THE ELASTIC PROPERTIES OF WOOD

The Moduli of Rigidity of Sitka Spruce and Their Relations to Moisture Content

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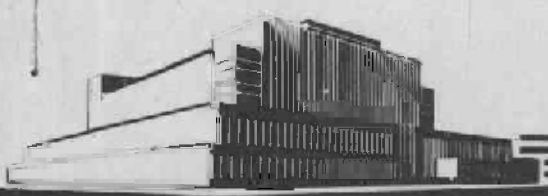

FOREST PRODUCTS LABORATORY
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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

THE ELASTIC PROPERTIES OF WOOD[1]

The Moduli of Rigidity of Sitka Spruce and Their Relations to Moisture Content[2]

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Summary

This report presents values of the moduli of rigidity of solid and glued Sitka spruce specimens at two values of moisture content as determined by tests performed at the Forest Products Laboratory. Summary tables are included, presenting average values for the three moduli of rigidity (G_{LR}, G_{LT}, and G_{RT}) and the ratios of these moduli to E_L for each of 14 planks tested and for the species in general. A comparison of average values obtained from solid and glued specimens is also provided.

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[1] This report is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available. Original report dated September 1946.

[2] This report is the third of a series presenting the elastic properties of wood. Previous reports have included data for balsa and quipo (Forest Products Laboratory Report No. 1528), and Sitka spruce (Forest Products Laboratory Report No. 1528-A).

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

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The values obtained from tests exhibited great variability among individual specimens. From the graphs that are included, showing the elastic constants plotted against the specific gravity of the specimens, it is apparent that no correlation with specific gravity was evident. The ratios of the G values to E_L were also extremely variable and exhibited no correlation with specific gravity.

The values of the moduli of rigidity at two moisture contents indicate an increase in each of the three moduli with a decrease in moisture content. This trend conforms with previous investigations of other strength properties in their relationship with moisture.

A study of the reliability of using built-up plates by gluing together closely related pieces indicates that values obtained from solid and glued specimens do not differ significantly.

Introduction

This report is one of a series presenting the results of tests performed at the Forest Products Laboratory for the determination of the elastic properties of wood.[2] The Moduli of rigidity and the ratio of these moduli to E_L for Sitka spruce at moisture contents of approximately 7 and 11 percent are presented. A report has been published presenting the Young's moduli and Poisson's ratios of Sitka spruce[2] at several moistures.

Definitions and Symbols

All symbols and terminology used in this report conform to the definitions and nomenclature presented in the Forest Products Laboratory Report No. 1528.[2]

Types of Specimens

The specimens consisted of solid and glued 8- by 8- by 1/4-inch plates, oriented with respect to the grain and growth rings of the tree to represent the three places of symmetry. A complete series of test specimens in the LR, LT, and RT planes was constructed by gluing together closely related pieces from the same plank. The glued LR and LT specimens were constructed by gluing together four 2- by 8- by 1/4-inch pieces, the long

dimension being in the direction of the grain, and the RT specimens were built up of 16 pieces 2- by 2- by 1/4-inch with the growth rings matched as closely as possible.

In addition to the glued specimens, a number of solid specimens were cut from those planks with a width of 8 inches or more. Four quarter-sawn planks and seven flat-sawn planks provided solid LR and LT specimens, respectively. Each solid specimen was matched as closely as possible with a glued specimen of similar orientation. Table 1 lists the number, construction, and types of specimens cut from each plank.

Particular care was taken in constructing the specimens to choose material with minimum ring curvature and maximum freedom from defects, and to aline the grain and growth rings parallel and perpendicular to the axes of the specimen.

In general, a moisture section was cut from the material adjacent to each LT and LR specimen during construction and conditioned with the specimen until test. This provided a preliminary moisture content determination without destroying the specimen.

Description of Material

The material for these tests was obtained from 14 Sitka spruce planks previously selected from Laboratory stock for the determination of other elastic constants. In general, a section approximately 6 feet in length had been cut from each plank for Young's moduli and Poisson's ratio tests.[2] The remaining sections were used in the present series of tests for determination of the moduli of rigidity.

