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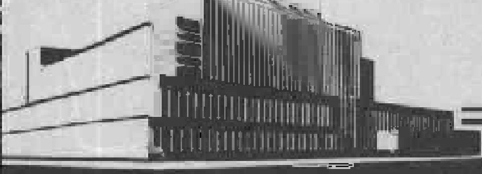

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

SIMPLIFIED PRINCIPLES FOR STRUCTURAL GRADING OF TIMBER[1]

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INTRODUCTION

It has long been recognized that individual pieces of timber, as they come from the saw, represent a wide range in quality and appearance with respect to freedom from knots, blemishes, defects, and other characteristics. Such random pieces likewise represent a wide range in strength, utility, and value. One of the obvious requirements for the marketing of timber is the establishment of grades that provide minimum standards of quality. From the strength standpoint, efficient utilization requires that in design each timber be stressed as nearly as possible in accordance with its inherent strength. Otherwise the level of design stresses would need to be uneconomically lowered to that of the poorest ungraded timber to insure safety. Developments toward efficient utilization have prompted what is known as structural grading. While present methods of structural grading differ widely, the object is the same; to classify material for strength purposes in order to enhance its efficiency and safety in timber design.

The selection of structural timbers for strength is far from new. Wood structures, some of large size, are still in existence in Europe and Asia after centuries of service. Buffon (2)[3] reported strength tests of oak beams of structural size in 1740. Tredgold (8) called attention to the strength reductions from knots and other defects early in the 19th century. Research on the strength of timber was being done at government and private

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[1] For presentation at the Fourth FAO Conference on Wood Technology, Madrid, Spain, April 22-May 2, 1958.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

laboratories in the United States as early as 1875. A survey of the evolution of timber testing and structural grading in the United States has been reported by the authors (6).

This wide diversity in the grading and use of structural timbers, together with the broad range of conditions under which they are produced and marketed, have made this a highly complex subject. The Wood Technology Panel of the Food and Agriculture Organization of the United Nations (4) has recognized the following factors as requiring consideration in the problem of unifying structural grading methods: The number of species for which structural grades are likely to be required; the number of grades required for each species considering the variation in quality of timber produced in existing forest stands; the feasibility of changing the defect limitations of an established grade with future changes in type of timber produced as, for example, the changes from virgin forest stands to reforested or cultivated stands; the amount of testing required to furnish the necessary technical data for establishing grades and working stresses; and the flexibility with which the system employed can be adapted to the establishment of grades for additional species. Consideration of these factors has led to the recognition of the principle of evaluating structural grades in terms of the strength of the clear timber, by what may be called grade-strength ratios (4). The present need is for simplification and unification of the method of measuring, evaluating, and limiting knots and other natural characteristics in timbers of different size and shape.

This report presents suggestions for simplified principles for the grading and stress-rating of structural timber. These are based on the fundamentals of wood strength and recognize the necessity of differences in application in different countries and under different conditions. At the same time, they attempt to provide, as a basis for discussion, a single unified system of simplified basic principles for structural grading.

STRUCTURAL GRADING OF TIMBER

Factors Affecting Strength

The work already done in many countries has shown what factors affect the strength of timber, and it is necessary only to review them briefly here. The most important factors are the strength and variability of strength of the clear wood substance, the duration of load, the moisture content, and the natural or acquired strength-reducing characteristics, such as knots and checks (1, 6).

Variability

Extensive data from many laboratories have shown the range of strength in the clear wood of the important species in structural use. It is now common to refer not only to species average values, but to standard deviations or exclusion limits that give numerical expression to the variability within a species. The selection of higher density and higher strength timbers, thus reducing that variability in the selected group, have been accomplished by establishing limits on weight per cubic foot and by employing "density rules" based on rate of growth and summerwood content. Classification based on some other kind of nondestructive test, such as sonic methods employed for other materials, have been discussed, but have not given encouragement of practical application as yet for the classification of timbers containing knots or other natural characteristics. In all instances, material of exceptionally low density should be excluded from structural grades.

Duration of Stress

Both the proportional limit and the ultimate strength of wood are lower under long-time than under short-time loading. This factor must be taken into account in establishing working stresses for structural timbers if laboratory test values are used as a basis for determining design stresses. Conversely, higher design stresses may be used where loads are of intermittent or shorter duration over those for long-time loading.

Moisture Content

The strength of clear wood is considerably increased for most properties as the moisture content is reduced below the fiber-saturation point. In structural timbers, that potential gain in strength is largely offset by checks and other defects that develop in seasoning. Such losses are greatest in the larger timbers or in pieces of low grade. Some net gain from drying is recognized in timber up to about 4 inches (10 cm.) in thickness.

Strength-Reducing Characteristics

The strength of structural timber is affected also by the natural characteristics of wood that reduce the strength. The most important of these are knots, spiral or diagonal grain, shakes, checks, and decay.

