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AN ANALYSIS OF STRESS GRADING
IN THE UNITED STATES

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WILLIAM L. PARRIMAN

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PREFACE

Through my association with the Montana Retail Lumbermens Association in the capacity of architectural draftsman, I have become interested in learning about methods used in the determination of working stresses for structural grades of lumber. Because of my interest, I have made this study, as a part of my architectural design thesis.

I wish to acknowledge gratefully the aid given by Robert J. Lawrence, Manager of the Montana Retail Lumbermens Association, in making available the Association library and files.

My thanks go to Carl Rasmussen, Director of Research at the Western Pine Association Laboratory, for material on the Northwest grading problems.

For all the invaluable information received from a large number of organizations and individuals, including the National Lumber Manufacturers Association, the Forest Products Laboratory, and the many lumber manufacturers associations, I acknowledge my sincere appreciation.

W. L. P.

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INTRODUCTION

Along with an increasing demand on the forests of the United States for paper and other chemical products, there is a continuing demand for timber as an important construction material. Well over one-half of the total lumber production, which is currently about 35 billion board feet annually¹, is used in building and construction. There is a marked contrast between the less critical use of timber in earlier years and the more efficient timber design of today, which involves the use of structurally graded timber with accompanying higher working stresses. Research over the past half century, including extended strength studies, research on factors affecting strength, and developments in structural grading, has been responsible for improving the efficient use of wood as an engineering material and for maintaining its place in competition with developments in other materials.

There is available much literature from research conducted in various countries on factors affecting the strength of structural timbers. The summary and analysis of these various studies would be an extensive undertaking. The detailed results of the research in the United States and Canada alone would require a large volume. For this reason, this paper provides only a brief summary of the background of

¹U.S. Forest Service, Division of Forest Economics, Materials Survey, (Compiled for Materials Office, 1950), p. 11.

American data, experience, and practice in the field of structural timber testing, stress grading, and timber design.

Chapter I gives the historical background of strength studies and structural timber research in the United States that underlies current practice.

Chapter II outlines present practices in strength testing, stress grading, and working stresses as they were developed from years of study and experimentation.

Chapter III discusses the factors that affect the strength of structural timbers and form the basis for the system of stress grading.

Chapter IV presents the principles of stress grading together with a detailed example of their application in writing grade specifications.

Chapter V discusses working stresses and their uses and shows how they are related to basic stress and to stress grades.

Chapter VI looks ahead and considers some of the problems awaiting further research in stress grading and structural timber design.

CHAPTER I

HISTORY OF STRENGTH STUDIES AND STRUCTURAL TIMBER RESEARCH IN THE UNITED STATES

American Forest Stands

To appreciate the nature and kind of research undertaken on the strength of timber and the development of stress grades, it is necessary to understand something of the forest conditions and the economic factors to which they are geared.

The original timber stands of North America were among the finest the world has ever known. In the United States alone these forests were estimated to contain 5 million million board feet of timber and to cover some 822,238,000 acres, nearly one-half of the land area of the country.¹ Not only was there an abundance of large softwood and hardwood trees, but many of the softwood forests, particularly, carried large volumes per acre of a relatively few species of great utility and commercial importance. This feature was an important factor in the exploitation of the forests and the development of timber markets.

The amount and distribution of these original forests, with indication of kind, are shown in Table I.

¹U.S. Forest Service, American Forests and Forest Products, (U.S. Dept. Agr. Statis. Bull. No. 21, 1927), p.3.

Table I. Original acreage of timber stands in the United States¹

Region	Acres Original Forest	Per cent of Total	Species*
	Thousand acres		
New England	38,908	4.7	2/3 Pine, Spruce, Hemlock; 1/3 Maple, Beech, Birch
Middle Atlantic	69,610	8.5	3/5 Hardwoods
Great Lakes	103,680	12.6	1/2 Pine, Hemlock, Spruce; 1/2 Maple, Birch, Elm, etc.
Central	170,560	20.7	7/8 Hardwoods--Oak, Poplar, Walnut, and several others
South Atlantic and East Gulf	170,240	20.7	3/4 Pine, Longleaf, Shortleaf; Hardwoods--Oak, Gum, etc.
Lower Mississippi Valley	128,400	15.6	3/5 Pine 1/5 Oaks, Gums, Hickories, Elms
Rocky Mountain	63,720	7.8	All Softwoods
Pacific	77,120	9.4	All Softwoods
Total in U.S.	822,238	100.0	60 per cent Softwoods

Considered broadly, three periods can be recognized in American forest history--the land-clearing period, the timber-mining period, and the timber-crop period, now well under development.

During the land-clearing period, forests were cleared to make

¹Ibid., p.3.

way for farms. Timber was a by-product of this land clearing, and there was no incentive for efficient utilization. Some of the best-known softwoods, such as White Pine and Southern Yellow Pine, together with such hardwoods as Oak, Maple, Birch, Yellow Poplar, and Black Walnut, furnished abundant material to supply needs of a fast developing country. Lumber was used largely in greater quantity and in better grades than were actually required, and wood of the best species found its way into commonplace uses. Local supplies were utilized, and long, expensive hauls were not required.

The period of timber mining, which began shortly after the beginning of the present century, furnished wood to meet the demand of industry for an abundant and versatile construction material. The term does not reflect favorably on public or industrial policies, but is nevertheless descriptive of a time following the early settlement and development when full industrialization went on without regard for future timber supplies. Abundance of desirable species admirably suited to the needs of the country, low-cost production, and economic pressures favoring liquidation of over-extended operations, resulted in an unparalleled period of timber use with an annual per capita consumption at times of over 500 board feet.¹

¹Ibid., p.7.

Through the exploitation of the abundant timber stands the nation became familiar with the qualities and utility of wood. However, lumber continued to be used in better grades than necessary, and utilization practices were wasteful. Many failed to realize that the extensive forests of the South and West could be depleted, although forestry leaders familiar with European forest history were pointing out the importance of maintaining forest stands. To help meet the increasing forestry and utilization problems, the U. S. Forest Service was organized in 1898, and national forests were acquired.¹ In 1910 the Forest Products Laboratory was established at Madison, Wisconsin, to coordinate forest products research on a national scale.

Recognition of the importance of the forest resource, together with the change in economic conditions, has brought about the timber-crop period. Except in the West, most of the virgin stands of large-sized trees have been cut and in all regions so-called second growth is being extensively harvested. Present estimates indicate that total forest growth is in balance with forest drain, although saw timber is still being used faster than it grows.² Forestry and forest products research have been and are being actively carried on, and the importance

¹ Ibid. p.8.

² U.S. Forest Service, Materials Survey, p.11.

of complete and efficient utilization is becoming more widely recognized.

Wood has thus established itself as an essential basic material in a highly industrialized era, where it serves in natural form as lumber or timber, in processed or modified form to meet special requirements, or as a basic material for chemical conversion.

Evolution of Timber Test Methods and Structural Grades in the United States

Wood is among the oldest structural materials and has served mankind for ages. Fashioned by the skill of early craftsmen, structural elements of timber found their way into monumental structures; many of them, centuries old, are still in existence in Europe and Asia. Later, in the colonization of America, skilled artisans erected many timber structures, notably the covered wooden bridges, a number of which are now well over a century old. The art of timber selection, undoubtedly practiced by early carpenters and craftsmen, has now developed into the more precise system we call stress grading, as a result of extensive studies concerned with improved timber utilization.

With the development of industrial America, interest in more efficient timber use and design increased. Some research on the strength of timber was being done at government and private laboratories

as early as 1881. But these tests were too few in number to give more than a rough indication of the properties of the wood from a given species. The need for more complete determination of the strength properties of timber became recognized. There was, of course, no precedent or general agreement as to standard test methods, nor was there a clear-cut picture of the specific objectives of such tests.¹

One group advocated tests of small, clear specimens for evaluating the various normal strength properties of different species, as well as the effect of growth conditions on strength. What constituted a small specimen had not been established; in some of the early testing, specimens four inches square and containing the defects common to the species were included as tests of small specimens.

Another group of experts, although they conceded that data on the inherent strength properties of various species from tests of small clear specimens would be desirable, emphasized the need for data directly applicable to the design problems of engineers and architects. They emphasized the importance of tests of full-sized structural members of the type used in construction, and believed the timbers should be selected in the market rather than in the forests.

Without fully resolving these problems a series of tests was

¹National Committee on Wood Utilization, Wood Construction, prepared by Dudley F. Holtman (1st ed.; New York: McGraw-Hill Book Co., 1929), p.13.

planned and conducted at Washington University, St. Louis, Missouri, about 1890, by Professor J. B. Johnson. Emphasis was given to obtaining data on the physical and mechanical properties of American woods. Test specimens were nominally four inches square, but limited tests of larger timbers were also made.

For the study of full-sized structural timbers an extensive decentralized testing program was developed by the Forest Service in cooperation with a number of the leading universities in various parts of the country at the beginning of the century.

With this experience and data as a background, a thorough re-evaluation of the research on timber was undertaken by the Forest Service just prior to the establishment of the Forest Products Laboratory in 1910. Under the direction of Dr. W. K. Hatt of Purdue University, test methods were reviewed and standards were established. Included were such methods as hardness tests, center loading for tests of small, clear specimens, and third-point loading for tests of structural timbers to afford better stress distribution for evaluating defects. These methods served as a nucleus for present American standards.¹

The Forest Products Laboratory was established as a centralized research institution as a result of difficulties in coordinating research at a number of widely separated locations throughout the country.

