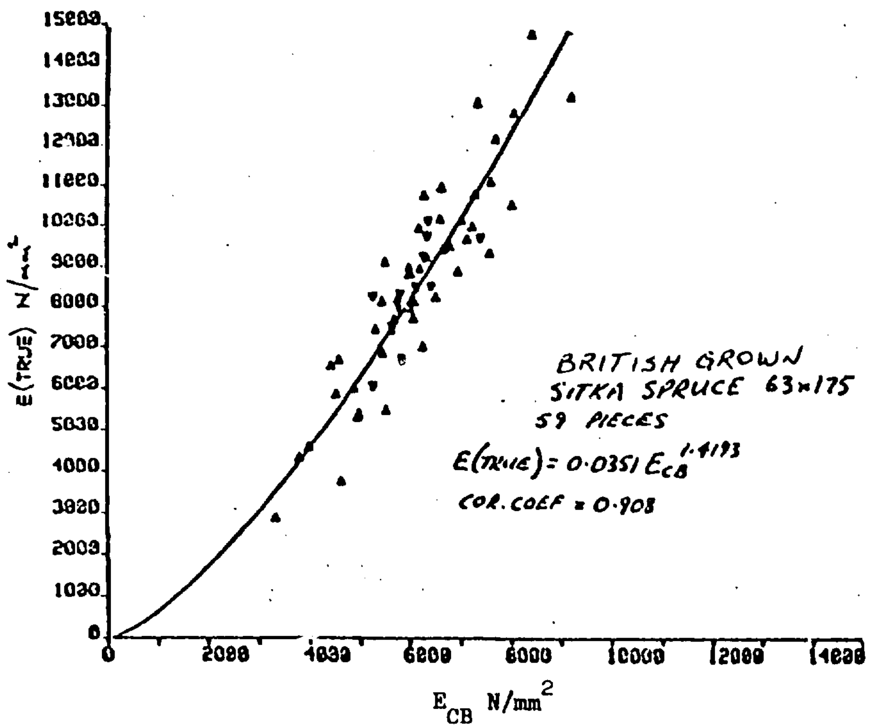


Indicating Property

FIGURE 14: Relation Between E(True) and Machine Indicating Property

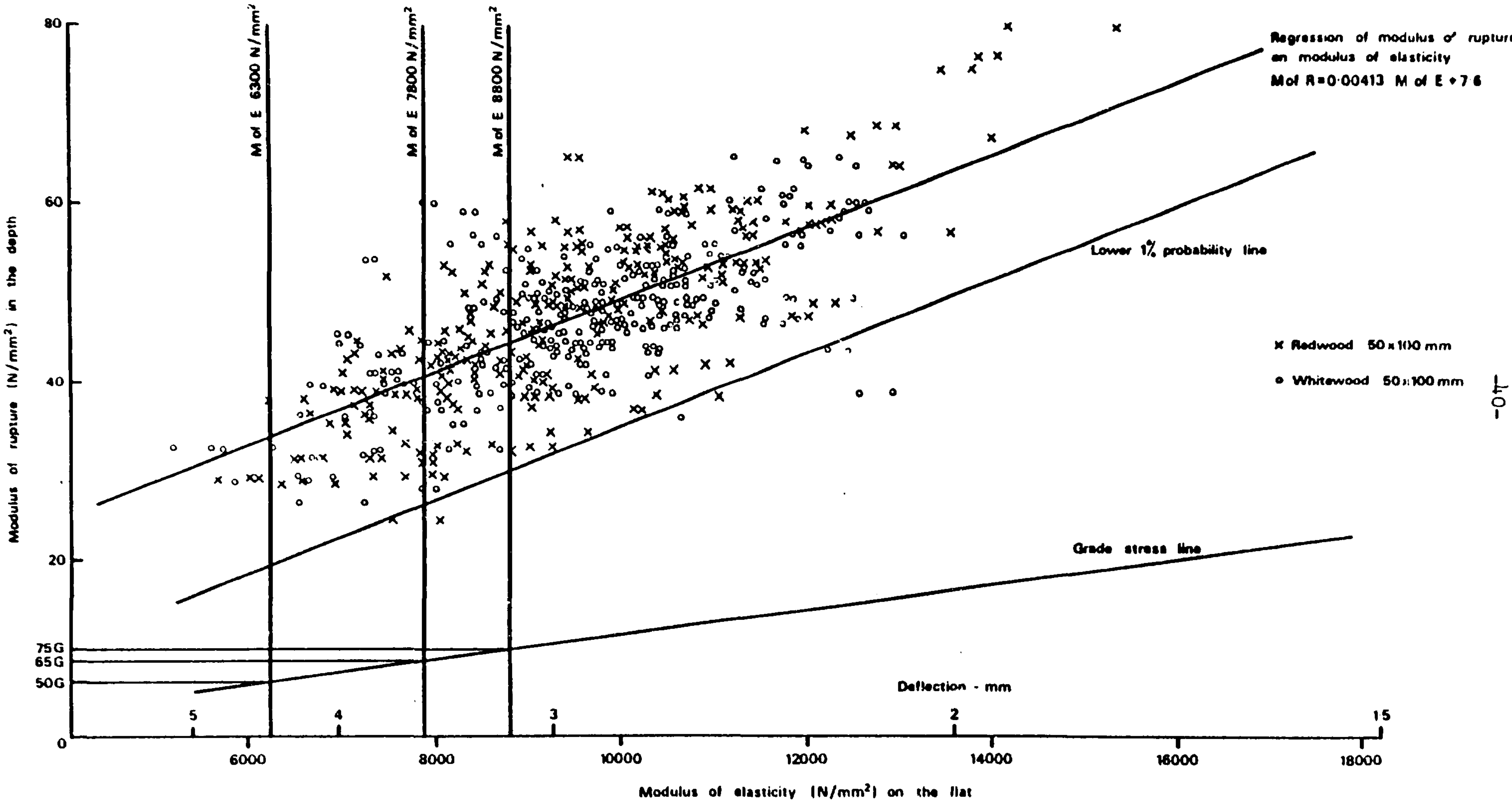


Fig 1 REGRESSION, LOWER 1% AND GRADE STRESS LINES: EUROPEAN REDWOOD/WHITEWOOD

modulus of elasticity included in any one grade, and the effect of this on minimum strength values.

For these reasons it was decided that the simple linear relation should be reviewed, and alternative procedures for defining the relation between strength and modulus of elasticity and for determining lower exclusion lines for strength should be examined. The outcome of this new work was a set of relationships of the type illustrated in Figure 16 (Curry and Tory, 1976).

