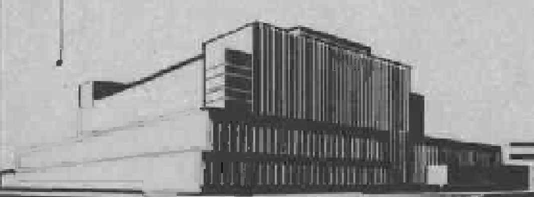
VARIATION OF STRENGTH PROPERTIES IN WOODS USED FOR STRUCTURAL PURPOSES

Information Reviewed and Reaffirmed

April 1960

No. 1780



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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

VARIATION OF STRENGTH PROPERTIES IN WOODS USED FOR STRUCTURAL PURPOSES[1]

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Summary

This survey of variability includes southern yellow pine, Douglas-fir, Sitka spruce, western hemlock, eastern hemlock, ponderosa pine, white oak, northern red oak, and red gum. Strength properties examined are modulus of rupture in transverse bending, maximum crushing strength in compression parallel to grain, modulus of elasticity in bending, maximum shearing strength parallel to grain, and proportional limit stress in compression perpendicular to grain. Specific gravity, being related to strength, is included. The survey is in two parts: (1) Variability of small clear specimens, and (2) variability of structural timbers in grade groups.

Variability of small clear specimens is examined by means of frequency distributions, and consideration is given both to the standard deviation and to the strength level that excludes the lower 5 percent of the individual values. Standard deviation is used in its percentage form (coefficient of variation). Both the coefficient of variation and the 5 percent exclusion level present similar pictures of variability. Green and air-dry specimens, where compared, are found to have about the same (percentage) variability. Strength properties have 1-1/2 to 3 times as much variability as specific gravity. Southern yellow pine,consisting of four species, has more variability than any of the single species. The frequency distributions show slight skewness, but not consistently in either direction, except in compression perpendicular to grain. Coefficients of variation range from 8 to 15 percent in specific gravity, 24 to 39 percent in compression perpendicular to grain, and 14 to 24 percent in the other properties examined.

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[1]Acknowledgement is due to the Vancouver Laboratory of the Forest Products Division, Forest Service, Canada, for making available its unpublished data on strength values in structural joists and planks for analysis in this report. Original report dated December 1950.

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

Variability of structural timbers in grade groups of southern yellow pine, Douglas-fir, ponderosa pine, Sitka spruce, western hemlock, and eastern hemlock is examined in bending strength of beams and joists and crushing strength of short columns. The principal purpose is to check assigned working-stress values against actual observed breaking strengths. Working stresses are compared with the 2 percent exclusion levels and other limiting values in each group. These comparisons indicate a range in value of the apparent factor of safety from a little less than one to as much as five. Examination of the values for bending strength of structural timbers in the larger groups indicates a nearly normal frequency distribution without significant skewness and with coefficients of variation from 1-1/2 to 2 times that for modulus of rupture of small clear specimens in the same species.

Introduction

Working stresses for the design of structural timbers are obtained through the application of various reduction factors to average strength values for the species. These factors are selected to represent the effects of various characteristics expected in the wood itself and of various conditions that are probable in its fabrication and use. One of the largest is the so-called variability factor, which is an allowance for the differences in structure and strength between individual pieces of clear wood within a species. Designation of this as "a variability factor" does not imply that there is no variability in other factors, such as weakening effect of knots; this is to be kept in mind in considering the data from this report, particularly from the standpoint of factors of safety in structural timbers.

The variability factor, along with others entering into working stresses, has recently been reviewed at the Forest Products Laboratory. The purpose of this report is to present information on the variability of the strength values brought to light in this review.

This report is restricted to the more important species from which structural timbers are obtained. These are southern yellow pine (including loblolly, longleaf, shortleaf, and slash pines), Douglas-fir, Sitka spruce, western hemlock, eastern hemlock, ponderosa pine, white oak, red oak, and red gum. It is further restricted in most of these species to the more important strength properties--modulus of rupture, maximum crushing strength in compression parallel to grain, and proportional limit stress in compression perpendicular to grain, with consideration of modulus of elasticity in bending and maximum shearing strength of southern yellow pine and Douglas-fir only. Specific gravity of most of the species is included, because, although not a strength property, it is related to strength and, being unaffected by minor defects such as might go undetected in supposedly clear material, it probably affords the most reliable measure of variability. The study included both green and air-dry material.

The report is divided into two parts. The first is a survey of variability from tests of small clear specimens. The second is a study of variability in strength of structural timbers containing defects but segregated into grade groups. As will be shown later, these two types of variability have somewhat different applications.

Sources of Data

No new tests were performed for this variability survey; the report is based entirely on variability analysis of existing strength data obtained in connection with other projects. The debt of this study to these other projects is hereby acknowledged.

A large number of small clear specimens of many species were tested at the Forest Products Laboratory, and the results were summarized in "Strength and Related Properties of Woods Grown in the United States," Technical Bulletin No. 479, U.S. Department of Agriculture. Trees from which the test specimens were cut were selected to represent the range and average for each species, and the data were thus particularly suitable for a study of variability of clear wood. Both green and air-dry material were used. Air-dry values were adjusted to the basis of 12 percent moisture content.

Results of tests of structural columns of southern yellow pine and Douglas-fir and tests of small clear specimens cut from those columns are summarized in "Tests of Large Timber Columns and Presentation of the Forest Products Laboratory Column Formula," Technical Bulletin No. 167, U.S. Department of Agriculture. Test values for the small clear specimens and for structural column sections with slenderness ratios of approximately 10 are used. The columns are in the Select grade of American Society for Testing Materials D245-27, with a requirement for close grain based on the rate of growth.

Tests of 8- by 16-inch stringers of Sitka spruce and western hemlock and tests of small clear specimens from the stringers are summarized in "The Distribution and Mechanical Properties of Alaska Woods," Technical Bulletin No. 226, U.S. Department of Agriculture. Test values from small clear specimens and from one grade of the stringers are used.

In connection with box-beam and texture studies at the Forest Products Laboratory, a large number of tests have been made on small clear specimens of air-dried Douglas-fir and Sitka spruce. The test values, adjusted to a common basis of 12 percent moisture content, are used in the study of variability of clear wood (projects 228-3 and 590A).

Specific gravity values for clear wood of green southern yellow pine were also taken from "The Density of Southern Pine; Its Significance in Terms of Properties and Grades," by E. M. Davis, published in 1927 in the trade journal, The Southern Lumberman. Specific gravities for white oak, red oak, and red gum were taken from test data in "Machining and Related Characteristics of Southern Hardwoods," Technical Bulletin No. 824, U.S. Department of Agriculture.

Bulletin No. 108 of the U.S. Department of Agriculture, "Tests of Structural Timbers," gives results of a considerable number of tests of timbers of several species and in various sizes. Accompanying information on the structural grading is not complete, but two grades of green Douglas-fir stringers, 8 by 16 inches, tested over a 15-foot span, are available and have been used.

A group of longleaf pine stringers, 6 by 12 and 8 by 16 inches in size, were tested over a 15-foot span at the Forest Products Laboratory (project 184). One grade group meeting the "density" requirement (based on summerwood content and rate of growth) is used in the study of variability of structural timbers.

The Vancouver Laboratory of the Forest Products Division, Forest Service, Canada, has made large numbers of tests of air-dry Douglas-fir and western hemlock in various joist and plank sizes. In view of the large number of tests and of the importance of those species in this country, permission has been obtained from the Canadian Laboratory to use the strength values in this study. The material includes both Select and Common Structural grades, with Dense Select Structural and Dense Common Structural grades of Douglas-fir. The Select and Dense Select Structural grades of Douglas-fir carry a requirement for "close grain," based on the rate of growth.

Joists and planks of Douglas-fir (Rocky Mountain type) and ponderosa pine (western yellow) in 4- by 12- and 4- by 16-inch sizes were tested in both green and dry conditions at the Forest Products Laboratory (project 256). Eastern hemlock joists and planks in 2- by 10- and 3- by 12-inch sizes were tested at the Forest Products Laboratory in both green and dry conditions (project 211). Two grades in these test groups were large enough to be used in the study of variability of structural timbers.

Part I. Variability of Small Clear Specimens

Organization of Data

The manner in which individual values are grouped about an average is known as a frequency distribution. Certain important characteristics of the frequency distributions from the data used in this study are shown in table 1, and some of the distributions are also charted in figures 1 to 11, inclusive. All frequencies are shown and used in the form of cumulative percentages with class limits being chosen so that the frequency curve shows the percentage of the total number that lies below the corresponding value of strength or specific gravity. All specific gravity and strength values are in terms of percentage of the average value for the group so as to facilitate comparisons among groups. The number of individuals in each group and the value of each group average are shown in table 1 and on figures 1 to 11.

The "coefficient of variation" indicated for each frequency distribution in table 1 and figures 1 to 11 is the standard deviation expressed in terms of percentage of the average value. Standard deviation is the square root of the mean of squares of individual deviations from the average value. Being affected by every value, it is a better measure of variability than can be obtained from the range of all or any part of the values. Coefficient of variation is shown to facilitate comparisons among species or among properties.

Since working stresses must give consideration to minimum as well as to average values, the lower ends of the frequency distributions are of special interest. Exclusion limits afford a means for further examination of this critical lower end of the frequency distributions. For example, it is of value to know what lower limit of strength includes all individuals, or what limit excludes 1 percent, 5 percent, or any other convenient percentage of the total number. In strength testing of clear wood, there is always a possibility of an abnormally low value from hidden defects or other causes, even though careful selection and testing techniques minimize that possibility. Therefore, a strength limit to include all the individuals of a frequency distribution has little significance. Limits that are less affected by the occasional abnormal value are more meaningful, and, for data groups of the size used in this study, the limiting value for 5 percent exclusion is used. That value for each groups is shown in table 1 and is indicated by the intersections of the various curves with the 5 percent ordinate in figures 1 through 11.

Examination of the characteristics of the frequency distributions from the various groups of data on the same property in the same species and moisture condition indicated no essential differences, and they were therefore combined in addition to being shown separately in table 1. Combinations were made by adding the frequencies in identical classes of data from the various sources and computing the total frequency as a percentage of the combined total number of individuals. In like manner, the combined standard deviation ("coefficient of variation") was obtained from the total of all the squares of individual deviations from the combined average value.

This calculation of combined frequencies takes into account the difference in average values between groups of similar data from different sources as well as the variability within each group. The combined frequency thus affords a better representation of the variability of the species than can be obtained from any one group of data.

Figures 1 through 11 show the combined frequency-distribution curves for each species, moisture condition, and property. Curves for the various species are superimposed to aid comparison. The curves for green material and at 12 percent moisture content are shown separately. Proportional limit stress in compression perpendicular to grain was examined only on material in the green condition.

Discussion of Data

Comparison of the variability of green and air-dry material yields no significant difference.

The greater variability in strength, as compared to specific gravity, is apparent and consistent in all species. Coefficients of variation for modulus of rupture and maximum crushing strength average about 1-1/2 times those for specific gravity in the four coniferous woods and about twice as much in the three hardwoods. Coefficients of variation in compression perpendicular to grain are still higher. This is to be expected from the fact that most strength properties are proportional to a power of specific gravity greater than unity. Among the strength properties, there is indication that modulus of rupture is less variable than the others, but whether this difference is inherent in wood or arises from differences in the nature of the tests is not known.

Variability of proportional limit stress in compression perpendicular to grain in comparison to other strength properties is noteworthy. Coefficients of variation (column 31, table 1) range up to twice the values observed in modulus of rupture. Two reasons are seen for this greater variability. One is the effect of angle of growth rings with respect to the direction of applied force, a major factor in compression-perpendicular strength, but generally unimportant in other strength properties. The second reason is that these are proportional limit values, as compared with ultimate strengths in the other properties. In stress-strain diagrams in compression perpendicular to grain, the change in slope begins almost imperceptibly, so that precise location of the proportional limit in this test is very difficult.

Comparisons among species show that southern yellow pine, consisting of four species, has generally greater variability than the others studied. Among the others, differences are inconsistent and, with one exception, probably not significant. Air-dry Douglas-fir shows a higher coefficient of variation in maximum shearing strength than does green Douglas-fir or green or dry southern pine. This species, as grown in some localities,may show a weakness of bond in shear between annual rings, a condition usually accompanied by the presence of shake. This condition, being aggravated by shrinkage stresses accompanying the seasoning process, is more evident in dry than in green material.

It adds abnormally low shearing strength values and increases the spread in the frequency distribution for that property in dry material.

Table 1 affords some data for examination of skewness of the frequency distributions. A symmetrical frequency distribution has 50 percent of the individuals on each side of the average value. Expressed in another way, the median value and the average value are identical. Skewness of a frequency distribution is indicated by the deviation from 50 of the percentage of individuals that have strength below average. That deviation in table 1 is uniformly small, ranging from minus 6 percent to plus 8 percent in all groups except the modulus-of-rupture group of red gum specimens, where the number is not large enough to give a significant measure of skewness.

There is some tendency toward plus deviation, most consistent in compression perpendicular to grain, but apparent also in specific gravity and maximum crushing strength. Plus deviation means that there are some very high values, raising the average value above the median value. Such very high values range up to 270 percent of the average in compression perpendicular, too high to be shown in the chart of figure 11. The frequency distribution of maximum shearing strength in dry Douglas-fir shows a minus deviation, probably because of abnormally low values caused by incipient shakes in material deficient in bond between annual rings.

In view of the small magnitude of most of the deviations and of the inconsistencies in their distribution, the presence of significant skewness does not seem to be proved by these data. This conclusion does not contradict the use of 94 percent of average values as an assumed mode for frequency distributions of strength of aircraft woods. Aircraft woods are culled at the lower end of the frequency distribution, and that culling raises the average without changing the mode, thus introducing skewness where none may have been present before.

Increased coefficients of variation are the result of increased dispersion of values and an increased spread between high and low values; it follows that where the coefficient of variation is higher, a value to exclude the lower 5 percent of the individuals is lower. The 5 percent exclusion values shown in table 1 thus give a picture of variability essentially similar to that from the coefficients of variation. No significant difference between green and air-dry material is seen. Specific gravity is less variable than strength, as is indicated by the higher values of the exclusion limits. The 5 percent exclusion values for proportional limit stress in compression perpendicular to grain are at a lower level than those in the other strength properties. Comparisons among species indicate that southern yellow pine, with a higher overall variability, has a generally lower 5 percent exclusion value than do the other species. Differences among the other species are not fully consistent, and their significance may be questioned, except that air-dry Douglas-fir has an abnormally low exclusion value in maximum shearing strength. Average values at 5 percent exclusion for all species are at about 83 percent of the average value in specific gravity, 73 percent in modulus of rupture, 71 percent in maximum crushing strength, and 57 percent in compression perpendicular to grain.

Part II. Variability of Structural Timbers in Grade Groups

Introductory

Information in this section of the survey of variability shows strength values in actual tests of structural timbers compared to their assigned working stresses. The purpose of stress grading is to segregate, into grade groups, timbers having like strength values. This study affords a measure of the extent to which that purpose is realized. Comparison of actual strength with assigned working stresses is also an indication of the factors of safety. It is to be remembered, however, that the true factor of safety depends upon conditions of use as well as upon the strength, so that ratios developed in this comparison are not in themselves the final factors of safety.

