APPENDIX A. WOOD CHARACTERISTICS

Structure of Wood

Wood Cells

The cells which make up the structural elements of wood are generally tubular and quite firmly grown together. Dry wood cells may be empty, or partly filled with deposits such as gums and resins.

Many wood cells are considerably elongated and pointed at the ends. Such cells are called fibers. The direction of the wood fibers with respect to the axis of the tree is one of the most important characteristics affecting the usefulness of a given piece of wood, since it has a marked influence on strength.

The length of wood fibers may vary considerably in a given tree, as well as between different species. Typically, hardwood fibers average about l/25 inch in length; softwood fibers average from l/8 to l/4 inch in length, or longer.

Growth Rings

Between the bark of a tree and the wood interior is a layer of thin-walled, nearly invisible living cells, called the cambium layer, in which all growth of the tree takes place. New wood cells are formed on the inside and new bark on the outside of the cambium. No growth in either thickness or length takes place in wood already formed, new growth is purely the addition of new cells -- not the further development of old ones.

In temperate climates there is usually enough difference in color and texture between the wood formed early and that formed late in the growing season to produce well-marked annual growth rings. The age of a tree at any cross-section may be determined by counting the growth rings. One ring represents one year of growth, provided the growth has been interrupted by cold or dry seasons so that the change in cell structure is sufficient to define the annual layer.

Springwood and Summerwood

In many species of wood each annual growth ring is divided into two distinct layers. The inner part of the ring, formed first in the growing season, is called springwood. The outer part, formed later in the growing season, is called summer-wood, The transition from springwood may be gradual or abrupt, depending on the kind of wood and the growing conditions when it was formed,

Springwood in generally characterized by cells with relatively large cavities and thin walls, whereas summerwood cells have smaller cavities and thicker walls. Summerwood generally will be heavier, harder and stronger than springwood.

The percentage of summerwood in a given piece of lumber determines the density of the piece. Other factors being equal, the higher the density, the greater the strength. Because of its greater density, the proportion of summerwood in a particular piece of lumber is sometimes used as an indication of its quality and strength.

Sapwood and Heartwood

The wood portion of a tree has two main parts. The outer part, which consists of a ring of wood around the tree just under the bark, is called sapwood. Within the sapwood ring is an inner core, generally darker in color, called heartwood.

The sapwood ring varies in thickness from one to three inches depending on the age and specie of the tree. Sapwood contains the living cells and takes part in the active life processes of the tree. Heartwood consists of inactive (not dead) cells and serves mainly to give strength to the tree. Except for the slightly darker color of heartwood, there is littIe difference in the strength or physical characteristics of heartwood and sapwood from a given tree.

As a tree grows older and larger, the inner layers of sapwood change to heartwood. Eventually the heartwood core forms the major part of the trunk and main branches.

Chemical Composition of Wood

Wood is a complex aggregate of compounds which may be divided into two major groups: (1) those which make up the cell structure, and (2) all other substances, which are commonly called "extractives" or infiltrated materials.

WOOD CHARACTERISTICS

The cell wall components consist primarily of cellulose and lignin, Cellulose is the most abundant constituent, comprising about 70 to 80 percent of the wood structure. Lignin, which comprises from 20 to 30 percent of the wood structure, is the cementing agent which binds the individual wood fibers together to form a substance of strength and rigidity.

In addition to cellulose and lignin, wood contains a small amount of mineral matter. These minerals, known as "ash forming" minerals because they are left as ash when the lignin and cellulose are burned, constitute less than one percent of the total wood substance.

The extractives are not part of the wood structure as such, but they contribute such properties as color, odor, taste and resistance to decay. They include tannins, starches, oils, resins, acids, fats and waxes. They are found within the hollow portions of the wood cells, and can be. removed from the wood by neutral solvents such as water, alcohol, benzol, acetone and ether.

Hardwoods and Softwoods

All wood species are classified for commercial purposes as either hardwoods or softwoods.

The hardwoods are the broad-leafed, deciduous trees which drop their leaves at the end of the growing season. Examples of commercially-grown hardwoodtrees include oak, maple, walnut and ash.

The softwoods are evergreen trees. Evergreen trees may have fern-like leaves, typical of the redwoods, or needle-shaped leaves typical of the pines and firs. Softwoods are also known as conifers (or "cone bearers") because all softwood trees bear cones of one kind or another.

