AN ANALYSIS OF VARIATION IN MODULI OF ELASTICITY AND RUPTURE IN YOUNG DOUGLAS FIR

by

THOMAS WILLIAM LITTLEFORD

B.A.Sc., University of British Columbia, 1950

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF FORESTRY

in the Department

of

Forestry

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

August, 1957

ABSTRACT

The results of two hundred and fifty-eight static bending tests on young Douglas fir were obtained from the Vancouver Laboratory of the Forest Products Laboratories of Canada. Twenty-two trees had been sampled; seven of approximately sixty years of age from Port Moody, eight of about seventy years of age from Coombs (on Vancouver Island), and seven of approximately ninety years of age from Stave Lake. Stand site quality in each locality was similar and above average for second-growth fir from the coastal region of British Columbia.

The laboratory's results were separated into two classes. Ninety-seven tests represented wood formed within the first five inches of radial growth in the tree. The remaining one hundred and sixty-one tests typified the older wood lying between the inner zone and the bark. Analyses of variance revealed highly significant differences in properties between zones. Wood from the inner zone had a faster growth rate, lower density (though wider bands of summerwood) and less strength and less stiffness in bending than wood from the outer zone.

The influence of ring width, summerwood width and specific gravity on the moduli of elasticity and rupture was assessed for each zone by regression analyses. Ring width and summerwood width accounted for a significant amount of variation

in modulus of elasticity and modulus of rupture in the two zones. Their influence on both moduli, however, was completely due to their association with specific gravity. Specific gravity, alone, accounted for almost twice as much of the variation in elasticity and bending strength as did ring width and summerwood width combined.

The presence of compression wood in a few specimens from the outer growth zone weakened the relationship between modulus of elasticity and specific gravity in this zone but had no effect on the modulus of rupture — specific gravity relationship. In consequence, the influence of growth zone on modulus of elasticity could not be determined. The difference in average values of specific gravity between zones did not fully explain the similar difference between zones for average modulus of rupture values; an indication that radial growth zone in the tree had some influence on the bending strength independent to that exerted by density.

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representative. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Forestry

The University of British Columbia,
Vancouver 8, Canada.

Date September 27, 1957.

ACKNOWLEDGEMENT

Work and time given by members of the Timber Mechanics Section of the Vancouver Laboratory of the Forest Products Laboratories of Canada to the assemblage of data used in this thesis deserves and receives full acknowledgement from the author.

For the privilege of using such information, he is indebted to Col. J. H. Jenkins and Messrs. K. G. Fensom and W. J. Smith all of the Forest Products Laboratories Division, Forestry Branch, Department of Northern Affairs and National Resources.

Finally, he wishes to thank Dr. R. W. Wellwood and Dr. J. H. G. Smith of the Faculty of Forestry at the University of British Columbia for their assistance in the preparation and presentation of the thesis.

CONTENTS

APPENDICES

ILLUSTRATIONS

TABLES

AN ANALYSIS OF VARIATION IN MODULI OF ELASTICITY AND RUPTURE IN YOUNG DOUGLAS FIR

1. Introduction

Wood strength depends in large part upon wood density. Studies such as those of Newlin and Wilson (1919) and Markwardt and Wilson (1935) have repeatedly shown an association between the two. Although density accounts for a substantial part of the variation in strength of wood, an important amount still remains unexplained. This suggests that additional characteristics of tree growth must also be related to strength. In this thesis, ring width, summerwood width, and radial growth zone in the tree, were tested for significance of their effect on the moduli of elasticity and rupture in young Douglas fir (*Pseudostuga taxifolia* Lamb. Britt.).

2. Review of Literature

Clarke (1939) has defined concisely the underlying relationship between tree growth and wood properties.

> In the living tree the wood of the trunk has three main functions, namely, the mechanical support of the crown, the conduction of sap, and the storage of food. Special tissues are developed for these purposes and the properties of timber depend on the character and distribution of these tissues and on the nature of the material composing their cell walls.

With this concept in mind, one can visualize the wide choice of variables available for correlation with strength. Some that have received close attention are reviewed in the following paragraphs.

Initially, a knowledge of strength variation was necessary for the establishment of reliable working stresses for wood. Data obtained for this purpose by the United States Forest Products Laboratory were also used by Newlin and Wilson (1919) for derivation of empirical formulae relating specific gravity to strength. These formulae were of the type: $S=KG^n$, where S is the desired strength property, G is the specific gravity, and K and n are constants dependent upon the strength property estimated, moisture content of the wood and tree species. Although Janka (1915), and others, had previously recognized that density and strength were related, this later study was the first to express the relationship convincingly in the form of an equation.

Douglas fir and the southern yellow pines have been selected for most tree growth — wood strength studies, as they were (and still are) species of prime importance for structural grades of lumber. Also, their distinct growth rings with marked delineation between springwood and summerwood lent themselves well to such work.

Brust and Berkley (1935) made one of the more thorough studies of the southern yellow pines. After testing a total of about two thousand small clear specimens of Loblolly pine (<u>Pinus taeda</u> Linn.), shortleaf pine (<u>Pinus echinata</u> Mill.) and longleaf pine (<u>Pinus palustris</u> Mill.), they concluded that strength, elasticity and density decreased from the stump upwards in the tree and increased with radial distance outwards from the pith. Their findings were in good agreement with the concurrent work of Alexander (1935) on old-growth Douglas fir and the much later work of Wangaard and Zumwalt (1949) on second-growth Douglas fir. A year after these last two authors published their results, Kraemer (1950) reported that radial growth zone in the tree influenced the strength of red pine (<u>Pinus resinosa</u> Ait.); specifically, the modulus of rupture, modulus of elasticity and fibre stress at the proportional limit determined from the static bending test.

Another conclusion of Brust and Berkley was that ring width and strength showed no consistent relationship to each other because of the larger overriding influences of age and species on strength. They did note, however, that a marked and sudden change in growth rate was accompanied by a corresponding change in strength.

Bethel (1950) reasoned that if the distinct springwood and summerwood bands in Loblolly pine were considered as laminates of light and dense material, one combination of laminates could be more effective than another of the same density in resisting a particular stress. To test his hypothesis, he made a curvilinear regression of compression strength divided by specific gravity on per cent summerwood. The regression was significant. By taking the first derivative of the curve and equating it to zero, he solved for the percentage of summerwood that gave the maximum strength in compression parallel to the grain independent of the density of the material. This value for Loblolly pine was forty-eight per cent. As laminate combinations likely vary with fluctuations in growth rate, his reasoning could explain the abrupt changes in strength found by Brust and Berkley.

Forsaith (1933) observed a connection between springwood and summerwood width and elasticity. Working with small matchstick-size beams of southern yellow pine, he found that the deflection under load depended partly upon the amount of summerwood present. From a microscopic examination of lines of failure in the beams, he concluded also that springwood tracheids failed in a manner different to summerwood ones. Springwood tracheids buckled under compressive stress whereas tracheids in the summerwood separated at the middle lamella. Garland (1939), reporting on Loblolly pine, noted that separation in specimens under compression was normally between the outer and central layers of the secondary wall. Both he and Forsaith were in agreement that bordered pits were not a source of weakness in the tracheid wall.

Garland, in addition, related the type of cell fracture to the fibril angle in the secondary wall, and was one of the first to introduce this characteristic. Later, Kraemer (1950) found evidence that fibril angle influenced the bending strength and stiffness of red pine. As the studies of tracheid length made by Liang (1948) and Bisset, Dadswell and Wardrop (1951) indicated inter-relationships between growth rate, age, cell length and fibril angle, this last characteristic of cell structure might well receive continued attention in future growth — strength work.

