UNIT STRESSES IN TIMBER

1927

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FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin
In Cooperation with the University of Wisconsin

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By

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The fact that there are several hundred species of arborescent plants in the United States and a greater multiplicity of such species in the tropics has led many engineers to consider the subject of wood and its properties too indefinite and complicated to justify even a superficial study, much less a close analysis.

The speaker's purpose is to correct some misconceptions concerning wood. Under his supervision about 700,000 strength tests of wood have been performed, many of which were on structural timbers. Many others were made during the World War in connection with aeroplane construction.

People see pieces of balsa wood, or read about its being only one-sixth as heavy as water, and about other species being heavier than water. They hear that the Army and Navy are using for spruce a stress in extreme fiber in bending of 9,400 lb. per sq. in., and also that aeroplanes have been examined and evidences found that the timber in them had been subjected to a stress of 11,000 to 12,000 lb. without failure; and then, as an anti-climax, they see a table of stresses recommended by the Forest Products Laboratory, in which a "Select" grade of spruce is rated as good for 1,100 lb. per sq. in. Usually, engineers and contractors stop here and say, "Well, since the factor of safety for spruce is evidently about 12, the load indicated by a stress of 1,100 lb. may be multiplied by 4 and still be within a good margin of safety; and with this wide margin almost any species can be substituted for another in the same sizes." They do not know wood thoroughly, or they would not conceive of this margin. Once in a while wood does fail. Most of the failures occur in concrete forms and falsework. The optimistic contractor thinks he has this large factor of safety, he quadruples the load, and down goes the structure.

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[1]Presented at the special meeting of the Structural Division, American Society of Civil Engineers, Oct. 28, 1925 and published in Transactions of American Society of Civil Engineers, Vol. 91, p. 387 (December 1927).

The engineer, as a rule, does not need to become an expert in the identification of species, nor does he have to be familiar with the properties of many species in order to use wood intelligently. It is not usually important to be able to distinguish between species that are quite alike in appearance and weight, since under these conditions their strengths would be approximately the same. As far as strength is concerned, for instance, it is not necessary to be able to distinguish between the fifty-seven different species of oak. Where resistance to decay is of importance they are divided into two groups. Again, it is not necessary--in fact, it is often impossible--to distinguish between the lumber of the various species that are classed as Southern pine. If a piece of true loblolly or shortleaf pine has the growth and appearance of typical longleaf it has the properties of the longleaf; or a piece of true longleaf may be soft and light in weight and be more representative of "Arkansas soft pine" than the average of shortleaf pine from which the "Arkansas soft pine" is selected.

The extremes of the species in general use for structural timbers, when considered from a strength standpoint, are Eastern hemlock and white fir, the weakest, and southern yellow pine and Douglas fir, the strongest. The latter have about one and one-half times the strength and stiffness of the hemlock and white fir. Southern pine and Douglas fir furnish not only most of America's structural timbers, but also more than one-half of all its lumber.

The characteristics of the species, their inherent properties, the prevalence of certain defects and their relative likelihood to develop other defects in service, and the influence of duration of stress are all considered in assigning working stresses. Different limitations imposed on factors which are common to all species explain the difference in recommended working stresses for wood in aeroplanes and in house construction. These factors will be illustrated in the inverse order of their importance, as follows: (1) The variability of the strength of the clear wood; (2) the effects of moisture on strength; (3) the duration of stress; and (4) defects.

Strength of clear wood

Figure 1 represents the variability in modulus of rupture of Sitka spruce in a green condition. Sitka spruce is taken as an example as more data are available on this species than on practically any other, on account of its war-time importance in aircraft. The curve is characteristic of all variability curves for wood. It will be noticed that it is not symmetrical, the greater number of tests (690 out of 1,304) giving values below the average and the greater range of variation lying above the average, while the most probable value, corresponding to the highest point on the curve, is slightly below the average. A density curve for any given species is practically a normal probability curve. The strength properties of a species vary usually as a power of the specific gravity, fractional but greater than unity, which produces an unsymmetrical curve of the type shown in Figure 1.