The division of the test data into bands of E(true) in Figure 16 simulates the action of a grading machine and this was the principle that was adopted to establish lower exclusion lines, ie the lines passing through the appropriate percentiles of the distributions within the bands. However, the percentiles of each distribution naturally depend upon the initial location of the bands and on the width of the band along the range of E(true). To take account of these effects the bands were advanced in steps of 100 N/mm^2 to produce a series of overlapping sub-groups and band widths of 500, 1000, 1500, 2000, 2500 N/mm^2 were considered independently. The overlapping of bands also has the effect of smoothing out irregularities toward the extremes of the E(true) range. The lower exclusion lines are of the form $f_m = aE(true)^b$, these equations having been found to give a good fit through the lower percentile values. Several other equations were tried for the lower exclusion lines but were less satisfactory.

When establishing limiting values of E(true) from the lower exclusion lines the choice of exclusion line should match the actual difference between the grade limits to the bandwidth used to establish the line. For example: the highest grade stress value (multiplied by factors for safety, duration of load, moisture content etc) is applied to the relevant species equation for 2500 N/mm^2 bandwidth to obtain an E(true) boundary level. The stress value for the next grade is applied to the same equation and the resulting E(true) value is compared with that for the highest grade. If the difference between the E(true) limits is greater than the bandwidth then the limits are acceptable. If however the difference between the limits is less than the bandwidth then the limit for the lower grade is recalculated using the next smallest bandwidth equation. This procedure continues until near equality is achieved between bandwidth and E(true) limits. If balance cannot be achieved then the higher grade limit is recalculated using the equation for a smaller bandwidth and the whole procedure is repeated.

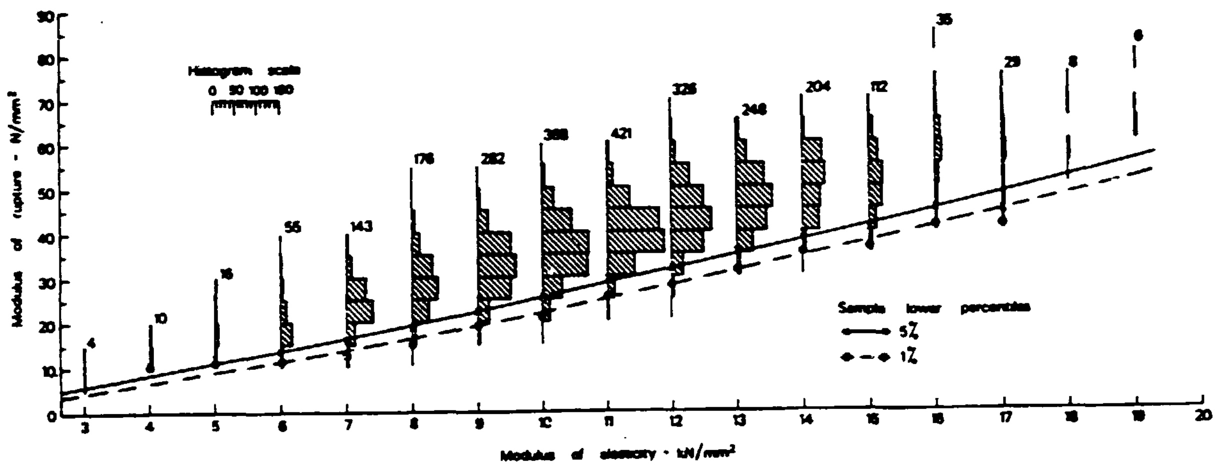


Figure 16 Distributions of modulus of rupture in 1000 N/mm^2 bands of modulus of elasticity for European redwood and whitewood, and 5% and 1% lower exclusion lines, strength adjusted to 200 mm depth

GENERALIZED RELATIONSHIPS

The relation described above is more general than the original species-by-species approach, with linear regressions, adopted in UK. However it was still a conclusion of the report by Curry and Tory (1976) that the relations between modulus of rupture and modulus of elasticity for Canadian western hemlock differ from those for European redwood and whitewood, and the species must be treated separately.

In Australia, a general relationship was established at an early stage (Huddleston and Anton, 1967). They commented that the use of a general working stress line from data obtained from a number of species, as shown in Figure 17 tends to be conservative, since in deriving it, the variation between the various species has to be taken into account. Although a separate relation for each species may of course be established, it is only of practical use where the species is separately harvested, marketed and marked, a point of relevance in considering suitable relationships for work in developing countries.

A species-independent machine grading system was proposed by Senft and Della Lucia (1979) for Brazilian hardwoods. The relation with which they illustrated their suggestion is reproduced in Figure 18. A generalized relationship was discussed by Mettem (1974) and Figure 19 shows a curvilinear strength - stiffness relation for tested structural-sized pieces in density ranging from that of spruce up to the top values which are for greenheart.

Such generalised relationships may be of importance where species-orientated utilisation is impractical, for example in Amazonian or similar diverse forests, or in clear-felling programmes. A possible objection arises if the scatter in relations such as that illustrated in Figure 18 becomes so great that the lower exclusion line is unduly depressed. For example, if for a given MOE, one timber is twice as strong on average as another, then the penalty of generalisation may be adjudged excessive. These considerations were addressed by de Frietas (1978). Stress grades based on the regression lines of species groups obtained according to density were examined, with some lessening of the variability, but a more promising approach was to base stress grades on the regression lines of groups of species having similar strength-stiffness relationships to one another.