Each plank was approximately 3-1/2 inches in thickness, and the planks varied in width from 7-1/2 to 13-1/2 inches. Four planks were quarter-sawn, or radial, sections of a tree and 10 were flat-sawn, or tangential, sections.

Information regarding the origin, quality, initial cutting, drying, and condition of the material has been reported previously.[2]

Marking and Matching

The plank form of the material available did not provide stock that would fully meet the requirements for the proper matching of specimens. In general, the planks were cut into sections approximately 12 to 24 inches in length for ease in handling, determination of ring direction and elimination of defects. Each section provided stock for the construction of a group of similar specimens. This method did not provide for the direct matching of shear-plate specimens or for the matching of these specimens with the associated E_L specimens. The solid specimens however, were closely related to the pieces used for the glued specimens of the same type.

The system of marking used in this study was similar to that used for the Young's modulus and Poisson's ratio specimens of Sitka spruce. The number to the left of the decimal point indicates the series or plank from which the specimens were cut. The first digit to the right of the decimal point designates the type of specimen and the second, the specimen number within the plank.

Testing Procedure

The testing technique employed was in accordance with the standard procedure as developed by the Laboratory.[4] The plate-shear apparatus commonly used for the moduli-of-rigidity tests was employed in the determination of G_{LR} and G_{LT}. The RT specimens were tested with the apparatus designed for greater sensitivity, described in Forest Products Laboratory Report No. 1528.

All specimens were conditioned at 75° F. and 64 percent relative humidity until representative pieces showed constant weight. It was not possible to conduct the tests under controlled temperature and humidity conditions. The specimens were weighed upon removal from the conditioning room at the beginning of the tests and again at the completion of the tests, the average of the two weights being used in computing the average approximate moisture content and specific gravity. These values were based on computed oven-dry

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[4] March, H. W., Kuenzi, E. W., and Kommers, W. J., Forest Products Laboratory Report No. 1301, Method of Measuring the Shear Moduli in Wood, June 1944.

weights for each specimen, determined on the assumption that, after conditioning to equilibrium, the moisture content of the specimens was the same as that of closely related moisture sections. A true moisture content determination for the individual specimens was not obtained, as the specimens were to be reserved for subsequent tests at moisture content values other than those included in this study.

In general, one and, in some instances two independent determinations of G were made on each specimen. A load-deflection curve was plotted during each run, and the specimen rotated horizontally 90° for each successive run until a total of four runs were completed for each determination The load-deflection ratio used in computing the modulus of rigidity was the average obtained from the four runs.

After the completion of these tests, all specimens were reconditioned at 80° F. and 30 percent relative humidity (approximately 7 percent moisture content). They were then subjected to a test procedure identical with that described in the preceding paragraphs, except that only one determination of G was made on each specimen.

Presentation of Data

Table 1, referred to earlier in the report, shows the number of specimens of each type tested and, therefore, the number of specimens represented in the averages given in tables 2 and 3.

Table 2 presents a summary of the average moduli of rigidity and the ratios of the moduli of rigidity to E_L for each of the 14 planks at 2 moisture contents. General averages, in which values for individual specimens were given equal weight, are also presented. Column 2 of this table shows the average approximate moisture-content values based on preliminary moisture determinations of samples associated with the LR and LT specimens. Likewise, the values in column 3 are approximate, as the specific gravity values were computed only for those specimens for which an approximate moisture determination had been obtained. In columns 7, 8, and 9 the values of E_L used in determining the elastic ratios were those determined for the same plank, previously reported.[2] The E_L values were corrected to the average moisture content of the corresponding G specimens in each series.

Table 3 compares the average moduli of rigidity values for solid LR and LT specimens at each moisture content with similar values from glued specimens.

Individual values of moduli of rigidity for LR and LT specimens, obtained from the tests at approximately 11 percent moisture content, are plotted against the corresponding approximate specific-gravity values in figures 1 and 2.

In figures 3 and 4, values of the ratios G_{LR}/E_L and G_{LT}/E_L for each series, listed in columns 7 and 8, table 2, are plotted against the average approximate specific gravity listed in column 3, table 2.