In many tree growth-wood property studies, such as those of Turnbull (1948), Chalk (1953) and Smith (1955 and 1956), specific gravity was selected as the dependent variable. These studies are of interest because variables that influence density probably also influence strength. Of the variables that might be associated with density, for example ring width, summerwood percentage, and age, age remains the most controversial.

After investigating the specific gravity of <u>Pinus insignis</u> Doug. and <u>Pinus patula</u> Schlech. and Cham., Turnbull (1948) proposed that the density of coniferous wood depended primarily on the number of rings from the pith. Chalk (1953) attempted to verify this conclusion for Douglas fir but found no evidence to support it, neither did he find a clear relationship between ring width and density; therefore Turnbull's hypothesis that a tree could be grown rapidly without decreasing its density was not refuted. In a comprehensive survey of literature pertaining to growth rate and specific gravity in conifers, Spurr and Hsuing (1954) concluded that growth rate had far less effect on specific gravity than did radial position in the tree or age of the wood.

Recent studies by McKimmy (1955), McGuinnes (1955) and Smith (1955 and 1956) have made good use of statistical methods to separate the interacting influences of growth rate, percentage of summerwood, and age on specific gravity. McKimmy used regression techniques to analyse specific gravity variation in second-growth Douglas fir. He noted that age of the tree at the time the wood was formed seemed to greatly affect the specific gravity. He particularly cautioned against predicting strength of material near the pith by either growth rate or percentage of summerwood because neither was an accurate estimate of specific gravity in this zone.

Smith (1956) also used methods of regression analysis. She found a definite relationship between percentage of summerwood and specific gravity in wide-ringed second-growth Douglas fir. As this relationship did not change significantly for three successive radial growth zones from the pith that she selected, she was able to show by a covariance analysis that differences in percentage of summerwood accounted for differences in mean specific gravity for whole annual rings from the three zones.

By analysis of variance and covariance, McGuinnes (1955) determined the influence of per cent summerwood, ring width, age, and crown class on specific gravity in eastern white pine (Pinus strobus Linn.). After adjusting for per cent summerwood differences between decades, he found that age had no significant effect upon density. His results concurred with those of Smith. The fact that McKimmy did not consider differences in percentage of summerwood between decades could explain why his results were in disagreement.

3. Purpose of Analysis

Douglas fir is an important structural timber in world markets. In the past, and to a lesser extent at present, the supply of timbers has come from large trees in old-growth stands. If a supply is to be maintained in the future, an increasing proportion of the timbers will have to be taken from second-growth stands because much of the limited amount of remaining old-growth material is in urgent demand for the manufacture of plywood.

It is quite possible that some of these young stands will be subjected to silvicultural treatment. Thinning and pruning can be planned most effectively when the desired properties of the final product are clearly defined and their relationship to tree growth is well understood. This study attempts to add to the understanding of growth—strength relationships in young Douglas fir; specifically, it investigates the influence of radial growth zone in the tree on two important mechanical properties, namely, the modulus of elasticity and modulus of rupture.

4. Source of Material

The basic data used in this thesis were obtained from the Vancouver Laboratory of the Forest Products Laboratories of Canada. They had been compiled from strength tests conducted on three shipments of second-growth Douglas fir. Twenty-two trees had been tested, seven of approximately sixty years age from Port Moody, eight of about seventy years of age from Coombs (on Vancouver Island), and seven of approximately ninety years of age from Stave Lake. Stand site quality in each locality was similar and above average for second-growth fir from the coastal region of British Columbia. The trees were selected over a period of twenty years (1931 to 1951) by J. B. Alexander and W. J. Smith of the Timber Mechanics Section of the Vancouver Laboratory. Dominant and co-dominant trees were taken because their larger size permitted the desired number of test pieces to be cut from each tree. Age, height and diameter measurements of the trees are presented in Appendix A.

5. Testing Procedure

Modulus of elasticity and modulus of rupture were determined from standard 2" x 2" x 30" specimens tested in the green condition. These specimens were selected (from a bolt twelve feet long sawn from the butt end of each tree) and tested, over a twenty-eight inch span, by the procedure prescribed for static bending in Part IV of the A.S.T.M. Standards, 1955.[1]

Specific gravity (volume at test—weight oven-dry), rings per inch and per cent summerwood were obtained by methods essentially the same as those described by Rochester (1933). Specific gravity was computed on the basis of weight, moisture content, and dimensions of the specimen. Rings per inch and per cent summerwood were estimated from cross-sectional discs (examined under low-power magnification) taken from the piece containing the test specimen. The boundary between spring-wood and summerwood was determined visually without reference to any standard definition of summerwood; consequently, the experimental error for per cent summerwood contained a personal bias.

6. Method of Analysis and Results

A total of two hundred and fifty-eight static bending tests had been made on specimens from the previously mentioned twenty-two trees. Ninety-seven specimens had been taken from young wood within the first five inches of radial growth. Modulus of elasticity and modulus of rupture values determined from these specimens were grouped under the heading Growth Zone A. The remaining one hundred and sixty-one specimens had been obtained from the older wood lying between the inner zone and

---

1 Standard Methods of Testing Small Clear Specimens of Timber, A.S.T.M. Designation: D143-52.

Table 1.

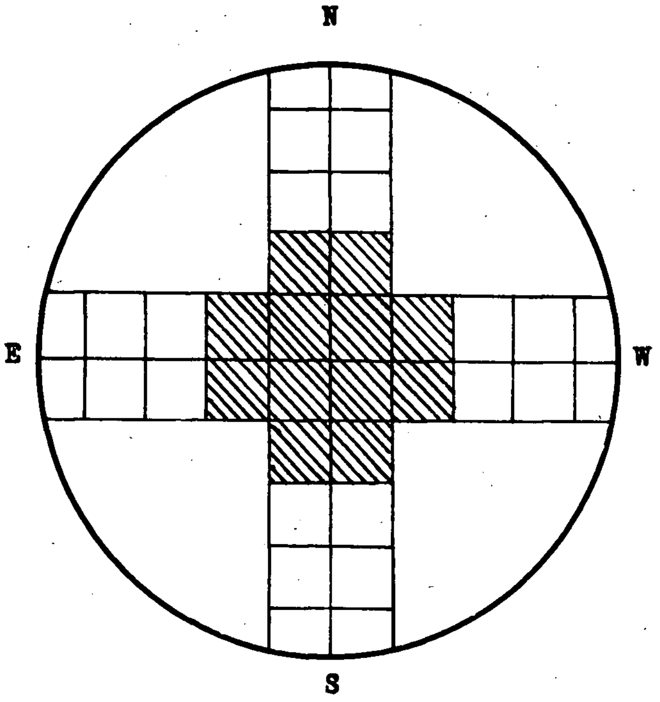
Summary of test results.

Property	Inner growth zone A. 97 tests	Outer growth zone B. 161 tests	All data A.+B. 258 tests
Modulus of elasticity (1000 p.s.i.)			
Mean	1470.7	1650.1	1582.6
Maximum	2140	2483	2483
Minimum	938	969	938
Modulus of rupture (p.s.i.)			
Mean	6899.4	8180.7	7699.0
Maximum	9940	11238	11238
Minimum	5045	6439	5045
Specific gravity (vol. green-Wt.O.D.)			
Mean	0.4171	0.4723	0.4516
Maximum	0.532	0.643	0.643
Minimum	0.338	0.367	0.338
Ring width (inches)			
Mean	0.2159	0.1487	0.1740
Maximum	0.333	0.333	0.333
Minimum	0.091	0.063	0.063
Summerwood width (inches)			
Mean	0.0764	0.0649	0.0690
Maximum	0.115	0.125	0.125
Minimum	0.037	0.028	0.028

LOCATION OF TEST SPECIMENS

SELECTED FROM TWENTY-TWO TREES REPRESENTING
THREE GEOGRAPHICAL AREAS

X-SECTION OF BUTT END OF BOLT



TEST PIECE FROM GROWTH ZONE A: TOTAL OF 97 PIECES.

