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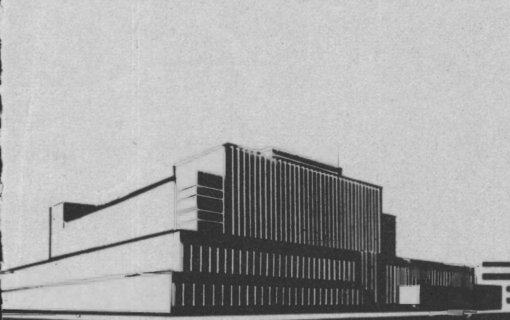

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

SOME PHYSICAL AND MECHANICAL PROPERTIES OF NOBLE FIR

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Introduction

Research on the physical and mechanical properties of noble fir (*Abies procera* Rend.) from Oregon made at the Forest Products Laboratory during World War II indicated that, in many of its properties, this species compares favorably with Sitka spruce and is in fact, when properly selected and inspected, suitable as an alternate for spruce in aircraft. Subsequent tests have shown that wood of this species from Washington and other areas of Oregon, while varying somewhat with region and locality of growth, generally conforms to the earlier concept of its properties. Specific gravity determinations, shrinkage measurements, and tests of toughness and compression paralled to grain were made on this material, which was secured from two locations in Washington and one in Oregon. The objects of the later tests were to obtain further data on the variability of the species, to discover differences that might exist among sources, and to provide data that could be reliably used for the comparison of noble fir with other species.

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

Source and Description of Material

The trees from which the sample material was selected grew in Clackamas County, Oreg., and Cowlitz and Pierce Counties, Wash. The three locations are in the Cascade Mountain range, the two in Washington at an elevation of 3,100 feet and the one in Oregon at 2,700 feet. A brief comparison of the three localities and of the sample trees is given in table 1.

The soil type in Clackamas County, Oreg., is described as a clay loam and that of both sites in Washington as a sandy loam. The trees sampled in Clackamas County, Oreg., and in Pierce County, Wash., were about the same age and range of sizes while those in Cowlitz County, Wash., were 90 to 130 years older, 16 to 18 inches larger in diameter at breast high, and 35 to 75 feet taller.

Samples were secured from five trees at each location. Sections 1 foot along the grain were taken from each tree (except No. 9) next to the stump and at intervals, usually log lengths, along the merchantable length. From three to five sections of this kind were obtained from each tree, except that in a few trees of large diameter, only half of the cross section was utilized. All sections were marked for identification, end coated to retard drying, and shipped at once to the Forest Products Laboratory.

Preparation of Specimens

The end-coated blocks from the sample trees arrived at the Laboratory within a short time and evidenced no interior drying. They were cut immediately into specimens for testing. Figure 1 and the following descriptive notes explain the method of preparation for each set of specimens.

1. Tangential shrinkage specimens were cut from a cross-sectional disk 1 inch along the grain taken near one end of each block. This disk was jointed on one side and photographed before being cut into specimens. The specimens were laid out on the curve of the annual rings on both sides of the pith, usually on a north-south axis and at intervals of from 1 to 3 inches along the radius. Specimens measured approximately 1 by 4 by 1 inches, with the

longest dimension in the tangential direction and with the ends parallel. The number of specimens on a given radius varied from 2 to 9 depending on the length of the radius, or the presence of rot, checks, knots, or other defects.

2. Toughness specimens, 5/8 by 5/8 by 10 inches in size, were obtained from a 1-inch board sawn through the pith of the remaining block, from bark to bark for full cross-sections, or radially from pith to bark for half-sections. While in the green condition, this board was cut parallel to grain into sticks measuring 1 inch in the radial direction and numbered consecutively from pith to bark.

3. A 1/2-inch board, 10 or more inches along the grain, was cut from the material immediately adjacent to the toughness board. This board was jointed and planed to 1/4 inch in thickness. It was cut into longitudinal shrinkage specimens which measured 1/4 inch tangentially, 5/8 inch radially, and about 10 inches along the grain. The number of such samples obtained from each radius varied from 2 to 11, depending on the length of the radius and the presence of defects.

4. A flitch approximately 2-1/2 inches in the tangential direction and adjacent to the boards for toughness or longitudinal shrinkage specimens, was cut from each of the two remaining portions. For full cross sections, the arrangement was the same as shown in figure 1 with alternate portions of the two flitches reserved for compression parallel-to-grain specimens, and the remaining parts for specific gravity and radial shrinkage specimens. For half sections, one of the flitches was designed for compression specimens and the other for specific gravity and shrinkage specimens.

   Two pieces, one 4 inches along the grain, 2 by 2 inches in cross section, for specific gravity specimens, and the other 1 inch along the grain, 1 by 4 inches in cross section, for radial shrinkage specimens were cut from each available section.

   Specific gravity specimens per radius ranged in number from 3 to 12. These specimens also furnished data on volumetric shrinkage. The radial shrinkage specimens were cut so that the annual rings were at right angles to the 4-inch dimension and ranged from 2 to 6 specimens per radius.

The sections for use in the compression-parallel-to-grain tests were cut while in the green condition parallel to grain into sticks measuring approximately 2-1/2 inches in the radial direction.

5. The number and kinds of test specimens by shipments are shown in table 2. Not included in these figures are the specimens that were culled because of decay, knots, defects, or compression wood. Altogether the three shipments provided 2,800 specimens, of which 442 were for specific gravity and volumetric shrinkage determinations, 439 for the measurement of longitudinal shrinkage, 323 for radial shrinkage, 389 for tangential shrinkage, 810 for toughness, and 397 for tests of compression parallel to the grain. The specimens for toughness and compression parallel-to-grain tests were divided almost equally between green and air-dry seasoning conditions.

Treatment of Specimens

All specimens were kept covered to prevent drying during their preparation and until the green dimensions and weights were obtained. Before cutting specific gravity specimens from the 2-1/2-inch flitches, the location of each specimen was marked and a radial line drawn across the end of each flitch from pith to bark. The annual rings were counted along this radius. The length of radius and the number of years growth for each specimen were recorded. Separate specimens were provided for heartwood and sapwood. After sawing the flitches into specimens, each specific gravity specimen was weighed, and its green volume determined by submersion in water. They were then allowed to dry progressively in conditioning rooms at 80° F. and 80, 65, and 30 percent relative humidity. Final drying to a moisture-free condition was accomplished in an oven at 100° to 105° C., after which weights and volumes were again determined.

Data on the radial and tangential shrinkage specimens were secured by weighing and measuring when green, and after reaching equilibrium moisture content in each of the above-mentioned humidity rooms. Final weights and measurements were obtained after oven drying. From this data, the relationship of shrinkage to moisture content was determined.

The longitudinal shrinkage specimens were conditioned in a manner similar to that used for the other shrinkage specimens. Longitudinal measurements were made of them when green, when at equilibrium in the 65 and 30 percent relative humidity rooms, and when oven dry.

Compression parallel-to-grain and toughness tests were made on approximately equal numbers of green and air-dry specimens. For compression tests, alternate sticks proceeding outward from the pith were designated for green and dry conditions. When a full cross section of the tree was available, the designation was reversed in the two sections, (fig. 1), so that each 2-1/2 inches of the radius of the tree was represented by a specimen for each seasoning condition.

For toughness tests, odd-numbered specimens were tested in the green, and even-numbered specimens in the dry condition.

All odd-numbered specimens, therefore, were cut to the required dimensions and tested as soon as possible after being cut from the log. Sticks designated for air-dry tests were conditioned to approximately 12 percent moisture content before being cut to the required dimensions. Final conditioning and all compression testing was done in a room controlled at 70° F. and 64 percent relative humidity. Toughness specimens were conditioned in this room, but were tested in small groups under prevailing atmospheric conditions.

Test Methods--Compression and Toughness

Compression tests were made in accordance with the methods described in "Standard Methods of Testing Small Clear Specimens of Timber" A.S.T.M. designation D143-27.

Toughness tests were made on the Forest Products Laboratory toughness testing machine, described in U. S. Dept. of Agriculture Technical Bulletin No. 479. All specimens were loaded on the tangential face nearest the pith.

Weights and measurements for both types of specimen were obtained immediately prior to the test. A representative section, cut from each specimen immediately after testing, was ovendried to determine moisture content. Specific gravity values were calculated, based on weight when ovendry and volume at time of test.

Presentation of Results

The data obtained from this study include values for specific gravity and radial, tangential, and longitudinal shrinkage, together with the results of toughness and compression parallel-to-grain tests. Earlier studies[2] furnished some data on noble fir that are included, where indicated, with values obtained from the current study.

Specific Gravity

The specific gravity of the noble fir included in this report, based on weight and volume when ovendry, ranged from 0.297 to 0.560 with an average value for all samples of 0.405. Figure 2 shows the variation between shipments 1597, 1598, and 1599 for three different height classes in the sample trees. The short vertical lines indicate average values, while the cross-hatched portions of the bars include values for three-fourths of the test specimens within the groups. Specific gravity values for the same specimens as those represented in figure 2, but based on weight when ovendry and volume when green, ranged from 0.273 to 0.474 with an average of 0.355.

As shown in figure 2, the specific gravity decreased with increased height above the ground in the merchantable length of the trees. This condition is presented in another manner in figure 8, which is based on the 442 specimens from the trees in shipments 1597, 1598, and 1599. The graph shows that the average specific gravity near the stump was about 0.44, whereas at a height of 120 feet it was about 0.38. The rate of change is greatest in the lower portion of the trunk. The trees from shipment 1598 showed greatest uniformity in specific gravity. Table 1 shows that these trees were considerably older and larger than those in the other two shipments.

Curve B in figure 3 presents the frequency distribution of specific gravity based on weight and volume when ovendry by 0.02 classes. This curve includes data on 442 specimens from shipments 1597,

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[2] Earlier studies included data from shipments 270 and 616. The nine noble fir trees in these shipments were cut in 1913 and 1918, respectively. They originated in the mountains in Multnomah County, Oreg., at elevations of 3,000 to 3,500 feet. The trees were probably over 30 inches in diameter at breast height and from 200 to 300 years old.

1598, and 1599, and 68 specimens from shipments 270 and 616. The average value of 0.405 for these 510 specimens is the same as the average for the three recent shipments shown in figure 2. Similarly, curve A in figure 3 presents specific gravity variation on an ovendry weight and green volume basis. Represented in this curve are 903 specific gravity specimens, of which 461 are from shipments 270 and 616. The average specific gravity value of 0.353 is within the class occurring most frequently.

The relatively high volumetric shrinkage of some specimens causes a wider and more irregular frequency variation for specific gravity values based on weight and volume when ovendry than for those based on weight when ovendry and volume when green. (Compare curves A and B, fig. 3.) In general, volumetric shrinkage increased as specific gravity increased. Shrinkage in volume ranged from 6.9 to 17.3 percent and averaged 12.4 percent for the specimens from shipments 1597, 1598, and 1599.

Figure 4 shows the relationship of volumetric shrinkage to specific gravity for individual specimens of shipments 1597, 1598, and 1599. The low and high values of 6.9 and 17.3 percent for shrinkage in volume are found in specimens having a specific gravity of 0.357 and 0.508 respectively, based on weight and volume when ovendry. Although there is a general relationship between specific gravity and shrinkage, figure 4 shows a considerable variation for any given specific gravity value.

Figure 5 shows the relationship between values of specific gravity based on weight when ovendry and volume when green and corresponding values of specific gravity for the same 442 specimens based on weight and volume when ovendry. A straight-line relationship is indicated, with the difference between the two sets of values increasing with an increase in specific gravity.