Discussion of Results

The average estimated specific gravity of the specimens used in these tests was 0.386 (based on an average estimated moisture content of 11.1 percent), and the estimated specific gravity of the individual specimens varied from 0.295 to 0.463. These values are approximate, as a true moisture content determination was not obtained for the individual specimens. Only specimens cut with an accompanying moisture disk served as a basis for these averages.

The G_{LR} and G_{LT} values for individual specimens plotted against the estimated specific gravity in figures 1 and 2 do not show a definite relationship for either modulus. Likewise, no correlation could be established between the ratios G_{LR}/E_L and G_{LT}/E_L and the estimated specific gravity as may be seen from figures 3 and 4.

Frequently it is desirable to construct specimens by gluing together closely related pieces. This method permits the construction of specimens from material not otherwise suitable because of inadequate size, excessive ring curvature or wide ranges of growth conditions. A comparison of group averages for glued and solid specimens at two moisture content values (table 3) shows that, in general, the glued specimens gave higher values for G_{LT}, while the solid specimens gave higher values for G_{LR}. Considering the variation between specimens of either type, these differences seem insignificant. The advantages gained by gluing together ring-matched pieces presumably offset any effects resulting from the presence of glue lines. The values for both glued and solid specimens within a series were averaged to give the values of G listed in table 2.

Values of the moduli of rigidity at two moisture contents indicate an increase in each of the three moduli with decrease in moisture content. This trend conforms with previous investigations of most strength properties, including modulus of elasticity. It cannot be concluded, however, that the

moduli of rigidity-moisture relationships follow the exponential law commonly applied to moisture relations, since the tests cover only two moisture contents. Further tests on the same specimens at other moisture contents will be necessary to substantiate a definite type of relationship. These tests indicate that the effect of moisture on G_{LR} and G_{LT} values is approximately the same, about 2.7 percent increase for 1 percent of decrease in moisture content from 11 to 7 percent. The effect of moisture on G_{RT} values, as determined from these tests, is about 3.9 percent for each 1 percent of decrease over the same range in moisture.

Conclusions

The conclusions from this study are based on the results obtained from tests of 192 specimens including solid and glued construction, cut from 14 planks. The moisture-content and specific-gravity values of the individual specimens are subject to correction, the values reported being based on the moisture content of material adjoining the LR and LT specimens.

(1) The moduli of rigidity values show no relationship with density. The average values presented in table 1 probably best represent the species.

(2) The average ratios G_{LR}/E_L, G_{LT}/E_L and G_{RT}/E_L for the several planks are extrememly variable and cannot be correlated with specific gravity. It would be advisable, when possible, to obtain values of G by direct measurements rather than to calculate for G by use of these ratios.

(3) With test values at only two moistures, no definite moduli of rigidity-moisture relationship can be determined. It would appear, however, that the three moduli of rigidity are affected by moisture in approximately the same manner as other properties.

(4) The results indicate that values obtained from tests of glued specimens can be used with the same reliability as those from solid specimens of the same type.

Table 1.--Number of solid and glued LR, LT, and RT specimens cut from each of 14 planks for determination of the moduli of rigidity of Sitka spruce

Series	Number of specimens				
	LR Plates		LT Plates		RT Plates
	Solid	Glued	Solid	Glued	Glued
10		2		2	1
20		2		2	
30	4	4		4	1
40	4	4		4	4
50	4	4		4	4
60		4	4	4	4
70		4	4	4	4
80		4	4	4	4
90		4	4	4	4
100		4	2	4	4
110	4	4		4	4
120		4	4	4	4
130		4	4	4	4
140		4		4	4
Total	16	52	26	52	46

Table 2.--Summary of the moduli of rigidity and their ratios to E_L for Sitka spruce