TEST PIECE FROM GROWTH ZONE B: TOTAL OF 161 PIECES.

SIZE OF SPECIMEN: 2" x 2" x 30".

Figure 1.

the bark. Moduli values for these specimens were grouped under the heading Growth Zone B. Zones A and B are illustrated in Figure 1. Test results are listed by shipment, growth zone and tree in Appendix B. Maximum, minimum and average values for each property from both zones are presented in Table 1.

Width of ring and width of summerwood in the ring were used in preference to rings per inch and per cent summerwood. The distribution of rings per inch was skewed in the direction of fast growth, decidedly so for the inner growth zone. The reciprocal, width of ring, had a much less skewed distribution. Summerwood width was used to facilitate the analysis of seasonal growth effects on strength and elasticity.

An example, giving the original measurements and the ones used, will clarify the method of transformation employed.

Original measurement	Transformation	Measurement used
4 rings per inch	reciprocal $= \frac{1}{4}$	ring width = 0.2500 inches
30 per cent summerwood	$\frac{1}{4}$ x 30/100	summerwood width = 0.0750 inches

Initially, differences in average values of modulus of elasticity and modulus of rupture from each zone were tested for significance. Analyses of variance revealed highly significant differences for both moduli (Table 2). Similar analyses for the properties of ring width, summerwood width and density showed that their average values differed in much the same manner (as can be seen also from Table 2).

Table 2.

Analysis of variance for properties between zones.

	Degrees of freedom	Sum Squares	Mean square	
Modulus of elasticity				
Total.............	257	21,464,420		
Within............	256	19,516,709	76,237	
Between means.....	1	1,947,711	1,947,711	**
Modulus of rupture				
Total.............	257	314,414,301		
Within............	256	215,031,731	839,968	
Between means.....	1	99,382,570	99,382,570	**
Specific gravity				
Total.............	257	680,074		
Within............	256	495,279	1,935	
Between means.....	1	184,795	184,795	**
Ring width				
Total.............	257	98,914,001		
Within	256	71,644,177	279,860	
Between means.....	1	27,269,824	27,269,824	**
Summerwood width				
Total.............	257	11,877,181		
Within............	256	11,066,907	43,230	
Between means.....	1	810,274	810,274	**

** Significant at the 1% level.

Table 3.

Analysis of variance for the regression of modulus of elasticity(Ye) on specific gravity (Xa), average ring width(Xb), and average width of summerwood(Xc).

	Degrees of freedom	Sum squares	Mean square
Growth zone A.			
Regression on XaXbXc	3	3,293,865	
Regression on XbXc	2	2,227,221	
Xa after Xb and Xc	1	1,066,644	1,066,644
Error	93	2,832,056	30,452
F = 35.027 **			
Regression on XaXc	2	3,243,890	
Xb after Xa and Xc	1	49,975	49,975
F = 1.641			
Regression on XaXb	2	3,261,731	
Xc after Xa and Xb	1	32,134	32,134
F = 1.055			
$R^2_{y.abc}$ = 0.5377			
Growth zone B.			
Regression on XaXbXc	3	5,522,075	
Regression on XbXc	2	4,552,481	
Xa after Xb and Xc	1	969,594	969,594
Error	157	7,868,713	50,119
F = 19.346 **			
Regression on XaXc	2	5,490,111	
Xb after Xa and Xc	1	31,964	31,964
F = 0.638			
Regression on XaXb	2	5,203,091	
Xc after Xa and Xb	1	318,984	318,984
F - 6.365 *			
$R^2_{y.abc}$ = 0.4124			

** Significant at the 1% level
* Significant at the 5% level

Table 4.

Analysis of variance for the regression of modulus of rupture(Yr) on specific gravity(Xa), average ring width(Xb), and average width of summerwood(Xc).

	Degrees of freedom	Sum squares	Mean square
Growth zone A.			
Regression on XaXbXc	3	60,440,710	
Regression on XbXc	2	35,431,396	
Xa after Xb and Xc	1	25,009,314	25,009,314
Error	93	26,922,726	289,492
F = 86.390 **			
Regression on XaXc	2	60,117,465	
Xb after Xa and Xc	1	323,245	323,245
F = 1.117			
Regression on XaXb	2	60,388,287	
Xc after Xa and Xb	1	52,423	52,423
F = 0.181			
$R^2_{y.abc}$ = 0.6918			
Growth zone B.			
Regression on XaXbXc	3	94,341,556	
Regression on XbXc	2	40,950,076	
Xa after Xb and Xc	1	53,391,480	53,391,480
Error	157	33,326,739	212,272
F - 251.524 **			
Regression on XaXc	2	94,188,112	
Xb after Xa and Xc	1	153,444	153,444
F = 0.723			
Regression on XaXb	2	94,337,988	
Xc after Xa and Xb	1	3,568	3,568
F = 0.017			
$R^2_{y.abc}$ = 0.7390			

** Significant at the 1% level

To determine if the between-zone variation in strength and elasticity was entirely due to the accompanying differences in ring width, summerwood width, and density, the effect of each of these latter variables on the two moduli in both zones had to be known. Regression analyses were set up to obtain this information. Modulus of elasticity and modulus of rupture were selected as the dependent variables, and specific gravity, ring width, and summerwood width were chosen as the independent variables. The influence of each of the independent variables on the two moduli was assessed by methods similar to those outlined by Snedecor (1956).

In both zones, the influence of specific gravity on modulus of elasticity (Table 3, Xa after Xb and Xc) and modulus of rupture (Table 4, Xa after Xb and Xc) was highly significant. Ring width (Table 4, Xb after Xa and Xc) and summerwood width (Table 4, Xc after Xa and Xb) had no significant influence on modulus of rupture in either of the two zones. With the possible exception of summerwood width in the outer zone (Table 3, Xc after Xa and Xb), their influence on modulus of elasticity was also negligible.

Following these analyses, the influence of specific gravity on the two moduli was evaluated indirectly by using only ring width and summerwood width as independent variables. The R^2 values of Tables 5 and 6 indicated that approximately one-third of the variation in both moduli from each zone was removed by their regression on ring width and summerwood width. The

Table 5.

Analysis of variance for the regression of modulus of elasticity(Ye) on average ring width(Xb) and average width of summerwood(Xc).

	Degrees of freedom	Sum squares	Mean square
Growth zone A.			
Regression on XbXc	2	2,227,221	
Xb alone	1	2,048,722	
Xc after Xb	1	178,499	178,499
Error	94	3,898,700	41,476
F = 4.304 *			
Xc alone	1	434,757	
Xb after Xc	1	792,464	792,464
F = 19.107 **			
$R^2_{y.bc}$ = 0.3636			
Growth zone B.			
Regression on XbXc	2	4,608,236	
Xb alone	1	4,608,009	
Xc after Xb	1	227	227
Error	158	8,782,779	55,587
F = 0.004			
Xc alone	1	3,630,184	
Xb after Xc	1	978,052	978,052
F - 17.595 **			
$R^2_{y.bc}$ = 0.3441			

* Significant at the 5% level
** Significant at the 1% level

Table 6.

Analysis of variance for the regression of modulus of rupture(Yr) on average ring width (Xb) and average width of summerwood(Xc).