¹Ibid., pp. 13-14.

With this centralization there emerged a basic concept of the functions of various types of tests and how research relating to them should be conducted. This concept involves a four-point program relating to strength studies and is still broadly followed in current practice as follows:

1. Small, clear specimens cut from trees identified and selected in the forest are tested to evaluate the strength and related properties of all the principal arborescent species. The tests are made in such a way as to afford data on the variation of properties within the cross section and throughout the height of the tree, as well as on variability and the influence of such factors as rate of growth and density. Specimens two by two inches in cross section were chosen as best suited for this evaluation; they are small enough to enable the determination of strength at various parts of the cross section and large enough to provide a substantial number of fibers and growth rings.¹

2. Tests of timbers in structural sizes, together with small, clear specimens cut from them are an essential part of the program on strength studies of timber. Such tests, to be made on various timber species, are essential to determine the influence of various strength-reducing characteristics and related factors on the strength of wood

¹American Society for Testing Materials, Standard Methods for Testing Small Clear Specimens of Timber (A.S.T.M. Standard D143-52, 1952 , pp. 2-4.

and to aid in establishing safe work stresses for timber design. Supplementary tests involving carefully matched specimens are also needed to determine the effect of such factors as cross grain and duration of stress.

3. Structural elements, such as nailed or bolted joints on various species and under various moisture conditions, are tested to provide data for developing design criteria for the efficient use of timber for construction.

4. Timber in its various manufactured forms, such as doors, and full-scale structural units, such as trusses or wall and roof sections of buildings, is tested to determine the strength of such members, to check design assumptions, and by methods based on this research and practical experience, to progressively improve design.¹

In developing this basic concept a number of proposals were considered. It was widely thought that the objective of tests on small, clear specimens could be accomplished by a relatively few tests of relatively few kinds. It was assumed that if the relations among the various strength properties could be established for certain species, then these relations would hold for large groups of species. On the contrary, it was found that the relationship among the different strength properties is a species characteristic and is far from con-

¹American Society for Testing Materials, Standard Methods of Static Tests of Timbers in Structural Sizes (A.S.T.M. Standard D198-27, 1927 , pp. 3-10.

stant between species. Attempts to apply the theory and to establish strength values with a few tests had accordingly proved futile. It was recognized also that the difference in relationships among different strength properties often makes one species more valuable than another for a given purpose and that it is important to establish these differences by conducting a complete schedule of tests for each species.¹

This extensive research program has been carried on at the Forest Products Laboratory continuously since it was established.

Much progress has also been made in obtaining data on the strength of structural timbers and factors influencing strength, and many developments have taken place in stress grading. Timber tests have indicated that the strength-reducing effect of natural characteristics was quite similar among different species, and that these could be standardized as to kind, size, and similarity of effect regardless of species. This and other findings of research on stress grading have made possible the establishment of standardized methods² for establishing structural grades of lumber.

¹L. T. Markwardt and T. R. C. Wilson, Strength and Related Properties of Woods Grown in the United States (U. S. Dept. Agr. Tech. Bull. 479, 1935), p.21.

²American Society for Testing Materials, Tentative Methods for Establishing Structural Grades of Lumber (A.S.T.M. Standard D245-57T, 1949; revised, 1957), pp.125-159.

CHAPTER II

PRESENT STANDARDS AND PROCEDURES IN STRENGTH STUDIES AND STRESS GRADING

The early discussions, explorations, and research findings in the fields of strength studies and stress grading have been crystallized into standard procedures that have been in use for many years.

Current practice in the United States relating to strength studies and stress grading involves basically six separate phases or steps covering (1) evaluation of the inherent strength and related properties of various species by means of tests of small, clear specimens; (2) evaluation of the effect of natural characteristics and other factors on the strength properties of different species by means of tests of structural timbers and other special studies; (3) establishment of basic principles of stress grading applicable to all species; (4) formulation of commercial stress-grade specifications by timber producers for their species; (5) establishment of basic stresses for each of the commercial timber species; and (6) establishment of safe working stresses for the commercial grades.

(1) Strength Studies of Small, Clear Specimens

The mechanical properties of the various species of wood are evaluated by means of standard tests of small, clear specimens from

trees identified and selected in the forest. The methods are described in A.S.T.M. Standard D143-52, "Standard Methods of Testing Small, Clear Specimens of Timbers"¹.

Ten different kinds of mechanical tests are made on both green and dry material. The standard specimen is two by two inches in cross section, and its length depends upon the kind of test. A secondary standard, applied to material from smaller trees, uses a 1- by 1-in. specimen for tests of static bending and compression parallel to the grain. However, the two-inch size is used for other tests employing shorter specimens, such as shear parallel to grain. The secondary standard is thus designed to give results as nearly comparable as possible to the standard.²

Standard methods were developed to insure the accumulation of comparable results over long periods, while at the same time permitting the use of improved techniques as they are developed for such details as strain measurement.³ Since the methods cover the entire procedure from selection of test trees in the forest to the techniques of testing, they provide control of all the important factors that may influence the results.

¹A.S.T.M., Stan. Meth. Test. Sm. Cl. Spcmns. Tmbr., p.1.

²Ibid., p.39.

³Ibid., p.7.

(2) Strength Studies of Structural Timbers

Tests of timbers of structural size, and of small, clear specimens cut from them are made by standard methods to determine the effect of strength-reducing natural characteristics such as knots, or of processes such as seasoning and preservative treatment. The methods are described in A.S.T.M. Standard D198-27, "Standard Methods of Static Tests of Timbers in Structural Sizes"¹, and have been employed in the thousands of structural timber tests that have been made in America.

The most common tests on timbers of structural size are transverse bending, compression parallel to grain, and compression perpendicular to grain. The studies have included tests of both green and seasoned timbers. An essential part of the data is a detailed record of the size, nature and position of all natural characteristics that affect the strength, so that the data can be re-analyzed at any future time.²

Small, clear specimens are cut from the uninjured portions of the structural timber after test. These are tested to show the strength values in the clear wood substances and thus to permit closer evaluation of the strength-reducing characteristics. Other studies on specially selected and carefully matched specimens are also made to evaluate the

¹ A.S.T.M., Stan. Meth. Static Tests of Tmbrs. in Struc. Sizes, p.1.

² Ibid., p.3.

effect on strength of factors such as cross grain and duration of stress.¹

(3) Basic Principles of Stress Grading

From the results of the studies of structural timbers, of factors affecting strength, and of small, clear specimens, methods have been established for measuring knots and other natural characteristics and for evaluating their effect on strength, taking into account their size and position in the timber, and the kind of stress to which the member is subjected. These basic principles provide a means of establishing the percentage strength of any structural timber containing strength-reducing characteristics as compared to a timber free from defects. They have been set forth as A.S.T.M. Standard D245-57T, "Tentative Methods for Establishing Structural Grades of Lumber"². This Standard covers the procedures for evaluation of the strength of an existing grade from the grade description or of an individual structural timber by visual inspection.

(4) Formulation of Commercial Grades

Commercial stress grades are formulated by associations of lumber manufacturers for the species they produce by applying the standard basic principles of stress grading. Reliable stress grades are

¹Ibid.,p.5.

²A.S.T.M.,Tent.Meth. for Estab. Struc. Gr. of Lmbr.,p.125.

thus assured. The grade is formulated to reflect the quality of current timber production and to meet the particular needs of various uses. Rules specifically defining available commercial grades are published by various lumber associations.

(5) Basic Stresses

An essential part of the system of stress grading and structural design with stress-graded lumber is the establishment of a basic stress for each commercial structural-timber species. The basic stress for a species represents the safe working stress for a structural timber free from strength-reducing characteristics of any kind. Basic stresses are related to the inherent strength of the wood and to the results of tests of structural timber, taking into account also such factors as density, variability, duration of stress, effect of seasoning, and a factor of safety.¹

(6) Establishment of Safe Working Stresses for Commercial Grades

Safe working stresses are established from strength characteristics of the grade (grade-strength ratio) and the basic stress for the species. Once the basic stresses are established, the appropriate working stress for any structural grade is obtained by multiplying the basic

¹Ibid., p.135.

stresses for the species by the strength ratio of the grade. It is thus possible to establish commercial grades of any desired strength ratio and readily determine the safe working stresses that may be used with them.¹

¹Ibid., p.135.

CHAPTER III

FACTORS AFFECTING STRENGTH OF STRUCTURAL TIMBERS

Use Classes of Structural Wood

The influence of various factors on the strength of structural timbers depends, among other things, on the size and proportions of the timber and the kind of stress to which it is subjected. In American practice certain use classifications for structural wood have been developed. These classifications should be understood to afford a more complete picture of the standards and practices that have been developed.

Beams and stringers.--Pieces of rectangular cross section, five by eight inches (nominal dimensions) and up, graded with respect to their strength in bending when loaded on the narrow face.

Joists and planks.--Pieces of rectangular cross section two to four inches thick and four or more inches wide (nominal dimensions), graded primarily with respect to their strength in bending when used edgewise or flatwise, but also when used where tensile or compressive strength is important.

Posts and timbers.--Pieces of square or approximately square cross section, five by five inches (nominal dimensions) and larger,

graded primarily for use as posts or columns, but adapted to miscellaneous uses in which strength in bending is not especially important.

Combined uses.--The principles of stress grading make it possible to assign strength ratios in compression or tension to the joist and plank grades and in bending to the post and timber grades. The most common of such combinations is in the assignment of compression or tension values to joist and plank grades used in the fabrication of chord or web members in timber trusses.

