FIBER STRESSES FOR WOOD POLES

March 1953

(Report)
No. D1619

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

FIBER STRESSES FOR WOOD POLES

By

T. R. C. WILSON, Formerly Chief
and
JOHN T. DROW, Engineer
Division of Timber Mechanics

Forest Products Laboratory,[1] Forest Service
U. S. Department of Agriculture

Summary

Considerable interest in design stresses for wood poles and particularly for poles of species formerly not extensively used for this purpose is occasioned by the need for war-deferred replacements and new construction. Data on pole production and needs are presented. Actions of the American Standards Association Sectional and War Committees are reviewed, and a systematic procedure for deriving design stresses for poles of any species is presented. In addition, several topics of interest in connection with pole-line design are considered.

Pole Production and Needs

Records of the total number of poles used in previous years are not complete. Careful records of the number of poles given preservative treatment have, however, been kept for a quarter of a century by the Forest Service and the American Wood-Preservers' Association. The available data are plotted in figure 1. These show a total of 1-1/2 million poles treated in 1923, rising steadily to 4-1/2 million in 1929, then dropping to 1-1/4 million in 1932, and again rising, but somewhat irregularly, to slightly more than 5 million in 1941. Following this, there was a drop to 2 million in 1943, and then a rise to 3 million in 1944, 4.2 million in 1945, 6.5 million in 1946, and a high point of 8.1 million in 1947. In the years 1948-1951 the total number of poles treated dropped to around 6 million.

---

[1] Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

In 1923 only about half the poles used in communication and power lines were given preservative treatment. At that time, the cedars and chestnut formed the bulk of the supply, and these species were used largely without treatment. Since then the proportion receiving preservative treatment has greatly increased in parallel with a large increase in the production of southern yellow pine poles, which from the first were recognized as requiring treatment because of the large proportion of nondurable sapwood. Also, the economy of preservative treatment to prolong the life of the likewise nondurable, but much thinner, sapwood of the cedars has been recognized. Hence, in recent years, a large proportion of all poles used has been preservatively treated, and the statistics on poles treated give a reasonable estimate of the total production and use.

During World War II, production of poles was hampered by shortages of labor and equipment, by demands for piling, and, in some instances, by dissatisfaction with established prices. Hence, during this period, production was, no doubt, considerably below the need for poles for maintenance of existing lines and for normal expansion.

The program of the Rural Electrification Administration, started in 1936, has had a considerable effect on pole requirements since that time. The program was built up to a high level during the years 1938-1941, after which, of course, the war conditions also caused a drastic reduction in the use of poles for this purpose. The very high consumption of treated poles during the years following the war, as shown in figure 1, reflected the extensive program of the REA from 1946 on, inasmuch as this agency alone accounted for the use of more than 2 million poles each year through 1950.

It appears that pole requirements in coming years will be less influenced by such extensive new construction, as the number of farms receiving central-station electric service increased from about 30 percent of the total in 1940 to 84 percent in June 1951. While it is difficult to predict the demand for poles in the coming years, it is reasonable to expect that a more normal rate of new construction, together with normal maintenance, will tend to stabilize pole requirements at some lower level than was experienced in the early postwar years.

It is probable that an increasing percentage of poles will be produced in coming years from species not formerly used in large quantities. Pole requirements in the Western States have increased materially because of the accelerated population growth in those areas, and it is logical that pole requirements in Western States will be supplied almost entirely from western species. In addition, there appears to be an increasing demand for larger poles, 40 feet and longer, and there is a definite feeling that poles in these classes are becoming more and more difficult to obtain from the species long established as the dominant suppliers. Even in poles of shorter length and smaller diameter, the increasing demands of the pulpwood industry for southern pine may have a direct influence on the availability of this species for poles in future years.

It is natural, therefore, that consumers are becoming more interested in the poles that can be produced in quantity and in all sizes from the forests of the Northwestern States. The fact that extensive additional pole-treating capacity in this area has been installed within the past few years is also of importance in the over-all picture.