The terms "hardwood" and "softwood" are somewhat misleading in that they have no direct application to the actual or relative hardness or softness of a particular kind of wood. Many hardwoods are softer than the average softwood. Douglas Fir, which is widely used in the west as a construction material, is a softwood by definition; nevertheless, the better grades of Douglas Fir are dense, hard and tough.

Specific Gravity

Although dry wood of most species will float in water, the absolute specific gravity of the basic substance of which wood is composed is about 1.55 for all species. Thus it is evident that a large part of the volume of wood is occupied by cell cavities and pores, so that the resultant relative specific gravity of wood is less than 1.00 for most species.

Variation in the size of the cell openings and the thickness of the cell walls causes some species to have more wood substance than others and therefore to have higher relative specific gravities. Consequently, the density of cut lumber will vary between species, averaging from 30 to 40 pounds per cubic foot at normal moisture content for most commerically grown softwoods.

Since density depends on the amount of wood substance in a given piece of lumber, it is an excellent index of strength. The higher the density, the greater the strength of cut lumber, all other factors being equal.

Grain

The term "grain" as it is applied to wood is most often used to indicate the direction of the wood fibers relative to the axis of the tree or the longitudinal edges of a piece of cut lumber. Thus, if the fibers are generally parallel to the axis of a tree, the lumber from the tree will be straight-grained; however, if the direction of the fibers makes an angle with the axis, the lumber will be cross-grained.*

Grain is also used in reference to the width and spacing of the annual growth rings. Thus, lumber may be close-grained, medium-grained or coarse-grained. Note, however, that these are relative terms without precise meaning.

Edge grain refers to lumber in which the growth rings are at approximately right angles to the surface of the piece. Flat grain refers to lumber in which the surface of the piece of lumber is approximately tangent or parallel to the direction of the growth rings.

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* Note that the term "cross-grain" is also used to indicate a direction which is actually perpendicular to the grain. This usage is generally associated with the direction, with respect to the grain, at which a load is applied.

WOOD CHARACTERISTICS

Moisture Content

Living trees may contain as much as 200 percent moisture by weight. After a tree is cut and converted into lumber, the wood begins to lose moisture. The process of removing moisture from green lumber is known as seasoning, which may be accomplished by exposure to the air or by kiln drying,

Green wood contains moisture in two forms: as "free water" in the cell cavities and as "absorbed water" in the capillaries of the cell walls. When green wood begins to lose water, the cell walls remain saturated until the free water has evaporated. The point at which evaporation of free water is complete and the cell walls begin to lose their moisture is called the "fiber saturation point." The fiber saturation point occurs at a moisture content of about 25 to 30 percent for most species.

Variations in moisture content above the fiber saturation point have no effect on the volume or strength of wood. As wood dries below the fiber saturation point and begins to lose moisture from the cell walls, shrinkage begins and strength increases.

Wood in use over a period of time will give off or take on moisture from the surrounding atmosphere until the moisture in the wood corresponds to the humidity of the surrounding atmosphere, When exposed to similar atmospheric conditions, different woods will have the same moisture content regardless of their density.

Moisture content has an important effect on susceptibility to decay. Most decay-producing fungi require a moisture content above the fiber saturation point to survive. In addition, favorable temperatures, an adequate supply of air and a source of food are essential. Wood that is continuously water-soaked (as when submerged) or is continuously dry (i.e., with a moisture content of 20 percent or less) will not decay.

Shrinkage

Shrinkage of wood takes place between the fiber saturation point and the oven-dry condition. It is stated as a percentage of the original or green dimension.

Wood shrinkage is greatest in the direction of the annual growth rings, somewhat less across the rings, and very little along the grain. Typically, shrinkage along the grain (longitudinal shrinkage) is usually less than one percent and therefore too small to be of practical significance.

Shrinkage of commercial softwood boards across the grain averages about one percent for each four-percent change in moisture content. Shrinkage of hardwoods is slightly larger.

Large structural timbers shrink proportionally less than smaller pieces of lumber because drying does not take place simultaneously in the inner and outer portions. The inner portion dries more slowly than the outer portion and prevents the wood near the surface from shrinking normally. Later, when drying of the interior occurs, the outer portion which has now set prevents the inner portion from shrinking to the extent that it otherwise would.

Strength of Wood

Introduction

The term "strength" as it is used in structural design terminology refers to-the ability of a given material to resist elastic deformation when subjected to external forces. Unlike most other building materials, however, wood exhibits different strength properties depending on whether the forces are applied parallel or perpendicular to the direction of the wood fibers or "grain" of the wood. In general, wood is strongest along the grain and weakest at right angles to it.