	Degrees of freedom	Sum squares	Mean square
Growth zone A.			
Regression on XbXc	2	35,431,396	
Xb alone	1	27,618,944	
Xc after Xb	1	7,812,452	7,812,452
Error	94	51,932,040	552,469
F = 14.141 ⁂			
Xc alone	1	2,269,004	
Xb after Xc	1	33,162,392	33,162,392
F = 60.026 ⁂			
$R^2_{y.bc} = 0.4056$			
Growth zone B.			
Regression on XbXc	2	40,950,076	
Xb alone	1	14,733,986	
Xc after Xb	1	26,216,090	26,216,090
Error	158	86,718,219	548,849
F = 47.766 ⁂			
Xc alone	1	1,006,738	
Xb after Xc	1	39,943,338	39,943,338
F = 72.777 ⁂			
$R^2_{y.bc} = 0.3208$			

⁂ Significant at the 1% level

individual significance of ring width (Tables 5 and 6, Xb after Xc) and summerwood width (Tables 5 and 6, Xc after Xb) showed that an estimate of strength and elasticity made from the two together was more accurate than that made from either one separately.

Because the direct influence of ring width and summerwood width on the moduli of elasticity and rupture was insignificant, only specific gravity differences between growth zones required adjustment to assess the effect of growth zone on the moduli. This assessment was made by a method of covariance analysis outlined by Snedecor (1956). The regression equations used, that is, modulus of elasticity versus specific gravity and modulus of rupture versus specific gravity, and the slopes and positions of these straight line equations through the basic data, are illustrated in Figures 2 and 3 respectively.

Snedecor has pointed out that two assumptions are made in carrying out such an analysis.

1. The two samples have a common mean square deviation from regression.
2. The slopes of the two regressions are the same.

It can be observed from Figure 2 that the dispersion of modulus of elasticity values about the regression line in the outer zone appears greater than in the inner zone. This unequal dispersion was tested for significance, as Snedecor has suggested, by calculating the ratio of mean square deviations for the two zones. The ratio (72,687:33,672) was highly significant for 159 and 95

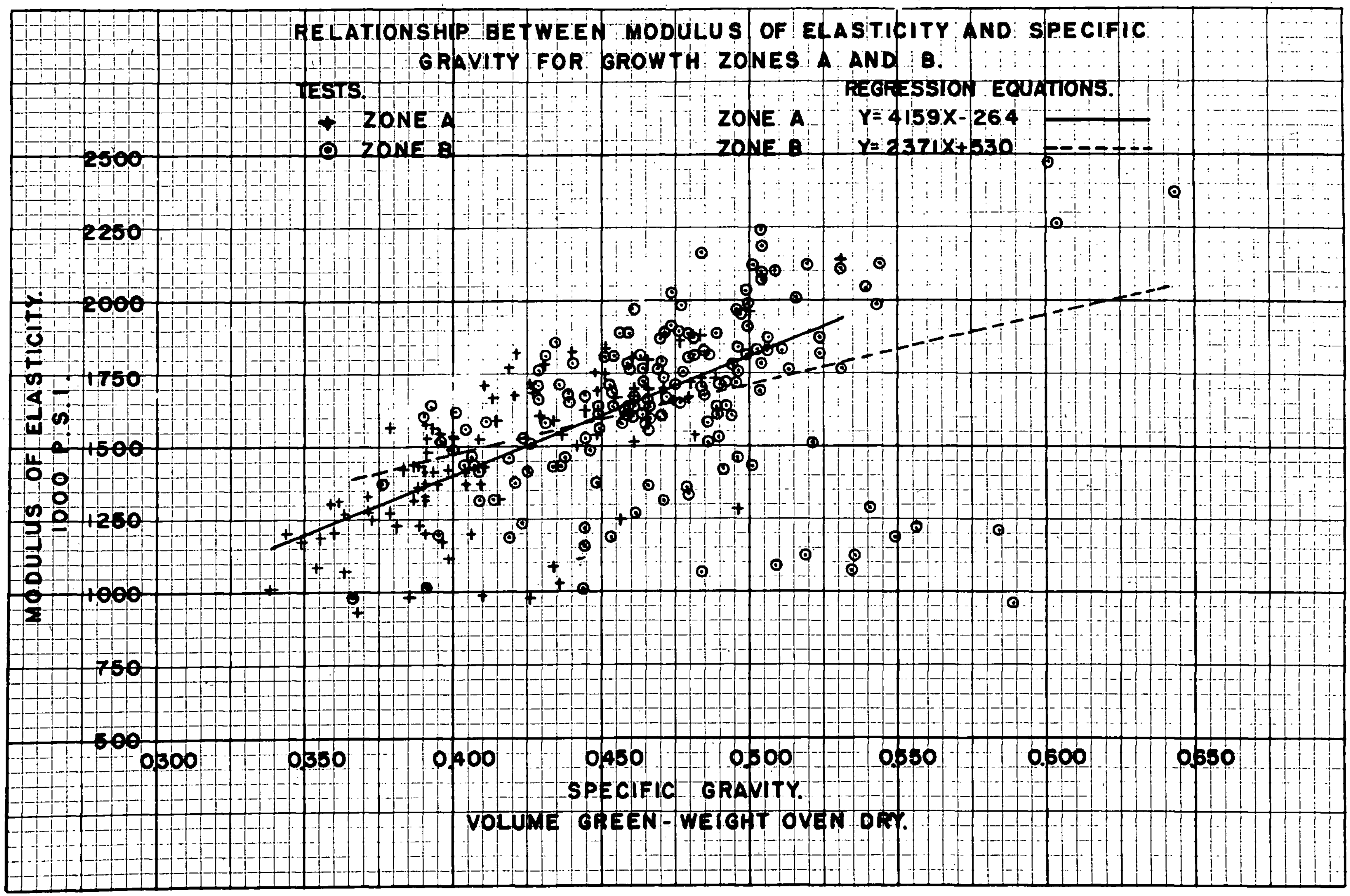

RELATIONSHIP BETWEEN MODULUS OF ELASTICITY AND SPECIFIC GRAVITY FOR GROWTH ZONES A AND B.
TESTS.
ZONE A
ZONE B
REGRESSION EQUATIONS.
ZONE A Y=4159X-264
ZONE B Y=2371X+530
MODULUS OF ELASTICITY.
1000 P.S.I.
2500
2250
2000
1750
1500
1250
1000
750
500
0.300
0.350
0.400
0.450
0.500
0.550
0.600
0.650
SPECIFIC GRAVITY.
VOLUME GREEN-WEIGHT OVEN DRY.

Figure 2.