Growth Pattern and Specific Gravity

The growth-ring measurements on the specific gravity specimens permitted a study of width of annual rings in relation to specific gravity. The sample trees followed a rather definite growth pattern which may, or may not be characteristic of the species. Near the pith wide growth rings were formed, and as few as 3 or 4 added an inch to the radius. The rings became progressively narrower toward the bark, with as many as 90 rings in the outer inch of radius of some of the trees. The early growth, largely springwood, was soft and light in weight, but as the rings narrowed, the percentage of summerwood increased to produce denser wood. When ring width decreased beyond 20 rings per inch, however, the specific gravity decreased, since the very narrow rings contained a smaller proportion of summerwood. The growth pattern (rings per inch variation from pith to bark) and accompanying specific gravity variation is presented in figure 6, which is based on the 442 specimens from the sample trees in shipments 1597, 1598, and 1599. Figure 6 shows the lightest wood near the pith and the heaviest just beyond the middle of the radius, where one inch contained approximately 20 rings. The wood near the bark, of intermediate density, represents an average of 36 years of growth per inch of radius.

Shrinkage

The shrinkage values for specimens from the 15 trees recently tested averaged 4.22 percent radially, 8.25 percent tangentially, 0.148 percent along the grain, and 12.4 percent volumetrically. All values represent the total dimensional change from the green to the ovendry condition, and are expressed as a percentage of the green dimensions. Frequency curves for the four types of shrinkage are shown in figure 7. The distributions of the radial, tangential, and volumetric values are quite normal, but the longitudinal shrinkage frequency curve is extended somewhat in the higher shrinkage classes. This extension is caused, at least in part, by the high values for the specimens near the pith in the soft, fast growth previously mentioned and possibly also by compression wood which is discussed later in the report. Table 3 is a brief summary of some values represented in figure 7.

Since specific gravity, in general, decreased at successive heights in the sample trees, and since shrinkage is related to specific gravity, it might be expected that shrinkage would likewise decrease. This, however, was not the case. For reasons not yet established, but possibly due to infiltrated materials, the wood next to the stump had relatively lower shrinkage radially, tangentially, and volumetrically than at any point from 16 to 40 feet high in the trees. However, from the point of highest shrinkage, there was generally a gradual reduction in shrinkage values progressively up the tree. Figure 8, a graphic presentation of the variation of specific gravity and shrinkage with height in the tree, is based on data from trees in shipments 1597, 1598, and 1599. This figure shows that the specific gravity and shrinkage relationships are fairly consistent for all heights except those in the lowest portion of the trees where the shrinkage values appear to be low with respect to specific gravity. Table 4 shows, by shipments, the average shrinkage values for three portions of the merchantable heights of the trees. Shrinkage in volume and across the grain are greatest at heights of 12 to 52 feet and they substantiate the curves shown in figure 8. The tangential values in table 4 reveal that this same relationship holds for both heartwood and sapwood.

A tendency exists for average longitudinal shrinkage values to increase at successive heights in the tree. This increase may result from the shortening radii, which would raise the percentage of samples taken from the lightweight wood near the pith. As already mentioned, this type of wood shrinks considerably in the direction of the grain.

Trees in shipment 1598 varied less in shrinkage than the trees in the other shipments. Average shrinkage values by trees and shipments are listed in table 5. Specimens from trees 1 and 14 exhibited the greatest transverse shrinkage but had only moderate longitudinal shrinkage. Tree 11 had the lowest transverse shrinkage, while trees 3 and 5,both in shipment 1597, had the lowest and highest longitudinal shrinkage values, respectively. In general, tangential shrinkage values were about double the radial figures.

Data recorded during the conditioning of specimens in the various humidity rooms indicate a straight-line relationship between moisture content and shrinkage with the fiber saturation point at about 27 percent moisture content. Only slight variations occurred between the heartwood and sapwood, although at a given moisture content, the sapwood generally showed a slightly higher shrinkage value. Since other factors such as width of annual rings, percentage of summerwood, and the like may also be involved, the difference between heartwood and sapwood is not significant as such. Figure 9, based on the trees in shipments 1597, 1598, and 1599, shows the way in which radial, tangential, and longitudinal shrinkage of both heartwood and sapwood varied with moisture content. It is interesting to note the behavior of mixed heartwood and sapwood radial samples, which have a higher shrinkage value than either heartwood or sapwood separately.

Compression Parallel-to-grain and Toughness Test

The values obtained from the compression parallel-to-grain tests, summarized by trees and shipments, are shown in table 6. In accordance with standard testing procedure, each 4-foot section of the tree was designated as a bolt, (a, b, c--z, aa, bb, --ll) starting at the ground and proceeding upward. Average values were calculated for all specimens within each bolt, and the bolt averages were, in turn, combined to provide an average value for each tree as listed in the upper portion of table 6.

This table also lists the average values for each shipment in which equal weight was given to all specimens, irrespective of their location in the tree. It may be noted that these values are generally somewhat higher than the corresponding values derived from the bolt and tree averages, probably as a result of the inclusion of a disproportionate amount of high density material in the "a" bolts.

For comparison, table 6 also includes data from the previous tests of material in shipments 270 and 616 from Multnomah County, Oreg. These shipments represent material largely from "c" and "d" bolts, in accordance with standard sampling procedures. The material included in the present tests was taken from various heights in the trees, and is not directly comparable, therefore, to that included in the previous investigations. Only 8 of the 60 bolts in the present tests represented "c" and "d" bolts, while over 20 percent of the tests represented material in "a" bolts that were located within the first 4 feet above the ground. Data included elsewhere in this report indicated that material from this location in the tree was more dense than that in other parts of the tree.

Scattered heights, up to 152 feet in some trees, are also represented. The average specific gravity and compressive strength values, however, may not differ greatly from those obtained from specimens selected by the standard procedure, since material from the higher positions was generally found to be comparatively low in density.

The variation of maximum crushing strength with density for the green specimens included in this report is shown in figure 10. For comparison, this figure also includes a curve representing similar relations for a combination of Sitka, red, and white spruce.

Results from the toughness tests included in this survey reveal that, as was the case for the compression tests, the lower bolts generally produced the heaviest material with correspondingly high test values.

Individual pieces showed great variability, probably due, at least in part, to the effect of local growth conditions in some of the trees.

The toughness data are summarized in table 7, where tree and shipment averages are presented on the same basis as for the compression tests. Figure 11 presents frequency distribution curves for toughness of the air-dry specimens included in this report (shipments 1597, 1598, and 1599), and for comparison, similar curves from data obtained in other recent studies. The curves indicate a considerable difference in the distribution characteristics of the several anlayses, with a disproportionate number of specimens in the present study having a low toughness value. About 65 percent of the toughness values were below the average (118 inch-pounds) for all tests, suggesting that possibly the higher and lighter sections of the trees were represented by the greater amount of material.

In figure 12 the toughness values for individual specimens are plotted with specific gravity. While the relationship is not as well defined as for compression, there is a definite trend toward an increase in toughness with an increase in specific gravity.

The relationship of toughness and compression properties to height in the tree varied considerably among the 15 trees. Figure 13 shows the average toughness value of green material plotted against height in tree. Figure 14 is a similar graph in which the average maximum crushing strength in compression parallel to grain for air-dry material is plotted against height in the tree. These curves were obtained by averaging values read from curves representing similar data for individual trees at six arbitrarily selected heights. While the relations were erratic within the individual trees, a general trend toward a decrease in these strength properties with an increase in height is clearly shown.

Similar composite curves representing green material were also determined for the specific gravity of toughness and compression specimens, and for fiber stress at proportional limit and modulus of elasticity in compression. A series of curves were similarly prepared to represent material at 12 percent moisture content. Figures 15 and 16 show, for material at about 12 percent moisture content and in the green condition, respectively, the average variations of these properties with height, based on percentages of the corresponding value for bolt "a."

Since all of the compressive strength properties are known to be related to specific gravity, and figure 12 shows that generally toughness is also broadly related to specific gravity, it might be expected that the curves representing the variation of strength properties with height would be similar in nature to those representing specific gravity. Examination of figures 15 and 16 shows that this is not the case. Furthermore, a comparison of the two figures discloses that, while the character of the variations of specific gravity, maximum crushing strength and modulus of elasticity with height are essentially alike for the two moisture conditions, the relations for fiber stress at proportional limit and toughness are materially different. Earlier in the report it was pointed out that the shrinkage-height relationship also differs materially from the specific gravity-height relationship, and such difference may account, at least in part, for the dissimilarity in property-height relations between the green and dry conditions.

Compression Wood

In coniferous trees that do not stand vertically, a type of abnormal wood called compression wood usually forms on the lower side of the trunk. This type of wood is common also on the under side of branches. Compression wood is undesirable because of high and uneven longitudinal shrinkage, low strength in certain properties, excessive hardness, and greater density due to stimulated development of thick-walled cells. The noble fir, in shipments 1597, 1598, and 1599 contained considerable amounts of compression wood in spite of an effort in the field to select sample trees that were standing as nearly vertical as possible.

When it became evident that sufficient compression wood was present in some of the specimens to cause the test values to be out of line with corresponding values for the normal wood, an effort was made to segregate the specimens containing appreciable amounts of this material. The light-box method for identifying compression wood was used with thin sections cut from the specific gravity specimens, but with this species, it was not entirely successful. By supplementing the light-box test with a close inspection of the specific gravity specimens, and an examination of the density and shrinkage values, it was possible to segregate 60 specific gravity specimens that obviously contained substantial amounts of compression wood. It is probable some additional specimens contained compression wood to a lesser degree.

The radii of the different trees with compression wood were identified, and the longitudinal shrinkage specimens from these radii examined. A close inspection of the specimens and an examination of the preliminary values permitted segregating 36 longitudinal shrinkage specimens that contained compression wood. Since compression wood has a more moderate effect on transverse shrinkage, no effort was made to locate specimens containing such material among the radial and tangential shrinkage specimens.

The data presented in the earlier part of this report do not include specimens that were identified as containing compression wood on specific gravity and longitudinal shrinkage. The 60 specific gravity specimens containing compression wood averaged about 10 percent higher in specific gravity than normal wood, and the 36 longitudinal shrinkage specimens shrank on an average 2.3 times as much as the specimens containing normal wood.

Conclusions

The following conclusions are based on a study of 2,800 specific gravity, shrinkage, toughness, and compression specimens cut from 15 noble fir trees grown in Washington and Oregon:

1. The specific gravity, based on weight and volume when ovendry, ranged from 0.297 to 0.560 with an average value of 0.405.

2. Specific gravity decreased with height in the tree and, except at the base of the trees, was closely related to volumetric shrinkage.

3. Specific gravity increased with the number of rings per inch up to 20 rings, beyond which it gradually decreased.

4. The average shrinkage was 4.22 percent radially, 8.25 percent tangentially, 0.148 percent longitudinally, and 12.4 percent volumetrically.

5. Shrinkage tests at different moistures indicated a fiber-saturation point in the vicinity of 25 to 28 percent moisture content. The shrinkage-moisture content patterns for heartwood and sapwood were very similar.

6. Sixty specific gravity specimens (not included in the preceding data) contained compression wood, and averaged 10 percent higher in density than the 442 specific gravity specimens of normal wood. The average shrinkage of 36 longitudinal shrinkage specimens that contained compression wood was more than twice as great as the average of 439 specimens of normal wood.