Because the strength of a given piece of wood depends on the direction of the wood fibers with respect to the direction of the applied load, it is necessary to consider the effect on wood strength of each of the stresses produced by a particular loading condition. These stresses, and the ability of wood to withstand them, are discussed in the following sections.

Tensile Strength

The tensile strength of wood parallel to the grain depends on the strength of the fibers and is affected not only by the nature and dimensions of the wood elements but also by their arrangement. It is greatest in straight-grained specimens with thick-walled fibers. Cross-grain of any kind will materially reduce the tensile strength of wood, since tensile strength perpendicular to the grain is only a small fraction of the strength parallel to the grain. The ratio of tensile strength parallel to the grain to tensile strength perpendicular to the grain is commonly as high as 40 to 1.

WOOD CHARACTERISTICS

When loaded in direct tension, strain and stress are proportional virtually to ultimate load, and there is no well-defined proportional limit below this point. Wood, therefore, will yield only a very slight amount prior to ultimate failure in direct tension.

As a matter of interest, if only the net cross-sectional area of a piece of wood is considered (i.e., if the cell cavity area is deducted) the ultimate tensile strength of a clear specimen is about 70,000 psi, which is comparable to the strength of mild steel.

Compressive Strength

There are two ways in which wood may be subjected to compressive stress: compression perpendicular to the grain sometimes referred to as cross-grain compression, and compression parallel to the grain.

Compression perpendicular to the grain is often critical in timber design. It is usually most severe at the ends of deep, narrow beams, and in the connecting members at the top and bottom of short, heavily-loaded columns.

The primary effect of compression perpendicular to the grain is compaction of the wood fibers. As the fibers compact, the load-carrying capacity of the wood increases as the density of the material increases.

If the load is applied to only a portion of the upper surface, the bearing plate or post indents the wood, crushing the upper fibers without affecting the lower part of the member. Under this loading condition, the projecting ends of the member increases the strength of the material directly beneath the compressing weight by introducing a beam-action which helps support the load; however, this beam-action is exerted for a short distance only.

Compression parallel to the grain will occur in many uses of wood (such as columns, props and posts) in which the member is subjected to loads which tend to shorten it lengthwise.

The compressive strength of wood parallel to the grain is from three to five times greater than the compressive strength perpendicular to the grain. The ratio is about the same for both green and seasoned material.

Maximum compressive strength parallel to the grain is a measure of the ability of a short column to withstand load, In long columns, however, bending is introduced before the full crushing or compressive strength is reached, and failure is by lateral bending of flexure, rather than by crushing.

In determining the strength of wood columns, the ratio of the unsupported length of the member to the least cross-sectional dimension is of primary importance. Short columns having an unsupported length of less than 11 times the least dimension have practically the full compressive strength of the material, whereas the strength of extremely long columns is governed entirely by the stiffness of the wood and resistance to endwise compression is not involved. For columns between these two extremes both the compressive strength and the stiffness of the wood are taken into consideration.

Shearing Strength

Shearing strength is a measure of the ability of wood to resist forces that tend to cause one part of a member to slip or slide along another part adjacent to it.

Shearing stresses will occur under almost all loading conditions, and the forces which produce them are classified according to the direction in which they act as shear parallel to (or along) the grain and shear perpendicular to (or across) the grain.

Under certain conditions, shearing stresses may act both perpendicular to the grain and parallel to the grain at the same time. For example, in a loaded beam the applied forces tend to shear the wood across the grain. This stress is equal to the resultant force acting perpendicular to the axis of the beam at any point. In a member uniformly loaded and supported at both ends, the stress is maximum at the points of support and zero at the center. In addition, there is a shearing force tending to move the fibers of the beam past each other in a longitudinal direction, or along the grain. In a beam this force is known as "horizontal" shear.

The presence of horizontal shear in the direction of the grain may be readily demonstrated by placing several boards one on top of the other and loading them at the center. As the boards bend, they slip over one another so that the ends of each project beyond those of the one below. In a solid beam this movement is restrained, and the longitudinal shear stresses developed are maximum at the neutral plane and decreased toward the upper and lower edges.

WOOD CHARACTERISTICS

The resistance of wood to shear perpendicular to the grain is much greater than its ability to withstand shear along the grain. So much so in fact, that shear perpendicular to the grain may be ignored in beams, stringers and similar members. However, horizontal shear is frequently critical in beams and caps, particularly in the case of short, deep members, and should be considered when designing or checking any member which is subjected to bending stresses.