Round timbers.--Round timbers, such as poles and piles, are not generally graded to a specific strength rating, although their strength is affected by such features as spiral grain and knots in much the same way as is the strength of sawed lumber. Logs or poles are sometimes used in the framing of resort or farm buildings where strength considerations govern their design.

Boards.--The increasing use of one-inch boards in lightweight trusses or other structural elements, or in glued laminated structural members, frequently requires that they be stress graded. Strength-reducing features are evaluated in much the same way as in the larger timbers, except that narrow-face grading is not necessary.¹

¹A.S.T.M., Tent. Meth. Est. Struc. Grds. Lmbr., pp.135-36.

Principal Factors Affecting Strength

The most important factors that influence the strength of structural materials are the quality of the wood, the duration of load, the moisture content, and the size, number, and location of strength-reducing characteristics.¹ For efficient utilization of material, these and other factors must all be considered, either in stress grading or in structural design.

Quality of Wood

The strength of clear wood in any species varies over a considerable range.² Basic stresses take into consideration the low range as well as the average of the strength values.

Ordinarily, the extent of decay is difficult to determine, and its effect on strength is greater than visual observation would indicate. Any decay present in timber may develop further under some service conditions. For these reasons decay in any form is usually prohibited in strength grades.³

Duration of Load

Both the proportional limit and the ultimate strength of wood

¹Forest Products Laboratory, Wood Handbook--Basic Information on Wood as a Material of Construction with Data for Its Use in Design and Specification (U.S. Dept. of Agric. Handbook No. 72, revised, 1955), p.137.

²L. W. Wood, Variation of Strength Properties in Woods Used for Structural Purposes (U.S. Forest Prod. Lab. Rpt. R17180, 1951), p.2.

³A.S.T.M., Tent. Meth. Est. Struc. Grds. Lmbr., p.128.

are higher under short-time loading than under long-time loading.¹ Wood is thus able to absorb overloads of considerable magnitude for short periods or smaller overloads for longer periods. This property is important in strength uses because it directly affects working stresses. A substantial reduction factor is applied to stress values obtained from laboratory tests in which the load duration is a few minutes, to convert them to working stresses suitable for long-time loading. Conversely, stresses for shorter periods of loading in service are increased above those for long-time loading.²

Moisture

Moisture affects the strength of structural timbers both directly and indirectly. The direct effect of loss of moisture is the stiffening and strengthening of the wood fibers. However, seasoning may be accompanied by checking, splitting, warping, and twisting; as a result, some of the strength that would otherwise be obtained in drying structural material is lost.

In material four inches and less in thickness, the development of seasoning defects does not offset the increase in strength from drying as much as in larger sizes. As a result, when these sizes are used

¹ _____, Relation of Strength of Wood to Duration of Load (Forest Prod.Lab.Rpt.R1916,1951),p.2.

² Forest Products Laboratory, Wood Handbook,p.138.

in dry locations, higher working stresses in extreme fiber in bending can be permitted than for larger timbers having the same grade-strength ratio, or larger defects can be permitted with the same working stresses. Higher working stresses are permitted in compression members of all sizes with seasoned material.¹

Construction material is used under a great variety of conditions affecting the moisture content, from the dry location of a heated building to the continually wet location of some pier and dock timbers. The condition of exposure must be taken into account in deciding on the working stresses to be employed.

Natural Characteristics

The principal natural characteristics which must be limited in structural grades are knots, shakes and checks, and slope of grain.

Knots

The influence of a knot in a beam is determined by its location and the area of its projection on the cross section of the piece; the method of measurement is such as to give the best approximation of this influence.²

¹A.S.T.M., Tent.Meth.Est.Str.Grds.Lmbr., p.134.

²Ibid., p.129.

Knots interrupt the direction of grain and cause localized cross grain with steep slopes. Intergrown or live knots resist some kinds of stress, but encased knots or knotholes are obviously of little or no value. On the other hand, distortion of grain is greater around an intergrown knot than around an encased or dead knot. As a result, overall strength effects are roughly equalized, and no distinction is made in stress grading between live knots, dead knots, and knotholes.

Knots reduce tensile strength more than compressive or shear strength.

The effect of knots on stiffness is small. Although the zone of distorted grain around a knot has less stiffness than straight-grained wood, such zones generally comprise only a minor part of the volume of a piece of lumber, and stiffness reflects the character of all parts.

The strength effect of a knot depends on the proportion of the cross section of the piece of lumber occupied by the knot. Limits on knot sizes are therefore made in accordance with the width of the face in which the knot appears. The effect of knots upon strength also depends upon their location and upon the distribution of stress in the piece. Compression members are stressed about equally throughout, and no limitation related to location of knots is imposed. In structural

members subjected to bending, stresses are greatest in the middle part of the length and are greater at the top and bottom edges than at mid-height. These facts are recognized in differing limitations on the sizes of knots in different locations. Since bending members may be used with either edge uppermost, and since the effect of knots on strength is greater in tension than in compression, knot requirements suitable for tensile stress are applied to both edges.

As knot size increases, the distortion of grain around the knot is more than proportionally increased. For that reason, sizes of knots in wide faces wider than twelve inches and narrow faces wider than six inches are permitted to increase only in proportion to the square root of the increase of the width of the face; whereas, below the twelve- and six-inch limits, the sizes permitted are generally proportioned to the width of the face.

Cluster knots are prohibited because neither the sizes of the individual knots nor those of the cluster are good measures of the extent of distortion of grain and the resultant effect on strength.

If two or more knots occur in the same cross section of a piece of structural lumber there is a cumulative effect on most of the strength properties. Two or more knots of maximum size are not permitted in the same cross section.¹

¹ Forest Products Laboratory, Wood Handbook, pp.138-39.

Shakes and Checks

Shakes and checks reduce the area of a beam acting in resistance to shear, and the limitations placed on shake in such material are based on this reduction. Checks are limited on the same basis as shakes, and no combination of shakes and checks is permitted that would reduce strength to a greater extent than would the allowable size of either separately. Shakes or checks in green material are assumed to reduce shearing stress in direct proportion to their extent. A slightly greater amount of shake or check is permitted in seasoned material because of the increased resistance of the remaining cross section. Checks are limited on the basis of the area actually open. Shakes are assumed to indicate a weakness of bond between annual rings that may extend throughout the length. They are therefore limited by their width, observed on the end of the piece.

In joist and plank, and beams and stringers, shake in green material is permitted in direct proportion of increase from none in a clear piece with no strength-reducing characteristics to one-half the width of the piece in a grade having one-half the strength of green, clear wood. In seasoned material, shake is similarly permitted from one-ninth the width of the piece in a grade of the strength of green, clear wood to five-ninths the width of the piece in a grade having one-

half the strength of green, clear wood. The only shakes or checks considered are those in the middle half of the height of a beam or joist, and in a distance from the end equal to three times the height. Shakes and checks, as a rule, have little influence on the strength of posts, unless they are unusually severe. Limitation on shakes and checks in posts may be of more importance from the standpoint of appearance than of strength.¹

Slope of Grain

Slope of grain, resulting either from diagonal sawing or from spiral or twisted grain in the log is limited in accordance with its effect upon strength. In zones of cross grain, where the direction of the wood fibers is not parallel to the edges of the piece, longitudinal tensile and compressive stresses have components acting across the grain, the direction in which wood is least strong. Cross-grained pieces are undesirable also because they tend to twist with changes in their moisture content. Stresses caused by shrinkage in seasoning are greater in structural lumber than in small, clear specimens and are increased in zones of sloping or distorted grain. To provide a factor of safety, the reduction of strength due to cross grain in structural lumber is taken as about twice the reduction observed in tests of small, clear specimens.²

¹Ibid., pp. 146-47.

²Ibid., p. 138.

Wane

Requirements of appearance, fabrication, or bearing or nailing surface generally impose stricter limitations on wane than does strength. The percentage reduction in strength resulting from wane toward the center of a beam is about double the percentage reduction in cross-sectional area. No combination of wane and knots is permitted that would reduce the strength more than the maximum allowable knot.¹

Pitch Pockets

Pitch pockets are not ordinarily important strength-reducing factors in a structural grade. A large number, however, indicate a general lack of bond, and such a piece should be carefully inspected for shakes.²

Heartwood and Sapwood

Heartwood and sapwood of the same density have been found to be of equal strength, and no requirement of heartwood is made when strength alone is the governing factor. When durability under conditions favorable to decay is a factor, as in bridges, trestles, docks, piers, or damp buildings, heartwood of naturally durable species or treated material is required. When preservative treatment is to be applied, sapwood is not restricted as it takes the treatment more readily than heartwood, and a large amount is preferred.³

¹Ibid., pp. 140-148.

²A.S.T.M., Tent. Meth. Est. Str. Grds. Lmbr., p. 134.

³Ibid., p. 128.

Density and Strength

The strength properties of individual pieces of wood are closely related to the density. Since the density of the wood substance of all species is practically the same, the dry weight affords a measure of the amount of wood substance present, and thus the strength of the clear wood. Pieces of exceptionally light weight are excluded in structural grades.

In species such as Southern Pine and Douglas Fir, the proportion of summerwood furnishes a practical means of estimating density. Selection of timbers for density assures material of higher inherent strength of the clear wood.