7. Results from compression tests indicate that the material from the younger and smaller trees in shipment 1597 from Oregon was somewhat higher in average specific gravity and maximum crushing strength than material in shipments 1598 and 1599 from Washington. The average values for compression properties of the three shipments, whether obtained by bolt and tree averages or from averages of individual values, were approximately the same as those obtained from previous tests. Consequently, it is believed the values from the present tests, which represent a substantial number of trees from several sources and cover a wide range in height, may be considered as adequately representative of noble fir as a species.

8. Results of toughness tests, although quite variable, indicated a general increase in toughness with increase in specific gravity. Since about 65 percent of the toughness values were below the average, it would appear that the higher and lighter sections of the trees were represented by a disproportionate number of specimens, with the average greatly influenced by the abnormally high density and correspondingly high toughness of specimens from the butts of the trees.

9. The variation of toughness and compression properties with height in the tree was quite erratic for individual trees. Average curves representing the 15 trees, however, were reasonably smooth, but the curves for the various properties differed considerably. Similarly, the curves for material at about 12 percent moisture content differed from those representing green material, especially for fiber stress at proportional limit in compression parallel to grain and for toughness. The causes of such differences are not known.

Table 1.--Location and description of sample trees

Item	Shipment No.		
	1597	1598	1599
Location of stand	Clackamas County, Oregon	Cowlitz County, Washington	Pierce County, Washington
Elevation	2,700 feet	3,100 feet	3,100 feet
Topography	Mountainous	Mountainous	Mountainous
Type of soil	Clay loam	Sandy loam	Sandy loam
Number of sample trees	5	5	5
Range in total age	212-263 years	331-394 years	243-274 years
Range in diameter of breast height	26-40 inches	44-66 inches	28-48 inches
Range in total height	133-191 feet	212-235 feet	150-200 feet
Range in merchantable height	62-133 feet	114-152 feet	97-151 feet

Table 2.--Number and kinds of test specimens by shipments

Distribution	Number of specimens			
	Shipment 1597	Shipment 1598	Shipment 1599	Total
Radial shrinkage	98	109	116	323
Tangential shrinkage	127	124	138	389
Longitudinal shrinkage	130	146	163	439
Specific gravity and volumetric shrinkage	126	159	157	442
Toughness	251	267	292	810
Compression parallel to grain	121	135	141	397
Total	853	940	1007	2800

Table 3.--Summary of shrinkage values

Type of shrinkage	Shrinkage (green to ovendry condition)[1]		
	Average	Total range	Range of 75 percent of specimens
	Percent	Percent	Percent
Radial	4.22	1.90 - 6.40	3.20 - 5.20
Tangential	8.25	4.40 -12.00	6.60 - 9.90
Longitudinal	.148	.042- .327	.095- .211
Volumetric	12.40	6.90 -17.30	9.80 -14.90

[1]Expressed as a percentage of the green dimension.

Table 4.--Shrinkage values by shipments and heights in tree

Shipment No.	Height in tree	Average shrinkage (green to ovendry condition)[1]					
		Volumetric	Longitudinal	Radial	Tangential		
					Total	Heartwood	Sapwood
	Feet	Percent	Percent	Percent	Percent	Percent	Percent
1597	0-4	12.5	0.114	4.15	8.22	7.84	8.84
	12-20	13.3	.160	4.49	9.12	9.00	9.40
	Over 20	11.9	.158	4.27	7.93	7.80	8.16
	Average	12.4	.148	4.30	8.35	8.18	8.67
1598	0-4	12.2	.132	4.16	8.18	8.14	8.31
	16-52	13.7	.132	4.64	9.37	9.48	8.99
	Over 52	11.5	.161	4.09	7.74	7.90	7.29
	Average	12.3	.146	4.25	8.32	8.44	7.92
1599	0-4	12.1	.106	3.93	8.53	8.36	8.83
	28-40	14.0	.159	4.63	9.25	9.28	9.17
	Over 40	11.5	.166	3.94	7.44	7.35	7.66
	Average	12.3	.152	4.12	8.10	8.05	8.22
All	Grand Average	12.4	.148	4.22	8.25	8.22	8.31

[1] Expressed as a percentage of the green dimension.

Table 5.--Average shrinkage values by trees and shipments

Shipment No.	Tree No.	Shrinkage (green to ovendry condition)[1]			
		Volumetric	Longitudinal	Radial	Tangential
		Percent	Percent	Percent	Percent
1597	1	14.1	0.140	4.9	9.2
	2	11.3	.154	3.8	7.9
	3	12.2	.131	4.1	8.3
	4	12.9	.145	4.4	8.4
	5	11.0	.180	4.1	7.6
	Average	12.4	.146	4.3	8.4
1598	6	11.2	.161	4.2	7.8
	7	11.8	.136	3.8	7.8
	8	12.3	.151	4.4	8.2
	9	12.8	.143	4.2	8.8
	10	13.1	.138	4.6	9.0
	Average	12.3	.146	4.2	8.3
1599	11	10.5	.157	3.3	7.3
	12	12.4	.161	4.2	8.2
	13	12.8	.155	4.4	7.3
	14	14.5	.145	5.0	9.4
	15	12.5	.134	4.0	8.4
	Average	12.3	.152	4.1	8.1
	Weighted average	12.4	.148	4.2	8.2

[1]Expressed as a percentage of the green dimension.

Table 6.--The compressive strength of noble fir from Oregon and Washington--Shipments 1597, 1598, 1599 - 15 trees

Shipment No.	Tree No.	Green condition: Moisture content	Green condition: Specific gravity[1]	Green condition: Compression parallel to grain: Stress at proportional limit	Green condition: Compression parallel to grain: Maximum crushing strength	Green condition: Compression parallel to grain: Modulus of elasticity	Air-dry condition: Moisture content	Air-dry condition: Specific gravity[1]	Air-dry condition: Compression parallel to grain: Stress at proportional limit	Air-dry condition: Compression parallel to grain: Maximum crushing strength	Air-dry condition: Compression parallel to grain: Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		Percent		Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent		Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.
1597	1	58.2	0.416	2,568	3,142	1,616	11.9	0.438	5,002	6,466	2,162
	2	77.0	.338	1,907	2,528	1,352	12.0	.365	4,054	5,247	1,619
	3	62.6	.378	2,709	2,968	1,647	12.1	.408	4,594	5,857	1,938
	4	69.1	.380	2,630	3,115	1,659	12.1	.403	4,600	5,928	1,862
	5	53.9	.362	2,518	2,998	1,338	11.5	.392	4,022	5,606	1,704
Average		64.2	.375	2,466	2,950	1,522	11.9	.402	4,454	5,821	1,857
1598	6	73.4	.352	2,470	2,775	1,504	12.0	.380	4,078	5,265	1,630
	7	74.8	.361	2,066	2,663	1,392	12.0	.384	3,615	5,280	1,553
	8	58.8	.345	2,035	2,484	1,347	12.2	.369	3,729	4,935	1,588
	9	41.0	.358	2,574	2,891	1,558	12.0	.391	4,404	5,533	1,644
	10	94.0	.352	2,559	2,788	1,592	12.1	.386	4,735	5,738	1,865
Average		68.4	.354	2,341	2,720	1,479	12.1	.382	4.112	5,350	1,656
1599	11	89.6	.313	1,806	2,153	1,201	12.4	.332	3,452	4,411	1,401
	12	65.8	.361	2,364	2,757	1,614	12.2	.387	4,497	5,676	1,806
	13	51.4	.366	2.121	2,678	1,499	12.4	.387	3,025	5,153	1,840
	14	78.5	.369	2,240	2,744	1,677	12.7	.416	5,093	6,163	2,261
	15	84.6	.346	2,184	2,526	1,464	12.2	.370	4,268	5,239	1,784
Average		74.0	.351	2,143	2,572	1,491	12.4	.378	4,067	5,328	1,818
Average of 3 shipments		68.9	.360	2,317	2,747	1,497	12.1	.387	4,211	5,500	1,777
Average of individual pieces											
1597	....	65.8	.379	2,558	3,002	1,586	11.9	.406	4,507	5,905	1,896
1598	....	70.8	.356	2,375	2,731	1,494	12.0	.384	4,144	5,389	1,679
1599	....	70.0	.349	2,157	2,555	1,522	12.4	.376	4,013	5,286	1,765
Average of 3 shipments		68.9	.361	2,363	2,763	1,534	12.1	.389	4,221	5,527	1,780
Data from previous tests											
270	....	41.2	.350	2,390	2,700	1,716	12.0	.380	5,020	5,760	2,148
616	....	28.5	.353	....	2,780	....	12.0	.368	....	5,280	....

[1]Specific gravity based on volume at test and weight when ovendry.

Table 7.--Noble fir--toughness. Specimens 5/8 by 5/8 by 10 inches, 8-inch span, loaded tangentially