Knots

Knots in the horizontal faces of bending members or in any face of a post or column reduce bending, tensile, or compressive strength in the proportion of the size of the knot to the width of the face. In the central portion of the depth of vertical faces of bending members, the same proportion may be used. The strength of a bending member with a knot at the top or bottom edge of a vertical face is in the proportion of the square of the net depth after deduction for the knot to the square of the full depth of the piece. There is greater proportional distortion of grain around large than around smaller knots, so the foregoing rules of proportionality are applied to narrow faces only up to 6 inches (15 cm.) wide or wide faces only up to 12 inches (30 cm.) wide. Above these widths, the increase of allowable knot sizes is proportioned to the square root of the increase of face width. Knots have relatively little effect on strength in longitudinal shear or compression perpendicular to grain or on stiffness. Knotholes are regarded as having the same effect on strength as knots.

Cross Grain

Spiral or diagonal grain reduces strength in accordance with its slope. Neither static bending nor tensile strength show reduction of strength with a slope of grain of 1 in 40; very little with a slope of 1 in 20; but are reduced to about half with a slope of 1 in 8. Strength in compression parallel to grain is reduced very little with a slope of 1 in 15, but is reduced to about half with a slope of 1 in 6. Strength values in longitudinal shear and compression perpendicular to grain are not reduced by slope of grain. With slope of grain as necessarily limited by strength considerations, the effect on stiffness is small. Slope of grain in members subjected to bending is most critical in the zones that are most highly stressed in tension or compression.

Shakes and Checks

Shakes, checks, or splits reduce the resistance to horizontal shear in a timber subjected to bending. The effect on shear strengths is considered only in the part of the cross section near the neutral axis where horizontal shear stresses are the highest. In this zone, the reduction of shear strength in green material is in the proportion of the reduction of area effective in resisting shear. In dry material, the net reduction of shear strength is somewhat less because of the increased shear resistance of the remaining area.

Wane, Borer Holes, and Pitch Pockets

Wane effects reduction in strength in accordance with its extent, but in the amounts usually permitted the effect is not large. It may also be limited in structural timbers from considerations of appearance or bearing or nailing surface. Holes from borers or other causes are evaluated on the basis of the amount of wood removed in relation to their prevalence and location. Pitch pockets have little effect on strength, but the presence of a large number may indicate a tendency toward shake.

Decay

Decay has a serious effect on strength that generally cannot be estimated from visual inspection. Decay is excluded from structural timbers, except that decayed knots may be admitted insofar as it can be shown that the decay has not spread into the wood adjacent to the knot.

Degree of Efficiency Required in Structural Grades

The highest efficiency in structural grading and in utilization results from the establishment of grades for specific uses. With this in mind special structural grades have been established in the United States for "beams and stringers," "joists and planks," and "posts and timbers." In addition to these use classifications, it is often possible to achieve additional efficiency within a class by limiting defects in different parts of a member in accordance with the stress distribution contemplated in use. For example, knots have only about half as much deleterious effect on the compression as on the tension face of the beam, so that larger knots could be permitted on the upper face. Such grading necessitates placing the member in service in a definite position with respect to the loading, and hence the beam must be appropriately marked in grading so that it will be properly installed. However, it is obvious that such efforts to achieve the maximum efficiency in structural grading involve increased complexity and detail.

The best solution to structural grading would obviously be a nondestructive test, such as previously referred to, that would give a precise evaluation of the strength under any type of loading. Since there does not seem to be any immediate hope for such a test, we must still rely on visual characteristics as a basis for structural grading. This raises the question as to whether the best interests of structural timber production, marketing, design, and use could not be satisfactorily achieved by the development of a simplified single all-purpose system of structural grading.

BASIC REQUIREMENTS FOR AN ALL-PURPOSE STRUCTURAL GRADE

An all-purpose structural grade should obviously provide for uses under compressive or tensile stresses as well as use in bending. In tension or compression members it is apparent that the same defect limitations must be applied throughout the length of the piece. The same is also true in continuous beams or beams with fixed ends. An all-purpose grade, therefore, involves limiting defects in the same manner throughout the full length of the piece.

The basic principles for establishing the strength of structural timbers that are presently employed were developed to apply to all species and to all sizes and to all use classes. It is believed that they can be satisfactorily translated into requirements for a single all-purpose system of structural grading. In fact, such an all-purpose timber grade has already appeared in the standard grading rules for southern yellow pine (7), one of the major structural woods in the United States. The basic requirements of an all-purpose structural grade suggested for consideration are as follows:

Knot Limitation and Measurement

Knots may be tight or loose, and must be sound except that unsound or hollow knots may be admitted insofar as it can be shown that the decay has not spread into the wood adjacent to the knot. Knots are limited according to their size and location as observed on the faces of the piece. The three different locations indicated are as follows:

1. Knots on the narrow faces
2. Knots on the outer one-fourth of the width of the wide faces
3. Knots on the center half of the width of a wide face

Knots on narrow faces are measured between lines parallel to the length of the piece. The dimension of a knot appearing on a wide face only is taken as the true diameter of the branch that forms the knot. Consequently, the knot size may be taken as the least dimension between parallel lines tangent to the knot. If the same knot appears on two opposite faces, the size is taken as that on the face showing the greatest measurement.