Series number	Average approximate moisture content[1]	Average approximate specific gravity[2]	Average moduli of rigidity[3]			Ratios of moduli of rigidity to E_L[4]		
			G_{LR}	G_{LT}	G_{RT}	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent		1,000 lb. per sq. in.	1,000 lb. per sq. in.	1,000 lb. per sq. in.			
10	6.0		169	180	6.7	0.123	0.131	0.005
	10.9	0.410	88	128	5.5	.070	.102	.004
20	6.2		128	156		.085	.104	
	10.6	.444	121	112		.083	.077	
30			112	89	5.8	.063	.050	.003
			114	92	4.0	.064	.052	.002
40	5.5		150	142	6.1	.103	.098	.004
	9.3	.359	124	131	5.3	.085	.090	.004
50	5.6		124	103	6.6	.095	.079	.005
	9.5	.321	111	93	5.4	.094	.078	.005
60	6.7		158	133	7.1	.110	.093	.005
	10.8	.361	130	104	5.6	.091	.073	.004
70	7.3		95	119	5.2	.047	.059	.003
	12.1	.413	85	105	4.4	.042	.052	.002
80	7.2		100	108	4.4	.069	.074	.003
	11.9	.343	94	93	4.2	.066	.065	.003
90	7.7		93	96	4.6	.049	.050	.002
	11.8	.374	82	89	3.9	.043	.046	.002
100	7.0		88	98	5.4	.037	.041	.002
	11.0	.422	86	91	5.3	.036	.038	.002
110	6.9		123	129	7.7	.067	.070	.004
	11.7	.406	116	113	6.1	.063	.062	.003
120	7.6		141	132	8.6	.071	.066	.004
	11.5	.436	131	127	7.1	.066	.064	.004
130	7.2		139	127	9.2	.077	.071	.005
	12.0	.432	124	113	8.5	.073	.066	.005
140	7.1		96	106	7.9	.048	.053	.004
	11.3	.384	89	95	6.7	.045	.048	.003
Average[5]	6.8		122	118	6.6	.070	.065	.004
	11.1	.386	109	105	5.6	.064	.061	.003

[1] Based on average test weights and computed weights when oven-dry for the LR and LT specimens, the weights when oven-dry being determined on the assumption that moisture content values of specimens were the same as for their related moisture sections.

[2] Based on weight when oven-dry, computed as in footnote 1, and volume at test.

[3] See table 1 for number of specimens represented in each average.

[4] The values of E_L are those reported in Forest Products Laboratory Report No. 1525-A for the same series, corrected to the moisture content values shown in column 2.

[5] Individual specimens were given equal weight in computing average values.

Table 3.--Comparison of glued and solid LR and LT specimens for Sitka spruce

Series number	LR specimens: Solid: Moisture content[1]	Specific gravity[2]	G[3]	Glued: Moisture content[1]	Specific gravity[2]	G[3]	Series number	LT specimens: Solid: Moisture content[1]	Specific gravity[2]	G[3]	Glued: Moisture content[1]	Specific gravity[2]	G[3]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Percent		1,000 lb. per sq. in.	Percent		1,000 lb. per sq. in.		Percent		1,000 lb. per sq. in.	Percent		1,000 lb. per sq. in.
30			124			99	60	6.6		116	6.2		146
			123			105		10.6	0.344	91	10.3	0.365	117
40	5.6		159	5.8		141	70	7.0		115	6.6		124
	9.1	0.355	126	9.8	0.351	122		11.6	.423	109	11.4	.412	101
50	5.4		120	5.7		129	80	8.1		99	7.5		103
	9.7	.318	107	9.4	.315	115		14.4	.341	92	11.8	.341	94
110	7.0		123	6.5		123	90	7.9		96	6.9		95
	11.5	.410	120	11.5	.408	118		11.5	.379	93	11.2	.380	85
							100	7.2		98	6.9		97
								11.8	.418	89	11.4	.429	92
							120	7.5		136			128
								11.5	.436	122			132
							130	7.3		127	7.2		127
								12.0	.420	114	11.9	.439	111
Average	6.0		132	6.0		123	Average	7.4		113	6.9		118
	10.1	.361	119	10.3	.358	114		11.4	.393	102	11.3	.394	105

[1] Based on average test weights and computed weights when oven-dry, determined on the assumption that the moisture contents of specimens were the same as for their related moisture sections.