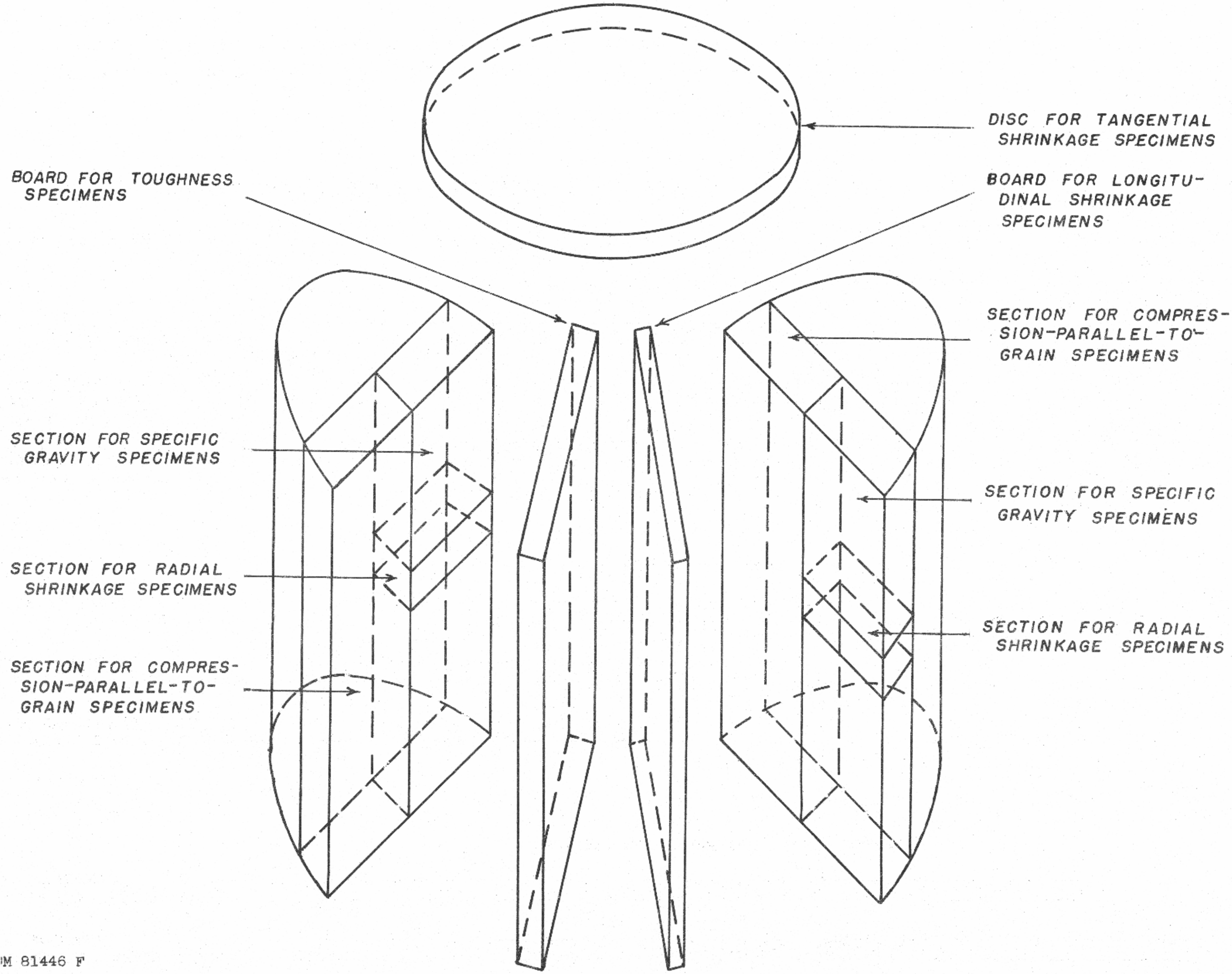
Shipment No.	Tree No.	Green condition: Moisture content	Green condition: Specific gravity	Green condition: Toughness	Air-dry condition: Moisture content	Air-dry condition: Specific gravity	Air-dry condition: Toughness
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		Percent		In.-lb. per specimen	Percent		In.-lb. per specimen
1597	1	56.6	0.422	178.1	11.8	0.448	163.8
	2	67.0	.350	139.2	11.8	.367	105.1
	3	62.1	.384	164.0	11.9	.404	147.6
	4	40.6	.384	151.5	11.8	.403	122.9
	5	52.7	.365	143.6	11.7	.390	107.9
Average		55.8	.381	155.3	11.8	.402	129.5
1598	6	67.7	.348	73.9	11.4	.383	90.6
	7	71.4	.363	117.4	12.2	.383	94.6
	8	55.3	.346	102.2	12.1	.363	97.0
	9	48.4	.358	89.2	11.8	.383	94.0
	10	81.8	.363	96.1	11.5	.393	110.8
Average		64.9	.356	95.8	11.8	.381	97.4
1599	11	80.5	.323	117.9	12.0	.337	95.3
	12	68.0	.368	133.2	12.1	.386	122.4
	13	48.2	.364	153.6	12.0	.387	112.2
	14	56.1	.381	149.8	12.0	.416	146.2
	15	71.2	.348	108.8	12.1	.370	103.7
Average		64.8	.357	132.7	12.0	.379	116.0
Average of 3 shipments		61.8	.365	127.9	11.9	.387	114.3
				Average by pieces			
1597	....	57.6	.385	160.7	11.8	.408	134.2
1598	....	69.9	.359	101.7	11.8	.386	103.2
1599	....	63.7	.354	125.8	12.1	.377	117.8
Average of 3 shipments		63.7	.366	129.4	11.9	.390	118.4
				Previous tests			
(1)	....	....	....	....	10.9	.396	101
1600	....	....	....	....	12.4	.385	121

[1] Data from Forest Products Laboratory Report No. 1329, "Chemical Stain in Noble Fir as Related to Strength."

Table 8.--Effect of compression wood on specific gravity and longitudinal shrinkage

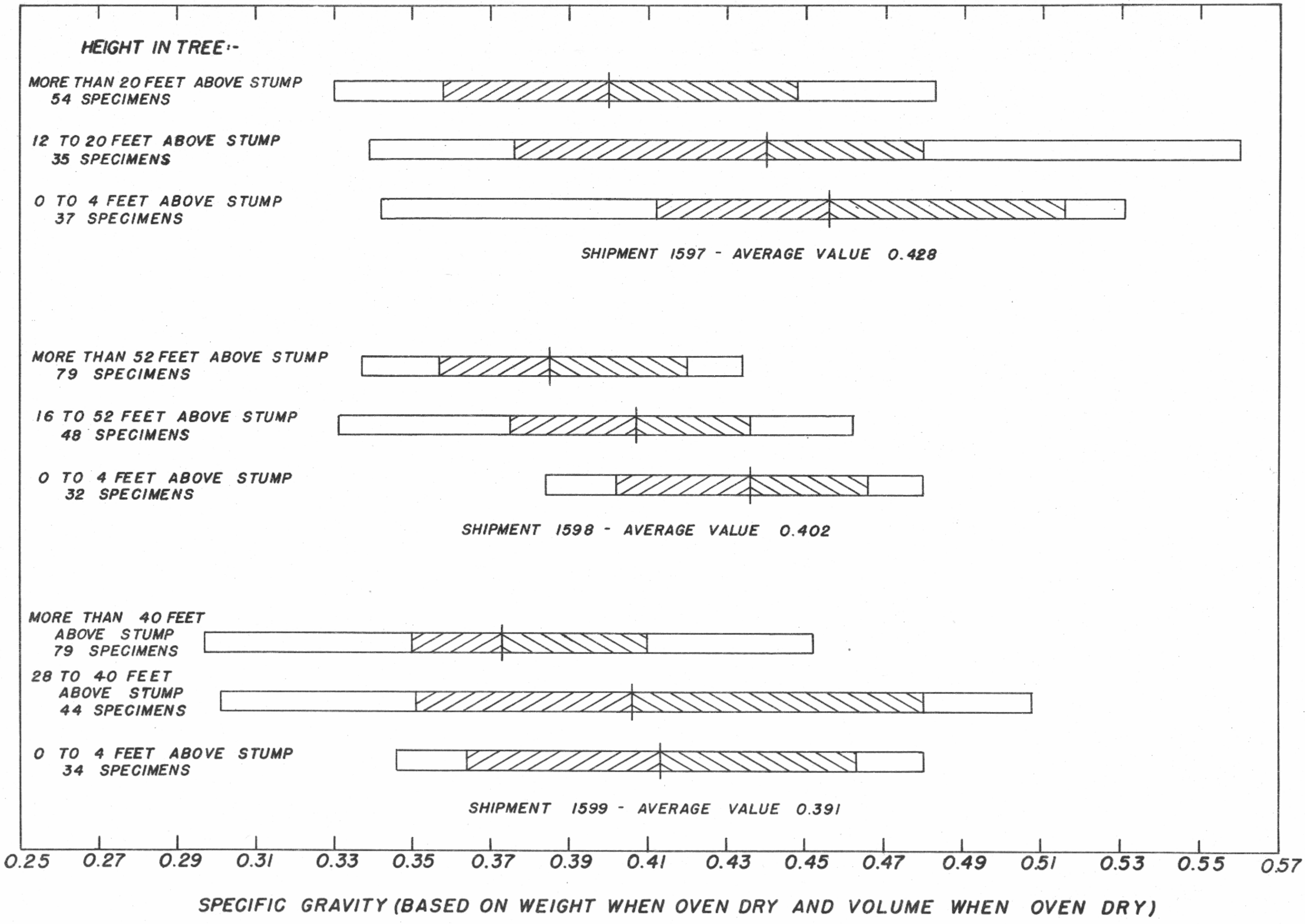
Shipment No.	Type of wood	Number of specimens: Specific gravity	Number of specimens: Longitudinal shrinkage	Average specific gravity based on ovendry weight and--: Green volume	Average specific gravity based on ovendry weight and--: Ovendry volume	Average longitudinal shrinkage[1]
						Percent
1597	Normal	126	130	0.374	0.428	0.146
	Compression	21	10	.396	.444	.306
1598	Normal	159	146	.352	.402	.146
	Compression	16	9	.393	.442	.396
1599	Normal	157	163	.342	.391	.152
	Compression	23	17	.378	.422	.344
Total	Normal	442	439	.355	.405	.148
	Compression	60	36	.388	.435	.347

[1] Expressed as a percent of the green dimension.



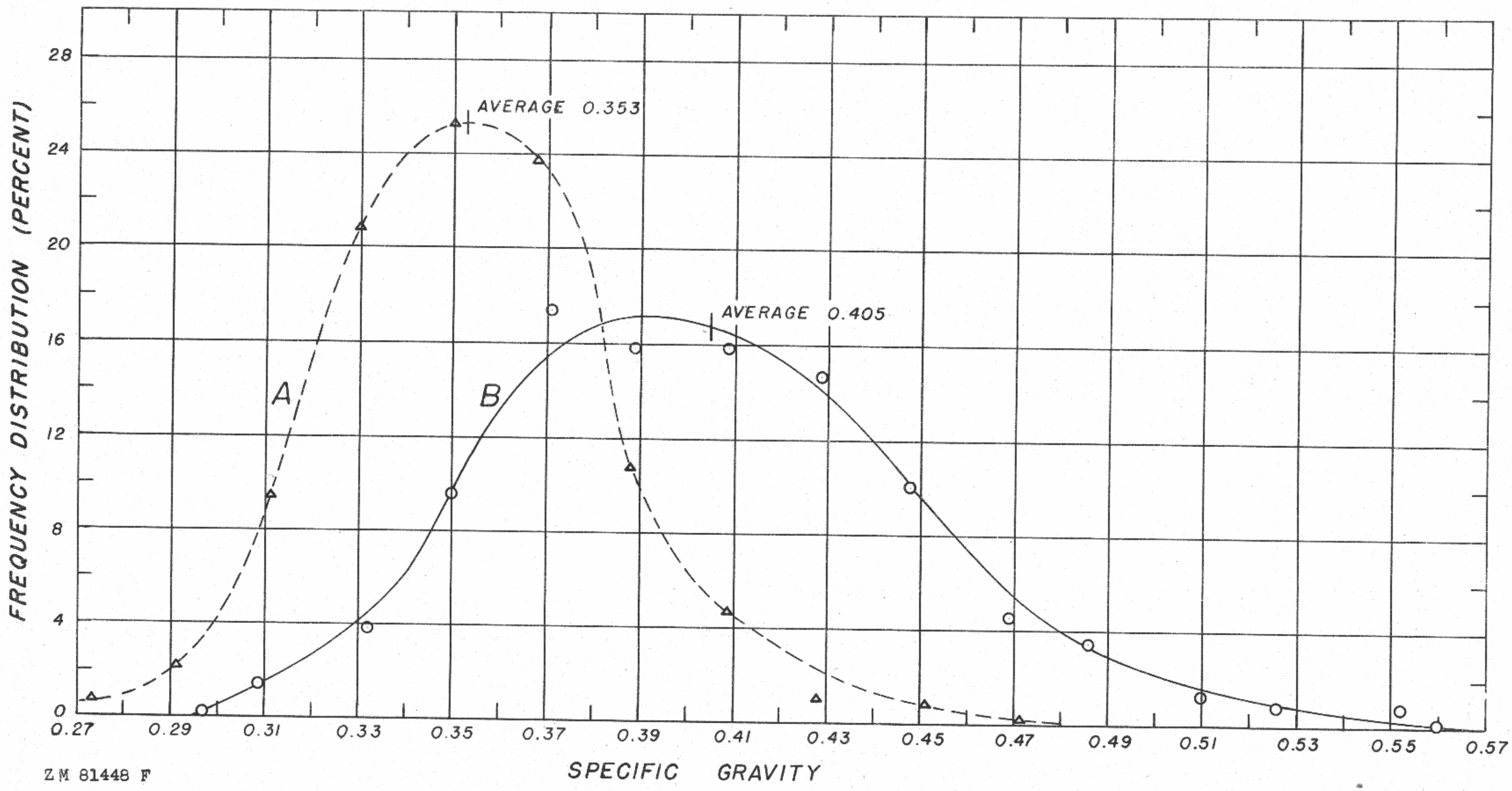
Z M 81446 F

Figure 1. --Sketch showing method of cutting blocks into sections from which various kinds of specimens were prepared.