Action of Previous Committee

War Committee

In anticipation of the situation described in the foregoing, a committee (War Committee on Specifications and Dimensions for Wood Poles -- miscellaneous Conifers, 05) was formed in 1945 by the American Standards Association to prepare war standard specifications for species not previously used as poles, and to set up values of modulus of rupture, or maximum fiber stress, for use in pole-line design. It may be recalled that a similar job was done several years earlier by an American Standards Association Sectional Committee and resulted in the adoption as American Standards of specifications and strength values for poles of chestnut, northern white-cedar, western redcedar, southern yellow pine, and Douglas-fir -- and shortly after, similar action on lodgepole pine, a western species then being for the first time considered for general use for poles, although it had been used in some experimental pole lines some years before. The strength values adopted as standard were incorporated in the National Electrical Safety Code.

American Standards Association Sectional Committee

Prior to the work of the Sectional Committee referred to previously, strength tests had been made on actual poles of all the species enumerated. These had been carried out by the American Telegraph and Telephone Company and its affiliates, the Canadian Forest Products Laboratories, U. S. Forest Service, and various other agencies. Most of these tests were subject to the criticism that they were made on poles in a variety of stages of seasoning and, consequently, were not directly comparable among the several species nor among different groups of poles of the same species, and were not comparable to the circumstances of service where a pole may be well soaked, particularly in the vicinity of the ground line, and, hence, no stronger than a green or completely unseasoned pole.

Beginning with its establishment at Madison in 1910, the Forest Products Laboratory has made systematic tests on a large number of native species in the form of small (2 by 2 inches in cross section with length depending on the type of test) sawed specimens free from knots or serious cross grain. These tests have been on both green and seasoned material. Specimens have been taken consecutively from pith to bark to get representation of all parts of the cross section and have for the most part been from the upper part of 16-foot butt logs. Systematic procedure in sampling and standardized methods of test have been followed in order to make the data fully comparable among various species. Results of tests of this kind have been published in U. S. Department of Agriculture Technical Bulletin No. 479 and will be referred to hereafter as "Bulletin 479 tests" or "Standard Tests." Similar tests have also been made by the Forest Products Laboratories of Canada.

In setting up the original American Standards Association fiber stress values, the Sectional Committee considered both the data from the tests that had been made on poles[2] and the data from the standard tests on green material. The values adopted were a compromise between the views of those who believed that the standard tests afforded the only fully valid comparison among species and of others who, despite the criticisms of the pole tests that have been pointed out, argued that tests on actual poles furnish the only realistic basis for setting up design values. The Forest Products Laboratory held the first view but concurred in the compromise as the most equitable schedule of values that could be agreed upon, except that concurrence in the value adopted for lodgepole pine was withheld on the ground that it was too far out of line with those assigned to the other species to be acceptable.

In addition to the adoption of strength values, the Sectional Committee prepared specifications for poles of each species. It also set up a scheme for grouping poles into a series of graduated strength classes such that the maximum side pull that could be sustained by a pole of a given class would be the same regardless of the species or the length. (With respect to side-pull requirements, the classes vary in approximate geometrical progression -- ratio about 1.25 -- from 1,200 pounds for class 7 to 4,500 pounds for class 1.) The required dimensions (circumferences at the top and the ground line) were then computed and tabulated for poles of each class, length, and species.

After the close of World War II the Sectional Committee undertook a revision of the American Standard Specifications and Dimensions for Wood Poles, which was approved as American Standard on April 9, 1948 (05.1 - 1948), and which had the effect of revoking the previous standards and war standards.

---

[2] Colley, R. H. Ultimate Fiber Stresses for Wood Poles. Bell Telephone System Monograph B-615.