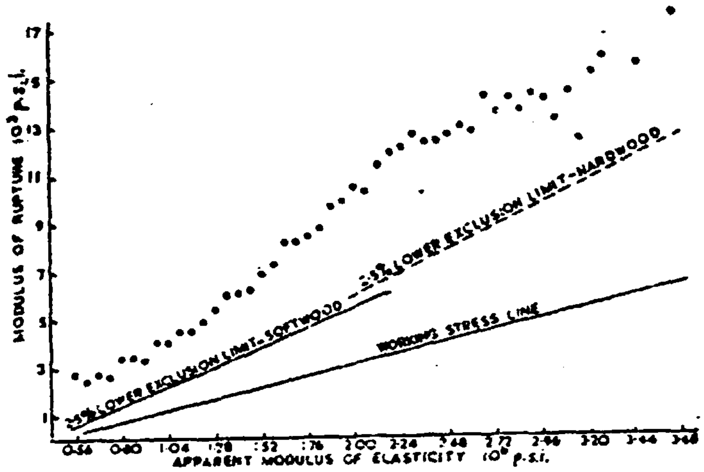


Figure 17 —*Mean Modulus of Rupture versus Mean Apparent Modulus of Elasticity.*

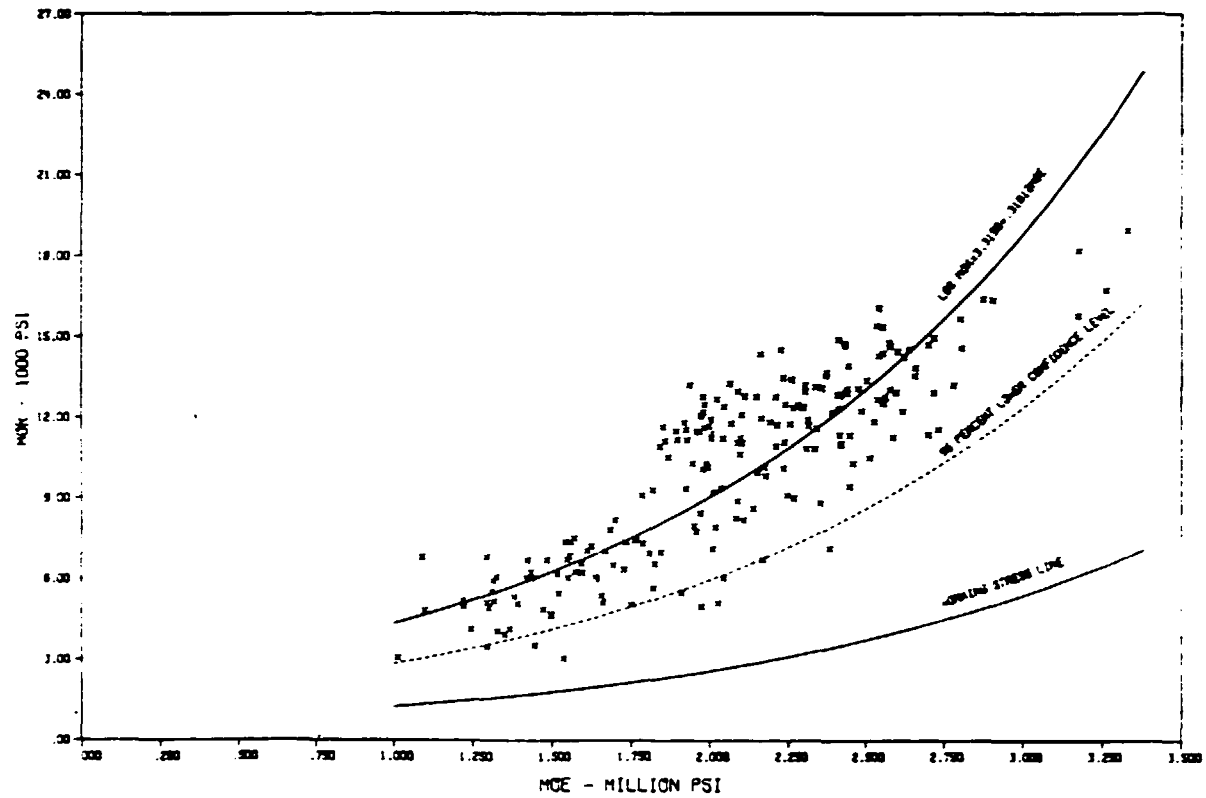
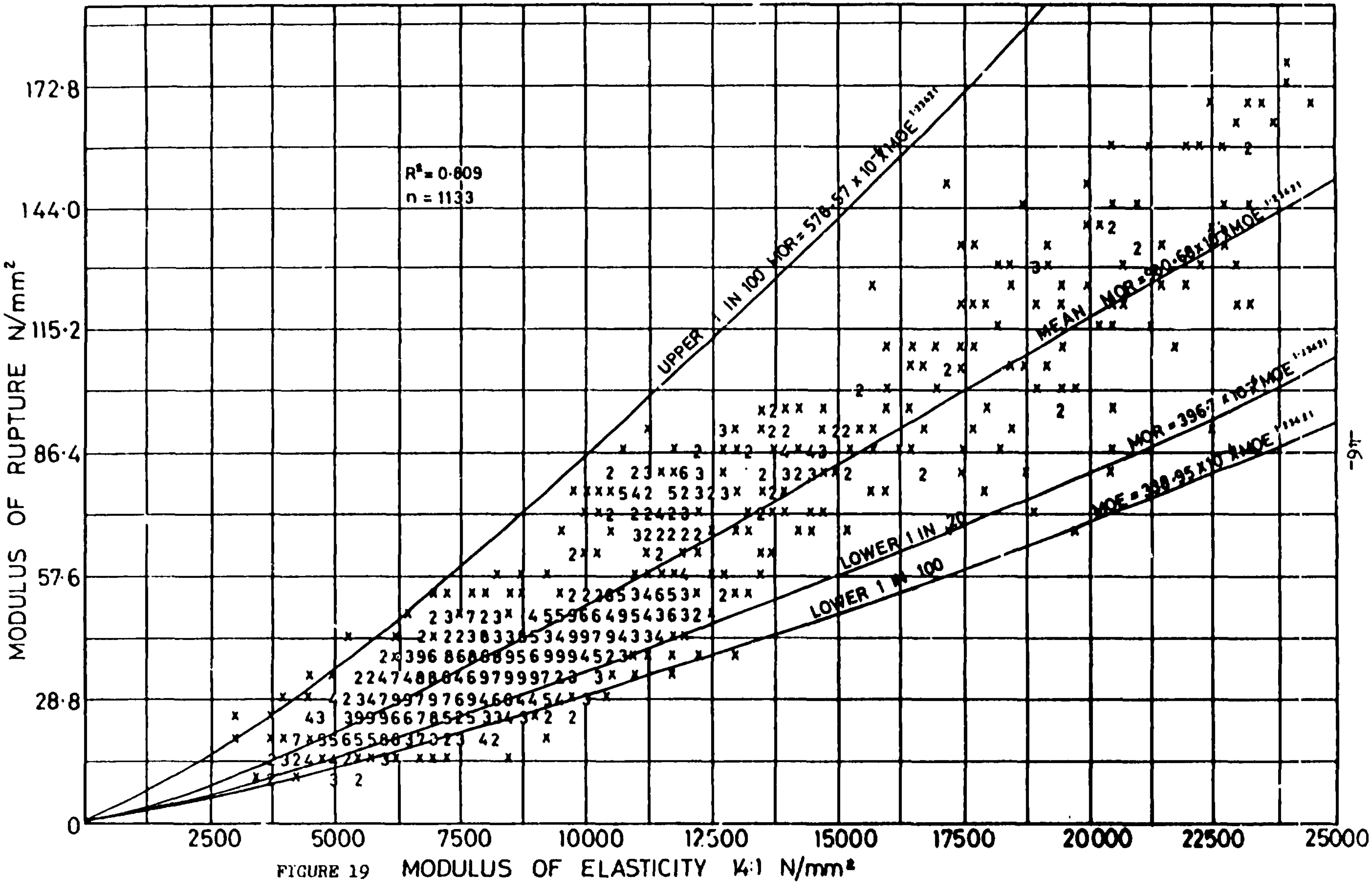


Figure 13— Working-stress line derived from a basic MOR/MOE regression equation for 2 by 4 and 2 by 6 structural lumber of banak, tachi, and pequia.