In assigning working stresses, primary consideration is given to the one-fourth of the pieces lowest in strength. For aeroplanes, a lower limit for specific gravity is set which eliminates most of the lower one-tenth of the material but does not change the most probable value. In southern yellow pine and Douglas fir it is possible to eliminate a little of this low material (along with a little of the higher) by the "ring" rule or "rate of growth" rule. A more satisfactory rule for selecting material of these species is that known as the density rule, by which density is determined from an estimate of the proportion of summerwood.

Variation of strength with moisture

In Figure 2 is shown the influence of moisture on the strength of spruce wood. These are old curves. They represent work that was done quite a number of years ago on relatively few pieces of small size. More recent data show the average strength of the green material to be slightly higher than these early tests indicate. The horizontal line at the right of each curve represents the strength of the green material; when the fiber saturation point is reached, that is, when all the free water is out of the cell, the cell wall begins to lose its water and the strength of the material goes up quite rapidly. Since in any ordinary drying some of the cells will contain free water while others are below the fiber saturation point, in practice the curve, instead of being straight to the fiber saturation point, and then having a sudden break upward, is a transition curve of varying radius, depending on numerous conditions. As between this "green" strength and the strength at 15% moisture, the most recent curve for modulus of rupture shows practically an increase of 50 percent. The increase in the shear strength is not sufficient to be of much importance in structural material.

Duration of stress

The diagram, Figure 3, shows the influence of duration of stress on the strength of timber. A logarithmic scale is used for the time co-ordinate because it illustrates the law better than a direct plotting. The upper curve is for fiber stress at the elastic limit and the lower one for modulus of rupture. In each curve the value from the Forest Products Laboratory's standard static-bending tests, which require on the average about 5 min., is taken as 100% (point marked a, Fig. 3). The point farthest to the right (b) represents the average strength of pieces which broke in from six months to a year under dead load. No rupture strength data are available for periods of time much less than 1 sec. The point in the extreme left-hand corner (c)[2] represents an elastic limit stress in impact. In developing the curves little weight was given this point (even though it represents thousands of tests), since there are several factors which cannot be eliminated and tend to raise the point slightly.

[2] From Bulletin 556, U.S. Dept. of Agriculture.

In aeroplane flight it is impossible to maintain the conditions which give maximum stress for more than a few seconds, in which case there is a factor of almost two as compared with the load that the same material will carry for a long time--as in a library floor, for instance. This shows why timber structures should be designed for static loads and the impact due to live load neglected unless the impact stress exceeds the static stress due to the live load.

Defects

The fourth and most important factor affecting the strength of timber is its defects. One of the most serious defects is decay, which should not be allowed in any important structural member. Timber that is thoroughly air-dry and constantly kept in that condition will not decay unless it is in contact with other material that is decaying. A mill floor in Philadelphia, Pa., recently examined, revealed that wet pine had been sealed in as a sub-floor, with paper and wet concrete below and a tight top floor above, thoroughly oiled, making the conditions ideal for decay. The sub-floor rotted out completely, and the fungi passed through the top floor and base moulding into the longleaf pine columns, rotting them out in two years. These columns in the ground, unprotected, ought to have stood for seven or eight years. Decay must be prevented in timber buildings.

Figure 4 shows a knot, another serious type of defect in timber which often reduces the strength of a piece almost to zero. A knot is a part of the limb which, as the tree grew, became a part of the trunk. The fibers run from the bottom out into the limb. On the top they produce a kind of crinkle around the knot. Some of them seem to end there, but a number run through into the limb. The strength of the wood along the grain and across the grain is tremendously different. The variation is fifteen to fortyfold. Therefore, it would be better to have a hole the size of the knot proper than to have the knot with its attendant cross-grain.