Understanding of the working stresses used in this comparison requires some explanation of how working stresses are derived. Stress grades are defined and limited on the basis of size and position of knots and other strength-affecting characteristics. These permitted sizes and positions determine the "strength ratio," a ratio of the strength of the weakest piece allowed in the grade to what its strength would be if knots or other strength-reducing characteristics were not present. A "basic stress" value is determined in each species from considerations of variability, duration of load, factor of safety, and other factors appropriate to the nature and use of structural lumber. The basic stress for a species, modified by the strength ratio for a stress grade, becomes the working stress for design with that grade of that species.

Southern yellow pine and Douglas-fir, with high summerwood content and a medium rate of growth, are recognized to be stronger than if without any such restrictions. "Dense" grades, restricting both summerwood content and rate of growth, are given basic stresses about one-sixth higher than those for unrestricted material. "Close-grain" grades restrict rate of growth and are recognized by a basic stress increase of about one-fifteenth.

Some of the groups of structural timbers were not graded for strength at the time of test by the rules that are now commonly used. These were graded for this study from photographs and sketches or other recorded information. The resulting strength ratios were grouped into an arbitrary series of stress grade groups designated S1, S2, S3, and S4, respectively. Pieces with strength ratios of 88 to 100 percent were placed in grade group S1, 75 to 87 percent in group S2, 63 to 74 percent in group S3, and 50 to 62 percent in group S4. These grade groups carry for design purposes strength ratios of 88, 75, 63, and 50 percent, respectively.

Other groups of structural timbers had previously been classified in the Select or Common grades as defined by the American Society for Testing Materials D245-27,"Standard Specifications for Structural Wood Joists, Planks, Beams, Stringers, and Posts." This earlier classification appeared satisfactory and was retained. The Select grades include strength ratios of 75 percent and up, and the Common grades have strength ratios from 60 to 74 percent.

The above grade groups are not identical with the stress grades sponsored by the lumber-producing industry, but are a continuous series of stress classes founded on the same stress-grading principles as are the commercial grades. This somewhat artificial classification has the advantage of giving the same levels and ranges of strength ratios in different species, thus affording closer comparisons among species than is possible with the commercial grades.

Discussion of Data

Table 2 identifies the various grade groups examined and shows the number of individuals and the average strength value for each grade group. Figures 12 to 21, inclusive, are cumulative frequency distributions for the same groups. These differ from the frequency distributions in figures 1 to 11, chiefly in that strength values are in absolute rather than in percentage terms. Working-stress values, appropriate to the various grades, are indicated by short vertical lines. All frequency values are cumulative percentages based on the total number of individuals in the group.

Although the wood substance in structural timbers increases in strength with drying, the increase is largely offset by checks or other defects that develop as the timbers season. For this reason, both green and dry structural timbers of equal grade are generally given the same working stress, and strength values under both moisture conditions can be combined in the same frequency distribution. Table 2 indicates a number of grade groups in which this has been done. Thinner pieces and pieces with few or small knots, however, dry with less development of seasoning defects, so that some gain in strength from drying is recognized. This drying benefit is estimated by increasing the strength ratio of pieces 4 inches or less in thickness (joists and planks) by half of its excess over 50 percent. Thus, in table 2, the strength ratio of eastern hemlock joists and planks in the S3 grade is 62-1/2 percent green and $(62\text{-}1/2 + \frac{62\text{-}1/2 - 50}{2} = 68\text{-}3/4)$ 69 percent dry. The S4 grade groups of joists and planks, with a strength ratio of 50 percent, do not receive any increase for drying by this rule.

Basic stresses and strength ratios used in calculating the working stresses of table 2 are indicated. Since the basic stresses include a reduction factor for long-time loading, this factor is removed by dividing by nine-sixteenths, which gives a 5-minute working stress (column 10) that can be compared directly to the strength test values. Strength values include the average, maximum, and minimum and, in groups of more than 25 individuals, the value at 2 percent exclusion (minimum observed value that excludes 2 percent of the test results). Large groups are likely to show a greater extreme range of values than do small groups of the same material, while comparison on the basis of the same percentage of exclusion tends to minimize this difference.

Comparisons of strength values in these groups to the corresponding working stresses affords an indication of the range in factors of safety. The true factor of safety, or ratio of the strength of a member to what is required of it, depends upon factors of use as well as of strength; and thus the ratio of a laboratory test strength value to a working stress is not the true factor of safety. Nevertheless, the true factor of safety is related to that ratio, which may be designated here as an apparent factor of safety.

Working stresses for design must be safe in all cases, so minimum strength values are of the greatest interest in examining apparent factors of safety. To facilitate comparisons among groups, the 2 percent exclusion value is shown as a near-minimum in column 14 of table 2. Apparent factors of safety of this near-minimum value on the working stress are indicated in column 15 of table 2. These apparent factors of safety range from 1.07 to 1.68, with large groups falling in about the same range as the small groups. The two groups for test columns exhibit about the same range as in the beam and the joist groups. The average of all values tabulated in column 15 is 1.35.

Extreme minimum values (column 13 of table 2) have, of course, smaller factors of safety, and in some cases they fall below the short-time working stress. A total of 6 values from a total number of 2,350 tests are thus deficient. Only five of these values appear in table 2, as two are in the same group. While such deficient values are cause for concern, it may be pointed out that the factor of safety that may be present in assumed loading or other conditions of use can increase the true factor of safety above this apparent value determined from strength alone.

Average and maximum strength values (columns 11 and 12, table 2) are also of interest in indicating higher ranges in factors of safety on some structural timbers. Average values are generally twice and, in some cases, about three times the corresponding short-time working stresses. Maximum values range as high as 5 times the working stress. Significance of occasional extremely high values, like the extremely low values, may be questioned.

Most of the grade groups shown in table 2 are not large enough to be useful in examining the character of the frequency distribution of strength values. Three of the groups of Douglas-fir and two of western hemlock tested at the Vancouver, Canada, Laboratory are, however, usable. Characteristics in these groups are shown in table 3, which is arranged similarly to table 1. Table 3 indicates that standard deviation in the various grade classes may be about the same when expressed in pounds per square inch. When expressed as a percentage of the class average (coefficient of variation), it is thus greater in the lower than in the higher grade groups. The coefficients of variation are 1-1/2 to 2 times as great as those in modulus of rupture of small clear specimens of the same species (column 10, table 1). This is to be expected as a result of adding the variability from knots or other defects to the variability of the clear wood substance.

The percentages of test values that are below the average value (column 6, table 3) do not appear to indicate significant skewness in the frequency distribution of strength in structural-timber grade groups.

Conclusions

The study of variability of small clear specimens indicates no significant difference in this respect between green and dry material. Strength values show a greater dispersion than do specific gravity values, becoming more than twice as much in the case of stress at proportional limit in compression perpendicular to grain. Southern pine, including four species, shows more dispersion than do any of the single species. The frequency distributions do not appear to be consistently or significantly skewed.

Apparent factors of safety for grade groups of structural timbers, when based on near-minimum values, range from 1.07 to 1.68. Corresponding factors on average strength values are two to three times as much, and on maximum values up to five times as much. These apparent factors of safety are not necessarily the true factors of safety, since the latter may depend upon the conditions of use as well as the strength values. Examination of a few frequency distributions in the larger grade groups shows more dispersion of values than in the small clear specimens of the same species. This is to be expected as a result of adding the variability from knots or other defects to the variability of the clear wood substance. These same frequency distributions in the structural grade groups do not appear to be significantly skewed.

Table 1.--Variability in strength properties of small clear specimens of wood

Species	Condition[1]	Source of data[2]	Specific gravity[3]: Number of tests	Specific gravity: Average value	Specific gravity: Coefficient of variation[4]	Specific gravity: Test values below average value	Specific gravity: Value at 5-percent exclusion	Modulus of rupture: Number of tests	Modulus of rupture: Average value	Modulus of rupture: Coefficient of variation[4]	Modulus of rupture: Test values below average value	Modulus of rupture: Value at 5-percent exclusion	Modulus of elasticity: Number of tests	Modulus of elasticity: Average value	Modulus of elasticity: Coefficient of variation[4]	Modulus of elasticity: Test values below average value	Modulus of elasticity: Value at 5-percent exclusion
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
					Percent	Percentage of total number	Percentage of average value		P.s.i.	Percent	Percentage of total number	Percentage of average value		1,000 P.s.i.	Percent	Percentage of total number	Percentage of average value
Southern yellow pine[5]	Green	Bull. 479	3,555	0.502	15.1	52	78	965	8,107	17.2	52	74	961	1,523	20.6	46	64
		Bull. 167	157	.507	11.3	56	82	159	8,040	17.3	52	75	159	1,422	21.4	52	63
		Density	4,672	.482	14.6	53	78										
		Combined group	8,384	.491	14.9	52	78	1,124	8,097	17.2	52	74	1,120	1,508	20.8	48	65
	Dry	Bull. 479	1,605	.539	13.9	52	80	802	13,916	19.7	53	69	801	1,875	21.9	50	61
		Combined group	1,605	.539	13.9	52	80	802	13,916	19.7	53	69	801	1,875	21.9	50	61
Douglas-fir (coast type)	Green	Bull. 479	2,648	.432	11.3	52	84	633	7,514	15.2	48	74	633	1,536	18.4	46	67
		Bull. 167	156	.431	9.5	50	85	158	7,198	13.9	50	77	158	1,469	21.4	53	70
		Combined group	2,804	.432	11.2	52	84	791	7,451	15.1	48	74	791	1,522	19.1	47	68
	Dry	Bull. 479	758	.477	11.5	52	82	376	11,933	17.2	48	71	376	1,843	18.3	54	72
		Box beam	641	.450	9.2	46	83	600	11,472	12.2	46	79	600	1,577	15.7	49	74
		Texture	190	.438	10.5	56	86	177	10,621	12.4	53	80	174	1,581	15.8	52	78
		Combined group	1,589	.462	11.0	52	83	1,153	11,492	14.6	48	76	1,150	1,664	18.4	52	72
Sitka spruce	Green	Bull. 479	1,331	.363	11.0	52	83	676	5,533	16.6	54	76					
		Bull. 226	119	.353	8.5	56	87										
		Combined group	1,450	.363	10.9	52	84	676	5,533	16.6	54	76					
	Dry	Bull. 479	1,120	.394	10.5	54	86	548	9,911	18.8	54	73					
		Box beam	854	.384	7.9	52	88	751	10,271	10.5	52	83					
		Combined group	1,974	.390	9.4	56	87	1,299	10,119	14.6	50	76					
Western hemlock	Green	Bull. 479	1,914	.389	10.5	52	84	901	6,068	13.6	51	80					
		Bull. 226	174	.431	9.7	48	85										
		Combined group	2,088	.392	10.8	53	84	901	6,068	13.6	51	80					
	Dry	Bull. 479	380	.403	10.4	52	86	169	9,831	16.1	49	72					
		Combined group	380	.403	10.4	52	86	169	9,831	16.1	49	72					
White oak	Green	Bull. 479	410	.596	7.4	48	87	245	8,231	16.7	49	72					
		Bull. 824	1,320	.564	10.9	49	82										
		Combined group	1,730	.571	10.4	48	82	245	8,231	16.7	49	72					
Red oak	Green	Bull. 479	704	.554	8.8	44	83	354	7,873	23.2	52	66					
		Bull. 824	1,231	.552	9.7	46	82										
		Combined group	1,935	.553	9.4	44	82	354	7,873	23.2	52	66					
Red gum	Green	Bull. 479	149	.454	5.4	49	92	78	7,010	14.8	39	66					
		Bull. 824	719	.465	8.2	48	86										
		Combined group	868	.463	7.8	50	86	78	7,010	14.8	39	66					

[1] Specific gravity and strength values for the dry condition are adjusted to the basis of 12 percent moisture content.

[2] Sources of data are identified more completely in the test.

[3] Based on oven-dry weight and volume at test. Values for the dry condition based on volume at 12 percent moisture content.

[4] Standard deviation in terms of percentage of average value.

[5] Includes loblolly, longleaf, shortleaf, and slash pines. In compression perpendicular to grain, includes only longleaf and shortleaf pines.

(continued)

Table 1.--Variability in strength properties of small clear specimens of wood (continued)

Species	Condition[1]	Source of data[2]	Maximum crushing strength in compression parallel to grain: Number of tests	Average value	Coefficient of variation[4]	Test values below average value	Value at 5-percent exclusion	Maximum shearing strength in shear parallel to grain: Number of tests	Average value	Coefficient of variation[4]	Test values below average value	Value at 5-percent exclusion	Stress at proportional limit in compression perpendicular to grain: Number of tests	Average value	Coefficient of variation[4]	Test values below average value	Value at 5-percent exclusion
(1)	(2)	(3)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)
				P.s.i.	Percent	Percentage of total number	Percentage of average value		P.s.i.	Percent	Percentage of total number	Percentage of average value		P.s.i.	Percent	Percentage of total number	Percentage of average value
Southern yellow pine[5]	Green	Bull. 479	3,555	3,806	21.2	52	66	1,770	896	21.1	52	67	796	519	36.6	58	53
		Bull. 167	240	3,906	19.1	48	66	160	940	14.0	55	60					
		Density															
		Combined group	3,795	3,812	21.1	52	66	1,930	900	20.6	52	68	796	519	36.6	58	53
	Dry	Bull. 479	1,606	7,659	21.1	52	67	773	1,458	18.8	56	73					
		Combined group	1,606	7,659	21.1	52	67	773	1,458	18.8	56	73					
Douglas-fir (coast type)	Green	Bull. 479	2,648	3,627	17.8	51	74	632	914	15.8	54	77	714	513	30.6	52	55
		Bull. 167	239	3,637	16.2	53	77	158	911	11.2	51	80					
		Combined group	2,887	3,628	17.6	51	74	790	913	15.0	54	78	714	513	30.6	52	55
	Dry	Bull. 479	759	7,193	18.4	52	72	349	1,121	24.0	48	60					
		Box beam	641	6,352	12.5	46	78										
		Texture	190	5,891	13.5	56	82										
		Combined group	1,590	6,698	17.7	54	75	349	1,121	24.0	48	60					
Sitka spruce	Green	Bull. 479	1,332	2,599	18.8	52	71						665	356	39.0	54	46
		Bull. 226															
		Combined group	1,332	2,599	18.8	52	71						665	356	39.0	54	46
	Dry	Bull. 479	1,120	5,458	18.3	54	72										
		Box beam	854	5,571	10.4	50	84										
		Combined group	1,974	5,507	15.4	52	75										
Western hemlock	Green	Bull. 479	1,914	2,909	16.4	52	76						530	393	28.0	52	59
		Bull. 226															
		Combined group	1,914	2,909	16.4	52	76						530	393	28.0	52	59
	Dry	Bull. 479	380	5,936	17.2	54	77										
		Combined group	380	5,936	17.2	54	77										
White oak	Green	Bull. 479	413	3,523	17.7	52	72						252	849	23.9	52	70
		Bull. 824															
		Combined group	413	3,523	17.7	52	72						252	849	23.9	52	70
Red oak	Green	Bull. 479	705	3,252	24.1	54	64						289	710	31.0	50	58
		Bull. 824															
		Combined group	705	3,252	24.1	54	64						289	710	31.0	50	58
Red gum	Green	Bull. 479	149	2,879	16.7	44	68										
		Bull. 824															
		Combined group	149	2,879	16.7	44	68										

[1]Specific gravity and strength values for the dry condition are adjusted to the basis of 12 percent moisture content.