MODULUS OF RUPTURE N/mm²
172·8
144·0
115·2
86·4
57·6
28·8
0
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
R² = 0·809
n = 1133
UPPER 1 IN 100
MEAN
LOWER 1 IN 20
LOWER 1 IN 100
MODULUS OF ELASTICITY 14:1 N/mm²

FIGURE 19

In Figure 19, which is a simplification of the relationships derived by de Freitas, the timbers in group 1 do not necessarily have any botanical affinity to one another, but share the property of having a similar MOR/MOE ratio. Likewise the timbers in groups 2 and 3 each relate to different strength-stiffness curves. Timbers were allocated to one group or another purely on the basis of their strength-stiffness ratio, the coefficient of determination (r^2) of the MOR, MOE regressions for each group having been optimised by computer program with respect to these groupings.

This method of optimising and standardising strength-stiffness relationships migh provide a key to the problem of implementing a machine grading system with predetermined settings and associated timber design stresses that could accept new, unidentified or mixed species without the need for a full testing programme each time. If a set of generalised relationships for three or four strength-stiffness ratios were to be established, and a suitable machine grading system provided on this basis, it ought to be possible to allocate new introductions of timbers or species groups to appropriate strength-stiffness classes by means of more limited tests. These might take the form of strength-stiffness tests using field portable apparatus, or simply simplified test programmes using fewer parameters or medium-sized specimens.

OPERATING PRINCIPLES OF GRADING MACHINES

References to actual working stress grading machines based on the mechanical strength-stiffness principle date from about 1962. In that year a prototype grading machine was demonstrated at the former Forest Products Research Laboratory, Princes Risborough, U.K. (Sunley and Curry, 1962) and a paper was published (McKean and Hoyle, 1962) referring to a machine manufactured in the USA, known as the 'Continuous Lumber Tester, CLT 1'. The 'Micro-stress' grading machine (Booth, 1966) was another early development.

The 'Computermatic' machine, which was a development of the Micro-stress machine, became firmly established on a commercial basis in Britain after its introduction around 1969. It is still operated in Europe in quite a number of installations. It may therefore be used as a basis for describing the operating principles of a typical 'first generation' stress grading machine and for discussing later types. Machines referred to in this paper as 'second generation' have been introduced within approximately the last

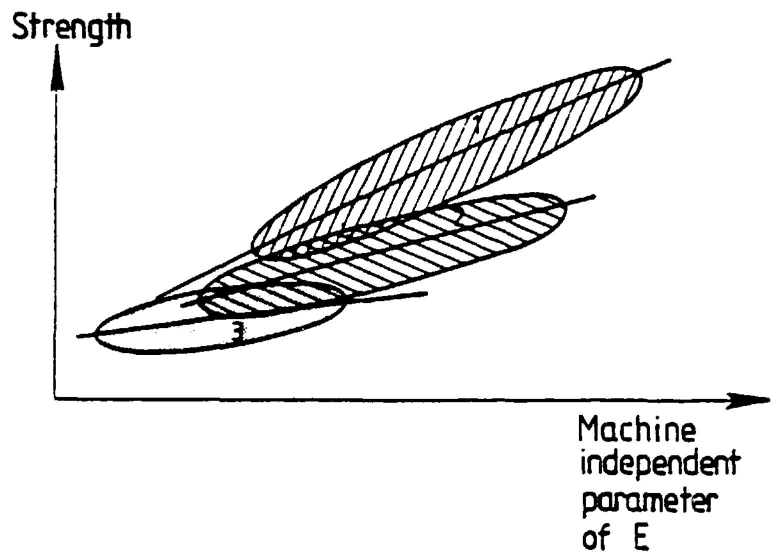


Figure 20 Generalized strength–stiffness relationships with timbers grouped according to their MOR/MOE ratio.

ten years. These generally take advantage of developments in micro-processor technology, and eliminate some of the measurement errors or variations experienced in the earlier designs, brought about for example by vibrations, and interrelations between machine and timber stiffness.

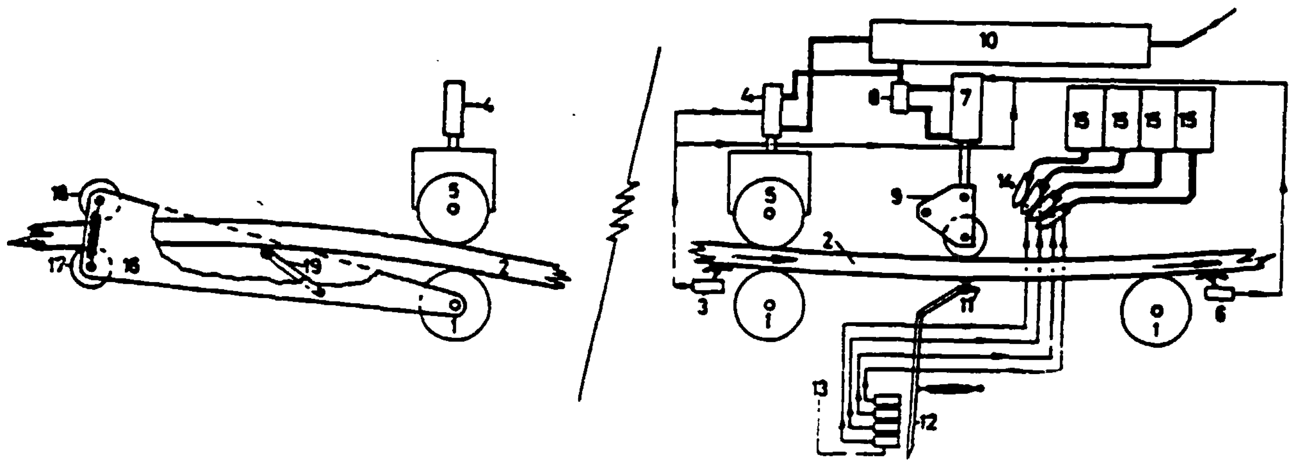
The final type of machine which may be mentioned and referred to as 'third generation', depends upon principles other than strength-stiffness, or 'mechanical grading', as it was known in the 1960 era. These new machines generally employ non-destructive methods of morphological analysis of the wood. Defect detection methods include optical scanning, ultrasonic transmission or pulsing, microwaves, x-rays and neutron radiography. Some machines combine more than one technique in evaluation of the wood. Methods other than mechanical grading are not actually a new proposal, ultrasonics for example having been investigated some twenty-four years ago (Lee, 1958). However recent progress in systems engineering has made on-line automated defect detection more commercially feasible. A recent state of the art report (Szymani and McDonald 1981) deals with automated defect detection systems for wood products in general.