In wood selected for density, the contrast in color between summerwood and springwood should be distinct. Absence of contrast occasionally occurs in bands of dense growth rings that appear darker than the adjacent material. Such material has been called by a number of names, including proud wood, red wood, and compression wood. It has a decided end-shrinkage that causes warping when present with normal wood, and is relatively weak in tension. Pronounced compression wood is undesirable in structural timbers.¹

Rate of Growth and Strength

Rate of growth is less efficient than proportion of summerwood as a criterion of strength, but has sufficient merit to warrant special

¹Ibid., pp. 127-28.

consideration. In some species, selection for close grain, that is, not less than six nor more than twenty annual rings per inch, will assure improved material.¹

¹Ibid., p. 128.

CHAPTER IV

STRESS GRADING PRACTICES IN THE UNITED STATES

Basic Principles of Stress Grading

Individual pieces of lumber, 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 naturally represent a wide range in strength, utility, serviceability and value. One of the obvious requirements for the orderly marketing of timber is the establishment of grades, so that it is possible to obtain any desired number of pieces of similar characteristics. Many of the grades for lumber are established on the basis of the appearance and physical characteristics of the piece, with certain uses in mind, but without particular regard for strength. Stress grades, on the other hand, are developed to provide timber of assured strength for structural use.

Economy of material is obtained when all structural units are stressed nearly to the allowable maximum, and this can be effected only when the material is of uniform quality. It is the function of an efficient structural timber grading specification to classify timber of any species into quality classes or grades by limiting the permissi-

ble strength-reducing characteristics to the end that definite minimum strength is assured and maximum efficiency in utilization is obtained.¹

Structural grading is accomplished from a visual examination of the timber in which the location as well as the size of the knots and other surface features are evaluated. Since a structural timber is no stronger than its weakest part, all four of the faces of timbers are graded, the worst defect on any face determining the grade. The grade of a structural timber applies only to the timber as originally graded; if the timber is resawn, the size and position of the strength-reducing characteristics appearing on the faces are changed and the smaller units must be regraded individually to establish their quality.

Practical considerations often limit the ultimate theoretical efficiency of a structural grade. For example, the compressive strength of wood is affected less by a knot of a given size than is the tensile strength. Hence larger knots may be permitted on the upper or compressive side of a beam than on the lower side or tension side. Practically, however, grading is done so that the beam can be used either side up, rather than in one definite position, the reversal of which might result in failure.² Again, greater efficiency might be

¹A.S.T.M., Tentative Methods for Establishing Structural Grades of Lumber, p.126.

²Ibid., p.132.

obtained with a more elaborate method of evaluating the size of knots, but such evaluation would be more complicated than the present system, and hence less practical.

The information on factors affecting the strength of structural timbers as described in the preceding chapter has been used in establishing basic principles of stress grading. These principles permit the determination of the percentage strength of any timber containing strength-reducing characteristics in terms of the strength of clear timber, and also give a basis for setting up a commercial grade for any species to have any desired percentage of the clear strength.

Strength Ratios

The concept of the strength ratio was developed to give numerical values to the strength-reducing characteristics in structural timber, and thus to bridge the gap between the strength of clear wood and the strength of structural lumber containing knots or other strength-reducing characteristics. The strength ratio of a piece of structural lumber containing strength-reducing characteristics is the ratio of its actual strength to what its strength would be if it were clear and free of defects.¹ Multiplying the basic working stress for clear wood of the species by the strength ratio gives the appropriate working stress for the piece.²

¹Ibid., p.126.

²Ibid., p.135.

The strength ratio of a grade is based on the most injurious of the strength-reducing features permitted. Strength reductions from knots and cross grain generally are not cumulative. Thus if the grade ratio from knots is 75 per cent and that from cross grain is 69 per cent, the designated strength ratio of the grade is 69 per cent.¹

Strength ratios may be employed in still another way. If a grade is required to which some specific working stress is to be assigned, the strength ratio is calculated from the relation of the desired working stress to the basic stress for the species. From tables in A.S.T.M. Standard D 245-49, "Methods for Establishing Structural Grades of Lumber," the sizes of knots, slope of grain, and extent of other characteristics corresponding to the desired strength ratio are selected. These tables thus provide a convenient means for establishing structural grades. Included are tables for knots in various positions, grade-strength ratios for various slopes of grain and for shakes, checks, and splits.² Working stresses in bending and in compression and tension parallel to grain are governed by the grade-strength ratios in the tables for knots and for cross grain. Working

¹Ibid., p.126.

²Ibid., p.136-141.

stresses for horizontal shear in beams are governed by the ratios for shakes, checks, and splits. Strength in compression perpendicular to grain and modulus of elasticity are little affected by these characteristics, and a strength ratio of 100 per cent is used for them.¹

A structural timber may have the same or differing strength ratios in bending, tension, compression, or shear. Commonly, strength ratios in the various properties for a single grade are adjusted to be approximately in balance under the loading for which that grade is designed.²

Example of Specification Requirements

The following is an example of how a specification for a stress grade may be prepared for joists and planks,³ assuming that a grade strength ratio of 60 per cent is required in bending and 85 per cent in shear.

Stress Grade for Joists and Plank

(a) The strength ratios⁴ for this grade are 60 per cent for

¹Ibid., p.153.

²Ibid., p.135.

³Ibid., p.147-48.

⁴The strength ratios are based on the assumption that the material will be used dry, as in most covered structures.

stress in extreme fibre in bending and 85 per cent for stress in horizontal shear.

(b) No piece of exceptionally light weight is permitted.

(c) No piece containing any form of decay is acceptable.

(d) Slope of grain is to be measured over a distance sufficiently great to determine the general slope disregarding slight local deviations. Within the middle half of the length of the piece the slope shall not be steeper than 1 in 10.

(e) The size of a knot on a narrow face is taken as the width between lines enclosing the knot and parallel to the edges of the piece. The only knots measured on the narrow faces of the piece are those that do not show on the wide faces.

(f) The size of a knot on a wide face is the average diameter of the knot as found by halving the sum of its largest and smallest diameters. The size of a spike knot is the half sum of its length and its greatest width. An exception is that knots at the edge of the wide face are measured between lines parallel to the edge.

(g) Shakes are measured at the ends of the piece. Only those within the middle half of the height of the piece are considered.

(Height equals width of wide face.) The size of a shake is the distance between lines enclosing the shake and parallel to the wide faces of the

piece. The permissible size is determined by the width of the narrow face of the piece.

(h) Maximum permissible size of knots are shown in the schedule below:

Table II. Maximum Permissible Sizes of Knots

Nominal width of face	Maximum permissible knot sizes		
	On narrow face or at edge of wide face, middle third of length	At centre line of wide face	
In.		In.	In.
2	On narrow face	$\frac{3}{4}$	
3		1	
4		$1\frac{1}{4}$	
4	At edge of wide face	1	$1\frac{1}{2}$
6		$1\frac{1}{2}$	$2\frac{1}{4}$
8		2	$2\frac{3}{4}$
10		$2\frac{1}{2}$	$3\frac{1}{4}$
12		3	$3\frac{3}{4}$
14		$3\frac{1}{4}$	4
16		$3\frac{1}{2}$	$4\frac{1}{4}$

(i) The size of shake in the middle half of height, when measured on the end of the pieces between lines parallel to the wide faces, shall not exceed one-fourth of the thickness of the piece.

(j) The sizes of knots on narrow faces and at edges of wide faces may increase proportionately from the size permitted in the

middle third of the length to a size at the ends of the piece that is the same as the size permitted at the center of a wide face.

(k) The size of knots on wide faces may increase proportionately from the size permitted at the edge to the size permitted along the center line.

(l) Cluster knots and knots in groups are not permitted.

(m) The sum of the sizes of all knots within the middle half of the length of any face, measured as specified by Paragraph (e) or (f) for the face under consideration, shall not exceed $4\frac{1}{2}$ times the size of the largest knot allowed on that face.

(n) Knotholes and holes from causes other than knots are measured and limited as provided for knots.

(o) Checks and splits are measured and limited in the same way as shakes. The following limitations apply to both ends, but only within the middle half of the height of the piece and within three times the height from the end. (Height equals width of wide face.) The size of a check within this portion of the piece shall be taken as its average depth of penetration into the piece, measured from and perpendicular to the surface of the wide face. When checks on two parallel faces are opposite or approximately so, the sum of their sizes is taken. The sum of the sizes of shakes, checks, and splits shall not exceed the permissible size of shake. The effective size of an end

split is one-third of its average length.

Commercial Structural Grades

Commercial structural timber grades are developed for individual species of wood by various associations or agencies of lumber manufacturers, by applying the basic principles for establishing structural grades.¹ The several lumber-producing associations or agencies prepare and publish grades for their individual species on the basis of any particular grade-strength ratio that seems best suited to their production and marketing needs. For example, a lumber association may establish three structural grades, one having a strength ratio in bending of 75 per cent, another having a ratio of 67 per cent, and a third with a ratio of 50 per cent.

The lumber manufacturer's agencies that sponsor stress grades provide one or more of the following services: (1) publication of detailed descriptions and grading rules for the various grades; (2) responsibility for inspection service either at the mill or at destination, and issue of certificates of inspection; and (3) application

¹A.S.T.M., Tent.Meth.Est.Struc.Grds.Lmbr., pp.125-159.

of a copyrighted grade mark to each graded piece.

All standard stress grades are listed in National Design Specification for Stress-grade Lumber and its Fastenings, published by the National Lumber Manufacturers Association, as representing the lumber manufacturing industry in general.¹

¹ National Lumber Manufacturers Association, National Design Specification for Stress-grade Lumber and Its Fastenings, (Nat'l. Lmbr. Mgrs. Assoc., 1957). pp. 1-70.