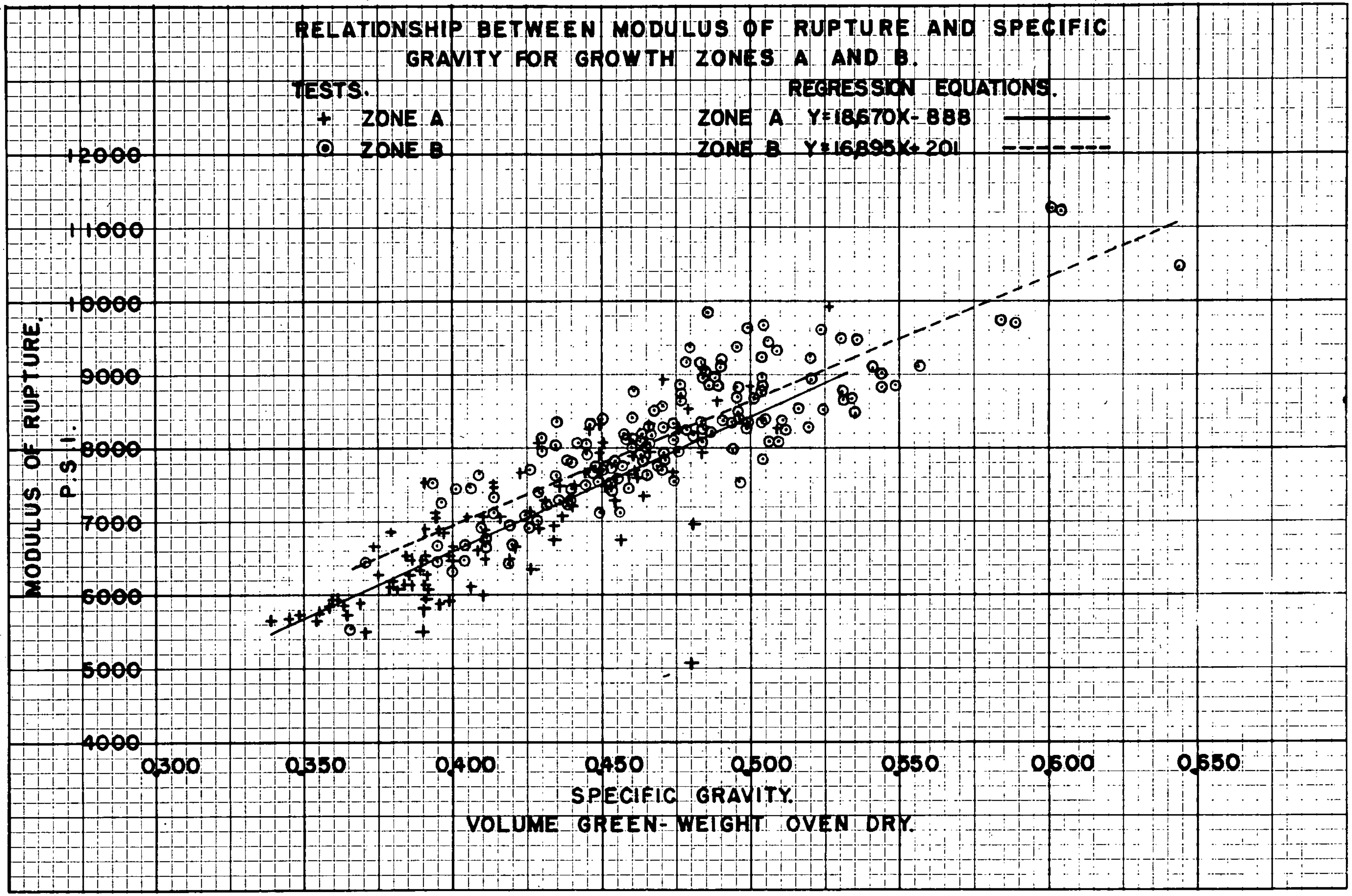

RELATIONSHIP BETWEEN MODULUS OF RUPTURE AND SPECIFIC GRAVITY FOR GROWTH ZONES A AND B.
TESTS.
+ ZONE A
⊙ ZONE B
REGRESSION EQUATIONS.
ZONE A Y=18,670X-888
ZONE B Y=16,895X+201
MODULUS OF RUPTURE. P.S.I.
12000
11000
10000
9000
8000
7000
6000
5000
4000
0.300
0.350
0.400
0.450
0.500
0.550
0.600
0.650
SPECIFIC GRAVITY.
VOLUME GREEN-WEIGHT OVEN DRY.

Figure 3.

degrees of freedom. The variance was heterogeneous. As the data did not satisfy the first assumption, no further attempt was made to determine the effect of growth zone on modulus of elasticity.

The two assumptions were fulfilled for the modulus of rupture data. Tests of significance are presented in Table 7. Neither F = 1.374, which tested for heterogenity of variance, nor F = 1.416, which tested for unequal slopes, was significant. The value F = 17.54, which tested for differences in modulus of rupture between the two zones after adjustment to a common specific gravity, was highly significant.

Table 7.

Analysis of covariance for the regression of modulus of rupture(Yr) on specific gravity(Xa).

	Regression coefficient	Deviation from regression			
		Degrees of freedom	$\Sigma Yr^2 - \frac{(\Sigma XaYr)^2}{\Sigma Xa^2}$	Mean square	F
Zone A.	18,670	95	28,392,995	298,874	1.374
Zone B.	16,895	159	34,587,731	217,533	
Within		254	62,980,726	247,956	1.416
Regression coefficient		1	350,758	350,758	
Common	17,501	255	63,331,484	248,359	17.54 **
Adjusted means		1	4,356,426	4,356,426	
Total		256	67,687,910		

** Significant at the 1% level

7. Interpretation and Discussion of Results

Table 4 showed that ring width and summerwood width had no influence on the modulus of rupture after the effect of specific gravity on the modulus had been removed. Thus the quality of wood substance, as measured by these gross anatomical features, did not seem to add to or detract from the load-carrying ability of the tested beams. This is in agreement with the work on second-growth Douglas fir of Wangaard and Zumwalt (1949) and Schrader (1949) who stated that rate of growth did not correlate mathematically in any recognized relationship with strength except as it affected specific gravity. Clark (1939) had made a similar study of the effects of specific gravity, growth rate, and amount of summerwood on the longitudinal compressive strength of European ash (*Fraxinus excelsior* Linn.). His results also concur with those reported here, although obtained for a different strength property from a wood of entirely different structure.

Table 3 revealed that summerwood width was significantly related to the modulus of elasticity in the outer zone after the effects of specific gravity and ring width had been eliminated — a result contrary to that for modulus of rupture. In other words, the quality of summerwood in the outer zone appeared to affect elasticity but not strength. It can be noted from Appendix B and Figure 2 that a few of the test pieces from the outer zone of Trees 5,7 and 8 in Shipment 98 (marked # in Appendix B) exhibited unusual properties. They had wide bands of summerwood and high density but very low values of elasticity. Although this shipment had been tested in 1952, several small specimens were found that had been used originally for estimating growth rate and per cent summerwood. One of these specimens had come from the test piece which had the low value of elasticity in Tree 7. This specimen was sectioned and examined under the microscope by Miss E. I. Whittaker of the Vancouver Laboratory. She found compression wood in three of the rings. Pillow and Luxford (1937) had observed that the greater slope of the fibrils in the cell wall accounted for the deficiency of strength in compression wood and that the decrease in modulus of elasticity with increasing fibril angle proceded at a more rapid rate than did the decrease in modulus of rupture. Their observations suggest that the amount and severity of compression wood present in Tree 7 (and probably present also in Trees 5 and 8) was sufficient to affect modulus of elasticity but not modulus of rupture in the outer zone.

Tables 5 and 6 disclosed the fact that ring width and summerwood width were significantly related to the moduli of elasticity and rupture if the influence of specific gravity on these last two properties was not first eliminated from the analyses. That is, ring width and summerwood width, through an association with density, appeared to have an indirect influence on the modulus of elasticity and modulus of rupture. Kramer and Smith (1956) investigated the strength properties of plantation-grown slash pine and reported that the separate use of rings per inch and per cent summerwood gave as reliable an indication of modulus of rupture as did the use of both combined. In the present study, the estimate of this modulus made from ring width alone was improved, in all cases, by the additional use of summerwood width. As ring width and summerwood width are not exactly comparable with rings per inch and per cent summerwood, there was no assurance that differences in growth conditions between the naturally-grown Douglas fir and the plantation-grown slash pine were responsible for the contrasting results.