Following this paragraph is a brief description of the Micro-stress and Computermatic machines, based on Curry (1969). Afterwards there is a short discussion of two second generation machines and a simpler machine based on a different strength-stiffness principle. Finally two third generation systems are mentioned. Appendix I gives names and manufacturer's addresses of the three machines approved under the British Standard Institution's Kitemark certification scheme for timber graded to BS 4978. Two other British machines and two third generation machines are also listed. Appendix II gives extracts from manufacturers' technical literature on the machines.

Micro-stress and Computermatic machines

Figure 20 shows schematic diagrams of the two machines, and their operation is as follows.

Two single fixed support rollers (1) mounted with their axes vertical are spaced 0.9 m (3 ft) apart, the timber (2) trips a microswitch (3) as it is fed on edge onto the machine, and this brings roller (5) via the air cylinder (4) into contact to drive the timber through the machine. By feeding the



1 - SUPPORT ROLLERS
2 - TIMBER
3&6 - MICROSWITCHES CONTROLLING AIR CYLINDERS
4 - SMALL AIR CYLINDER
5 - DRIVE ROLLER
7 - LOADING AIR CYLINDER
8 - AIR PRESSURE CONTROL
9 - LOADING ROLLER

10 - AIR ACCUMULATOR
11 - DEFLECTION SENSING ROLLER
12 - DEFLECTION LEVER
13 - DEFLECTION MICRO SWITCHES
14 - SPRAY GUNS
15 - DYE STORAGE TANKS
16 - LIGHT FRAME OF OUTRIGGER
17 - FIXED ROLLER
18 - SPRING-LOADED ROLLER
19 - BOW SENSING ROLLER

Microstress and Computermatic stress grading machines

Figure 21

timber through on edge, the overhanging ends will have little effect on the lateral deflexion. When the leading end of the timber trips a second microswitch (6), the larger air cylinder (7) applies a force via the loading roller (9), the magnitude of which is controlled by a pressure valve. The deflexion of the timber is sensed by a small roller (11) mounted on a lever (12) and, depending on the magnitude of the deflexion, microswitches (13) are tripped. Each of these microswitches is connected to one of four spray guns (14), which spray the timber with dye from the storage tanks (15). When the trailing end of the timber passes the microswitch (3) both air cylinders open and the first phase of the grading is completed. A compressor (10) ensures a sufficient supply of air at the correct pressure.

The deflexions recorded in this first pass through the machine will obviously be influenced by any natural bow or irregularity in the timber. Each piece of timber has, therefore, to be fed through twice, in the second pass, with the same end leading, but with the load applied on the opposite face. By summing the deflexions from a visual inspection of the colour combinations, the effect of bow can, to a large extent, be eliminated.

The Microstress machine can handle timber ranging in thickness from 25 to 75 mm and in widths up to 300 mm. It has an operating speed of 30 m/min but, because of the double pass, the effective speed of the machine is of the order of 12 m/min. The grade limits are set by adjusting the position of the microswitches (13), so that they will trigger when the deflexion of the timber exceeds the limiting value established for the grades from the modulus of rupture/modulus of elasticity relations.

An improved version of this machine, the Computermatic model, will carry out the grading operations in a single pass. The outrigger shown on the left of Figure 20 has been added. This consists of a light frame (16) which can rotate freely in a horizontal plane on the axle of the first support roller (1) of the main machine. A fixed roller (17) is mounted in the outrigger at a distance of 0.9 m (3 ft) from the first support roller. A spring-loaded roller (18) holds the latter against the timber and a small roller (19) at the centre detects any deviation from a straight line in the lower surface of the timber. These datum readings are taken at 155 mm (6 in.) increments of length, converted into a binary number with a quantum of 0.4 mm (0.015 in.) (0.2 mm or 0.0075 in. on later models) and stored in a small computer unit. Similarly, with the timber under load in the main body of the machine, deflexion readings are taken which are phased to correspond to the same positions in the length of the timber at which the datum was established. The computer then eliminates the influence of the initial shape of the timber, provides a true reading of the deflexion actually generated by the load and classifies this according to the pre-set limits required for the grades. These operations are carried out continuously as the timber passes through the machine, and the computer can be used to activate the spray guns so that the grade can be identified by a splash of dye at 155 mm intervals along the length of the timber. Simultaneously, or alternatively, the computer can store the grade signals and simply spray the trailing end with the colour corresponding to the lowest grade encountered throughout the length of each piece. Since the span of the machine is 0.9 m, there will be 0.45 m at both ends of each piece of timber which will not be graded as effectively as the remainder of the length. This is of little significance for timber used as a beam or joist.

The Computermatic Mark IVB is a British-made machine with a number of improvements over earlier models. These include a programme terminal to set the machine's computer for a given timber type and cross-sectional dimension. The details in Appendix II refer to this model.

<u>Cook Bolinder SG-AF stress grading machine</u>

This machine, which was introduced in 1979, receives the timber on edge, and deflects it laterally over a 0.9 m span, in the same configuration as the Computermatic. A high level of accuracy is claimed, probably justly, by using the principle of constant deflection, load sensing. This is a reversal of the Computermatic method which loads a given timber and size to a constant stress, and senses the ensuing deflections, which vary along the piece.

The timber is deflected in opposite directions in two separate passes through the Cook Bolinder machine. A computerised sensing mechanism reads off the variable force caused by the fixed deflection, the force being detected by a load cell. During the second pass the computer provides a continuous read-out of the mean values. Dye marks and stamp marks are applied to indicate grade.

By using separate passes the interference effects associated with double bending are eliminated, and by using a constant deflection it is possible to avoid errors in load-deflection measurement caused by timber vibrations.

The Raute Timgrader stress grading machine

The technical literature describing this machine dates from 1978, the approximate date of its introduction, although work on prototypes had started earlier.

Timber is deflected horizontally, whilst passing through on edge, in common with both machines described above. The Timgrader is a fixed deflection, variable load machine, like the Cook Bolinder type. A difference in principle is that in this machine the method of allowing for bow is to bend the timber successively in opposite directions in a single pass. The variable forces required to provide fixed deflections in this manner are sensed and averaged electronically. The measuring frequency is synchronised with the feed speed of the timber at about 100 mm intervals along the length passing through.

