STRENGTH GRADING BY RULES FOR DENSITY AND CLOSE GRAIN

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STRENGTH GRADING BY RULES FOR DENSITY AND CLOSE GRAIN

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Summary

The purpose of this study is to review the stress-grading rules by which dense or close-grained material is classified in the southern pines, coast type Douglas-fir, and redwood, and to show the effects upon strength from those rules, either in their existing or in modified forms. The study has been based on data from a large number of green small clear specimens carefully selected so as to be representative of their species. Since working stress depends upon minimum as well as average strength values, a near-minimum value (average minus twice the standard deviation) is chosen as the basis for comparison of classified with unclassified material.

Existing rules for density and close grain give material whose increased strength is for the most part adequately reflected in the present working stress bonuses. Elimination of the bonus for density in shearing strength of all species is proposed. No bonus for medium grain appears desirable.

A limitation of one-half summerwood in southern pine results in material about 25 percent stronger than unclassified material. A limitation of 11 to 40 rings per inch in redwood gives increases of about 20 percent in bending and crushing strengths. These offer immediate means for

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

selecting material to which working stresses above the current values can be assigned.

Introduction

Superior strength in wood has been shown to be associated with high specific gravity. In the grading of timbers for strength, actual specific gravity determinations are usually impractical, but segregation of high-gravity material from certain visual characteristics has been found to be a workable substitute. Where summerwood is well defined, as in Douglas-fir and the southern pines, the estimated proportion of summerwood is taken as a criterion of specific gravity and strength, and dense grades carrying increased working stresses have been set up on that basis. In these species and redwood, certain optimum rates of growth have been recognized; although these are considered to be less reliable than summerwood as a criterion of strength, they are recognized in the so-called "close grain" grades with increased working stresses. Rules for "density" (as estimated from the proportion of summerwood) and close grain have thus become established in the practice of stress grading.

A common density rule has been based on a minimum requirement of one-third summerwood, and the increase of stress on material so classified has been set at one-sixth of the stress for unclassified material. Rules for close grain are less uniform, but rates of growth between limits of about six rings per inch and 20 or more rings per inch have been recognized by a stress increase of one-fifteenth of the stress for unclassified material. The search for more efficient means of utilizing the strength in structural timber has led to questioning of these rules and has indicated the desirability of re-examining them. This study of the effects of such rules on strength has therefore been made.

Grades incorporating both density and close grain requirements are described in current grading rules for Douglas-fir,[2] and dense grades are described in the current rules for southern pine.[3] Grades of close

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[2] "Standard Grading and Dressing Rules," No. 14, of the West Coast Lumbermen's Association.

[3] "Standard Grading Rules for Southern Pine Lumber," 1948, of the Southern Pine Association.

grain are in the current rules for redwood.[4] These rules have long been applied to these species, and the present study is restricted to them. Three major strength properties, modulus of rupture in transverse bending, maximum crushing strength in compression parallel to grain, and maximum shearing strength in shear parallel to grain, are examined. In order to eliminate the effect of moisture differences upon strength comparisons, the study is restricted to green material.

Source of Data

No new tests were run for this purpose. Project 124 of the Forest Products Laboratory consists of standard strength tests on small clear specimens of wood carefully selected so as to be representative of their species. Evaluation of the strength effects from rules for density or close grain can be made from test results on clear material, since the resulting increases are applied to the basic stresses for clear material. This report is therefore based entirely on analysis of data from the standard strength tests. These data have been recorded on a punch-card system, thereby greatly facilitating the necessary operations of classification and tabulation for analysis.

Five southern pines, loblolly, longleaf, pond, shortleaf, and slash, were tabulated separately. Longleaf pine was carried separately throughout the analysis because of its greater summerwood content and its higher strength values; the other four pines were placed together in one group. All old-growth Douglas-fir of coast type was placed together, while one shipment of second-growth coast-type Douglas-fir (shipment 1625) was analyzed separately. The redwood group includes both virgin growth and closely grown second growth, excluding the openly grown second growth. Modulus of rupture, maximum crushing strength, and maximum shearing strength were examined in each of the groups except for shipment 1625 of Douglas-fir, for which punch-card data were available only in maximum crushing strength.

Data on the pines and Douglas-fir were classified by percentage of summerwood, but rate of growth for each specimen was also recorded. Redwood data do not show the summerwood content and were classified by rate of growth.

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[4] "Standard Specifications for Grades of California Redwood Lumber," 1946, of the California Redwood Association.

Summerwood counts were not made on all old-growth Douglas-fir in the standard strength tests under Project 124, and the sample used in this study is thus incomplete; however, since the majority of the test specimens had summerwood counts, it is believed that the sample is representative.

Analysis of Data

The large number of test results used (upwards of 2,000 in some groups) necessitated some method of analysis en masse rather than on any individual basis. After some experimenting with various methods of treatment, the normal frequency distribution with its standard deviation was chosen as the basis for comparison. A recent survey of variability[5] of structural woods indicated that frequency distributions of strength values for groups of small clear specimens tend to approach normal frequency distribution of the type $y = e^{-x^2}$ where y is the frequency, x is the deviation from the average value, and e is the base of natural logarithms. The normal frequency distribution is defined by its average value and its standard deviation. The standard deviation is the root mean square of individual deviations from the average; since it is affected by each individual value, it is a better measure of comparative dispersion among groups of various sizes than is the total or any partial range of values. Standard deviation, when expressed as a percentage of the average value, is known as the coefficient of variation.