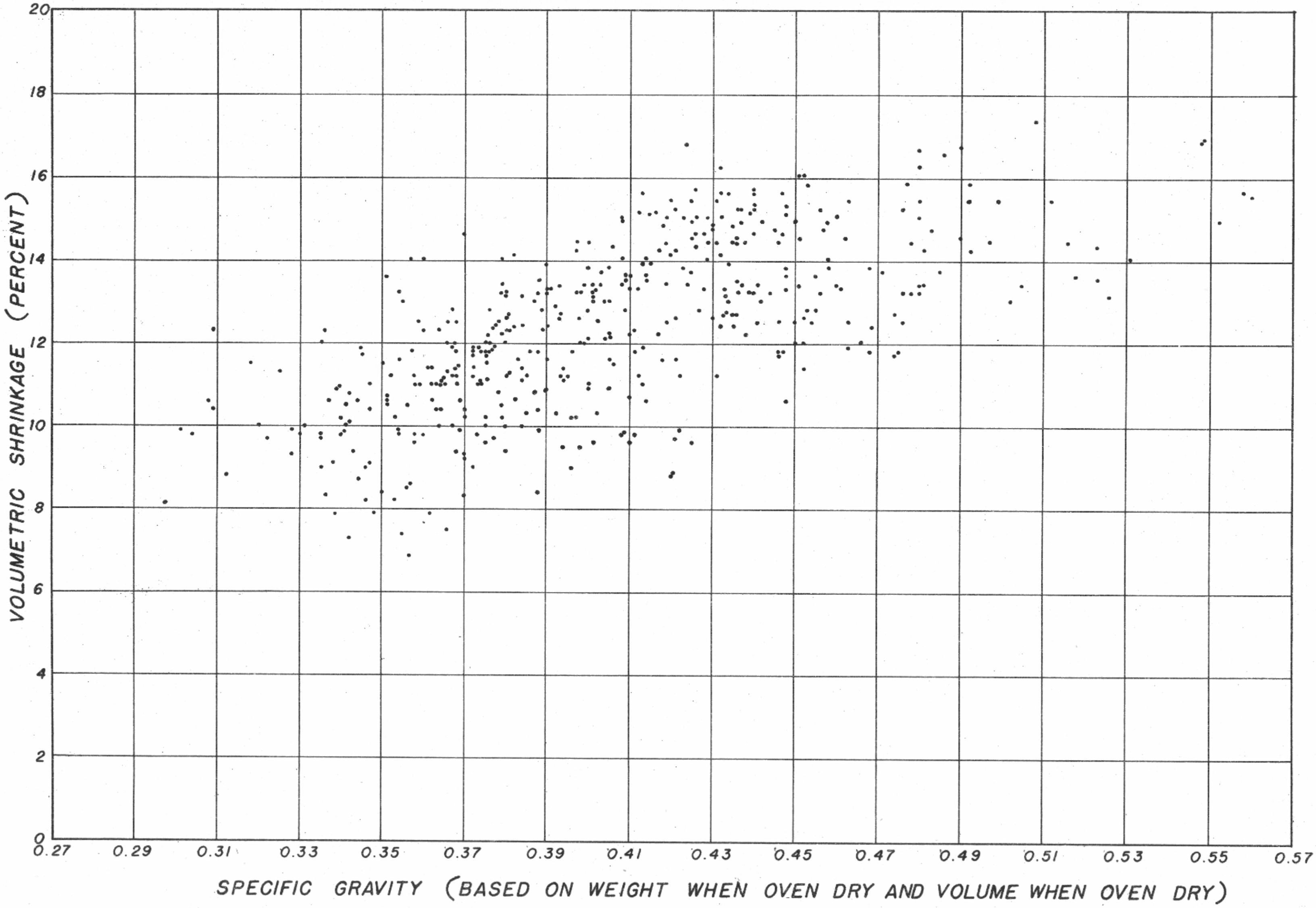
Z M 81447 F

Figure 2. --Range in specific gravity by three height groups in each of the shipments of noble fir. Shaded portions represent ranges of middle 75 percent of specimens. Short vertical lines mark average values.



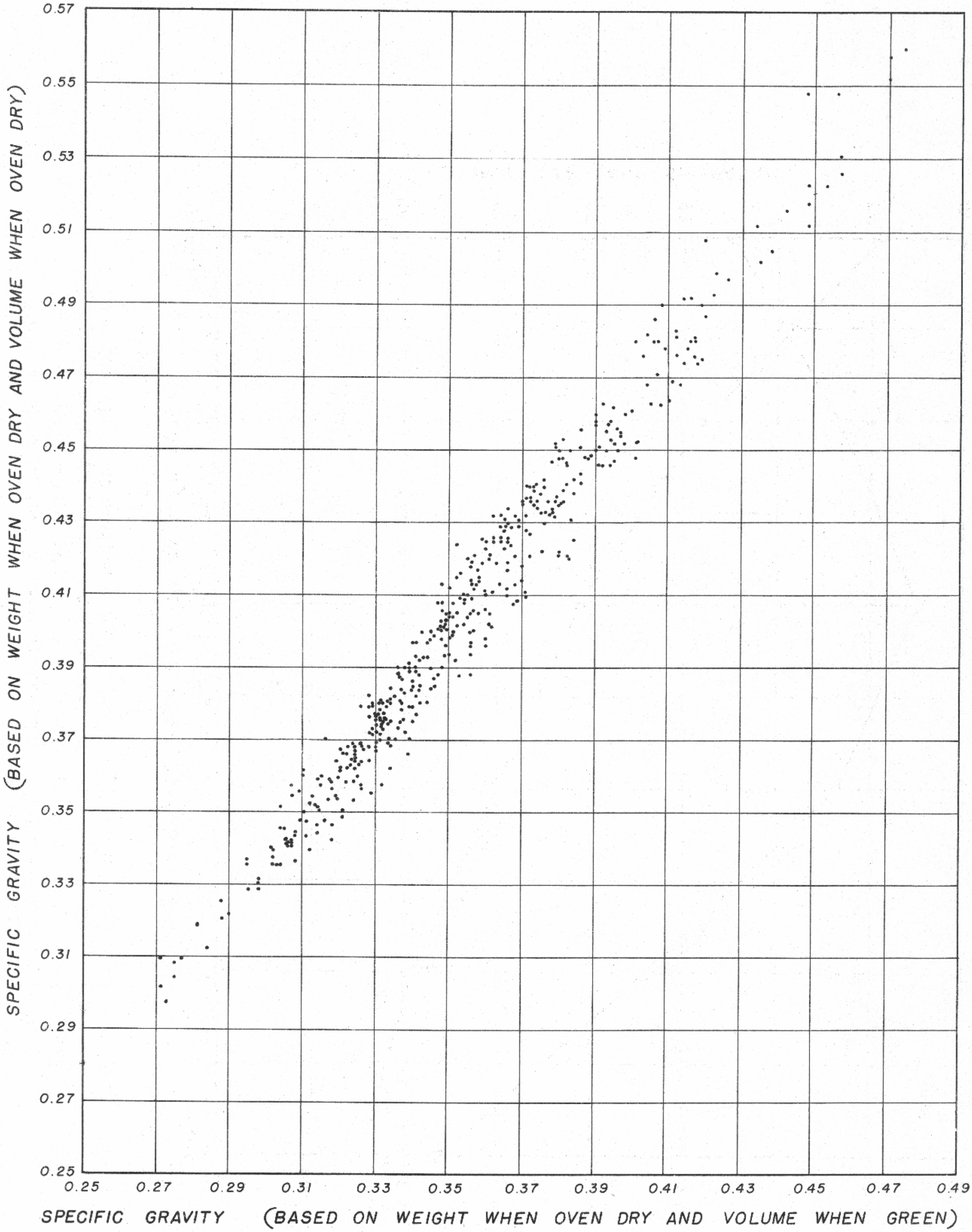
Z M 81448 F

Figure 3.--Frequency distribution showing variability in specific gravity of noble fir. Curve A was determined from 903 specimens and is based on weight when ovendry and volume when green. Curve B is based on weight when ovendry and volume when ovendry as computed from 510 specimens. Small circles and triangles represent group averages.



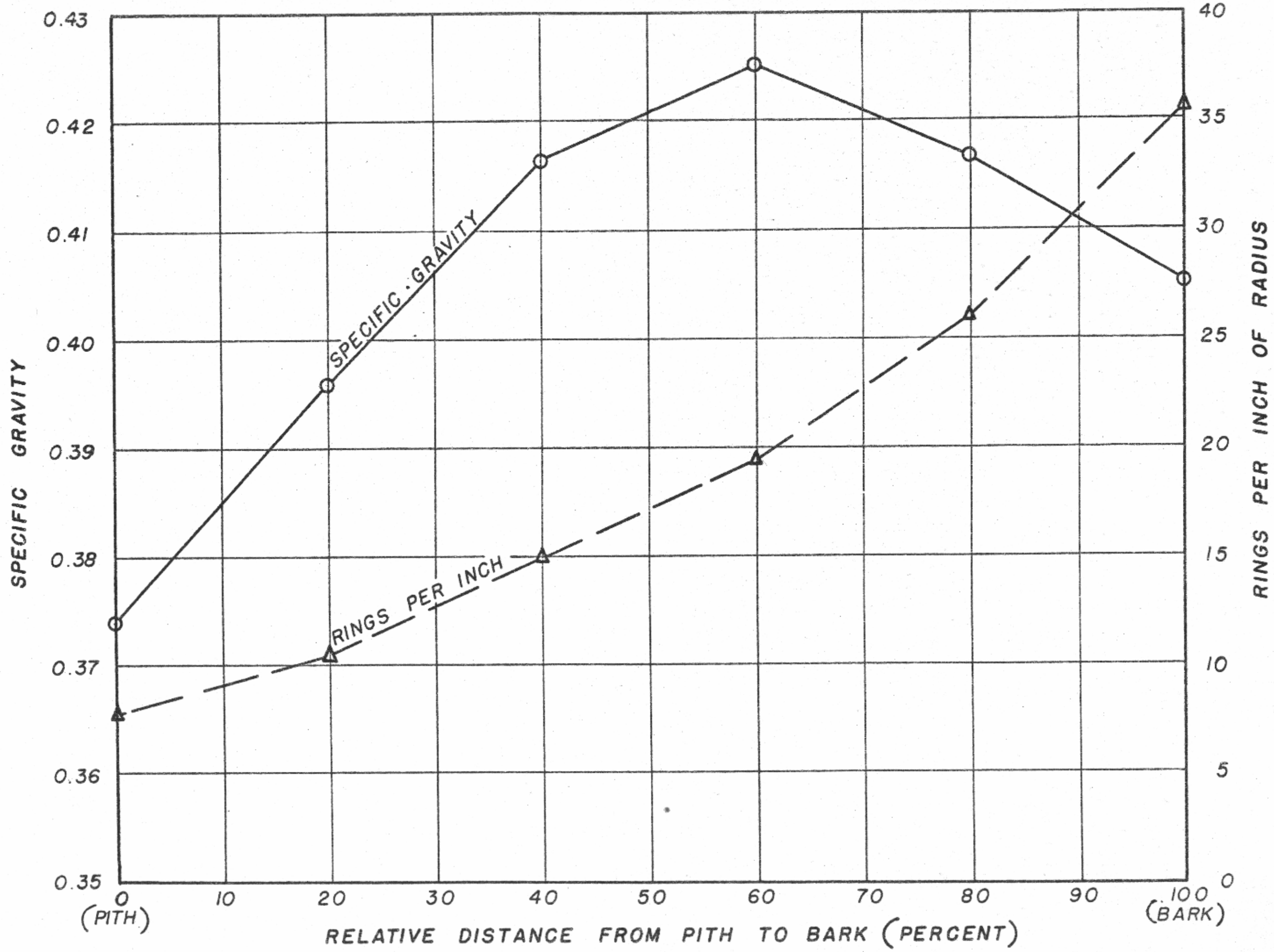
Z M 81449 F

Figure 4. --Relation between specific gravity and volumetric shrinkage of noble fir. Shrinkage values are based on dimensional change from green to ovendry condition expressed as a percentage of the green dimension. Data on 442 specimens.