[2] Based on weight when oven-dry, computed as footnote 1, and volume at test.

[3] See table 1 for number of specimens represented in each average.

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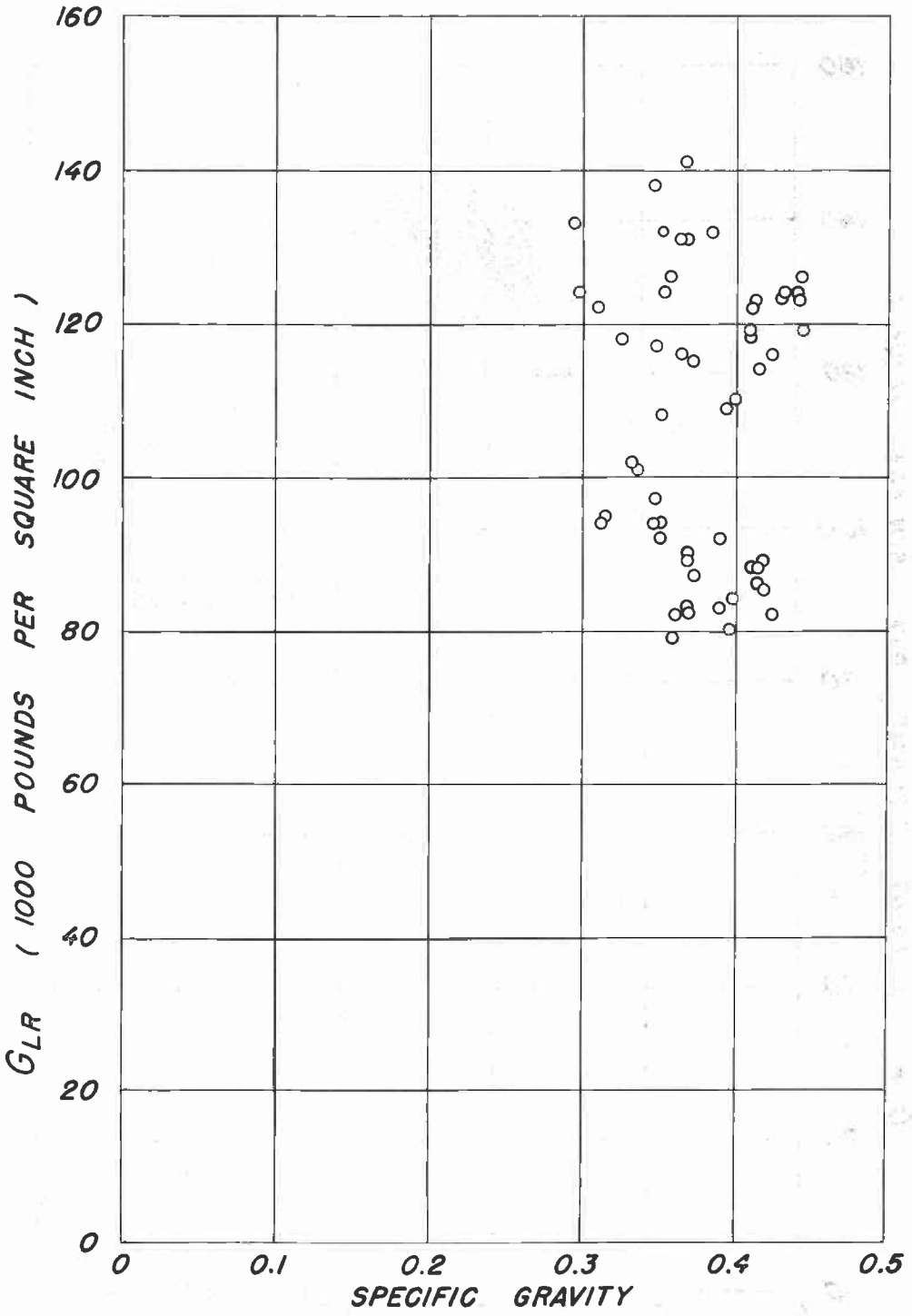

Figure 1.--Modulus of rigidity (G_{LR}) of Sitka spruce plotted against specific gravity.

