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U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—BULLETIN 88.

HENRY S. GRAVES, Forester.

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PROPERTIES AND USES OF DOUGLAS FIR.

PART I. MECHANICAL PROPERTIES.
PART II. COMMERCIAL USES.

BY

McGARVEY CLINE, Director, Forest Products Laboratory,

AND

J. B. KNAPP, Assistant District Forester.

1862 1889

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LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Forest Service,
Washington, D. C. January 16, 1911.

Sir: I have the honor to transmit a manuscript entitled "Properties and Uses of Douglas Fir," by McGarvey Cline, Director of the Forest Products Laboratory, and J. B. Knapp, Assistant District Forester, and to recommend its publication as Bulletin 88 of the Forest Service. The 3 plates and 15 diagrams which accompany the manuscript are necessary for its proper illustration.

Respectfully,

Henry S. Graves, *Forester.*

Hon. James Wilson,
Secretary of Agriculture.

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PROPERTIES AND USES OF DOUGLAS FIR.

INTRODUCTION.

It is the purpose of this bulletin to present the facts about the mechanical properties and uses of Douglas fir which have been collected by the Forest Service. Part I, which deals with the mechanical properties of Douglas fir, is based on an exhaustive series of tests made in the laboratories of the Forest Service. The results of these tests are of special interest to the users of structural timber. Part II, which deals with the commercial uses of the timber, is based on information furnished by lumber manufacturers and other industrial concerns that use Douglas fir. The gathered facts are of interest in that they show the wide utilization of this tree.

Since 1903 the Forest Service has been making a comprehensive series of tests to determine the mechanical properties of the commercial woods of the United States. The work has been done at laboratories conducted in cooperation with the Yale Forest School, New Haven, Conn.; Purdue University, Lafayette, Ind.; the University of Colorado, Boulder, Colo.; University of California, Berkeley, Cal.; the University of Washington, Seattle, Wash.; and the University of Oregon, Eugene, Oreg. General summaries of the results secured have been published in Forest Service Circulars 32 and 115, "Progress Reports on the Strength of Structural Timber," and from time to time other circulars dealing with particular series of tests have been issued.

The tests on Douglas fir were made at the Oregon and California laboratories; the material was cut in Lane County, Oreg., and was contributed by the Pacific Coast Lumber Manufacturers' Association and by the Oregon and Washington Lumber Manufacturers' Association. For the information contained in Part II the Service is indebted to many manufacturers and users of Douglas fir, and especially to the officers of the Oregon, Washington, and Pacific coast lumber manufacturers' associations, for their cordial cooperation.

Douglas fir may, perhaps, be considered as the most important of American woods. Though in point of production it ranks second to southern yellow pine, its rapid growth in the Pacific coast forests, its comparatively wide distribution, and the great variety of uses to which its wood can be put place it first. Estimates of the available supply range from 300,000,000,000 to 350,000,000,000 feet board measure. It is very extensively used in the building trades; by the railroads in the form of ties, piling, car, and bridge material; and by many of the manufacturing industries of the country. As a structural timber it is not surpassed, and probably it is most widely used and known in this capacity.

The species is most abundant and attains its largest size not far above the sea level in southern British Columbia and in the region between the coast of Washington and Oregon and the western foothills of the Cascade Mountains. (See Diagram 1, map.) Here large trees crowded close together rise to a height of from 200 to 300 feet, forming, either alone or mixed with hemlock, very dense forests that yield from 35,000 to 60,000 board feet per acre and sometimes as much as 100,000, and in one recorded instance 500,000 feet.[1]

The wood is strong and hard, not very heavy, and fairly durable. These qualities particularly recommend it for structural purposes. The grain is straight. The spring and summer wood vary greatly in density; the spring growth is soft and spongy and almost white in color, while the summerwood is hard and flinty and very dark. The grain varies from as few as four or five rings to the radial inch to as many as forty-five.

In the eastern part of its range in the Rocky Mountain region, where the rainfall is not abundant and where extremes of climate occur, the trees are much smaller, rarely over 1½ feet in diameter and over 90 feet high. In this section the stand ranges from 2,000 to 8,000 board feet per acre.[2]

Douglas fir is known by various names in different sections of the country. The most common names and the States in which they are used are:

Douglas fir (Utah, Oregon, Colorado, Washington).
Red fir (Oregon, Washington, Idaho, Utah, Montana, Colorado).
Douglas spruce (California, Colorado, Montana).
Yellow fir (Oregon, Montana, Idaho, Washington).
Spruce (Montana).
Oregon pine (California, Washington, Oregon).
Fir (Montana).
Red pine (Utah, Idaho, Colorado).
Puget Sound pine (Washington).
Douglas tree.
Cork-barked Douglas spruce.

The name Douglas fir has been adopted by the Forest Service and by various trade and technical associations, and is coming into general commercial use.

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[1] Transactions of the Royal English Arboricultural Society, Vol. VI, p. 228.

[2] For a comparison of the Rocky Mountain and Pacific coast forms of Douglas fir see Forest Service Circular 150 Douglas Fir, by E. H. Frothingham.

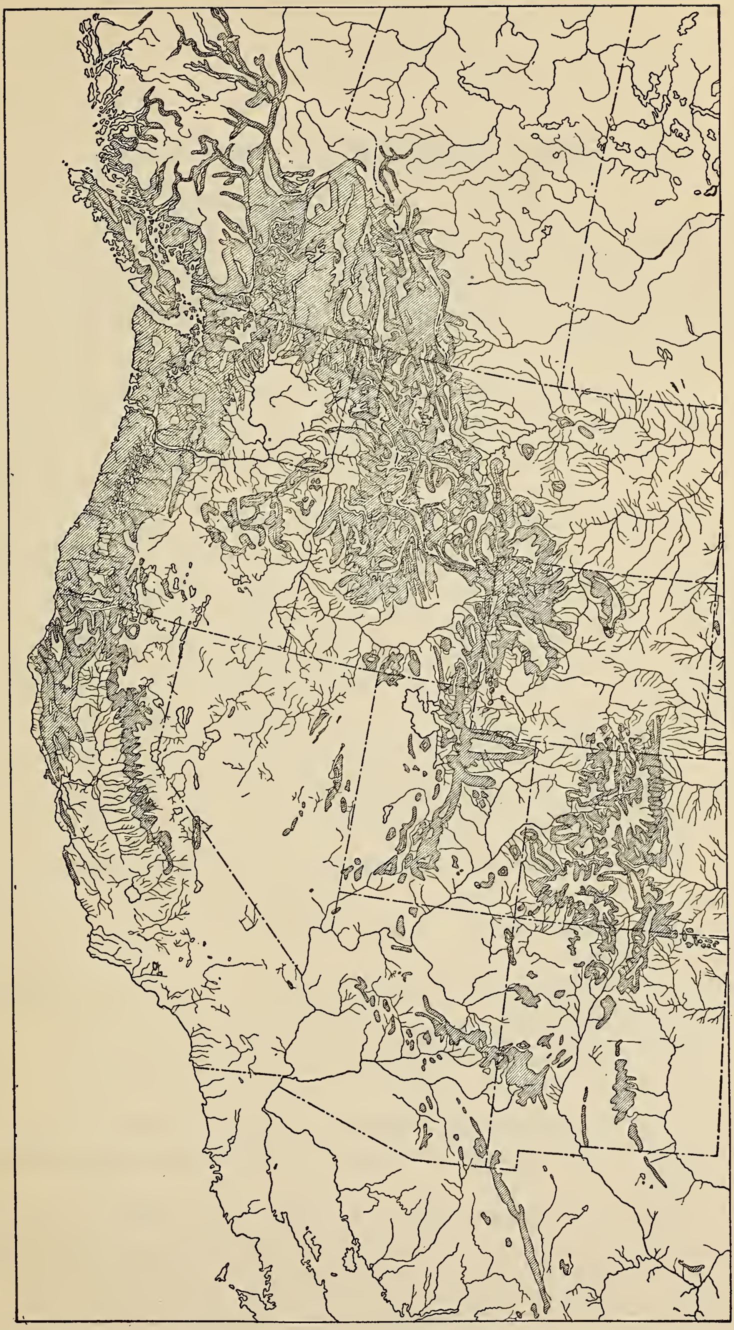

Diagram 1.—General range of Douglas fir.

PART I.—MECHANICAL PROPERTIES.

GENERAL RESULTS OF TESTS.

1. Tests on 8″ x 16″ x 16′ bridge stringers gave the following average stresses.[1] The likelihood of variations from these averages, due to defects in the timber and to other causes, is discussed under separate headings.

TABLE 1.—*Results of tests on green Douglas fir bridge stringers.*

	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
	Lbs. per sq. in.	*Lbs. per sq. in.*	*1,000 lbs per sq. in.*
Selects:			
Green	4,346	6,753	1,654
Air-dry	4,690	7,070	1,644
Merchantable:			
Green	3,895	5,878	1,481
Air-dry	4,625	6,472	1,567
Seconds:			
Green	3,538	5,188	1,328
Air-dry	3,740	4,551	1,280
All grades:			
Green	4,000	6,000	1,510
Air-dry	4,467	6,327	1,540

The properties of green material as derived from tests on small pieces free from defects are as follows:

TABLE 2.—*Results of tests on small clear pieces of green Douglas fir.*

	Pounds per sq. in.
Bending:	
Fiber stress at elastic limit	5,500
Modulus of rupture	8,400
Modulus of elasticity	1,600,000
Compression parallel to grain:	
Crushing strength at elastic limit	3,600
Crushing strength modulus of elasticity	4,100
Shearing	770

By careful air-seasoning to a moisture content as low as 15 per cent the strength of small clear specimens may be increased approximately 35 per cent.

2. Douglas fir varies greatly in quality, the different strength functions ranging in value 50 per cent above and below the averages

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[1] The material upon which the tests discussed in this bulletin were made was grouped according to the export grading rules of the Pacific Coast Lumber Manufacturers' Association into the grades of select, merchantable, and seconds.

quoted. The manner in which the tests are grouped between these limits is shown in diagrams 2 and 3, pages 20 and 21.

3. The analyses of the results to determine the relations existing between physical characteristics and mechanical properties of the wood show—

(*a*) That so-called red and yellow fir have practically the same strength; the yellow fir, however, contains fewer defects and is much more uniform in rate of growth.

(*b*) The mechanical strength varies directly with dry weight; that is, the heavier the wood the greater is its mechanical strength. The average oven-dry weight of Douglas fir is 28.8 pounds per cubic foot; the average weight of the green material is, approximately, 38.4 pounds per cubic foot; and the average weight of thoroughly air-seasoned material is, approximately, 33.1 pounds per cubic foot.

(*c*) The greatest strength of Douglas fir is most frequently associated with the rate of growth between 12 and 16 rings per radial inch.

(*d*) Knots and cross grains are the most significant factors in grading Douglas fir in structural sizes. The size and position of knots and the condition of the wood around them should be considered in judging their effect on the mechanical properties of the wood. The presence of knots appreciably decreases the strength of green Douglas fir in compression parallel to grain; the decrease is 22 per cent with knots greater than 1½ inches in diameter; 14 per cent with knots less than 1½ inches and greater than one-half inch; and 6 per cent in knots one-half inch in diameter or less. The decrease in compression strength at the elastic limit is 22 per cent, 13 per cent and 5 per cent, respectively. (See Table 6.) In beams the presence of knots affects most the modulus of rupture; the fiber stress at the elastic limit and the modulus of elasticity apparently are more dependent upon the quality of the wood, and are much less influenced by such defects.

4. The tendency of specifications for Douglas fir in structural sizes is toward too great severity. The efforts to secure high-grade material generally result in throwing out much material of high structural merit. The specifications adopted by the American Society for Testing Materials and the American Railway Engineering and Maintenance of Way Association in a slightly modified form appear to be the most effective yet devised. In framing specifications, in addition to the points already brought out, the following general conclusions are of interest:

(*a*) Sound knots 1 inch or less in diameter which do not cause a marked disturbance in the grain should not be regarded as defects in structural timber.

(*b*) Sound knots larger than one inch in diameter should not be regarded as defects when they occur on the vertical faces and at a distance from the edge equal to at least one-fourth the height of the piece.

(*c*) Knots and cross grains which interrupt the continuity of the grain within 2 inches of the edge should not be allowed except in the lowest grade.

(*d*) Diagonal grain, due to sawing, that has a slant greater than 1 inch in 45 should not be allowed in the higher grades.

5. Douglas fir dimension stock seasons rapidly on the Pacific coast between April and October; in three months the loss of weight in 8″ x 16″ x 16′ pieces is approximately 40 pounds out of a possible 60 pounds. During the subsequent rainy season timbers cease to lose weight, but during the second summer they reach a thoroughly air-dry condition.

METHODS OF TEST.

The wide use of Douglas fir as a structural material; that is, for purposes where the size of the pieces is determined to some extent by the magnitude of the forces acting upon it, makes its mechanical properties of unusual interest. A knowledge of these mechanical properties, by which the material is able to resist the action of deforming forces, can readily be secured by subjecting the material to tests in which the forces acting upon it can be measured.

The tests made on Douglas fir may be divided into two general classes:

Class 1.

Tests on bridge stringers and car sills containing knots, checks, and other defects ordinarily encountered in such material purchased in the open market. The car sills were 5 by 8 inches in cross section and the bridge stringers 8 by 16 inches in cross section. Both were tested over a 15-foot span. The purpose of these tests was to secure moduli for design and to determine the influence on the strength of structural timbers of knots, checks, and other defects that distinguish one grade of material from another, and also to determine the influence of seasoning on the strength of structural timber.

Class 2.

Tests on small-sized specimens free from defects, such as knots, checks, etc. The purpose of these tests was to study the influence of such factors as rate of growth, per cent of summerwood, and moisture content on the strength of wood. Such factors can not be studied when the results of the tests are greatly influenced by the presence of defects which commonly occur in large pieces. These tests are also useful in showing the relation existing between the properties of specimens free from defects and those containing knots, checks, cross grains, etc.

The tests were made in a universal testing machine. Plate I, figure 2, shows a machine of this type rigged for testing a piece of wood in compression parallel to grain. The machine essentially consists of two parts, a high-capacity weighing scale and a screw press. The screws which raise or lower the crosshead of this machine are rotated by means of gearing. As the crosshead is moved down upon the specimen it bears with increasing force upon it; the pressure is transmitted through the specimen to the weighing platform of the scale and then through a system of levers to a scale beam clearly shown in the illustration. The scale beam indicates the total force in pounds acting on the specimen.

The tests made may be divided into four classes:

1. Bending tests to determine the cross-breaking strength of the wood, made on both bridge stringers and car sills and on pieces 2 by 2 by 30 inches.
2. Tests to determine the strength of the wood in compression parallel to grain, made on specimen 6 by 6 by 24 inches and 2 by 2 by 8 inches.
3. Tests to ascertain the strength in compression perpendicular to grain, made on pieces 8 by 16 inches and 5 by 8 inches in cross section, taken from the bridge stringers and car sills tested.
4. Shearing tests, made on small clear specimens only.

BENDING TESTS.

Plate I, figure 1, shows the method used in the laboratories of the Forest Service for bending tests on large beams. The machines used for this purpose are provided with an extension weighing platform. The beam is placed on two "knife-edge" supports, *A A*, which rest on this platform. In a part of the tests on Douglas fir the load was applied at two points, *B B*, one-third as far apart as the distance between the knife-edge supports, as indicated in the plate. In the tests on bridge stringers, however, the load was applied at one point midway between the supports. As the head of the screw press, *C*, is moved down, the straining beam, *D*, bears with increasing force on the specimen under test. As the load increases the beam deflects. A fine wire, *E E*, kept taut by a spring, is strung between two small nails driven midway between the top and bottom faces of the beam vertically above the knife-edge supports. This wire crosses the face of a steel scale, *F*, fastened to the beam midway between the supports. As the beam deflects the scale moves down, while the wire does not change its original position. The distance the scale moves relative to the wire indicates the amount of deflection or bending. This method gives deflection to one-hundredth of an inch, which is sufficiently accurate for tests on structural sizes. A special deflectometer has been designed for measuring the deflection of small beams.[1]

Tests on beams give these important quantities: Modulus of elasticity in bending, fiber stress at elastic limit, and the modulus of rupture. The significance of these factors is generally understood by engineers and architects. An elementary discussion of them, however, may prove helpful to some readers in interpreting the results given in the various tables.

MODULUS OF ELASTICITY.

The significance of the modulus of elasticity may be best explained by supposing two beams of exactly the same dimensions under the test as shown in Plate I, figure 1. Let a load of 5,000 pounds be applied to each beam. Under this load suppose that one of the beams bends one-fourth inch and the other one-half inch. The stick which bends one-fourth inch has twice the modulus of elasticity or is twice as stiff as the other stick. The modulus of elasticity indicates stiffness, and may be defined as that quantity which measures the ability of the beam to resist bending within its elastic strength.

The allowable deflection often controls the design of a beam, and therefore stiffness has great significance. It is also an important property in other structural forms, such as columns, posts, and sills. The modulus of elasticity, which shows the stiffness of material when subjected to forces acting in compression parallel or perpendicular to grain, may also be determined. In each case, however, this factor represents the ability of the material to resist some kind of deformation or distortion.

FIBER STRESS AT ELASTIC LIMIT.

Suppose that when the load on the beam shown in Plate I, figure 1, is 5,000 pounds the deflection is one-tenth of an inch; when the load is 10,000 pounds the deflection is two-tenths of an inch; 15,000 pounds, three-tenths of an inch, and so on. As the load is applied to a beam up to a certain point, the deflection varies directly with the load, and the beam will return to its original form when the load is removed. A point is soon reached, however, when an increase in the load of 5,000 pounds will cause more than one-tenth of an inch increase in the deflection, and a set or permanent deformation will remain after the removal of the load. The load at this point indicates the elastic strength of the timber. The fiber stress at the elastic limit is proportional to this load. A load but little greater

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[1] For detailed description of methods of test see Forest Service Circular 38, Revised, Instructions to Engineers in Timber Tests.

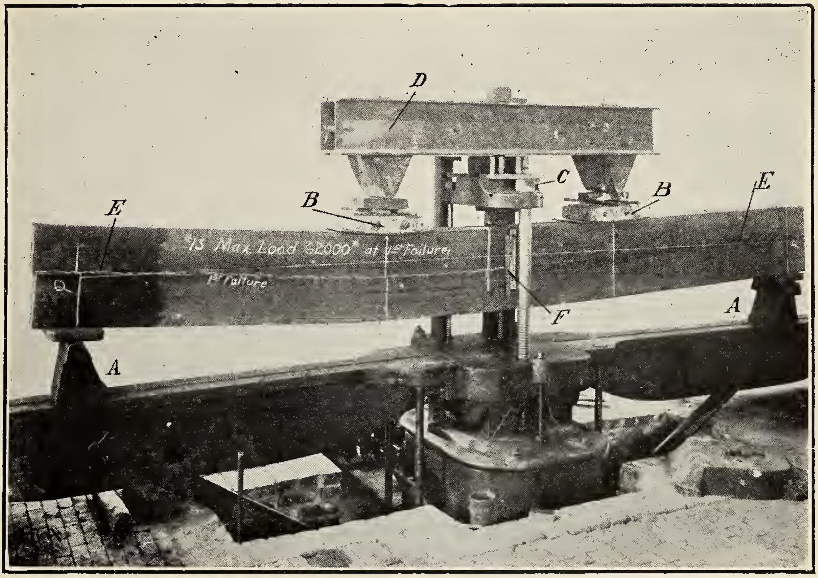


FIG. 1.—METHOD OF MAKING BENDING TESTS ON LARGE BEAMS.

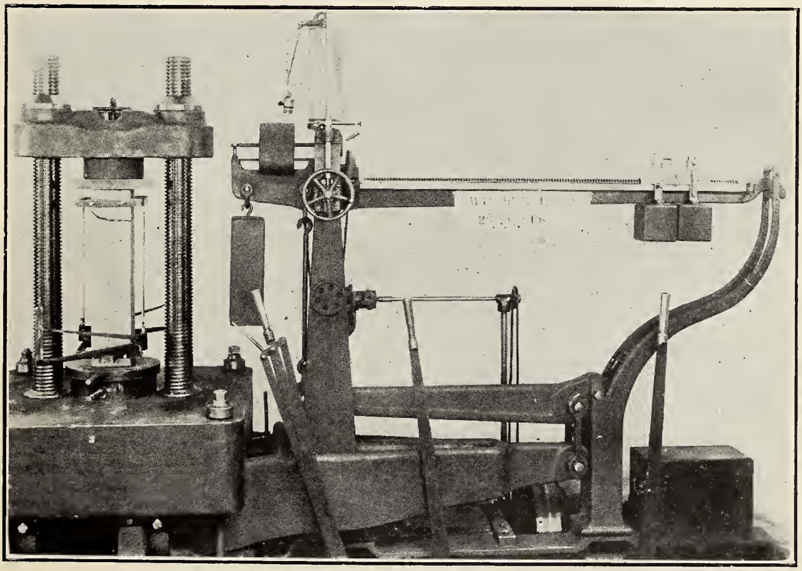


FIG. 2.—METHOD OF MAKING TESTS IN COMPRESSION PARALLEL TO GRAIN.