Relation of Design Values Adopted by Sectional and War Committees to Strength Values for Green Wood

Sectional Committee

In figure 2, the stress values recommended by the Sectional Committee and adopted as standard by the American Standards Association in 1948 are plotted as abscissas opposite the so-called standard values for green material as ordinates and shown as dots. In connection with this chart and the subsequent discussion, it should be emphasized that the principal interest of the Laboratory is that design values should be fair, equitable, and consistent among the several species used for poles. What the general level of design values should be is for decision by those who are more intimately acquainted with the performance of poles under service conditions and with the numerous provisions relative to so-called safety factors set forth in the National Electrical Safety Code and by the state regulatory bodies.

The continuous inclined line in figure 2 is through the origin and at an angle of 45°. For points to the right of this line, the design value is obviously higher than the value used as ordinate and vice versa. The dashed line is through the origin and the point for lodgepole pine; hence, it may be noted that the adopted design value for this species is higher relatively than for nearly all of the other species represented by the dots, since these dots are all on or above the line mentioned except for western hemlock. (Inclusion of higher strength values for western hemlock as found by the Canadian Forest Products Laboratories would raise the point for this species and locate it above the designated line.)

For comparison, the stress values recommended by the Canadian Standards Association for certain species of timber used extensively for poles in Canada are shown as a Δ on the same basis as for the species covered in the American Standards.

War Committee

Plotted also in figure 2 on the same basis as previously outlined are the values set up for poles of additional species by the War Committee. These are shown as circles. A number of the species included in the War Standard Specifications were included in the 1948 revision of the Standards and are, therefore, shown in figure 2 as dots. The circles include only those species for which design stresses were assigned in the War Standard Specifications, but which are not found in the 1948 Standards. Tests of actual poles of all the additional species were not available, and the principal guides to fixing design values were the results of tests on small clear specimens, together with experience in the use of the design values previously adopted by the Sectional Committee. It is reported that over a period of years lodgepole pine poles rated in design at an ultimate fiber stress of 6,600 pounds per square inch have given fully satisfactory service. As may be noted, this value of 6,600 pounds per square inch is 20 percent above the modulus of rupture of small clear green specimens. The ratings assigned to the new species, on the basis of data then available, were accordingly taken as 20 percent or less above the corresponding values of modulus of rupture.

It may be noted that the circles all fall on verticals that are already occupied by one or more dots; that is, the additional species were assigned design values that had already been in use. This was done in order to avoid increasing the number of dimension tables required.

Now, if it is conceded that use of a design value of 6,600 pounds per square inch, which is 20 percent above the modulus of rupture of small clear green specimens, has resulted in lodgepole pine poles of adequate strength and satisfactory service, it should be fair, equitable, and safe to rate other species on the same basis. This suggests a scheme for classifying or grouping pole species with respect to strength values for use in design.

Classification of Pole Species

The assignment of a separate design value to each species would lead to a multiplicity of dimension tables and in general to unnecessary refinement. Hence, it is considered sufficient to classify the various species into groups and assign a design value to each group. If these design values are made to differ progressively by about 10 percent, the required minimum ground-line circumferences will differ by a little more than 3 percent, or about 1 inch for the average pole. This appears to be sufficient refinement of the grouping. Such a series of group values is listed at the right of figure 2. The lower limit for the 6,600 group is fixed by the assumption that 6,600 pounds per square inch is an acceptable design value for lodgepole pine and the further assumption that no species that is weaker (on the ordinate scale) than lodgepole will be given this rating. The lower limit for the 7,400 group is then taken at the intersection of the vertical line through 7,400 with the line through the origin and the point for lodgepole pine. Other division points are determined similarly.

Under this scheme, any species whose modulus of rupture (ordinate of fig. 2) is between a pair of horizontals would be assigned the indicated design value, except when other considerations dictate a deviation from the general scheme. A means is thus provided for classifying with respect to values for use in pole-line design any species for which strength values are available from tests of small clear specimens.

The scheme outlined with lodgepole pine as the guide or criterion was designed to give design values ranging from 20 percent (as for lodgepole itself) down to about 6 percent above the modulus of rupture as found from tests on green material. Subsequently, revised data for small clear specimens in the green condition for Engelmann spruce and eastern white pine had the effect of locating these points below the line connecting the origin and the point for lodgepole pine. Hence, these species would be 24.5 and 22.5 percent, respectively, higher than the modulus of rupture as found from tests of green material.