In all normal frequency distributions, about 68 percent of the individual values lie within the range encompassed by the standard deviation on either side of the average value. Thus, if there are 100 individual values in a normal frequency distribution with a standard deviation of 100 around an average value of 1,000, about 68 individual values will lie within the range of 900 to 1,100. In like manner, twice the standard deviation encompasses about 95 percent of the individuals. Of the remaining 5 percent, about half, or 2-1/2 percent, are excluded at the upper end, and the other 2-1/2 percent at the lower end of the frequency distribution.

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[5] "Survey of Variability of Structural Woods," unpublished report, Forest Products Laboratory, Division of Timber Mechanics, 1947.

Working stresses are determined, not from the lowest individual in a group of strength values, but from some near-minimum value that excludes a small percentage of the individuals. In normal or nearly normal frequency distributions, the average minus twice the standard deviation meets the requirement of a near-minimum value, as it excludes about 2-1/2 percent of the individuals at the lower end of the distribution. Comparisons in this report are based on the average minus twice the standard deviation, thus taking into account the variability of the material as well as its average strength.

While the foregoing value is related to the working stress, it is not in itself a working stress. Other factors for duration of load, structural grade, factor of safety, etc., are necessary to convert it to a suitable working value for use in design. Since these other factors apply equally to material with or without classification for density or close grain, they are not required in the present comparisons, and valid comparisons for the purpose of this report can be made from the average minus twice the standard deviation.

The basis for calculation of ratios to show the effects of the various density and close grain rules is taken as the average minus twice the standard deviation for material without classification. Basic stresses are derived from values representing the whole species without any segregation or classification, and the stress increases appropriate to the various rules are made on those basic stresses. Consequently, the unclassified values form the proper base for comparison of the strength increases.

Tables 1 to 3 for density rules and tables 4 to 7 for close-grain rules are prepared by the foregoing principles. Each table shows the effect of classification by the various rules on the strength properties of one species group. The last column of each table gives percentage ratios indicating the gain in strength from application of each rule, the percentages being calculated from unsegregated material as the base. The number of specimens and other information for material segregated by the various groups is also shown.

Values from the last two columns in tables 1 to 7 relating to the existing rules for density and close grain are brought together in table 8. Those for longleaf and other southern pines are modified from tables 1, 2, 4, and 5 to agree with the method by which working stresses are now assigned. By that method, the stress bonus for density in longleaf pine is applied, not to the value for that species alone, but to a composite value representing all southern pines. The bonus for density in other southern pines is applied to the same composite value. For the purpose of table 8, a composite value giving longleaf pine one-half the weight of all other pines is used. This changes the base of calculation and modifies the ratios indicating gain of strength in longleaf and other southern pines (last col., tables 1, 2, 4, and 5). The ratios in table 8 are shown graphically in figure 1 for density and figure 2 for close grain.

It is to be noted that longleaf pine in this study includes all specimens of Pinus palustris and none of any other species. This differs from the commercial "longleaf pine" of the current grading rules[3] which includes slash pine and has a requirement on summerwood content. By those grading rules, Pinus palustris may appear either in the unrestricted "Southern Pine" group or in the "Longleaf Pine" group.

Discussion of Results

Reduction of Variability

Classification of material by rules either for density or for close grain results rather consistently in reduction of the dispersion of the individual strength values. This may be verified in column 7 of tables 1, 2, 3, and 7 and column 6 of tables 4, 5, and 6 showing coefficients of variation. This reduction of dispersion means that the various rules increase minimum values more than they do average values, an important favorable factor in the application to working stresses.

Rules for Density

Effects of classification by the existing density rules on strength are examined most conveniently in table 8 and figure 1. Strength increases there range from 9 to 19 percent in modulus of rupture and maximum crushing strength of southern pines and coast-type Douglas-fir. Increases in shear are inconsistent, one group indicating some decrease. These increases may be compared in figure 1 with the stress increase of one-sixth (broken vertical lines) now given for density. It appears that classification by the existing density rules results in increases of near-minimum strength values in bending and compression that are adequately reflected in the present working stress allowances. On the other hand, the increases in shearing strength do not appear to warrant a stress bonus.

Tables 1 to 3 show the proportions of material qualifying under existing density rules, about 78 percent of longleaf pine, 57 percent of other southern pines, and 35 to 40 percent of Douglas-fir.

Existing density rules call for one-third summerwood, but with certain additional limitations on rate of growth. Tables 1 to 3 show the effect of the summerwood requirement without limit on rate of growth. The amount of material qualifying is increased about 5 percent by removing the limit on rings per inch. Strength increases in southern pine are essentially unchanged by removal of ring limitation, but in coast Douglas-fir (table 3) they are significantly reduced. Existing density rules are apparently being applied with little difficulty, and these data indicate that the only significant advantage to be gained by removing the limitation on rate of growth from them is a possible simplification of grading.

A requirement of one-half summerwood in the southern pines results in increases of near-minimum strength values that range from 18 to 36 percent (tables 1 and 2, col. 9), with only one increase out of the six that is less than 25 percent. A stress bonus of 25 percent for material in this class appears to be justified. While these data indicate that only about 8 percent of the material qualifies for this requirement, it is believed that the proportion is much higher in certain areas or at some mills. The proportion of material with half or more summerwood is about 5 percent in coast Douglas-fir. Since strength increases in Douglas-fir for half summerwood are smaller on the average and less consistent than in the southern pines, there is less reason for applying a bonus for such a grade in Douglas-fir. When the ratios for one-half summerwood in southern pines are recomputed to a common base after the manner of table 8, the strength increases remain in the same range.