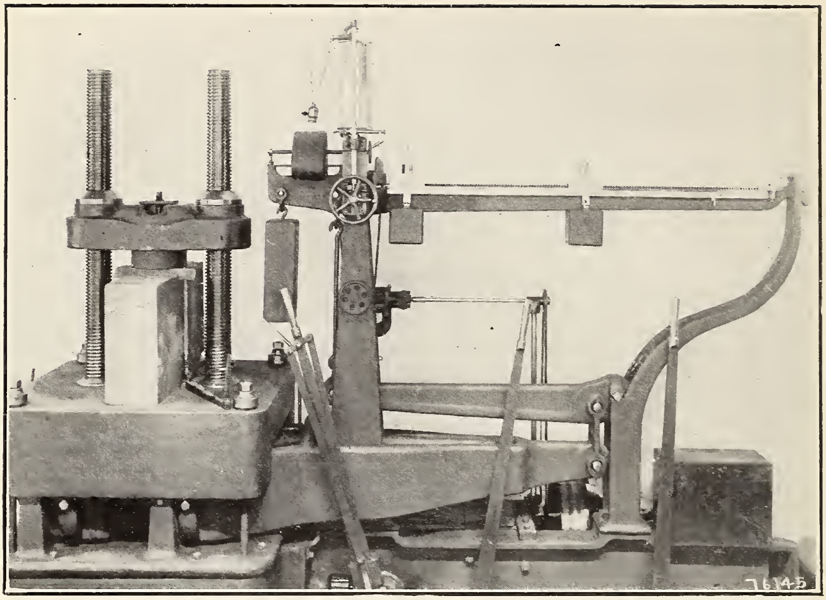


FIG. 1.—METHOD OF MAKING TESTS IN COMPRESSION PERPENDICULAR TO GRAIN.

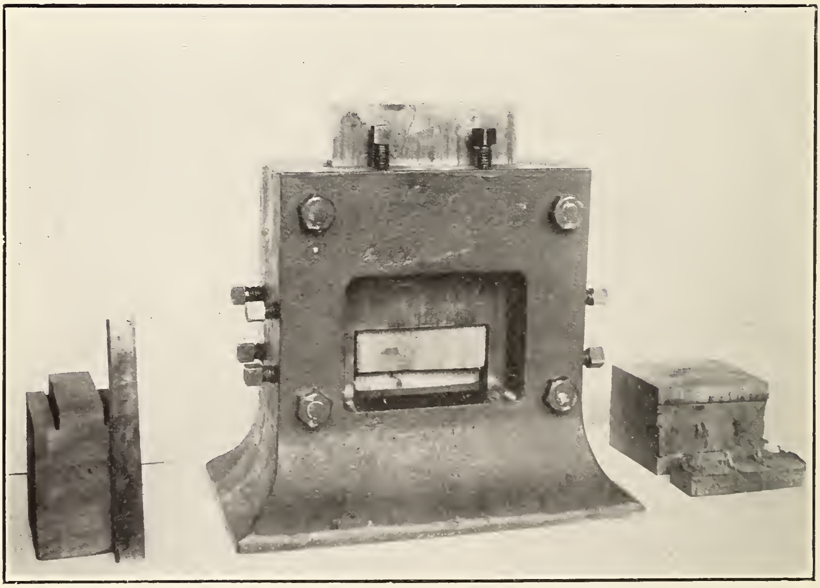


FIG. 2.—METHOD OF MAKING SHEARING TESTS.

than the elastic-limit load will continue to increase the deflection unduly if it is allowed to rest on the beam for a considerable length of time.

MODULUS OF RUPTURE.

If the load on a beam is gradually increased beyond its elastic limit the stick will ultimately break. The load causing failure represents the ultimate bending strength of the stick, and this load is proportional to the modulus of rupture.

TESTS IN COMPRESSION PARALLEL TO GRAIN.

Plate I, figure 2, shows the method of making tests in compression parallel to grain. The ends of the specimen are carefully squared, and it is then placed, with the grain vertical to the base of the machine, upon a flat block having a ball-and-socket joint which rests on the weighing table of the machine. In tests where the modulus of elasticity is desired, two yokes are placed on the specimen a specified distance apart. The load is applied by moving the crosshead down at a very slow speed. The decrease in length between the yokes is measured by means of two deflectometers, which are clearly shown in the illustration. The average of the readings given by the two deflectometers is used in plotting the stress-strain diagram, which shows the progressive relation between load and deformation during test.

Three quantities are determined from this test—the modulus of elasticity in compression parallel to grain, the fiber stress at elastic limit, and the maximum crushing strength. These quantities are analogous to the modulus of elasticity, fiber stress at elastic limit, and modulus of rupture defined under bending tests.

TESTS IN COMPRESSION PERPENDICULAR TO GRAIN.

Plate II, figure 1, illustrates the method of making a test in compression perpendicular to grain. In this test the specimen is set in place so that the grain is horizontal, or parallel to the base of the machine. A steel plate of specified width is adjusted on top of the specimen. The moving crosshead of the machine as it descends upon this plate and the amount of deformation produced by a given load is indicated by the deflectometers, which are set up as shown in the illustration. The only quantity secured from this test is the strength at the elastic limit in compression perpendicular to grain, which is the stress at which the bearing plates begin to permanently deform the wood.

SHEARING TESTS.

The method of making shearing tests used by the Forest Service is indicated in Plate II, figure 2. The block to the left shows the test specimen prepared with a projecting tongue which is to be sheared off parallel to the grain. The body of the block is held firmly in the shearing tool by means of set screws, the movable plunger bearing on the projecting tongue. When the specimen is in place the shearing tool is placed in the testing machine, and the load is applied to the specimen by means of the plunger. The block to the right shows the specimen after test. The horizontal shearing stress developed in beams was also calculated. (See Table 14, p. 58.)

AVERAGE RESULTS OF TESTS.

Table 3 gives the average results secured from the tests on Douglas fir and of those on other structural timbers which have been tested by the Forest Service. The figures in bold-face type are the results on large specimens, the other figures the results on small specimens free from defects.

The species are arranged in order of their breaking strength. In all of the tests upon which this table is based green material was used except for longleaf pine, which was partially air-dried and contained an average moisture content of 25 per cent. This fact explains, in part, the apparent superiority of longleaf pine over Douglas fir. Table 12 (p. 56) shows that the modulus of rupture for partially air-dried fir is 6,325 pounds per square inch.

TABLE 3.—*Average strength values, green structural timber with ordinary defects and small specimens of green material without defects.*

Species.	Weight per cubic foot-pound.		Bending.			Compression parallel to grain.		Compression perpendicular to grain.	Shear.
	Air-dry weight.	Oven-dry weight.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Compressive strength at elastic limit.	Crushing strength at maximum load.	Compressive strength at elastic limit.	Shearing strength.
	Lbs. per cu. ft.	*Lbs. per cu. ft.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Longleaf pine	41	36	**3,800**	**7,200**	**1,560**	**3,500**	**4,800**	**570**	....
			5,000	9,100	1,540	....	....	....	970
Douglas fir	33	29	**4,000**	**6,000**	**1,510**	**2,800**	**3,500**	**570**	....
			5,500	8,400	1,600	3,600	4,100	....	770
Loblolly pine	36	31	**3,200**	**5,600**	**1,430**	**2,400**	**3,500**	**470**	....
			4,100	7,900	1,440	....	4,100	....	630
Shortleaf pine	35	30	**3,300**	**5,600**	**1,470**	**2,500**	**3,400**	....	....
			4,400	7,700	1,400	....	3,600	400	710
Western hemlock	32	28	**3,700**	**5,600**	**1,320**	**2,800**	**3,700**	**480**	....
			5,200	7,900	1,360	3,700	4,100	....	750
Western larch	35	30	**3,500**	**5,400**	**1,410**	**2,600**	**3,700**	**480**	....
			4,600	7,500	1,370	3,200	3,800	....	700
Tamarack	35	30	**2,800**	**4,600**	**1,220**	**2,400**	**3,200**	....	....
			3,300	5,800	960	....	3,200	....	670
Norway pine	29	25	**2,600**	**4,000**	**1,190**	**2,090,**	**2,600**	....	....
			2,800	5,200	960	....	2,500	....	590

The species given in the table may be grouped, according to their breaking strength, into three classes: Douglas fir and longleaf pine are strongest; loblolly pine, shortleaf pine, western hemlock, and western larch, form an intermediate group; while Norway pine and tamarack are the weakest.

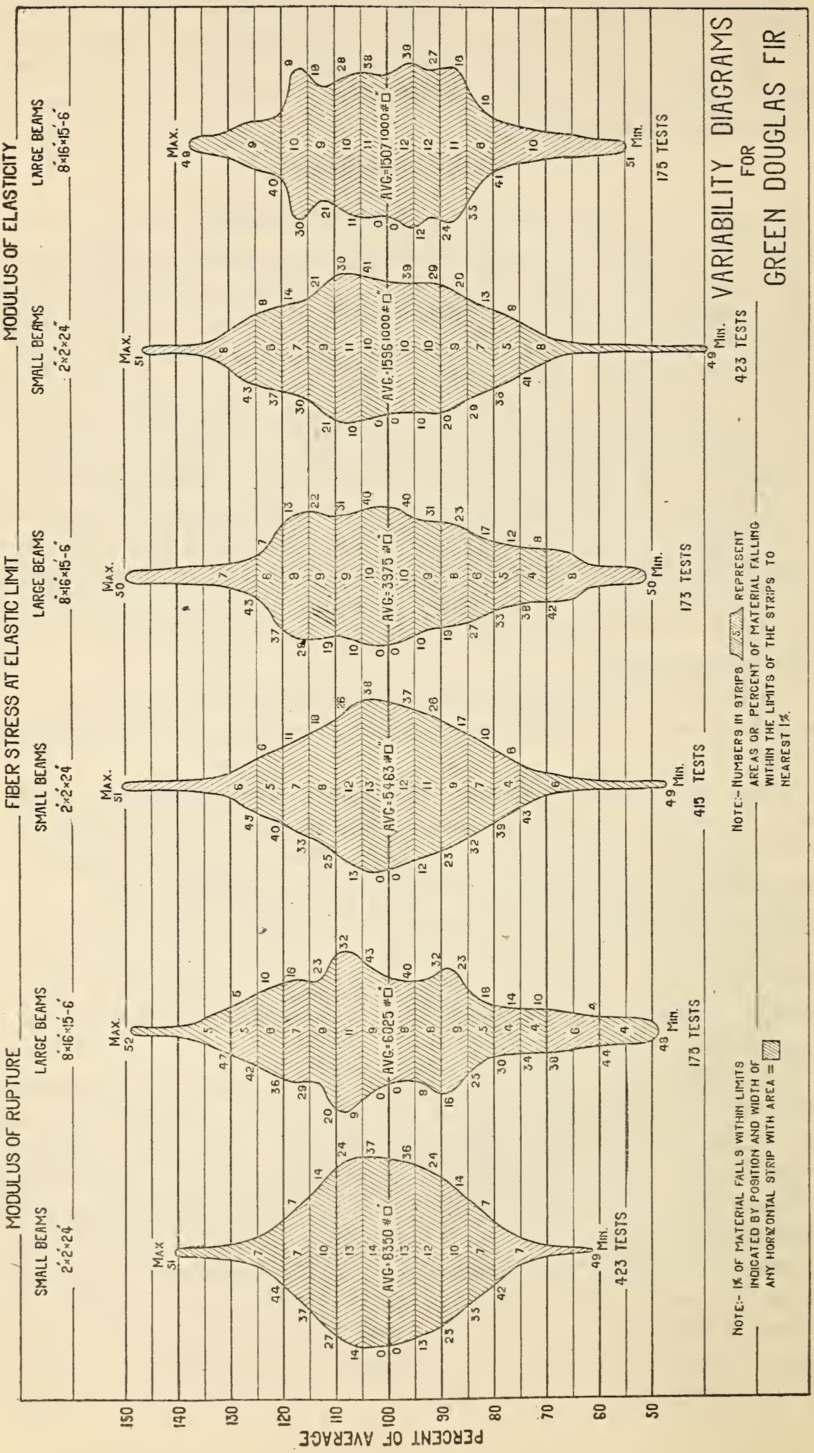
VARIATION OF RESULTS.

Douglas fir varies greatly in quality. Average results such as are given in Table 3 are representative only when they are based upon a great number of tests. In most of the tables of this bulletin the general range in the results is indicated by quoting the average of the lowest and highest 10 per cent of the tests upon which the respective averages are based. The results of individual tests, however, differ widely. Diagrams 2 and 3 show graphically how individual results may vary from the averages quoted in Table 3. They also permit a judgment of the reliability of the average values, and of the extent to which the investigator has chosen a proper range of material. Erratic tests on poorly selected material will yield a very irregular diagram, but an extensive series of tests on fully representative material will yield a symmetrical diagram, like that on the left of diagram 2. The following explanation of the diagrams will assist in their interpretation.

1. The areas of the various cross-hatched diagrams are equal, and in each diagram the total area represents the total number of specimens tested.

2. The area between adjacent horizontal lines represents graphically the percentage of the total number of tests that fell within the limits indicated on the scale to the left. The percentage is expressed numerically by the figures within the cross-hatched areas. For example, by referring to the modulus of rupture diagrams for small and large beams (diagram 2) it will be seen that, in the case of small beams, 13 per cent of the tests fell between 105 and 110 per cent of the average strength. In the case of the large beams, 11 per cent of the tests fell between the same limits.

3. The figures on the left edge of the diagram sum up the percentages within the cross-hatched areas, starting from the 100 per cent line; while those to the right sum up the percentages starting, respectively, from the maximum and minimum points. These scales facilitate the use of the diagrams. For example, again referring to the modulus of rupture diagrams for small and large beams, by using the scale to the left it will be seen that 44 per cent of the tests on small beams fell within 100 and 120 per cent of the average. In the case of large beams, 36 per cent of the tests fell within these limits. By using the scale to the right of the diagram, it is seen that 7 per cent of the tests for small beams were higher than 120 per cent of the average,



NOTE:- 1% OF MATERIAL FALLS WITHIN LIMITS INDICATED BY POSITION AND WIDTH OF ANY HORIZONTAL STRIP WITH AREA = ▨

NOTE:- NUMBERS IN STRIPS ▨5 REPRESENT AREAS OR PERCENT OF MATERIAL FALLING WITHIN THE LIMITS OF THE STRIPS TO NEAREST 1%.

VARIABILITY DIAGRAMS
FOR
GREEN DOUGLAS FIR

DIAGRAM 2.—Variability of green Douglas fir in modulus of rupture, fiber stress at elastic limit, and modulus of elasticity.

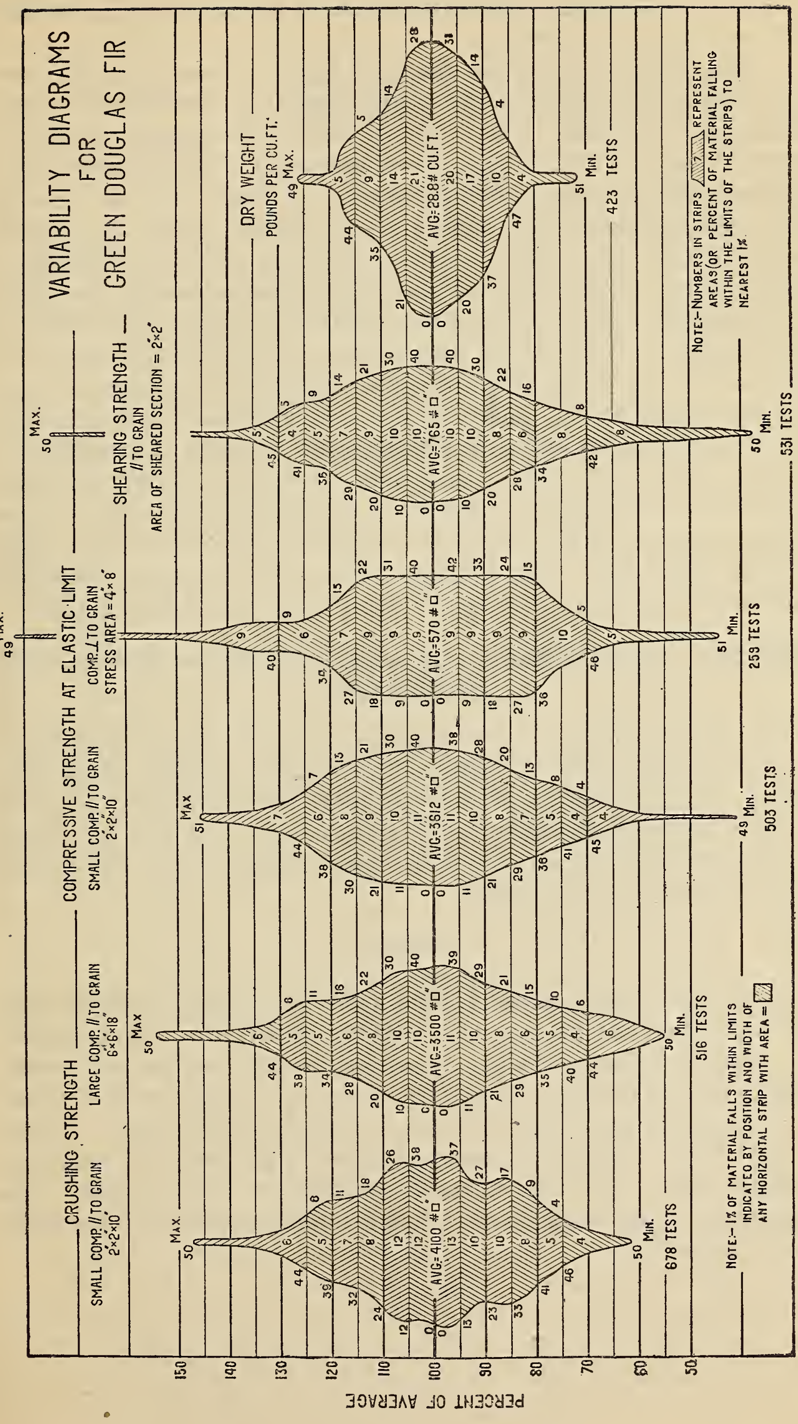


DIAGRAM 3.—Variability of green Douglas fir in crushing strength, compressive strength at elastic limit, shearing strength, and dry weight.

In the case of the large beams, 16 per cent of the tests were higher than 120 per cent of the average.

It will be noticed that the diagrams based on tests of small specimens are in general much more symmetrical than those based on large specimens. Doubtless this is largely due to the greater number of variables encountered in large specimens and to the difference in the number of tests. If a sufficient number of tests could be made on large beams selected at random from mill-run stock, the average secured would approximate very closely the average properties of Douglas fir in structural sizes, and the diagrams showing the range of individual results would have smooth contours and would be approximately symmetrical with respect to the line indicating 100 per cent. The shape of the diagram, therefore, is apparently significant in judging the quality of the sample tested. In this connection it will be observed that the diagrams showing the modulus of rupture and fiber stress at elastic limit for small beams are relatively symmetrical and regular in outline. It would appear that the averages of these functions have, therefore, reached a condition of what might be termed stability. The averages of the other functions considered would in all probability be changed more or less by additional tests.

RELATION OF PHYSICAL CHARACTERISTICS TO MECHANICAL PROPERTIES.

The wide variation in the mechanical properties of Douglas fir suggests the possibility of judging the relative strength of different pieces by an inspection of their physical characteristics. The elements which might be used for this purpose are: (1) Color, (2) weight, (3) proportion of summerwood, (4) rate of growth, and (5) defects, such as knots and cross grains.

COLOR.

Douglas fir varies in color from a decided reddish tinge to a light yellow, and on this account is sometimes classified as red and yellow fir. The red fir, as a rule, has a coarser grain and contains a considerable amount of the dark-colored summerwood. It is usually obtained from second-growth timber or from the heart of older trees. Yellow fir is the soft, fine-grained wood obtained from the outer portion of mature trees. It yields a large proportion of clear lumber. The difference in color is supposed to be due mainly to the difference in the rate of growth.

TABLE 4.—*Strength of red and yellow Douglas fir bridge stringers.*

Color and grade.	Number of tests.	Rings per inch.	Moisture content.	Weight as tested.	Oven-dry weight.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
		Number.	*Per cent.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Red:								
Select	32	9.2	31.7	39	30	4,380	6,780	1,625
Merchantable	36	8.8	31.8	37	28	4,020	6,180	1,535
Seconds	25	8.2	30.2	36	28	3,630	5,230	1,360
Yellow:								
Select	20	15.5	30.5	39	30	4,360	6,670	1,705
Merchantable	15	15.5	30.3	38	29	3,790	5,930	1,455
Seconds	7	14.5	28.4	39	30	3,440	5,070	1,260
RATIOS BY GRADES (RED FIR=100).								
Yellow:								
Select		168	96	100	100	100	98	105
Merchantable		176	95	103	104	94	96	95
Seconds		177	94	108	107	95	97	93
RATIOS, ALL GRADES (RED FIR=100).								
Yellow		174	95	104	104	96	97	98

In order to determine the relative strength of so-called red and yellow fir timbers, the test specimens were classified according to color. Table 4 summarizes the results of tests on red and yellow fir bridge stringers of each color, graded according to the export grading rules of the Pacific Coast Lumber Manufacturers' Association. In the lower part of the table the factors quoted for the different grades of yellow fir are expressed in per cent of those for red fir. A study of these ratios shows that the fiber stress at elastic limit, modulus of rupture, and modulus of elasticity in merchantable and second grades are slightly greater for red fir. In the select grades, however, they are practically equal; the yellow fir showing a slightly smaller modulus of rupture and a slightly greater modulus of elasticity. On the basis of all grades, the difference in favor of red fir varies from 2 to 4 per cent.