A knot extending across the full width of a face in a pithless piece is measured on its ends as they appear on the adjacent faces. The knot size is taken as the perpendicular distance between lines parallel to the length of the piece, and is limited in respect to the face where measured that shows the largest size.

The dimension of a knot appearing at the intersection of two faces of a piece, and consequently showing on both of those faces, is measured on each face between lines parallel to the length of the piece; the size is taken as the one that indicates the greatest effect on strength as established by the permissible size of knots in the grade requirements.

Knots at the intersection of two faces in pithless pieces are ignored if not extending beyond the area of permissible wane. Knots in pieces of square cross section are measured and limited as if each face were a wide face.

Limitations on knots are the same throughout the length of the piece. The sum of sizes of all knots in any 6 inches (15 cm.) of length is not allowed to exceed one and one-half times the size of the largest permitted knot. Burls and cluster knots are prohibited. Figure 1 illustrates the measurement of knots.

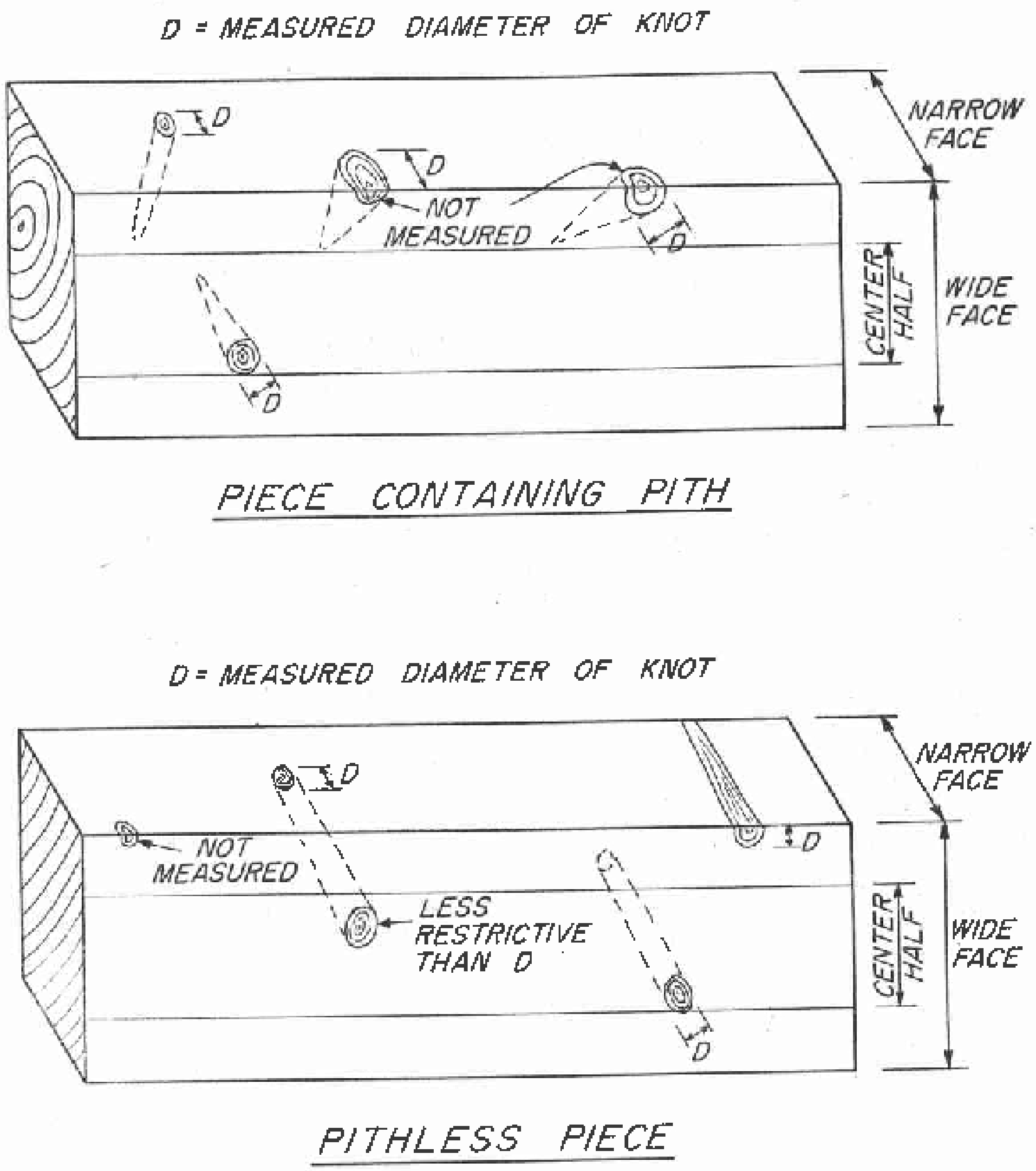

Figure 1. --Measurement of knots in structural timbers.