To qualify for a stress bonus, any rule for a high summerwood content should stipulate a sharp contrast in color between springwood and summerwood, or some equivalent provision to exclude compression wood.

Increases in near-minimum strength values resulting from a requirement of one-fourth summerwood in southern pine and old-growth Douglas-fir do not exceed 7 percent in bending and compression and 1 percent in shear. More than 90 percent of southern pine and about 80 percent of Douglas-fir qualified under this requirement. It does not appear practical to recognize such a small increase, although, as will be shown later, the increase in second-growth Douglas-fir is larger.

Close Grain in Pine and Fir

The effects of existing rules for close grain in the southern pines and in old-growth Douglas-fir are shown in table 8 and graphically in figure 2. Increases in near-minimum strength values for these species in figure 2 range from 4 to 9 percent in bending and compression. Increases in shearing strength are inconsistent. Figure 2 indicates a large increase in shearing strength for longleaf pine when computed against the weighted average for all southern pines, but table 4 shows no increase when computed against the average for longleaf pine. Strength increases appear to be adequately reflected in the allowance of a stress bonus of one-fifteenth in bending and compression and no bonus in shear. It may be noted here that the present grading rules for southern pine[3] do not give stress recommendations for close-grained material. About 90 percent of the material in fir and pine qualifies under the existing rules for close grain.

Existing rules in pine and fir require 6 to 20 rings per inch but broaden the permissible range in rate of growth to 5 and more than 20 rings when the material contains one-third or more summerwood. This provision adds 4 to 13 percent to the amount of material qualifying. Tables 4, 5, and 6 show that it has no consistent effect on the strength of the classified material. Existing rules are apparently being applied with little difficulty, and there does not appear to be good reason for changing in this respect.

Some grading rules specify "medium grain," with no limitation other than a minimum of 4 rings per inch. This classification appears to be of little importance (tables 4, 5, and 6). It excludes only about 2 percent of the material and gives no significant increase in strength. No stress bonus for medium grain appears to be warranted in southern pine or old-growth Douglas-fir.

Close Grain in Redwood

Redwood differs from southern pine and Douglas-fir in that summerwood is not so readily distinguished from springwood. The rule for close grain is based entirely on rate of growth as shown by the ring count. Existing lower and upper limits are 8 and 35 rings per inch, respectively.

Figure 3 shows that the relation of modulus of rupture to ring count falls considerably short of perfection. Nevertheless, it can be seen that the range from about 10 to 40 rings per inch yields very few extremely low values. Plots of data for crushing and shearing strengths show similar distributions.

Table 7 and figure 2 show that classification under the existing rule for close grain gives an increase in near-minimum strength values of 12 percent in modulus of rupture, 15 percent in maximum crushing strength, and 2 percent in maximum shearing strength. The 12 percent increase in bending strength is indicated on figure 3. This compares with existing stress increases of one-fifteenth (6-2/3 percent) in the two first-named, and no increase in shear. More than half of the material qualifies under this rule.

Increases of near-minimum strength values in bending and compression are somewhat greater than one-fifteenth, and it has been suggested that the ring count limits might be broadened. Table 7 shows that a lower limit of 6 rings gives strength increases of 9 percent in bending and 11 percent in compression, less than the increases with a limit of 8 rings, but still enough to warrant a stress bonus of one-fifteenth. The amount of material qualifying is increased by about 10 percent. On the other hand, the strength increases are greater when the lower limit is raised from 8 to 11 rings per inch, this resulting in 21 percent increase in bending and 24 percent in compression with about 10 percent reduction in the amount of material that qualifies. A bonus of 20 percent on the working stress for material in such a classification appears to be warranted.

Table 7 does not show the result of raising the upper limit from 35 to 40 rings per inch, but figure 3 indicates little effect from such a change. Plots of data in compression and shear also indicate little effect.

Old-Growth and Second-Growth Douglas-fir

Tables 3 and 6 afford a basis for comparison between old-growth and second-growth (shipment 1625) Douglas-fir of coast type in one property, maximum crushing strength. The comparison indicates benefits to near-minimum values of maximum crushing strength from density and close-grain classifications greater in second growth than in old growth. The increase of 59 percent from a density rule of one-half summerwood (table 3) is noteworthy, but in view of the small number of tests, probably not significant. There is indication that stress bonuses accompanying existing rules for density and close grain might be liberalized, but in view of the limited scope of the data and the unknown proportion of second growth to old growth in present production, no change is proposed at this time.

The density requirement of one-fourth summerwood excludes about the same amount of material but gives a greater strength increase in second-growth than in old-growth Douglas-fir. In view of the amount of this increase, some recognition in working stress for material containing one-quarter or more summerwood may be appropriate at some time in the future when data are more complete.

Conclusions

The validity of the conclusions from this study is limited by the scope of the data on which the work is based. It may be pointed out that the data used in this study are based on specimens carefully selected so as to be representative of their species, so that the results warrant the following conclusions.

Classification either for density or for close grain results in a reduction of the dispersion of individual strength values. Working stresses thus enjoy greater benefits than do the average values.

Existing rules for density and close grain of southern pine and coast Douglas-fir give strength increases in bending and crushing strength that are adequately reflected in the present working stress allowances. No change in these rules appears necessary.