The influence that a knot on the tension face at the point of maximum moment exerts on the strength of a green beam is approximately measured by the ratio of the diameter of the knot to the width of the face. The diameter of the knot is measured between lines parallel to the edges of the face. That is, a knot one-fourth the width of the face will reduce the the strength 25 percent. The same knot on the compression side would have about one-half this influence. Large knots have a somewhat greater influence on the strength than is indicated by this rule, owing to the relatively larger distortion of the grain around them. This effect is taken care of in the grading rules recommended by the U. S. Forest Products Laboratory so that the "Select" grade will insure 75% of the strength of the clear wood.

Large timbers never dry to as low a moisture content as small stock, and they develop more checks, especially around knots. The result is that although the average strength is increased by drying, about 25% of the timbers show no increase, and, therefore, no increase in working stress on account of seasoning is allowed. In the higher grades of joists, 4 in. and less in thickness, a slight increase in strength is recognized. In aeroplane stock the full strength of clear wood at 15% moisture and duration of stress of 4 sec. may be developed.

How working stresses are determined

In arriving at a safe stress for a "Select" grade of spruce structural timber, the starting point would be 5,760 lb. per sq. in., which is the average modulus of rupture for small, clear stock tested green at standard speed. Reduce this by one-fourth to take care of variability of the clear wood; make another reduction of one-fourth to take care of the maximum defect permitted in the grade; then take off about seven-sixteenths for the dead load effect over a number of years. This gives

$$5{,}760 \times \frac{3}{4} \times \frac{3}{4} \times \frac{9}{16}, \text{ or } 1{,}820 \text{ lb. per sq. in.}$$

as the stress under long-time loading at which an occasional timber, possibly 1 in 25, would be expected to fail. Thus, the recommended stress of 1,100 lb. per sq. in. gives a factor of safety of 1-2/3 for this bad timber and this worst condition of loading. The average timber has a factor of safety of about 2-1/4 for long-time loading, and for a few minutes will show a factor of safety of 4. With average timbers under impact there would be a factor of about 6. When the influence of duration of stress on the strength of timber is considered, it is apparent why it is recommended that timber be designed for dead load and for a long period of time neglecting any impact stresses unless they exceed the stresses due to the live load which produces those stresses. Wherever tests of structural timbers are available they are found to check these factors quite closely.

For many years the Forest Products Laboratory refrained from assigning any stress to timber and it always has refused to recommend stresses where the grading rule does not limit quite closely the weakest timber that could be accepted. The stresses were finally recommended at the urgent request of engineers, and although the lumber interests were given attention, they have had no vote in fixing these final values.