The machine embodies quite a substantial electronic system including a process control microcomputer and a unit which can transmit grading information to a sorting machine.

In deriving settings for this machine it is necessary to calculate allowances for interaction between a low stiffness portion of the length (due perhaps to a gross defect) passing one deflection station whilst material of a different quality (another part of the length) passes the second station.

The Sontrin timber selector

This machine has not been approved for general purpose stress grading to BS 4978 under the Kitemark scheme because of its insensitivity to localised gross defects, particularly away from the centre of the span. These may be of importance in structural members with built-in or partially fixed ends such as rafters of trussed rafters. The timber selector is of value however in grading simply supported bending members such as joists. It may be used either as an adjunct to visual grading, taking advantage of the machine's ability to eliminate pieces of low gross stiffness, or in conjunction with a setting procedure which has been devised to weight the required apparent modulus in the settings according to the distance of the suspected defect from the lateral centre line of the piece.

The machine subjects a piece of timber to a predetermined central load and senses the ensuing deflection, giving a simple pass/fail indication for a particular setting. The material is deflected in the depthwise direction, not laterally as in the machines described above. Variable spans are used, these being related to the intended end use of the piece and ranging from 2.4 m to 5.4 m.

The Plan-Sell, Innotec Oy Finnograder device

This third generation device uses non-contacting measurement methods, and consequently it is possibly not strictly correct to refer to it as a machine. The manufacturing company was established in 1973 and was taken over as a subsidiary of Plan-Sell Oy in 1978. The Finnograder has been assessed at the Finnish VTT Technical Research Centre.

The Innotec instruments, which include also an on-line moisture meter and an automatic control system for edging, perform measurements by various kinds of electromagnetic radiation. The Finnograder is claimed to detect density, knottiness, slope of grain and moisture content. By relations between these features and tested strengths, performance can be predicted in bending about either axis or in tension.

The ISO-GreComat grader

The principle of this machine, which has been assessed at the Otto-Graf Institute in Stuttgart during 1980 and 1981, is to grade timber by measuring its density through use of isotopes. Knot area ratios are assessed by determining ratios between local and general density, and allowances are made for influences of moisture content and dimensional variations.

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Appendix I

Names and manufacturers of European stress grading machines

1. Machines with BSI Approval

Computermatic	- available from -	Measuring & Process Control Ltd. 16 Redhills Road Eastern Industrial Estate South Woodham Ferrers Chelmsford England
SG - AF	- available from -	Cook Bolinders Ltd. Commerce Way Stanbridge Road Leighton Buzzard Beds. LU7 8RW England (Telex: 826139)
Timgrader	- available from -	Raute Lahden Rautatdollisuus Oy PL 138 15111 Lahti 11 Finland

2. Other UK Machines

Micromatic	- available from -	Measuring & Process Control Ltd. (see above)
Sontrin	- available from -	Sontrin Engineering Ltd. 143 Hythe Hill Colchester Essex England

3. Other Machines Available

Finnograder	- available from -	Plan-Sell Oy PO Box 24 18101 Heinola 10 Finland
ISO-Gre Comat	- available from -	Gre Con Greten GMBH & Co KG Postfach 1530 3220 Alfeld - Hannover West Germany (Telex: 92977 GRETN D)

Appendix II

The following pages give selected extracts from manufacturers' technical literature on the stress grading machines listed in Appendix I.

Computermatic Mark PIVB

The Computermatic Mark PIVB is a fast computer controlled non-destructive timber stress grading machine. Its function is based upon the discovery that the stiffness (modulus of elasticity) of any short length of square-edged sawn timber is the most accurate indication of the strength (modulus of rupture) of that length. The current model is an improved design of the Mark PIVA which has been proved in the hard conditions of commercial practice, (over 100 installations). The machine feeds the timber through at an adjustable speed, checks the stiffness of each overlapping span of 900mm at 150mm increments and sorts it for strength. It gives colour grade indication for each span – the lowest grade registered throughout the piece determines the grade of the piece as a whole.

The machine is set in seconds. The fixed pre-determined load is set by switching on the appropriate number of cylinders and by adjusting the air pressure. Each combination of species-group and section of timber has its own computer programme setting, controlled by a programme card or with the aid of a programme terminal. The whole system is lockable to ensure quality control. Timber to be tested at one run must all be of one cross section but it can be of mixed length.

The Computermatic Timber Stress Grading Machine has been thoroughly engineered and comes with a complete kit of recommended spare parts, including spare plug-in computer, calibration kit, colour sprays and bottles. The handbook gives exact and detailed information about the functioning, commissioning, maintenance and spare parts. In addition comprehensive maintenance and servicing support is available from MPC's experienced team of engineers.

The productivity of the machine can be increased with sophisticated mechanical handling equipment on both the infeed and outfeed, including semi or fully automatic de-stacking and stacking. Details of various stages of mechanisation are available from MPC Ltd.

Technical Specification

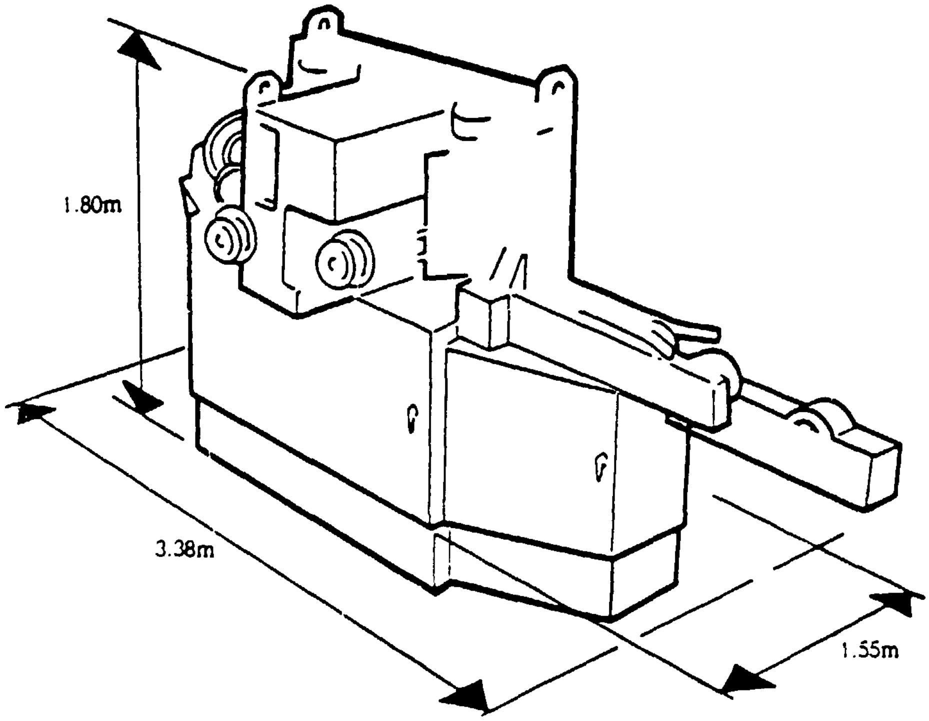
Machine Dimensions
Length – 3.38m   Width – 1.55m
Height – 1.8m   Weight – 1450kg