In shearing strength under the existing rules, a bonus is now given for density but not for close grain. The bonus for density should be discontinued.

A density requirement of one-half summerwood without limitation of ring count appears to justify a stress bonus of 25 percent in all three strength properties for the southern pines. No bonus for one-fourth summerwood in southern pine or Douglas-fir seems advisable at this time, although additional new data from second-growth Douglas-fir may later indicate a possibility for stress increase there.

No stress bonus for medium grain, based on a minimum of 4 rings per inch, seems advisable in pine or fir.

With a stress bonus of one-fifteenth, the limitations on rate of growth for close grain in redwood can probably be broadened to a minimum of 6 and a maximum of 40 rings per inch. If, on the other hand, the limitation is narrowed to 11 and 40 rings per inch, a bonus of 20 percent on strength is realized. These conclusions apply to bending and crushing strengths only; shearing strength gains very little from any of the rules for close grain.

There appears to be a gain in strength from the existing rules for density and close grain that is greater in second-growth than in old-growth coast Douglas-fir. This may warrant further study, but no distinction in working stress seems practical at this time.

While this study does not indicate that existing classifications for density and close grain can be recognized by greater working stress increases than at present, it points out possibilities in closer selection of material. The proposed increases for one-half summerwood in the southern pines and for 11 to 40 rings per inch in redwood are illustrations in point. Such means of selecting material for increased working stress are to be desired, and in this case, are already available.

Table 1.--Effect of classification by density rule on the strength of longleaf pine

Classification	Test specimens		Average summerwood	Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (8)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number	Percent of total	Percent	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MODULUS OF RUPTURE								
All specimens without classification	639	100	39	8,406	1,564	18.6	5,278	100
One-half or more summerwood	53	8	53	9,776	1,310	13.4	7,156	136
Existing rule for density[2]	494	77	42	8,617	1,518	17.6	5,581	106
One-third or more summerwood	514	80	42	8,585	1,514	17.6	5,557	105
One-fourth or more summerwood	628	98	40	8,410	1,560	18.5	5,290	100
MAXIMUM CRUSHING STRENGTH								
All specimens without classification	1,234	100	40	4,148	855	20.6	2,438	100
One-half or more summerwood	106	9	53	4,806	748	15.6	3,310	136
Existing rule for density[2]	965	78	41	4,258	816	19.2	2,626	108
One-third or more summerwood	1,010	82	42	4,231	815	19.3	2,601	107
One-fourth or more summerwood	1,219	99	40	4,150	856	20.6	2,438	100
MAXIMUM SHEARING STRENGTH								
All specimens without classification	499	100	40	1,023	170	16.6	683	100
One-half or more summerwood	34	7	54	1,140	166	14.6	808	118
Existing rule for density[2]	388	78	41	1,039	167	16.1	705	103
One-third or more summerwood	414	83	42	1,039	163	15.7	713	104
One-fourth or more summerwood	497	100	40	1,023	171	16.7	681	100

[1] Ratio of average strength minus twice standard deviation (col. 8) of material with summerwood classification to material without classification.

[2] One-third or more summerwood with not less than six rings per inch.

Table 2.--Effect of classification by density rule on the strength of southern pines other than longleaf. (Shortleaf, slash, loblolly, and pond pines)

Classification	Test specimens		Average summer-wood	Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (8)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number	Percent of total	Percent	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MODULUS OF RUPTURE								
All specimens without classification	1,277	100	36	7,597	1,289	17.0	5,019	100
One-half or more summerwood	102	8	54	8,881	1,217	13.7	6,447	128
Existing rule for density[2]	729	57	42	8,137	1,136	14.0	5,865	117
One-third or more summerwood	767	60	42	8,104	1,136	14.0	5,832	116
One-fourth or more summerwood	1,155	90	38	7,751	1,222	15.8	5,307	106
MAXIMUM CRUSHING STRENGTH								
All specimens without classification	2,314	100	36	3,589	652	18.2	2,285	100
One-half or more summerwood	185	8	54	4,228	571	13.5	3,086	135
Existing rule for density[2]	1,285	56	42	3,888	559	14.4	2,770	121
One-third or more summerwood	1,383	60	42	3,859	566	14.7	2,727	119
One-fourth or more summerwood	2,094	90	37	3,673	611	16.6	2,451	107
MAXIMUM SHEARING STRENGTH								
All specimens without classification	1,381	100	36	829	161	19.4	507	100
One-half or more summerwood	116	8	54	949	146	15.4	657	130
Existing rule for density[2]	783	57	42	862	160	18.6	542	107
One-third or more summerwood	829	60	42	864	159	18.4	546	108
One-fourth or more summerwood	1,265	92	38	837	163	19.5	511	101

[1] Ratio of average strength minus twice standard deviation (col. 8) of material with summerwood classification to material without classification.

[2] One-third or more summerwood with six or more rings per inch, with the addition of less than six rings per inch when one-half or more summerwood.