VARIABILITY IN MODULUS OF RUPTURE OF CLEAR WOOD

GREEN SITKA SPRUCE

SHIPMENTS 325-504-563-578-654-885-939

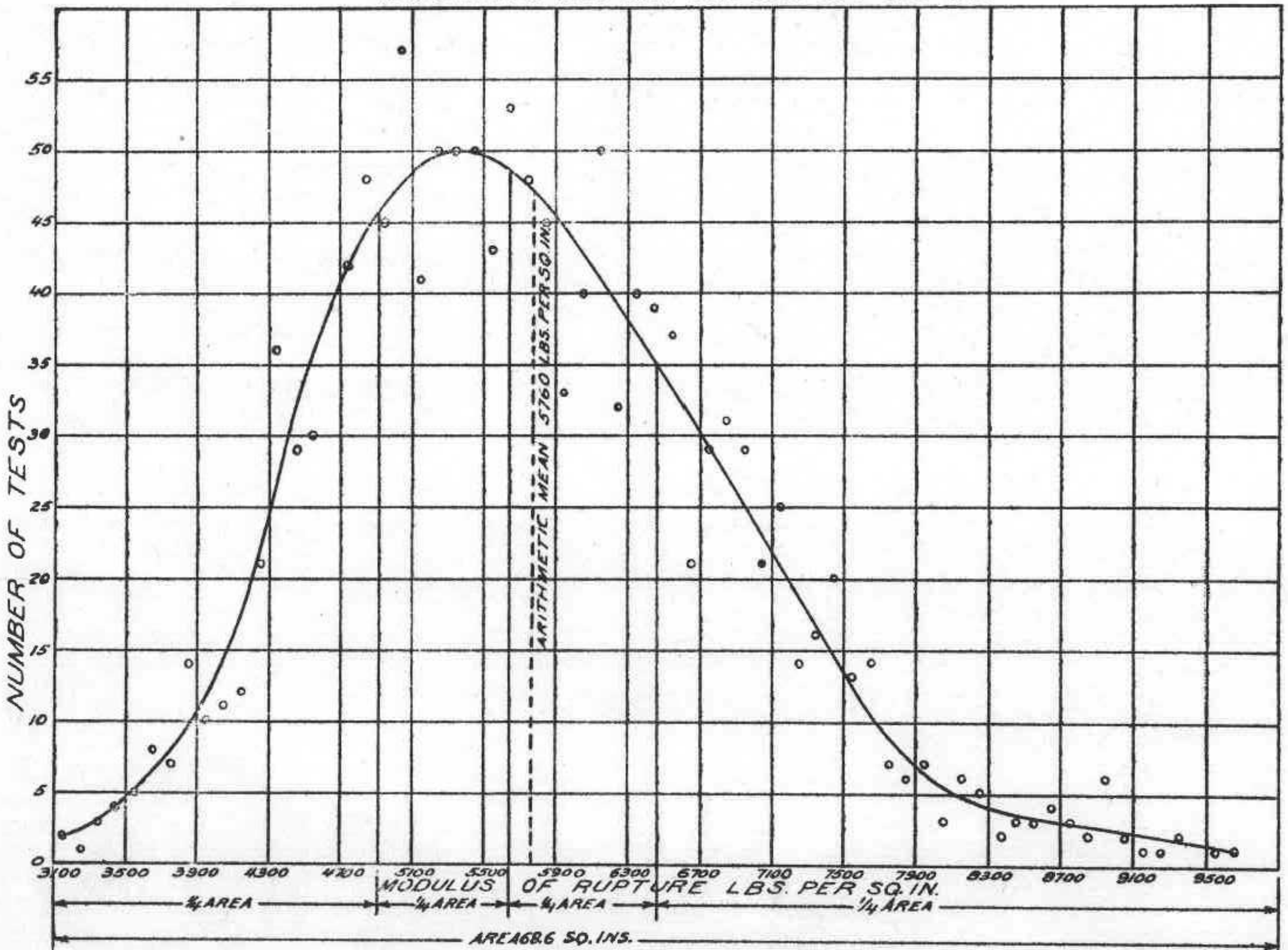

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Fig. 1

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