Obviously, no mathematical procedure such as that just outlined should be applied blindly and without giving weight to such other considerations as properly should influence decisions. As an example, the procedure would bring northern white cedar into the 4,800 group. This has been considered undesirable because poles of this species are likely to be weakened to a considerable extent by the presence of heart rot, and retention of the lower rating of 3,600 was considered desirable as a compensation.

The design-stress grouping indicated by figure 2 and discussed in the foregoing is premised on fully satisfactory service having been given by lodgepole pine poles whose necessary sizes were figured from the value of 6,600 pounds per square inch as the stress in extreme fiber. An alternative grouping derived by the same process used for that in figure 2 but based on western redcedar is shown in figure 3. Western redcedar was for many years the principal pole species and, prior to the adoption of the present value of 5,600 pounds per square inch, was rated at 5,000 pounds per square inch in the National Electrical Safety Code. Dense southern yellow pine was rated at 6,500; other yellow pine, chestnut, and cypress at 5,000; and northern white-cedar and redwood at the present value of 3,600 pounds per square inch.

The two procedures illustrated by figures 2 and 3 result in grouping of species with ultimate fiber stress values as shown in table 1. These groups and values may require some modification because of such factors as characteristic defectiveness of some species, restrictions on deflections, and difficulty of separating species produced together. As an example of the latter, longleaf pine is shown in table 1 at a rating lower than its modulus of rupture suggests because it is not distinguished in production from other southern pines, such as shortleaf and loblolly, which average lower in strength.

Additional Considerations

The strength rating given lodgepole pine by the National Electrical Safety Code is, as has been shown, 20 percent above the average modulus of rupture of small, clear, green specimens. The procedure of figure 2 does similarly for additional species and that of figure 3 causes ratings above the modulus of rupture but by a lesser percentage.

It may be asked how such figures can be justified and how pole lines designed from them can be expected to prove adequate. The following discussion relates to topics of interest in connection with pole lines and includes some that bear on these questions.

Moisture Relations

The strength of wood is essentially unchanged by changes or differences in its moisture content as long as this is above the fiber saturation point, which is some 25 percent (based on the weight of the oven-dry wood). Below this point, most strength properties increase, and at 12 percent moisture content modulus of rupture averages about 60 percent higher and longitudinal compressive strength nearly 100 percent higher than for green or wet wood. In partially seasoned poles or other products, moisture content is low at the outside and increases toward the center, and modulus of rupture may consequently be raised considerably above the value corresponding to the average moisture content. No reliable procedure is available for adjustment of strength values derived from tests on material in this condition. Hence, tests on partially seasoned poles are of very limited usefulness in deciding on design values. On the other hand, in an arid region a pole will have a strength above that of green material and the same may be true of a pole in well-drained soil in other regions.

Form and Size Factors

The stress (as computed by the usual formula) both at the proportional limit and ultimate in a wood member under transverse load depends on the shape of the cross section. The ratio of such stress to the corresponding stress for a rectangular member is called the form factor of the section. Tests have shown that the form factor of a wood I-beam with thin flanges may be as low as two-thirds. For a square section loaded in the direction of a diagonal, the value is about 1.41, and for a circular section about 1.18. This latter figure means that a round beam will sustain a bending moment 18 percent greater than is computed from its moment of inertia or section modulus, using the modulus of rupture derived from tests of square or rectangular beams. A wood pole has this advantage initially. After decay beings, the remaining sound portion may be round or at least convex in outline and some of the advantage be retained. On the other hand, the unit flexural strength of rectangular wood members decreases with the depth. This effect has not been explored for round members; but if it is quantitatively the same as for rectangular sections, it would in poles of average size offset the advantageous effect ot the form or shape factor.