Table 5 summarizes the tests of car sills on the basis of color, not only for the full-sized pieces, but also for small, clear specimens having no defects. It is seen from the ratios at the bottom of the table that both in the large and small sizes yellow fir has a slightly higher fiber stress at elastic limit, modulus of rupture, and modulus of elasticity. The difference, however, in no case exceeds 7 per cent.

The general deductions to be drawn from both Tables 4 and 5 are:

1. That there is a considerably larger proportion of select and merchantable grades in yellow fir than in red; the percentage of selects, merchantable, and seconds being respectively for red fir, 34, 39, and 27; for yellow fir, 48, 35, and 17. This indicates that, as a rule, yellow fir contains fewer defects than red.

2. That the rate of growth in yellow fir is considerably slower and more uniform than in red. The yellow specimens tested show an average of about 15 rings per inch, while red fir shows an average between 8 and 9.

3. The tests on bridge stringers indicates that red fir in dimension sizes is slightly stronger than yellow, while the tests on car-sill sizes and small, clear specimens show a slight increase in strength for yellow fir. The entire summary, however, indicates that the difference in strength is not enough to warrant a discrimination in favor of either red or yellow fir.

Table 5.—*Comparison of red and yellow Douglas fir car sills.*

5 INCHES BY 8 INCHES BY 180 INCHES.

Color.	Number of tests.	Rings per inch.	Proportion of summer-wood.	Moisture content.	Weight per cubic foot.		Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
					Green weight.	Oven-dry weight.			
		Number.	*Per cent.*	*Per cent.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Yellow:									
High 10 per cent	4	23.4	59	37.1	41.4	31.7	5,068	6,773	1,871
Low 10 per cent	4	6.4	31	26.6	31.8	24.4	2,415	3,770	1,201
Average	41	13.2	42	30.0	36.7	28.2	3,833	5,371	1,561
Red:									
High 10 per cent	4	17.2	52	36.1	44.4	34.0	5,058	7,440	2,106
Low 10 per cent	4	3.9	26	26.3	31.4	24.2	2,415	3,270	1,146
Average	44	8.5	37	30.1	36.7	28.2	3,571	5,009	1,510

2 INCHES BY 2 INCHES BY 30 INCHES—SMALL, CLEAR SPECIMENS CUT FROM CAR SILLS.

Color.	Number of tests.	Rings per inch.	Proportion of summer-wood.	Moisture content.	Green weight.	Oven-dry weight.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
Yellow	81	14.3	43	29.9	36.5	28.1	5,336	8,151	1,495
Red	86	8.9	39	30.9	36.8	28.1	5,077	7,996	1,483

RATIOS (RED FIR=100).

Color.	Number of tests.	Rings per inch.	Proportion of summer-wood.	Moisture content.	Green weight.	Oven-dry weight.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
Yellow fir:									
Car sills	....	155	114	100	100	100	107	107	103
Small beams	....	161	110	97	99	100	105	102	101

WEIGHT.

All wood contains moisture in varying quantities. Green Douglas fir may contain as much as 10 pounds of water per cubic foot, and ordinary seasoning may reduce the quantity to about 3 pounds per cubic foot. In comparing the weights of various woods it is necessary, therefore, to reduce them to the same moisture content. In the work of the Forest Service, when wood reaches a constant weight in air maintained at a temperature of 100° C. it is said to be dry, and this weight is termed the "dry weight."[1]

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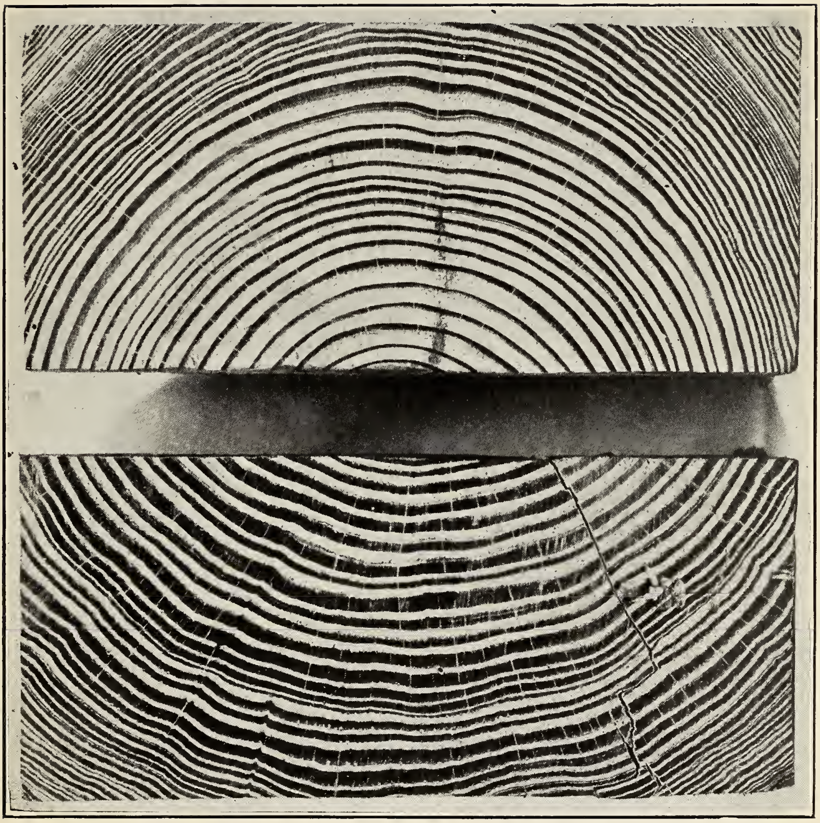
[1] The calculation of dry weight is based on volume at time of test and does not take shrinkage into consideration.



CROSS-SECTION OF TWO LOBLOLLY PINE BEAMS WITH APPROXIMATELY EQUAL RATES OF GROWTH, BUT WITH DIFFERENT PROPORTIONS OF SUMMER WOOD.

[Although both pieces represent approximately the same number of years' growth, the top piece is made up of one-third summerwood and two-thirds springwood, while the bottom one has more than three-fifths summerwood and less than two-fifths springwood.]

Diagram 4 shows the relation of dry weight to the modulus of rupture and modulus of elasticity in bending, as well as to the strength in compression parallel to grain. These quantities are given both for large specimens containing defects and for small specimens free from defects. All the quantities increase with increased dry weight of the wood, and the rate of increase is greatest in the modulus of rupture. In large beams the modulus of rupture and the modulus of elasticity, as well as the crushing strength, are uniformly lower than for small, clear specimens of equal weight. The modulus of elasticity is less affected by weight. Only one curve for it is shown, because the curves for large and small timbers practically coincide. This is a significant fact because it indicates that defects, such as knots, have quite an appreciable effect on the modulus of rupture and the crushing strength, and practically have no effect on modulus of elasticity. The general deduction that can be drawn from diagram 4 is that the dry weight is of great significance in judging the relative strength of different pieces of Douglas fir. Since, however, the dry weight can not be obtained very readily, the relation is of little practical importance in the grading of commercial timbers.

PROPORTION OF SUMMERWOOD.

Summerwood is the dark, relatively dense portion of each annual ring, the light, more porous part being termed springwood. Plate III shows two pieces of timber having approximately the same number of annual rings per inch, but differing greatly in the amount of summerwood they contain. In the laboratories of the Forest Service the summerwood is expressed as a percentage of the area of the cross section. When one-half of the cross section is summerwood the specimen is said to contain 50 per cent summerwood; when one-fourth of the area is summerwood, it is said to contain 25 per cent.

Diagram 5 shows the relation of summerwood to dry weight. Attention has already been called to the impracticability of using dry weight as an element in grading green Douglas fir, but it is seen from diagram 5 that dry weight increases as the summerwood increases. The relative dry weights of two pieces of Douglas fir, therefore, can be approximated by an inspection of the cross section of the pieces.

Diagram 6 shows the relation of the modulus of rupture, crushing strength, and modulus of elasticity to the percentage of summerwood in small, clear pieces. The relation shown in this diagram is to be expected, since it has been shown that these strength functions increase as the weight increases, and that the weight increases as the per cent of summerwood increases.

In studying these relations tests were made only on small, clear specimens, because the great variation in the percentage of summer-

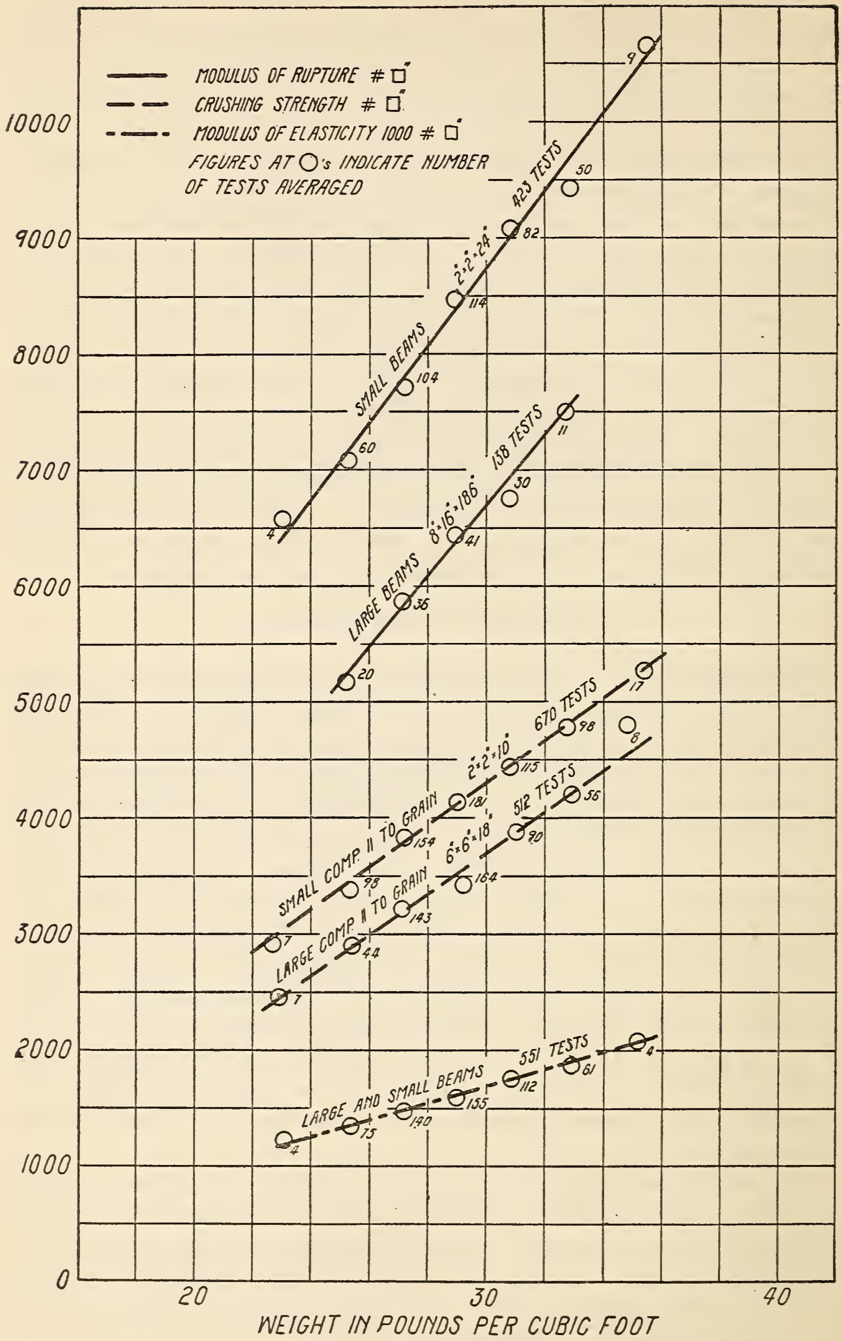


Diagram 4.—Relation of dry weight to modulus of rupture and modulus of elasticity in bending, and to compression strength parallel to grain.

wood in the cross sections of large timbers unfits them for this purpose. It will be noticed that in both diagrams 5 and 6 none of the relations is expressed by a straight line. This is due to the variation in the density of summerwood. In specimens that show a large proportion of summerwood it is noticeably more porous and weighs proportionately less than the summerwood in pieces which contain but little. This decrease in density is not taken into consideration in measuring the summerwood. Accordingly, in the higher percentages of summerwood, while the weight increases it is at a decreasing rate, and this, shown in diagram 5, explains the decrease in strength shown in diagram 6.

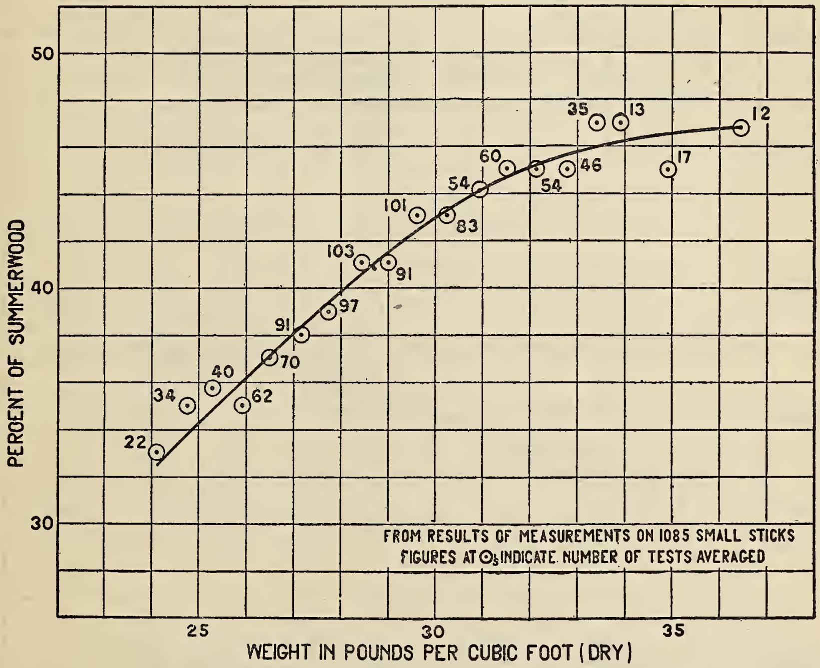


DIAGRAM 5.—Relation of the proportion of summerwood to dry weight.

The pertinent deduction to be drawn from diagrams 5 and 6 is that the appearance of the cross section is very significant in judging the relative weight and strength of small-sized pieces of Douglas fir. The relative weights of two large timbers can be judged with considerably certainty by a visual inspection of the cross sections, but on account of the wide variation in the percentage of summerwood in different parts of the cross section, the average percentage of summerwood bears no apparent relation to the strength of large timbers. This conclusion is supported by an analysis of the tests on green bridge stringers.

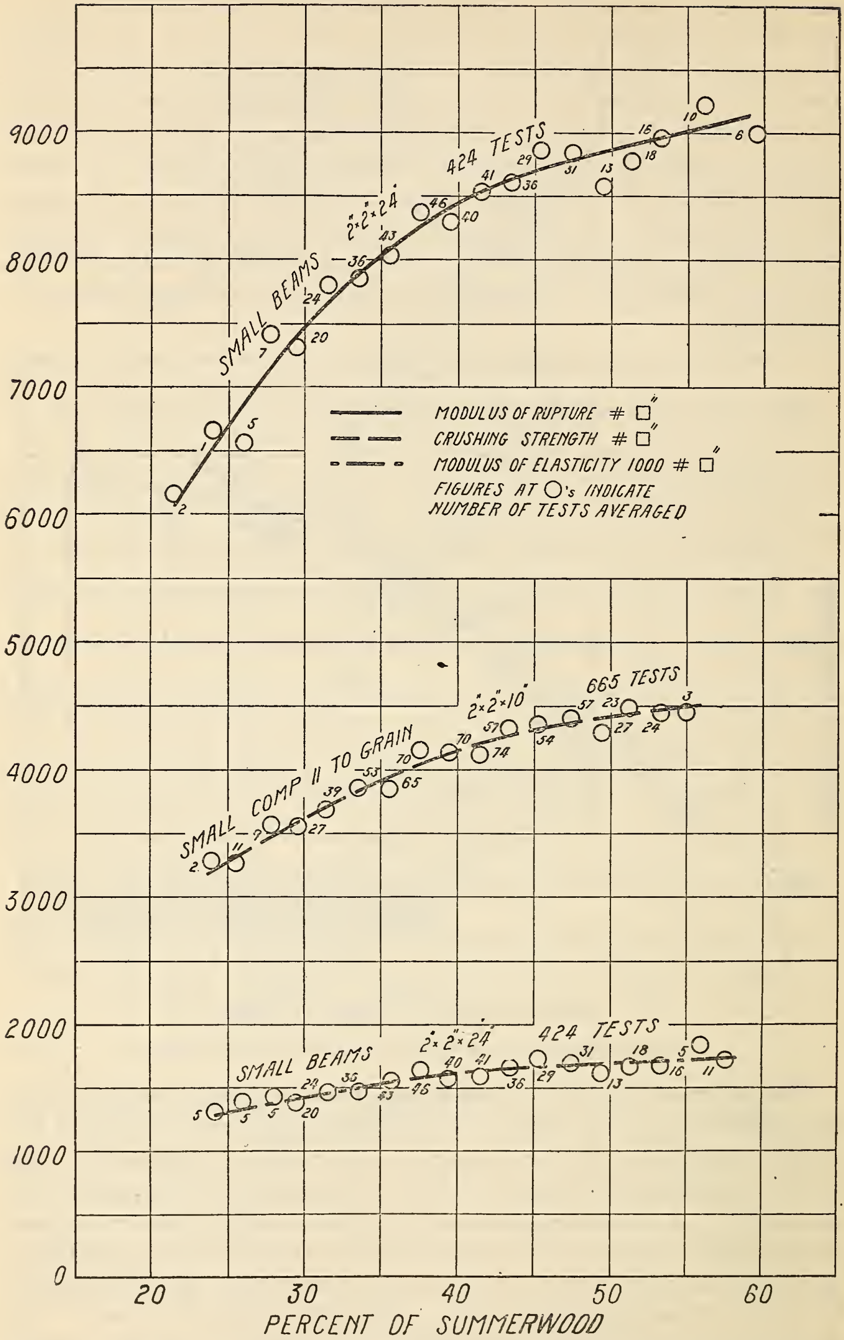


DIAGRAM 6.—Relation of modulus of rupture, crushing strength, and modulus of elasticity to the proportion of summerwood.

RATE OF GROWTH.

The rate of growth is shown by, and may be stated in, the number of annual rings per radial inch. It is sometimes used in specifications for Douglas fir. In this connection, diagram 7 is of considerable interest. In interpreting the diagram, however, it should be borne in mind that the points through which the curve is drawn are averages of a number of tests. The figure near each circle indicates the number of tests averaged. It was impracticable to show the individual points in the diagram, but the strength of the specimens having approximately the same number of rings per inch varies widely. The diagram indicates:

1. That, in general, rapidly grown wood (less than 8 rings per inch) is relatively weak. A study of the individual tests upon which the average points are based shows, however, that when it is not associated with light weight and a small proportion of summerwood, rapid growth is not indicative of weak wood.
2. An average rate of growth, indicated by from 12 to 16 rings per inch, seems to produce the best material.
3. In rates of growth lower than 16 rings per inch, the average strength of the material decreases, apparently approaching a uniform condition above 24 rings per inch. In such slow rates of growth the texture of the wood is very uniform, and naturally there is little variation in weight or strength.

An analysis of tests on large beams was made to ascertain if average rate of growth has any relation to the mechanical properties of the beams. The analysis indicated conclusively that there was no such relation. Average rate of growth, therefore, has little significance in grading structural timber.

DEFECTS.

The defects encountered in green Douglas fir lumber may be classified as pitch seams and shakes, cross grain and knots. Practically these defects are the basis of all grading rules, and their number and character largely determine the use to which the product of the sawmill is put. Material which is free from them is usually manufactured into finish, flooring, and other high-grade products, in which the appearance of the wood is of prime importance. Also, it is generally believed that, aside from their effect on the appearance of the wood, these defects influence greatly the strength and other mechanical properties of the timber in which they occur.