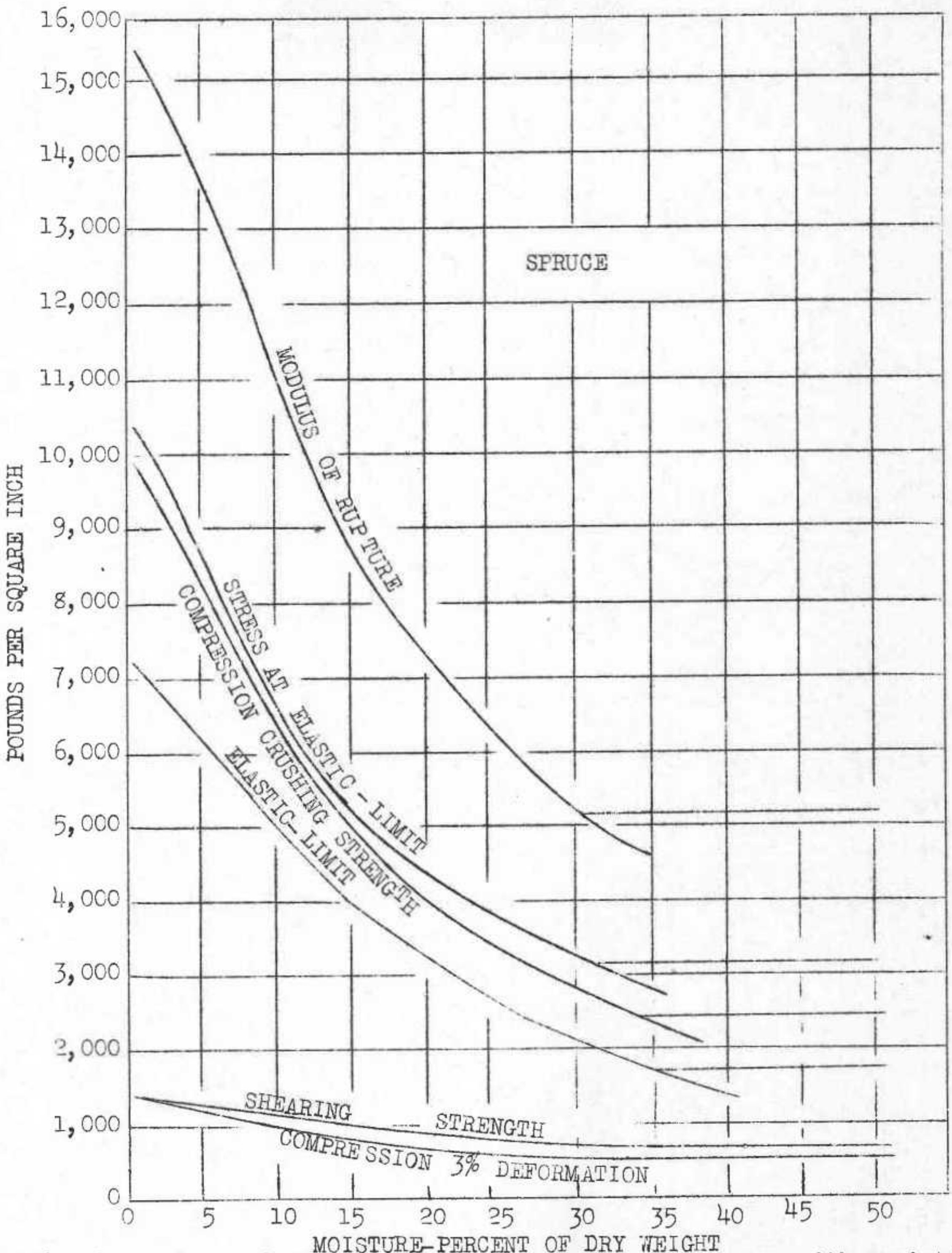

Fig. 2.--Comparison of the various strength values of spruce with variation in moisture. (The two upper curves are from bending tests and the lowest one from compression at right angles to grain.)