Table 7 showed that a highly significant difference in strength remained between zones when the average values of modulus of rupture for each of the two zones were adjusted to a common specific gravity. This discrepancy in strength was somewhat anticipated. Forsaith (1933) had already noted in his work on matchstick-size beams of southern pine that the wood formed early in the life of the tree was weaker than that produced during the later years.

Clarke (1939) had indicated that the effect of cell-wall composition, lignin content in particular, on the longitudinal compressive stress of ash was quite independent of specific gravity. Wardrop (1951) had found that the tensile strength, cell length, and cellulose content of tangential sections from stems of _Pinus radiata_ D. Don. increased with successive growth rings from the pith. Their results suggest that the difference in modulus of rupture between zones was due to changes in chemical composition and microscopic structure of the cell walls which occurred with advancing age.

8. Conclusions

Ring width and width of summerwood in the ring have some value in predicting elasticity and bending strength in young Douglas fir but one must be used in combination with the other if the estimate is to be realistic. Moduli of elasticity and rupture tend to increase as ring width decreases and width of summerwood in the ring increases. Thus, there is no basis for concluding, for example, that wood having six rings per inch is stronger or stiffer than wood having four rings per inch unless, in addition, the width of summerwood is known for the wood of each growth rate. There is also one further complication — summerwood width cannot be determined as accurately as ring width.

Because ring width and summerwood width were related to both moduli only through their association with density, density itself would be the logical variable to estimate elasticity and bending strength. Density accounted for almost twice as much of the variation in these properties as that explained by ring width and summerwood width. Unfortunately, the specific gravity of structural timbers is difficult to determine accurately and quickly. Moisture content fluctuates considerably from piece to piece excluding the weight of a timber as a relative measure of its density.

Although it may not be feasible to set up separate stress grades by density classes for all Douglas fir timbers, consideration could be given to segregating by density the material used in laminated construction. This material is conditioned to a specified moisture content; therefore, the specific gravity of each laminate might be determined quite precisely from its size and weight. Corrections for minor fluctuations in moisture content could be made from moisture meter readings. If working stresses recognized the fact that elasticity and bending strength increase as density increases, laminated beams could be designed very efficiently. The densest material could be used advantageously in the outer and most highly stressed laminations.

The influence of age on the moduli of elasticity and rupture requires further study. No results were obtained for modulus of elasticity. The presence of compression wood in a few specimens from the outer growth zone probably caused the heterogeneity of variance between zones which nullified any attempt to examine the effect of age on elasticity. The results for modulus of rupture were not decisive but they did suggest that age had some influence on the modulus. That is, difference in average modulus of rupture values between growth zones was not explained by the similar difference in average specific gravity values between zones.

Current grading rules for Select Structural Douglas fir timbers specify that such timbers be selected for close grain.[2]

---

2 Standard Grading and Dressing Rules. No. 56 British Columbia Lumber Manufacturers Association. Vancouver, B.C. June 22, 1956.

Close grain is defined as pieces having not less than six rings per inch (pieces having from five to six rings per inch and containing one-third or more summerwood are accepted as equivalent to six rings per inch). In the future, some control may be exerted over growth rate in young stands of Douglas fir. The indication that strength increases with age makes it advisable to determine whether or not these present specifications will discriminate against wood formed rapidly after a stand has been thinned at a later age.

9. Future Work

A subsequent study of variation in the strength properties of fast growth Douglas fir has been initiated. The method of analysis in this investigation differs from that employed in the study reported here. Average age and range in age of the wood in each test piece are also considered. One specific objective of this project is to find out whether or not age of the wood in the tree has a significant influence on strength in rapidly grown trees. If it has, a second objective will be to determine at what age this relationship becomes strongest.

10. Bibliography

Alexander, J.B. 1935. The effect of the rate of growth upon the specific gravity and strength of Douglas fir. Canada Dept. Int. Forest Serv. Circ. 44. 8pp.

______________ 1950. The physical and mechanical properties of second-growth Douglas fir. Amer. Soc. Test. Mat. Bull.169:33-38.

Bethel, J.S. 1950. The influence of wood structure on the strength of Loblolly pine wood. North Carolina State College of Forestry Tech. Rpt. No.3. 6pp.

Bisset, I.J.W., H.E. Dadswell and A.B.Wardrop. 1951. Factors influencing tracheid length in conifer stems. Australian Forestry 15(1):17-30.

Brown, H.P., A.J.Panshin and C.C.Forsaith. 1952. Textbook of wood technology. Volume II. McGraw Hill Book Company Inc. New York. 783 pp.

Brust, A.W. and E.E. Berkley. 1935. The distribution and variations of certain strength and elastic properties of clear southern yellow pine wood. Proc. Amer. Soc. Test. Mat. 35:643-673.

Bryant, B.S. 1950. The significance of specific gravity distribution with respect to tree form. Univ. of Wash. Forest Club Quarterly. 24(1):18-24.

Chalk, L. 1930. The formation of spring and summerwood in ash and Douglas fir. Oxford Forestry Memoirs. No.10 47 pp.

________ 1953. Variation of density in stems of Douglas fir. Forestry 26(1):33-36.

Clarke, S.H. 1939. Recent work on the growth, structure and properties of wood. Dept. of Sci. and Ind. Res., For. Prod. Res. Spec. Rpt. No.5. 32 pp. London.

Forsaith, C.C. 1933. The strength properties of small beams (matchstick-size) of southern yellow pine. New York State College of Forestry Tech. Pub. 42. 38 pp.

Garland, H.A. 1939. A microscopic study of coniferous wood in relation to its strength properties. Mo. Bot. Garden Ann. 26:1-94.

Janka. 1915. Mitteilungen a.d. forstichen Versuchswesen Osterreichs. (News of the Austrian Forestry Research Institute). kk. Versuchsaustalt Mariabrunn, Heft XXXV, u. XXXIX. (Royal imperial Research Institution of Mariabrunn, Papers 35 and 39).

Kraemer, J.H. 1950. Growth—strength relations of red pine. Jour. Forestry 48(12):842-849.

Kramer, P.R. and R.L. Smith. 1956. Strength properties of plantation-grown slash pine. Jour. For. Prod. Res. Soc. 6(3):129-136.

Liang, S.C. 1948. Variation in tracheid length from the pith outwards in the wood of the genus Larix. Forestry 22(2): 222-237.

Lodewick, J.E. 1933. Some summerwood percentage relationships in the southern pines. Jour. Agr. Res. 46(6):543-566.

Markwardt, L.J. and T.R.C. Wilson. 1935. Strength and related properties of wood grown in the United States. U.S. Dept. Agr. Tech. Bull. 479. 99 pp.

Marts, R.O. 1951. Influence of crown reduction on spring and summerwood distribution in Longleaf pine. Jour. Forestry 49(3):183-189.

McGuinnes, E.A. 1955. The influence of per cent summerwood, ring width, age and crown class on the specific gravity of eastern white pine. Ph.D. Thesis, State University of New York College of Forestry.

McKimmy, M.D. 1955. Factors related to specific gravity variation in second-growth Douglas fir. Ph.D. Thesis, State University of New York. College of Forestry.

Newlin, J.A. and T.R.C. Wilson. 1919. The relation of the shrinkage and strength properties of wood to its specific gravity. U.S. Dept. Agr. Bull. 676. 35 pp.

Paul, B.H. 1950. Quality of second-growth Douglas fir and suggested means of improvement. Ann. Proc. For. Prod. Res. Soc. 4:16-20.

__________ 1950. Wood quality in relation to site quality of second-growth Douglas fir. Jour. Forestry 48(3):175-179.

__________ and R.O. Marts. 1931. Controlling the proportion of summerwood in Longleaf pine. Jour. Forestry 29(5):784-796.