CHAPTER V

STRESS GRADES IN RELATION TO SAFE WORKING STRESSES

Basic Stresses

Basic stress is a generalized working strength value for the clear wood of a species. It is reduced from the average laboratory value obtained in strength tests in order to conform more closely to the conditions of use of structural lumber. This reduction provides a factor of safety, but it does not allow for the effect of any knots or other strength-reducing features. Basic stress is thus independent of grade and provides a measure of the inherent strength of the clear wood of a species, from which any grade of that species can be evaluated.¹ Table III shows basic stresses for the most important structural species in the United States.²

¹Forest Products Laboratory, Wood Handbook, p.140.

²A.S.T.M., Tent.Meth.Est.Struc.Grds.Lmbr., pp.152-53.

TABLE III.

BASIC STRESSES FOR CLEAR LUMBER
UNDER LONG-TIME SERVICE AT FULL DESIGN LOAD^a

For use in determining working stresses according to
grade of lumber and other applicable factors.

Species ^b	Extreme fiber in bending or tension parallel to grain	Maximum horizontal shear	Compres- sion per- pendicular to grain	Compres- sion parallel to grain L/d= 11 or less	Modulus of elasticity in bending
(1)	(2)	(3)	(4)	(5)	(6)
HARDWOODS	P.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 P.s.i.
Ash:					
Black	1,450	130	220	850	1,100
Commercial white	2,050	185	365	1,450	1,500
Aspen, bigtooth and quaking	1,300	100	110	800	800
Beech, American	2,200	185	365	1,600	1,600
Birch, sweet and yellow	2,200	185	365	1,600	1,600
Cottonwood, eastern	1,100	90	110	800	1,000
Elm:					
American and slippery (soft elm)	1,600	150	185	1,050	1,200
Rock	2,200	185	365	1,600	1,300
Hickory, true and pecan	2,800	205	440	2,000	1,800
Maple, black and sugar (hard maple)	2,200	185	365	1,600	1,600
Oak, commercial red and white	2,050	185	365	1,350	1,500
Sweetgum (gum, red gum, sap gum)	1,600	150	220	1,050	1,200
Tupelo, black (black gum) and water	1,600	150	220	1,050	1,200
Yellow-poplar (poplar)	1,450	130	160	1,050	1,200

^aThese stresses are based on the strength of green lumber and are applicable, with certain adjustments, to lumber of any degree of seasoning or lumber used under any conditions of duration of load.

TABLE III. (Continued)

Species ^b	Extreme fiber in bending or tension parallel to grain	Maximum horizontal shear	Compress- ion per- pendicular to grain	Compress- ion parallel to grain L/d= 11 or less	Modulus of elasticity in bending
(1)	(2)	(3)	(4)	(5)	(6)
SOFTWOODS	P.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 P.s.i.
Baldcypress (cypress)	1,900	150	220	1,450	1,200
Cedar:					
Alaska	1,600	130	185	1,050	1,200
Atlantic white- (southern white- cedar) and northern white-	1,100	100	130	750	800
Port-Orford	1,600	130	185	1,200	1,500
Western redcedar	1,300	120	145	950	1,000
Douglas-fir:					
Coast type	2,200	130	235	1,450	1,600
Coast type, close-grained	2,350	130	250	1,550	1,600
Rocky Mountain type	1,600	120	205	1,050	1,200
All types, dense	2,550	130	275	1,700	1,600
Fir:					
Balsam	1,300	100	110	950	1,000
California red, grand, noble, and white	1,600	100	220	950	1,100
Hemlock:					
Eastern	1,600	100	220	950	1,100
Western (west coast hemlock)	1,900	110	220	1,200	1,400
Larch, western	2,200	130	235	1,450	1,500
Pine:					
Eastern white (northern white), ponderosa, sugar, and western white (Idaho white)	1,300	120	185	1,000	1,000
Jack	1,600	120	160	1,050	1,100
Lodgepole	1,300	90	160	950	1,000
Red (Norway pine)	1,600	120	160	1,050	1,200
Southern yellow	2,200	160	235	1,450	1,600
Dense	2,550	160	275	1,700	1,600
Redwood	1,750	100	185	1,350	1,200
Close-grained	1,900	100	195	1,450	1,200
Spruce:					
Englemann	1,100	100	130	800	800
Red, white, and Sitka	1,600	120	185	1,050	1,200
Tamarack	1,750	140	220	1,350	1,300

^bSpecies names approved by U.S. Forest Service.

From Table III, for example, it may be noted that basic stress in extreme fiber in bending for coast type, medium-grained Douglas Fir and medium-grained Southern Yellow Pine is 2200 lb./sq. in. (p.s.i.).

Basic working stresses are developed from a consideration of a number of factors, including (a) strength of the 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.¹

Some of these factors are well understood or can be accurately evaluated from available data; others are definable only in the light of engineering judgment and experience. It is therefore not possible to arrive at efficient basic stresses by mathematical calculation alone.²

¹Ibid., pp. 150-58.

²Ibid., p. 151.

The following principles are assumed in determining working stresses:

- (1) Each individual timber must be capable of safely carrying its full design load for the life of the structure.
- (2) Reliable stress grading, competent design, good fabrication, adequate maintenance, and supervision to prevent overloading are assumed.
- (3) The working stresses must be applicable to all conditions of use.
- (4) A reasonable factor of safety must be provided.¹

Working Stresses

By multiplying the basic stress of a species by the grade-strength ratio for a stress grade, the working stress for that grade and species is obtained.²

Factors in the Development and Use of Safe Working Stresses Variability

Because each timber is assumed to carry its design load, the safe working stresses must be related to the lower portion of the

¹A.S.T.M., Tent.Meth.Est.Struc.Grds.Lmbr., p.151

²Ibid., p.135.

strength range of the species. With the requirement in stress grading that timbers of exceptionally light weight be excluded, the factors of safety then provide for the occasional low-line timber.¹

Seasoning Effects

The effects of moisture on the strength of structural timbers was discussed in Chapter III. Certain increases above the basic-stress values in Table III can be made for wood that will be continuously dry in use, as in most covered structures. No increase for drying is made in working stresses for beams and stringers, which are thicker than four inches.

The effect of seasoning on strength in bending or in tension parallel to grain of joist and planks depends upon grade, the improvement being greater for the higher than for the lower grades. For lumber two to four inches in nominal thickness (joist and planks) that will be continuously dry in use, the strength ratio for bending stress in the extreme fiber or for stress in tension is increased by one-half of its excess over 50 per cent. If, for example, the strength ratio for green lumber for a grade of joist and planks is 68 per cent, the strength ratio for dry lumber is 77 per cent $(68 + \frac{68 - 50}{2} = 77)$.

¹Forest Products Laboratory, Wood Handbook, p.157.

Since many joists remain continuously dry in use, it is common commercial practice to take advantage of the increase in strength from drying by increasing permissible sizes of knots or other characteristics rather than by increasing the working stress; under this circumstance, the working stress may require reduction if lumber with knots of these sizes is to be used under wet conditions.

Basic stresses for use in obtaining the working stresses for all grades of 1-inch boards used under dry conditions may be increased from the values of Table III by one-quarter in bending or tension parallel to grain, one-eighth in horizontal shear, one-half in compression perpendicular to grain, three-eighths in compression parallel to grain, or one-tenth in modulus of elasticity. Similar increases are allowed for plywood or for stock used in fabricating glued-laminated structural members that are to be used under dry conditions.

Strength in compression parallel to grain is less affected by drying defects than in bending strength, and the increase in this strength property on drying is significant in all grades of compression members. A strength increase of 10 per cent above the values of Table III for columns of all lengths may be taken for drying regardless of size or grade. If existing grades of joist and planks are allowed an increase for drying in the permitted knot sizes, a 10 per cent in-

crease in the basic stress values for compression parallel to grain also may be made.

A seasoned timber with shakes or checks of a given size receives a higher strength ratio than a green timber with shakes of the same size. Working stresses for dry material in compression perpendicular to the grain are increased 50 per cent above the values in Table III. An increase of 10 per cent in modulus of elasticity from the values of Table III is assumed for seasoned lumber.¹

Duration of Load

The effects of duration of load on the strength of wood have been discussed in Chapter III. Studies have shown that wood under long-time loading has only about 9/16 of the strength observed in the standard laboratory test of about five minutes' duration. The basic stresses of Table III and all other safe working stresses derived from them are based on the assumption of long-time loading; that is, that the structure must be capable of sustaining the design load throughout its useful life. On the other hand, if the conditions of use, such as design for wind, impact, and snow loads, permit shorter periods of maximum load to be assumed, the working stresses (except modulus of elasticity) can be increased in accordance with the curve shown in Figure 1, on Page 48.

¹A.S.T.M., Tent. Meth. Est. Struc. Grds. Lmbr., pp. 153-55.