Machine Capacity
Timber height – 304.8mm maximum
– 50.8mm minimum
Timber thickness – 76.2mm maximum
– 25.4mm minimum
Timber length – 1.6m minimum

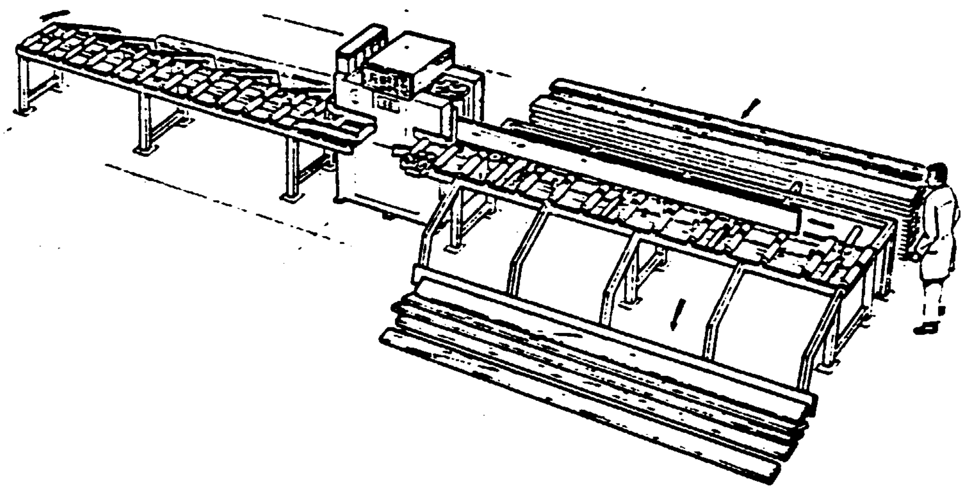
Throughput
Continuously adjustable – 25 – 150m/min

Standard Power Requirements
Nominal 240V ± 5%
Single phase 50/60Hz
Power consumption (ave) 3200 watts
Supply rating 15 amps @240V, 50Hz
Other electrical systems by arrangment

Air Supply
Clean and unlubricated
Average consumption 0.24m³/min
Pressure = 8.5atm



COOK BOLINDERS LIMITED



STRESS GRADING SYSTEM
Incorporating Auto. Return and Ejection.

SG-AF STESS GRADING MACHINE
TECHNICAL DATA

Machine length	1.8 m
width	0.95 m
height	1.6 m
weight	approx. 1 Tonne
Timber Species	Structural softwoods and certain hardwoods.
Timber Sizes — cross section (sawn)	63 mm x 19 mm min 300 mm x 75 mm max
— length	2.0 m/min 9.0 m/max
— size tolerance Thickness	+ 3 — 1 mm
Width	+ 3 — 1 mm less than 100 mm + 6 — 2 mm over 100 mm
Feed Speed	94 m/min
Feed Power	3 h.p. geared motor
Feed Line Height	800 mm
Spray Marking — capacity	2 grades + 1 optional
Stamp Marking (Optional)	2 grades
Compressed Air — capacity (free air)	0.3 m^3/min. (10 C.F.M.)
— pressure	0.7 m.pa. (100 p.s.i. max)
Loa 1 Measurement Intervals	100 mm
Grading Facility	3 grades + reject Entry error lamp to check correct sequence of entry.
Piece Counting Facility	Resetable 8 separate 4 digit counters.
Electrical Supply	3 phase 3Kw.
Conveyors, Infeed and Outfeed, each	4 m x 800 mm wide
Grading Rate (Manual Operation).	Assuming average length 4 m Assuming average size 50 x 150 4 pieces per minute 8,000 running m/8 hour shift 9,000 m^3 vol. per annum.

TIMGRADER

Operation data

Timber, thickness	25 to 75 mm
" width	75 to 300 mm
" minimum length	1800 mm
Measuring intervals, approx.	100 mm
Speed range, steplessly adjustable	0,8 to 2,5 m.p.s.
Normal operating speed, steplessly adjustable	1,2 to 2,0 m.p.s.
Grades per throughput, max.	
Identification sprays	5

— rejects are not marked

Identification dye marking programmes:

- — assessment points only
- — assessment points and final token indicating the lowest grade
- — final colour token only
- — no colour tokens (information transmitted to grade printer for readable marking)

Measurements, approx.

— length	2000 mm
width	2100 mm
height	1700 mm
— working height	800 mm
— weight, net	3300 kg
— weight, gross	3800 kg
-- shipping volume	5,2 cu.m.
Connection power	11,5 kW
Pneumatic connection	700 kPa (approx. 7 kp/sq. cm)
Compressed air consumption max.	0,1 norm. sq. cm/h

TIMGRADER-MARKER

Operation data

Printing rollers	4

— rejects are not marked

Marking

— length, max. approx.	375 mm
— height, max. approx.	25 mm

Measurements, approx.

— length	4250 mm
— width	1000 mm
— height	1350 mm
— working height	800 mm
— weight, net	830 kg
— weight, gross	1150 kg
— shipping volume	5,2 cu.m.