__________ and D.M. Smith. 1950. Summary of growth in relation to quality of southern yellow pine. U.S.F.P.L. Rpt. No. D1751. 19 pp.

Pillow, M.Y. and R.F. Luxford. 1937. Structure, occurrence, and properties of compression wood. U.S. Dept. Agr. Tech. Bull. 546. 32 pp.

Rochester, G.H.1933. The mechanical properties of Canadian woods. Canada Dept. Int. Forest Serv. Bull. 82. 88 pp.

Schrader, O.H. 1939. Variation in the specific gravity of springwood and summerwood in southern pines. Thesis, Univ. of Wis., 1932. Published in part under similar title by B.H. Paul in Jour. Forestry 37(6):478-482.

_____________ 1949. Some strength properties of second-growth Douglas fir. Report of Symposium on Wood. Office of Naval Research Dept. of the Navy. Wash. D.C. pp.304-310.

_____________, J.W. Allen and W.G. Hughes. 1949. Strength properties of second-growth fir. Trend in Engineering 1(2):16-20.

Smith, D.M. 1955. Relationship between specific gravity and per cent of summerwood in wide-ringed second-growth Douglas fir. U.S.F.P.L. Rpt. No. 2045. 14pp.

__________ 1956. Effect of growth zone on specific gravity and percentage of summerwood in wide-ringed Douglas fir. U.S.F.P.L. Rpt. No.2057 9 pp.

Snedecor, G.W. 1956. Statistical methods. Iowa State College Press. Ames, Iowa. 534 pp. 5 ed.

Spurr, S.H. and W. Hsuing. 1954. Growth rate and specific gravity in conifers. Jour. Forestry 52(3):191-200.

Turnbull, J.M. 1948. Some factors affecting wood density in pine stems. Jour. So. African Forestry Assoc. 16:22-43.

Vikhrov, V.E. 1949. Stroenie i. Fiziko-mekhanicheskie Svoistva Rannei i Pozdnei Drevesiny Sibirskoi Listvennitsy (The structure and the physical and mechanical properties of the springwood and summerwood of Siberian larch). Akademiia nauk SSR, Trudy instituta lesa (Academy of Sciences of the U.S.S.R. Transactions of the Wood Institute), vol. 4:174-194. Translated from the Russian by H.P. Kippe, U.S.F.P.L. Translation No. 31. 1951.

Wangaard, F.F. and V.E. Zumwalt. 1949. Some strength properties of second-growth Douglas fir. Jour. Forestry 47(1):18-24.

Wardrop, A.B. 1951. Cell wall organization and the properties of the xylem. 1. Cell wall organization and the variation of breaking load in tension of the xylem in conifer stems. Australian Jour. Sci. Res. Series B—Biological Sciences 4(4):391-414.

Wardrop, A.B. and H.E. Dadswell. 1952. The nature of reaction wood III. Cell division and cell wall formation in conifer stems. Australian Jour. Sci. Res. Series B—Biological Sciences 5(4):385-398.

Wellwood, R.W. 1952. The effect of several variables on the specific gravity of second-growth Douglas fir. Forestry Chronicle 28(3): 34-42.

Yandle, D.O. 1956. Statistical evaluation of the effect of age on specific gravity in Loblolly pine. U.S.F.P.L. Rpt. No. 2049 4pp.

Zobel, B.J. 1956. Genetic, growth and environmental factors affecting specific gravity of Loblolly pine. Jour. For. Prod. Res. Soc. 6(10):442-447.

11. Appendices

Appendix A.

Measurements taken in the field
on twenty-two second-growth Douglas fir trees.

Shipment number	Tree number	Height at stump	Age at stump	D.b.h.	Total tree height
		ft. and in.	years	in.	ft.
78. Port Moody	1	1-0	60	Missing	133
	2	2-0	58	24	139
	3	1-6	58	23	137
	4	1-0	61	24	141
	6	1-4	58	26	132
	7	1-3	62	Missing	139
	8	1-6	62	Missing	146
93. Stave Lake	1	2-4	85	37	178
	2	2-4	85	30	182
	3	2-6	82	35	177
	4	3-3	86	29	181
	6	2-6	89	30	175
	7	2-4	87	33	173
	9	2-3	92	33	164
98. Coombs, V.I.	1	4-0	79	27	129
	2	6-0	73	28	137
	3	3-0	71	25	127
	4	3-0	72	25	140
	5	3-0	71	30	133
	6	4-0	71	30	125
	7	4-0	71	28	131
	8	3-0	72	27	127

Appendix B.

Results of two hundred and fifty-eight static bending tests made on specimens from twenty-two second-growth Douglas fir trees.

Shipment number 78. Port Moody. Growth zone A.

Tree no.	Rings per inch	Per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
I.	4	35	0.387	1316	6519
	6	36	.442	1499	7429
	4	32	.387	1441	6098
	4	34	.392	1523	6867
	5	43	.500	1959	8883
2.	6	42	0.451	1847	7481
	5	40	.429	1601	6902
	6	46	.431	1779	7324
	7	38	.483	1881	7780
	8	42	.423	1805	7613
3.	4	28	0.393	1407	6064
	4	32	.385	1493	6530
	4	33	.380	1563	6159
	5	34	.400	1523	6443
4.	3	24	0.362	1309	5976
	4	29	.414	1666	7520
	4	33	.405	1372	7088
	4	20	.391	1372	6116
	4	36	.419	1759	6534
6.	5	36	0.372	1339	5518
	5	42	.390	1355	5810
	6	31	.391	1200	5996
	5	34	.384	1428	6140
	5	40	.408	1523	6602
	6	44	.421	1671	6602
7.	4	34	0.363	1264	5880
	5	38	.411	1715	6865
	5	40	.396	1368	5892
	7	43	.427	1715	7140
	11	41	.440	1816	7219
8.	6	42	0.411	1434	6470
	5	40	.394	1569	7086
	3	32	.360	1207	5962
	4	34	.373	1250	6654
	6	47	.497	1267	8213
	7	47	.428	1686	8021

Appendix B.

Shipment number 78. Port Moody. Growth zone B.

Tree no.	Rings per inch	Per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
1.	7	36	0.467	1599	8157
	10	39	.448	1649	7742
	7	40	.511	1824	8390
	6	37	.460	1978	8436
	6	35	.471	1881	8587
	8	39	.458	1885	7409
2.	6	39	0.474	1912	7530
	6	40	.499	2033	8374
	5	40	.454	1199	7592
	7	43	.440	1614	7481
	6	33	.472	1307	8138
	8	40	.457	1892	7147
3.	10	43	0.454	1690	7589
	5	35	.462	1666	8061
	5	40	.466	1352	8369
	8	50	.497	1452	8724
	6	38	.487	1503	9880
	6	38	.436	1444	7639
	8	43	.448	1614	7560
4.	9	50	0.487	1881	8211
	5	36	.463	1759	7900
	6	33	.401	1622	7413
	6	40	.445	1688	8061
	6	39	.435	1853	8022
6.	6	42	0.470	1876	7766
	7	42	.432	1588	7204
7.	6	45	0.476	1750	8262
	5	42	.403	1554	6461
8.	7	48	0.497	1750	7595
	5	42	.445	1215	7508
	5	43	.414	1187	7131
	5	48	.463	1260	7823

Appendix B.

Shipment number 93. Stave Lake. Growth zone A.