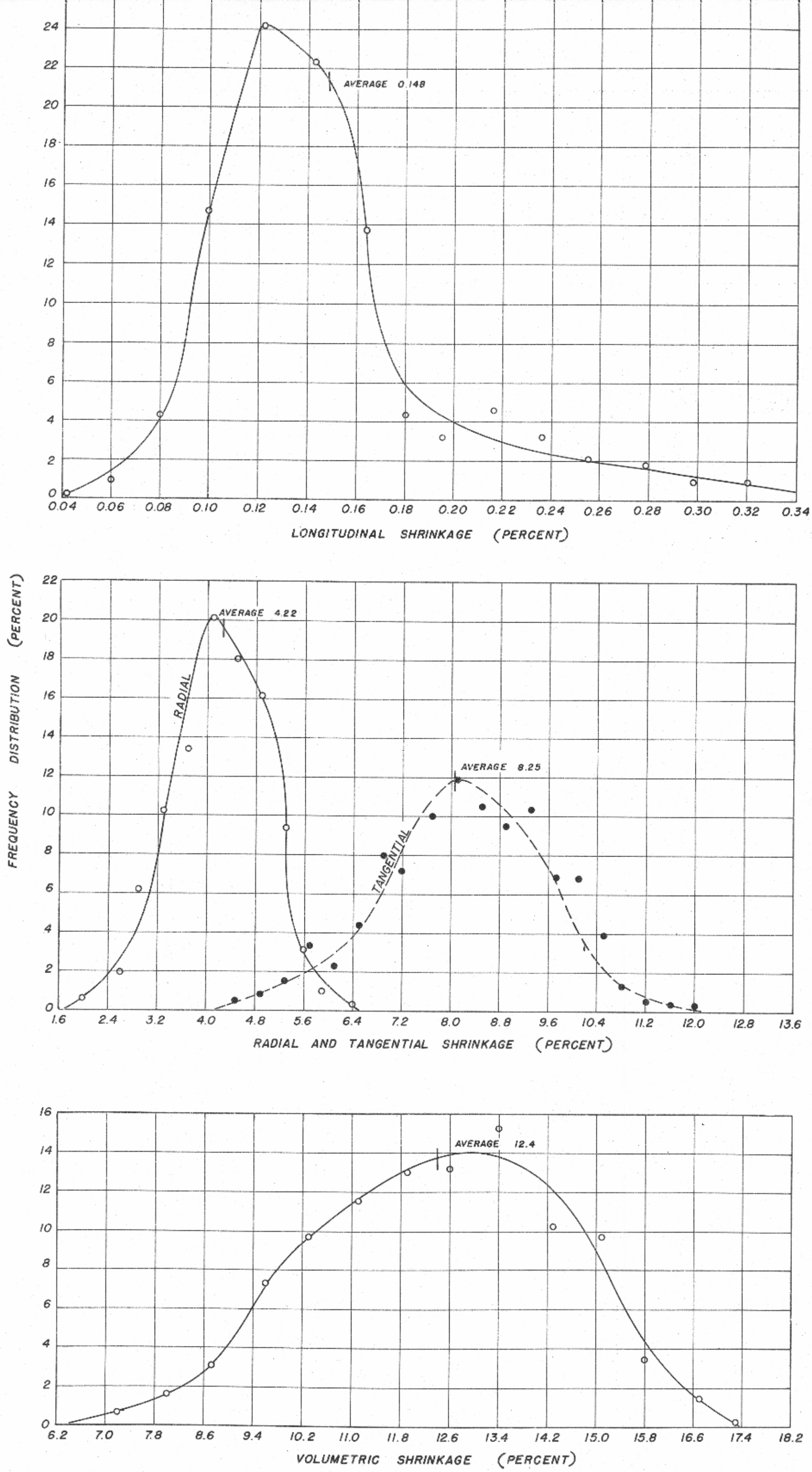
Z M 81450 F

Figure 5. --Specific gravity based on weight when ovendry and volume when ovendry compared to specific gravity based on weight when ovendry and volume when green. Data from 442 noble fir specimens in shipments 1597, 1598, and 1599.



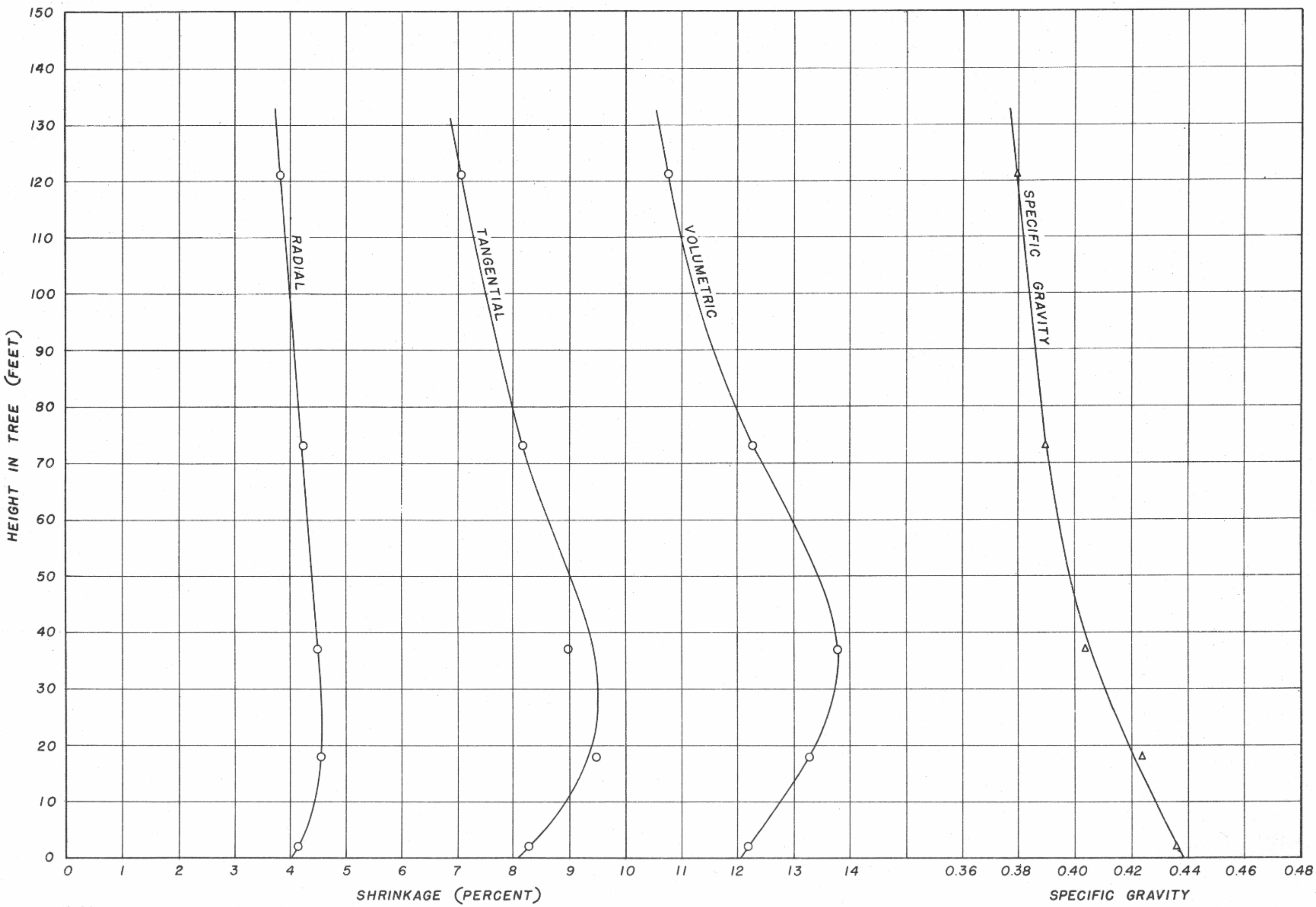
M 81451 F

Figure 6.--Variation of specific gravity and growth pattern (rings per inch) with relative location between pith and bark for noble fir at all heights investigated. Specific gravity based on weight and volume when ovendry. Small circles and triangles represent group averages. Data from shipments 1597, 1598, and 1599.