Dimensions

In computing the required minimum circumferences used in the dimension tables, the decimals in the computed values were rounded upward to the nearest 0.5 inch. The circumferences of poles of a given species, length, and class vary from this minimum for the class up to just under the similar minimum for the next stronger class. Consequently, the poles in such a group vary in section modulus from the minimum required value up to about 25 percent above the minimum (since for poles of the same species and length, the factor for moment resistance between classes is 1.25) with an average some 10 to 12 percent above the minimum.

Rate of Load Application

Tests of wood beams and other members have demonstrated that the maximum load that can be resisted and the period during which it can be sustained vary with the rate of loading. Under successively and uniformly increasing impacts (as applied in the impact bending tests included in the standard series), for example, the stress at proportional limit is equal to or greater than the modulus of rupture developed under continuous increase of load at the rate used in standard tests, and the ultimate is probably nearly twice as great. (On the other hand, the load that can be sustained indefinitely is only slightly more than half as great as that found in the usual test.) Hence, under gust action poles may be expected to resist for very brief periods stresses substantially in excess of static values.

Deflections

It has been claimed that the use of high unit stresses in pole computations results in flexibility that is objectionable to linemen and in excessive lateral deflections under wind load or unbalanced wire pull. Insofar as this is valid it affords a reason for not assigning to poles of some of the stronger species a design value as high as their strength would justify.

Loading Assumptions

As in similar structural problems, loading assumptions and factors of safety are intimately related and economy requires that they be considered together. To be considered also is the seriousness of the results of structural failure and whether such failure will be hazardous to human life or only to property. Success of pole-line design at stresses above the actual strength may be expected if, in addition to factors applied in design, a further factor of safety is included in assumed loads. The infrequency of occurrence of the heavy loading combination of 1/2 inch of radial ice and wind pressure of 8 pounds per square inch is recognized in some of the codes by permitting deterioration of poles in certain classes of construction to two-thirds the required strength before replacement.