Cross Grain

Slope of grain is measured and limited at any point on any face that shows the greatest general slope over a distance of about 3 feet (1 meter) disregarding local deviations around knots. In pieces 2 inches (5 cm.) or less in thickness, no local deviation of grain affecting more than half of the cross section shall pass through the full thickness of the piece in a lengthwise distance less than 10 times the thickness of the piece.

Shakes

Only those shakes in the middle half of the width of the wide face are considered. Ring shakes are measured at the ends of the piece, and the size is taken as the distance between lines enclosing the shake and parallel to the wide faces. On pieces of square cross section, the size of a shake is the longer side of a rectangle enclosing the shake and having sides parallel to the faces. The size of shake permitted is established by the ratio of the measured size to the thickness of the piece (width of the narrow face) as established for the grade. Where two shakes are nearly opposite, the sum of their sizes is limited to the allowable size of a single shake.

Checks and Splits

Checks and splits are limited to the same nominal dimension as shakes. Only those in the middle half of the width of the wide face are considered. The size of a check is its average depth of penetration into the piece measured from and perpendicular to the surface of the wide face. The size of an end split is one-third of its average length. Where two checks or a check and a shake are nearly opposite, the sum of their sizes is limited to the allowable size of a single check.

Decay and Wane

Decay is not permitted except that decayed knots may be admitted insofar as it can be shown that the decay has not spread into the wood adjacent to the knot.

Wane is limited to one-fourth of the width of any face or to a width of 2 inches (5 cm.) at any point along the length of the piece.

FACTORS RELATED TO STRUCTURAL GRADING

The purpose of structural grading is to promote more efficient use of structural timber and to permit the assignment of working stresses for design. It is recognized that the establishment of specific working stress values for different species and different grades involves an element of engineering judgment, and that practices in different countries may vary with differences in design requirements and differences in construction practices. There are, however, some broad features of working stresses that merit consideration in connection with the principles of structural grading.

Working stresses for structural grades may be obtained by adjustment of data obtained directly from tests of structural timbers in representative species and grades, or more simply from a system of basic stresses established for each species by application of grade-strength ratios. The basic stresses are of course in themselves established from strength tests of structural timbers, or small clear specimens, or both. The grade-strength-ratio method was agreed upon by the Working Party on Structural Grading at the Third Conference on Wood Technology of the Food and Agriculture Organization of the United Nations (4). The method of basic stresses and grade-strength ratios is ideally suited to the economical and efficient establishment of structural grades and working stresses when a large number of species are involved, where grades must be changed from time to time in response to changing production and marketing conditions. The development of an all-purpose structural grading system employing the associated principles of grade-strength ratios and basic stresses, is established on the general premise that like strength-reducing characteristics have essentially the same effects among different species. Accordingly, the method of grade-strength ratios is directly applicable to the determination of working stresses for established grades or to the establishment of grades appropriate to desired working stresses.

Grade-Strength Ratios

A grade-strength ratio is the numerical ratio of the strength of a grade of structural timber containing defects, as established by the grading, to the strength of the clear wood; thus, if a timber contains knots or other characteristics that reduce the strength of the timber by 25 percent, its strength ratio is said to be 75 percent. When a series of timbers have been graded and are found to pass the minimum requirements of the grade, they are assigned the strength ratio established for the particular grade.

Tables 1 to 5, inclusive, provide a means for determining strength ratios related to the maximum characteristics permitted in grades of an all-purpose timber. Tables 1, 2, and 3 give strength ratios in bending, tension, or compression parallel to grain, corresponding to various sizes of knots in narrow faces, center of the width of wide faces, or edge of the width of wide faces, respectively. Table 4 gives strength ratios in bending, tension, or compression parallel to grain corresponding to various slopes of grain. Table 5 gives strength ratios in horizontal shear of beams corresponding to various sizes of shakes, checks, and splits. These tables permit the determination of strength ratios for an existing grade, or they may be used to determine the allowable characteristics in a grade to have a desired strength. Compression perpendicular to grain and modulus of elasticity are little affected by grade, and strength ratios for those properties may be taken at 100 percent of basic stress. The tables are intended to be applicable to all species of timber.

Table 1.--Strength ratios in bending tension, or compression parallel to grain, for knots in narrow faces