Table 3.--Effect of classification by density rule on the strength of coast type Douglas-fir

Classification	Test specimens		Average summer-wood	Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (8)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number	Percent of total	Percent	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MODULUS OF RUPTURE								
All specimens without classification	1,070	100	32	7,137	1,102	15.4	4,933	100
One-half or more summerwood	57	5	57	7,655	1,093	14.3	5,469	111
Existing rule for density[2]	364	34	42	7,841	995	12.7	5,851	119
One-third or more summerwood	409	38	42	7,703	1,055	13.7	5,593	113
One-fourth or more summerwood	851	80	35	7,353	1,070	14.6	5,213	106
MAXIMUM CRUSHING STRENGTH (OLD GROWTH)								
All specimens without classification	2,209	100	32	3,556	631	17.7	2,294	100
One-half or more summerwood	117	5	57	3,829	605	15.8	2,619	114
Existing rule for density[2]	770	35	42	3,879	594	15.3	2,691	117
One-third or more summerwood	876	40	42	3,776	651	17.2	2,474	108
One-fourth or more summerwood	1,771	80	35	3,661	620	16.9	2,421	106

Table 3.--Effect of classification by density rule on the strength of coast type Douglas-fir (continued)

Classification	Test specimens		Average summer-wood	Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (8)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number	Percent of total	Percent	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MAXIMUM CRUSHING STRENGTH (SHIPMENT 1625)								
All specimens without classification	414	100	32	3,740	666	17.8	2,408	100
One-half or more summerwood	7	2	52	4,290	230	5.4	3,830	159
Existing rule for density[2]	173	42	40	4,236	486	11.5	3,264	136
One-third or more summerwood	176	43	40	4,221	495	11.7	3,231	134
One-fourth or more summerwood	320	77	35	3,945	587	14.9	2,771	115
MAXIMUM SHEARING STRENGTH								
All specimens without classification	428	100	35	904	143	15.8	618	100
One-half or more summerwood	52	12	57	944	153	16.2	638	103
Existing rule for density[2]	183	43	44	924	142	15.4	640	104
One-third or more summerwood	200	47	44	914	144	15.8	626	101
One-fourth or more summerwood	356	83	38	914	144	15.8	626	101

[1]Ratio of average strength minus twice standard deviation (col. 8) of material with summerwood classification to material without classification.

[2]One-third or more summerwood with six or more rings per inch, with the addition of five rings per inch when one-half or more summerwood.

(Sheet 2 of 2)

Table 4.--Effect of classification by close-grain rule on the strength of longleaf pine

Classification	Test specimens		Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (7)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Number	Percent of total	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MODULUS OF RUPTURE							
All specimens without classification	639	100	8,406	1,564	18.6	5,278	100
Six to 20 rings per inch	528	83	8,599	1,501	17.5	5,597	106
Existing rule for close grain[2]	608	95	8,468	1,537	18.1	5,394	102
Four or more rings per inch (medium grain)	638	100	8,409	1,564	18.6	5,281	100
MAXIMUM CRUSHING STRENGTH							
All specimens without classification	1,234	100	4,148	855	20.6	2,438	100
Six to 20 rings per inch	1,014	82	4,251	802	18.9	2,647	109
Existing rule for close grain[2]	1,168	95	4,191	828	19.8	2,535	104
Four or more rings per inch (medium grain)	1,229	100	4,149	854	20.6	2,441	100
MAXIMUM SHEARING STRENGTH							
All specimens without classification	499	100	1,023	170	16.6	683	100
Six to 20 rings per inch	426	85	1,028	171	16.6	686	100
Existing rule for close grain[2]	471	94	1,026	171	16.7	684	100
Four or more rings per inch (medium grain)	497	100	1,023	171	16.7	681	100

[1] Ratio of average strength minus twice standard deviation (col. 7) of material with ring classification to material without classification.

[2] Six to 20 rings per inch, with the addition of 5 and more than 20 rings per inch when one-third or more summerwood.

Table 5.--Effect of classification by close-grain rule on the strength of southern pines other than longleaf. (Shortleaf, loblolly, slash, and pond pines)

Classification	Test specimens		Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (7)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Number	Percent of total	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MODULUS OF RUPTURE							
All specimens without classification	1,277	100	7,597	1,289	17.0	5,019	100
Six to 20 rings per inch	1,094	86	7,727	1,220	15.8	5,287	105
Existing rule for close grain[2]	1,148	90	7,730	1,212	15.7	5,306	106
Four or more rings per inch (medium grain)	1,252	98	7,623	1,251	16.4	5,121	102
MAXIMUM CRUSHING STRENGTH							
All specimens without classification	2,314	100	3,589	652	18.2	2,285	100
Six to 20 rings per inch	1,957	85	3,674	612	16.7	2,450	107
Existing rule for close grain[2]	2,056	89	3,677	609	16.6	2,459	108
Four or more rings per inch (medium grain)	2,253	97	3,612	638	17.7	2,336	102
MAXIMUM SHEARING STRENGTH							
All specimens without classification	1,381	100	829	161	19.4	507	100
Six to 20 rings per inch	1,194	86	832	160	19.2	512	101
Existing rule for close grain[2]	1,244	90	834	161	19.3	512	101
Four or more rings per inch (medium grain)	1,351	98	829	162	19.5	505	100

[1] Ratio of average strength minus twice standard deviation (col. 7) of material with ring classification to material without classification.

[2] Six to 20 rings per inch, with the addition of 5 and more than 20 rings per inch when one-third or more summerwood.