A special series of tests was made on 5 by 8 car sills over a 15-foot span, and on small specimens cut from the uninjured parts of the sills after they were tested. The load was applied at the third point on the large beams of this series, and a careful diagram was made

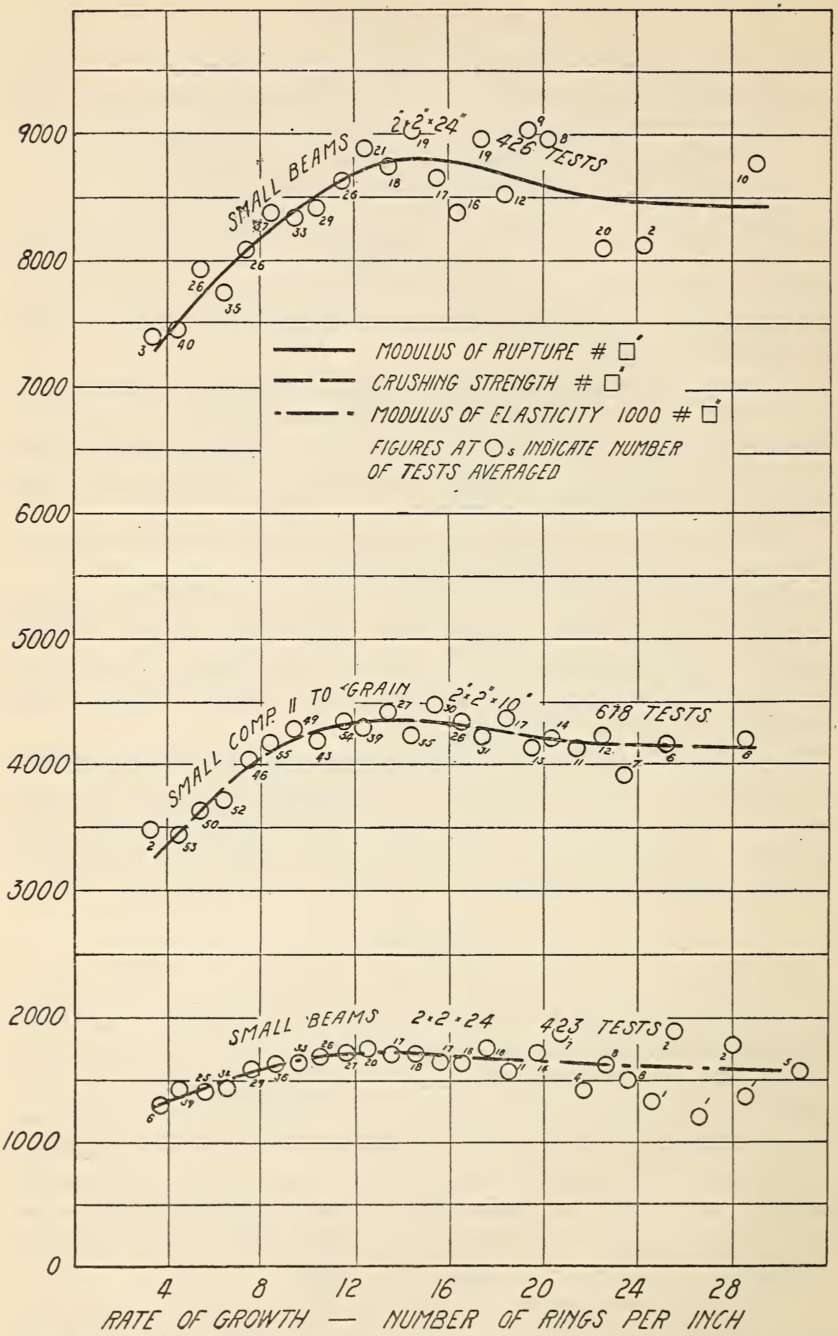


Diagram 7.—Relation of modulus of rupture, crushing strength, and modulus of elasticity to rate of growth as shown by the number of rings per inch.

showing the number, size, and location of defects and the manner in which the beam failed. Tests on the smaller specimens were for the purpose of studying the influence of elements such as the rate of growth and the proportion of summerwood, and to determine the quality of the clear wood. These tests formed the principal basis for the study of the influence of defects.

PITCH SEAMS AND SHAKES.

The pitch seams were narrow, but in some cases were several inches long. The seams invariably occurred between two annual rings, and caused only a slight disturbance in the grain of the specimen. In no case did their presence have any apparent effect on the results of the tests. It is reasonable to suppose, however, that large pitch pockets or pitch seams, which cause a decided derangement in the grain of the specimen, will prove detrimental to its strength. In green Douglas fir timbers shakes are seldom apparent. This is due in part to the fact that they seldom become evident until the wood is partially seasoned. The presence of shakes near the neutral axis of the beam, that is, about midway between the top and the bottom faces, may seriously influence the strength of the specimen by decreasing its resistance to horizontal shear. The fact that none of the green sills failed in horizontal shear indicates the absence of such shakes in the specimens tested.

CROSS GRAIN.

Cross grain may be divided into two general classes:

1. *Diagonal grain.*—When, in sawing lumber, the plane of the saw is not approximately parallel to the axis of the log, the grain of the lumber cut is not parallel to its edges. In such cases the grain is termed diagonal.

2. *Spiral grain.*—In Douglas fir, as well as in other species, the fibers composing each year's growth in some trees are arranged spirally instead of vertically. The reason for this is not definitely known. The danger of spiral grain as a defect depends largely on what might be termed the pitch of the spiral. Its presence is not generally noticeable from a casual inspection of the piece, as it does not show in what is commonly spoken of as the visible "grain" of the wood. This is because the prominent "grain" in softwood lumber is in reality a sectional view of the annual rings cut longitudinally, and since the annual rings are not distorted by spiral grain the appearance is not changed thereby. A careful inspection, however, of the medullary rays, particularly on the tangential or bastard section, will invariably reveal spiral grain, since the rays necessarily incline with the spiral direction of the fibers around the trunk. Spiral grain may readily be detected also by splitting a small piece radially.

Knots frequently cause a considerable disturbance of the grain, and such disturbances are also called cross grain. They seriously affect the strength of a beam when they occur so near the edge as to interrupt the continuity of the grain on the edge. All forms of cross grain may be regarded as serious defects. Of the 85 car sills composing this special series of tests, 23 showed cross grain, and in 12 cases the failure was due to cross grain. In the other 11 cases the full compressive strength of the wood was developed; that is, the beam first failed in compression before the final failure due to cross grain occurred. It was observed that beams showing cross grain to a marked extent were almost invariably weak.

KNOTS.

The effect of knots on the strength of timber is largely dependent on their position, size, and number, and on the condition of the wood around them. These elements are so intimately associated with each other and occur in such infinite numbers and combinations that it has been impossible to make specific deductions regarding the relative effect of different kinds and sizes of knots. But a study of their general relation to the results of the tests and to the failures warrants certain deductions that may prove of help in framing grading rules and specifications.

EFFECT ON SHEARING STRENGTH AND STRENGTH IN COMPRESSION AT RIGHT ANGLES TO GRAIN.

The effect of knots on the shearing strength of wood was not investigated directly. The tests on air-dried beams, however, in which pieces very frequently failed in horizontal shear, indicate that knots do not decrease the shearing strength of the wood, but rather tend to increase it by acting as pins, thus preventing the sliding of one surface over the other. They also have practically no influence in decreasing the strength in compression at right angles to grain.

EFFECT ON STRENGTH IN COMPRESSION PARALLEL TO GRAIN.

Table 6 shows the effect of different classes of knots on the strength in compression parallel to grain. In this table the strength of compression blocks containing knots from one-half inch to 1½ inches in diameter and of blocks containing knots over 1½ inches in diameter are compared with the strength of clear specimens. This comparison indicates that the presence of knots appreciably decreases the strength of Douglas fir in compression parallel to grain, the decrease being approximately 22 per cent in the case of knots greater than 1½ inches in diameter, 14 per cent for knots between one-half inch and 1½ inches in diameter, and 6 per cent in the case of knots one-half inch or less.

TABLE 6.—*Effect of knots on strength values of green material, average values in compression parallel to grain; size, 6 inches by 6 inches by 18 inches.*

[Figures in black-face type indicate the ratio of average strength of pieces with knots of average strength of clear pieces.]

Condition of material.	Number of tests.	Rings per inch.	Proportion of summer wood.	Per cent of moisture content.	Weight.		Compressive strength at elastic limit.	Crushing strength at maximum load.	Modulus of elasticity.
					As tested.	Oven dry.			
		No.	*Per ct.*	*Per ct.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Clear:									
High 10 per cent	13	21.7	53	36.1	43.4	33.4	4,390	4,959	2,707
Low 10 per cent	13	5.3	31	25.7	33.2	25.8	2,070	2,850	623
Average	130	11.8	42	30.4	38.1	29.2	3,099	3,918	1,321
							100	**100**	**100**
Pin knots (knots ½ inch or less in diameter):									
High 10 per cent	6	21.0	52	36.6	43.6	33.1	33808	4,525	2,681
Low 10 per cent	6	4.7	33	27.4	32.5	24.5	2,017	2,857	642
Average	62	10.4	41	31.6	37.7	28.6	2,931	3,698	1,401
							95	**94**	**106**
Standard knots (knots ½ inch to 1½ inches in diameter):									
High 10 per cent	23	17.5	55	39.7	43.8	33.4	3,798	4,538	2,467
Low 10 per cent	23	4.4	26	24.7	32.7	31.0	1,832	2,428	576
Average	227	9.0	41	30.9	37.8	28.9	2,708	3,386	1,187
							87	**86**	**90**
Large knots (knots over 1½ inches in diameter):									
High 10 per cent	10	19.0	53	37.2	44.5	33.8	3,426	4,367	2,119
Low 10 per cent	10	3.5	24	24.7	33.0	25.5	1,669	2,129	472
Average	97	9.4	39	29.9	38.0	29.3	2,406	3,062	940
							78	**78**	**71**

EFFECT OF KNOTS ON BEAMS.

Efforts to determine the influence of knots on the strength of beams are attended with considerable difficulty, due to the complicated distribution of stresses. Diagram 8 shows the modulus of rupture, fiber stress at elastic limit, and modulus of elasticity for each of the green car sills tested. The average modulus of rupture and modulus of elasticity, as well as the crushing strength, secured from the tests on small, clear beams (2 by 2 by 30 inches), and compression specimens (2 by 2 by 8 inches) cut from each of the car sills, are also shown. The following explanation will assist the reader in interpreting the diagram:

1. The tests are arranged in the diagram from left to right in order of the breaking strength or modulus of rupture, and all of the other results secured from each car sill are shown on the same vertical line with its modulus of rupture.
2. The Arabic numerals along the horizontal axis are for reference only.
3. The Arabic numerals and letters by the points showing the modulus of rupture for each car sill indicate the classification of the car sills with respect to the defects they contain.

The scheme of classification used is as follows. Each beam was divided into the volumes indicated by diagram 9.

Class 1: Clear.

Class 2*a:* Containing knots in volume 3 only, all knots being less than 1½ inches in diameter.

Class 2*b:* The same as class 2*a*, except that some of the knots are 1½ inches or greater in diameter.

Class 3*a:* Knots less than 1½ inches in diameter in volumes 2 and 3 only, volume 1 being clear.

Class 3*b:* The same as class 3*a*, except that some of the knots in volumes 2 and 3 are 1½ inches or over in diameter.

Class 4*a:* Scattered knots in all volumes, those in volumes 1 and 2 being less than 1½ inches in diameter.

Class 4*b:* The same as class 4*a*, except that some of the knots in volumes 1 and 2 are 1½ inches or greater in diameter.

While the above classification is based, in a general way, on the size and location of the knots, it also indicates fairly well the total number of knots. That is to say that timbers in classes 3 and 4 contain more knots than those in class 2.

The attention of the reader is called to the following points:

1. That the modulus of elasticity for the large beams and that for the small clear beams cut from them are approximately equal. This would seem to indicate that the modulus of elasticity is not influenced by the presence of defects in the large specimens; in other words, knots do not affect the stiffness of Douglas fir timbers, this factor apparently being dependent almost entirely upon the quality of the clear wood.

2. That the fiber stress at elastic limit for large beams does not vary with their modulus of rupture, but is, with very few exceptions, practically equal to the crushing strength of the small clear specimens. This is an extremely significant fact, because it indicates that the elastic limit of Douglas fir beams is not greatly affected by the presence of knots. It will be noticed, however, that in the car sills having a low modulus of rupture, the elastic limit usually falls below the crushing strength of the clear wood, while in the sills having a relatively high modulus of rupture the fiber stress at elastic limit frequently exceeds the crushing strength of small clear specimens. This would apparently indicate that the elastic limit is but slightly influenced by the presence of defects.

3. By comparing the modulus of rupture curves for large beams with the modulus of rupture and crushing strength of the small clear specimens, it will be seen that in the class 1 beams the modulus of rupture is considerably higher than the crushing strength of the

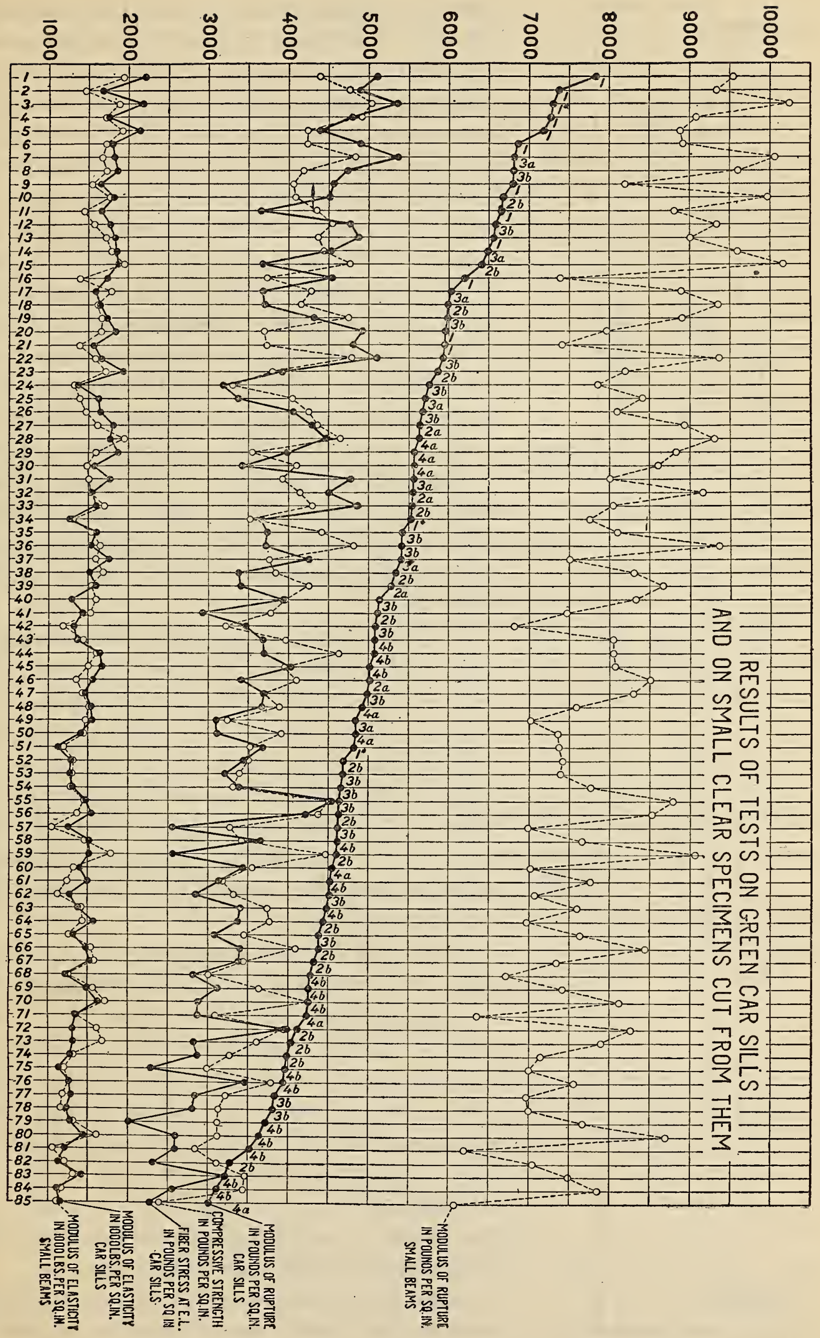


DIAGRAM 8.—Modulus of rupture, fiber stress at elastic limit, and modulus of elasticity for green car sills.

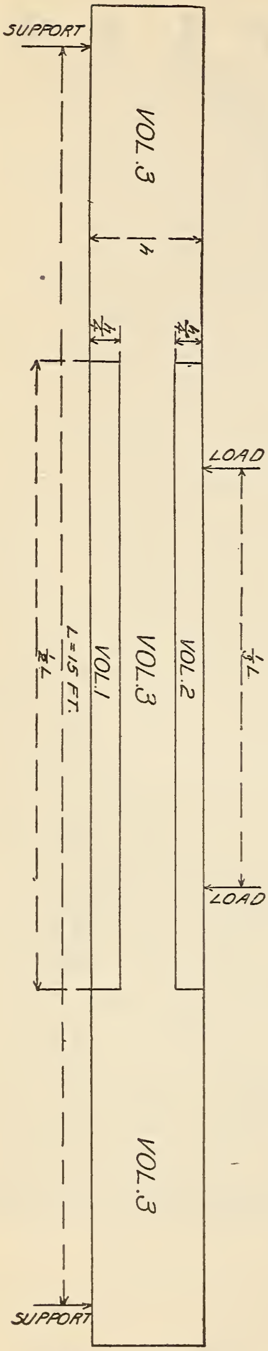


Diagram 9.—Basis of classification for tests on green car sills.

clear wood, and falls approximately midway between this function and the modulus of rupture for small beams. It will be observed that as the number and seriousness of the defects in the large beams increase the modulus of rupture approaches in value the crushing strength of the clear wood and the elastic limit of the beam. In the low-grade material there is very little difference between the modulus of rupture of large beams and their elastic limit and the crushing strength of the clear wood. It will also be observed that as the modulus of rupture of the large beams approaches in value the crushing strength of the clear wood, the difference between it and the modulus of rupture of the small clear beams increases. These relations indicate that the presence of knots influence most the breaking strength of the beams in which they occur.

4. Class 4 are beams having knots within their middle half on the bottom face, or within 2 inches of the bottom edges. It will be noticed that in the lower classes of large beams the modulus of rupture is relatively much closer to the elastic limit of the beam and to the crushing strength of the clear wood. In class 4*b* beams, containing large knots on the tension face, this tendency is most marked.

5. It will be observed that in class 1 beams the modulus of rupture is almost 50 per cent greater than the fiber stress at elastic limit and crushing strength; this fact, in conjunction with the one stated just above, would seem to indicate that the principal effect of knots upon timber beams is to decrease the energy required to break the beam after the elastic limit is reached. The ability to resist rupture after the elastic limit is passed indicates toughness.

Large knots and knots in great numbers are associated with and indicative of poor wood. Diagram 8 shows this by a gradual decrease in the modulus of rupture of small clear beams and in the crushing strength of clear specimens cut from the lower grade timbers containing such knots. As the quality of the wood fiber thus decreases, a general dropping off in the compressive strength and the fiber stress at elastic limit is observed. It is noticeable that even in the beams having a very low modulus of rupture, when the tests on small clear specimens indicate a good quality of fiber, the elastic limit of the beam and its modulus of elasticity are almost invariably higher than they are in beams having approximately the same breaking strength, but in which the quality of the wood fiber is poor.

Table 7 summarizes the results of tests according to the classes indicated on diagram 8. It also gives the maximum and minimum values for each class. This table emphasizes the following points:

1. The average properties of class 1, or clear beams, are considerably higher than the average for the other classes containing defects more or less serious in character. The range indicated by the maximum and minimum values, however, is practically as great in clear material as it is in material containing defects, thus indicating that clear material is sometimes weaker than material containing knots.
2. It will be noticed that in each of the other classes the average values for the (*a*) group is considerably higher than the average of the (*b*) group, indicating that in general the size of a knot is significant in determining its influence upon the strength of the timber in which it occurs.
3. Class 3, group for group, is slightly superior to class 2. It appears therefore that knots in volume 2 are at least no more serious than knots in volume 3. (Similar analyses made on tested loblolly pine, however, show that knots on the compression face decrease the strength slightly more than knots in volume 3.)
4. Class 4, group for group, is considerably weaker than the other classes, indicating strongly that knots in volume 1 are considerably more serious than knots in other parts of the stick.

FAILURE.

The manner in which the test specimens fail is also indicative of the relative seriousness of different defects. The three types of failures observed in the special series of tests on green car sills are as follows:

COMPRESSION.

Compression failure consists of the buckling of the fibers in the upper one-half of the beam. This usually begins on the top side shortly after the elastic limit is passed, and, as it develops, extends downward in the piece, sometimes almost reaching the middle of the cross section before complete failure occurs. Frequently two or more compression failures develop almost simultaneously.

CROSS-GRAIN TENSION.

Wood is comparatively weak in tension at right angles to grain. This is especially true of straight-grained woods that split readily, such as Douglas fir. When the beam has a diagonal or a spiral grain the internal stresses develop a tensile force which acts approximately at right angles to the grain. This condition almost invariably results in what is termed a failure in cross-grain tension.

TENSION FAILURE.

When the fibers on the bottom side of the beam are torn apart in a manner similar to the tearing apart of the fibers in a piece of string the failure is called a tension failure.

HORIZONTAL SHEAR.

Sometimes the beam under load splits, the splits extending from the end of the beam to the middle and in some cases from both of the ends. This is called a failure in horizontal shear. Such failures, it will be shown later, are comparatively common in air-dry material and in green timber where the ratios of the height of the beam to the length of span is relatively large. None of them were observed in the tests on green car sills.