Size of knot		Percentage strength ratio when nominal width of narrow face in inches (mm.) is --									
		2 (51)	3 (76)	4 (102)	5 (127)	6 (152)	8 (203)	10 (254)	12 (305)	14 (356)	16 (406)
In.	Mm.										
1/4	(6)	90	93	95	96	96	97	97	97	98	98
3/8	(10)	83	89	92	93	94	95	96	96	96	97
1/2	(13)	77	85	88	91	92	93	94	95	95	95
5/8	(16)	71	81	85	88	90	92	92	93	94	94
3/4	(19)	65	76	82	86	88	90	91	92	92	93
7/8	(22)	58	72	79	83	86	88	89	90	91	91
1	(25)	52	68	76	81	84	86	88	89	89	90
1-1/8	(29)	46	64	73	78	82	84	86	87	88	89
1-1/4	(32)	26	60	70	76	80	83	84	86	87	88
1-3/8	(35)	...	56	67	73	78	81	83	84	85	86
1-1/2	(38)	...	51	63	71	76	79	81	83	84	85
1-5/8	(41)	...	47	60	68	74	77	80	81	83	84
1-3/4	(44)	...	35	57	66	71	75	78	80	81	83
1-7/8	(48)	...	30	54	63	69	73	76	78	80	81
2	(51)	...	25	51	61	67	72	75	77	79	80
2-1/8	(54)	...	...	48	58	65	70	73	75	77	79
2-1/4	(57)	...	...	45	56	63	68	71	74	76	77
2-3/8	(60)	...	...	36	53	61	66	70	72	74	76
2-1/2	(64)	...	...	32	51	59	64	68	71	73	75
2-5/8	(67)	...	...	29	48	57	63	67	70	72	74
2-3/4	(70)	...	...	25	46	55	61	65	68	70	72
2-7/8	(73)	...	...	...	...	53	59	63	67	69	71
3	(76)	...	...	...	...	51	57	62	65	68	70
3-1/8	(79)	...	...	...	...	...	55	60	64	66	68
3-1/4	(83)	...	...	...	...	...	54	59	62	65	67
3-3/8	(86)	...	...	...	...	...	52	57	61	64	66
3-1/2	(89)	...	...	...	...	...	50	55	59	62	65
3-5/8	(92)	...	...	...	...	...	...	54	58	61	63
3-3/4	(95)	...	...	...	...	...	...	52	56	59	62
3-7/8	(98)	...	...	...	...	...	...	50	55	58	61
4	(102)	...	...	...	...	...	...	...	53	57	60
4-1/8	(105)	...	...	...	...	...	...	...	52	55	58
4-1/4	(108)	...	...	...	...	...	...	...	50	54	57
4-3/8	(111)	...	...	...	...	...	...	...	...	53	56
4-1/2	(114)	...	...	...	...	...	...	...	...	51	54
4-5/8	(118)	...	...	...	...	...	...	...	...	50	53
4-3/4	(121)	...	...	...	...	...	...	...	...	...	52
4-7/8	(124)	...	...	...	...	...	...	...	...	...	51

Table 2.--Strength ratios in bending, tension, or compression parallel to grain, for knots at the center of the width of wide faces

Size of knot[1]		Percentage strength ratio when nominal width of wide face in (mm.) inches is --												
In.	Mm.	3 (76)	4 (102)	5 (127)	6 (152)	8 (203)	10 (254)	12 (305)	14 (356)	16 (406)	18 (457)	20 (508)	22 (559)	24 (610)
1/4	(6)	......	95	96	96	97	98	98	98	98	99	99	99	99
1/2	(13)	......	88	91	92	94	95	96	96	97	97	97	97	97
3/4	(19)	......	82	86	88	91	93	94	94	95	95	95	96	96
1	(25)	......	76	81	84	88	90	92	93	93	93	94	94	94
1-1/4	(32)	......	70	76	80	85	88	90	91	91	92	92	93	93
1-1/2	(38)	......	63	71	76	82	85	88	89	89	90	91	91	91
1-3/4	(44)	......	57	66	71	79	83	86	87	88	88	89	89	90
2	(51)	......	51	61	67	75	80	84	85	86	87	87	88	88
2-1/4	(57)	......	45	56	63	72	78	82	83	84	85	86	86	87
2-1/2	(64)	......	32	51	59	69	75	79	81	82	83	84	85	85
2-3/4	(70)	......	25	46	55	66	73	77	79	80	82	82	83	84
3	(76)	......	......	36	51	63	70	75	77	79	80	81	82	83
3-1/4	(83)	......	......	31	47	60	68	73	75	77	78	79	80	81
3-1/2	(89)	......	......	25	37	57	65	71	73	75	76	78	79	80
3-3/4	(95)	......	......	......	33	54	63	69	71	73	75	76	77	78
4	(102)	......	......	......	28	50	60	67	69	71	73	74	76	77
4-1/4	(108)	......	......	......	......	47	58	65	67	70	71	73	74	75
4-1/2	(114)	......	......	......	......	41	55	63	66	68	70	71	73	74
4-3/4	(121)	......	......	......	......	37	53	61	64	66	68	70	71	72
5	(127)	......	......	......	......	34	50	59	62	64	66	68	70	71
5-1/4	(133)	......	......	......	......	31	48	57	60	62	65	66	68	69
5-1/2	(140)	......	......	......	......	27	45	54	58	61	63	65	66	68
5-3/4	(146)	......	......	......	......	......	40	52	56	59	61	63	65	66
6	(152)	......	......	......	......	......	37	50	54	57	59	61	63	65
6-1/4	(159)	......	......	......	......	......	35	48	52	55	58	60	62	63
6-1/2	(165)	......	......	......	......	......	32	46	50	53	56	58	60	62
6-3/4	(171)	......	......	......	......	......	29	42	48	52	54	57	59	60
7	(178)	......	......	......	......	......	27	39	46	50	53	55	57	59
7-1/4	(184)	......	......	......	......	......	......	37	42	48	51	53	56	57
7-1/2	(190)	......	......	......	......	......	......	35	40	46	49	52	54	56
7-3/4	(197)	......	......	......	......	......	......	33	38	42	48	50	53	55
8	(203)	......	......	......	......	......	......	31	36	40	46	49	51	53
8-1/4	(210)	......	......	......	......	......	......	29	34	38	42	47	49	52
8-1/2	(216)	......	......	......	......	......	......	26	32	37	40	45	48	50

[1] Ratios corresponding to other sizes of knot can be found by interpolation.