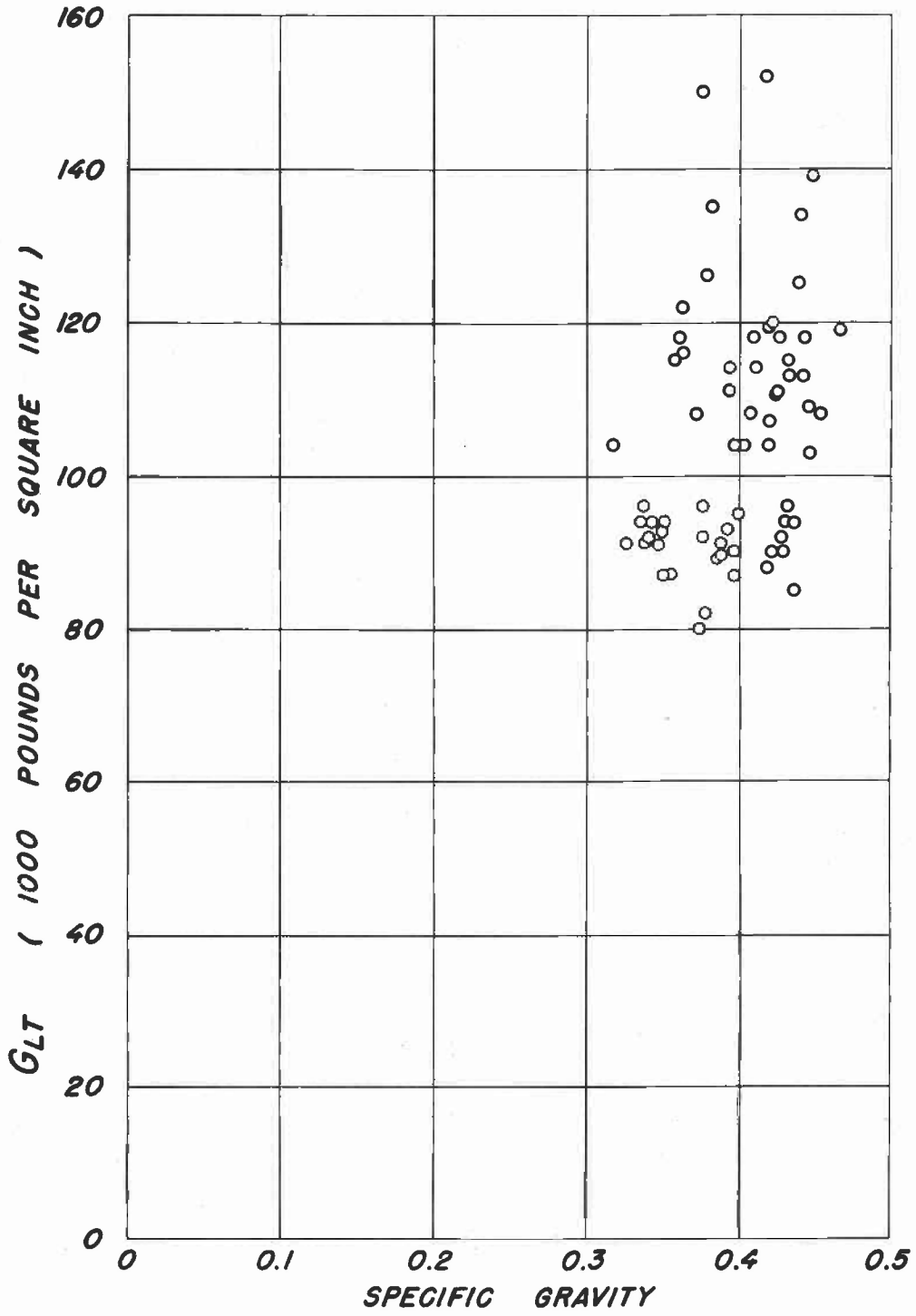

Figure 2.--Modulus of rigidity (G_{LT}) of Sitka spruce plotted against specific gravity.