[2]Sources of data are identified more completely in the test.

[3]Based on oven-dry weight and volume at test. Values for the dry condition based on volume at 12 percent moisture content.

[4]Standard deviation in terms of percentage of average value.

[5]Includes loblolly, longleaf, shortleaf, and slash pines. In compression perpendicular to grain, includes only longleaf and shortleaf pines.

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Table 2.--Working stresses and strength values of structural timbers in grade groups

Species	Moisture condition[1]	Type[2]	Grade group[3]	Source of data[3]	Number of individuals	Basic stress for species[4]	Strength ratio for grade	Working stress for grade: Long-time loading	Working stress for grade: 5-minute loading[5]	Average strength value	Limiting strength values: Maximum observed in group	Limiting strength values: Minimum observed in group	Limiting strength values: 2-percent exclusion limit[6]	Ratio of 2-percent exclusion limit to short-time working stress
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
						P.s.i.	Percent	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	
						Bending Strength								
Longleaf pine	Green	B and S	S2 (dense)	Project 184	13	2,550	75.0	1,912	3,400	7,260	9,360	5,630		
Douglas-fir (coast type)	do	do	S1 (close grained)	Bulletin 108	36	2,350	87.5	2,056	3,660	7,070	9,000	5,660	5,770	1.58
Do	do	do	S2 (close grained)	Bulletin 108	66	2,350	75.0	1,762	3,130	6,240	8,790	3,480	3,560	1.14
Do	Air dry	J and P	Dense select	Canada	153	2,550	75.0	1,912	3,400	8,040	12,660	3,070	4,380	1.29
Do	do	do	Select	do	557	2,350	75.0	1,762	3,130	7,330	13,920	2,900	3,610	1.15
Do	do	do	Dense common	do	20	2,550	60.0	1,530	2,720	5,880	9,730	3,350		
Do	do	do	Common	do	246	2,200	60.0	1,320	2,350	5,540	12,520	2,060	2,530	1.08
Douglas-fir (Rocky Mt. type)	Green	do	S3	Project 256	12	1,600	62.5	1,000	1,780	3,720	4,920	2,370		
Do	Both	do	S4	Project 256	27	1,600	50.0	800	1,420	3,360	5,960	2,130	2,190	1.54
Ponderosa pine	do	do	S4	Project 256	12	1,300	50.0	650	1,160	3,740	6,760	1,880		
Sitka spruce	do	B and S	S2	Project 189	12	1,600	75.0	1,200	2,130	5,040	7,120	3,770		
Western hemlock	do	do	S2	Project 189	35	1,900	75.0	1,425	2,530	5,300	7,220	3,700	3,740	1.48
Do	Air dry	J and P	Select	Canada	743	1,900	75.0	1,425	2,530	7,140	12,270	2,180	3,740	1.48
Do	do	do	Common	do	242	1,900	60.0	1,140	2,030	5,980	11,700	1,720	2,400	1.18
Eastern hemlock	Green	do	S3	Project 211	12	1,600	62.5	1,000	1,780	3,810	5,590	2,000		
Do	Air dry	do	S3	Project 211	11	1,600	69.0	1,104	1,960	4,610	7,020	2,420		
Do	Both	do	S4	Project 211	37	1,600	50.0	800	1,420	4,150	6,100	2,260	2,390	1.68
						Column Strength[7]								
Southern yellow pine	Both	P and T	Select	Project 230-2	68	1,550	75.0	1,162	2,070	4,610	6,040	2,820	3,070	1.48
Douglas-fir (coast type)	do	do	do	Project 230-2	48	1,550	75.0	1,162	2,070	4,020	5,920	2,210	2,220	1.07

[1] "Air dry" indicates moisture contents near 12 percent, whether obtained by air seasoning or kiln drying. No correction of strength values for variation of moisture content is made. "Both" indicates that that the group contains both green and dry timbers.

[2] "B and S" indicates beams and stringers, "J and P" indicates joists and planks, and "P and T" indicates posts and timbers groups.

[3] Grade groups and sources of data are identified more completely in the text.

[4] Basic stresses from table 1 of "Recommendations for Basic Stresses," Forest Products Laboratory Report No. R1715. Basic stress for Select posts and timbers of southern yellow pine is assumed to be the same as for Select Douglas-fir.

[5] Calculated by dividing long-time working stress by the ratio nine-sixteenths.

[6] Test value below which 2 percent of the individual values fall.

[7] Obtained on columns approximately 10 feet long and 11-1/2 inches square.

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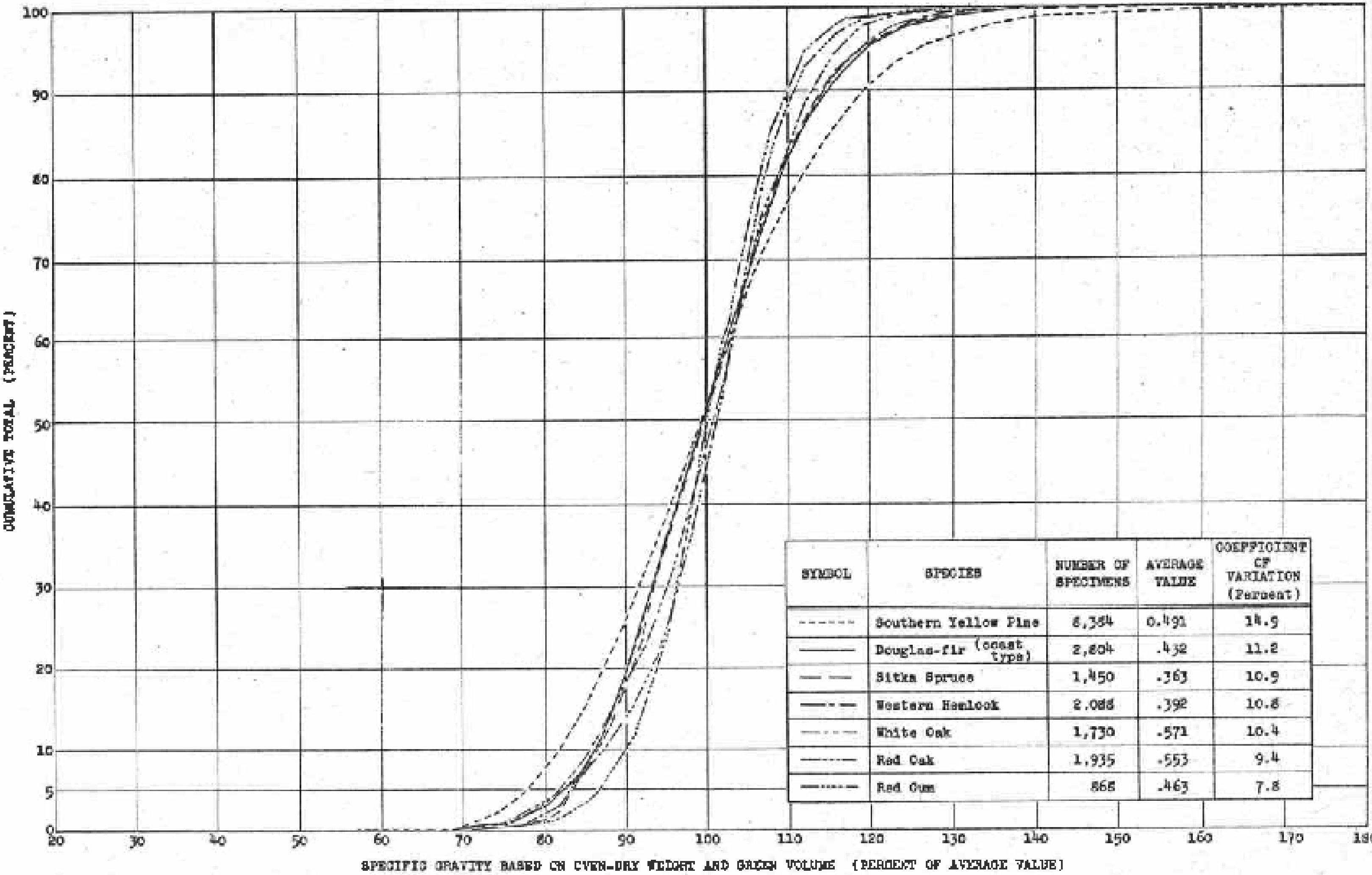
Table 3.--Characteristics of frequency distributions of bending strength values from tests of joists at Forest Products Laboratory of Canada at Vancouver

Grade group	Number of tests	Average value	Standard deviation	Coefficient of variation[1]	Test values below average value
(1)	(2)	(3)	(4)	(5)	(6)
		P.s.i.	P.s.i.	Percent	Percentage of total number
DOUGLAS-FIR (COAST TYPE)					
Dense Select	153	8,040	1,780	22.2	50
Select	557	7,330	1,800	24.6	50
Common	246	5,540	1,720	31.0	53
WESTERN HEMLOCK					
Select	743	7,140	1,560	21.9	48
Common	242	5,980	1,820	30.5	46

[1] Standard deviation in terms of percentage of average value.



SYMBOL	SPECIES	NUMBER OF SPECIMENS	AVERAGE VALUE	COEFFICIENT OF VARIATION (Percent)
------	Southern Yellow Pine	6,364	0.491	14.5
———	Douglas-fir (coast type)	2,604	.432	11.2
— —	Sitka Spruce	1,450	.363	10.9
—-—	Western Hemlock	2,086	.392	10.8
-·-·-	White Oak	1,730	.571	10.4
——·-·-	Red Oak	1,935	.553	9.4
—······	Red Gum	866	.463	7.8

Figure 1. --Cumulative frequency-distribution curves for specific gravity of various species obtained from small clear specimens in the green condition.

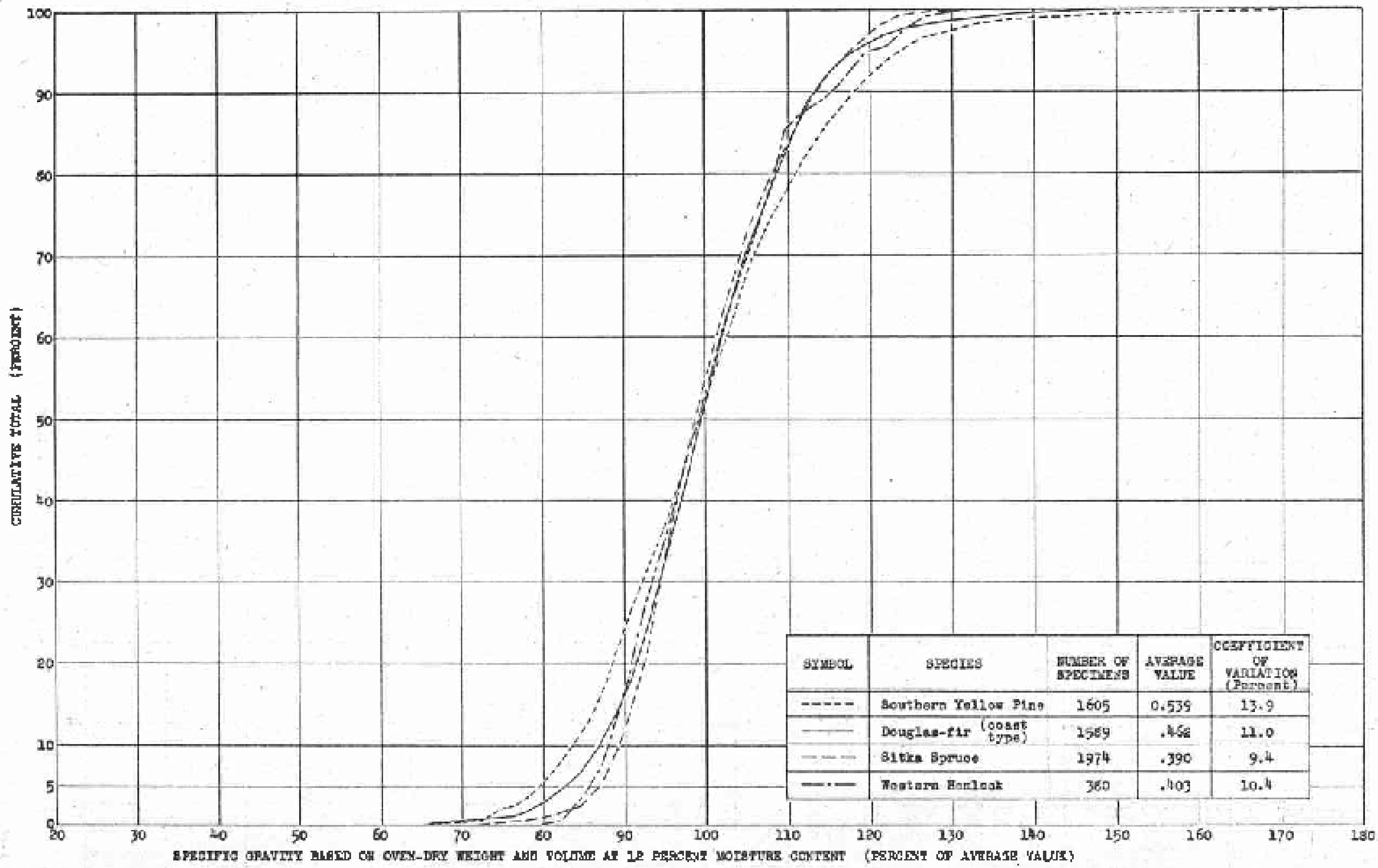


Figure 2. --Cumulative frequency-distribution curves for specific gravity of various species obtained from small clear specimens in the air-dry condition (12 percent moisture content).