Effect of Knots and Other Defects

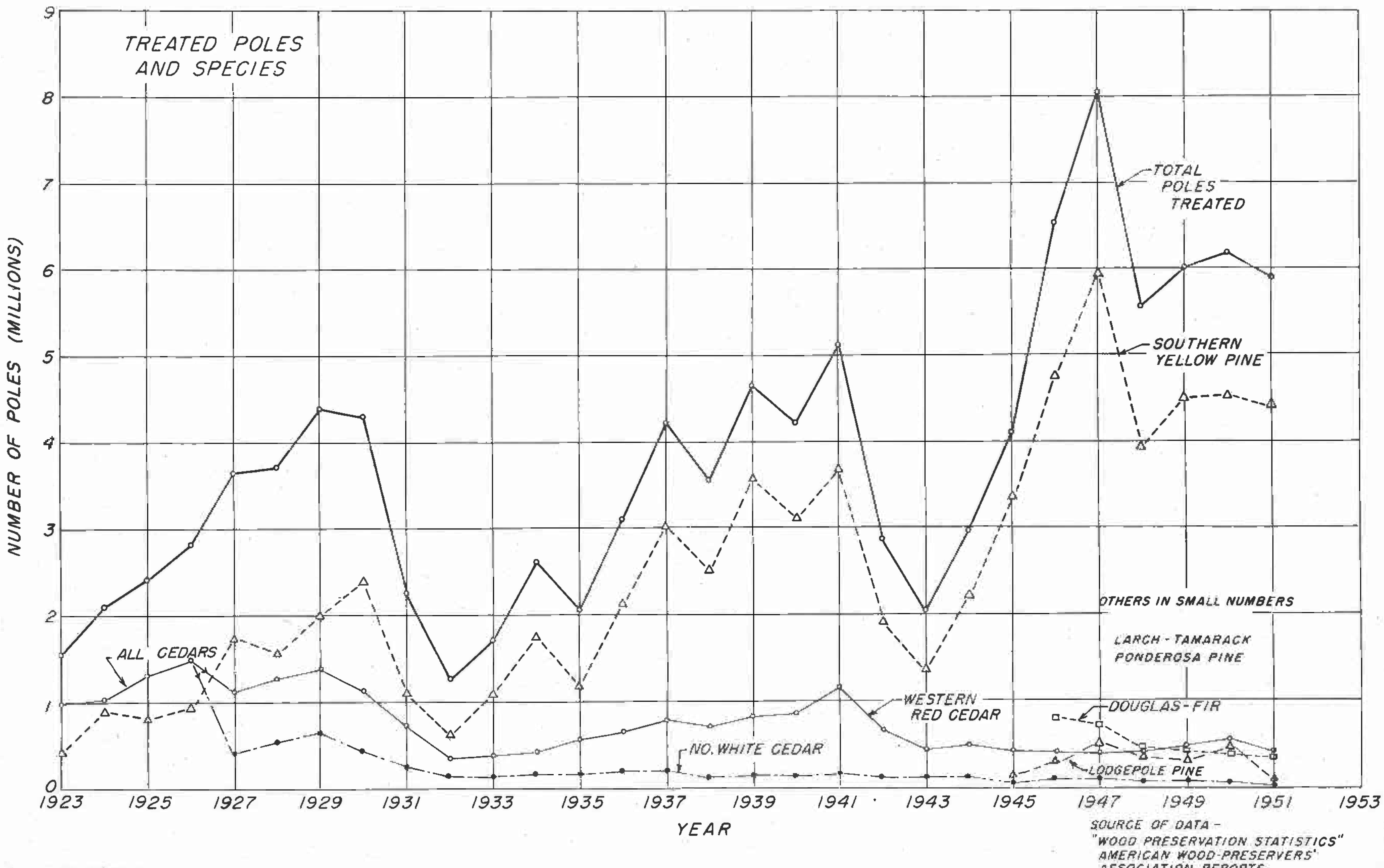
The National Electrical Safety Code specifies that "wood poles shall be of suitable and selected timber free from observable defects that would decrease their strength or durability." The Sectional and War Committees have attempted to give effect to this by specific limitations on knots and other defects. In general, knots of a size to cause a significant reduction in strength will not be present in the ground-line region.

Decay in new poles is limited to amounts that will have very little effect on strength. If poles are properly cared for subsequent to cutting, such decay is only that caused by fungus species that presumably become inactive when the tree is cut. Also sterilization is accomplished by the temperatures applied in preservative treatment.

Determination of the strength of poles that have been attached by decay in service and of the point at which such poles should be removed is a difficult problem. The Bell System lines have developed specific rules for deciding on removal and replacement and the Detroit Edison Company has experimented with the use of X-rays for this purpose.

Table 1. --Ultimate fiber stresses for wood poles derived by two procedures

Species	Lodgepole pine basis (fig. 2)	Western redcedar basis (fig. 3)
	P. s. i.	P. s. i.
Northern white-cedar	4,800	4,400
Engelmann spruce	5,200	4,800
Southern white-cedar	5,600	4,800
Eastern white pine	5,600	5,200
Ponderosa pine	6,000	5,200
Sugar pine	6,000	5,200
Western white pine	6,000	5,200
Western redcedar	6,000	5,600
Black spruce	6,000	5,600
White spruce	6,600	6,000
Sitka spruce	6,600	6,000
Red spruce	6,600	6,000
White fir	6,600	6,000
California red fir	6,600	6,000
Grand fir	6,600	6,000
Noble fir	6,600	6,000
Pacific silver fir	6,600	6,000
Jack pine	6,600	6,000
Red pine	6,600	6,000
Lodgepole pine	6,600	6,000
Eastern hemlock	7,400	6,600
Western hemlock	7,400	6,600
Douglas-fir (All)	8,400	7,400
Tamarack	8,400	7,400
Southern yellow pine	8,400	7,400
Western larch	9,400	8,400



ZM 92427 F

Figure 1. --Statistics on poles and species treated.