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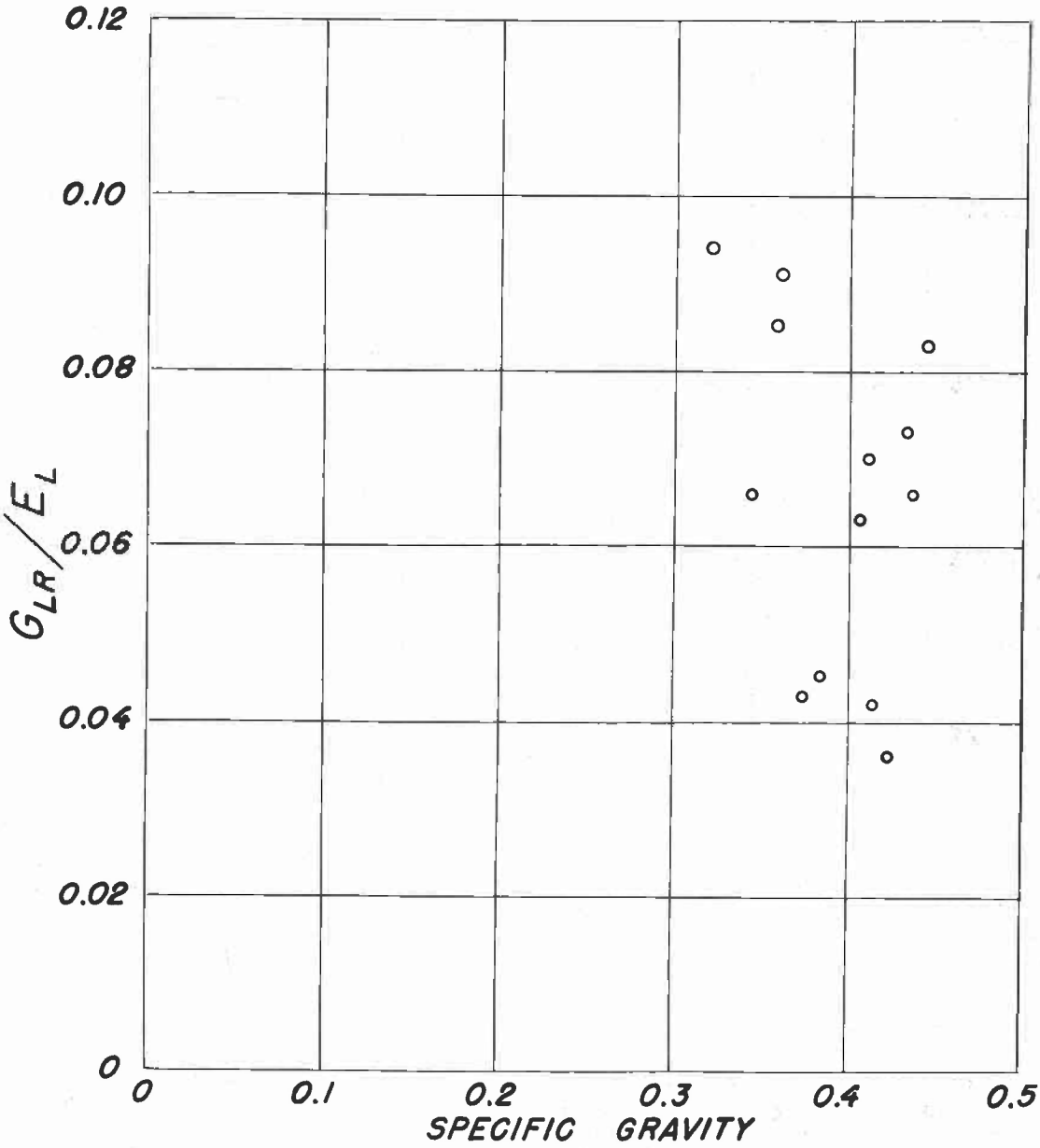

Figure 3.--The ratio G_{LR}/E_L for Sitka spruce plotted against specific gravity.