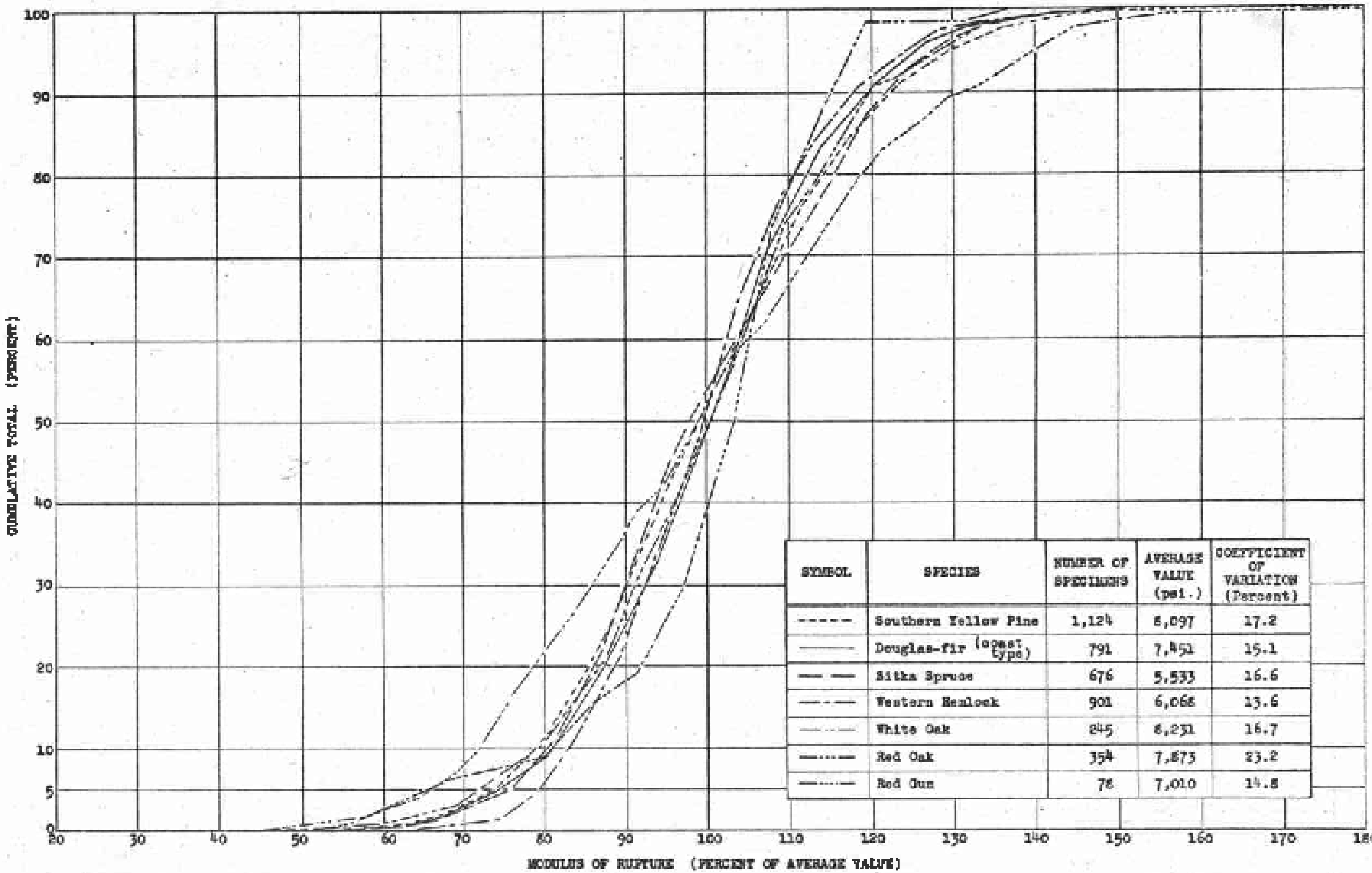


Figure 3. --Cumulative frequency-distribution curves for modulus of rupture of various species obtained from small clear specimens in the green condition.

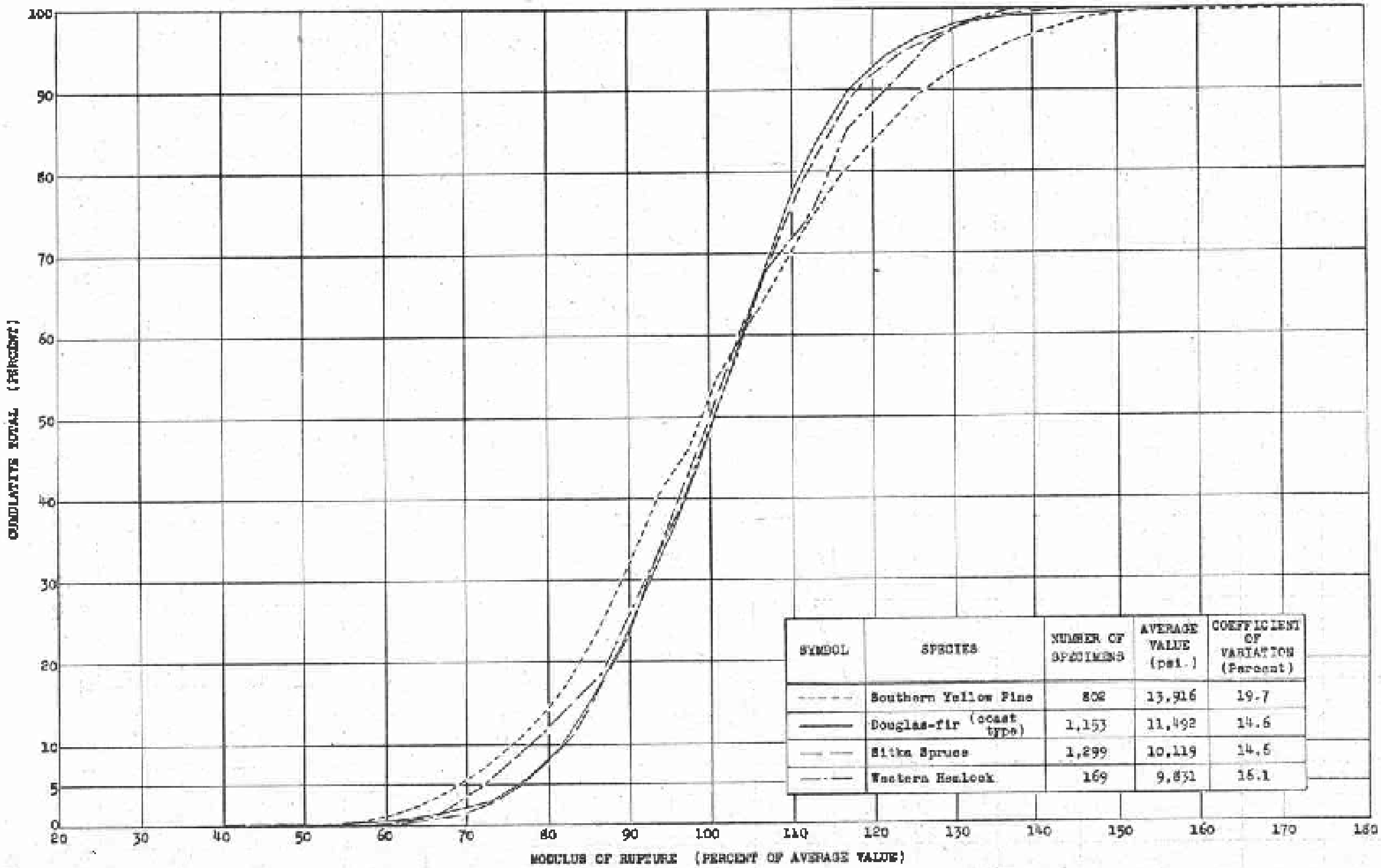


Figure 4.--Cumulative frequency-distribution curves for modulus of rupture of various species obtained from small clear specimens in the air-dry condition (12 percent moisture content).

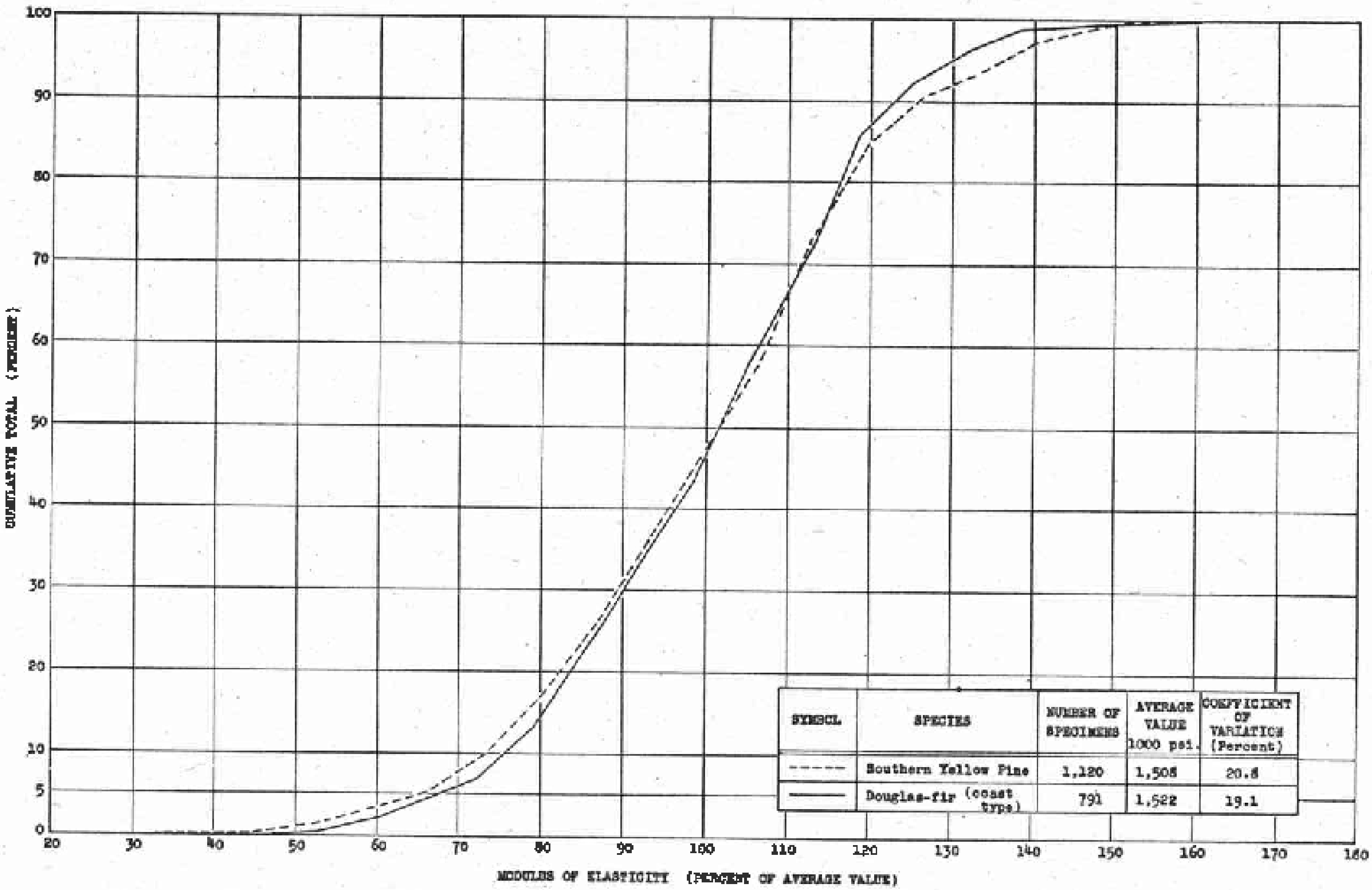


Figure 5. --Cumulative frequency-distribution curves for modulus of elasticity of southern yellow pine and Douglas-fir obtained from small clear specimens in the green condition.

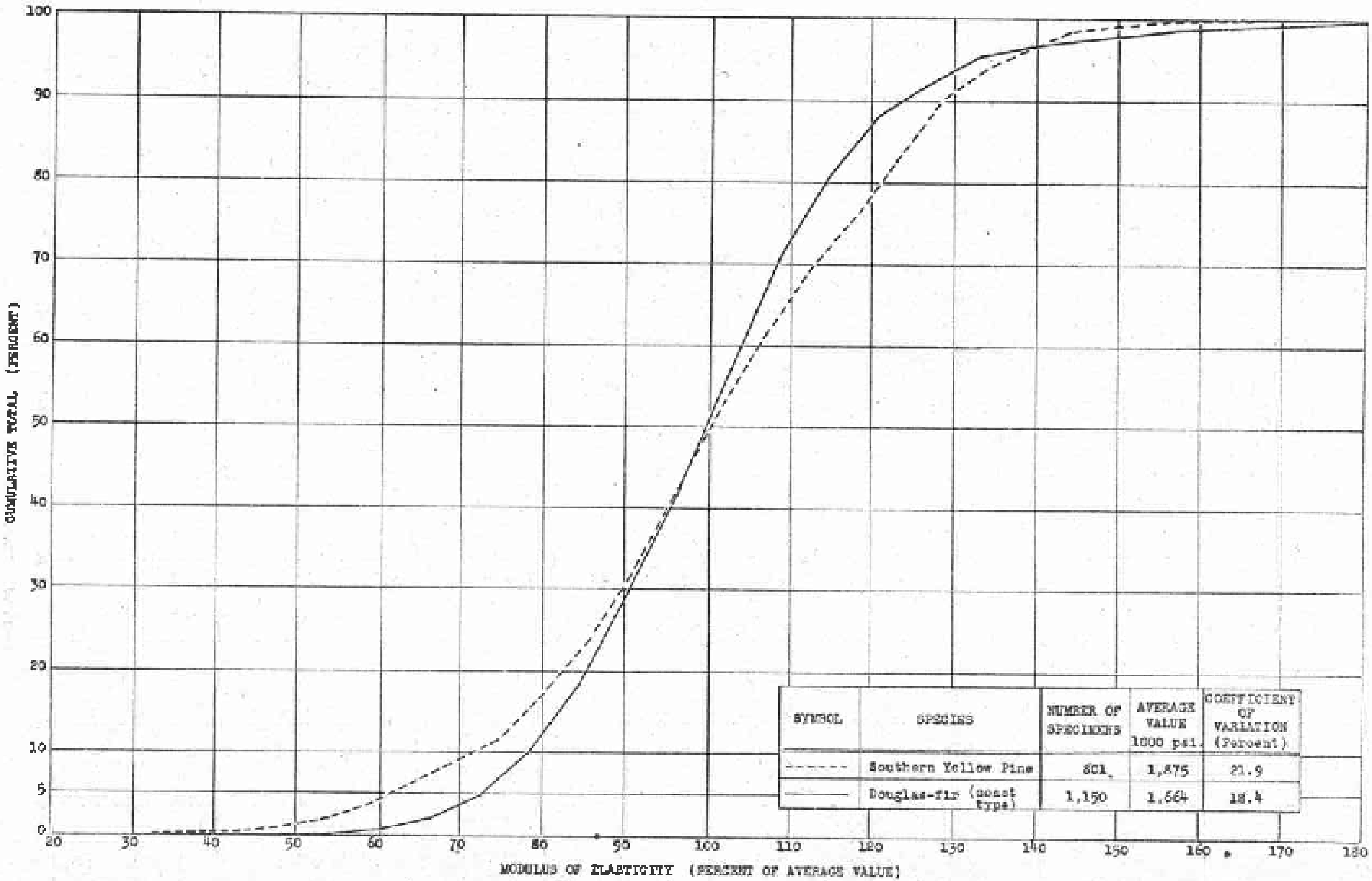


Figure 6. --Cumulative frequency-distribution curves for modulus of elasticity of southern yellow pine and Douglas-fir obtained from small clear specimens in the air-dry condition (12 percent moisture content).