Table 6.--Effect of classification by close-grain rule on the strength of coast type Douglas-fir

Classification	Test specimens		Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (7)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Number	Percent of total	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MODULUS OF RUPTURE							
All specimens without classification	1,070	100	7,137	1,102	15.4	4,933	100
Six to 20 rings per inch	892	83	7,301	1,045	14.3	5,211	106
Existing rule for close grain[2]	927	87	7,299	1,048	14.4	5,203	106
Four or more rings per inch (medium grain)	1,037	97	7,178	1,080	15.0	5,018	102
MAXIMUM CRUSHING STRENGTH (OLD GROWTH)							
All specimens without classification	2,209	100	3,556	631	17.7	2,294	100
Six to 20 rings per inch	1,844	83	3,665	582	15.9	2,501	109
Existing rule for close grain[2]	1,923	87	3,659	587	16.0	2,485	108
Four or more rings per inch (medium grain)	2,141	97	3,587	609	17.0	2,369	103
MAXIMUM CRUSHING STRENGTH (SHIPMENT 1625)							
All specimens without classification	414	100	3,740	666	17.8	2,408	100
Six to 20 rings per inch	263	64	3,943	551	14.0	2,841	118
Existing rule for close grain[2]	298	72	3,983	559	14.0	2,865	119
Four or more rings per inch (medium grain)	392	95	3,780	652	17.2	2,476	103
MAXIMUM SHEARING STRENGTH							
All specimens without classification	428	100	904	143	15.8	618	100
Six to 20 rings per inch	357	83	921	141	15.3	639	103
Existing rule for close grain[2]	371	87	920	139	15.1	642	104
Four or more rings per inch (medium grain)	419	98	907	142	15.7	623	101

[1]Ratio of average strength minus twice standard deviation (col. 7) of material with ring classification to material without classification.

[2]Six to 20 rings per inch, with the addition of 5 and more than 20 rings per inch when one-third or more summerwood.

Table 7.--Effect of classification by close-grain rule on the strength of redwood (Virgin growth and closely grown second growth)

Classification	Test specimens		Average rate of growth	Average strength	Standard deviation	Coefficient of variation	Average minus twice standard deviation	Ratio based on data from col. (8)[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number	Percent of total	Rings per inch	P.s.i.	P.s.i.	Percent	P.s.i.	Percent
MODULUS OF RUPTURE								
All specimens without classification	508	100	24	6,798	1,364	20.1	4,070	100
Eleven to 35 rings per inch	258	51	23	7,369	1,214	16.5	4,941	121
Eight to 35 rings per inch	307	60	21	7,152	1,295	18.1	4,562	112
Six to 35 rings per inch	341	67	19	7,041	1,311	18.6	4,419	109
MAXIMUM CRUSHING STRENGTH								
All specimens without classification	1,060	100	25	3,772	864	22.9	2,044	100
Eleven to 35 rings per inch	556	52	22	4,104	785	19.1	2,534	124
Eight to 35 rings per inch	647	61	21	3,987	813	20.4	2,361	115
Six to 35 rings per inch	713	67	19	3,917	827	21.1	2,263	111
MAXIMUM SHEARING STRENGTH								
All specimens without classification	309	100	25	756	132	17.5	492	100
Eleven to 35 rings per inch	149	48	23	791	139	17.6	513	104
Eight to 35 rings per inch	173	56	21	776	137	17.7	502	102
Six to 35 rings per inch	198	64	19	769	134	17.4	501	102

[1] Ratio of average strength minus twice standard deviation (col. 8) of material with ring classification to material without classification.

Table 8.--Strength values and ratios as related to density and close grain rules[1]

Species	Modulus of rupture		Maximum crushing strength		Maximum shearing strength	
	Base for calculation	Strength ratio	Base for calculation	Strength ratio	Base for calculation	Strength ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent
DENSITY						
Longleaf pine	5,105	109	2,336	112	566	125
Southern pine other than longleaf	5,105	115	2,336	119	566	96
Douglas-fir, coast, old growth	4,933	119	2,294	117	618	104
CLOSE GRAIN						
Longleaf pine	5,105	106	2,336	109	566	121
Southern pine other than longleaf	5,105	104	2,336	105	566	90
Douglas-fir, coast, old growth	4,933	106	2,294	108	618	104
Redwood	4,070	112	2,044	115	492	102

[1]All ratios are obtained from comparisons of a near-minimum strength value obtained by subtracting twice the standard deviation from the average strength. Ratios showing strength of material classified by the existing rules (see tables 1 to 7) are calculated from strength of unclassified material as a base. In the case of longleaf and other southern pines, the base is a composite value giving longleaf pine one-half the weight of all other pines.