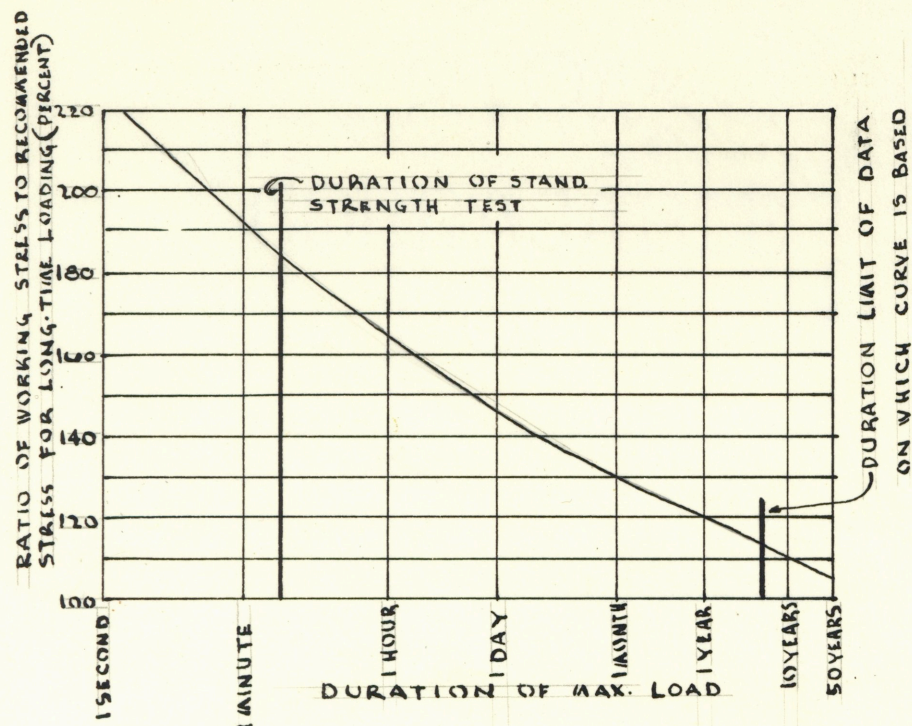


Fig. 1.--Relation of working stress to duration of load.¹

These increases apply to intermittent loading as well as continuous loading, for tests have shown that repeated loads separated by periods of rest have a cumulative effect.²

In applying a stress increase for conditions of less than full duration of load, the safe stress for the permanent portion of a combined loading must not be exceeded. If the assumed loading conditions involve an infrequent large load and a more frequent smaller load, the

¹Ibid., pp.153-55.

²Ibid., p.160.

working stresses and sizes of structural members should be safe for each of the assumed loads. It is possible for sizes of members to be governed by the permanent load or by some semi-permanent load below the maximum load.

Working stress values, except modulus of elasticity, are used without allowance for occasional impacts up to 100 per cent of the static load, provided that the sizes of structural members are safe for the static loadings.¹

Wood under continuing load takes on a continuing increment of deformation known as plastic flow or yield, usually very slow but persistent over long periods of time. Deflection of this nature occurring in timbers acting as beams is sometimes known as "set" or "sag". This increase of deformation with time may become as much as the initial deformation without endangering the safety of the timber. This effect is of importance only where the long-continued load is at or near the maximum design level. It is necessary, where deformation or deflection under long periods of loading must be limited in amount, to provide extra stiffness. This can be done by doubling any dead or long-time loads when calculating deformation, by setting an initial deformation limit at half the long-time limit, or by using one-half of the recommended value of modulus of elasticity in calculating the

¹Ibid., p.161.

immediate deformation. In any case, it is to be understood that the recommended values for modulus of elasticity will give the immediate deflection of a beam, and that this will increase under long-continued load. The increase may be somewhat greater under varying temperature and moisture conditions than under uniform conditions.¹

Decay and Preservation

Since there is no satisfactory way of appraising the effect of decay on the strength of wood, decayed material is excluded from most structural grades. No working stress can be assigned to decayed material with assurance of its dependability. Structural lumber exposed to the hazard of decay should be inspected frequently and removed if decay appears in or near highly stressed areas. Special attention to such features as drainage and ventilation will help reduce or eliminate the decay hazard. Treated material or the heartwood of species of high natural decay resistance should be used wherever conditions are favorable to decay.

Where the hazard of decay cannot be avoided, a more conservative basis for structural design is sometimes afforded by reducing the working stress. Such reductions may be applied either to treated wood

¹A.S.T.M., Tent.Meth.Est.Struc.Grds.Lmbr., p.156.

or to untreated material of species with natural decay resistance.¹

Other Conditions

Stress values in Table III are applicable to lumber used under ordinary ranges of temperature, and should be reduced for lumber subjected to abnormally high temperatures, particularly for long periods of time. Recommended stress values contain factors of safety that are applicable to the usual conditions of design. In structural design, the engineer may encounter special conditions in which he will modify the working stresses, sometimes upward and sometimes downward, if he is permitted to do so without restriction of building codes or similar regulations.²

¹Ibid., pp. 157-58.

²Ibid., p. 158.

CHAPTER VI

OPPORTUNITIES FOR IMPROVEMENTS IN STRESS GRADING AND TIMBER DESIGN

Although significant progress has been made in obtaining comparable data on the strength and related properties of many timber species, in gathering information on factors affecting strength, in developing stress grades, and in improving structural timber design, there are still many challenges for continued research. Present structural grading is not yet as efficient as it should be, for there is much too wide a range in the strength of timbers in a single stress grade. There are variations in strength rating within a single tree equal to the variation over the entire range of the species; there is often more variation in physical properties within an individual tree than between species. These factors make absolute determination of strengths difficult.

A related problem which has become the subject of much controversy recently is the assignment of widely differing stress ratings within the species of Douglas fir, and its classification into coast region and inland (Rocky Mountain) region types. As can be seen from Table III, the inland fir is assigned much lower basic stress values than is coast fir.

The physical properties of Douglas Fir, along with its abundant supply, make it an outstanding material for house framing. The first distinction between types was made in 1916, when a test was made of Wyoming timber by the U. S. Forest Products Laboratory. Results indicated lower value than some tests from the coastal area; this, then, was the beginning of the Rocky Mountain classification. But, for many years after that, the two types were used interchangeably, with satisfactory performance.

Late in the 1930's the Federal Housing Administration began to require that houses be engineered or structurally designed. This was to ensure the structural soundness of houses and to make possible more efficient and economical use of material.

When this program went into effect, maximum span tables were calculated for floor and ceiling joists, and rafters; a separate table was required for Rocky Mountain Douglas Fir because the lower assigned basic values resulted in shorter maximum spans. Because of the tremendous demand for lumber at that time, no immediate effect on the sale and use of the inland fir production occurred. The use of Rocky Mountain fir on Coast Region spans has continued until just the last few years, when the demand for lumber has declined. Also, in 1955, F.H.A. brought to the attention of their regional offices the existence of

these span differences, and advised checking the origin of the Douglas Fir. This trend is now leading to the marking of stock for the inspector's identification. Unidentified material assumes the lower rate.

The Western Pine Association,¹ concerned for the future of the species, sponsored a thorough study of Douglas Fir basic stresses throughout the entire Western Pine Region, including both western and inland mills. These tests, recently completed by the Western Pine Association Laboratory in Portland, Oregon, revealed very little difference between inland and coast fir. The results of these tests, Table IV, show that, although the average modulus of elasticity of lumber from inland mills is slightly lower than that of lumber from western mills, some of the highest values were found inland, and some of the lowest on the coast.

The U. S. Forest Products Laboratory has recently renounced responsibility for the assignment and grouping of working stresses for all species, and issued a table of individual species values to members of the A.S.T.M. Committee D-7 on Wood for future consideration. An excerpt from this table is shown in Table V, on Page 57. By referring to

¹An association for the producers of lumber in these species: Ponderosa pine, Idaho white pine, Sugar pine, Douglas fir, larch, White fir, Engelmann spruce, Lodgepole pine, Incense cedar, and Red cedar.

TABLE IV.

DOUGLAS FIR TESTING PROGRAM

Averages: 110 Specific Gravity Samples
10 Static Bonding Samples

Ship- ment	Mill	Location	Average Specific Gravity Western Mills	Average Ring Count Summerwood	Average Percent	Average Modulus of Elasticity "E"
B	U. S. Plywood Lbr.	Seattle, Wn.	.442	16	26	1,080,394
C	U. S. Plywood Lbr.	Roseburg, Ore.	.428	23	26	1,182,723
D	Roseburg Lbr. Co.	Roseburg, Ore.	.422	15	26	1,461,015
E	Timber Prod. Co.	Medford, Ore.	.438	17	27	1,196,736
F	Guistina Bros. Lbr.	Eugene, Ore.	.427	21	26	1,259,066
H	U. S. Plywood Lbr.	Redding, Calif.	.445	18	23	1,251,532
J	Georgia Pacific Corp.	Coos Bay, Ore.	.459	17	23	1,357,547
L	Georgia Pacific Corp.	Toledo, Ore.	.453	9	27	1,729,034
N	Oja Lbr. Co.	Sandy, Ore.	.425	8	25	1,184,270
O	Long Bell Lbr. Co.	Longview, Wn.	.469	18	28	1,722,801
P	Simpson Logging Co.	Shelton, Wn.	.395	30	28	1,313,916
Averages - Western Mills			.437	17	26	1,339,912
Maximum			.469			1,729,034
Minimum			.395			1,080,394
Inland Mills						
A	St. Maries Lbr. Co.	St. Maries, Ida.	.424	23	28	1,252,833
G	Southwest Lbr. Mills	McNary, Ariz.	.394	21	21	1,145,625
I	Deer Park Pine Ind.	Deer Park, Wn.	.446	22	23	1,301,450
K	Intermountain Lbr. Co.	Missoula, Mont.	.424	15	22	1,537,058
M	Boise Cascade Corp.	Emmett, Idaho	.430	18	22	1,381,232
Averages - Inland Mills			.424	20	23	1,323,639
Maximum			.446			1,537,058
Minimum			.394			1,145,625

Tables III and V, it can be determined that the following groupings are now in effect:

1. Southern Pine encompasses the following eight species: Longleaf (11%), Slash (10%), Loblolly (49%), Shortleaf (22%), Virginia (3%), Pond (3%), Pitch (1%), and Sand Pine (1%), which are assigned a Modulus of Elasticity value of 1,600,000 with the individual values ranging from 1,000,000 to 1,600,000.
2. Western Hemlock is assigned a value of 1,400,000 (Table III) but Table V shows the E value to be 1,200,000. This species grows within the same region as Mountain Hemlock and White Fir which have an E value of 1,000,000 and are not readily distinguishable, so are intermixed in production and use.