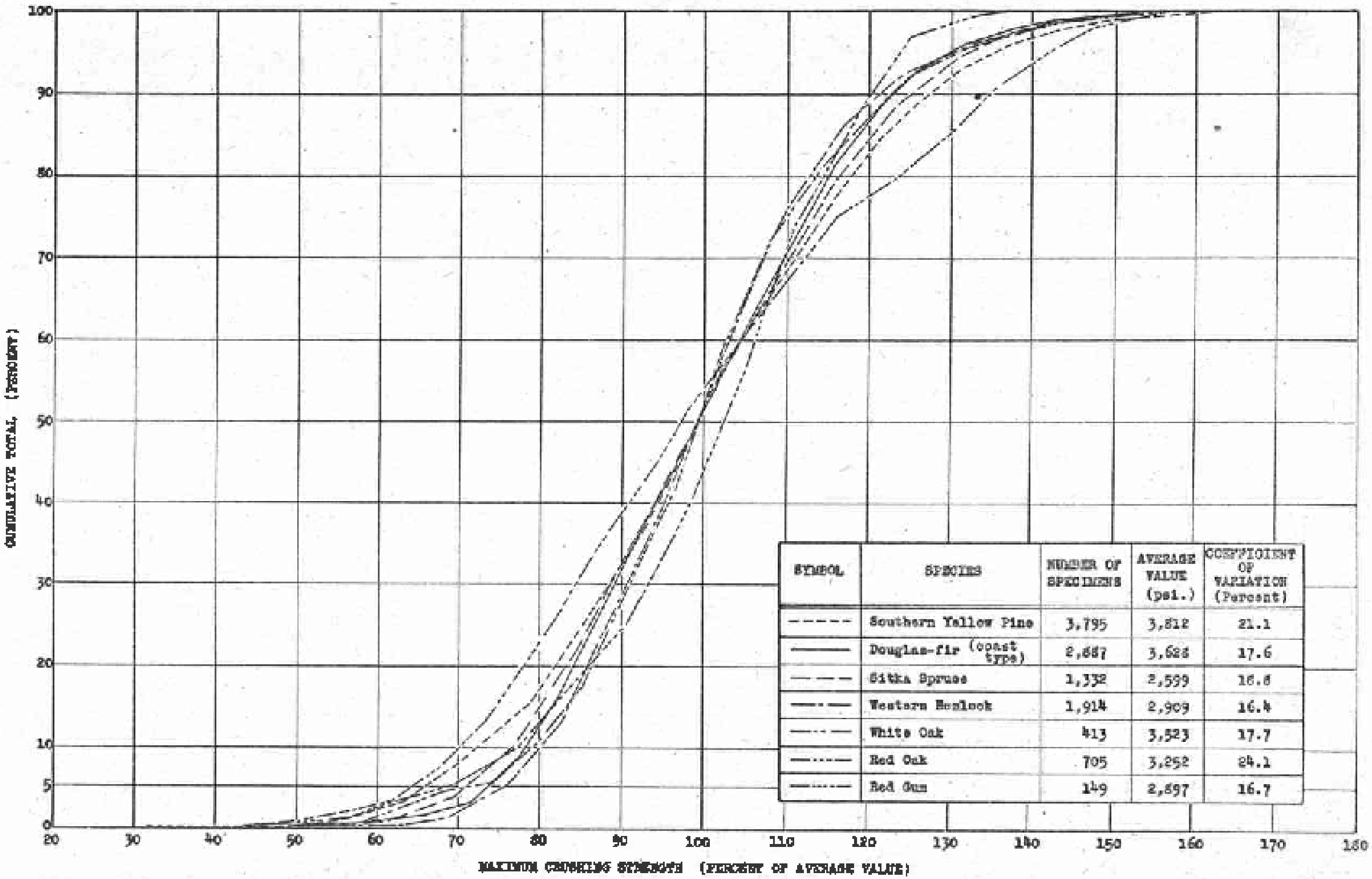


Figure 7.--Cumulative frequency-distribution curves for maximum crushing strength of various species obtained from small clear specimens in the green condition.

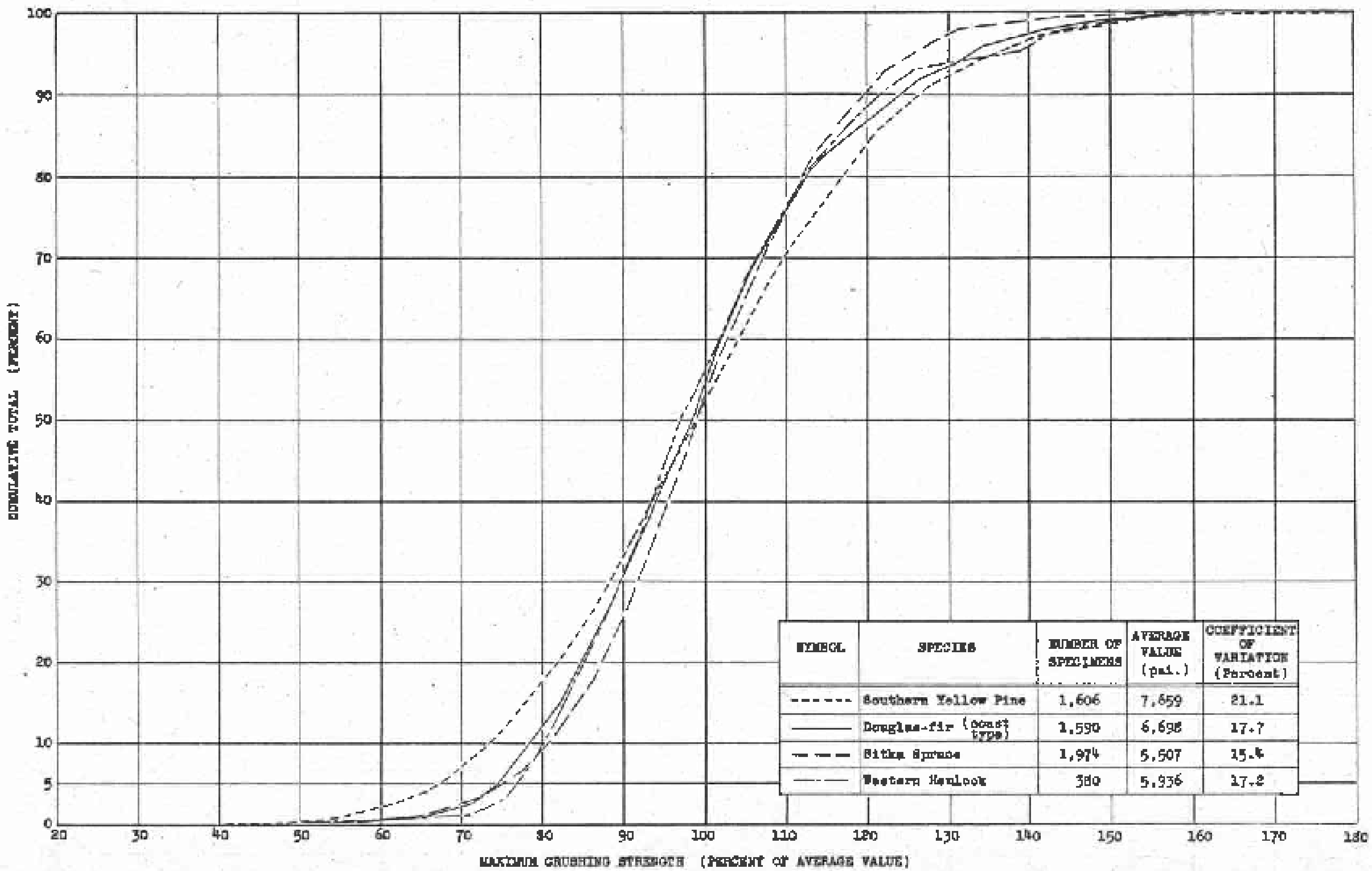


Figure 8.--Cumulative frequency-distribution curves for maximum crushing strength of various species obtained from small clear specimens in the air-dry condition (12 percent moisture content).

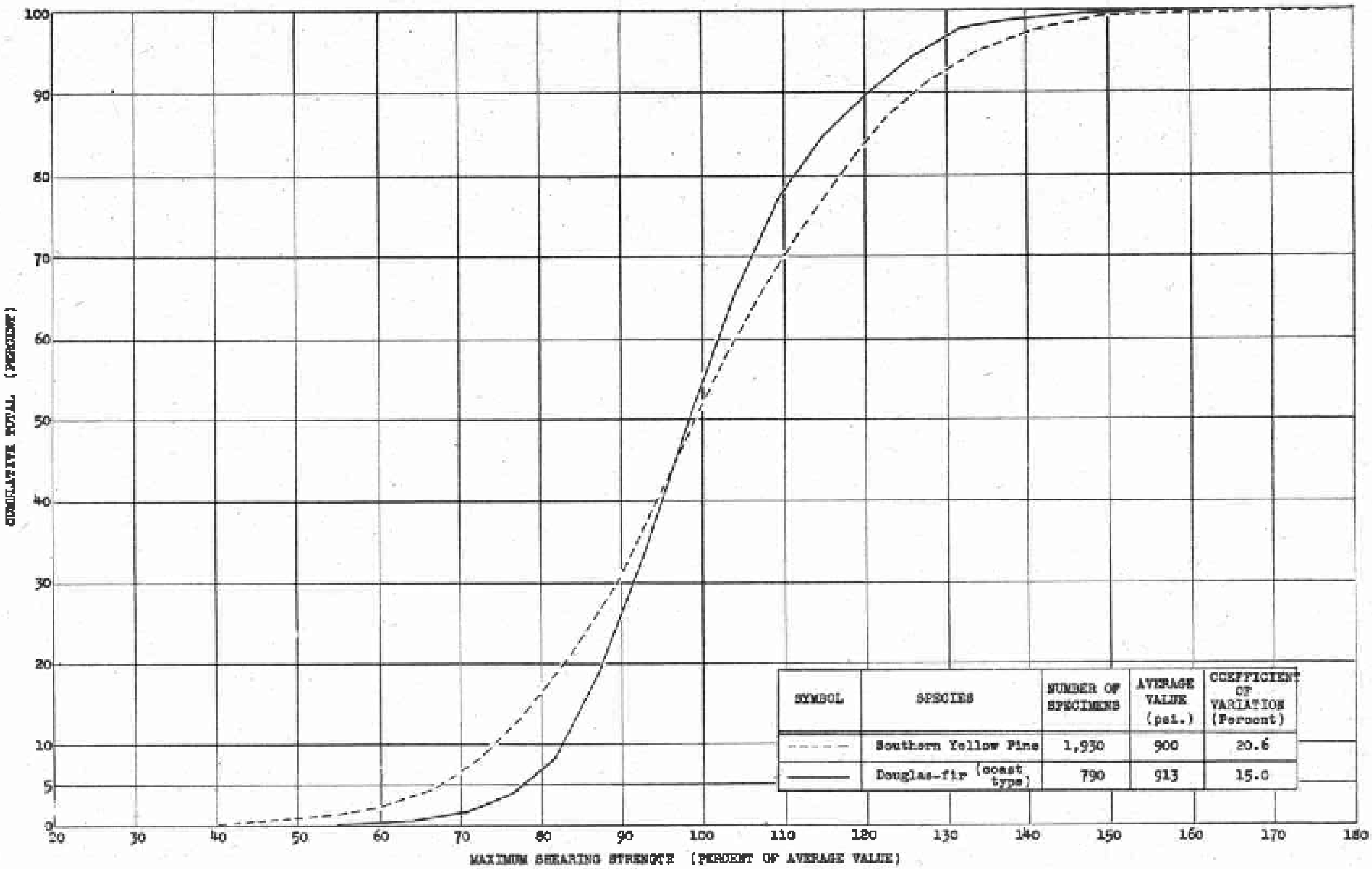


Figure 9.--Cumulative frequency-distribution curves for maximum shearing strength of southern yellow pine and Douglas-fir obtained from small clear specimens in the green condition.