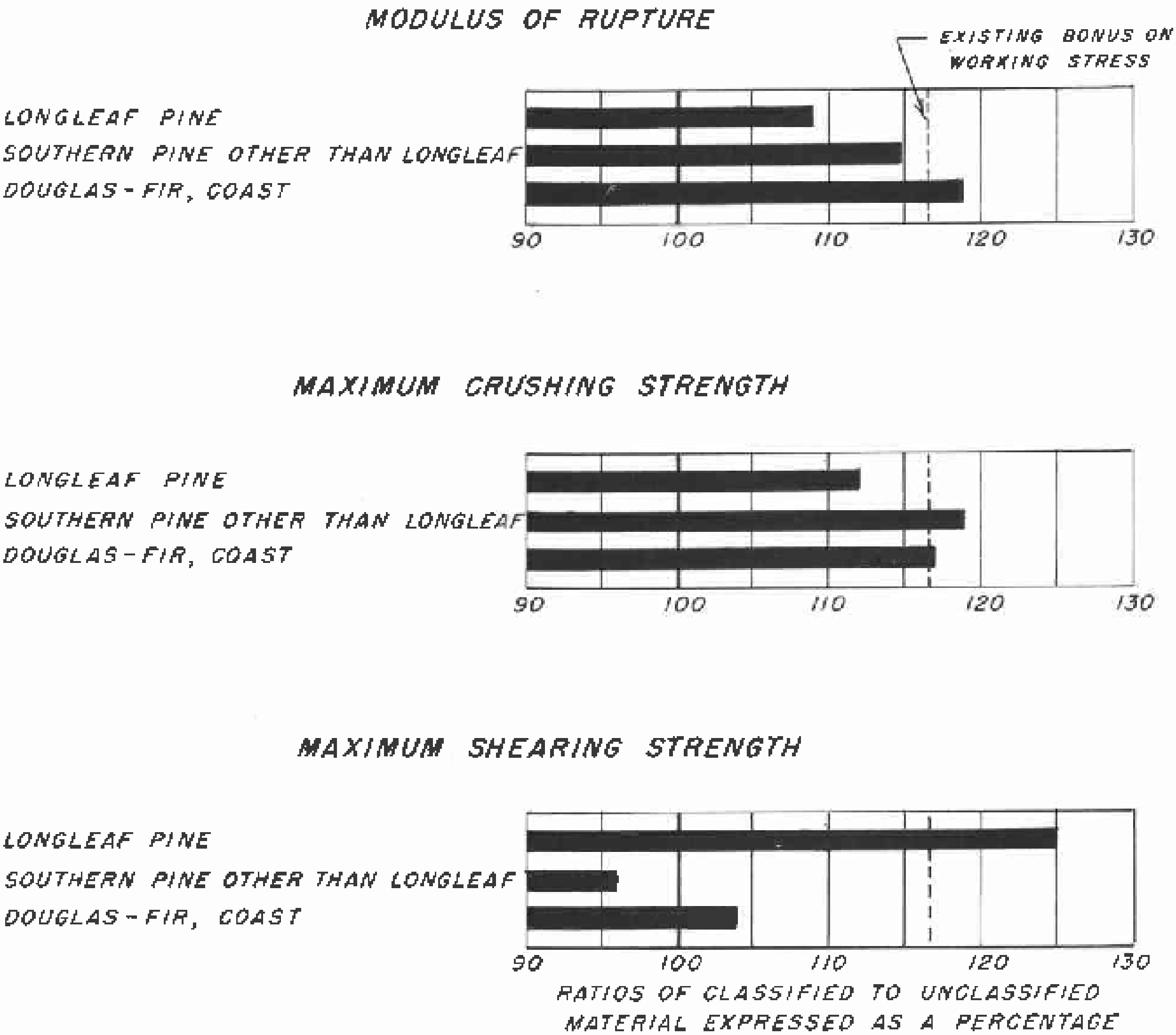

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Figure 1.--Effect of classification by existing density rules on strength.