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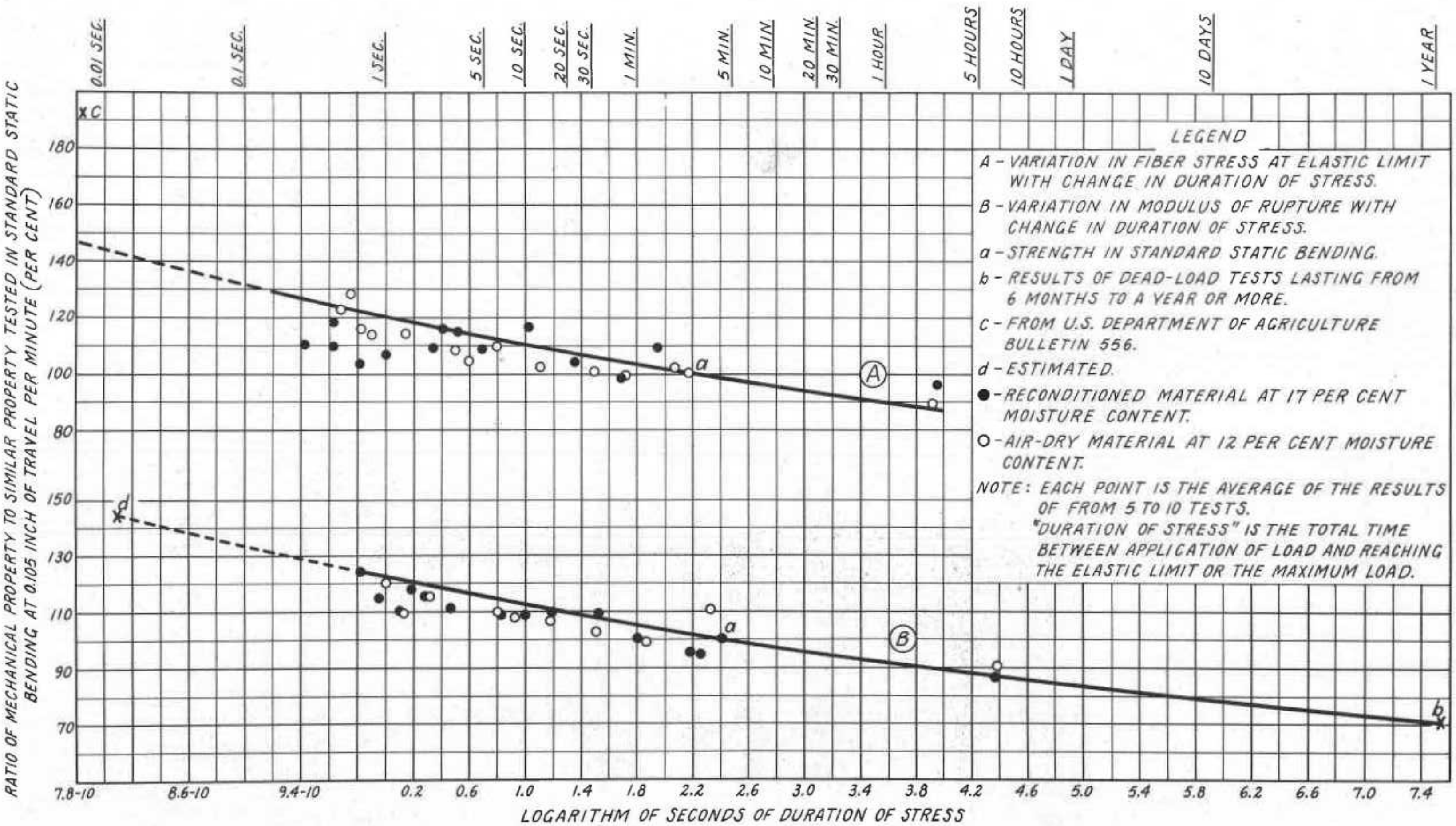
Figure 3.--Relation between mechanical property of Sitka spruce and duration of stress.


0.01 SEC.
0.1 SEC.
1 SEC.
5 SEC.
10 SEC.
20 SEC.
30 SEC.
1 MIN.
5 MIN.
10 MIN.
20 MIN.
30 MIN.
1 HOUR
5 HOURS
10 HOURS
1 DAY
10 DAYS
1 YEAR
LEGEND
A - VARIATION IN FIBER STRESS AT ELASTIC LIMIT WITH CHANGE IN DURATION OF STRESS.
B - VARIATION IN MODULUS OF RUPTURE WITH CHANGE IN DURATION OF STRESS.
a - STRENGTH IN STANDARD STATIC BENDING.
b - RESULTS OF DEAD-LOAD TESTS LASTING FROM 6 MONTHS TO A YEAR OR MORE.
c - FROM U.S. DEPARTMENT OF AGRICULTURE BULLETIN 556.
d - ESTIMATED.
● - RECONDITIONED MATERIAL AT 17 PER CENT MOISTURE CONTENT.
○ - AIR-DRY MATERIAL AT 12 PER CENT MOISTURE CONTENT.
NOTE: EACH POINT IS THE AVERAGE OF THE RESULTS OF FROM 5 TO 10 TESTS.
"DURATION OF STRESS" IS THE TOTAL TIME BETWEEN APPLICATION OF LOAD AND REACHING THE ELASTIC LIMIT OR THE MAXIMUM LOAD.
RATIO OF MECHANICAL PROPERTY TO SIMILAR PROPERTY TESTED IN STANDARD STATIC BENDING AT 0.105 INCH OF TRAVEL PER MINUTE (PER CENT)
LOGARITHM OF SECONDS OF DURATION OF STRESS
7.8-10
8.6-10
9.4-10
0.2
0.6
1.0
1.4
1.8
2.2
2.6
3.0
3.4
3.8
4.2
4.6
5.0
5.4
5.8
6.2
6.6
7.0
7.4
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90
70
A
B
a
b
c
d