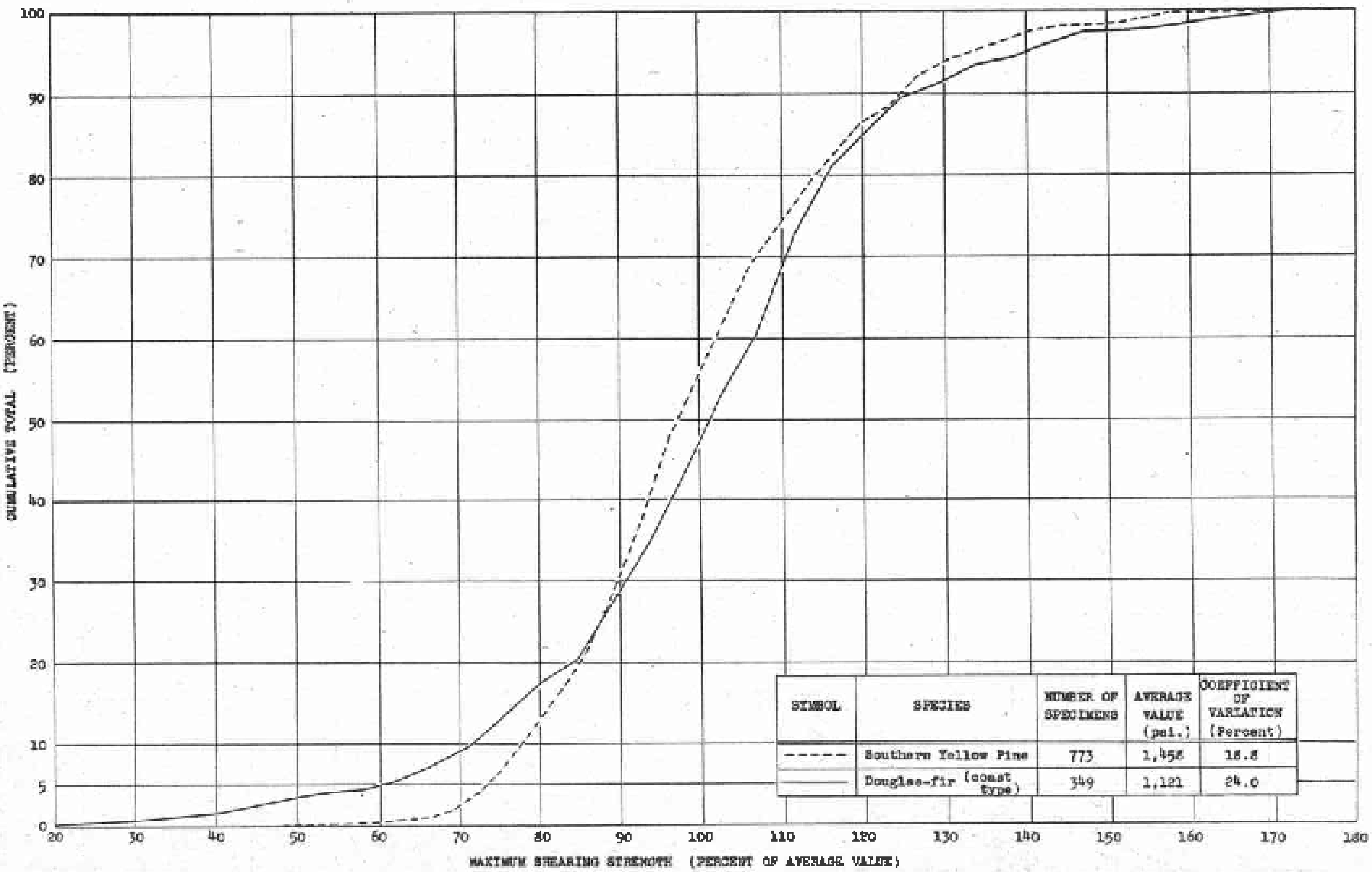
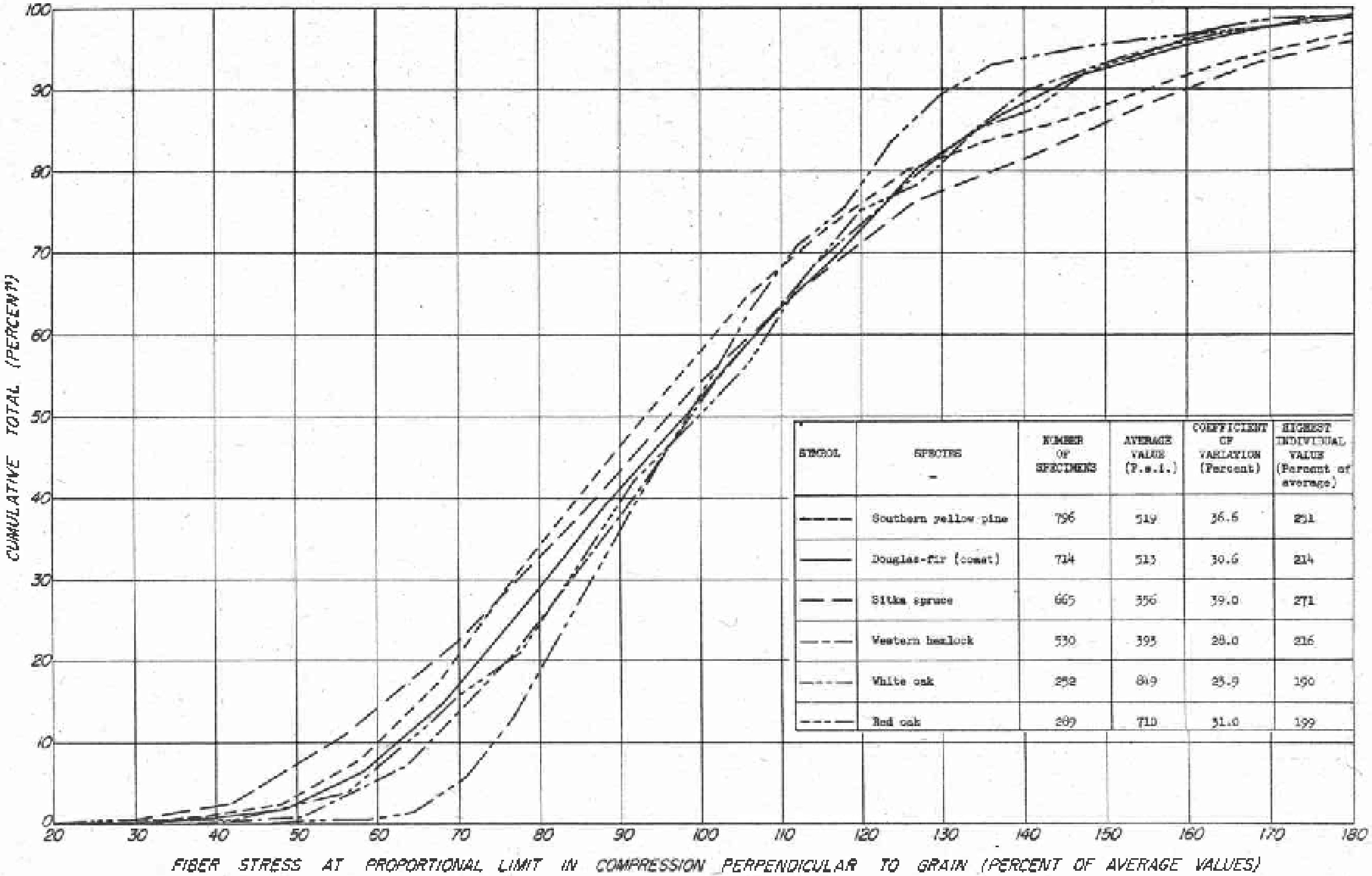


Figure 10. --Cumulative frequency-distribution curves for maximum shearing strength of southern yellow pine and Douglas-fir obtained from small clear specimens in the air-dry condition (12 percent moisture content).



SYMBOL	SPECIES	NUMBER OF SPECIMENS	AVERAGE VALUE (P.s.i.)	COEFFICIENT OF VARIATION (Percent)	HIGHEST INDIVIDUAL VALUE (Percent of average)
----	Southern yellow pine	796	519	36.6	251
——	Douglas-fir (coast)	714	513	30.6	214
— —	Sitka spruce	665	356	39.0	271
—-—	Western hemlock	530	393	28.0	216
—··—	White oak	252	849	25.9	190
—-·—	Red oak	289	710	31.0	199

Figure 11. --Cumulative frequency-distribution curves for stress at proportional limit in compression perpendicular to grain of various species obtained from small clear specimens in the green condition.

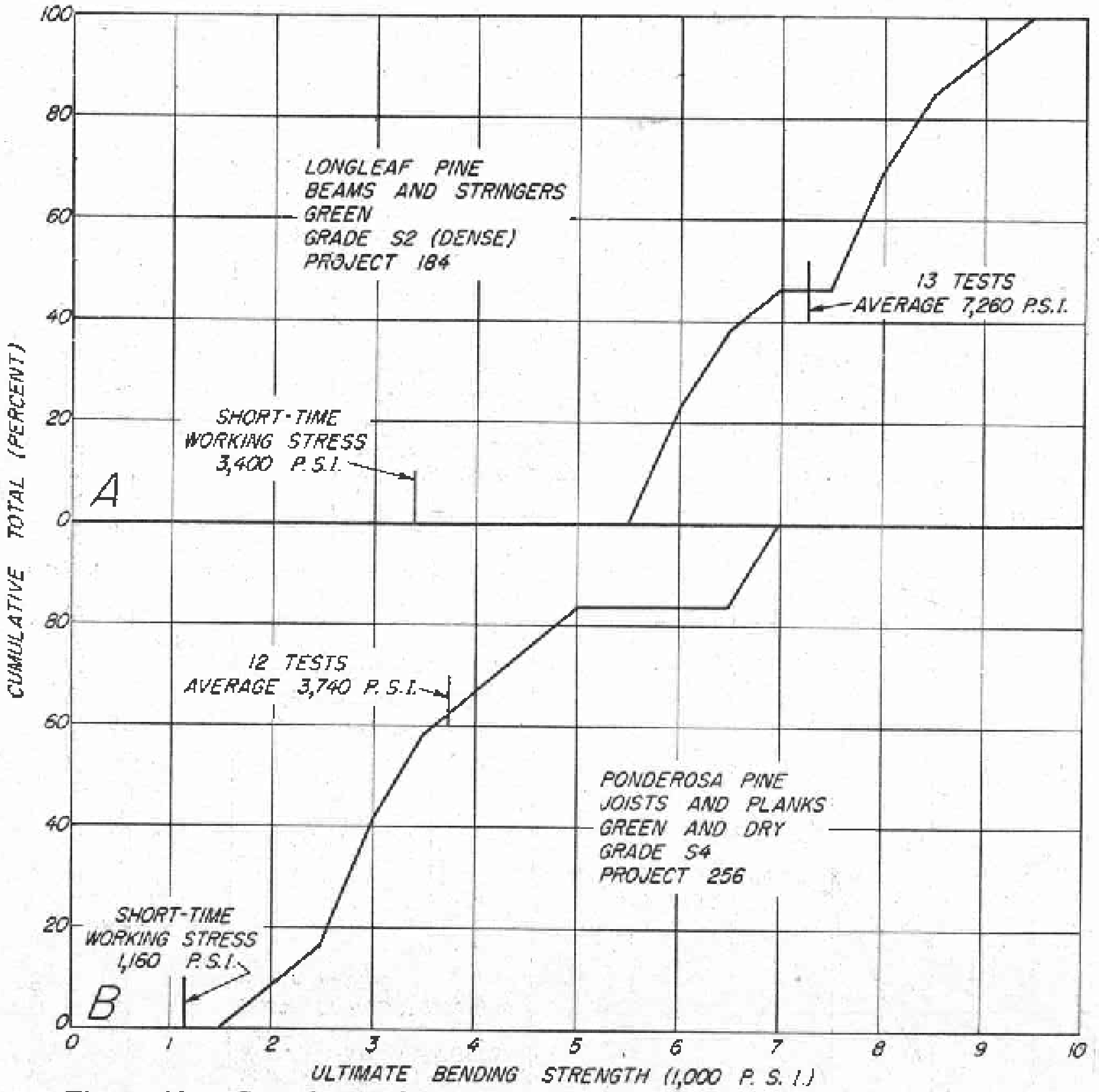


Figure 12. --Cumulative frequency-distribution curves for bending strength in grade groups of (A) longleaf pine beams and stringers and (B) ponderosa pine joists and planks.

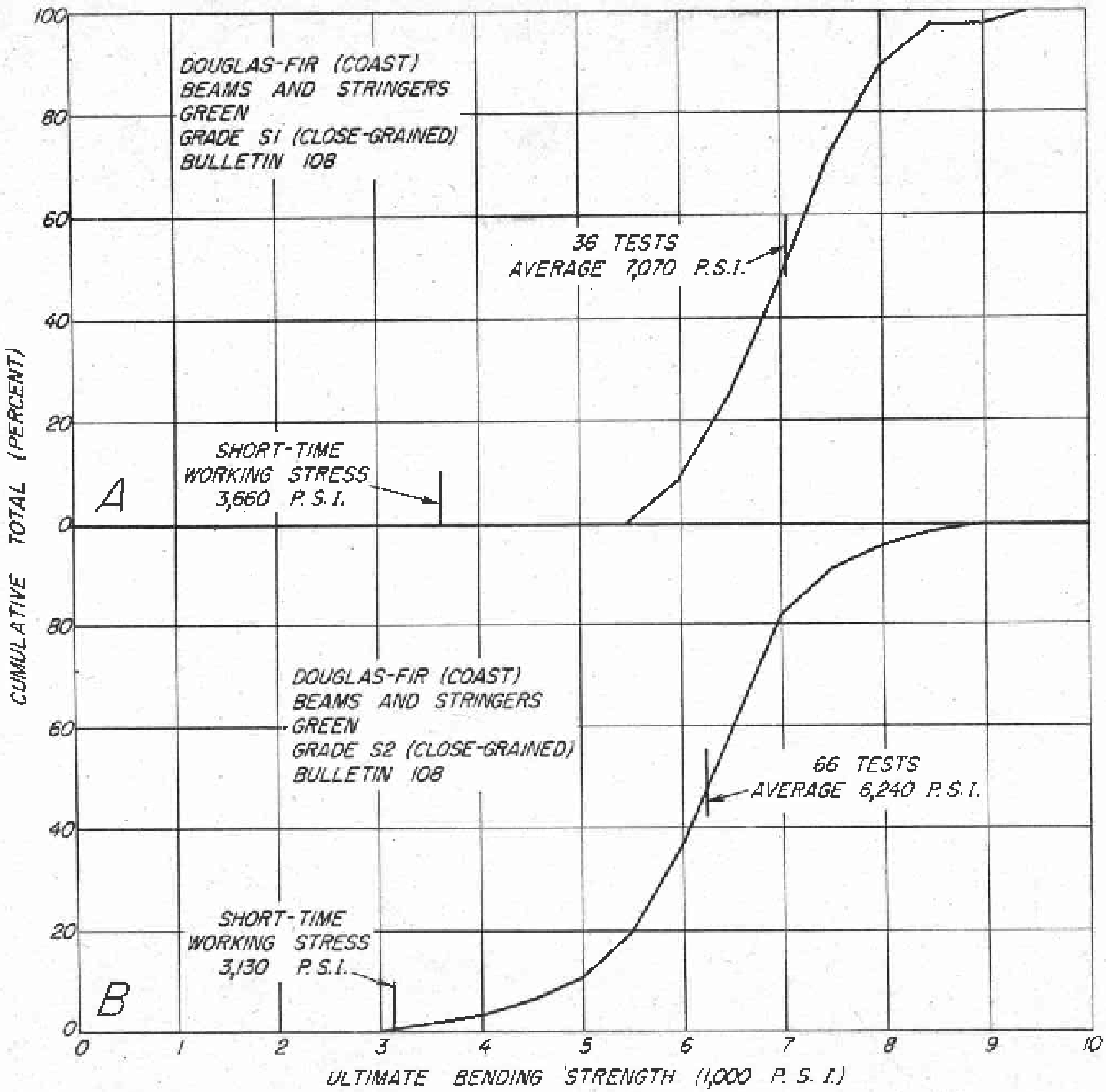


Figure 13. --Cumulative frequency-distribution curves for bending strength in (A) S1 and (B) S2 grade groups of coast-type Douglas-fir beams and stringers.