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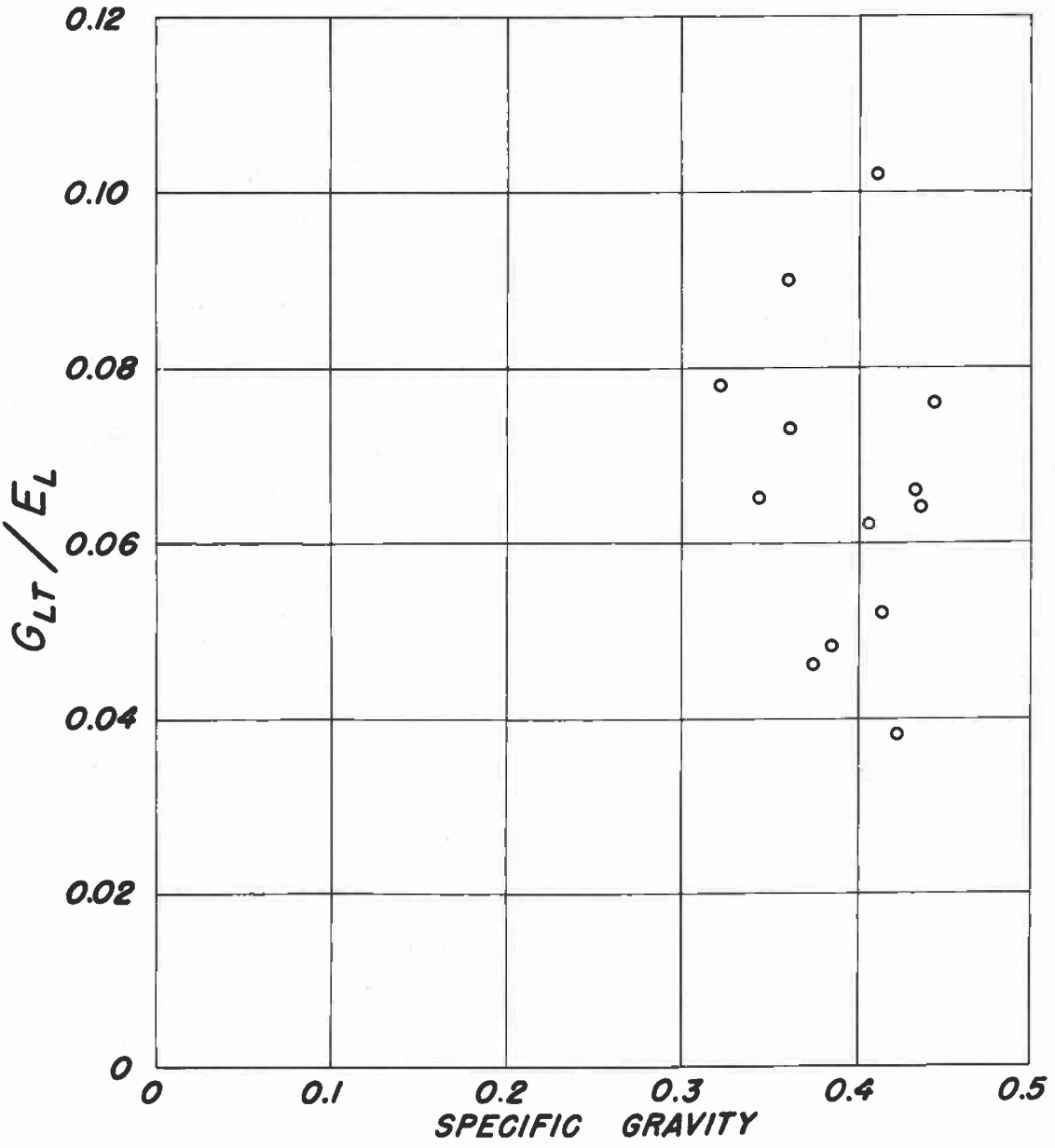

Figure 4.--The ratio G_{LT}/E_{L} for Sitka spruce plotted against specific gravity.

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Doyle, Donald Vincent
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7 p., illus. (F.P.L. rpt. no. 1528-B)

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