Table 3.--Strength ratios in bending, tension, or compression parallel to grain, for knots at the edge of the width of wide faces

Size of knot		Percentage strength ration when nominal width of wide face in inches (mm.) is --												
		2 (51)	3 (76)	4 (102)	5 (127)	6 (152)	8 (203)	10 (254)	12 (305)	14 (356)	16 (406)	18 (457)	20 (508)	22 (559)	24 (610)
In.	Mm.														
1/4	(6)	80	86	90	92	93	95	96	97	97	97	97	97	97	98
3/8	(10)	70	79	84	87	89	92	93	94	95	95	95	96	96	96
1/2	(13)	60	72	78	82	85	89	91	92	93	93	94	94	94	95
5/8	(16)	50	65	73	78	81	86	89	90	91	92	92	93	93	93
3/4	(19)	32	58	68	74	78	83	86	88	89	90	91	91	91	92
7/8	(22)		52	63	69	74	80	84	87	88	88	89	89	90	90
1	(25)		46	58	65	71	77	82	85	86	87	87	88	89	89
1-1/8	(29)		34	53	61	67	75	79	83	84	85	86	86	87	88
1-1/4	(32)		29	49	57	64	72	77	81	82	83	84	85	86	86
1-3/8	(35)			40	54	60	69	75	79	80	82	83	83	84	85
1-1/2	(38)			36	50	57	67	73	77	79	80	81	82	83	84
1-5/8	(41)			32	47	54	64	71	75	77	78	80	81	81	82
1-3/4	(44)			28	40	51	62	69	74	75	77	78	79	80	81
1-7/8	(48)				36	48	59	67	72	74	75	77	78	79	80
2	(51)				33	45	57	65	70	72	74	75	76	77	78
2-1/8	(54)				30	40	55	63	68	70	72	74	75	76	77
2-1/4	(57)				27	37	52	61	67	69	71	72	73	75	76
2-3/8	(60)					34	50	59	65	67	69	71	72	73	74
2-1/2	(64)					32	48	57	63	66	68	69	71	72	73
2-5/8	(67)					29	46	55	62	64	66	68	69	71	72
2-3/4	(70)					27	41	53	60	63	65	66	68	69	71
2-7/8	(73)					25	39	51	58	61	63	65	67	68	69
3	(76)						37	50	57	60	62	64	65	67	68
3-1/8	(79)						35	48	55	58	60	62	64	66	67
3-1/4	(83)						33	46	54	57	59	61	63	64	66
3-3/8	(86)						31	42	52	55	58	60	62	63	65
3-1/2	(89)						29	40	51	54	56	58	60	62	63
3-5/8	(92)						27	39	49	52	55	57	59	61	62
3-3/4	(95)						26	37	48	51	54	56	58	60	61
3-7/8	(98)							36	46	50	52	55	57	58	60
4	(102)							34	45	48	51	53	55	57	59
4-1/8	(105)							33	42	47	50	52	54	56	58
4-1/4	(108)							31	40	46	48	51	53	55	57
4-3/8	(111)							29	39	43	47	50	52	54	55
4-1/2	(114)							28	37	41	46	48	51	53	54
4-5/8	(118)							27	36	40	45	47	50	51	53
4-3/4	(121)							25	35	39	42	46	48	50	52
4-7/8	(124)								34	37	41	45	47	49	51
5	(127)								32	36	40	42	46	48	50

Table 4.--Strength ratios corresponding to various slopes of grain

Slope of grain	Strength ratio		Slope of grain	Strength ratio	
	Bending or tension parallel to grain	Compression parallel to grain		Bending or tension parallel to grain	Compression parallel to grain
	Percent	Percent		Percent	Percent
1 in 6	....	56	1 in 15	76	100
1 in 8	53	66	1 in 16	80	....
1 in 10	61	74	1 in 18	85	....
1 in 12	69	82	1 in 20	100	....
1 in 14	74	87			

Table 5.--Strength ratios in horizontal shear corresponding to various combinations of size of shake or check and thickness at end of piece[1]