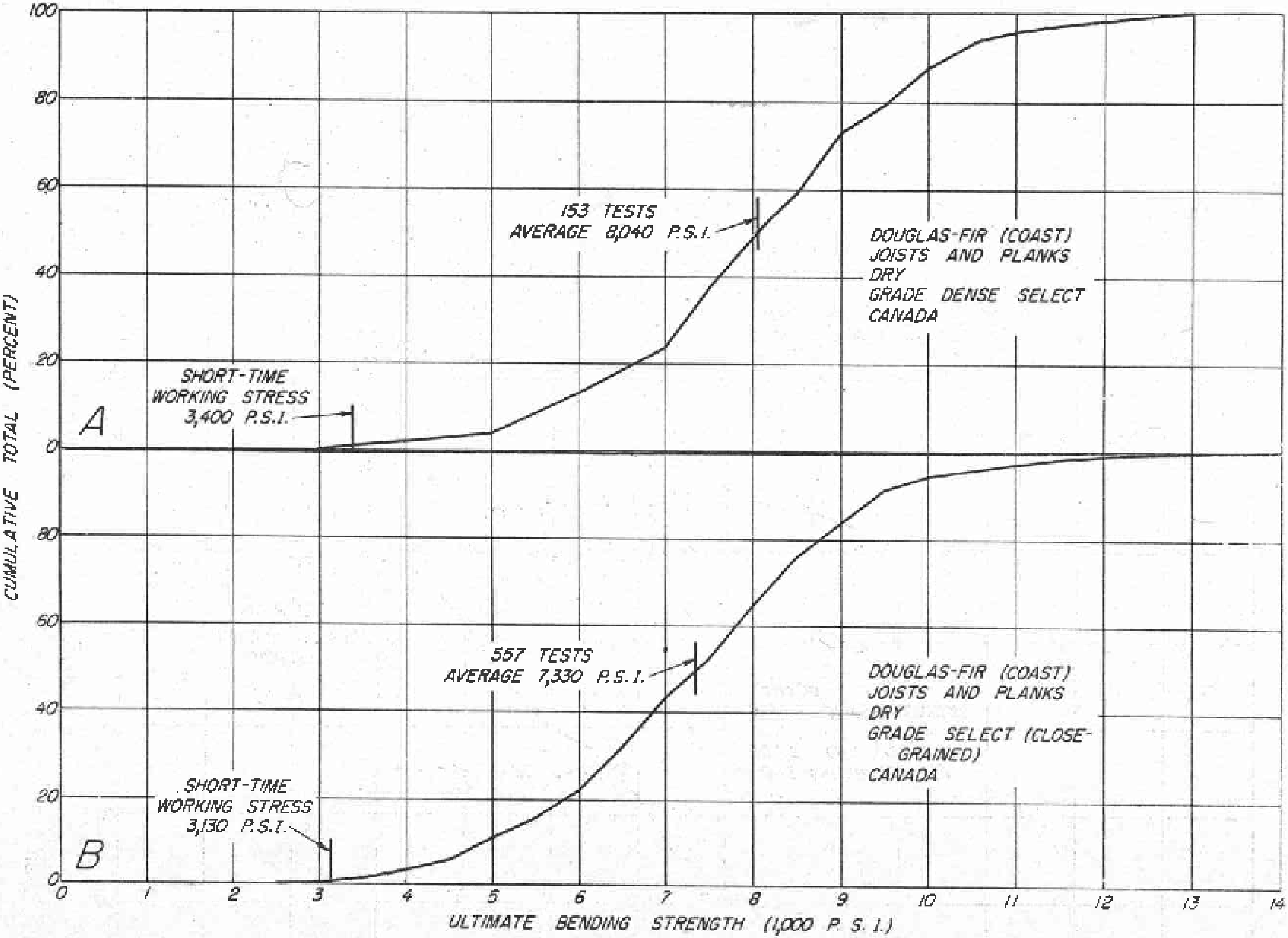


Figure 14.--Cumulative frequency-distribution curves for bending strength in (A) Dense Select and (B) Select grade groups of coast-type Douglas-fir joists and planks.

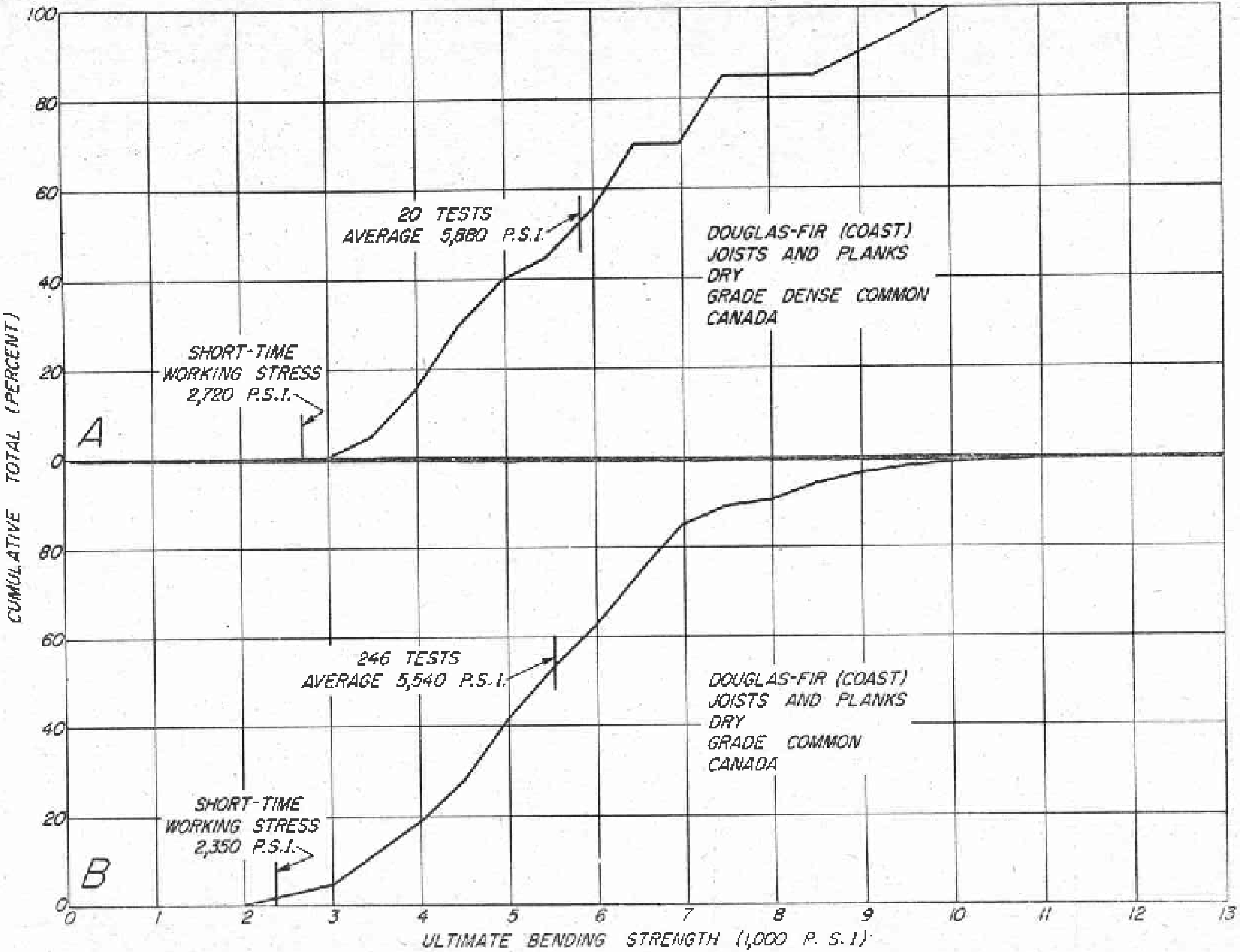


Figure 15.--Cumulative frequency-distribution curves for bending strength in (A) Dense Common and (B) Common grade groups of coast-type Douglas-fir joists and planks.

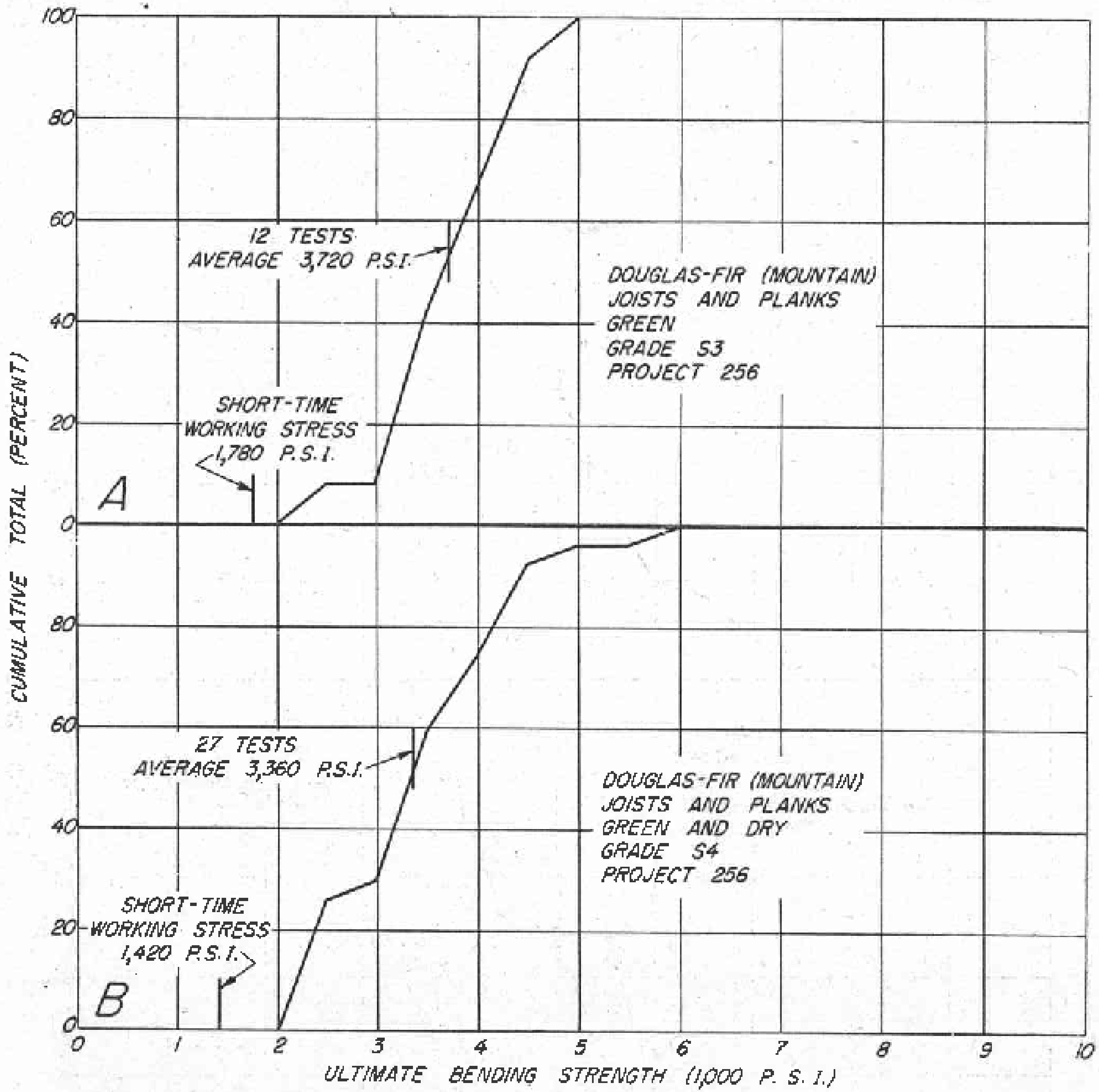


Figure 16. --Cumulative frequency-distribution curves for bending strength in (A) S3 and (B) S4 grade groups of mountain-type Douglas-fir joists and planks.

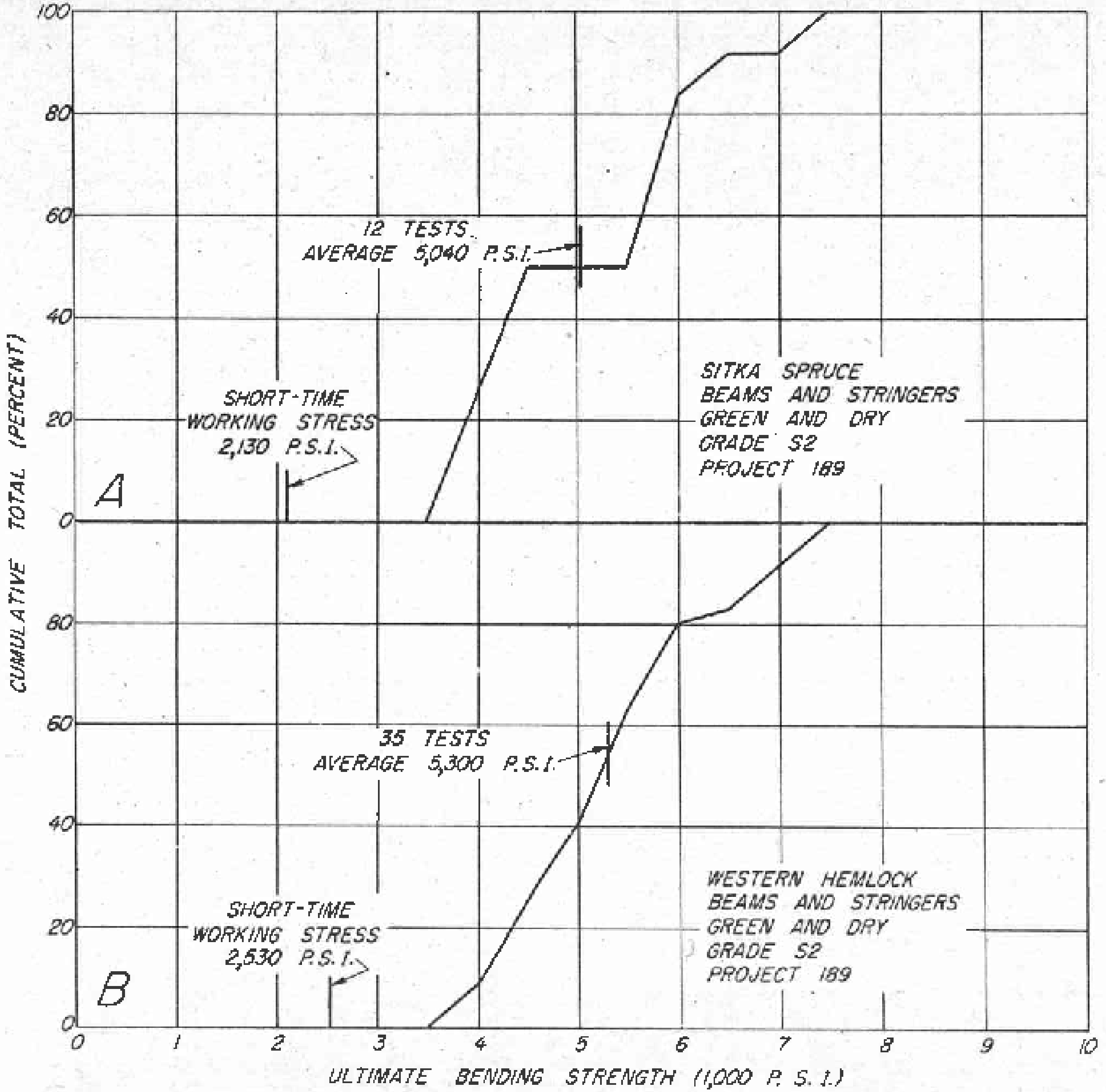


Figure 17.--Cumulative frequency-distribution curves for bending strength in the S2 grade groups of (A) Sitka spruce beams and stringers and (B) western hemlock beams and stringers.