Flexural Strength

When external forces acting in the same plane are applied at right angles to the axis of a simple beam causing it to deflect or bend, three fundamental stresses -- compression, tension and shear -- will occur within the member, all acting in a direction parallel to the grain.

If the beam is loaded too heavily, it will break or fail in some manner. Beam failures are classified according to the way in which they develop; i.e., compression failure, tension failure or horizontal shear failure. A combination of failures may develop if the beam is completely ruptured.

Since the tensile strength of wood parallel to the grain is normally from two to five times greater than the compressive strength in the same direction, beam failure w-ill occur first by crushing on the compression side, followed by tearing or rupture of the wood on the tension side. Horizontal shear failure is fairly common when the ratio of the height of the beam to the span is relatively large, since it is the short, deep beam which is subjected to the loading condition which produces maximum shearing stress.

Stiffness

The stiffness of wood, when used in reference to either a beam or long column, is a measure of its ability to resist deformation or bending. It is expressed in terms of the "modulus of elasticity" and applies only within the proportional limit.

Because of its fibrous structure, wood is characterized by three moduli of elasticity, one for each structural direction. Values for modulus of elasticity in the two directions perpendicular-to the grain are relatively low, being approximately l/12 to l/20 of the value parallel to the grain. As far as solid wood beams are concerned, however, the value for modulus of elasticity parallel to the grain is the only one of importance.

The modulus of elasticity is used in calculating the deflection of beams and joists, and in computing safe loads for long and intermediate columns.

Although stiffness is independent of bending strength, woods which rank high in one respect usually rank high in the other as well.

Effect of Moisture Content

Wood increases in strength as it dries. The strength increase begins at the fiber saturation point (the point at which the cell walls begin to loose moisture) and increases rapidly as drying continues.

Drying wood from the fiber saturation point to five-percent moisture will usually double and in some cases triple end-crushing strength and bending strength. However, this increase in strength with seasoning is greater in small, clear specimens of wood than in large timbers. In the latter, increase in strength-bay be offset to some extend by checking, if checking develops during the seasoning process.

Not all strength properties increase with a decrease in moisture content; in fact, properties indicative of toughness. or shock resistance may actually decrease as wood dries. This is because dried wood will not bend as far as green wood before failure (although it will sustain a greater load) and because toughness depends on both strength and flexibility.

Duration of Load

Wood has a unique property not found in other building materials. This is its ability to withstand a proportionally greater stress as the length of time the load is applied is decreased.

Both the elastic limit and the ultimate strength of wood are higher under short-time loading than under long-time loading. Wood is thus able to absorb overloads of considerable magnitude for short periods of time, or smaller overloads for longer periods of time, Obviously, the duration of a load is an important factor in determining the total load that a member can safely carry.

WOOD CHARACTERISTICS

Wood Defects

Definition

As defined by ASTM, a defect is any irregularity occurring in or on wood that reduces its strength as compared to the strength of a clear-grained specimen.

Knots

A knot is that portion of a branch or limb which has been incorporated into the body of the tree. Knots are the most prevalent defect in structural timber.

In structural beams, the effect of a knot on bending strength depends on the size and location of the knot. In a simply-supported beam, for example, knots on the lower side are placed in tension, those on the upper side in-compression and those at or near the neutral axis in horizontal shear. On the tension side at the point of maximum stress, a knot has a marked effect on the total load a beam will carry, while knots on the compression side are somewhat less serious. In any location, knots have little effect on shearing strength.

Knots have little or no effect on stiffness; hence in long columns where stiffness is the controlling factor knots are not viewed as a strength-reducing defect. In short and intermediate columns, thereduction in strength due to knots is approximately proportional to the size of the knot. Large knots, however, have a somewhat greater relative effect than small knots.

The reduction in strength due to the presence of knots in a given piece of lumber is caused primarily by local distortion of the wood grain in and around the knot. Knots interrupt the normal direction of the grain and cause localized cross grain with very steep slopes. As knot size increases, the distortion of the grain around the knot is more than proportionally increased; consequently, the size of a knot compared to the size of the piece is an important consideration.

Since the strength-reducing effect of a knot depends more on the distortion of the surrounding grain than on the knot itself, knotholes have the same effect on strength as knots. Since holes due to other causes are not accompanied by a distortion of the grain, the limitations that apply to knotholes are sufficient to determine the effect of other holes as well.