Size of shake or check	Green lumber										Seasoned lumber									
	Percentage strength ratio when nominal end thickness of piece in inches (mm.) is --										Percentage strength ratio when nominal end thickness of piece in inches (mm.) is --									
	2 (51)	3 (76)	4 (102)	5 (127)	6 (152)	8 (203)	10 (254)	12 (305)	14 (356)	16 (406)	2 (51)	3 (76)	4 (102)	5 (127)	6 (152)	8 (203)	10 (254)	12 (305)	14 (356)	16 (406)
In. : Mm.																				
1/4: (6)	90	93	95	96	96	97	98	98	98	99	100	100	100	100	100	100	100	100	100	100
3/8: (10)	83	89	92	93	94	96	97	97	98	98	94	100	100	100	100	100	100	100	100	100
1/2: (13)	77	85	88	91	92	94	95	96	97	97	87	95	100	100	100	100	100	100	100	100
5/8: (16)	71	81	85	88	90	93	94	95	96	96	80	91	96	99	100	100	100	100	100	100
3/4: (19)	65	76	82	86	88	91	93	94	95	96	73	86	93	97	99	100	100	100	100	100
7/8: (22)	58	72	79	83	86	90	92	93	94	95	66	81	89	94	97	100	100	100	100	100
1 : (25)	52	68	76	81	84	88	90	92	93	94	59	77	85	91	94	99	100	100	100	100
1-1/8: (29)		64	73	78	82	86	89	91	92	93	52	72	82	88	92	97	100	100	100	100
1-1/4: (32)		60	70	76	80	85	88	90	91	92		67	78	85	90	95	99	100	100	100
1-3/8: (35)		56	67	73	78	83	87	89	90	92		62	75	82	87	94	97	100	100	100
1-1/2: (38)		51	63	71	76	82	85	88	90	91		58	71	80	85	92	96	99	100	100
1-5/8: (41)			60	68	74	80	84	87	89	90		53	68	77	83	90	95	98	100	100
1-3/4: (44)			57	66	71	79	83	86	88	89		48	64	74	80	88	93	96	99	100
1-7/8: (48)			54	63	69	77	82	85	87	88			61	71	78	87	92	95	98	100
2 : (51)			51	61	67	75	80	84	86	88			57	68	76	85	90	94	97	99
2-1/8: (54)			48	58	65	74	79	83	85	87			54	66	73	83	89	93	96	98
2-1/4: (57)				56	63	72	78	82	84	86			50	63	71	81	88	92	95	97
2-3/8: (60)				53	61	71	77	81	83	85				60	69	80	86	91	94	96
2-1/2: (64)				51	59	69	75	79	82	85				57	66	78	85	89	93	95
2-5/8: (67)				48	57	68	74	78	81	84				54	64	76	83	88	92	94
2-3/4: (70)					55	66	73	77	81	83				52	62	74	82	87	91	93
2-7/8: (73)					53	65	72	76	80	82				49	59	73	81	86	90	93
3 : (76)					51	63	70	75	79	81					57	71	79	85	89	92
3-1/4: (83)						60	68	73	77	80					52	67	76	82	87	90
3-1/2: (89)						57	65	71	75	78					48	64	74	80	85	88
3-3/4: (95)						54	63	69	73	77						60	71	78	83	86
4 : (102)						50	60	67	72	75						57	68	75	81	85
4-1/4: (108)							58	65	70	74						53	65	73	79	83
4-1/2: (114)							55	63	68	72						50	62	71	77	81
4-3/4: (121)							53	61	66	71							59	68	75	79
5 : (127)							50	59	65	69							57	66	73	78
5-1/4: (133)								57	63	67							54	64	71	76
5-1/2: (140)								54	61	66							51	61	69	74
5-3/4: (146)								52	59	64								59	67	72
6 : (152)								50	57	63								57	65	71
6-1/4: (159)									56	61								54	63	69
6-1/2: (165)									54	60								52	61	67
6-3/4: (171)									52	58								50	59	65
7 : (178)									50	56									57	64

[1]Ratios for sizes of shake or check other than those listed can be found by interpolation.

Basic Stress

Safe and economical working stresses require consideration of many factors. Besides the strength-reducing characteristics that are recognized in establishing the grade-strength ratio, the working stress is affected by the strength of clear wood, variability, the duration of load, size of piece, and many other factors of strength and use, including the factor of safety. These other factors are not related to the grade-strength ratio, and their combined effect can be expressed in a "basic stress" that is a species characteristic and independent of grade. Thus, the basic stress is essentially a safe working stress for clear wood. When the basic stress for a species is multiplied by the grade-strength ratio for a structural grade, there is obtained directly a working stress for that grade of that species.

Factors considered in basic stresses are only briefly reviewed here. They include (a) strength of clear wood and its variability, (b) strength tests of structural timbers, (c) the characteristics of the species as evidenced by its natural characteristics and its behavior in seasoning, (d) manufacturing variables, (e) reliability of stress grading, (f) competence of design and construction, (g) possibility of overloading, (h) degree of maintenance, (i) duration of load, (j) temperature and moisture effects, (k) a degree of engineering judgment, and (l) a factor of safety. Of these factors, the strength and variability of the clear wood, the duration of stress, the factor of safety, and engineering judgment are of major importance. The other major factor in working stress, the strength-reducing characteristics in structural timber, is expressed in the strength ratio.