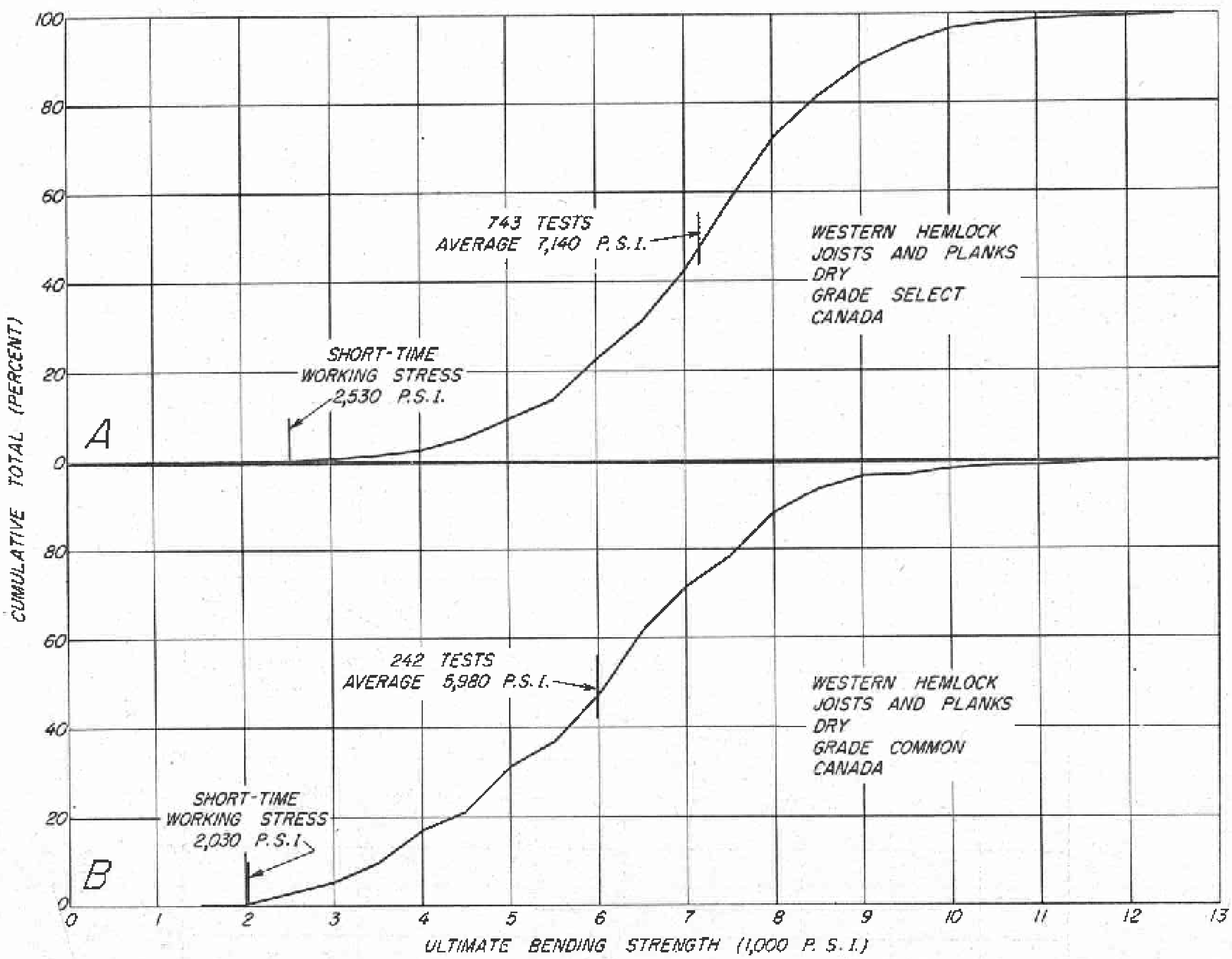


Figure 18.--Cumulative frequency-distribution curves for bending strength in (A) Select and (B) Common grade groups of western hemlock joists and planks.

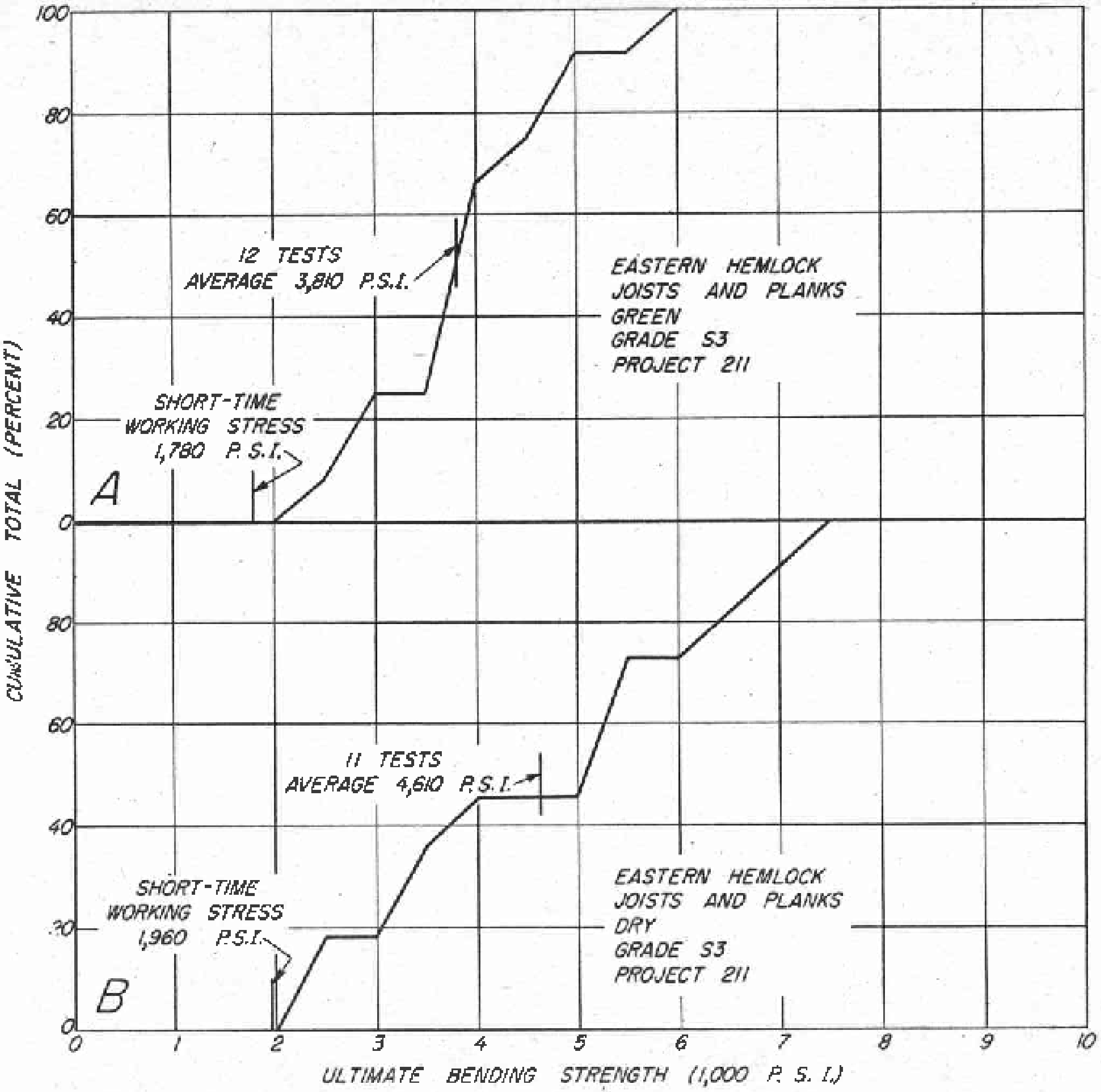


Figure 19.--Cumulative frequency-distribution curves for bending strength in (A) green and (B) dry grade groups of eastern hemlock joists and planks.

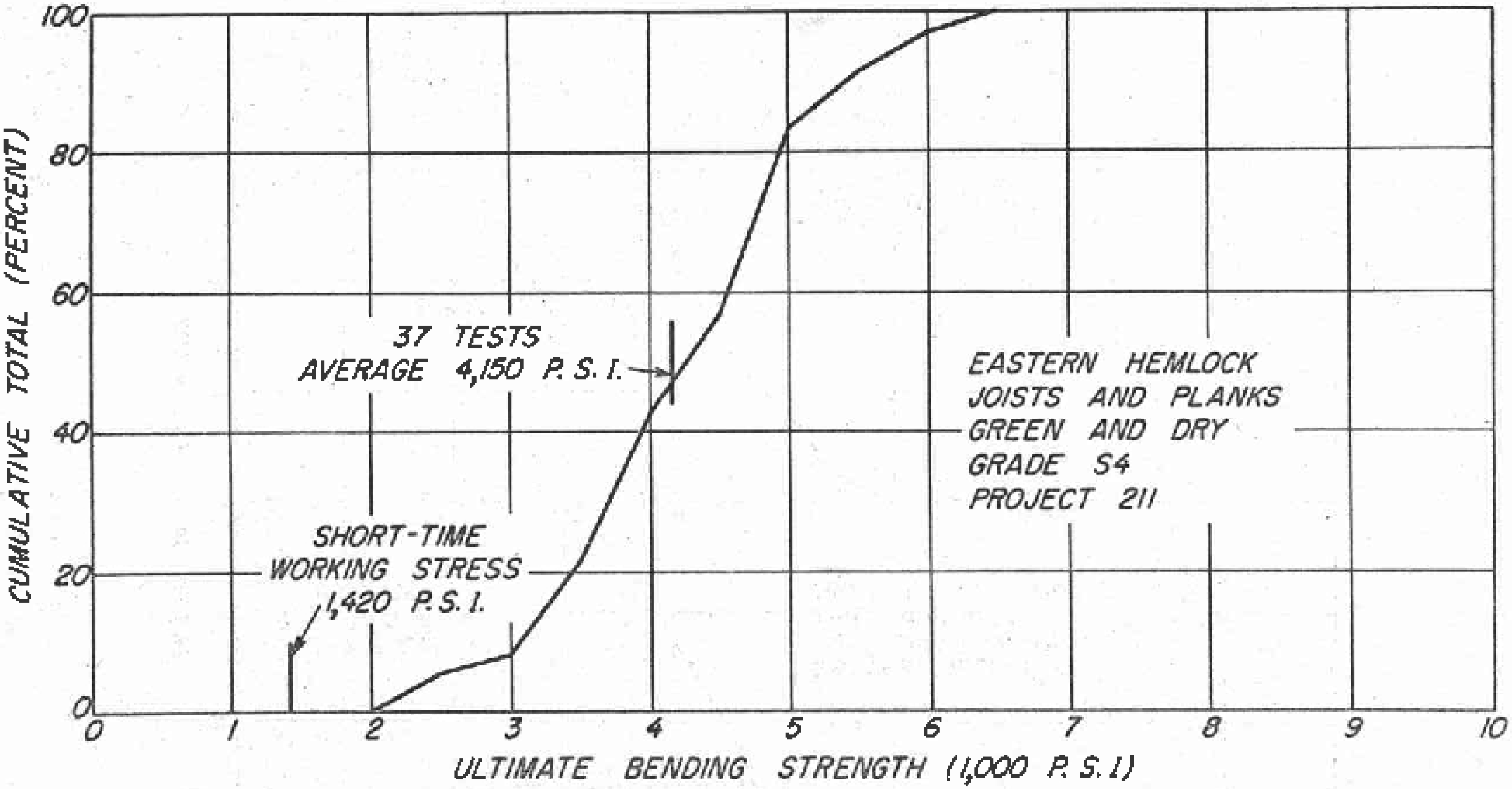


Figure 20.--Cumulative frequency-distribution curve for bending strength in the S4 grade group of eastern hemlock joists and planks.

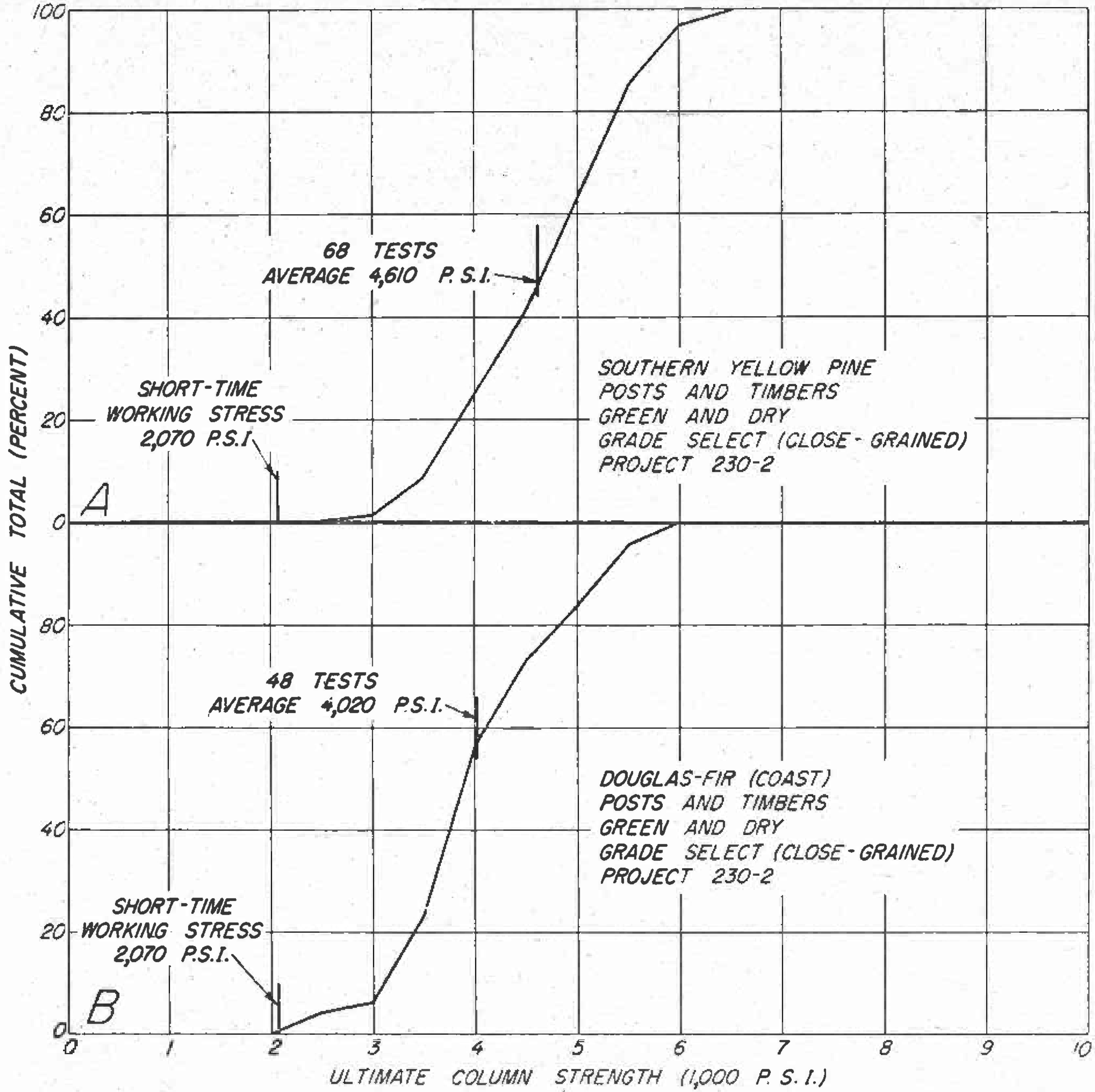


Figure 21.--Cumulative frequency-distribution curves for column strength in Select grade groups of (A) southern yellow pine and (B) coast-type Douglas-fir posts and timbers.