TABLE 7.—*Results of tests on green car sills classified according to size and position of knots. Size, 5 inches by 8 inches by 180 inches.*

	Number of tests.	Rings per inch.	Summer wood.	Moisture content.	Weight per cubic foot.		Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
					As tested.	Oven dry.			
			Per ct.	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 pounds.*
Class 1:									
Maximum		27.0	62	33.1	45.9	35.5	5,350	7,840	2,220
Minimum		5.9	33	28.7	32.8	25.4	3,650	4,810	1,124
Average	14	16.1	45	30.2	39.7	30.5	4,588	6,586	1,746
Class 2*a*:									
Maximum		13.9	62	30.5	40.5	31.0	4,500	5,640	1,795
Minimum		6.9	33	28.5	34.8	27.0	3,400	5,010	1,538
Average	4	9.2	43	29.5	37.2	28.8	3,898	5,370	1,619
Class 2*b*:									
Maximum		15.0	57	38.2	41.7	32.1	4,870	6,660	1,923
Minimum		4.9	32	25.4	32.0	24.7	2,300	3,270	1,124
Average	17	9.4	42	30.0	36.6	28.2	3,484	4,905	1,520
Class 3*a*:									
Maximum		21.2	42	33.8	42.5	33.3	5,370	6,810	1,841
Minimum		8.8	32	27.6	35.3	27.4	3,090	4,840	1,547
Average	7	15.2	37	30.1	37.7	29.0	4,151	5,833	1,702
Class 3*b*:									
Maximum		22.2	51	32.8	39.1	30.3	5,090	6,800	1,855
Minimum		4.3	27	25.7	33.9	25.9	2,550	3,800	1,236
Average	19	10.1	35	29.4	36.2	28.0	3,682	5,151	1,450
Class 4*a*:									
Maximum		13.0	45	44.6	38.1	29.3	4,480	5,630	1,865
Minimum		4.7	26	25.6	30.4	22.6	2,250	3,000	1,155
Average	8	8.0	34	31.9	34.7	26.4	3,398	4,785	1,502
Class 4*b*:									
Maximum		16.6	56	40.1	39.0	30.6	4,020	5,080	1,653
Minimum		3.5	20	27.2	31.1	23.8	2,000	3,090	1,111
Average	16	8.2	38	29.9	35.0	27.0	3,066	4,161	1,386

SUMMARY.

Of the 85 car sills in the special series of tests upon which this discussion is based, 68, or 80 per cent, failed in compression first. In 51 of the cases the compression failure was apparently influenced by a knot on the compression face, or on a side near the compression face. It would seem, however, from the results shown in Table 7 that the presence of knots does not greatly decrease the crushing strength of Douglas fir.

In 45 of the 68 cases the final failure was in tension, usually due to a knot or cross grain.

In 8 of the 68 cases the final failure was in tension, and apparently not influenced by defects.

Fifteen out of the 68 failed entirely in compression. These pieces were entirely clear in the lower one-half. The pieces that did not fail in compression first, with two exceptions, had either cross grains or large knots on the tension face.

This summary of the failures apparently indicates that the tensile strength of Douglas fir is much greater than its strength in compression parallel to grain. On this account, unless there are unusally serious defects on the tension side of the beam, the full compressive strength of the wood will be developed before failure occurs. The fact that in so many cases (51 out of 68) the first failure in compression was apparently influenced by a defect, indicates that knots in the compression half of the beam lessen, to a certain extent, the ultimate strength of the timber. The elastic limit, however, is not greatly affected by such knots. It is shown in Table 6 that the elastic limit in compression is decreased approximately 13 per cent by the presence of knots 1½ inches or less in diameter; while it is decreased approximately 22 per cent by knots larger than 1½ inches.

In the green bridge stringers compression failure was also the most common. One hundred and seventy-five such stringers were tested, and were divided, according to their modulus of rupture, into three classes. Seventy-one of the stringers developed a modulus of rupture of over 6,500 pounds per square inch; 70 of these stringers failed first in compression. Seventy developed a modulus of rupture between 5,000 and 6,500 pounds per square inch; 64 of this group failed first in compression. Thirty-four stringers developed a modulus of rupture of less than 5,000 pounds per square inch; 14 of this class failed first in compression.

In the tests that did not show first failure in compression, as in the tests on green car sills, the first failure was in tension or cross-grain tension, due, respectively, to large knots on the tension face or to a spiral or diagonal grain, and in horizontal shear. Out of the 175 green stringers tested, 3 failed first in horizontal shear, and 31 had secondary failures in horizontal shear, but in such cases the shearing failure did not occur until the primary failure had developed to a considerable extent.

GRADING RULES AND SPECIFICATIONS.

Grading rules and specifications for structural timbers are, primarily, for the purpose of classifying them on the basis of stength and durability. Engineers until recently, however, have given very little consideration to specifications for such timber. A few years ago it was possible to secure the highest grade material at a very moderate cost, and early specifications almost invariably called for material free from such defects as might even be suspected of impairing its strength and durability.

With the increased consumption of lumber and the rapid depletion of supply of high-grade material available for structural purposes, the user of structural timber has been forced to modify specifications and to accept material which a few years ago would have been rejected. It is reasonable to suppose that further modification will have to be made with changing conditions of supply and demand.

Almost without exception structural timber is graded in a green condition. On this account the following comparison of different grading rules and specifications for Douglas fir is based on data secured from tests on green material. The comparison is of interest in that it indicates along what lines specifications and grading rules can be modified to the best advantage.

The following specifications and grading rules for Douglas fir in structural sizes are typical of those now in use:

Specification A.—Used by one of the leading transcontinental railway systems:

All timber must be of the best description of the kind required. It must be sawed square and to proper dimensions. It must be free from all loose, large, or unsound knots, sap, sun cracks, shakes, wanes, or other imperfections or defects which would impair its strength or durability.

Specification B.—Used by one of the leading railway systems operating east of the Mississippi River:

Fir stringers, bridge ties, and plank.—Must be from good, sound, live, straight, and close-grained Douglas fir, sawed square edge and true to dimensions ordered, free from splits, shakes, loose, rotten, or grouped knots and other defects. Sound knots 2 inches in diameter or less will be permitted if not less than 4 inches from the center of the knot to any edge. Ninety per cent of the stringers and ties must be free from sap. Ten per cent may have sap not in excess of 2 inches on each of the two edges only.

Specification C.—Isthmian Canal Commission:

Stringers of Douglas fir.—Shall show not less than 85 per cent heart on any face and not less than 70 per cent on any edge; it shall show not less than an average of 12 annual rings to the inch. Sound knots less than 3 inches diameter shall be permitted in the vertical faces of the stringer at points not less than one-fourth the depth from the edge of the piece.

Specification D.—Export grading rules of the Pacific Coast Lumber Manufacturers' Association, adopted 1903:[1]

Selects.—Shall be sound, strong lumber, good grain, well sawed. Will allow in sizes 6 x 6 inches and less, knots not to exceed 1 inch in diameter; sap on corner one-fourth the width and one-fourth the thickness; small pitch seams not exceeding 6 inches in length. In sizes over 6 x 6 inches, knots not to exceed 2 inches in diameter, varying according to the size of the piece; sap on corner not to exceed 2 inches on both face and edge; pitch seams not to exceed 6 inches in length. Defects in all cases to be considered in connection with the size of the piece and its general quality.

Merchantable.—This grade shall consist of sound, strong lumber, free from shakes, large, loose, or rotten knots, and defects that materially impair its strength; well manufactured and suitable for good substantial constructional purposes. Will allow occasional variations in sawing or occasional scant thicknesses, sound knots, pitch seams, and sap in corners, one-third the width and one-half the thickness. Defects in all cases to be considered in connection with the size of the piece and its general quality.

Seconds.—This grade shall consist of lumber having defects which exclude it from grading as merchantable. Will allow knots and defects which render it unfit for good substantial constructional purposes, but suitable for an inferior class of work.

Specification E.—This specification was tentatively adopted by the American Railway Engineering and Maintenance of Way Association and by the American Society for Testing Materials. It has also been adopted by the Yellow Pine Manufacturers' Association as a basis for grading yellow pine bridge and trestle timbers:

Standard specifications for bridge and trestle timbers—

To be applied to solid members and not to composite members.

1. General requirements: Except as noted all timber shall be cut from sound trees, true and straight, and sawed standard size; shall be square edged, close grained, solid and out of wind; free from defects such as injurious ring shakes and crooked grain, unsound or loose knots, knots in groups, decay, large pitch pockets, or other defects that will materially impair its strength.

2. Standard size of sawed timber: Rough timbers sawed to standard size means that they shall not be over one-fourth inch scant from the actual size specified. For instance, a 12-inch x 12-inch timber shall measure not less than 11¾ x 11¾ inches.

3. Standard dressing of sawed timber: Standard dressing means that not more than one-fourth inch shall be allowed for dressing each surface. For instance, a 12-inch x 12-inch timber after being dressed on four sides shall measure not less than 11½ x 11½ inches.

No. 1 railroad grade—Longleaf yellow pine and Douglas fir—

4. Stringers: Longleaf pine shall show not less than 85 per cent heart on the girth anywhere in the length of the piece; provided, however, that if the maximum amount of sap is shown on either narrow face of the stringer, the average depth of sap shall not exceed one-half inch. Douglas fir shall show not less than 90 per cent heart as measured above. Knots greater than 1½ inches in diameter will not be permitted at any section within 4 inches of the edge of the piece.

No. 2 railroad grade—Longleaf and shortleaf yellow pine, Douglas fir, and western hemlock—

10. Stringers: Shall be square edged, except they may have 1 inch wane on one corner. Knots shall not exceed in their largest diameter one-fourth the width of the face of the stick in which they occur, and shall in no case exceed 4 inches. Ring shakes shall not extend over one-eighth of the length of the piece.

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[1] These rules have been modified since their adoption, but the changes have been made to express the conditions with greater clearness rather than to indicate a different quality of timber. The rules quoted were in force when the material used in these tests was selected and graded.

DISCUSSION OF SPECIFICATIONS.

In addition to the general requirements in the various specifications, such as "strong, good timber," etc., are specific ones with regard to—

(*a*) Quantity of sapwood permitted.
(*b*) Sawing.
(*c*) Grain.
(*d*) Knots; size, position, and number.
(*e*) Checks, shakes, and pitch pockets.

The relation of most of these elements to the mechanical properties of the timbers tested has been discussed in another part of this bulletin, but a brief recapitulation of the facts brought out will assist in the critical examination of the sample specifications.

SAPWOOD.

The sapwood specifications are inserted to secure material having the desired durability. They are readily complied with in Douglas fir, since the trees have a comparatively small amount of sapwood and practically all structural timbers are cut from that portion of the tree nearest the heart.

SAWING.

Attention has been called to the effect of diagonal and cross grains upon the strength of structural timbers. Diagonal grain, due to the sawing, is a serious defect, and there is ample justification for guarding against it in specifications and grading rules. The results of the tests indicate that a slant in the grain as great as 1 inch in 45 inches can be admitted without seriously affecting the strength of the timber, but if the diagonal grain is much more pronounced than this, the timber, if heavily loaded, may fail suddenly in cross-grain tension some time before the compression strength of the wood is developed.

GRAIN.

The specifications regarding grain are of two general characters—those dealing with the straightness of the grain and those dealing with the rate of growth indicated by the number of rings per inch. Any waving or crossing of the grain, such as is frequently caused by knots, may prove a serious defect if the disturbance breaks the continuity of the grain near the edges of the timber. When, however, the continuity of the grain within 1 or 2 inches of the edges is not disturbed, wavy or cross grain has little significance as a defect in structural timber.

The average rate of growth is also of little importance in grading structural timber, no apparent relation existing between it and the mechanical properties of the timber.

KNOTS.

On page 33 the effect of knots on the strength of Douglas fir in structural sizes is discussed. It is there shown that the significant factors with respect to knots are their size, position, and the condition of the wood around them. In a general way the results of the tests also show that a large number of knots is almost invariably indicative of a poor quality of wood.

CHECKS, SHAKES, ETC.

Checks and shakes are only occasionally encountered in green Douglas fir; checks, however, almost invariably develop as the timber seasons. Except in sticks of the lowest grade, the development of checks does not reduce the strength of the timber below what it is in a green condition, since the increase in the strength of the wood due to seasoning more than offsets the weakening effect of the checks. Under certain conditions the presence of checks tends to decrease the durability of the wood by making it more vulnerable to the attack of insects and wood-destroying organisms. Especially is this true of treated timber, where the checks extend through that portion of the wood which is impregnated with the preservative.

SPECIFICATIONS.

To determine the effectiveness of the different grading rules and specifications quoted an attempt was made to apply them to the 175 green bridge stringers tested.

Specification A.—The wording of Specification A is so general that it practically leaves the whole question of grading to the judgment of the inspector. With an efficient inspector such specifications frequently give very satisfactory results, both to the purchaser and to the seller. Results secured from its application, however, will vary with the judgment of the inspector, and on this account the use of such specifications is frequently the cause of more or less serious misunderstanding. It was thought impractical to use this specification in grading the material tested. It is cited merely as being typical of a class of specifications in use.

Specification B does not allow knots more than 2 inches in diameter, and no knots at all are permitted unless the center of the knot is at least 4 inches from the edge. Only 19 of the 175 stringers tested passed this knot specification, indicating that it is by all means too severe.

The average fiber stress at elastic limit, modulus of rupture, and modulus of elasticity of the stringers passing this specification were, respectively, in pounds per square inch, 4,887, 7,414, and 1,728,000. The maximum value of these functions were, respectively, 5,850, 8,890, 1,945,000, while the minimum values were, respectively, 4,100, 6,440, and 1,523,000.

Specification C.—The pertinent provisions of Specification C are (1) that the average rate of growth shall not be less than 12 rings per inch; (2) knots greater than 3 inches in diameter are not allowed; (3) knots less than 3 inches in diameter are permitted on the vertical faces at points not less than one-fourth of the depth from the edge of the piece.

Only 9 stringers of the 175 tested met this specification. As in the specification just preceding, the fact that no knots at all were permitted within a certain specified distance of the edges was the reason for rejecting most of the material. The rate of growth specification was also the cause of throwing out some material which passed the knot specification.

The average fiber stress at elastic limit, modulus of rupture, and modulus of elasticity of the stringers passing this specification were, respectively, 4,835, 7,062, 1,767,000 pounds per square inch. The maximum values were, respectively, 5,540, 7,930, and 1,970,000; the minimum, 4,300, 5,320, and 1,565,000.

Specification D.—These grading rules contain very few specific statements regarding the character of the different defects which will be permitted, but, like Specification A, they leave a great deal to the judgment of the inspector.

All of the material tested was graded according to these rules by one of the inspectors of the lumber manufacturers' associations cooperating in the work.

Tables 8 and 9 give, respectively, the average properties, as well as the range in them, for bridge stringers and car sills graded in accordance with these rules.

TABLE 8.—*Results of bending tests on green material with defects; average values; size, 8 inches by 16 inches by 15 feet 6 inches.*

Grades.	Number of tests.	Rings per inch.	Proportion of summerwood.	Moisture content.	Weight as tested.	Oven-dry weight.	Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
		No.	*Per ct.*	*Per ct.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	*Pounds.*	*Pounds.*	*1,000 pounds.*
Select:									
High 10 per cent	6	21.4	41	35.4	42.6	32.7	5,420	8,150	1,962
Low 10 per cent	6	6.2	27	26.3	34.5	25.9	3,221	4,910	1,340
Average	59	11.9	35	31.2	38.9	29.6	4,346	6,753	1,654
Merchantable:									
High 10 per cent	8	20.0	43	35.9	42.4	32.2	5,180	7,670	1,880
Low 10 per cent	8	5.5	27	25.7	32.1	24.5	2,780	3,915	1,133
Average	79	10.7	34	31.5	36.8	28.0	3,895	5,878	1,481
Seconds:									
High 10 per cent	4	17.4	38	35.1	40.3	31.1	5,340	7,413	1,714
Low 10 per cent	4	4.4	25	24.7	32.2	24.7	2,283	3,175	921
Average	37	10.0	32	30.1	36.9	28.4	3,538	5,188	1,328

TABLE 9.—*Results of bending tests on green material with defects, graded according to Pacific coast export grading rules; average values; size, 5 inches by 8 inches by 15 feet.*

Grades.	Number of tests.	Rings per inch.	Proportion of summer wood.	Moisture content.	Weight as tested.	Oven-dry weight.	Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
Select:		*No.*	*Per ct.*	*Per ct.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	*Pounds.*	*Pounds.*	*1,000 pounds.*
High 10 per cent	3	23.7	56	37.2	45.0	34.6	5,280	7,497	2,187
Low 10 per cent	3	6.6	32	27.0	34.0	25.9	3,187	4,827	1,262
Average	25	14.8	42	30.6	38.7	29.7	4,320	6,147	1,698
Merchantable:									
High 10 per cent	3	17.8	57	32.6	40.4	31.5	4,597	6,353	1,848
Low 10 per cent	3	4.3	27	26.2	31.5	24.1	2,580	3,710	1,221
Average	30	9.4	38	29.2	35.6	27.6	3,532	4,946	1,513
Seconds:									
High 10 per cent	3	17.3	50	37.9	40.0	30.6	4,790	6,457	1,848
Low 10 per cent	3	4.0	27	26.5	31.2	23.9	2,177	3,100	1,125
Average	30	8.7	38	30.4	36.1	27.7	3,344	4,618	1,419

Specification E[1] was first compiled by Committee Q of the American Society for Testing Materials, and, with minor modifications, was adopted by the American Railway Engineering and Maintenance of Way Association as its standard specification for bridge and trestle timbers.

Table 10 gives for the different grades defined in the specification their average properties and the ranges within them. The specification defines only two grades, but in this analysis of the test data the stringers which failed to make either of these grades have been classified as culls.

TABLE 10.—*Results of bending tests on green material with defects, graded according to the specifications of the American Railway Engineering and Maintenance of Way Association; average values; size, 8 inches by 16 inches by 15 feet 6 inches.*

Grades.	Number of tests.	Rings per inch.	Proportion of summer wood.	Moisture content.	Weight as tested.	Oven-dry weight.	Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
R. R. I:		*No.*	*Per ct.*	*Per ct.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	*Pounds.*	*Pounds.*	*1,000 pounds.*
High 10 per cent	5	22.7	44	35.9	43.6	33.6	5,800	8,468	1,964
Low 10 per cent	5	6.2	29	24.9	35.4	26.6	3,374	5,750	1,303
Average	54	12.0	36	31.4	39.2	29.9	4,516	7,108	1,678
R. R. II:									
High 10 per cent	8	18.0	41	35.8	41.5	31.8	5,006	7,430	1,875
Low 10 per cent	8	5.6	27	26.7	33.2	25.2	3,109	4,761	1,239
Average	67	10.3	34	31.3	37.2	28.3	4,057	6,116	1,528
Culls:									
High 10 per cent	5	19.3	39	34.9	40.0	31.0	4,656	6,700	1,715
Low 10 per cent	5	4.4	26	24.7	30.9	23.6	2,292	3,232	915
Average	54	10.7	32	30.5	36.1	27.7	3,330	4,845	1,310

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[1] Since this bulletin was sent to press these specifications have again been revised.

Specifications D and E are evidently the most practical of those quoted. To further compare their efficiency in grouping material according to its mechanical properties, the results of the tests are shown graphically in diagram 10. For each grade indicated in the diagram, the modulus of rupture and modulus of elasticity are shown to the right of the heavy vertical line, and the fiber stress at elastic limit to the left. The vertical scale is in pounds per square inch, except that part of it which indicates the modulus of elasticity which should be read in 1,000 pounds per square inch. The length of the shaded portions between the horizontal lines is proportional to the total number of tests falling within the limits indicated on the vertical scale. The points within the shaded areas show the grouping of the individual tests.

A study of the diagram brings out the following points:

1. That, according to Specification D, the 175 stringers tested were made up of 59 selects, 75 merchantables, and 37 seconds; according to Specification E, they were made up of 54 R. R. No. 1, 66 R. R. No. 2, and 54 culls.

2. Specification E succeeds in eliminating from the highest grade material having a modulus of rupture less than 6,000 pounds per square inch, with the exception of one stick which developed a modulus of rupture of approximately 4,200 pounds per square inch. This exception makes the extreme range in strength of the grades R. R. No. 1 and selects the same.

3. The grade R. R. No. 2, with four exceptions, rules out material having a modulus of rupture of less than 5,000 pounds per square inch, the extreme range in the modulus of rupture being from 4,200 pounds per square inch to 7,800 pounds per square inch. The merchantable grade admits 14 sticks having a modulus of rupture less than 5,000 pounds per square inch, and shows an extreme range in the modulus of rupture of from 3,500 to 8,800 pounds per square inch.

4. The extreme range in the seconds is from 3,000 pounds per square inch to 8,300 pounds per square inch, while the culls of Specification E range in strength from 3,000 pounds per square inch to 7,600 pounds per square inch.

5. It is noteworthy that 40 of the culls, or 74 per cent of the timbers excluded from the grades R. R. No. 1 and R. R. No. 2, were stronger than the weakest timbers of the grade R. R. No. 2. Thirty-one seconds, or 84 per cent of the seconds, were stronger than the weakest timbers in the merchantable grade.