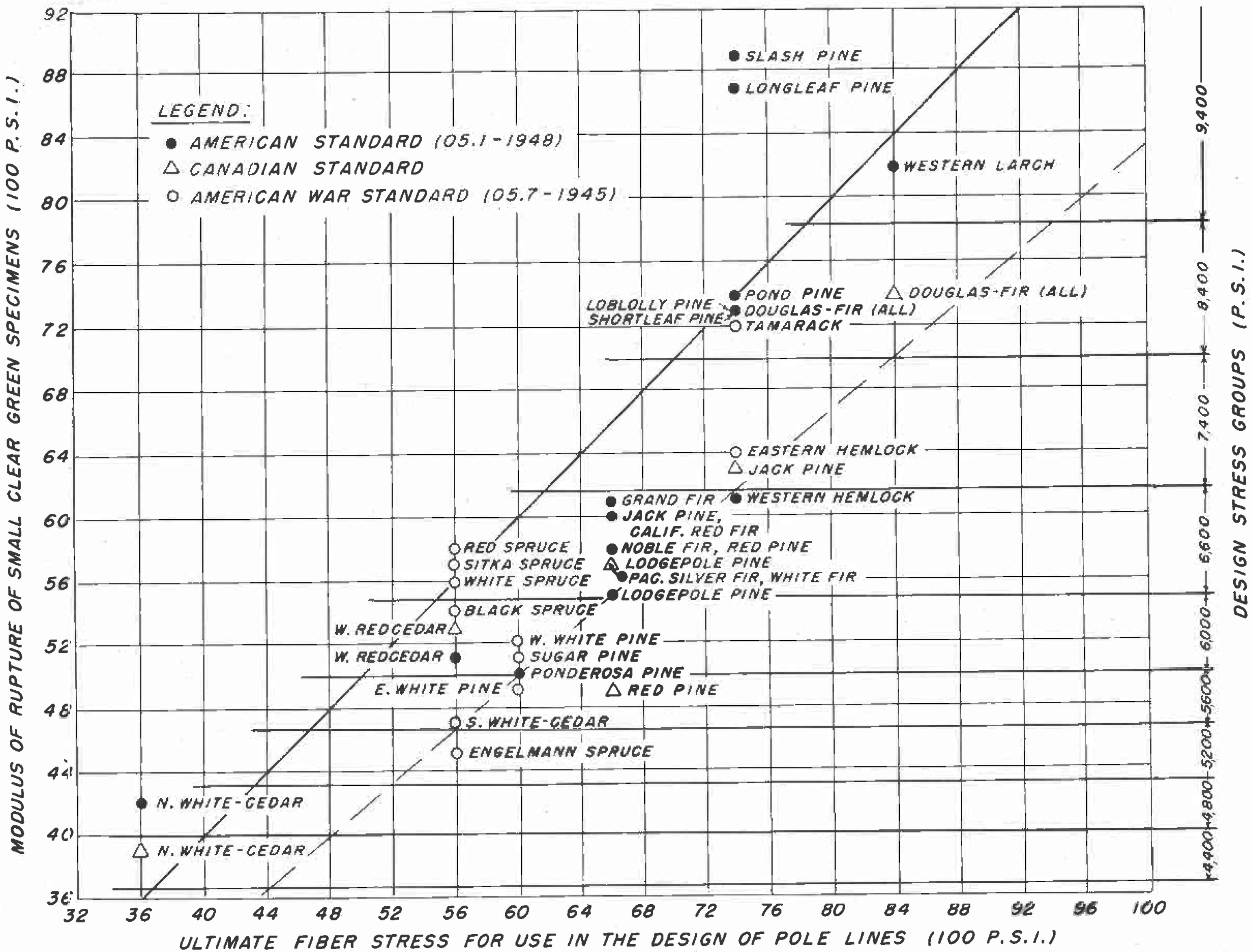


Figure 2. --Suggested procedure for deriving design values. Lodgepole pine basis.