Checks and Shakes

A "Check" is a separation of the wood fibers along the grain but across the rings of annual growth. A "shake" is a separation of the wood fibers along the grain between and parallel to the rings of annual growth.

Checks commonly occur as a result of unequal shrinkage during seasoning. Shakes are the result of the rupture of wood cells in a weakened portion of the wood; they seldom develop unless they were present to some degree before the tree was felled.

Checks and shakes will reduce the shearing strength of members subject to bending, particularly if they are located near the neutral axis. They have little effect on the strength of members subject to compression parallel to or perpendicular to the grain.

Splits

Splits are lengthwise separations of the fibers extending from one surface completely through a piece to another surface. Splits are the result of internal stresses or rough handling. Splits affect strength in the same way as checks and shakes.

Cross Grain

Cross-grained wood is defined as wood in which the cells or fibers run at an angle with the axis, or sides, of the piece.

To determine the effect of cross grain on the strength of wood, it is necessary to have some measure of its degree. This is afforded by the "slope" of the cross grain, which is defined as the deviation of the grain from the edge of the piece or from a line parallel to its principal axis. Slope is usually designated by the ratio of a one-inch deviation of the grain from the edge to the distance along the edge over which the deviation occurs. Thus a slope of one-in-twenty means that over a distance of 20 inches along the edge, the grain deviates one inch from the edge.

Since the ratio of tensile strength parallel to the grain to tensile strength at right angles to the grain ranges from about 25 to 1 in unseasoned wood to as high as 45 to 1 in air-dry material, it is apparent that even the slightest deviation from straight grain will tend to reduce the tensile strength bf a given piece of lumber. However, this decrease does not become appreciable until a slope of about one-in-twenty is reached; hence lumber in which the slope of the grain is less than one-in-twenty is considered as straight-grained material for all practical purposes.

WOOD CHARACTERISTICS

In compression, the effect of cross grain is less marked, since, strength parallel to the grain in both unseasoned and dry material is only about three to five times the strength perpendicular to the grain. Therefore the slope must approach one-in-ten before a decided decrease in compressive strength is evident.

In shear, the weakening effect of cross grain is small and usually is neglected.

Diagonal Grain

Diagonal grain is produced in lumber entirely by the method of sawing and has no reference to the natural alignment of the wood elements. In cutting lumber, if the plane of the saw blade is not approximately parallel to the bark surface, the grain of the wood will not be parallel to the edges and thus is termed "diagonal."

Diagonal grain has the same strength-reducing effect on a piece of lumber as cross grain.

Warping

Warping is defined as any deviation of a piece of lumber from a true or sawed surface. Warping most often occurs as a result of differences in the longitudinal shrinkage of the two faces of a board. It also may be caused by internal stresses present in the log at the time of sawing.

Warping has no effect on the inherent strength of wood; however, pronounced warping will materially reduce the bearing area of joists and beams and thus make it difficult to develop a satisfactory connection.

Wane

Cut lumber is sometimes characterized by the presence of bark, or by a lack of wood, on the otherwise square edges or corners of a piece. This condition, which is termed wane, is commonly considered a defect although it has no direct effect on strength except as it reduces the cross-sectional area of the piece.

As with warping, wane present at the end of a piece will reduce the bearing area and thus indirectly increase the bearing stress.

Decay

Wood is subject to attack by many low forms of plant life known as fungi. These "wood inhabiting" fungi differ from ordinary green plants in form, lack of green coloring matter, and methods of nutrition. Unlike green plants, they are unable to manufacture their own food, but must have organic material already prepared for their use. This they find in the wood substance composing the cell walls. The action of the fungi results in disintegration of the actual wood substance and gives rise to the condition known as decay.

The development of decay is dependent on the presence of an appreciable amount of moisture in the wood. Although the minimum requirements vary with different fungi, it is generally considered that wood must contain at least 20 percent moisture before decay will occur. Consequently, thoroughly air-dried or kiln-dried lumber is immune from decay unless it is subjected to wetting over a long enough period of time that its moisture content is raised to approximately the fiber-saturation point.

A small supply of oxygen is necessary for the fungi to grow and develop, so that wood which is completely saturated is immune to decay.

Since decay involves an actual breaking down of the cell walls, it is evident that it vitally affects the strength of wood, particularly in the advanced stage. Decayed lumber should never be used for any structural purpose.