While eight Southern pine species have been grouped together for simplification, as have six species of White Fir and two of Hemlock, Douglas Fir has been separated for classification. Coast type is granted an E value of 1,600,000¹, but does not include Northern Interior (9%) at 1,300,000 and Southern Interior (1%) at 1,100,000.

The Western Pine Association, feeling that inland Douglas Fir has been subjected to discriminatory evaluation in the past, all

¹A great deal of the information upon which the Forest Products Laboratory based its analysis was taken from old-growth Douglas fir stands on the Coast more than thirty years ago. Considerable material produced now is cut from young-growth stands.

TABLE V.

Table 1.--Average strength properties for green wood of commercial native softwood species and suggested values for use in establishing working stresses

Species		Extreme fiber in bending	Modulus of elasticity in bending	Horizontal shear	Compression perpendicular to grain	Compression parallel to grain					
Common name	Scientific name	Species average ¹	Suggested value ²	Species average ¹	Suggested value ²	Species average ¹	Suggested value ²				
		P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.				
Baldcypress	<i>Taxodium distichum</i>	6,640	1,900	1,184	1,200	812	135	426	250	3,580	1,300
Cedar											
Alaska	<i>Chamaecyparis nootkatensis</i>	6,450	1,850	1,135	1,100	842	140	431	215	3,050	1,100
Port Orford	<i>Chamaecyparis lawsoniana</i>	6,180	1,750	1,419	1,400	834	140	351	175	3,130	1,150
Atlantic white	<i>Chamaecyparis thyoides</i>	4,740	1,350	752	750	694	115	300	150	2,390	850
Northern white	<i>Thuja occidentalis</i>	4,250	1,200	643	650	616	105	288	145	1,990	700
Eastern red	<i>Juniperus virginiana</i>	7,030	2,000	649	650	1,008	170	864	430	3,570	1,300
Western red	<i>Thuja plicata</i>	5,120	1,450	919	900	710	120	335	170	2,750	1,000
Douglas-fir	<i>Pseudotsuga menziesii</i>										
Wide-ringed		6,110	1,750	1,157	1,200	867	145	327	165	2,860	1,050
Southern interior		6,180	1,750	1,053	1,100	857	145	389	195	2,920	1,050
Northern interior		6,750	1,950	1,276	1,300	878	145	403	200	3,160	1,150
Coast medium grain (4 RPI and up) ³											
Coast close grain (6 RPI and up) ³											
All regions dense											
		7,600	2,150	1,567	1,600	930	155	455	230	3,880	1,400
		7,760	2,200	1,605	1,600	938	155	475	240	3,980	1,450
		8,040	2,300	1,639	1,600	951	160	500	250	4,060	1,450
Pine, so. yellow											
Longleaf	<i>Pinus palustris</i>	8,670	2,500	1,598	1,600	1,037	175	591	295	4,300	1,550
Slash	<i>Pinus elliotii</i>	8,570	2,450	1,588	1,600	958	160	652	325	4,210	1,500
Loblolly	<i>Pinus taeda</i>	7,340	2,100	1,406	1,400	850	140	480	240	3,490	1,250
Shortleaf	<i>Pinus echinata</i>	7,300	2,100	1,391	1,400	851	140	435	220	3,430	1,250
Pitch	<i>Pinus rigida</i>	6,830	1,950	1,200	1,200	860	145	450	225	2,950	1,050
Pond	<i>Pinus serotina</i>	7,450	2,150	1,281	1,300	936	155	544	270	3,660	1,300
Sand	<i>Pinus clausa</i>	7,500	2,150	1,024	1,000	1,143	190	556	280	3,440	1,250
Virginia	<i>Pinus virginiana</i>	7,330	2,100	1,218	1,200	888	150	390	195	3,420	1,250
Larch, western	<i>Larix occidentalis</i>	8,180	2,350	1,532	1,500	904	150	425	210	3,990	1,450
Fir											
Sub-alpine	<i>Abies lasiocarpa</i>	4,450	1,250	861	850	614	100	307	155	2,060	750
California red	<i>Abies magnifica</i>	5,950	1,700	1,206	1,200	800	135	359	180	2,850	1,050
Grand	<i>Abies grandis</i>	6,060	1,750	1,298	1,300	760	125	336	170	3,020	1,100
Noble	<i>Abies procera</i>	5,790	1,650	1,269	1,300	746	125	338	170	2,740	1,000
Pacific silver	<i>Abies amabilis</i>	5,890	1,700	1,333	1,300	692	115	242	120	2,840	1,000
White	<i>Abies concolor</i>	5,700	1,650	1,034	1,000	750	125	374	185	2,710	1,000
Bemlock											
Eastern	<i>Thuja canadensis</i>	6,420	1,850	1,073	1,100	848	140	443	220	3,080	1,100
Mountain	<i>Thuja mertensiana</i>	6,270	1,800	1,038	1,000	933	155	408	205	2,880	1,050
Western	<i>Thuja heterophylla</i>	6,140	1,750	1,221	1,200	806	135	393	145	2,990	1,100
Pine											
Jack	<i>Pinus banksiana</i>	6,030	1,700	1,068	1,100	754	125	306	155	2,950	1,050
Red	<i>Pinus resinosa</i>	5,820	1,650	1,281	1,300	684	115	281	140	2,730	1,000
Eastern white	<i>Pinus strobus</i>	4,940	1,400	904	1,000	678	115	254	130	2,440	900
Western white	<i>Pinus monticola</i>	5,220	1,500	1,078	1,200	635	105	293	145	2,650	950
Lodgepole	<i>Pinus contorta</i>	5,490	1,550	1,076	1,100	685	115	311	155	2,610	950
Ponderosa	<i>Pinus ponderosa</i>	5,130	1,450	997	1,000	704	115	335	170	2,450	900
Sugar	<i>Pinus lambertiana</i>	5,080	1,450	938	950	678	115	351	175	2,530	900
Redwood	<i>Sequoia sempervirens</i>	7,500	2,150	1,176	1,200	833	135	524	260	4,200	1,500
Spruce											
Engelmann	<i>Picea engelmannii</i>	4,540	1,300	957	950	594	100	251	125	2,190	800
Red	<i>Picea rubens</i>	5,800	1,650	1,188	1,200	762	125	341	170	2,650	950
Sitka	<i>Picea sitchensis</i>	5,660	1,600	1,230	1,200	757	125	344	170	2,670	950
White	<i>Picea glauca</i>	5,580	1,600	1,066	1,100	692	115	292	145	2,570	950
Tamarack	<i>Larix laricina</i>	7,170	2,050	1,236	1,200	863	145	480	240	3,480	1,250

¹Modulus of rupture.²Average modulus of rupture value divided by 3.5 (to take into account variability, long-time loading, factor of safety, and minor effects).³Average modulus of elasticity value rounded to nearest 100,000 p.s.i. (values of 1,000,000 or greater) or nearest 50,000 p.s.i. (values less than 1,000,000).⁴Average value for maximum stress in shear parallel to grain divided by 6.0 (to take into account variability, long-time loading, stress concentration, and factor of safety).⁵Fiber stress at proportional limit.⁶Average fiber stress at proportional limit divided by 2.0 (to take into account variability and factor of safety).⁷Maximum crushing strength.⁸Average maximum crushing strength divided by 2.77⁸ (to take into account variability, long-time loading, and factor of safety).⁹Includes material from region designated as Interior West in Forest Products Laboratory Report No. 2078.

Douglas fir by F.H.A., basing its arguments on the foregoing material.^{1, 2, 3.}

Improved Efficiency in Structural Timber Use

From a practical standpoint it is almost impossible to avoid grouping of some lumber species. Similarity in appearance after manufacture, marketing and identification of the material, and circumstances of use all contribute to the grouping of certain lumber species as one.

It has long been recognized that individual pieces of any species, independent of strength-reducing characteristics that may be present, represent a wide range in strength as a result of variations in growth conditions. In developing working stresses, it is necessary to consider the lower strength material on the premise that for many critical uses each piece must carry its design load. Without some adequate means of classifying individual timbers with respect to the inherent properties of the wood, it is obvious that any structural grade will contain timbers representing a wide range in strength. The efficiency of structural use would be greatly improved if some simple and

¹Herb McKean and others, An Analysis of Stress Problems in Inland and Coast Douglas Fir(mimeographed report, Feb. 3, 1959),pp.1-3.

²Carl A. Rasmussen, Director of Research, Inland Douglas Fir Structural Properties(West. Pine Assn. mimeographed report to the Wood Products Clinic, April 15, 1958),pp.1-3.

³Western Pine Association, Request for Equal Recognition of All Douglas Fir(mimeographed copy; presented to F.H.A. February 8, 1960), p.1.

effective means were developed to grade timbers for their inherent strength, as well as on the basis of knots and other natural characteristics, so that each timber could be used to its full strength. If a suitable method were available, a large portion of the individual timbers in present stress grades could be safely reclassified to carry much higher stresses.