ZM 92428 F

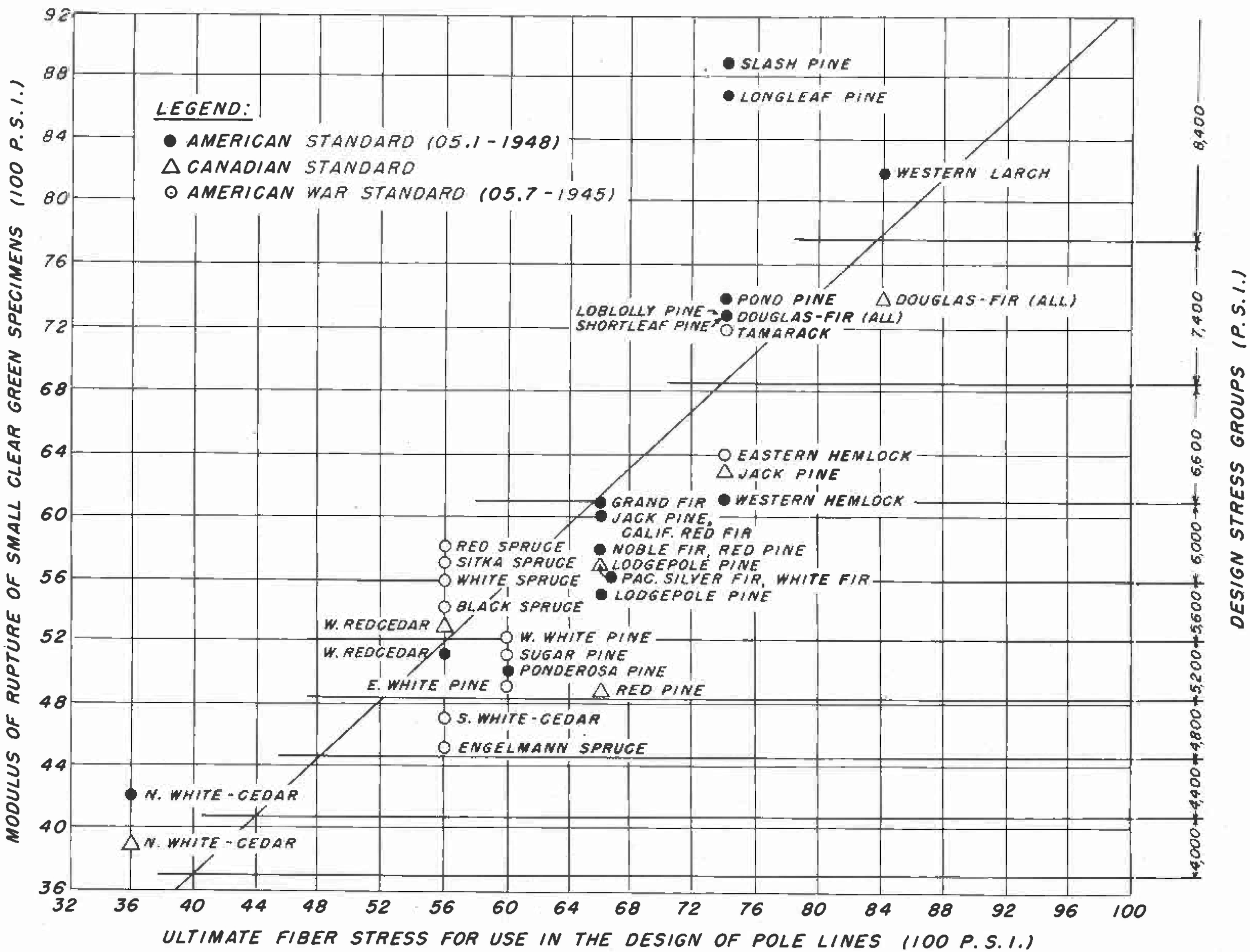


Figure 3. --Suggested procedure for deriving design values. Western redcedar basis.

ZM 93429 F