6. The effectiveness of the specifications in grading material according to its fiber stress at elastic limit and its modulus of elasticity is also shown in the diagram. Specification E apparently is effective in culling material having a fiber stress at elastic limit of less than 3,000

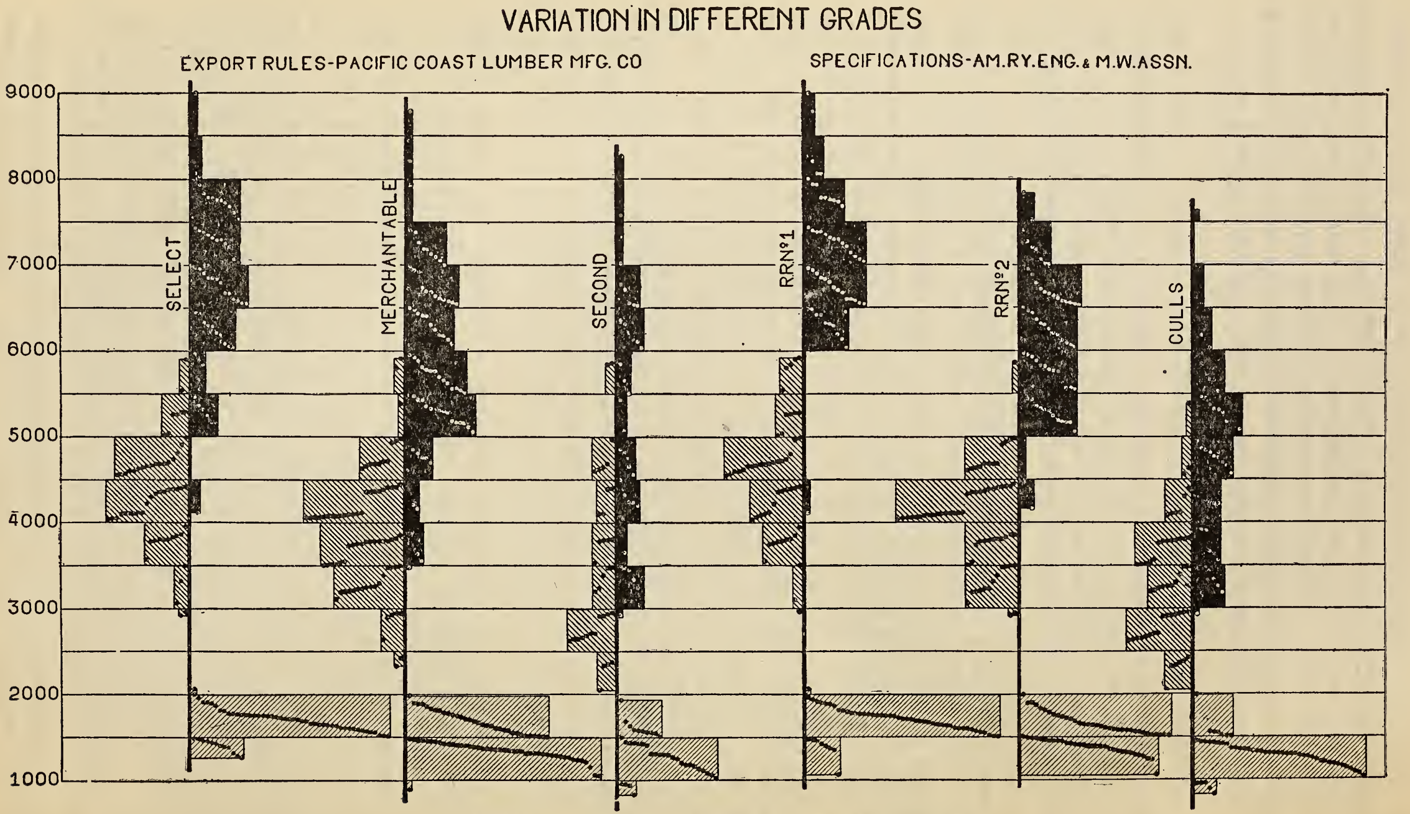

DIAGRAM 10.—Variability in grading by different specifications.

pounds per square inch. Approximately 60 per cent of the material culled, however, had a fiber stress at elastic limit greater than this.

The value of a specification or grading rule depends largely upon its reliability in excluding material which is deemed undesirable, and in admitting material adapted to the needs of the purchaser.

The range in the properties of the different grades considered in diagram 10 indicates that Specification E is somewhat more reliable in grouping material according to the merchantable properties than is Specification D. On the other hand, more material having the required properties is culled by Specification E than by Specification D; 40 sticks as good as those admitted to R. R. No. 2 are thrown into the lowest grade in order to exclude the 14 sticks falling below the minimum strength shown in the R. R. No. 2. In Specification D, 30 timbers as good as those included in the merchantable grade are thrown into the lowest grade in order to exclude the 5 pieces falling below the minimum strength shown in the merchantable grade.

So many factors which can not be detected by a visual inspection influence the properties of structural timbers that the problem of formulating grading rules which can be relied upon to exclude material falling below a specified strength is one extremely doubtful of solution. The one timber having a modulus of rupture of approximately 4,000 pounds to the square inch which passed the specification for R. R. No. 1 makes it unsafe to rely upon greater strength in timbers of this grade than in timbers of the next lower grade. The practicability, therefore, of having more than one grade for Douglas fir in structural sizes seems questionable.

Various attempts were made to introduce other factors, such as summerwood and rate of growth, with the idea of modifying Specification E so that fewer sticks having a modulus of rupture greater than 4,000 pounds to the square inch would be excluded, but none of the attempts were attended with much success. This specification seems to be as practical and effective as any that have been devised for grading Douglas fir. The results of the tests show, however, that much of the material falling in the two lowest grades (seconds and culls) has considerable structural merit, and could be safely and economically used in false work and structures of a temporary character.

SEASONING.

At the time the material was secured for the tests on green timber—the tests on which the discussion to this point is based—a certain part of the material was set aside to air-season. This consisted of ten 8 inch by 16 inch by 16 foot stringers and thirty 5 inch by 8 inch by 16 foot car sills. The green material was secured in 32-foot lengths, one-half of each being chosen for the seasoning tests.

DISTRIBUTION OF MOISTURE IN GREEN AND IN AIR-SEASONED SPECIMENS.

The distribution of moisture in the specimens at the time they were put out was secured by cutting a disk from each. The disks were divided as shown in diagrams 11 and 12. The sections were so proportioned that the combined area of the four outer sections was approximately equal to the area of the four intermediate sections and the central section. These disks were taken when the 32-foot pieces were cut in two. At the conclusion of the seasoning the specimens were tested, and the distribution of moisture in the seasoned pieces was determined. Diagram 11 shows the average distribution of moisture in the green stringers and in the air-seasoned halves. In the green condition the moisture distribution was fairly uniform, averaging 32.7 per cent, the moisture content being highest in the middle of the timbers. After seasoning from the middle of June, 1906, to the middle of September, 1907 (15 months) the average moisture content of the center of the stringers had been reduced from an average of 34.1 per cent to 19.7 per cent, while the surface moisture content had been reduced from approximately 32 per cent to a little less than 15 per cent. In diagram 12 the moisture content of the green and

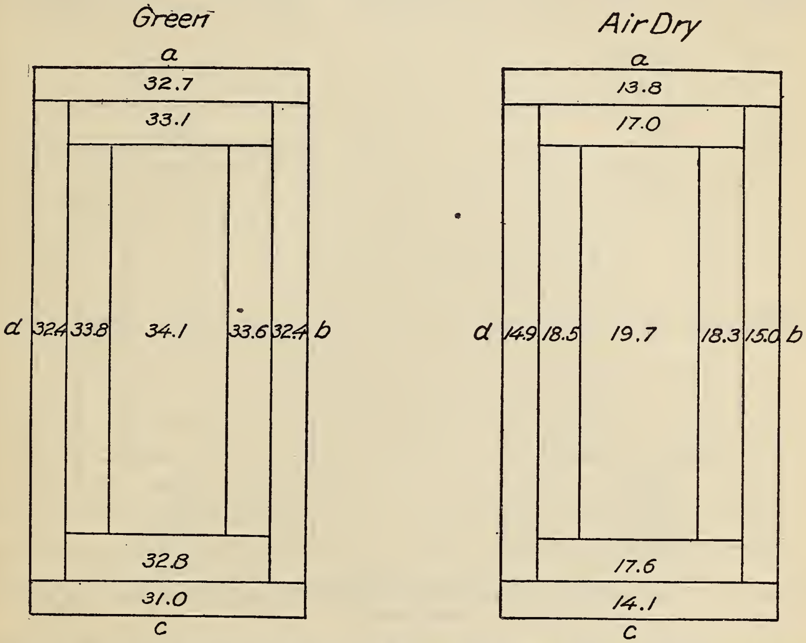

DIAGRAM 11.—Average moisture distribution as determined by sectional disks cut from green and air dry bridge stringers.

air-dry car sills is shown in the same manner. The car sills, however, seasoned from about the middle of June, 1907, to the middle of August, 1909, a little less than two years. The moisture in the center of the car sills had been reduced from 31.6 per cent to 15.9, while the surface moisture had been reduced from approximately 28 per cent to 14. The surface moisture content of the car sills, after two years' seasoning, was approximately the same as it was for the bridge stringers after seasoning only 15 months. The moisture content of the car sills, however, is more uniformly distributed, there being a difference of slightly more than 1 per cent in the surface portion and in the center of the stick. Only in very dry climates can wood be air-dried to a moisture content of less than from 15 to 12 per cent. It would seem, therefore, that all of the material when tested was pretty thoroughly seasoned, and that the car sills had about reached a condition of moisture equilibrium.

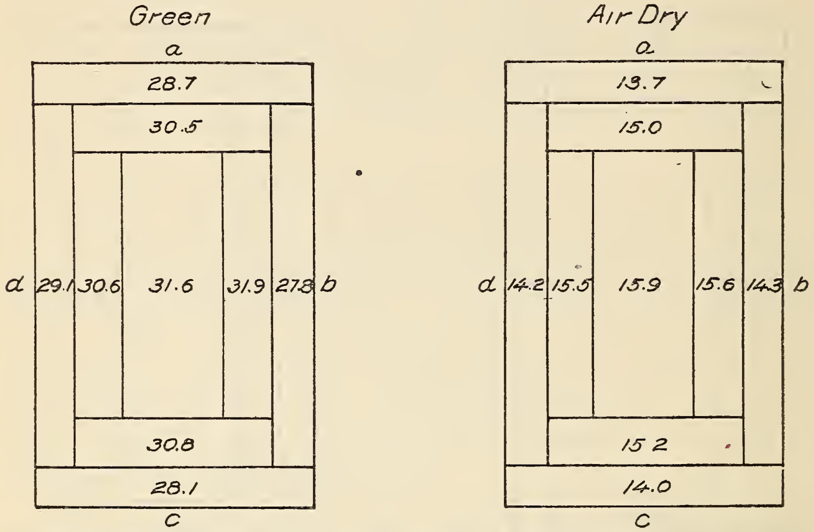

Diagram 12.—Average moisture distribution as determined by sectional disks cut from green and air dry car sills.

RATE OF SEASONING.

The specimens used in the seasoning tests were weighed at the beginning of the seasoning and at intervals during the seasoning process. Diagrams 13 and 14 show the various weights secured. In diagram 13 the different weights of each of the 10 bridge stringers are given. This was not practicable with the car sills, on account of the greater number of tests. The curves in diagram 14 do not represent the weights of the different specimens, but the average weight of specimens placed out to air season on the same date. The number of specimens averaged is shown on each of the curves.

From the latter part of June to the first of August each of the stringers lost approximately 25 pounds in weight, or a little less than 5 per cent of the average green weight. The loss in weight by October averaged 40 pounds per stringer, or a little less than 8 per cent of the green weight. From October to April a slight increase in weight is shown. From April until the time the stringers were tested there was a decrease in weight of about 20 pounds, the loss being much more gradual than in the previous summer.

Diagram 14 shows that the car sills placed out to air season in June lost from 19 to 28 pounds by the middle of September. Those placed out in July lost from 14 to 18 pounds by the middle of September. It is noticeable that none of these latter car sills gained weight between October and May. However, in the case of the sills which had lost from 19 to 28 pounds an average increase in the weight of approximately 2 pounds was shown. From May until September, 1908, all of the material lost weight much more gradually than when first placed out, as in the case of the bridge stringers. About the middle of September, when the rainy season on the Pacific coast usually begins, there was a marked increase in the weight of each of the specimens, but in most cases the increase was considerably less than the total decrease in weight during the summer. Only one weighing was made between the middle of November and the middle of August, when the specimens were tested. The weighings in August, 1909, were approximately the same as they were in August, 1908. If the seasoning had been continued it is probable that the minimum weight which might have been reached in 1909 would have been slightly less than the minimum reached in 1908.

Diagram 12, it must be remembered, represents the moisture distribution of the specimens in the middle of August, 1909. It is very probable that the change in the moisture content of the timbers after September, 1908, was confined largely to the surface and intermediate sections, indicating that the car sills were thoroughly seasoned by September, 1908, about 15 months after the seasoning began. The rapid loss in the green weight of the timbers of this class between June and September is of interest in estimating the freight which might be saved by seasoning such timbers before shipment. During this period of the year each of the bridge stringers lost a little more than 20 pounds per month, and in the car sills the loss ranged from 10 to 15 pounds per month.

SHRINKAGE DURING SEASONING.

At the time the different weighings were made in this series of tests the timbers were also measured to determine the shrinkage in the cross sections during seasoning. Diagrams 13 and 14 show the average area of the cross sections at various stages of the seasoning process. Diagram 13 shows the shrinkage in the bridge stringers. A comparison of the shrinkage and weight curves shows that shrinkage became noticeable as soon as the specimens began to lose weight, and that the rate of shrinkage was approximately proportional to the loss of weight. During the wet season, when the weight increased, there was also a slight swelling, followed by a continued shrinkage, when the specimens again began to lose weight. Yet, relatively, the shrinkage from April to September, 1907, was greater than it was from July to October, 1906, while the weight lost was almost twice as much during the earlier period as during the later. In general, diagram 14 shows the same thing for the car sills. The shrinkage during the second summer, however, was not more marked than it was during the first summer of the seasoning process. The fact that there is a rapid shrinkage as soon as seasoning begins indicates that

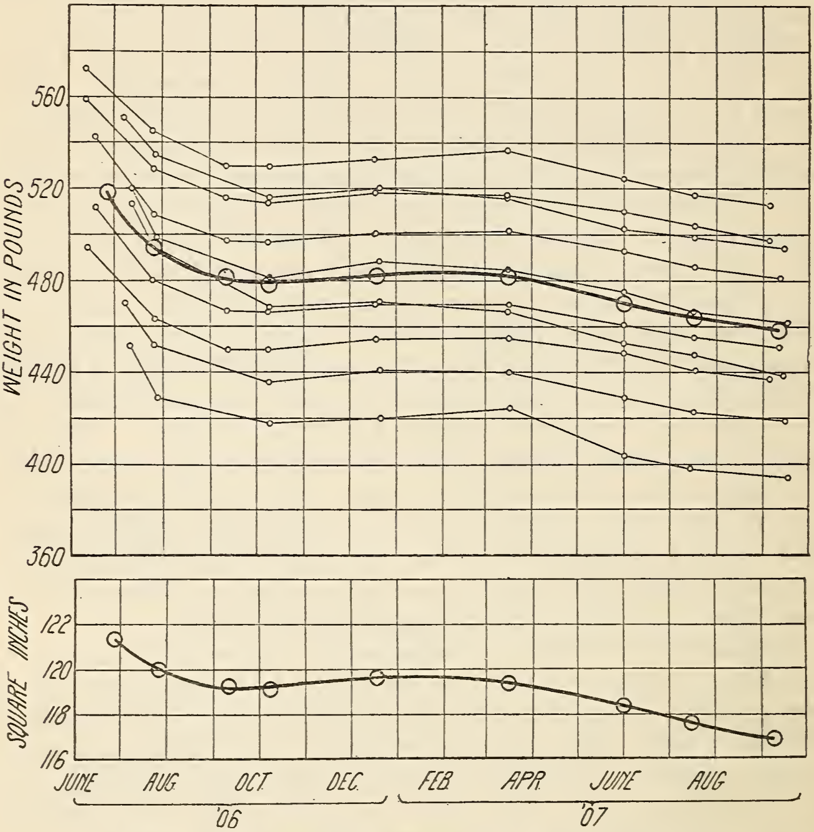

DIAGRAM 13.—Loss in weight and shrinkage through seasoning, 10 bridge stringers.

the shrinkage in its early stages is largely confined to the surface fibers. This explains the marked tendency of Douglas fir timbers to check very badly. Checks from one-fourth to one-half inch wide and 2 inches deep were quite common, extending through the entire length of the pieces. This checking was especially noticeable in boxed-heart pieces, often at the ends of the stick extending from the side faces entirely to the pith line. A study of diagram 14 shows that the car sills placed out to air season in July had only lost between 14 and 17 pounds by the middle of the following September, while the sills placed out in June lost from 19 to 28 pounds. In this latter class of material an increase in moisture was observed during the winter months, while in the first class the weight decreased slightly during the winter. This apparently indicates that green material will season during the winter months under climatic conditions that ordinarily prevail in the Willamette Valley and Puget Sound region. The seasoning would, of course, be much less rapid, and would be more uniform throughout the section of the timbers. This would produce more uniform shrinkage, and accordingly lessen considerably the checking which occurs when the seasoning process begins during the summer months.

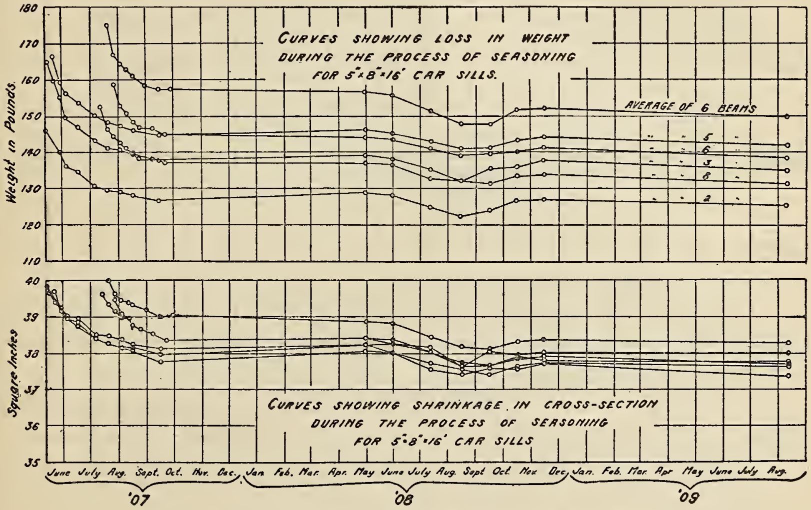

DIAGRAM 14.—Loss in weight and shrinkage in cross section during the seasoning of car sills.

EFFECT OF SEASONING ON STRENGTH.

Forest Service Bulletin 70 [1] and Circular 108 [2] discuss very fully the effect of moisture on the mechanical properties of different woods. The curves shown in diagram 15 were obtained from a

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[1] The Effect of Moisture on the Strength and Stiffness of Wood.

[2] The Strength of Wood as Influenced by Moisture.

similar series of experiments and show to what extent the strength of small pieces of Douglas fir is affected by their moisture content. These diagrams show that when the moisture content is reduced to below approximately 23 per cent the modulus of rupture and crushing strength begin to increase at a rapid rate; and it is possible to increase the crushing strength of clear wood from approximately 4,200 pounds per square inch in the green condition to 13,000 pounds per square inch when the moisture content is reduced to about 2 per cent. Since the minimum moisture content which can be secured by air seasoning is practically 10 per cent, the crushing strength of Douglas fir could be increased by air seasoning from approximately 4,200 to about 8,000 pounds per square inch, and the breaking strength or modulus of rupture for small beams from 9,000 pounds per square inch to a little less than 13,000. The modulus of elasticity is much less affected by the moisture content. The above results are only true of small specimens of wood that contain no defects.

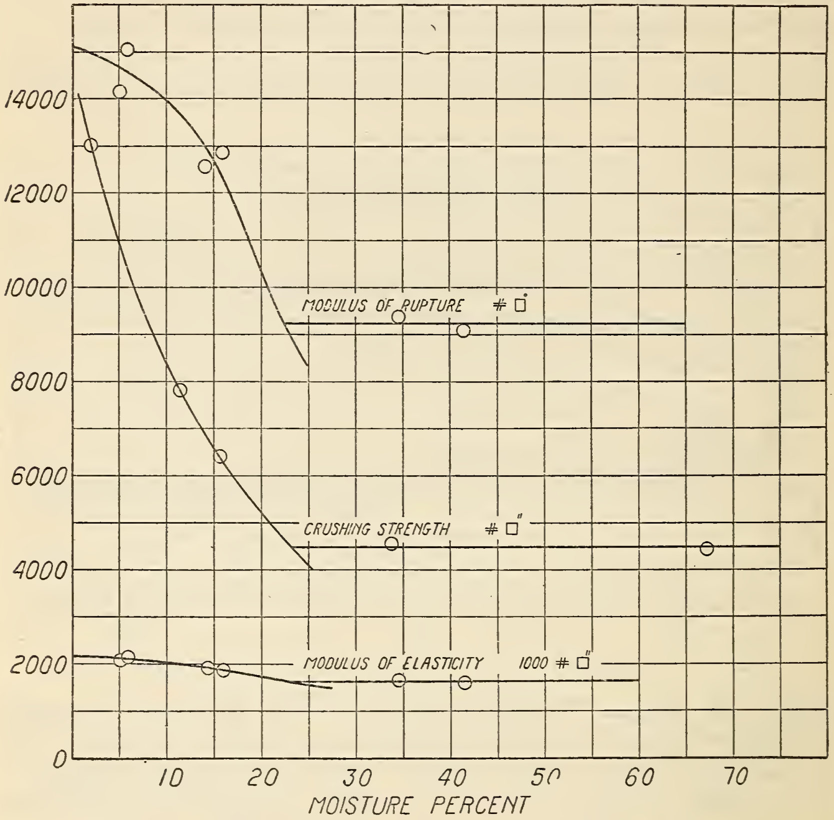

DIAGRAM 15.—The effect of moisture on modulus of rupture, crushing strength, and modulus of elasticity.