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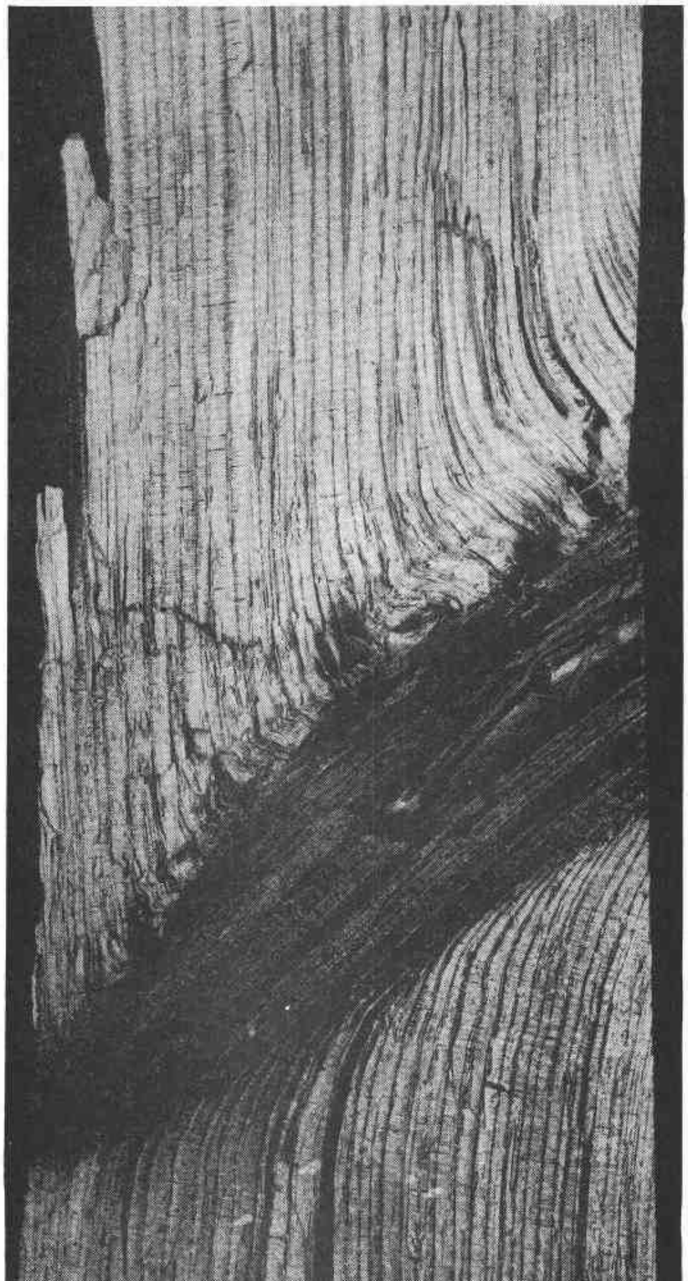

Fig. 4.--Knot showing characteristic difference in behavior of fibers on lower and upper sides.