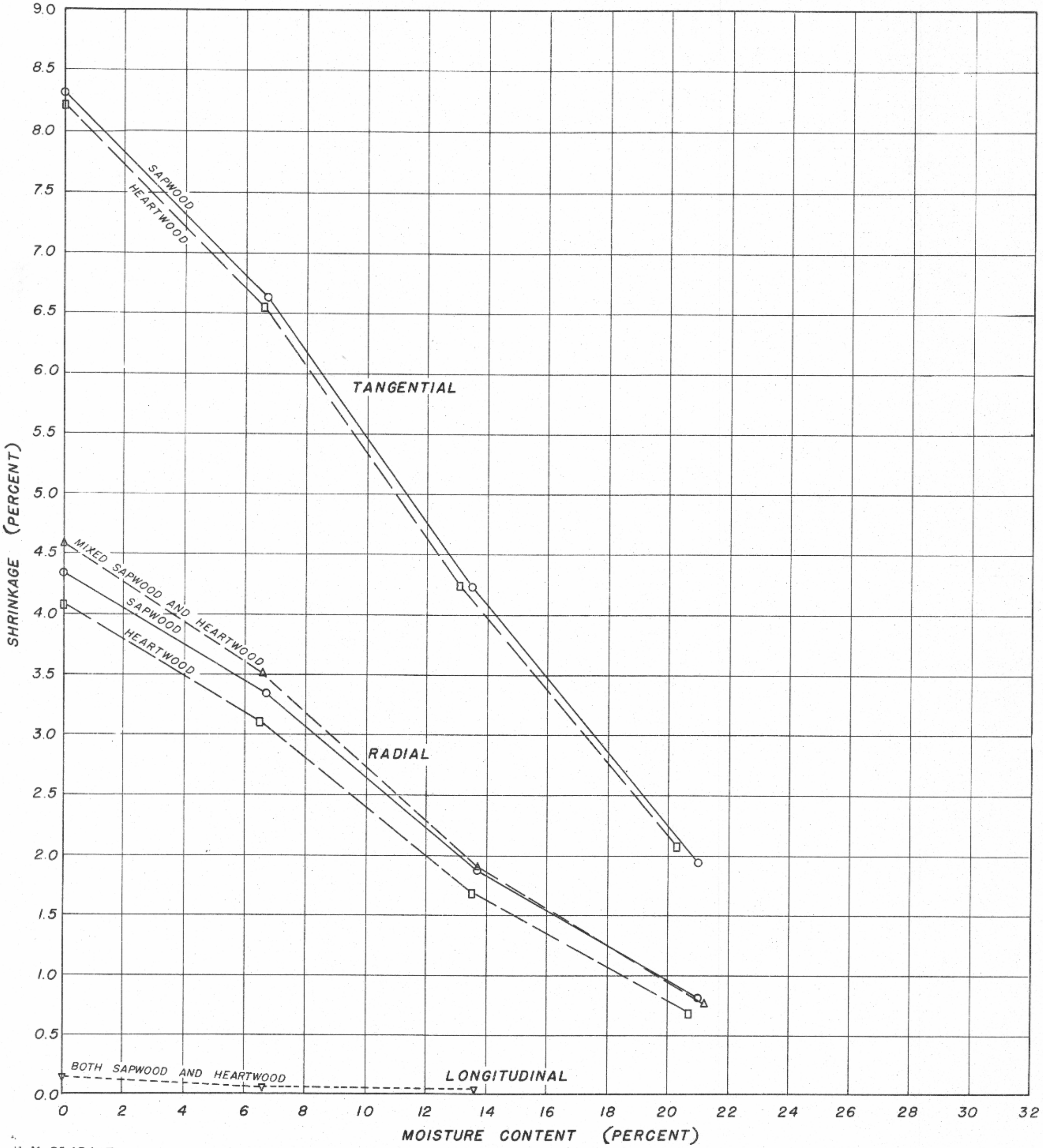
Z M 81452 F

Figure 7. --Frequency distribution for longitudinal, radial, tangential, and volumetric shrinkage. Shrinkage values are based on dimensional change from green to oven-dry condition expressed as a percentage of the green dimension. Shrinkage curves based on 439, 323, 389,



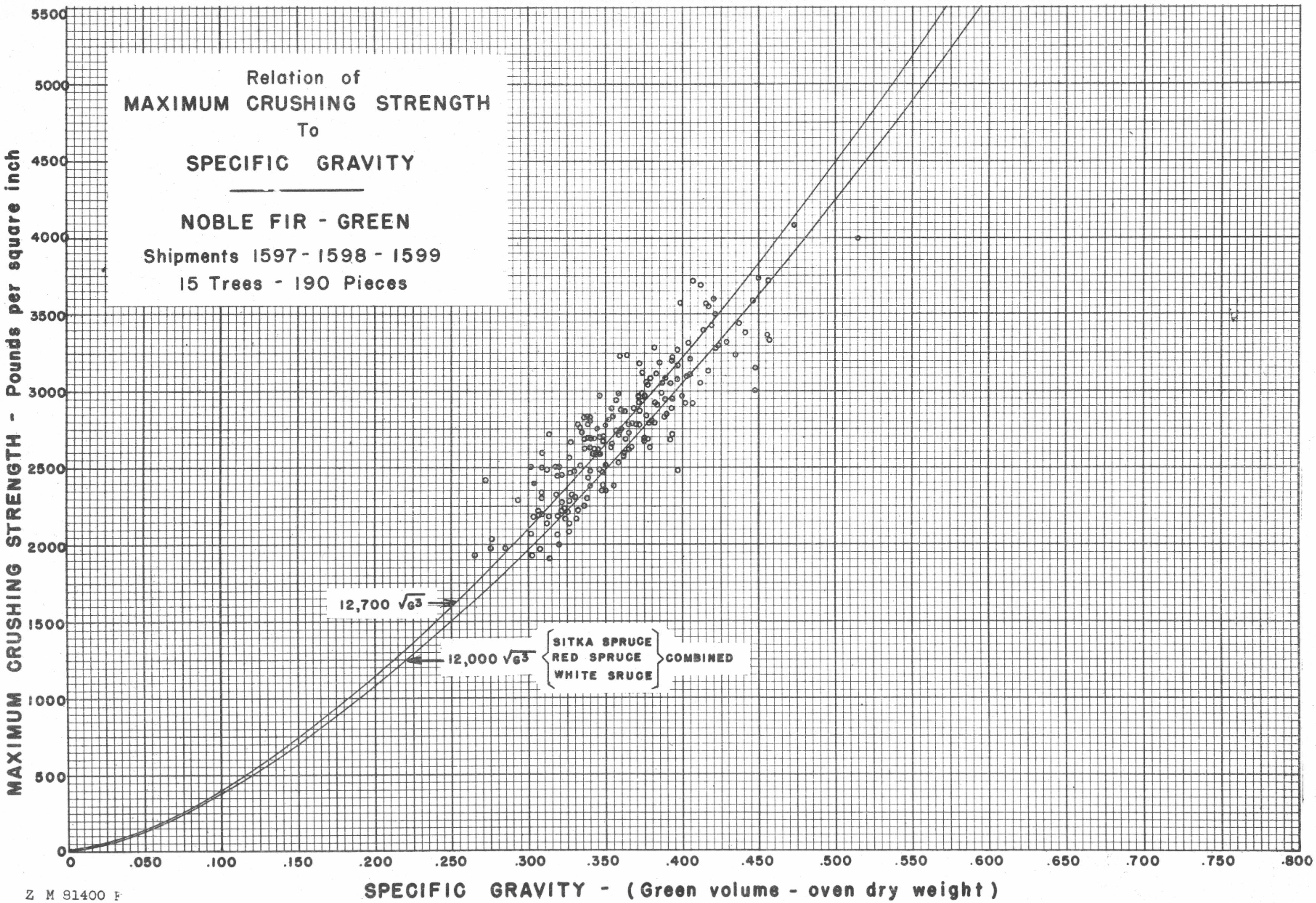
Z M 81453 F

Figure 8. --Effect of height in tree on specific gravity and shrinkage of noble fir. Small circles and triangles represent group averages. Data from shipments 1597, 1598, and 1599.



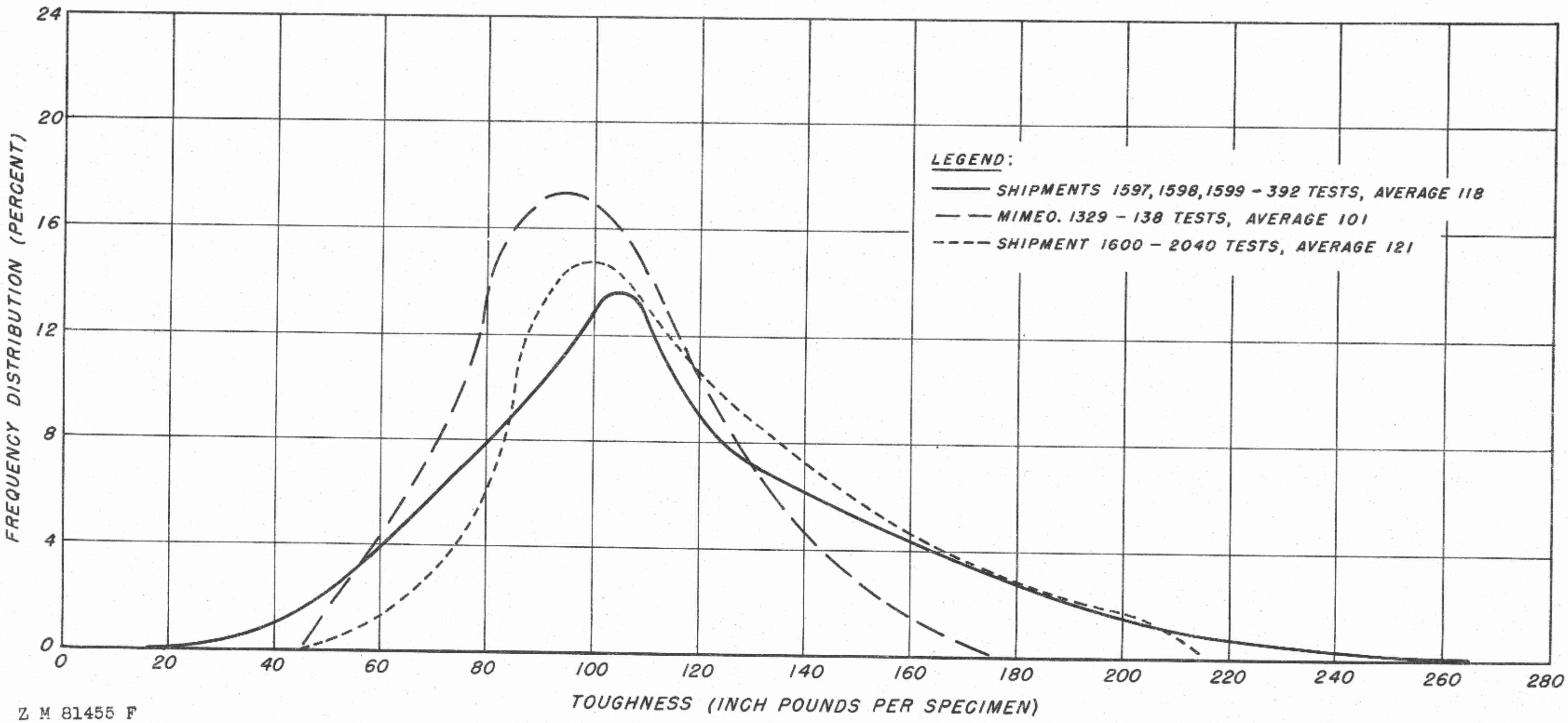
Z M 81454 F

Figure 9.--Variation in tangential, radial, and longitudinal shrinkage of noble fir with moisture content.