Several methods of approaching this problem have been considered. These include a density classification, a non-destructive hardness test an an index of density and other properties, and other non-destructive tests, such as sonic and supersonic methods.

Many studies have shown the relation of density to strength properties both within a species and among different species. Since the denser pieces are the stronger, any simple means of accurately evaluating the density of a structural timber would be useful in classifying it with respect to mechanical properties. Some consideration has been given to density classification in American structural timber grading practice.¹ In Douglas fir and Southern pine, for example, the proportion of summerwood is an index of density. As a result, timbers of these species showing on the end surface one-third or more summerwood

¹Frederick Wangaard, The Mechanical Properties of Wood (New York: John Wiley and Sons, 1950), p.128.

are recognized as "dense" and are allowed an increase on one-sixth in safe working stresses.¹ However, a greater refinement by some other method is still to be desired.

The possibility of rapidly and accurately evaluating the density of individual pieces has been considered, but no simple method is as yet available. A complicating factor in this evaluation is the moisture content, which may vary considerably within a piece and among different species.

Consideration has also been given to the possibility of a rapid method of determining hardness and from this an interpretation of density and strength. A hardness tool has been patented that operates by measuring the penetration of the tool under a given load. However, this instrument has not as yet been perfected, and its operation is complicated by the influence of moisture content when it is used on anything but fully green material.

More recently, attention has been given to the possibility of sonic and supersonic methods for evaluating the properties of individual pieces of wood. Research at a number of laboratories has shown that modulus of elasticity can be closely evaluated through non-destructive sonic test methods. However, the calculation for modulus of elasticity involves a knowledge of the density which, if it were available, would

¹Forest Products Laboratory, Wood Handbook, p.149.

in itself afford an index of strength. Further, it does not appear that there is a close enough relation between modulus of elasticity and modulus of rupture to effectively employ this property as an index of bending strength. However, it is hoped that further research will eventually provide a simple test for evaluating the inherent strength of the wood as well as the effect of strength-reducing characteristics.¹

Simplification of Stress Grades and Working Stresses

In spite of the advances in grading, the present American commercial stress grades are exceedingly complex and involved. The complexity has resulted at least in part from changes made to increase their efficiency. For example, in order to simplify the inspection of joist and plank grades so that only the two wide faces need be inspected, the method of measuring knots and calculating grade ratios was changed from the method used in beams and stringers. The challenging problem is to simplify the grades without loss of efficiency.

In respect to this problem, Housing Research Paper No. 33, prepared by the University of Illinois Small House Council for the Housing and Home Finance Agency, Washington, D. C., states:

"The greatest need to assure the efficient use of wood in residential framing is the establishment of a full-length, all-purpose

¹ Frederick Wangaard, The Mechanical Properties of Wood, pp.128-129.

grade with established working stresses for all loads to which wood is subjected--bending, tension, compression, shear, etc. This grade should be independent of the size and length of the member and should include 1-inch boards for use in trusses and other light framing."

In the lumber industry generally, stress ratings and methods of grading vary for the different sizes and contemplated uses of structural lumber. Joists and planks are graded one way, beams and stringers another, and posts and timbers still another. If in the process of fabrication it becomes necessary to cut the members into shorter length, the stress rating of the original piece no longer is applicable.

However, in 1956, the Southern Pine industry made a complete revision of its grading rules so that it could provide stress-rated grades in all sizes on a basis that would enable the designer to use the finished product under any condition of stress requirement. All items are graded alike and may be used interchangeably as joists, beams or posts, since the universal value for each piece makes it suitable for any category of use. Graded members may be cut to shorter lengths without impairment of stresses.

The unique all-purpose Southern Pine stress grades are a radical departure from the simple-beam principle of grading the middle third of the length only, and require the grade restrictions to apply

throughout the length of each piece. This affords versatile stress ratings for continuous beams, cantilevered beams, double spans, concentrated loads, and all uses both flatwise and edgewise, without the necessity of regrading for special shear or other special stress requirements.¹

Another approach to improved stress grading that has the endorsement of designers, architects and engineers, involves the development of a system of universal preferred design stresses and grade-strength ratios. By preferred design stresses is meant a series of stress grades among different species that will provide a series of design stresses separated by systematic steps. Such a scheme would enable a designer to select a stress with the assurance that stress grades would be available in several species with that exact stress. To apply such a system would, of course, involve close cooperation among lumber associations in revising stress grades.

Such preferred values might be in a geometric progression, in which each value has the same ratio to the next above or below. Such a progression would be particularly useful, since basic stress, strength ratios, and working stresses could all be given values from the same

¹Southern Pine Association, A Stress Grade Guide (printed pamphlet; n.d.)

series. In this way, grading rules and strength ratios could be standardized among species at the same time that working stresses are standardized.¹

¹ A.S.T.M., Tent.Meth.Est.Struc.Grds.Lmbr., p.147.

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GLOSSARY OF TERMS¹

Annual growth ring.--(See Ring, annual growth)

Beam.--A structural member transversely supporting a load.

Check.--A lengthwise separation of the wood, which usually occurs across the rings of annual growth.

Compression parallel to grain.--A measure of the capacity of a short column to withstand loads acting in the direction of the length.

Compression perpendicular to grain.--A measure of the bearing strength of the wood across the grain.

Cross grain.--Grain not parallel with the axis of a piece. It may be either diagonal or spiral grain or a combination of the two.

Decay.--Disintegration of wood substances due to the action of wood-destroying fungi.

Defect.--Any irregularity occurring in or on wood that may lower its strength.

Density.--The mass of a body per unit volume.

Density rule.--Rules for estimating the density of wood, based on percentage of summerwood and rate of growth. The rules at present apply only to Southern Yellow pine and Douglas fir.

Encased knot.--(See Knot)

Fiber stress in bending.--A measure of the bending strength; is proportional to the load which can be carried by a beam of a given size.

Grade.--The designation of the quality or class of a manufactured piece of wood.

Grain.--The direction, size, arrangement, appearance, or quality of the fibers in wood.

Green.--Unseasoned, wet.

Growth ring.--(See Ring, annual growth)

Hardwoods.--The botanical group of trees that are broadleaved. The term has no reference to the actual hardness of the wood.

Heartwood.--The wood, extending from the pith to the sapwood, the cells of which no longer participate in the life process of the tree. Heartwood may be infiltrated with gums, resins, and other materials which usually make it darker and more decay-resistant than sapwood.

Horizontal shear stress.--In relation to beams, the measure of the resistance to the tendency of the upper half of the beam to slide upon the lower when the beam is loaded.

Knot.--That portion of a branch or limb that has become incorporated in the body of the tree.

Decayed knot.--A knot which, due to advanced decay, is not so hard as the surrounding wood.

Encased knot.--A knot whose rings of annual growth are not intergrown with those of the surrounding wood.

Intergrown knot.--A knot whose rings of annual growth are completely intergrown with those of the surrounding wood.

Sound knot.--A knot which is solid across its face and which is as hard as the surrounding wood.

Spike knot.--A knot sawn in a lengthwise direction.

Loads.--

Dead load.--The weight of all permanent stationary construction included in a building.

Live load.--The total of all moving and variable loads that may be placed upon a building.

Lumber.--The product of the saw and planing mill not further manufactured than by sawing, resawing, and passing lengthwise through a planing machine, crosscut to length and worked.

Modulus of elasticity.--A measure of the stiffness or the rigidity of a material. It is the ratio of stress per unit area to corresponding strain per unit length, the distortion or strain being within the proportional limit.

The deflection of a beam under load varies inversely as the modulus of elasticity; that is, the higher the modulus the less the deflection. Modulus of elasticity is useful for computing the deflection of joists, beams and stringers under loads that do not cause stress beyond the proportional limit. It is also used in computing the load that can be carried by a long column, because for such columns the load depends on the stiffness, and not on the crushing strength of the wood parallel to the grain.

Moisture content of wood.--Weight of the water contained in the wood, usually expressed in percentage of the weight of the oven-dry wood.

Pitch pocket.--A well-defined opening between rings of annual growth, usually containing, or which has contained, pitch, either solid or liquid.

Rate of growth.--The rate at which a tree has laid on wood, measured radially in the trunk or in lumber cut from the trunk. The unit of measure in use is the number of annual growth rings per inch.

Ring, annual growth.--The growth layer put on in a single growth year.

Sapwood.--The outer layers of growth in a tree, exclusive of bark, which contain living elements; usually lighter in color than heartwood.

Seasoning.--The evaporation or extraction of moisture from green or partially dried wood.

Second growth.--Timber that has grown after the removal by any means of all or a large portion of the previous stand.

Shake.--A separation along the grain, most of which occurs between the rings of annual growth.

Softwoods.--The botanical group of trees that have needle-like or scale-like leaves and are evergreen for the most part, cypress, larch and tamarack being exceptions; often referred to as conifers. The term "softwood" has no reference to the actual hardness of the wood.

Split.--A lengthwise separation of the wood, due to the tearing apart of the wood cells.

Springwood.--The portion of the annual growth ring that is formed during the early part of the season's growth. It is usually less dense and weaker mechanically than summerwood.

Summerwood.--The portion of the annual growth ring that is formed during the latter part of the yearly growth period. It is usually more dense and stronger mechanically than springwood.

Virgin growth.--The original growth stand of mature trees.

Wane.--Bark, or lack of wood or bark, from any cause, on the edge or corner of a piece.

¹ National Lumber Manufacturers Association, Wood Structural Design Data (2nd. Ed., revised; N.L.M.A., 1941), pp.25-28.

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