Modifications of Working Stress

Working stresses established for specific conditions of design and use may be modified for other conditions. The principal modifications are for seasoning, duration of load, severe exposures, or unusual conditions of hazard. Since the published basic stresses are related to the strength of unseasoned wood and contemplate long-time loading, increases are in order for seasoned timber or for short-time loading. Decreases may be made for severe exposure conditions or in the design of structures like railway bridges, on whose integrity human life may depend. Increases for low-hazard or temporary uses are also possible.

PREFERRED STRESS VALUES

The orderly establishment of stresses suggests the desirability of a related set of values based on preferred numbers. The concept of preferred numbers was originated in France three-quarters of a century ago, and has been widely used in many countries (5). Based on a geometric or logarithmic progression, it is particularly applicable to working stresses based on grade-strength ratios. Since a working stress is the product of a basic stress times a strength ratio, both may be taken from the preferred series, and their product will also be in the preferred series. Values in a geometric progression can be rounded to numbers that are easy to remember and use. The use of a preferred-number series in connection with working stresses has been proposed in Australia (3), in the United States (6), and perhaps other countries.

The system of preferred numbers divides each logarithmic cycle (1 to 10, 10 to 100, etc.) into equal logarithmic steps. A series that has 20 steps in each cycle gives adequate definition to the strength properties and design values of wood. The following tabulation shows calculated and rounded values in the 20-step series:

Calculated number	Rounded equivalents	
	Pounds per square inch	Kilograms per square centimeter
1,000	1,000	70
1,122	1,120	80
1,259	1,250	90
1,413	1,400	100
1,585	1,600	112
1,778	1,800	125
1,995	2,000	140
2,239	2,250	160
2,512	2,500	180
2,818	2,800	200
3,162	3,200	225
3,548	3,600	250
3,981	4,000	280
4,467	4,500	320
5,012	5,000	360
5,623	5,600	400
6,310	6,300	450
7,079	7,000	500
7,943	8,000	560
8,913	9,000	630
10,000	10,000	700

The calculated numbers span the logarithmic cycle from 1,000 to 10,000; other cycles contain the same digits, but with a shift of the decimal point. Common values like 1,000 pounds per square inch and 100 kilograms per square centimeter are present. Other common working stresses in the series are 2,000 pounds per square inch and 70 kilograms per square centimeter. Still other common values are close to one of the numbers in the series.

Grade strength ratios in the series may be 90, 80, 70, 63, 56, 50, or 45 percent, as desired. These are close to the grade strength ratios in many of the existing standard grades of timber. The product of any basic stress from the series times any strength ratio from the series will give one of the other values in the series. The same working stress is available in a high grade of a species of lower basic strength as in a lower grade of a species of high basic strength. To illustrate, a stress of 1,250 pounds per square inch may be given to a 50-percent grade in a species having a basic stress of 2,500 pounds per square inch, or to an 80-percent grade in a species having a basic stress of 1,600 pounds per square inch.

Modifications of working stresses may be made in the same series. For example, a long-time-loading stress may be increased by 1 or 2 steps for snow load or 3 or 4 steps for wind or earthquake load. Increases for drying may be one or more steps according to the property affected.

Further simplification could be achieved by a series having 10 steps in each cycle, thus using only every second value in the foregoing tabulation. Such a 10-step series could be devised to contain either 1,000 pounds per square inch or 100 kilograms per square centimeter, but not both. Grade-strength ratios might be in the 90- 70- 56-percent series or in the 80- 63- 50-percent series, depending on which 10-step series was chosen. The difficulty with the 10-step series is that it does not define the strength properties as closely as the 20-step series.

Conclusions

Structural grading has long been recognized as a means of promoting the more efficient use of timber, but is even more important in the modern economy in the face of increased costs and competition with improved structural materials of all kinds. These provide a challenge to wood to maintain markets, even in those applications for which it is best fitted. This challenge suggests to the producer of structural timber improved processing and grading and to the timber engineers the most efficient designing in use, consistent with the requirements of safety and economy.

Present structural grading is dependent on an evaluation of the timber on the basis of appearance, but a better way of selecting structural timber for strength is greatly to be desired. Work in this direction is now going on and will be continued. A rapid method of specific gravity determination would refine, but not replace, the present visual appraisal of strength-affecting characteristics. The possibilities of a simple hardness test that would correlate with strength as a means of establishing clear wood quality in structural grading should be further explored. One hope for the future lies in some more efficient nondestructive test method for directly evaluating the strength. While the present status of nondestructive testing of wood gives little cause for optimism, search should be continued.

Pending such major advances, an evaluation of present methods shows great opportunity for improvement, particularly with respect to unification and simplification. To this end a simplified system of structural grading involving the concept of an all-purpose structural timber is suggested for consideration, together with an associated concept of a preferred number system of basic stresses.

These simplified principles of structural grading as here presented are recognized as having certain limitations, but they are offered as suggestions for review and study. Comments are invited by the authors, and suggestions will be welcomed, in this program to find ways and means of simplifying and improving structural timber grading and use.

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