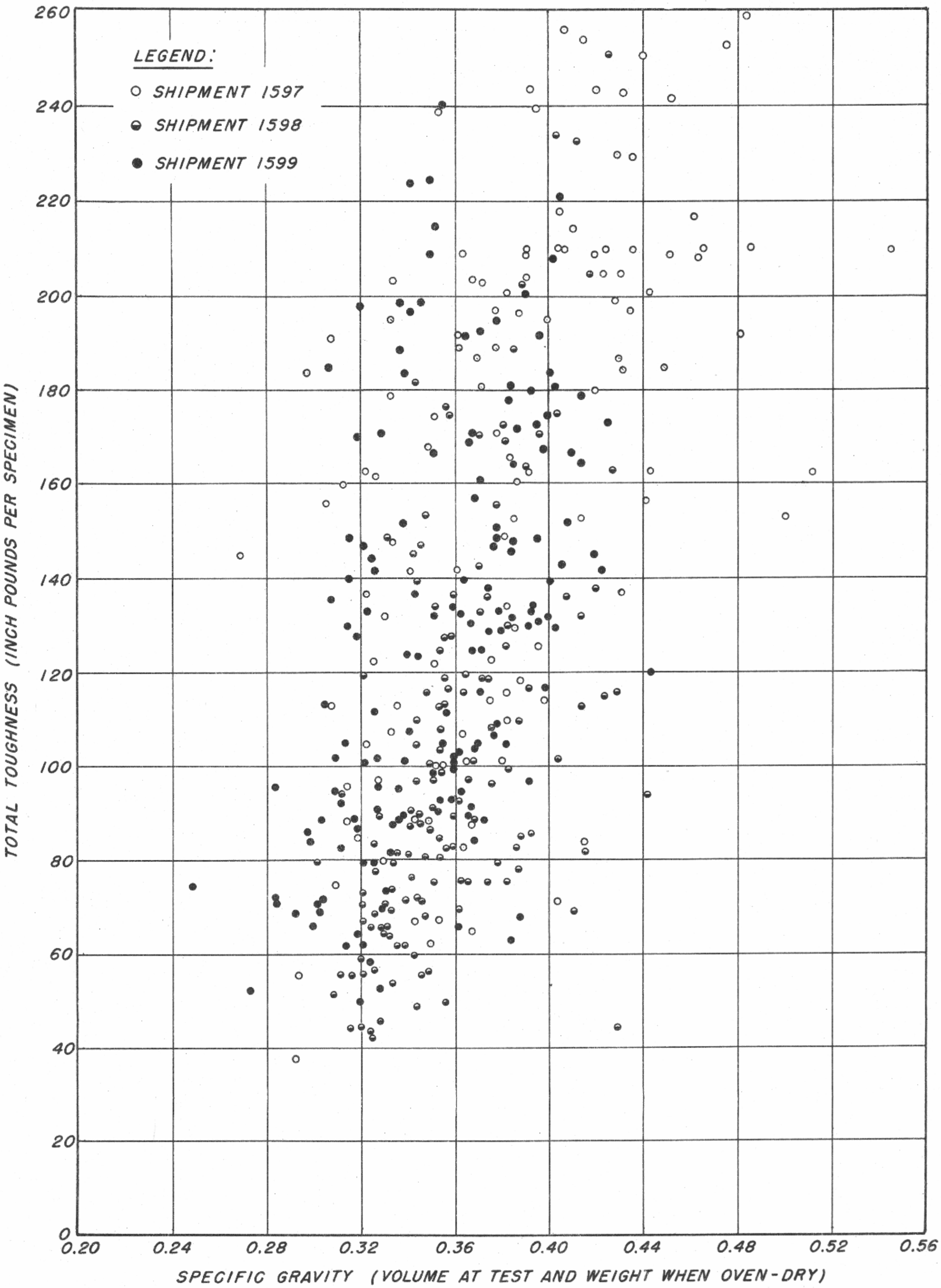
Z M 81400 F

Figure 10. --Relation of maximum crushing strength to specific gravity for individual specimens of green noble fir. An average curve, determined by the method of least squares, is shown for noble fir and, for comparison, a similar curve is shown also for spruce.



Z M 81455 F

Figure 11.--Approximate frequency distribution curves for toughness of noble fir at about 12 percent moisture content.



Z M 81456 F

Figure 12. --Toughness of individual specimens of green noble fir plotted against specific gravity.

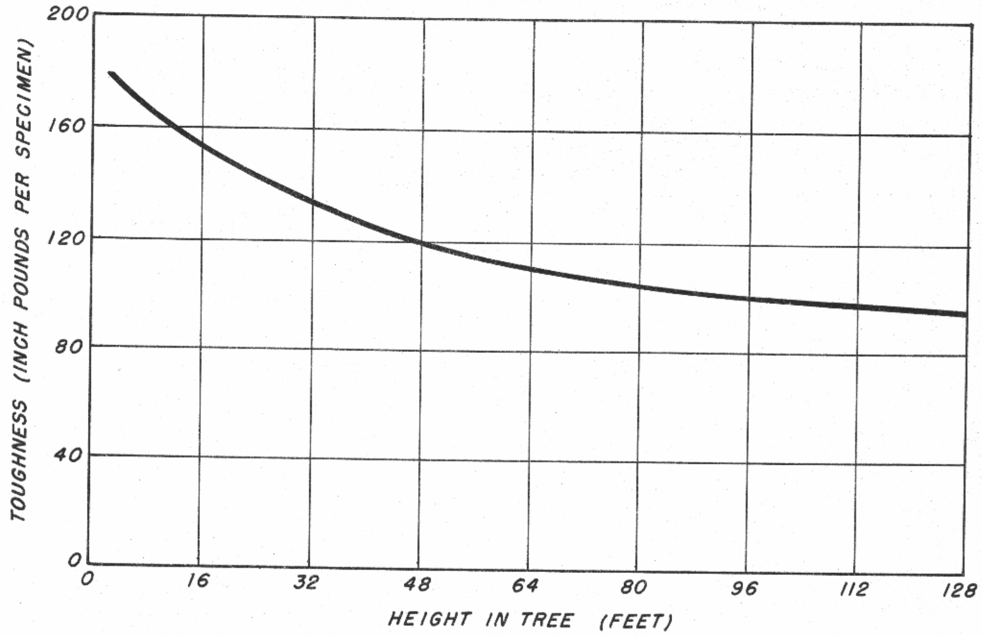
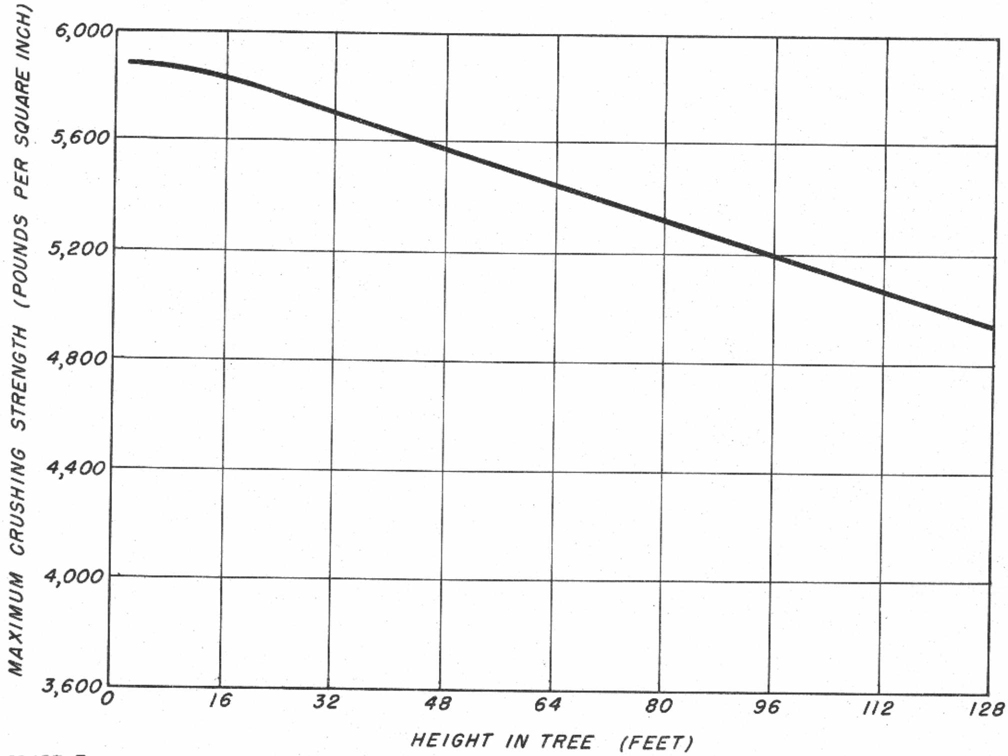


Figure 13.--Variation of toughness with height in tree for green noble fir.



Z M 81457 F

Figure 14.--Variation of maximum crushing strength in compression parallel to grain with height in tree for noble fir at about 12 percent moisture content.

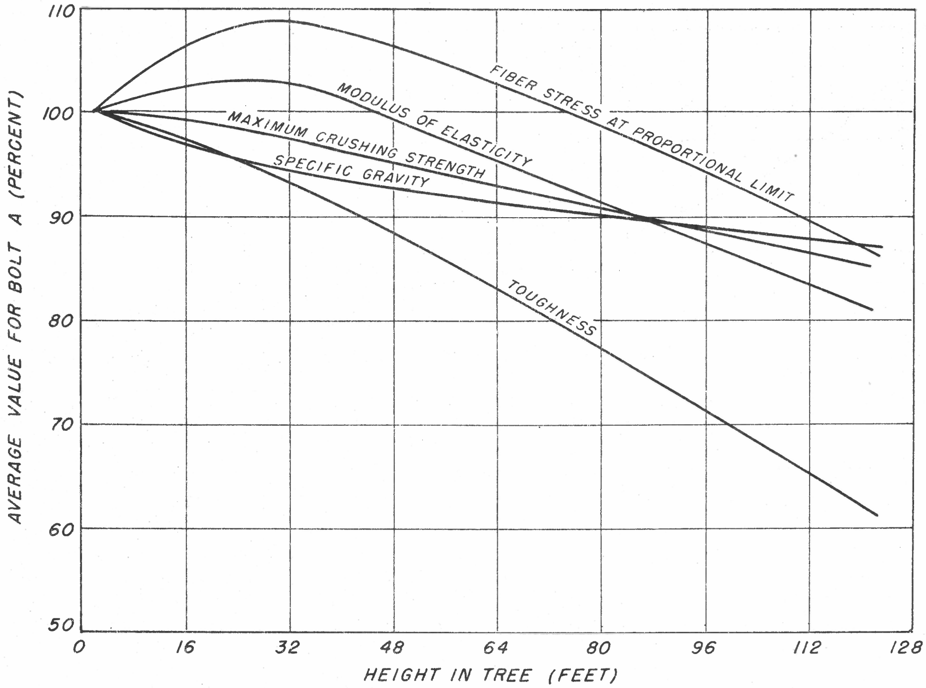
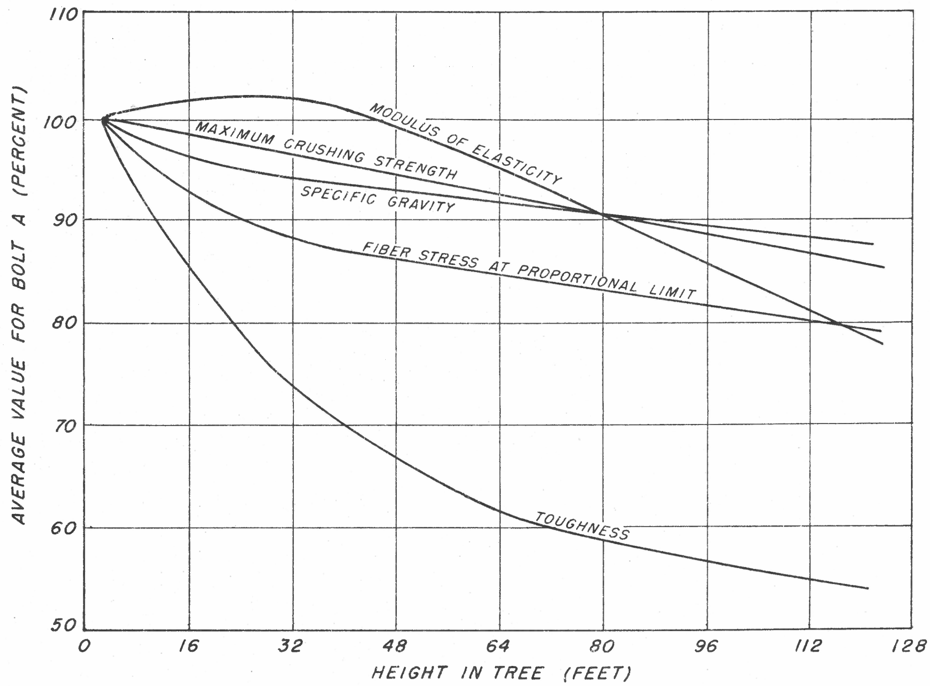


Figure 15.--Average variation with height in tree for specific gravity, toughness and compression parallel-to-grain properties of noble fir at about 12 percent moisture content.



Z M 81458 F

Figure 16.--Average variation with height in tree for specific gravity, toughness, and compression parallel-to-grain properties of green noble fir.