Table 11.—*Effect of air seasoning on strength as shown by tests on green and air-dried halves of ten 8-inch by 16-inch by 32-foot bridge stringers.*

Green.							Air dried.						
Stick No.	Moisture content.	Weight.		Fiber stress at elastic limit per sq.in.	Modulus of rupture per sq.in.	Modulus of elasticity per sq. in.	Stick No.	Moisture content.	Weight.		Fiber stress at elastic limit per sq.in.	Modulus of rupture per sq.in.	Modulus of elasticity per sq.in.
		As tested.	Oven dry.						As tested.	Oven dry.			
	Per cent.	*Lbs. per cu.ft.*	*Lbs. per cu.ft.*	*Lbs.*	*Lbs.*	*1,000 lbs.*		*Per cent.*	*Lbs. per cu.ft.*	*Lbs. per cu.ft.*	*Lbs.*	*Lbs.*	*1,000 lbs.*
1	31.2	38.8	29.6	4,980	6,090	1,645	1A	16.8	35.8	30.6	6,830	8,590	1,735
2	32.0	38.9	29.5	4,690	5,550	1,465	2A	16.8	36.4	31.2	6,120	8,110	1,670
3	35.5	34.8	25.7	3,860	5,970	1,390	3A	16.3	31.4	27.0	4,960	5,860	1,440
4	32.3	41.4	31.3	4,690	6,310	2,000	4A	16.5	35.3	30.3	6,240	6,800	1,695
5	27.0	35.8	28.2	4,420	6,640	1,380	5A	16.6	32.2	27.6	4,960	5,560	1,380
6	25.5	36.5	29.1	2,950	5,170	1,050	6A	16.7	35.8	30.7	6,210	7,410	1,570
7	31.3	33.3	25.4	2,920	4,830	1,120	7A	15.4	29.9	25.9	5,530	7,090	1,890
8	28.3	34.6	27.0	3,320	5,170	1,600	8A	16.3	32.1	27.6	4,600	5,040	1,720
9	32.2	32.3	24.4	2,930	4,810	1,450	9A	15.7	28.6	24.7	4,340	5,870	1,395
10	32.9	36.1	27.2	2,640	3,900	1,270	10A	17.3	32.9	28.1	4,990	7,040	1,715
Average	30.8	36.3	27.7	3,740	5,440	1,437	Average	16.4	33.0	28.4	5,478	6,740	1,621
Maximum	35.5	41.4	31.3	4,980	6,640	2,000	Maximum	17.3	36.4	31.2	6,830	8,590	1,890
Minimum	25.5	32.3	24.4	2,640	3,900	1,050	Minimum	15.4	28.6	24.7	4,340	5,040	1,380
							Ratio air dried to green	53	91	103	146	124	113

Table 11 shows the effect of air seasoning on the strength of Douglas-fir bridge stringers. The green 32-foot stringers were selected to be as uniform as possible throughout their length. One half of each 32-foot piece was tested in a green condition, and the other half tested after air seasoning.

The results of the two tests on the green and air-seasoned specimens secured from each 32-foot stringer, as well as the ratio between the results, are grouped under the numbers from 1 to 10, inclusive; the results in bold-faced type being secured from the green material. This table shows that, with few exceptions, the fiber stress at elastic limit, modulus of rupture, and modulus of elasticity were increased by seasoning, the average increase in these functions being respectively 46, 24, and 13 per cent. The average moisture content of the air-seasoned material was 16.4 per cent.

TABLE 12.—*Results of bending tests on partially air-dry material with defects; average values; size 8 inches by 16 inches by 15 feet 6 inches.*

Grade.	Number of tests.	Rings per inch.	Proportion of summerwood.	Moisture content.	Weight per cubic foot.		Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
					As tested.	Oven dry.			
Select:		*Number*	*Per ct.*	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*1000 lbs.*
High 10 per cent	4	28.6	34	28.3	41.7	34.3	6,048	8,515	2,044
Low 10 per cent	4	8.1	19	15.8	28.5	23.9	3,413	5,340	1,298
Average	35	17.4	27	21.4	34.4	28.3	4,690	7,070	1,644
Average for green material							4,346	6,753	1,654
Ratio (green=100)							108	105	99.5
Merchantable:									
High 10 per cent	3	29.4	31	25.5	36.8	29.4	5,597	7,937	1,883
Low 10 per cent	3	4.2	15	15.1	28.2	24.1	3,250	4,740	1,349
Average	29	12.6	21	21.2	32.4	26.7	4,625	6,472	1,567
Average for green material							3,895	5,878	1,481
Ratio (green=100)							119	133	1.06
Seconds:									
High 10 per cent	2	11.8	35	28.6	37.6	31.8	5,925	8,060	1,720
Low 10 per cent	2	3.1	18	15.9	31.9	25.7	1,830	2,495	900
Average	17	6.9	25	21.3	33.9	27.9	3,740	4,551	1,280
Average for green material							3,538	5,188	1,328
Ratio (green=100)							106	88	9.65

In addition to the results shown in Table 11, a number of tests were made on various grades of Douglas-fir stringers seasoned from six to eight months; the grades select, merchantable, and seconds being those defined in the export grading rules of the Pacific Coast Lumber Manufacturers' Association adopted in 1903. The results of these tests are shown in Table 12. It will be seen that in this group of stringers the fiber stress at elastic limit and modulus of rupture, in the case of select material, are increased, respectively, 8 per cent and 5 per cent by seasoning, the modulus of elasticity remaining practically unchanged. In the merchantable material the increase in these functions is respectively 19, 33, and 6 per cent. In the seconds the fiber stress at elastic limit increased 6 per cent, while the modulus of rupture and modulus of elasticity show, respectively, a decrease of 12 and 2 per cent. In Table 13 it is seen that these three functions, in the case of select car sills, are increased by seasoning 35, 27, and 15 per cent, respectively. In the merchantable grades the increases are 53, 49, and 32 per cent. In the seconds the increases 19, 12, and 14 per cent. These results show that the greatest increase in the three strength functions is shown in the merchantable grade and the smallest increase in the second grade.

TABLE 13.—*Results of bending tests on air-dry material with defects, graded according to Pacific coast export grading rules; average values; size 5 inches by 8 inches by 15 feet.*

Grade.	Number of tests.	Rings per inch.	Proportion of summerwood.	Moisture content.	Weight per cubic foot.		Fiber stress at elastic limit, per square inch.	Modulus of rupture, per square inch.	Modulus of elasticity, per square inch.
					As tested.	Oven dry.			
Select:		*Number*	*Per ct.*	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 lbs.*
High 10 per cent	1	29.9	57	15.0	39.0	33.9	9,240	9,350	2,393
Low 10 per cent	1	9.6	30	13.9	30.4	26.5	4,440	6,040	1,431
Average	10	18.3	47	14.7	33.7	29.4	5,814	7,801	1,956
Average for green material							4,320	6,147	1,698
Ratio (green=100)							135	127	115
Merchantable:									
High 10 per cent	1	16.7	65	15.6	40.9	35.4	8,170	10,170	2,481
Low 10 per cent	1	4.8	29	14.3	28.2	24.6	2,170	2,730	1,583
Average	10	9.7	43	15.1	32.9	28.6	5,399	7,359	1,991
Average for green material							3,532	4,946	1,513
Ratio (green=100)							153	149	132
Seconds:									
High 10 per cent	1	16.0	54	15.8	35.1	30.4	5,000	7,480	1,906
Low 10 per cent	1	4.4	23	14.3	29.0	25.3	2,920	3,440	1,290
Average	10	8.5	37	15.1	32.1	27.9	3,981	5,170	1,613
Average for green material							3,344	4,618	1,419
Ratio (green=100)							119	112	114

FAILURES IN SEASONED TIMBER.

The failures in seasoned Douglas-fir stringers and car sills were similar to those in green material, except that failures in horizontal shear were more common. In the seasoned stringers 6 per cent of the selects, 20 per cent of the merchantables, and 5 per cent of the seconds failed first in horizontal shear. In the green stringers the percentage of numbers failing first in horizontal shear were for the three grades, respectively, 2, 2.6, and 0. As a secondary failure, however, horizontal shear was much more common. Forty-three per cent of the air-dry stringers and 18 per cent of the green developed a failure in horizontal shear. These secondary failures, however, never occurred until after the characteristic compression failure so common in green material made its appearance. Sixty-five of the 81 air-dried stringers tested failed first in compression. In the car-sill sizes 78 out of 97 specimens failed first in compression.

Failure in horizontal shear is more common in seasoned than in green timbers, because the net area resisting shear along the neutral plane is often considerably decreased by checks. It seldom occurs in weak, low-grade material, which fact is doubtless due to the dowelling-pin action of the knots invariably associated with low-grade timbers.

Table 14 shows the calculated shearing stresses developed in beams which failed first in horizontal shear; in beams which had a secondary failure in horizontal shear; and in beams which did not fail in shear.

The fact that the 8 by 16 inch timbers were tested under center loading accounts to a certain extent for the small number of cases in which shear was the first failure. It is seen from Table 1 that the shearing strength of green Douglas fir ascertained from tests on small pieces is 770 pounds per square inch, while the calculated shear in beams seldom exceeds 300 pounds per square inch. Unless, therefore, the area resisting shear is greatly decreased by checks or shakes, shear is not likely to occur in the sizes tested.

This summary of failures, as well as that for green material, page 39, indicates conclusively that in general the point of greatest weakness in Douglas-fir beams is the part subjected to the highest stresses in compression parallel to the grain. The principal exceptions to this rule are beams that have large knots on or near the tension face, beams that have bad diagonal or cross-grain, and beams that contain deep checks along the neutral plane. The elastic limit of the beam is closely related to the strength of the wood in compression parallel to grain, while the modulus of rupture is most dependent upon the quality of the wood that is subjected to tensile stresses.

TABLE 14.—*Calculated shearing stresses developed in beams which failed in horizontal shear.*

	8″ by 16″–16′.				5″ by 8″–16′.			
	Green.		Air dry.		Green.		Air dry.	
	No. tests.	Av.	No. tests.	Av.	No. tests.	Av.	No. tests.	Av.
		Lbs. per sq. inch.		*Lbs. per sq. inch.*		*Lbs. per sq. inch.*		*Lbs. per sq. inch.*
First failure by horizontal shear	3	166	5	221	0	......	1	169
Horizontal shear following other failure	35	274	40	298	1	222	0	......
Calculated shear—no shear failure	133	254	36	240	83	171	29	219

PART II.—COMMERCIAL USES.

Douglas fir is manufactured into almost every form known to the sawmill operator, and much round or hewed timber is used which never passes through a sawmill. A list of such forms and uses would represent many industries and would include piling and poles; mine timbers, railway ties, and bridge and trestle timbers; timbers for car construction; practically all kinds of lumber for houses, material for the furniture maker and boat builder; special products for cooperage, tanks, paving blocks, boxes, and pulpwood; fuel; and a long line of miscellaneous commodities including wood for distillation.

Table 15.—*Reported products from Douglas fir in the United States in 1908.*

Commodity.	Quantity.	Value.
Lumber.........feet..	3,675,114,000	$43,973,111
Railway ties.........ties..	7,976,950	3,958,856
Poles..........	19,542	80,024
Lath..........	572,276,000	[1] 567,123
Veneers.........feet, log scale..	333,000	5,192
Distillation.........cords..	974	4,581

[1] This includes lath made from all species in Washington and Oregon. Report by species was not made.

PILING.

Piling is extensively employed in harbor-improvement work and in preparing foundations in soft ground for bridges, trestles, and other heavy structures. The long, straight, slightly tapering trunk of Douglas fir fits it for this use, and it is strong, resilient, and fairly durable. It has no important competitor as a pile timber in the western part of the United States, and is used almost exclusively for marine and railroad work on the Pacific coast. The wood is sufficiently hard to penetrate readily most soils, and it acts well under the hammer. It is occasionally necessary to band the tops of piles to prevent brooming and splitting, but bands are used only where hard subsoils must be penetrated.

PRESERVATIVE TREATMENT.

Untreated Douglas fir piling is fairly durable, though its durability will vary, of course, according to the place where it is used. West of the Cascade Mountains, in trestle construction, the average life of the untreated pile is about 8 years; east of the Cascades, when not affected by alkali, it is expected to last 10 years; but an alkaline soil or situation may cut its period of usefulness to 6 years. The first indications of decay in untreated fir piling are usually seen about 3 inches below the ground line or just under the cap. When the piling is to be creosoted it is best to wind 6 or 8 feet of the top of the pile with 15 or 20 turns of telegraph wire, and to put on a ring to lessen its tendency to split and shatter under the impact of the hammer. The sapwood contains most of the preservative, and if this is split in driving the effect of the treatment is in part nullified. In driving creosote piles the best results are obtained with a steam instead of a drop hammer, as there is less likelihood of shattering the stick and thereby opening seams through the casing of treated wood to the untreated interior.

Untreated piling lasts from 3 years to 6 years on the California coast. The teredo and other marine borers attack it, as they do nearly all timbers exposed in salt water. On Puget Sound, piling has been destroyed by marine borers in 6 months. When intended for permanent work, fir piling should always be treated with a preservative to repel marine borers, or it should be protected in some other way against their attacks. Creosoted Douglas fir piling has remained sound for 20 years in salt water on the Pacific coast. Fir piles find wide use as far east as the Mississippi River. A set of standard specifications for fir piling follows, in order to show the requirements for this use:

PILING SPECIFICATIONS.

Piles must be straight with not more than 1 inch deviation per 10-foot length of pile from a true line drawn from butt to tip; for instance, a pile 60 feet long can deviate 7 inches from a straight line drawn from butt to tip.

They must be stripped of bark and be not less than 9 inches diameter at the tip or small end. At the butt they must be not less than 13 inches nor more than 17 inches diameter.

They must be sound, free from large knots, wind shakes, felling checks, rot, or other defects.

All limbs and knots must be cut flush.

All piling is subject to inspection at point of delivery.

POLES.

Railroad and telegraph companies use a limited number of Douglas fir poles in regions where this timber is cut. Usually the poles are logged from forest land where clean cutting is practiced, but occasionally second-growth stands are logged for poles alone. The young tree's long, tapering trunk gives it an admirable form for this use, but it can not compete with the abundant and more durable western red cedar, and to that fact is due the limited use of Douglas fir for poles in regions where the cedar may be had. Its use for poles is restricted chiefly to county telephone and telegraph lines and to lines for carrying block-signal wires, in regions where the cedar is more difficult to obtain. As the supply of cedar poles diminishes, and a satisfactory butt preservative treatment is developed for Douglas fir, it may be substituted for cedar. Large and attractive sawed poles of fir are in use on many electric car lines in cities where utility and handsome appearance are combined. Some of the street car lines in the vicinity of Washington, D. C., are equipped with Douglas fir poles.

FLAG POLES.

Douglas fir flagstaffs are in use in all parts of the United States, and probably those of no other one wood approach them in number, especially in large sizes. The flagstaff at Kew Gardens in England is of this wood, and is 159 feet high.[1] The wood is widely used for tent poles and camp outfits.

MINE TIMBERS.

Douglas fir is used as a mine timber, both in the square and round forms, in the western part of the United States. Squared mine timbers of Douglas fir also go to Pennsylvania and to foreign countries. It is frequently preferred to all other available species, because of its durability and strength, and because of the desirable sizes in which it may be obtained. Where a supply of this timber is at hand, it also goes largely into temporary work, such as lagging, sills, posts, and caps. When it can not be conveniently procured, substitutes are frequently found in lodgepole pine and western yellow pine.

SQUARE.

In the square form, Douglas fir has no competitor for shaft and tunnel timbers in regions where it is plentiful. Few of the large western mines use any other wood for that purpose, especially in permanent work. Its particular and most common use in the square form is for caps, sills, and posts in tunnels, and for square sets in stopes.

ROUND.

The round form of mining timber seems to be most common in Colorado, where the local species of Douglas fir, commonly called "red spruce," is used. Even in this region the coast fir is preferred for permanent work. In the southwestern section of the country,

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[1] The Trees of Commerce, Wm. Stevenson.

where western yellow pine is the prevailing local species, mine operators think that Douglas fir is much better, and they bring the square forms sometimes from a distance of more than 1,000 miles.

PRESERVATIVE TREATMENT.

Both square and round timbers of Douglas fir are in some cases treated when used in permanent mine work. The treatment generally consists in impregnating the wood with creosote, but carbolineum and zinc chloride have been used. Round timbers are easily treated, because the soft sapwood readily absorbs the fluids. The wood should be peeled clean of bark before treatment. In the square form, the impregnating of Douglas fir with preservative fluids has never been entirely successful, because the density of the heartwood hinders the penetration of the preservative. Of late years, however, considerable progress has been made in developing a successful treatment of Douglas fir heartwood by the boiling process, followed by pressure. When treated with zinc chloride, a 3 per cent solution is generally used. The timber is first steamed for the purpose of seasoning, and is then impregnated with the solution. When carbolineum is used, the timber is merely dipped in a tank containing the heated preservative.

RAILWAY TIES.

Ties of Douglas fir are both sawed and hewed, though three-fourths are sawed. Much of the inferior timber in logging operations is worked into ties. Those which are sawed are made both from second growth and from mature trees. About two-thirds of the ties supplied by the forests of the western part of the United States are of Douglas fir, the remaining one-third consisting chiefly of western yellow pine, lodgepole pine, redwood, and western hemlock. Practically all the large sawmills in Washington and Oregon cut fir ties to order, and some small mills cut little or nothing else. It is customary to saw ties from a large portion of low-grade material obtained in the usual milling operations. Douglas fir generally yields about 25 per cent of high-grade lumber and the remaining 75 per cent must be worked into lower grade lumber, dimension products, timbers, and ties. Though the season in which the trees are cut probably influences the durability of the wood, no consideration is given to this element by the tie makers. A set of standard specifications which shows the requirements of Douglas fir ties follows:

SPECIFICATIONS FOR SAWED TIES.

Ties must be sawed out of red or yellow fir, and must be 7 inches thick, 9 inches wide, and 8 feet long. They must be sawed out of sound, straight, live timber, and must be free from bark, splits, shakes, cross grain, loose or decayed knots, pitch seams, or any other imperfections which may impair their strength or durability. A variation of 1 inch over in length, one-half inch over in thickness, and 2 inches over in width will be permitted. All ties which do not come up to the requirements of the above rule are to be termed "culls," and will not be accepted.

PRESERVATIVE TREATMENT.

Several railroad companies and a number of private companies operating in the Northwest have devoted much attention in recent years to the treatment of Douglas fir ties, both with creosote and zinc chloride. A large portion of the ties now going into the tracks receive such treatment. The sapwood is easily impregnated with preservative fluids, but the heart, because of the density of the summerwood, is probably harder to treat in a satisfactory manner than any other softwood species. Fairly good results are obtained by the pressure and boiling method, which has been recently developed. It is believed that the time is not distant when all Douglas fir ties will be treated with preservatives. The wood resists rail cutting moderately well, but it is customary to use a steel tie plate under the rail, and this insures a mechanical life equal to the physical life of the ties. Untreated Douglas fir ties last about six years on the west slope of the Cascades in Washington and Oregon. The use of Douglas fir ties rose from 3,633,276 in 1905 to 14,524,266 in 1907, and the next year fell to 7,986,950. The decline was due to a falling off in railroad construction.

LOGS.

In the Puget Sound region in Washington most of the Douglas fir logs are transported to the mills by water, either by driving on the small streams or by towing in rafts on the sound. Occasionally roads are constructed on which logs are carried to the mills. The rafting method is often employed by operators along the Columbia River, where the camps are generally near the stream, and the logs are brought out of the woods with donkey engines and skid roads, or by short logging roads, and then towed in rafts to the mills. In the Willamette Valley and coast regons of Oregon many of the old mills continue to drive their logs, though at the present time a large majority of the logs go to the mills by rail.

GRADES OF LOGS.

Many mill operators own land and do their own logging, while others depend for supplies upon logging companies. Purchase in the Puget Sound region is according to grades, and the grading is done by scalers at the mill. Three grades are recognized—flooring, merchantable, and No. 2. The flooring logs are large and sound, and yield a high percentage of clear lumber for flooring, ceiling, and general finish work. The poorest grades of top logs, knotty timber, and small logs containing much sap go into the No. 2 class. They are generally manufactured into railroad ties, timbers, and common lumber. The merchantable logs are intermediate between the two.

PROPORTION OF GRADES SECURED.

The percentage of grades of lumber cut from Douglas fir logs varies with the locality where the timber grows. Occasional stands yield as high as 35 per cent clear lumber from an average raft of logs. In other cases the percentage is as low as 15. The average raft in Washington and Oregon yields 20 to 25 per cent clear lumber. Logs on the Columbia River are usually purchased in raft lots scaled by grade. Three grades of logs are recognized—No. 1, No. 2, and No. 3. These correspond with the flooring, merchantable, and No. 2 logs on Puget Sound. No. 1 logs must be sound and should cut 50 per cent clear lumber and be not less than 30 inches in diameter inside the bark and 16 feet long. No. 2 logs must be 16 inches in diameter and 16 feet long. No. 3 logs include all other logs classed as saw logs. Scale allowances are made to compensate for defects. Timber classed as yellow fir is of slow growth, yellow in color, and cuts a large percentage of clear lumber. Red fir comes from small, young timber, and yields a low percentage of clear lumber, running largely to common grade, but quite satisfactory for timber and dimension sizes for building purposes. The color of the wood is slightly red. Bastard logs represent a grade between the yellow and the red. In the Willamette Valley and Coos Bay regions, no grades are recognized, and logs are purchased entirely on a scale basis. The mills in these regions generally get their logs from their own near-by holdings.

LUMBER.

SEASONING.