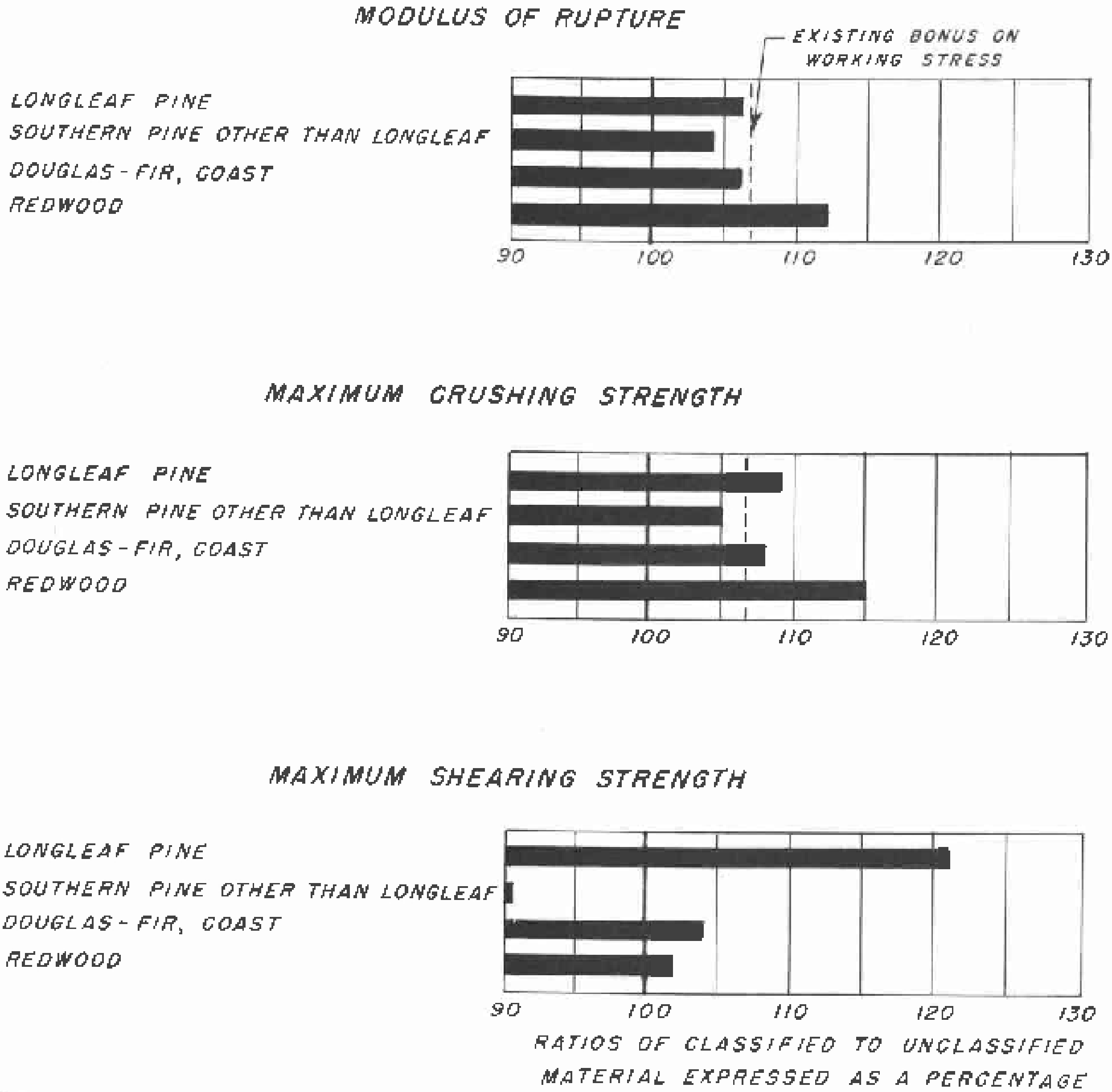

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Figure 2.--Effect of classification by existing close grain rules on strength.

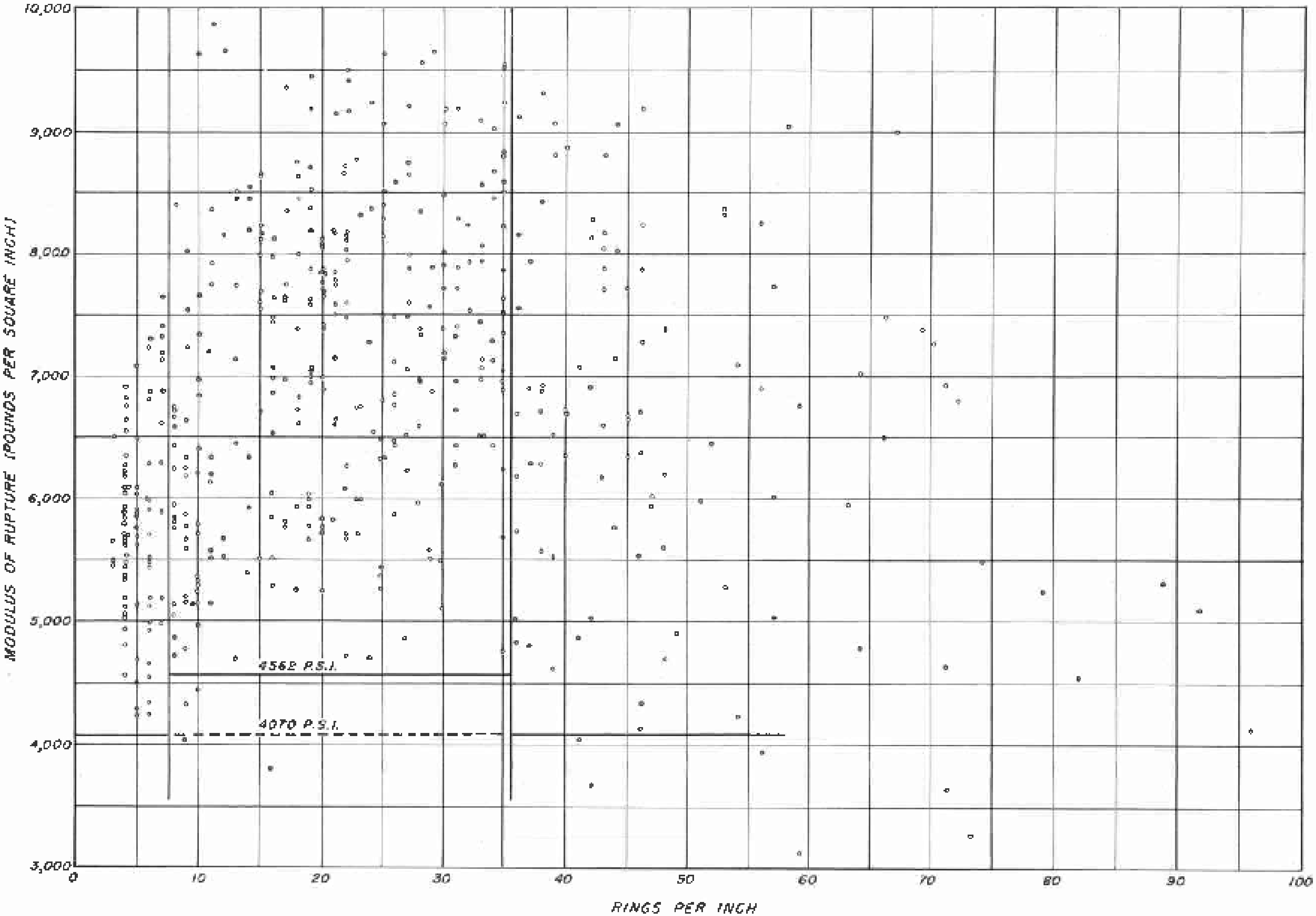

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Figure 3. --Relation of modulus of rupture to rate of growth in green small clear specimens of redwood. Project 124 -- Old growth and second growth excluding openly grown.