Tree no.	Rings per inch	Per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
1.	4	39	0.427	971	6381
	5	41	.410	989	5988
	5	34	.400	1536	6627
	4	45	.436	1011	7418
	4	38	.369	938	5870
	4	43	.388	1351	6339
2.	3	27	0.415	1318	7032
	3	33	.392	1318	6574
	3	29	.398	1420	6587
	7	41	.479	1657	8578
	7	48	.488	1726	8621
	4	23	.392	1318	6217
	7	40	.466	1695	8357
	8	46	.471	1695	8943
	4	31	.379	1266	6149
3.	3	28	0.349	1181	5069
	3	34	.386	989	6217
	3	31	.382	1230	6064
	5	42	.389	1434	6510
4.	4	33	0.372	1274	6030
	4	33	.375	1434	6304
	4	38	.467	1796	7993
	8	50	.462	1681	7655
6.	4	25	0.364	1072	5749
	5	47	.394	1409	7024
	4	31	.374	1405	6817
	10	37	.396	1548	6844
	11	43	.391	1585	7539
	4	33	.397	1172	6829
7.	3	31	0.407	1201	6090
	5	48	.461	1506	7693
	4	34	.410	1365	6739
	4	36	.398	1115	5944
9.	4	18	0.338	1014	5606
	4	24	.390	1239	5534
	3	23	.359	1332	5940
	4	24	.345	1199	5692
	3	22	.355	1189	5744
	4	32	.413	1593	7496

Appendix B.

Shipment number 93. Stave Lake. Growth zone B.

Tree no.	Rings per inch	Per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
1.	6	42	0.410	1318	6625
	5	46	.445	1003	7650
	5	42	.392	1024	7314
	5	40	.404	1448	6739
	4	37	.395	1199	6701
	3	42	.367	989	5578
	7	38	.377	1379	6439
	6	35	.418	1233	6458
	6	42	.419	1461	6991
	5	40	.400	1494	6387
	5	33	.411	1593	6713
2.	7	42	0.467	1648	7950
	10	46	.487	1882	8877
	8	39	.488	1648	8994
	11	43	.497	1841	9397
	11	49	.503	1822	8398
	9	36	.477	1988	8785
	8	44	.468	1764	8531
3.	5	46	0.409	1425	6931
	11	43	.460	1758	8103
	5	47	.428	1673	6999
	6	46	.459	1771	7796
	10	45	.479	1887	8551
	5	45	.463	1811	8109
	11	53	.499	1809	8311
	16	46	.504	2100	8881
	10	42	.478	1698	8473
4.	5	46	0.451	1802	7732
	11	51	.502	2130	8706
	11	48	.545	2132	9008
	10	45	.508	2100	9288
	9	57	.503	2194	9691
	13	50	.520	2112	9252
	9	46	.492	1707	8358
	13	46	.504	2087	8792
	12	47	.485	2172	8759
	8	52	.504	2241	9206
	12	47	.516	2001	8558

Appendix B.

Shipment number 93.(cont.) Stave Lake. Growth zone B.

Tree no.	Rings per inch	Per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
6.	5	42	0.425	1536	7131
	6	46	.407	1454	7448
	6	45	.444	1164	8068
	5	47	.480	1350	9398
	11	34	.393	1648	7542
	8	40	.429	1754	7400
	12	33	.390	1601	6956
	7	47	.467	1665	7682
	7	42	.408	1442	7669
	9	42	.435	1447	8383
	7	39	.445	1521	7950
7.	5	49	0.485	1681	8275
	6	49	.541	1298	9056
	6	63	.524	1838	8574
	5	41	.464	1601	7887
	12	53	.453	1802	7797
	10	50	.490	1524	9135
	6	55	.521	1502	8915
	9	61	.471	1606	7705
	6	44	.484	1630	8120
	9	51	.544	1999	8844
	5	48	.448	1365	7131
	8	50	.489	1601	8844
	10	61	.513	1763	8239
9.	5	45	0.396	1511	6510
	6	36	.436	1707	7314
	7	43	.426	1420	6973
	9	40	.466	1582	8109
	5	37	.427	1506	7179
	5	37	.421	1365	6634
	6	37	.438	1454	7241
	8	38	.429	1715	8006
	6	25	.458	1617	8123
	5	37	.414	1325	7323
	10	38	.472	1665	7810
	5	39	.447	1491	8321
	9	42	.450	1517	8395
	9	36	.440	1681	7836

Appendix B.

Shipment number 98. Coombs, V.I. Growth zone A.

Tree no.	Rings per inch	per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
1.	8	41	0.405	1443	7042
	3	26	.354	1088	5625
2.	5	29	0.449	1548	7619
	10	38	.474	1650	7663
	9	36	.448	1682	7954
3.	4	39	0.451	1741	8063
	5	38	.461	1690	7784
	7	39	.433	1585	6926
4.	5	53	0.532	2140	9940
5.	5	42	0.463	1660	7369
	5	41	.460	1782	7644
	4	42	.482	1531	6944
	5	42	.457	1250	6728
	5	31	.437	1539	7084
6.	4	46	0.454	1658	7308
	5	55	.509	1813	8232
	7	48	.448	1750	8288
	5	42	.433	1093	6784
7.	7	40	0.444	1628	7644
8.	7	36	0.483	1724	9101
	10	42	.476	1862	8254
	5	41	.480	1707	5045

Appendix B.

Shipment number 98. Coombs, V.I. Growth zone B.

Tree no.	Rings per inch	per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
1.	7	42	0.476	1716	8811
	10	47	.485	1613	9078
	10	47	.531	1633	9550
	11	38	.496	1950	8855
	12	40	.476	1899	8670
	8	47	.474	2030	8318
	8	49	.478	1347	9137
2.	6	33	0.457	1588	7746
	8	45	.432	1819	8173
	9	40	.531	1770	8765
	4	44	.459	1640	8164
	8	32	.438	1668	7833
	6	41	.497	1732	8400
	8	40	.531	2109	8750
	8	45	.539	2044	8663
	9	38	.466	1556	8208
	9	38	.464	1735	8154
	8	42	.503	1696	7924
3.	8	39	0.461	1652	8759
	8	38	.454	1648	7695
	4	44	.471	1740	8299
	12	41	.496	1903	8452
4.	9	57	0.643	2376	10420
	9	50	.602	2483	11301
	7	57	.603	2252	11238
5.	5	47	0.504	1787	8935
	6	43	.506	1774	8119
	# 5	54	.508	1098	8114
	# 5	50	.484	1053	8378
	# 6	38	.584	1216	9767
	# 4	56	.536	1116	9686
	7	35	.460	1600	8005
	# 7	49	.549	1197	8862
	# 7	62	.557	1211	9173
	8	36	.477	1652	7971

Appendix B.

Shipment number 98 (cont.). Coombs, V.I. Growth zone B.

Tree no.	Rings per inch	Per cent summerwood	Basic specific gravity	Modulus of elasticity 1000 p.s.i.	Modulus of rupture p.s.i.
6.	7	43	0.506	1868	9413
	6	52	.486	1581	8275
	7	54	.499	1974	9610
	6	55	.524	1877	9609
	8	54	.500	1920	8332
	7	43	.470	1796	7940
	8	40	.480	1804	8196
7.	11	39	0.440	1787	7355
	6	42	.458	1648	8383
	7	43	.453	1712	7502
	4	50	.501	1433	8816
	## 5	52	.535	1067	8501
	9	41	.494	1770	7899
8.	7	44	0.483	1715	9135
	10	38	.493	1721	8388
	6	47	.491	1418	9163
	# 5	50	.518	1131	8332
	# 5	62	.589	969	9759

Signifies that compression wood was probably present in the test piece.

Signifies that compression wood was present in the test piece.