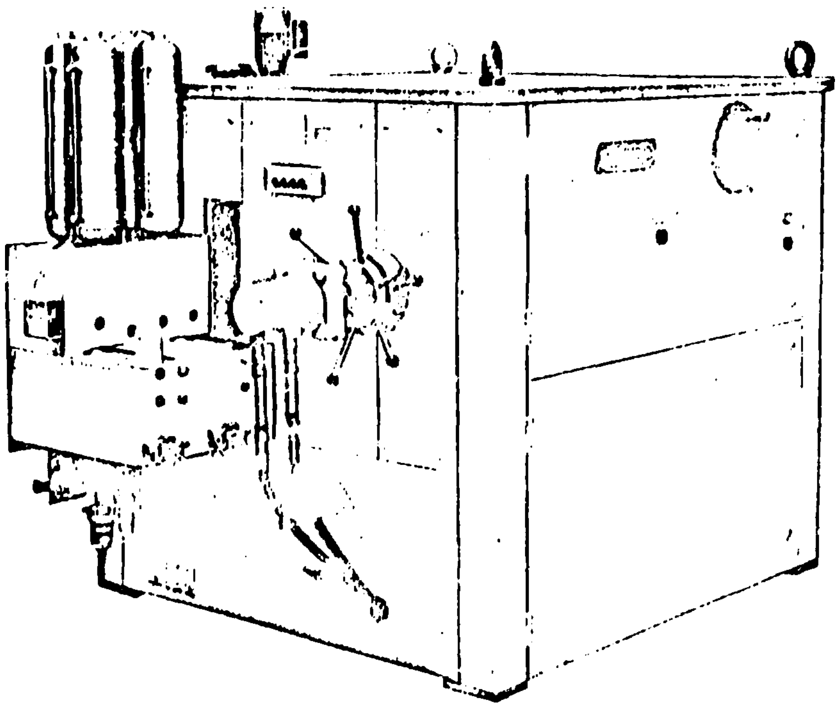
Rau-te

LAHDEN RAUTATEOLLISUUS OY

P.O.B. 139 15111 Lahti 11 Finland

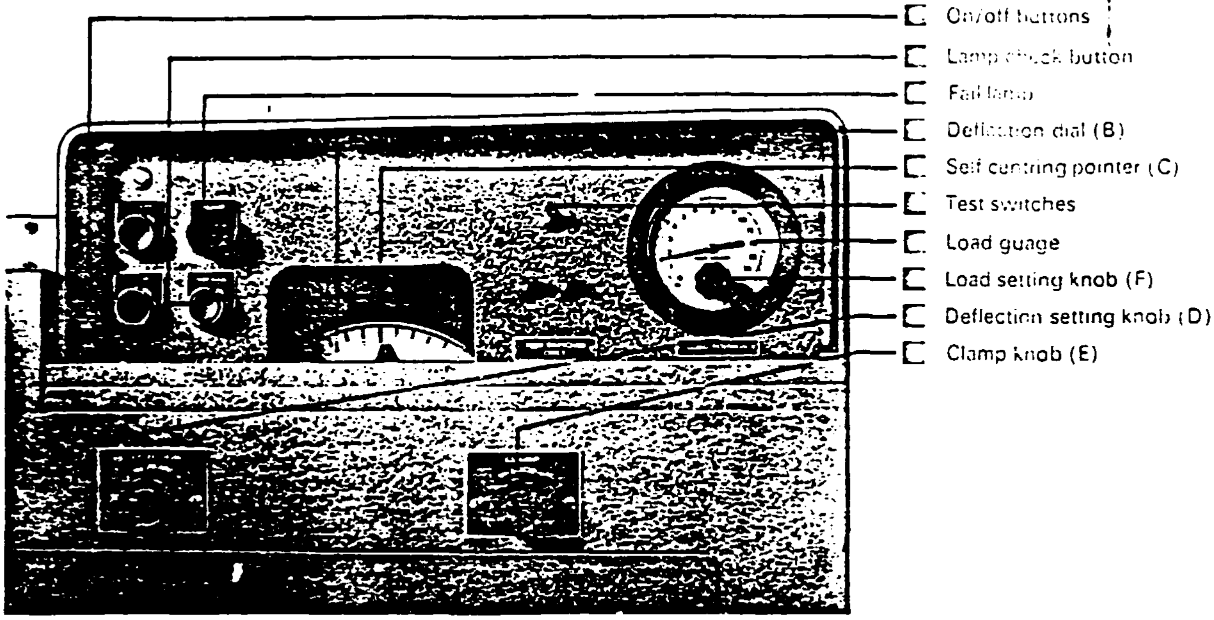
Tel. 918-44911 Telex 16162

LAHTI 1978 — SCANPRINT



Rau-te

TIMGRADER



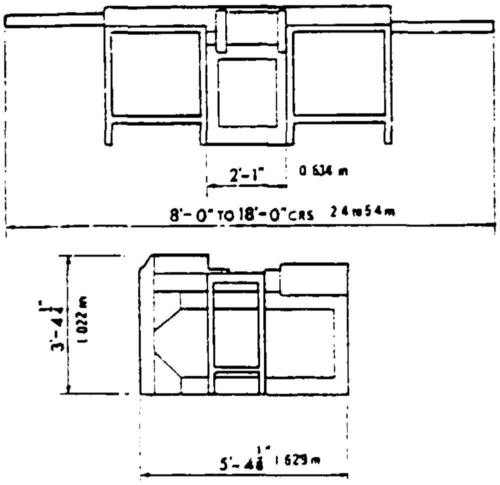
Setting Data Charts

The information on the Setting Data Charts is based on non-destructive testing to a maximum fibre stress of 2,000 lbs./sq. in. 689.48 N/m² x 10³ with the modulus of elasticity varying according to the grade and species of timber being selected. The data is based on figures agreed with Forest Products Research Laboratory.

Operating Instructions

1. **Select Data Chart for grade required to correspond with species and size of timber to be selected.**
2. **Set and clamp support arms to span figure required.**
3. **Set load guage (knob F) to match chart reading.**
4. **Set deflection figure on dial B against pointer C (by means of knob D and clamp knob E) to match chart reading.**
5. **Press lamp check button two or three times to check lamp and then reset load setting (see note 3).**

Basic Dimensions



Maintenance

Apart from normal cleaning down, the only maintenance required is:

(a) Check oil level in air line lubricator and refill when necessary.

(b) Release dirt and moisture from a ine filter

Quality Control

After testing approx 250 pieces:

1. Check loading guage.
2. Check reject lamp.
3. Place test member in machine and test. This should be a member of the same size as those being selected, and one of such strength that it will just be rejected.
4. Should the machine not be selecting correctly it must be reset and the 250 pieces retested.

Types of Machine

Model TS2, 40–380 lbs., 20—200 kgf.
Model TS4, 125–1250 lbs., 50—700 kgf.
Model TS6, 500–2800 lbs., 400—1500kgf.
} loading requirement

Ram baseplate is drilled to accept all sizes of ram.

All models: measure up to 4¾" (120 mm.) deflection.
accept timber at 8' 0"—18' 0" (2.4—5.4 mm.) test span.
accept sections from 1⅜" x 2⅞" (35 x 72 mm.) to 3" x 9" (75 x 200mm.)

A warning bell can be included to supplement the red warning light as an optional extra.

SONTRIN

Sole Agents throughout the world:

William Brown and Company (Ipswich) Limited
P.O. Box 13
Grey Friars Road, Ipswich
Telephone 0473 56761 Telex 98450