Rough Douglas fir lumber, consisting of boards and dimension, is either air seasoned in the yards or is shipped green. It is never kiln-dried at the coast mills. During the summer about 90 days is required in the Pacific Northwest to give a fair seasoning to common 1-inch lumber properly piled. Dimension lumber is usually shipped green, but occasionally it is air-dried for a short time before shipment.

DISTRIBUTION.

The distribution of Douglas fir lumber is practically world wide, though the largest part of it is used in the United States. Most of the common 1-inch stuff is consumed locally for concrete forms for sheathing and rough structural purposes, or, when shipped, is sold in the Plains States east of the Rocky Mountains and adjacent regions. The distribution of dimension material does not differ greatly from that of common lumber, except that a considerable quantity is exported to China, Japan, the Philippine Islands, and elsewhere. The large size timbers, however, go all over the world. The Orient depends largely upon them for heavy construction, as does the entire western part of the United States. Much of the massive timbering required by the Panama Canal is of this wood, and large shipments go regularly to Australian and Japanese ports, where they are resawed into various building forms. Europe affords a market, as do the Atlantic Coast States, for many cargoes of Douglas fir timbers that compete successfully with the yellow pines of the South. Douglas fir lumber is very widely distributed in all the countries of the Orient, in most European countries, South Africa, South America, and the South Sea Islands. Large amounts of it are sold in the central and eastern parts of the United States through retail yards.

BRIDGE AND TRESTLE TIMBERS.

Probably the Pacific coast railroads use more Douglas fir than is consumed by any other single industry. Bridge and trestle timbers of the wood compare favorably in their structural merits with those from any other American species. They are light and strong, fairly resilient and durable, and can be had in any desired size or specification. In trestles, fir is used in the round form for piling, and in dimension sizes for posts, caps, sills, ties, girts, and braces.

CAR MATERIAL.

Douglas fir car sills are used in the construction and repair of freight and passenger cars throughout the United States. Their strength, elasticity, durability, and the ease with which the wood may be worked make them preferable to all others. The wood is much employed in car building for purposes other than sills. In fact, it is used for nearly all purposes, except for draft-rigging supports, which are of oak or maple. It is employed for siding, framing, flooring, roofing, and many other parts of passenger cars. Though the interior finish of cars is generally of hardwood, Douglas fir has been given place in some dining and private cars, because of the beauty of its grain.

HOUSE CONSTRUCTION MATERIAL.

For house construction Douglas fir is manufactured in all forms of dimension stock, and is used particularly for general building and construction purposes. Its strength and comparative lightness fit it for joists, floor beams, rafters, and other timbers which must carry loads. Occasionally entire buildings are constructed of it, and in some parts of the Pacific States it is practically the only common lumber used. The largest consumption is in Washington, California, Oregon, Utah, Idaho, and Colorado.

FLOORING.

The comparative hardness of the wood fits it for flooring, and it meets a large demand. Douglas fir edge-grain flooring is often considered superior to that made from any other American softwood, and it is used on the Pacific coast to the exclusion of nearly all others. In residences and high-priced buildings, hardwood floors sometimes take precedence over Douglas fir.

BEVELED SIDING.

Fir comes in direct competition with Sitka spruce and western red cedar in the manufacture of beveled siding, and it usually yields place to them where they may be conveniently had.

FINISH.

In the Northwest, where the merits of Douglas fir are best known, the wood has recently gained an important place for finish. Clear lumber, sawed flat grain, shows pleasing figures, and the contrast between the spring and summer wood has been considered as attractive as the grain of quarter-sawed oak. It takes stain well, and, by staining, the beauty of the grain may be more strongly brought out, and a number of costly woods can be successfully imitated. Fir finish has been widely advertised, and the demand for it in the Eastern States, the Middle Western States, and in the Upper Mississippi Valley is rapidly increasing. Its chief use is for door and window casing, baseboards, and all kinds of panelwork. Practically all of the finish is used by the building trades, and the largest use naturally is near the points of production, though it is in great demand in southern California and in Hawaii.

SASHES AND DOORS.

The best grades of "yellow fir" lumber are used for sash and door work, and for this purpose it competes in the Northwest with spruce and western red cedar. Even in other parts of the country, its strength and cheapness and the ease with which it is finished give it an advantage which has enabled it to displace other woods to a large extent, and factories in the Northwest are competing with white pine and southern yellow pine for sash, frame, and door work. In products of this kind, as in others, the wood's adaptability to staining adds greatly to its appearance and value.

VENEER.

Douglas fir is made into rotary cut veneer, which goes chiefly into the manufacture of door panels. The logs intended for veneer are steamed about three days to soften the wood and make it easier to cut.

BOAT CONSTRUCTION MATERIAL.

Douglas fir has long been the most important timber for boats and ships on the Pacific coast. It is suitable for both outside and inside work, and ships which are built almost wholly of this wood have been long in service in the carrying trade to many parts of the world. Nor is Douglas fir confined to Pacific coast dockyards, but finds its way to shipbuilding ports on the Atlantic coast, in England, and on the Continent. It finds a place in all sizes of vessels, from the rowboat to the ocean liner. It is particularly suited for decking, planking, keels, yards, ribs, and finish. A considerable quantity is made into rough-hewed knees for large ships. These knees are obtained by so splitting stumps as to leave pieces of the stump with each root, and they are then hewed to the required shape and size. Ribs of this wood give much rigidity and strength, though in the better class of vessels preference is generally given to eastern oak or to oak grown in Oregon. It is claimed that fir is not inclined to soften when used in boats. In the building of small vessels it is customary to substitute eastern oak or Port Orford cedar for inside planking. Though Douglas fir is sometimes used for cabin work, it generally gives place to cedar, teak, oak, mahogany, and rosewood. Few woods meet the requirements for masts as well as Douglas fir, and the demand is great and widespread. The regular taper, durability, strength, and resilience give it its chief value.

FURNITURE MATERIAL.

The use of Douglas fir in furniture making in the West follows pretty closely the lines of the use of yellow pine for similar purposes in the South and East. Many factories in the large cities of the Northwest use the fir in large amounts, though local hardwoods and those shipped from the East are also used. The fir is manufactured, for the most part, into the cheaper grades of furniture, such as couches, kitchen cabinets, low-grade tables, bedroom washstands, dressers, chiffoniers, wardrobes, mirror frames, chairs, sideboards, and pews and other church furniture. Not only can it be stained to resemble many other woods, but it is sometimes stamped to simulate quarter-sawed oak, and is thus seen in furniture and other woodwork. If it is to be stained or stamped, it is thoroughly air-dried or kiln-dried to "kill" the pitch, which is one of its most objectionable features for furniture.

MISSION FURNITURE.

The recent popularity of the so-called "mission" or "handcraft" furniture has opened a new field for the use of this wood. Chairs, tables, and buffets in this style are now manufactured from Douglas fir, and they compare in beauty with the same class of furniture made from chestnut and the more expensive oaks.

COOPERAGE.

Tight and slack cooperage are made from Douglas fir on the Pacific coast, though little of the wood is put to this use outside the region where the timber grows. Some cooperage plants employ fir almost exclusively. The slack barrels are provided with elm hoops imported from the East, and the tight barrels with metal hoops. The tight packages can be used as containers for all liquids except those that contain alcohol, and serve for the shipping of oil, vinegar, fish, pickles, and meat. In some cases the barrels are coated inside with paraffin, in order that the wood may not impart its taste to the contained foodstuffs. Coopers like the wood for barrels because it is cheap, strong, durable, and nearly impervious to water.

TANKS.

Tanks of nearly all descriptions and sizes are made of this wood. Tank stock is regularly listed by the lumber companies which saw Douglas fir, and it finds ready sale in the Rocky Mountain and Pacific Coast States.

CONDUITS.

The manufacture of conduits and water pipes is near akin to cooperage. Staves are largely used in the construction of conduits, and high-grade Douglas fir supplies great quantities. Such staves are made from flat-grained lumber, with the wood as nearly of uniform growth as may be had. They are made in such shape as to give the finished conduit a cylindrical form, and its different parts are so closely fitted as to make it waterproof. When the pipe is 24 inches or less in diameter it is constructed from staves of special pattern, with grooved edges. Such pipes are built up at the factory, and are wound from end to end with mild steel wire, after which the exterior is covered with an asphalt-and-tar mixture for preservative purposes. The thickness of the staves and the pitch of the wire reenforcement varies according to the pressure under which the pipe is to be used. Conduits larger than 24 inches are set together at the place where they are to be used. Such pipes are always continuous, the staves being so placed as to break the joints. In large conduits the staves are usually 6 inches wide, with beveled edges, and are curved to conform to the diameter of the pipe. When the staves have been set in place, the pipe is drawn tight with steel bands and bolts, and all the joints are closed. Conduits thus constructed form important parts in the water systems of many western towns and cities, and are widely used for manufacturing plants, irrigation works, hydraulic mining, dredge work, oil pipes, wire conduits, for steam-pipe casing, and for various other purposes. Douglas fir pipes of this kind are used not only in the Pacific Coast States, but also in the Eastern and Middle States, in British Columbia, and in Alaska.

PAVING BLOCKS.

Paving blocks of Douglas fir, when given preservative treatment, are rapidly coming into use in municipal improvements. The wood's hardness and the comparative ease with which the blocks may be treated with creosote make it compare favorably with other paving woods. The blocks wear slowly under heavy traffic, are nearly noiseless, furnish fair toe hold to horses, are resilient, and are practically impervious to water. It is important, however, that they be thoroughly impregnated with preservatives.

BOXES.

Douglas fir lumber is not extensively employed in box making. There is a convenient and abundant supply of the better Sitka spruce and western hemlock, which do not split so easily in nailing.

PULP.

Several large paper mills operate in the Douglas fir region, and to a limited extent they make pulp of this wood, but generally combine it with other woods. Much more spruce, hemlock, white fir, and cottonwood pulp is manufactured, however. The density of the summerwood of Douglas fir, and the difficulty in bleaching the pulp, make it impracticable to manufacture the finer grades of papers from it, though mixed with black cottonwood it makes good wrapping paper. It may be reduced by either the mechanical or the soda process.

FUEL.

The mills of the Pacific coast which cut Douglas fir produce about four-tenths of a cord of slabwood for each 1,000 feet of lumber manufactured. The slabs which go for fuel are generally run through a slasher which cuts them in 4-foot lengths. Many mills still operate burners, where slabs and mill trimmings are disposed of, but a large number sell their slabs for fuel to manufacturing industries and to private residences.

Much cordwood is cut by farmers in clearing land. Such wood is known as "body" fir, and is generally considered superior to slabs for fuel. Slabwood sells at from $2.50 to $4.50 per cord, "body" fir at from $4 to $6. While the actual fuel value of this wood has never been determined, it has been estimated that for heating large office buildings and hotels a cord of fir slabwood, with an average value of $3.50, is equivalent, in heat units, to 2½ or 3 barrels of crude oil, at about $1.30 per barrel or approximately $3.60. The economy in the use of oil, therefore, would seem to lie chiefly in the ease with which the oil may be handled. Many mills manufacture the better portion of their slabs and edgings into lath.

MISCELLANEOUS.

Douglas fir has many miscellaneous uses, and these show the fitness of the wood for various purposes, It is excellent for certain classes of turnery, where strength is required, notably for porch and portico columns. It is put to some use for broom handles, ladder rungs, and balusters. Makers of agricultural implements draw upon it for many purposes. In fanning mills and thrashing machinery it is used for the frames, hoppers, sieve frames, seed boxes, chutes, drawers, and fans. It is often used for rakes and tedders, and for barn, mill, warehouse, and harvest machinery, and in carriage and wagon making and repairing. It is employed in the construction of organs, and for portable houses it has no superior. It goes into saddle trees and crosspieces for packsaddles, porch and lawn swings, and settees.

WASTE.

The waste in logging and milling Douglas fir, and the question of putting this waste to use, has received much attention. Waste begins with the felling of the timber in the woods and continues through the transportation of the logs, particularly if they are carried by water. It is conspicuous at the sawmill, planing mill, manufacturing plants and shops, through the various branches of the building trades, and among the makers and users of railway ties.

WASTE IN THE WOODS.

It is claimed that the waste incident to the logging of Douglas fir is often as much as 30 or 40 per cent—that that much of the tree is actually left in the woods. The top-cut log is likely to be thrown away, because it contains defects which would reduce to low grade the lumber sawed from it. The market for such lumber is poor, and the operator simply leaves the log to decay or to increase the fire menace. In rare instances the tops and branches are cut into cordwood, but nearly always they are left where they fall. The breakage of trees in felling constitutes a waste of large proportion though it is usually unavoidable, since the tree's size and weight, brings it down with great violence, and if the ground is uneven a broken trunk is likely to result. Then, too, smaller trees are broken by the fall of the large trunks, though the practiced feller tries to avoid this.

WASTE IN DRIVING.

When driving is resorted to, many logs are broken in jams, or by impact against rocks or other obstacles. Where splash dams are employed, the waste due to driving is increased by the many logs which are usually left stranded on the banks of the stream and never reach the mill. From 5 to 10 per cent of the logs may be so wasted. This large item of waste is generally eliminated when the logging is done by rail.

SAWMILL WASTE.

Slabs and other refuse, if converted into lath and other salable commodities, can not properly be classed as waste; neither should sawdust and other odds and ends burned for fuel in operating the plant. Some loss is, of course, unavoidable, but the material that goes into the refuse burner is sheer waste. Fortunately, these burners are becoming less numerous, and there is more care in sorting the stuff which goes into them. However, a number of Douglas-fir mills still operate burners where practically all of the mill waste is consumed.

PLANING-MILL WASTE.

It is a general rule that the item of waste is reduced in each succeeding stage of manufacture. Therefore, since the lumber which goes to the planing mill has nearly reached its final form, the planing-mill waste is less than that of the sawmill. Planing-mill waste consists chiefly of shavings and trimmings; the former usually goes under the boilers for fuel, and when the latter does not go there also it is usually sold for kindling.

WASTE IN MANUFACTURING INDUSTRIES.

The waste in manufacturing varies greatly through a long list, and the waste in one factory is not a sure measure for the waste in others. In practically all wood-using industries the shavings and small pieces which can not be worked into finished products go as fuel to furnish power for operating the plant. If the factory does not need all the fuel for its own use, a sale is generally found outside.

WASTE IN BUILDING TRADES.

A considerable part of the waste chargeable to the building trades is due to the even lengths in which siding, flooring, joists, scantling, and other building materials are sold. Douglas-fir manufacturers have recently agitated the question of making odd lengths, whereby the waste can be reduced, and it now seems probable that both odd and even lengths will be produced in the near future. The waste due to the nonmanufacture of odd lengths in planing-mill products amounts to about 2 per cent of the total amount so manufactured.

WASTE IN RAILWAY TIES.

The waste item in railway ties and other large material is considerable because of the rigid inspection rules. Most Douglas-fir ties are sawed, and the waste is much less than it would be if hewed ties were demanded. The rejected timbers which the inspectors throw out may be sawed into blocks and sold for fuel, and the actual waste is thereby lessened.

DISTILLATION.

Several distillation plants operate in the Douglas-fir belt west of the Cascades in Washington and Oregon, and depend entirely on the waste at nearby sawmills for their wood supply. Only the pitchy wood is used, for the distillation of the regular run of fir is not commercially profitable at the present time. Pitchy wood is unsuited to the manufacture of lumber, and would be often a total loss if not taken by the distillation plants. It is carefully selected from the scrap piles at the mills, and the price varies with the quantity of pitch. The operations are said to be profitable, and will undoubtedly be much extended as better processes and markets are developed.

PROCESSES.

Both the steam and the destructive distillation processes are employed in all the plants, the retorts being specially constructed to use both forms of distillation. The wood is chipped into blocks not more than 6 inches long and 2 inches in cross section, and when the retort is charged with them the steam distillation process is commenced. It continues for from six to eight hours, depending on the quantity of pitch in the wood. The temperature of the steam in the retort is gradually raised until it reaches about 325° F., at which point practically all the turpentine has passed over to the condensers. The crude turpentine is then piped from the condensers to a refining still. As soon as the distillate which comes from the condensers shows the presence of oils, the steam is turned off and the dry distillation process is begun, and is continued about 32 hours, the temperature rising gradually from 323° F. to 832° F. Between 350° F. and 600° F. pyroligneous acid and tar oils pass over in the form of vapor, are condensed, and are next piped to a tank where they can be mechanically separated, because the acid is heavier and is drawn off at the bottom of the tank after the liquid has stood for a short time. Between 600° F. and 800° F. pyroligneous acid, tar vapors, and wood gas pass over to the condensers. The gas is either allowed to escape into the air or is run through a scrubber and is used for fuel under the retorts. Pyroligneous acid and gases continue to pass off until about 832° F. is reached, when the process is finished and only charcoal remains. The commercial products of the distillation of this wood are turpentine, pyroligneous acid, tar oil, tar, pitch, and charcoal.

PRODUCTS.

TURPENTINE.

The crude turpentine obtained during the steaming process is redistilled, and is purified by being passed through caustic soda and other chemical solutions. No. 1 turpentine is sold at about 65 cents a gallon, and No. 2 at 50 cents. Chemically pure turpentine, which is produced in small quantity, sells at $2 a gallon.

PYROLIGNEOUS ACID.

Wood alcohol, acetic acid, and acetone are the chief constituents of pyroligneous acid. A small amount of tar oil, which can not be separated mechanically, is present in the solution. In the distillation of hardwoods in the northern United States, the pyroligneous acid is manufactured into wood alcohol and acetate of lime. The process consists in heating the acid, thereby distilling over the alcohol and the acetic acid, and leaving the tar oil as a residue. This distillate, which contains the acetic acid and alcohol, is piped to another still, where lime is added. This, combining with acetic acid, forms calcium acetate, which remains in the still when the alcohol is driven off. This process could undoubtedly be applied to the conversion of the pyroligneous acid obtained from Douglas fir, although there is less alcohol in acid from this wood than in that from hardwoods. Pyroligneous acid from Douglas fir is sold to orchardists for a tree spray at about 15 cents a gallon, and finds an excellent market for this purpose.

TAR OIL.

Pyroligneous acid and tar oil leave the retort together, but can be separated mechanically. The oil may be marketed straight, but it is found more profitable to add a little turpentine and sell the mixture as a shingle stain. Any desired color may be had by grinding a pigment with the oil. Not only does the stain add to the attractiveness of the shingles, but it acts as a preservative and lessens or prevents the growth of fungus and moss. Shingle stains of this kind sell at about 40 cents a gallon without coloring and at 65 cents when coloring pigments are added.

TAR.

Tar product is obtained in two ways. Some of it passes over with the pyroligneous acid and may be mechanically separated from it. The other portion is obtained by drawing it off from the bottom of the retort as "pitch." It sells for about $8.50 per barrel of 50 gallons, but the market for it is rather limited. Tar in this form is capable of further distillation, and yields wood creosote, dead tar or pitch, and a low grade of turpentine. The creosote sells at about 50 cents a gallon as a wood preserver, but its value in comparison with other common preservative fluids has not been determined.

CHARCOAL.

The charcoal obtained in the distillation of Douglas fir is not of high grade, because the pieces of wood required in the retorts are small. The wood is fairly hard, and if it could be distilled in larger pieces it would produce a fair grade of charcoal. That which is made by the present process sells at about $10 a ton in bulk, and for $12 in sacks.

PITCH.

The dead tar or pitch produced by the redistillation of the tar obtained from the retort is sold to shipbuilders at approximately $4.50 per barrel. It is used in the calking of vessels.

YIELD OF PRODUCTS.

Following is a record of the yield of distillation products from a cord of selected Douglas fir sawmill waste at one of the commercial distillation plants in Oregon:

Pyroligneous acid	gallons	150
Tar oils	do	12
Tar	do	20
Charcoal	pounds	800
Turpentine	gallons	4 to 12
Pitch	pounds	200 to 400

The Forest Service has given some attention to the question of the distillation of Douglas fir stumps in connection with the clearing of logged-off lands for agriculture in river bottoms in Washington and Oregon. Experimental runs were made with a small steam distillation apparatus on stumpwood selected near Astoria, Oreg. The work was done in cooperation with the chamber of commerce of that city. Various samples of wood yielded from 60 gallons of turpentine per cord to none at all. Samples taken from the same stump varied from 3 to 40 gallons per cord, but the quantity of wood which distilled at the rate of 40 gallons was very small in comparison with that which gave 3 gallons. The average yield of products per cord of stumpwood approximately is as follows:

Turpentine	gallons	8
Tar oils	do	20
Tar	do	35
Charcoal	bushels	42

Douglas fir stumpwood will vary from 5 to 15 cords per acre, according to the density of the original timber stand and the condition of the stumps. On the basis of these figures, the products would have a net value of from $9.80 to $29.40 per acre to apply against the cost of clearing the land, which ranges from $75 to $250 per acre. The distilling of stumpwood has not thus far been profitable commercially, though as a rule the stumps are fairly rich in pitch. The costs of handling and transportation of the wood and the operation of a still are hardly warranted by the quantity of distillates obtained. The distillation of selected slabs from the waste at sawmills is much more profitable, so some of the concerns that attempted the distillation of stumps have discontinued it. Some method by which stumps could be made a source of profit would greatly assist in the clearing of lands. Many rich tracts in the Pacific Northwest have been logged off and are well adapted to agriculture, but the cost of clearing is so large that the work can not be undertaken on an elaborate scale unless some use can be found for the stumps.

The average run of fir is not a profitable wood for distillation at this time, but it may become so when the demand for charcoal, turpentine, and other important by-products increases.